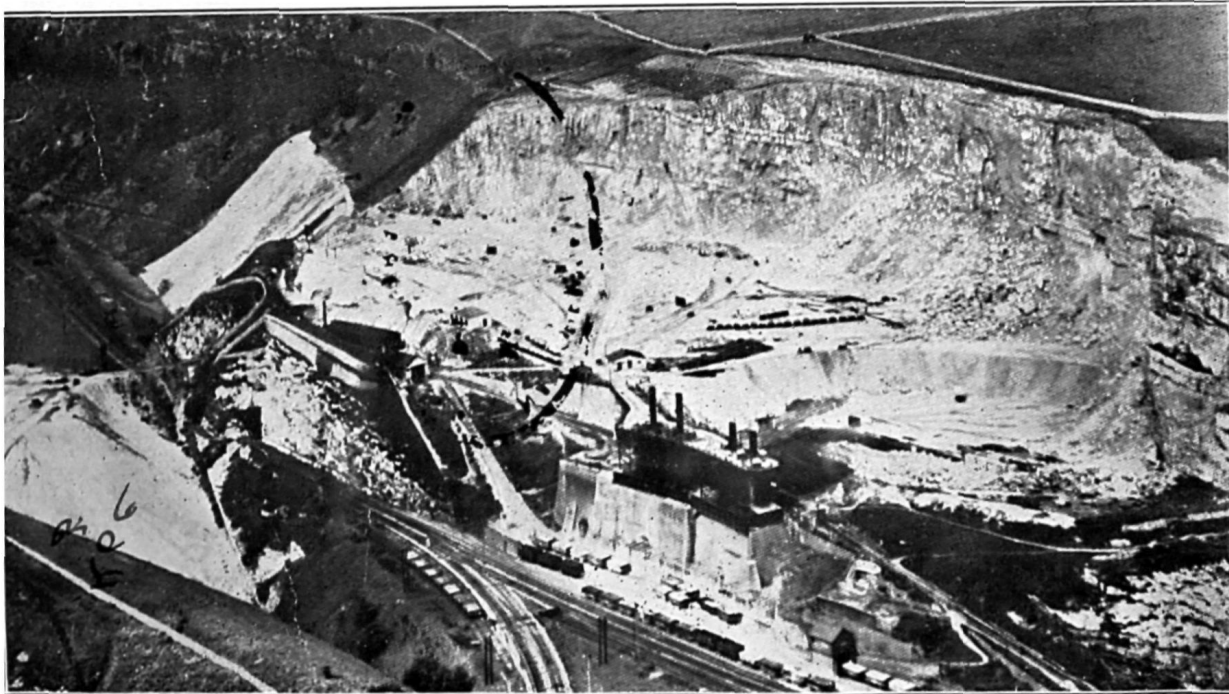


LIMESTONE AND ITS PRODUCTS



Frontispiece

TYPICAL MODERN LIME WORKS
(By courtesy of "Cement, Lime, and Gravel.")

LIMESTONE & ITS PRODUCTS

THEIR NATURE, PRODUCTION, AND USES

BY

ALFRED B. SEARLE

CONSULTING TECHNOLOGIST AND TECHNICAL
ADVISOR TO THE LIME AND ALLIED INDUSTRIES;
AUTHOR OF "REFRACTORY MATERIALS,"
"MODERN BRICKMAKING," ETC.



LONDON
ERNEST BENN LIMITED

1935

PRINTED IN GREAT BRITAIN

PREFACE

THE purpose of this volume is to point out the manifold industrial uses of limestone and its products, to indicate the kinds desired by some of the principal industries, and to describe the modes of preparation as well as the properties required in order that the various products may be suitable for the numerous purposes for which they can be employed.

The industrial uses of limestone or some of its products date back to prehistoric ages and have been important in almost all the great stages of civilization, but it was not until well on in the nineteenth century, when the era of great manufacturing industries dawned, that there began that great expansion in the sphere of usefulness of limestone and its products which render it one of the most important of raw materials in industry to-day.

At the present time, limestone surpasses all other minerals in the number and diversity of its uses. Thus, the iron and steel industry as at present constituted could not exist without large supplies of limestone. In other branches of metallurgy limestone plays an important part. It is indispensable in all the important industries mentioned in Chapters IV and XII—a mere list of which would occupy a page or more—and, indeed, there is scarcely a single large industry in which limestone or one of its products is not employed, directly or indirectly.

Great as is its importance, no text-book has yet been written which deals with the subject as a whole. There are excellent treatises on the origin and distribution of limestone which contain some reference to its uses and there is a considerable amount of information on lime scattered through many books and journals. Many of the latter are not readily accessible and it seemed desirable, therefore, to summarize within the compass of a single volume the large amount of information of industrial and technical importance which is now so widely distributed.

The mineralogical and geological aspects of the subject have been allowed to occupy only a small space, as the volume is written primarily for industrialists and not for mineralogists or geologists. For a similar reason, many chemical matters of great scientific interest but small industrial importance have been purposely omitted.

It is hoped that owners of estates bearing limestone will be able, from the following pages, to reach wise decisions as to the possibilities of profitable development and that quarry-owners and others will find uses which they had not previously realized. It is also anticipated that lime-burners will find cheaper methods of working and fresh markets for the lime, and that other users of limestone and its products will be able to ascertain with a minimum of trouble the purposes for which these substances may be employed and the kind most suitable for their requirements.

Several statements are repeated in various forms in different sections so as to call the reader's attention to them in a way which would have been impossible if all repetitions had been excluded.

The author's experience as a Consultant to the lime and allied industries for more than thirty years has necessarily placed him in possession of a large amount of confidential information which cannot be included in the present volume. Other information, excluded for lack of space, is available under certain conditions, on application to the author.

To the many clients and others who have permitted information and illustrations to be included in this book and to those members of his Staff—particularly Mr. Thomas Bartholomew and Mr. George H. Duvall—who have so greatly assisted in its compilation the author tenders his thanks.

ALFRED B. SEARLE.

CHARLBURY, OXFORD.

1935

CONTENTS

CHAPTER I

LIMESTONES : THEIR OCCURRENCE, COMPOSITION, AND PROPERTIES

Varieties of limestones—Minerals in limestone—Marble—Marls—Dolomite—Chalk—Shell-limestone—Geological Distribution of Limestones—Prospecting for Limestones—Properties of Limestones—Impurities in Limestones	1
--	---

CHAPTER II

EXTRACTION, QUARRYING, AND MINING OF LIMESTONE

Quarrying—Mining—Selection and Lay-out—Drainage—Stripping Overburden—Excavators—Sources of Power—Separating Useful Stone and Rubbish—Blasting—Boring—Drilling—Explosives—Loading Devices—Transport and Haulage—Disposal of Useless Stone—Suppliers of Machinery and Appliances	39
--	----

CHAPTER III

THE PREPARATION OF THE STONE

Sorting—Seasoning—Weathering—Drying—Dressing—Saws—Moulding—Carving—Polishing—Crushing—Grinding—Screening—Air-Separators—Dust-collectors—Levigation—Elutriation—Filtration—Centrifugal Separators—Storage—Broken Stone—Whiting—Levigated Chalk—Precipitated Chalk—Artificial Chalk—Black Chalk—Atomized Lime—Limestone-flour—Technical Carbonate—Prepared Chalk—Purifying Limestone and Chalk—Quarry Waste—Coated Limestone—Macadams—Asphalt—Suppliers of Machinery and Appliances	112
---	-----

CHAPTER IV

THE USES OF LIMESTONE, CHALK, AND OTHER FORMS OF CALCIUM CARBONATE

Uses in Agriculture and Horticulture—in the Building and Allied Industries—in Cement Manufacture—in Road Construction—in the Chemical Industries—in Glass Manufacture—in Medicinal and Pharmaceutical Preparations—in Metallurgy—in Paints and Allied Materials—in Paper Manufacture—in Pottery Manufacture—in Printing—in Railway Engineering—in the Rubber Industries—in the Soap and Allied Industries—Miscellaneous Uses	211
--	-----

CHAPTER V

THE MATERIALS USED IN LIME-BURNING

Alkali-waste—Shells—Calcium Sulphate—Limestone—Chalk	267
--	-----

CHAPTER VI

LIME KILNS

INTERMITTENT KILNS—Flare-kilns—Draw-kilns	270
CONTINUOUS KILNS—Vertical kilns—Mixed-feed kilns—Furnace-fired kilns—Oil-fired kilns—Gas-fired kilns—Draught—Cooling—Use of Steam—Discharging—Sorting—Charging the kiln—Defects in Gas-fired kilns—Advantages of Vertical kilns—Defects in working—Horizontal Lime-kilns—Tunnel-kilns—Rotary kilns—Electric kilns—Retorts for Lime—Other Appliances for Burning Lime	273
SELECTING A KILN—Effect of Improvement in Kilns	383
SUPPLIERS of Kilns, Machinery, and Appliances	394

CHAPTER VII

FUEL FOR LIME-KILNS

Coal—Coke—Lignite—Wood—Grass—Oil—Gas	395
--	-----

CHAPTER VIII

BURNING LIME

Chemical changes—Heat required—Effect of Impurities—Defective Heat-supply—Conditions essential to economy—Burning a Flare-kiln—Burning a Mixed-feed kiln—Burning a Kiln with External Fires—Burning a Kiln with Semi-producers—Burning a Gas-fired kiln—Burning a Hoffmann kiln—Burning a Tunnel-kiln—Burning Sintered Lime—The Use of Steam—Defects in Burning Lime—Kiln-control—Cooling Lime—Drawing Lime—Sorting or Picking Lime—Tests of Kiln-performance	404
---	-----

CHAPTER IX

THE UTILIZATION OF WASTE-PRODUCTS FROM LIME-WORKS

Small Stone—Small Lime—Underburned Lime (Core)—Overburned Lime—Kiln-gases—Carbon dioxide—Recovery of Waste Heat and Dust	447
--	-----

CHAPTER X

THE MANUFACTURE OF SPECIAL FORMS OF LIME

Calcareous Limes—Magnesian limes—Siliceous limes—Argillaceous limes—Selenitic limes—Slaked lime—Quicklime—Caustic lime—Fat lime—Lean lime—Properties of Highly Calcareous limes—Hydraulic limes—Water-lime—Lump lime <i>v.</i> Small lime—Ground lime—Hydrated lime—Slaking—Hydrating—Hydrators—Milk-of-lime—Lime-water—Soda-lime—Lime-putty—Plaster-lime—Carbide-lime—Cement-lime—Electrically-fused lime—Vienna-lime—Jewellers' and Platers' Buffing-lime—Arsenical lime—Suppliers of Machinery and Appliances	463
--	-----

CHAPTER XI

STORING, PACKING, AND DESPATCHING LIME

Modes of Packing—Packing-Machines—Suppliers of Machinery and Appliances	529
---	-----

CHAPTER XII

THE USES OF LIME

Uses of Lime in the Abrasive and Polishing Industries—in Agriculture and Horticulture—in the Building Industries—in Road and Pavement Construction—in the Chemical Industries—in the Manufacture of Dyes and Intermediates—in the Distilling Industries—in Coke and Gas Manufacture—in the Food Industries—in Fuel—in Furnace-construction and for Refractory Materials—in Glass-manufacture—in Glue, Size, and Gelatin Manufacture—in Leather-manufacture—in Medicine and Pharmacy—in Metallurgy—in Oil-refining and Lubricants—in Paint and Allied Industries—in the Paper and Cellulose Industries—in Refining Petroleum—in Pottery, Glass, and Enamel Industries—in Rubber and Resin Industries—in Sanitation—in Soap and Allied Industries—in Textile Industries—in the Softening and Purification of Water—Miscellaneous Uses of Lime	531
APPENDIX	682
INDEX	683

LIST OF ILLUSTRATIONS

FIG.	TYPICAL MODERN LIME WORKS	<i>Frontispiece</i>
		PAGE
1.	ARRANGEMENT OF TRACKS IN QUARRY FOR HAND- AND MECHANICAL-LOADING	45
2.	DRAG-LINE EXCAVATOR	48
3.	MECHANICAL NAVVY	49
4.	GRAB-EXCAVATOR	50
5.	LADDER-EXCAVATOR AT HIGH LEVEL	50
6.	LADDER-EXCAVATOR AT LOW LEVEL	51
7.	USE OF PLUGS-AND-FEATHERS IN QUARRYING	53
8.	POWER-DRILL	61
9.	CORE-DRILL	62
10.	EFFECT OF EXPLOSION BY LIQUID OXYGEN	63
11.	CRANES WORKING IN QUARRY	70
12.	BUCKET-LOADER	77
13.	TRACTOR MOUNTED ON CATERPILLARS	79
14.	HAULING GEAR WITH ENDLESS ROPE OR CHAIN	81
15.	TIPPING-WAGON IN FRAME	86
16.	AERIAL CABLEWAY	88
17.	" BLONDIN " CONVEYOR	89
18.	TUB HANGING FROM ROPE	93
19.	" NOTANOS " DRYER	117
20.	" SANGWIN " DRYER	117
21.	" RAYMOND " KILN-MILL	118
22.	FRAME-SAW	120
23.	DIAMOND CIRCULAR SAW	121
24.	" SUPER-SIMPLEX " CROSS-CUT SAW	123
25.	PLANING- AND MOULDING-MACHINE	124
26.	POLISHING MACHINE	125
27.	JAW-CRUSHER	128
28.	GYRATORY CRUSHER	131
29.	CRUSHING-ROLLS	132
30.	TOGGLELESS CRUSHER	135
31.	" DEVIL " DISINTEGRATOR	136
32.	CARR'S DISINTEGRATOR	137
33.	" ROSS " CHAIN-FEEDER	138
34.	PAN-MILL	139
35.	" STAG " BALL-MILL	143
36.	" HARDINGE " CONICAL MILL	145
37.	TUBE-MILL	146
38.	FULLER-LEHIGH PULVERIZER MILL	146
39.	ROLL-MILL, WITH DOOR OPEN	147
40.	GRIFFIN PENDULUM-MILL	148
41.	VIBRATING SCREEN	157
42.	POLYGONAL ROTARY SIEVE	160
43.	ROTARY SCREEN	161
44.	CONICAL ROTARY SCREEN (SHOWING EASR OF REPLACEMENT)	161
45.	" VICONA " SEPARATOR	164
46.	ROTARY MULTIPLE SCREEN	166
47.	ROTARY MULTIPLE SCREEN	166
48.	JIGGING SCREEN	168
49.	AIR-SEPARATOR	169
50.	" PULVER-BLENDER "	170
51.	DUST-COLLECTOR	172
52.	FILTER-PRESS	175
53.	CONTINUOUS VACUUM-FILTER	175
54.	" DORR " HYDRO-SEPARATOR AND BOWL-CLASSIFIER	180
55.	" DORR " RECTANGULAR CLASSIFIER	181
56.	THREE POSITIONS OF BREAKER BARS IN HUTCHINS DRYER	185
57.	TYPICAL MODERN LIME-KILNS	270
58.	FLARE-KILN	271

LIST OF ILLUSTRATIONS

FIG.		
59.	DIPPING CHIMNEY	27
60.	DIETZSCH KILN	28
61.	" R " KILN	29
62.	BROCKHAM KILN	30
63.	AALBORG KILN	31
64.	CORNET KILN	32
65.	DUCHEZ KILN	23
66.	CHAUDIÈRE KILN	306
67.	BROOMELL KILN	303
68.	KEYSTONE KILN	304
69.	ARNOLD KILN	305
70.	VERTICAL SECTION AND PLAN OF DOHERTY-ELDRED LIME-KILN	305
71.	VARIOUS ARRANGEMENTS OF AIR- AND GAS-INLETS	311
72.	BURNER FOR GAS-FIRED KILN	312
73.	SCHMATOLLA GAS-FIRED KILN	314
74.	PRIEST'S KILN	316
75.	DOWSON AND MASON GAS-FIRED KILN	317
76.	CROSLAND KILN	319
77.	MOUNT KILN AND ACCESSORIES	320
78.	PERETTI AND FUNCK LIME-KILN	321
79.	ISSERLIS' GAS-FIRED KILN	323
80.	MANNSTAEDT KILN	326
81.	CURVED BARS—CLOSED	335
82.	CURVED BARS—DISCHARGING POSITION	335
83.	KILN WITH CENTRAL CONE NEAR BASE	3
84.	" ANKER " DISCHARGING DEVICE	3
85.	EFFECT OF PERIPHERAL DISCHARGE	3
86.	EFFECT OF CENTRAL DISCHARGE	337
87.	EFFECT OF " ANKER " DISCHARGE	337
88.	LÖHNERT'S DISCHARGING DEVICE	339
89.	DISCHARGING CONE	339
90.	SCREENS AT BASE OF KILN	339
91.	SCREENS WITH EXTENSION	340
92.	SCREENS FOR " LARGE " LIME	340
93.	PERIPHERAL CHARGING	340
94.	CHARGING THROUGH TOP OF KILN	343
95.	BELL IN WRONG POSITION	344
96.	BELL IN RIGHT POSITION	344
97.	CHARGING DEVICE	345
98.	TIME REQUIRED FOR BURNING LIMESTONE	368
99.	PLAN OF HOFFMANN KILN	369
100.	PLAN OF BÜHRER KILN	371
101.	ROTARY KILN AND COOLER	375
102.	SINTERING MACHINE	382
103.	HERMAN'S KILN WITH GAS-PRODUCER USING LIGNITE	398
104.	DISTRIBUTION OF FUEL IN MIXED-FEED KILNS	417
105.	KILN WITH MASONRY CORE	421
106.	COLD CORE DUE TO INSUFFICIENT GAS-PRESSURE	423
107.	GAS-PRESSURE TOO LOW	424
108.	CORRECT GAS-PRESSURE	424
109.	SEGER CONES	430
110.	THERMO-COUPLE	441
111.	STICKING LIME	444
112.	PLANT FOR MAKING CARBON DIOXIDE FROM LIME	454
113.	PLANT FOR LIQUEFYING CARBON DIOXIDE	455
114.	THIBLE KILN WITH AUTOMATIC DISCHARGE	475
115.	HYDRATING AND GRINDING PLANT FOR HYDRAULIC LIME	483
116.	TYPICAL " RAYMOND " No. 0 AUTOMATIC PULVERIZER INSTALLATION	501
117.	SECTIONAL VIEW OF " CLYDE " HYDRATOR	506
118.	PLAN OF " CLYDE " HYDRATOR	507
119.	LIME-HYDRATOR	507
120.	" SCHULTESS " HYDRATOR	510
121.	" VICTORY " HYDRATOR	512
122.	LIME-MIXING MACHINE FOR MILK-OF-LIME	521
123.	LIME-SAND BRICK-PLANT	584

LIMESTONE AND ITS PRODUCTS : THEIR NATURE, PRODUCTION AND USES

CHAPTER I

LIMESTONES : THEIR OCCURRENCE, COMPOSITION, AND PROPERTIES

THE term *limestone* is applied in a very broad sense to many forms of calcium carbonate, each with distinct physical properties, and occurring in Nature as a variety of rocks which, at first sight, appear to have little resemblance to each other. It is difficult, for example, to regard a beautiful piece of polished marble, a lump of chalk, a crystal of calc-spar or of aragonite, a marine shell, and a piece of grey limestone as all being composed essentially of the same substance, yet such is, indeed, the case. The differences between them are so marked, and yet, when they are separated from any small percentage of impurity present and are then carefully investigated, it will be found that they all consist of calcium carbonate.

The appreciation of this essential unity of each widely different substance grows on the investigator as he proceeds with his work, just as a child who heats a piece of ice under suitable conditions realizes that ice, water, and steam—whilst apparently so unlike each other—are in reality only different forms of the same substance. Similarly, when calcium carbonate is precipitated from a solution it forms an amorphous white powder ; if it has been sufficiently heated and then cooled or precipitated under the conditions which facilitate its production in a crystalline form it is obtained in the squat crystals of calc-spar, or the long crystals of aragonite, or as a compact mass of minute crystals which is known as marble or one of the various limestones. Finally, if it has been withdrawn from solution by a minute creature which has required it for the construction of a shell or other refuge, it is found as chalk, coral, shells, etc.

The great variety of forms of calcium carbonate are, therefore, due to the manner of their production, and this, in turn, may be affected by the rate of deposition, the presence of impurities, or the conditions under which they were used by the living creatures concerned. In many instances, deposits of calcium carbonate have been subjected to heat and other conditions whereby they have been converted from an amorphous into a crystalline material, and this altered or metamorphosed material may, at a later stage, have undergone still further changes as the result of the intrusion of other substances into the cracks or joints of the material. From some parts of the country immeasurably large deposits of calcium carbonate have been removed by solution, and all that is left are the insoluble impurities which remain behind in the form of rottenstone and certain varieties of ochre and clay.

The chief forms in which calcium carbonate occurs in nature may be divided into two chief groups :—

(i) Those formed by deposition, either in an amorphous form, as *travertine*, *tuff*, *tufa*, or *calcsinter*, or in a crystalline form, as *calcite* or *aragonite*, in each case with a very variable proportion of clay, sand, and other minerals.

(ii) Those forms of organic origin, the individual particles having at one time formed part of the structure of a living organism.

The *inorganic* forms of calcium carbonate may be classified as : (a) limestone rocks ; (b) travertine, tuff, tufa, etc. ; (c) marble ; (d) lime-spars ; (e) marls, and (f) dolomite.

The chief *organic forms* are : (g) chalk ; (h) shell limestone ; (i) crinoidal limestone ; (j) foraminiferal limestone ; (k) coral ; (l) bryozoa deposits.

The inorganic or chemically-formed varieties of calcium carbonate all consist essentially of the minerals *calcite* or *aragonite*, both of which have the same percentage composition. In their crystalline form, and in several other properties they are, however, quite distinct. In comparison with calcite, which is very abundant, aragonite is comparatively rare, for whilst calcite composes the bulk of limestone and marbles, including some which appear to be amorphous, aragonite generally occurs in smaller masses in acicular crystals often in radiating, columnar, globular, uniform, stalactitic, coralloidal and encrusting forms.

MINERALS IN LIMESTONE

The following minerals—all consisting essentially of calcium carbonate—occur in the various forms of limestone :

Aragonite crystallizes in the right prismatic system, generally long prismatic, short prismatic, or short pyramidal, though single crystals are rare ; linear, rosette, fibrous and columnar forms are common, also crusts, stalactites, and other forms. Cleavage is parallel to the shorter lateral axis and very distinct. The fracture is conchoidal or uneven. Hardness, 3·5–4·0 ; sp. gr., 2·9–3 (massive 2·7). The crystals are transparent or translucent, and are vitreous. They are usually colourless, but sometimes are yellowish white, brick red, violet blue, or grey.

When heated in a closed tube aragonite swells, before reaching a red heat, and falls to a coarse powder, evolving a little water.

Basic Calcium Carbonate, Ca_2CO_4 or $2\text{CaO}\cdot\text{CO}_2$, is formed when lime is heated in a current of carbon dioxide at 415°C . This substance does not disintegrate in moist air, and does not take up water from steam. When finely powdered it hardens like a hydraulic cement, forming $\text{CaCO}_3\cdot\text{Ca}(\text{OH})_2$. On heating to dull redness it loses water, and is converted into a mixture of calcium carbonate and lime. On very prolonged heating at 412°C . in a current of carbon dioxide, $2\text{CaO}_3\cdot\text{CaO}$ and, later, $3\text{CaCO}_3\cdot\text{CaO}$ are formed.

Bitterspar is another name for dolomite.

Calcite—a very pure form of calcium carbonate—crystallizes in hexagonal and rhombohedral forms, the combinations of these exceeding those of any

other mineral. Its cleavage is rhombohedral along the chief angles, parallel to the faces of the rhombohedron, and is very easily effected and very perfect, conchoidal fractures being rare. The hardness is 3 on Mohs' scale; specific gravity 2.6 to 2.8 (very pure transparent crystals 2.72). Calcite is pellucid in all degrees, has very distinct double refraction of light, and is used for this purpose in optical instruments. It has also a vitreous lustre. Calcite is usually colourless or white, but when impure it is grey, blue, green, yellow, red, brown, or black. Its streak is greyish white. It is infusible except in the electric arc. It is soluble in hydrochloric or other acids, with effervescence, evolving carbon dioxide, and in this way is distinguished from dolomite.

Calcium Bicarbonate, $\text{CaH}_2\text{C}_2\text{O}_6 = \text{CaCO}_3 \cdot \text{H}_2\text{CO}_3$, has never been prepared in a solid state, but it is supposed to be formed when calcium carbonate is dissolved in water containing carbon dioxide. On evaporating the solution, carbon dioxide escapes and calcium carbonate is precipitated.

Dolomite in the strict sense of the term is a double salt containing 21.68 per cent. of calcium, 13.3 per cent. of magnesium, 13.0 per cent. of carbon and 52.0 per cent. of oxygen, so that it corresponds to CaMgC_2O_6 or $\text{CaCO}_3 \cdot \text{MgCO}_3$. It crystallizes in the same system as calcite, has an equally perfect rhombohedral cleavage, hardness of 3.5-4.5, and a specific gravity of 2.85-2.95. Single crystals are colourless and of pearly lustre, but the mass is often compact or granular and frequently cellular and porous. The crystals are often curved, and when impure are pale red, yellow, or green.

Dolomite does not effervesce readily with cold hydrochloric acid, but does so on heating.

The term dolomite is also used, however, for masses of limestones consisting of both calcium and magnesium carbonates, and that form is described on p. 10.

Rice dolomite is a washed dolomite in pieces which would pass through a $\frac{1}{8}$ -in. hole, but be retained on a 20-mesh sieve; it is used as a refractory material in the interior of furnaces.

LIMESTONE ROCKS

The term "limestone" is applied generally to all calcareous rocks, *i.e.* those composed chiefly of calcium carbonate, but it is also used in a more restricted sense as excluding marble and certain other distinct forms.

The appearance of limestones and lime-producing products are so characteristic that they cannot easily be mistaken for other minerals. Their hardness and specific gravity are also guides in the identification of specimens. In any case, if a drop of hydrochloric or nitric acid is placed on a small fragment of the rock it will cause effervescence with the evolution of carbon dioxide (CO_2) and the formation of a calcium salt, the nature of which depends on the particular acid used. Limestones which are contaminated by clay, magnesium carbonate, or other impurities, effervesce less strongly according to the amount of impurity present.

Limestones vary greatly both in texture and composition. In some localities, they are a hard, close-grained mass which breaks with a splintery or conchoidal fracture ; in others, limestone is a crystalline rock composed of fine crystals of calcite and resembling loaf sugar in colour and texture ; in still others it is a dull, friable, chalk-like deposit, and, finally, it sometimes forms a compact massive finely granular rock resembling a closely-grained sandstone or free stone.

The colours of limestone vary greatly, the most common being shades of bluish grey and cream, the latter passing to white.

The grey colour of many limestones is often due to particles of impurity being intermixed. Pure crystalline limestone is naturally snow white, as in Carrara marble.

All limestones contain small proportions of alumina, silica, magnesia, and iron oxide, with still smaller proportions of other oxides, sulphur, phosphorus, etc. The purer varieties contain 99 per cent. of calcium carbonate.

Some limestones are highly siliceous, the silica and calcium carbonate being deposited simultaneously.

Clay, sand, iron oxide, magnesia, and bituminous matter also occur in limestones, and such mixtures are known as argillaceous, arenaceous, ferruginous, dolomitic, and bituminous limestones respectively.

Limestones (using the word in its narrower sense) cannot be very sharply divided into clearly defined groups, as they pass gradually from one form to another, with the pure calcium carbonate at one end of the series and a highly siliceous limestone or calcareous sandstone, such as Kentish Rag, at the other. For practical purposes, however, it is convenient to divide limestones into the following groups :

Oolite, or Roestone, a granular limestone composed of small grains, resembling fish-roe, each grain consisting of a series of concentric layers of calcium carbonate. This oolitic texture is common to several sandstones and grits as well as to oolite proper, formed around a harder nucleus of shell or sand, but sometimes the material is finely crystalline. Adventitious fragments of various shells occur in some oolite limestones, which are then known as "shelly oolite." The grains may have their outlines clearly defined or they may be of amorphous material.

Oolitic limestones occur principally in Jurassic rocks, and between the marls of the Kimmeridge and Oxford clays, and in the carboniferous limestones extending from South Wales, through Bristol into Derbyshire, and also in Ireland. Oolitic stone is generally easy to work and affords an excellent architectural building stone of good weathering properties. Where the rock is veined with small threads of silica, introduced after formation, the stone is harder to work.

Pisolite Limestones are of an oolitic character, but the grains are as large as peas. Such deposits occur at Vichy, and similar ones are found around the lakes of West America.

Argillaceous or Clayey Limestones have usually been deposited

in the form of marine muds in which various molluscs have lived. The composition of such limestones varies, from those containing only a small proportion of clay or siliceous matter to those containing only a little lime.

The argillaceous limestones are hard, smooth, and compact, but gradually break down on exposure to the weather. They are largely used in the manufacture of cement and hydraulic limes.

Estuarine Mud is a soft type of argillaceous limestone, containing calcium carbonate in varying proportions. Such materials are particularly common in the London basin and elsewhere. Owing to the comparatively low content of lime they are seldom used in the production of lime, though they are largely used for cement manufacture.

Gault, which occurs in Sussex and elsewhere, contains a varying proportion of calcium carbonate, not usually sufficient to make calcination remunerative. It is, however, largely used as one constituent in the manufacture of Portland cement.

Siliceous Limestones resemble the argillaceous ones, except that the clay is replaced by silica in the form of grains of sand, quartz, chert, or flint, or of sponge spicules. The famous *Chaux de Theil* is a limestone of this class, found at Ardreche-on-Rhone, which contains about 20 per cent. of very finely divided silica; it was largely used in the harbours of Port Said and Suez. Siliceous limestones are principally employed in the preparation of hydraulic limes.

Hydraulic Limestone is a naturally occurring mixture of calcium carbonate and siliceous material—usually clay—which, when burned, forms a complex calcium alumino-silicate having the power of “setting” or hardening under water, and, therefore, used for hydraulic mortar.

Hydraulic limestone occurs chiefly in the Lias and Oolite formations, and in the Septarian nodules found in the shallow seas round the Thames estuary from which the nodules are dredged.

Cornstone is a natural mixture of calcium carbonate and sand, which occurs in some Palaeozoic red sandstone formations.

Travertine, Tufa, etc., are limestones which have been deposited by springs, streams, or percolating water containing carbon dioxide gas and calcium carbonate in solution. When the gas is liberated the calcium carbonate is precipitated and forms a somewhat porous stone, which is soft when fresh, but attains a great hardness on exposure. Algæ and muscoid organisms also play a prominent part in the formation of fresh-water lime, travertine, and tufaceous limestone. These forms of limestone are usually white or cream coloured when fresh, but they darken on exposure and are frequently stained brown by iron compounds and other impurities.

Travertine occurs in small quantities at Matlock Bath, Alport, and Monsal Dale in Derbyshire, near Wrexham and Llangollen in Wales, and in several other localities. Foreign deposits of travertine occur in Clermont, Normandy, and Auvergne (France), Tuscany, Tivoli, and near Rome (Italy), Karlsbad (Bohemia), near Constantine (Africa), Hierapolis (Asia Minor), and Yellowstone

Park (America). It forms a good, though rather porous, building stone.

Closely allied to travertine, tufa, and calcareous sinter are the *stalactites*, or pendant deposits of fairly pure calcium carbonate, which are formed by the percolation of water containing carbon dioxide in solution through rocks containing calcium carbonate, dissolving some of this material, and re-depositing it in the form of an inverted cone. Some of the solution falls on to the ground beneath and there builds up columnar, conical or hemispherical deposits of calcium carbonate, which are termed *stalagmites*.

Calcium carbonate is practically insoluble in pure water (0.018 parts dissolve in 100 parts of water at 15° C.), but as most natural waters contain some carbon dioxide in solution, in which calcium carbonate is more soluble (0.88 gm. per litre) most deep well waters, and some others, contain considerable proportions of calcium bicarbonate in solution. Later, part of the dioxide escapes, and the calcium carbonate is precipitated. Even at ordinary temperatures the "bicarbonate" is easily decomposed and the precipitated calcium carbonate is deposited on any nucleus which may be present, forming stalactites and stalagmites. The evaporation of natural solutions of calcium bicarbonate may also result in the formation of six-sided rhombic prisms of $\text{CaCO}_3 \cdot 5\text{H}_2\text{O}$.

Both these forms of calcium carbonate are found in caverns in limestone rocks, and they also occur on the underside of bridges and other structures where extensive percolation occurs, a particularly striking example being the bridge at Berwyn, near Llangollen.

Alabaster is another form of calcium carbonate. Some kinds of it are closely allied to stalactites and, like them, consist of a translucent mass of calcium carbonate. True alabaster does not occur in this country, but is found in Egypt, Assyria, and Algeria, and is often erroneously termed onyx marble. The circular markings indicate its stalactitic origin. Alabaster is employed for internal decorative work, but it is not sufficiently weather-resisting to be employed for outside architecture. The term alabaster is also applied to a translucent mass of calcium sulphate, this gypseous alabaster being of more common occurrence than the calcareous alabaster just mentioned.

Petrified Objects are composed of a porous or fibrous material, which acts as a nucleus for the calcium carbonate slowly precipitated from aqueous solution (see Stalactites). In time, the objects are completely covered by a crust of compact calcium carbonate, which resembles their shape so closely that they appear to be made of stone. Some of the wells in Matlock Bath are famous for their petrifying power.

MARBLE

Marbles are limestones which have acquired a granular or crystalline structure, and are composed of minute crystals of calcite interspersed with coloured veins of other minerals and with minute flakes of talc and mica. A thin section of marble may be seen under the microscope to consist of grains each being an imperfect crystal of calcite, and made up of a number of crystal

plates twinned together. The structure of marble is probably due to the combined action of heat and pressure, as even an earthy limestone or precipitated carbonate becomes saccharoidal when heated very strongly under pressure.

The term "marble" is also used, however, for various unaltered limestones which are capable of taking a high polish and of being used as decorative stones. Hence, "marble" is an architectural, rather than a geological term.

The best known marbles are chiefly formed by the metamorphism of Mesozoic and Tertiary limestones. True marble, in the geological sense, is the massive crystalline variety of calcite, and is produced by the action of heat on limestone. Wollastonite marbles occur in the carboniferous limestone rocks, where igneous intrusions have metamorphosed the original limestone, as in the neighbourhood of Carlingford (Ireland). Carboniferous limestones seldom contain any aluminous impurities, but contain numerous bands and nodules of chert.

Marbles may be divided into :

(i) Marbles suitable for the production of statues and architectural features.

(ii) Pure marbles, which are unsuitable for architectural use. These are burned to produce a very pure lime required for special purposes.

(iii) Impure marbles, suitable only for building lime and other common uses.

The early Grecians obtained their marble from Paros, Naxos, and Tenedos. At the present day, the chief supplies of marble are at Carrara, near the Gulf of Genoa (white), the districts of Verona and Vicenza (red and yellow), Florence (yellow), Turin, Bergamo, and Brescia (variegated), and the Apuan Alps (white and coloured). Several varieties of coloured marbles also occur in Belgium—chiefly at Namur, Hainault, and Dowlais. Marble is also imported into this country from France, Norway, Sweden, Spain, Portugal, Switzerland, Australia, Canada, and the United States.

True British marbles (with the exception of some in Ireland) are not of great commercial importance, though they should not be overlooked as there is a considerable demand for the marbles of Derbyshire and Devonshire, the jaspers of North Wales, and the Iona marbles of Scotland. What are often termed marbles in this country are merely grey limestones to which fossils impart a patterned nature when polished.

Paludina marble, obtained from the Upper Purbeck beds of Swanage, is so named on account of the *Paludina* shells which it contains. It is not of great importance as a building stone. A variety called Sussex or Bethersden marble, containing a large species of *Paludina*, occurs in the Weald clay, and has been used in the construction of a number of churches in Kent. It should not be confused with the Purbeck marble.

A red oolitic limestone found near Bristol and of Carboniferous age, is common as a *red marble* in collections. The small concretionary grains with their concentric structure have become iron stained, as well as the fossils of the

ground, and the stones are often cut for ornaments. *Black marbles* are sometimes coloured by a mere impurity of mud, but a very small quantity of anthracite or graphite, arising no doubt from the decay of organisms, suffices to give a deep colour to a limestone, which is intensified when the marble is polished. The curving white shells in the black limestone of Kilkenny produce a natural pattern of a somewhat vivid character. *Green marbles* are usually coloured by serpentine or chlorite. In the splendid banded variety from Connemara the colour is partly due to the introduction of pigments at a late stage.

In many parts of the British Isles the climatic conditions are not suitable for marble on the exteriors of buildings so that it is usually employed for internal decorative purposes. It is seldom burned for the production of quicklime, unless of such inferior quality as to be unsuitable for architectural use. Lime, made from white marble is too expensive to be used for building purposes, but is sometimes used where an exceptionally pure lime is required.

Marbles differ greatly in their physical properties, particularly in their power of transmitting light. Uniformity of grain is usually desirable; for some purposes a coarse-grained texture is required, for others a medium, and for others a fine grain. The texture is influenced by the impurities present and by the folding of the beds. The porosity should be low (less than 1.0 per cent. by volume).

LIME-SPARS

Calc-spar consists of calcite in crystals of considerable size, and it is important as a source of such crystals as it possesses their properties in a marked degree. The principal varieties of calc-spar are :

Iceland-spar, which occurs in large crystals in a trap rock in Iceland. Its principal property is that it exhibits double refraction on account of its rhombohedral form. For this reason, it is employed in the construction of Nicol prisms for optical polarizers.

Slate-spar, which consists of thin lamellar crystals, having a pearly lustre and greasy feel.

Satin-spar is a variety occurring in crevices of rocks, and is so named on account of the finely fibrous arrangement of the crystals in a manner similar to fibrous gypsum which is also called satin-spar.

Dog tooth spar, in which the crystals are a combination of scalenodron and prism.

The largest deposits of calc-spar in the British Isles were discovered in 1921 in some derelict mines at Tokscliff, in the High Peak of Derbyshire.

MARLS

Marl is the term applied somewhat loosely to friable earthy materials. It is used in a more limited sense for natural mixtures of calcium carbonate and clay, and thus forms an additional term for argillaceous limestones. Such marls are formed by the deposition of calcium carbonate in the beds of lakes

by streams containing the soluble calcium salt in solution. The calcium carbonate is deposited as a result of the combined action of physical and chemical influences, as well as indirectly by animal and vegetable life. The principal causes of deposition are :

- (i) Escape of carbon dioxide owing to decrease in pressure.
- (ii) Supersaturation owing to rise in temperature and evaporation.
- (iii) Abstraction of carbon dioxide by plants.
- (iv) Freeing of oxygen by plants, resulting in the formation of carbonates from bicarbonates.
- (v) Direct abstraction and crystallization of lime salts by *chara*.
- (vi) Abstraction of lime by molluscs and formation of shell deposits.

Fresh water marls usually occur in small basin-shaped deposits, which favours the suggestion that they are formed by lacustrine deposition. Marls may contain up to 50 per cent. of water. They usually contain a certain amount of organic matter, but this burns out in the kiln. They seldom contain much sand or grit (2-3 per cent.). They are generally extremely fine, though in some cases coarse material, including shells, etc., occurs. The clay occurring in marls is objectionable where a pure hydraulic lime is required, as the percentage of magnesia and sulphur are often increased.

Where the calcium carbonate is in the form of easily recognizable fragments of shells, the material may be termed a "shell marl" (see "Shell Limestone").

Moor lime is a highly calcareous marl found on moors and the like.

Meadow lime is a term (seldom used, except as a translation of *Wiessenkalk*) relating to highly calcareous marls found in some flat and low-lying lands.

Dolomitic marl is a magnesite marl, containing, usually, about 10-30 per cent. of calcium carbonate, 10-40 per cent. of magnesium carbonate, and 20-50 per cent. of silicates and silica.

DOLomite

Dolomite or *Magnesian limestone* in the compact and massive form consists essentially of a double carbonate, corresponding to $\text{CaCO}_3 \cdot \text{MgCO}_3$, but dolomite rocks vary so greatly in composition that they are better described as complexes of calcium carbonate and magnesium carbonate.

The composition of dolomite normally corresponds to a mixture of 54.3 per cent. calcium carbonate and 45.7 per cent. of magnesium carbonate, but iron carbonate usually replaces some of the magnesium carbonate.

Dolomite is usually of a saccharoidal texture, but of a yellowish colour.

Dolomite appears to have been formed by two distinct processes : (a) by the addition of magnesium carbonate to a calcareous limestone or ooze under such conditions as to form dolomite, or (b) by the precipitation of the double carbonate and its subsequent deposition. The existence of dolomite has also been attributed to certain organisms which settle constantly on the outside of coral reefs and carry 10-13 per cent. of magnesium. They supply ample

material for the formation of land, which is transformed into dolomite after the solution of some of its calcium carbonate. Shells, containing only little magnesia, absorb enormous quantities when brought into contact with a magnesia solution, and are thus transformed into dolomite. The magnesian limestones and dolomites in the carboniferous limestones of Derbyshire, South Wales, and Ireland appear to belong to the first class, whilst those of Mansfield, etc., in the Permian system, belong, at least in part, to the second class. Sometimes the conversion of a calcareous material into dolomite appears to have occurred whilst the former was in a soft oozy state, or as the result of the evaporation of saline waters; this variety contains gypsum and rock salt.

Other dolomite appears to be due to the gradual transformation of ordinary limestone by water, containing magnesia, percolating through the rock and especially through the joints, faults, etc., of a calcareous limestone, as at Harboro Rocks, near Brassington, Derbyshire, which are highly dolomitized.

Reef limestones, which are of organic derivation, are particularly subject to dolomitization. Some of the raised reefs of the Pacific and Indian Oceans are almost pure dolomite rocks, though they are not usually referred to by this name. Magnesium salts are also introduced by secondary minerals, such as talc, chlorite, serpentine, and various zeolites, which, when decomposed by weathering, etc., produce solutions of carbonate and sulphate of magnesium, which impregnate surrounding rocks.

Magnesian limestone is a term sometimes used as synonymous with dolomite, but it has a more extended meaning and is applicable to limestones containing a far smaller proportion of magnesium carbonate than does true dolomite.

There are at least three kinds of magnesian limestone :

(i) A *definite chemical compound* containing 54·35 per cent. of calcium carbonate and 45·65 per cent. of magnesium carbonate, *i.e.* equal molecules of each.

(ii) A less definite compound, possibly what is known as a *solid solution*, from which the magnesium carbonate can readily be separated.

(iii) A mixture of the two carbonates in any proportion.

It is very unfortunate that all three kinds of limestone are known as dolomite, as it leads to much confusion; only the first kind should be termed *dolomite*, the others are magnesian limestones. Other varieties of dolomite are :

Brown spar and Pearl spar, consisting of simple crystals which are often red on account of iron compounds present.

Parian and Iona marbles are true dolomite.

Technical Carbonate is an artificial magnesium carbonate made from dolomite.

The massive and compact varieties of dolomite are valued as building stones, and are used in York Minster, the Houses of Parliament, etc. Limestones containing magnesia are generally of good weathering quality and are valuable as building stones, the rock being merely cut to the right shape. Such

limestones may also be burned to produce a mixture of magnesia and quick-lime, which may be employed for various purposes. It should not, however, be used for cement manufacture as the magnesia is deleterious to the resultant cement. It is also desirable to use a purer lime for lime-sand bricks as, although magnesia is equally as good a binder as lime, magnesian limestones are more costly to hydrate.

ORGANIC LIMESTONES

The chief limestones and allied rocks of organic origin are composed of the remains of living organisms, and occur in thin layers and also in masses of enormous thickness, as in the English and Irish mountain limestone. Some of these organic deposits are of fresh water, and others of marine origin. They owe their origin to various shell-covered creatures withdrawing the calcium carbonate of which their shells are composed from the solution produced by the percolation of rain-water through limestone rocks. Some of the solution is evaporated, forming stalactites, stalagmites, and petrified objects, but the greater part finds its way to the lakes and eventually the sea, where it is used by the creatures requiring it for the production of shells. In many cases, the shells have been subjected to such prolonged grinding that it is impossible to recognize the origin of many of the smaller particles. In addition, organic limestones often contain some amorphous calcium carbonate, which has been precipitated from solution and eventually acts as a cementing agent which binds the shell fragments together. These deposits of organic origin occur in a variety of forms of which the most important are as follows :

CHALK

Chalk is a white, soft rock composed of minute particles (flour) formed by the crushing of foraminifera, echinoderms, molluscs, and other marine shells. It occurs in massive beds over the greater part of the south-east of England. In Ireland and elsewhere it tends to pass into a more compact limestone, and is often coloured.

Chalks vary greatly in the proportion of calcium carbonate present *White chalk* being usually fairly pure, whilst *Greystone chalk* contains 5–20 per cent. of silica, lime made from it having slight hydraulic properties.

Several substances known as chalk are not true chalks, but are used for some of the same purposes. The chief of these substances owe their name to their use for writing on blackboards, pavements, etc. They include :

Writing chalk, which may be made of plaster of Paris mixed with an inert diluent, such as whiting, China clay, starch, or finely-ground gypsum.

Black chalk, which is a soft carbonaceous shale.

Brown chalk, which is a soft umber.

Red chalk, which is a soft form of iron oxide—usually a crude, but soft, iron ore.

French chalk is a white or light grey variety of soft steatite.

SHELL-LIMESTONE AND SHELLS

Shell-limestones consist chiefly of the fragmentary shells of marine creatures, but some are of fresh-water origin. They occur in many geological formations, and are readily recognized under the microscope, and, in many instances, by the naked eye. They vary greatly in purity, some containing a considerable percentage of silica which acts as a bonding agent or cement. When very compact and capable of a high polish (as the Paludina stone in Dorset) some of these limestones are termed "marble."

Shell marl is a lake deposit of shells and entomostraca cemented by clay or mud. When compacted it forms *lacustrine limestone*, which is usually white or of a very light grey colour.

Shell sand is a sandy material composed mainly of crushed shells which, when subjected to the prolonged action of water, is converted into a harder limestone by the bonding together of the original particles by means of a redeposited calcium carbonate, similar in character to that in stalactites.

Crinoidal limestone is a rock composed of joints of encrinites with the remains of foraminifera, molluscs, and other shell-forming creatures. It is a characteristic constituent of the Lower Carboniferous Limestone and of other formations. Owing to the organic matter present, this stone is usually grey in colour, but is sometimes red or brown, and occasionally black.

The majority of limestones show no trace of their origin. Originally all were produced by living creatures withdrawing calcium salts from the sea-water to form their shells. The gypsum in solution in sea-water is probably the sole source from which the marine shell-forming organisms and coral-building creatures obtained the lime they required. Most limestones, however, have been altered during the period after their deposition, with the result that instead of shells, coral reefs, etc., they form grainy crystalline stone, or a combination of beautiful crystals, such as marble and crystalline limes, formed by carbonic waters and gases which dissolved the shells and coral reefs. Pressure and heat also played a prominent part in this process, causing the crystallization of calcium carbonate. Some, however, have remained practically unaltered, and their marine origin is revealed by their internal structure. The principal deposits of this kind are :

Foraminiferal limestone, composed of minute shells formed by foraminifera—a group of many-celled organisms, the calcareous shells of which are pierced with numerous pores or foramina, through which protrude the delicate filaments of the organism—and its nature is readily recognized under the microscope unless the stone has been subjected to such pressure that the fragments are too small for identification. Chalk is one of the most representative of this class of limestone, but portions of the carboniferous limestone are equally characteristic, and still other varieties are found abroad.

Calcareous ooze is composed chiefly of foraminifera and globigerina shells, and is found at great ocean depths. It corresponds in many ways to chalk which has not as yet been consolidated. Various types of this material occur. The blue mud contains up to 35 per cent. of calcium carbonate, whilst the green

mud, coral, and other muds contain much greater quantities, some being nearly pure. These materials are usually inaccessible, and where near the shore they are not employed to any great extent.

Coral rock is a limestone formed by coral-building polypi, the original structure being gradually obliterated by the action of water, which first dissolves and then re-deposits calcium carbonate in a form similar to that in stalactites. In Great Britain, the rocks known as *Devonshire marble*, *Frosterley marble*, and other decorative stones in the Devonian and Carboniferous systems are coral limestones.

Bryozoa limestones are composed of the remains of Bryozoa. The term "Bryozoa" embraces all minute mollusca which inhabit compound structures and were formerly regarded as zoophytes. The term refers to their branched and mossy form. In the British Isles they are best represented in some of the Yorkshire magnesian limestones. The crags of Suffolk, Norfolk, and north-eastern Essex are Pliocene beds, and contain large quantities of shells and fragments of Bryozoa.

GEOGRAPHICAL AND GEOLOGICAL DISTRIBUTION

In order to appreciate the geographical distribution of the various calcareous materials previously described, it is necessary to bear in mind that they have been laid one upon another—often with enormously thick layers of other substances between them. The action of the weather and other natural forces has resulted in the removal of some of these layers in some localities, whilst in other areas the lowermost layers are exposed at the surface. In many places the layers are not flat, but at a steep angle with the horizontal, and the rocks are often broken and "faulted."

Calcareous materials occur in almost all geological formations, but those of commercial importance in England all occur above what is known as the Ordovician System, and are chiefly confined to the Devonian, Lower Carboniferous, Jurassic and Chalk formations. These formations occupy something like two-thirds of the country. The order in which they occur is shown in Table I. The most important lime-bearing deposits in Scotland are between the Firths of Forth and Clyde. Some small deposits of travertine also occur in different parts of the country. The chief lime-bearing deposits in Wales occupy the greater part of the country to the east of Cardiganshire, Carmarthenshire, and Merionethshire, with the exception of an area in the south occupied by the Devonian slates and the S. Wales coalfield (the latter, however, is surrounded on three sides by limestone) and another in the north-east occupied by the North Wales coalfield. In Ireland, the chief lime-bearing deposits occur in the centre of the island, whilst carboniferous limestone also occurs at Skerries, Lexlip, Tullamore, Gillogue, Limerick, Brachernagh, and Foyne.

No complete account of the distribution of the various limestone chalk, and marble-bearing deposits has yet been written;¹ the information—which is

¹ A highly informative and unusually readable volume *Limestones* (London: Murby and Co.) by Dr. F. J. North should be read by those requiring fuller information on the geography and geology of limestone than is contained in the present chapter.

very voluminous, though much of it is of minor commercial importance—is scattered through numerous Memoirs of the Geological Survey, Transactions of the Geological and kindred Societies, and in various semi-private memoranda. Much of it is only of interest in connection with particular localities. The following notes from the sources mentioned above, are purposely confined to matters of more general and industrial interest :

PRE-CAMBRIAN AND CAMBRIAN LIMESTONES-

There are no pre-Cambrian limestones in England. In Wales, they occur in *Anglesey, Holy Isle, and Lleyn Peninsula*. In Scotland the best known pre-Cambrian limestones are the *Appin, Ballachulish, Islay, Iona, and Lismore*, and in Ireland the best known is the *Connemara Marble*.

TABLE I

Systems.	Groups.	Periods.	
Post-Tertiary (Quarternary)	Now being formed (<i>cement-clay, silt, fluvial and alluvial clays and sand</i>).	Cainozoic or Tertiary	
	Fresh-water (<i>limestones, tufa, stalagmites</i>).		
	Recent (<i>brick-earths, sand</i>).		
Tertiary	Pleistocene (<i>boulder clay, brick-earths, sand and gravel</i>).		
	Pliocene (<i>shelly sands, brick-earths</i>).		
	Oligocene (<i>shelly clays, sand, limestones</i>).		
	Upper Eocene (<i>sands, clays</i>).		
	Lower Eocene (<i>pebble beds, sands, clays</i>).		
Cretaceous	Chalk (<i>chalk, Totternhoe Stone, Kentish Rag, Marble</i>).		Mesozoic or Secondary
	Upper Greensand and Gault Clay.		
	Lower Greensand (<i>sands, clays</i>)		
Wealden (<i>sand, sandstone, clay</i>).			
Jurassic (Oolitic)	Purbeck beds (<i>clays, limestones</i>).		
	Upper Oolite (<i>limestones, sands, clays</i>).		
	Middle Oolite (<i>limestones, sands, sandstone, clays</i>).		
	Lower Oolite (<i>limestones, sandstones, marls, clays</i>).		
	Upper Lias (<i>shales</i>).		
	Middle Lias (<i>ironstone, limestones, sand, clay</i>).		
Lower Lias (<i>clays, limestones</i>).			

Triassic	{ Upper Trias (<i>marls, shale, sandstones</i>). Lower Trias (<i>sandstone, dolomite, clays</i>).	Mesozoic or Secondary		
Permian			Permian (<i>magnesian limestones</i>).	
Carboniferous	{ Coal Measures (<i>shales, sandstones, coal</i>). Millstone Grit (<i>grits, sandstones, shales</i>). Yoredale Series (<i>shales, limestones</i>). Carboniferous Limestone.	Palaeozoic or Primary		
			Devonian	{ Devonian (<i>shales, grits, limestones</i>). Old Red Sandstone (<i>calcareous beds in sandstone</i>).
			Silurian	{ Upper Silurian (<i>shales, limestones</i>). Lower Silurian (<i>grits, flags</i>).
			Ordovician	Ordovician (<i>limestones, slates, grits</i>).
Cambrian	{ Upper Cambrian (<i>slates, flags</i>). Lower Cambrian (<i>slates, grits</i>).			
			{ Upper beds (<i>schists, serpentines</i>). Lower Beds (<i>quartzites, schists, unimportant marbles</i>).	
Archaean or Pre-Cambrian				
Metamorphic	Metamorphic (<i>clay-slate, quartzites, micaschists, gneiss</i>).	Azoic or Hypozoic.		
Igneous	Granites, etc.			

Among the more important foreign pre-Cambrian limestones are *Silician Marble* (Tuscany), *Carrara Marble* (North Italy), and some limestones in *Ontario* and *Quebec* (Canada).

Cambrian limestones are commercially unimportant in England and Wales, but in the north-west of Scotland the Durness limestones form very thick and rather inaccessible beds of dolomitic nature.

ORDOVICIAN LIMESTONES

In the *Ordovician strata* the most important limestones are the Bala limestone in the Bala district, the Shalebrook limestones near Haverford West, and the Hirnant limestone of the Lake District. These are all too impure to be used for the manufacture of high-grade lime, and can only be employed for building purposes and as roadstones.

SILURIAN LIMESTONES

In the *Silurian strata* the limestone usually occurs in large lenticular masses, sometimes miles in length, which are crowded with corals, indicating their coral origin. They also contain finely preserved fossils, including sea-lilies or crinoids. The deposits in the Silurian system, known as the Aymestry,

Wenlock, and Woolhope limestones, are largely used for building stone and for lime. The "Dudley Limestone" is a variety of Wenlock limestone much used for lime-burning and as a flux, whilst "Ledbury Marble" is an oolitic variety of the same stone.

LIMESTONE IN THE OLD RED SANDSTONE

The *Old Red Sandstone* contains thin irregular beds of limestone known as "cornstone" on account of the fact that they are suitable for treating fields used for corn growing. These limestones were probably deposited by a chemical process from the solution of the Silurian limestones.

DEVONIAN LIMESTONES

In the *Devonian system* are thick beds of limestone interbedded between shales. These were probably formed as coral reefs on the shores of volcanic islands. They vary greatly in character in different areas, only those in South Devon being suitable for use as building stones, but much of the limestone in Devon, Somerset, etc., might be used for lime-burning for agricultural purposes and for mortar, and some may be polished and used as marble.

CARBONIFEROUS LIMESTONE

The *Carboniferous* or *Mountain limestone* occurs in the lower part of the carboniferous series and forms the Mendip Hills, the Pennine Range, and some hills in South Wales and Flintshire. It is suggested that the Carboniferous limestone was formed after the subsidence of the Devonian and Old Red Sandstone rocks, the lower beds containing various fossil corals.

It is interstratified by beds of shale and sandstone and in some cases by trap rocks, and, in Scotland, fresh-water limestone is interstratified with marine limestones. In the North of England the limestone is subordinate to clays, shales, and grits, but further south it is of great importance. From the Tweed, limestone-bearing strata occur in more or less isolated areas and run southwards through the Lancashire and Yorkshire coalfields, with extensions westward to Morecambe, Furness, and the Cumberland coalfields. A broad tract extends over Derbyshire and into Staffordshire. In Derbyshire and Yorkshire the greater part of the Carboniferous limestone quarried is used for lime-burning and as a flux in metallurgical processes, though it makes a fair building stone, and has been much used for that purpose.

Some of the Derbyshire limestones are exceptionally pure and hard. One of the best known is the White Bed at Buxton. This stone consists of about 99 per cent. of pure calcium carbonate with about $\frac{3}{4}$ per cent. of free silica and $\frac{1}{4}$ per cent. of iron oxide.

The *Hopton Wood stone* quarried from the Carboniferous limestone at Middleton, near Wirksworth, in Derbyshire, is particularly well known as a desirable building stone; it also produces an excellent fat lime when burned.

Small areas of Carboniferous limestone of varying quality occur in Leicester, Shropshire, and Somerset, include the Mendip Hills, and encircle the

coalfields of the Forest of Dean and South Wales. In North Wales, this limestone occurs in Flint, Denbigh, Carnarvonshire, and Anglesey. In Scotland it occupies the lowland tract between the Firths of Forth and Clyde, and in Ireland it covers almost the whole of the centre of the country. The greater part of the Carboniferous limestone presents great uniformity of appearance, yet, when observed more closely, several varieties of structure may be observed. In some localities it is slightly magnesian, in others gypseous, and in most areas it is replete with the remains of corals, encrinites, and shells, which give to the marbles from this group their characteristic "figure" or markings. The so-called "black marble," used for statuary, etc., from this system is a limestone naturally impregnated with bitumen. Although the thicker-bedded greyish-blue stone, of definitely crystalline texture, is very suitable for building purposes, the greater part of the purer portions is used for lime-burning, as a flux in the smelting of ores, and as a neutralizing agent in some chemical processes. The so-called marbles found in the carboniferous limestones of Derbyshire, Yorkshire, and Kilkenny, are used for decorating purposes.

Among the fossiliferous marbles in this formation are the *Frosterley* (Durham), *Scar limestone* (Alston), *Dukes' Red* and *Hopton Wood* (Derbyshire), *Halkyn* (Flint), *Poolvash* (Isle of Man), and, in Ireland, the *Kilkenny*, *Irish dove*, *Armagh red*, and *Cork red marbles*.

Dolomite limestone of commercial importance occurs near Skipton, Porth-y-waen (near Oswestry), Clydach, and elsewhere in South Wales. It is formed by alteration of the Carboniferous limestone.

PERMIAN LIMESTONES

The Permian limestones in the British Isles are almost wholly magnesian and are commonly known as the "Magnesian limestone" even when—as is the case with some portions of the formation—no appreciable proportion of magnesium is present.

The main deposit lies almost due north and south, and extends from the coast at South Shields, Sunderland, and Hartlepool, through Darlington, Knaresborough, Doncaster, Worksop, and Mansfield, to Nottingham, the best qualities being from the lower portion of the deposit. When freshly broken, the best permian limestones are pale yellow, and have a bright or "sugary" appearance which soon disappears on exposure, the rock turning dull grey. In some localities the limestone is crypto-crystalline, but in others (*e.g.* Brodsworth, near Doncaster) it is almost entirely composed of fragments of bryozoa embedded in a crystalline matrix.

The *Mansfield Woodhouse* (Notts.) stone is visibly crystalline and contains specks of black iron oxide. Numerous small cavities are filled with secondary calcite.

The *Bolsover Moor* (Derbyshire) stone closely resembles it, but contains rather more quartz in the form of scattered grains.

Some of the *Steelley stone* quarried near Worksop (Notts.) also resembles

the Mansfield Woodhouse stone, but is rather coarser. At this quarry there are also Yellow Beds and White Beds.

The *North Anston* (Yorks.) stone is warm yellow, fairly compact and hard, with a duller and less crystalline texture. Its composition approaches that of true dolomite.

Roche Abbey and *Huddlestone* (Yorks.) stones are highly dolomitic in structure, and are chiefly useful as building stones.

The magnesian limestone near *Brodsworth* and *Cadeby* (Yorks.) consist wholly of fragments of bryozoa, which have been dolomitized and lie in a dolomite matrix.

Permian or magnesian limestone is used as a building stone and for mortar; selected pieces of fine texture are used for lithographic purposes. Magnesian limestone is not usually suitable for lime-burning, as the magnesia present in the burned product slakes more slowly than the lime, and the plaster is liable to rupture on setting. It is largely used as a lining for steel furnaces working the basic hearth process.

TRIASSIC ROCKS

The Trias rocks contain no limestone of importance.

LIAS AND OOLITIC LIMESTONES

The Oolitic system in England is separable into three well-marked groups

Wealden	{	Weald clays.
		Hastings sand.
		Sussex marble.
Oolite	{	Purbeck Beds ("Purbeck marble").
		Portland stone.
		Kimmeridge clays
		Coral rag (mainly limestone).
		Oxford clay and Kelloway rock.
		Cornbrash and "Forest Marble."
Lias	{	Bath or Great Oolite.
		Stonesfield slate.
		Fuller's earth, etc. (clay).
		Inferior oolite.
		Upper lias (clay and shale).
		Marlstone.
		Lower lias (clay, shale, and limestone).
Lias rock (limestone).		

The *Lias* rocks consist chiefly of clay with relatively thin beds of limestone, the latter being mainly concentrated in the lower part of the series.

The more important portions of the Lias limestone occur in an area bounded on the north by Redcar in Yorkshire, on the south by Lyme Regis in Dorset, on the east by Lincoln, and on the west by Gloucester.

There is also a small area in Glamorgan.

The *Sutton stone*, found near Bridgend, Glam., is a useful building stone, and portions of it are very suitable for use as lithographic stones. A similar, but more porous stone, is the Brockley Down Stone, found on the north of Shepton Mallet.

Aberthaw limestone—now largely used for Portland cement—is famous as having been the source of the hydraulic lime used in Smeatons' Eddystone Lighthouse.

The *Marlstone* or *Rock Bed* in Somerset, Gloucester, Northamptonshire, and Rutland is chiefly used as a building stone.

The *Hornton stone* at Edge Hill is a very soft stone, mostly used for sinks and tombstones, but too soft for external work.

The so-called White Lias at Sparksford, Somerset, really belongs to the Rhaetic formation. It is excellent for internal carving, but rather too soft for external work.

The composition and general characteristics of Lias limestone vary greatly in different localities, the proportion of calcium carbonate varying from 30 to over 90 per cent. The middle beds of the series are usually the best; they contain about 16–20 per cent. of clay, and 80–84 per cent. of calcium carbonate.

Lias limestone is not a first-class building stone, but produces excellent paving stones. It is chiefly used in the production of the well-known Lias (hydraulic) lime and for Portland cement. Selected portions are used as lithographic stones.

The best qualities of Lias lime are produced in Warwickshire, Leicester, and the neighbourhood of Bath, Rugby, and Aberdare.

The *Oolitic limestones* comprise some of the most important in the country. They are often interbedded with clays and sandstones, indicating that the sea varies frequently in depth and distance from the shore. Taking the lowest beds first and the others in rising succession:

The *Inferior Oolite* rocks extend from Lofthouse in North Yorkshire and Winteringham in Lincolnshire, diagonally in a south-easterly direction to the coast of Dorset. They comprise almost every variety of stratified rock from fine freestone, as in the Cotswolds, to a material which is so ferruginous as almost to constitute an iron ore, and from a markedly oolitic or roe-stone structure to a compact limestone with scattered oolitic grains.

The Inferior oolite beds are composed of several different series, of which the most typical are:

Ragstones (including the Trigonias and Gryphite grits).

Freestones (including Upper Freestone, oolitic marl, and Lower Freestone).

Pea Grit¹ (including Pea Grit and Lower Limestone).

The Ragstones often contain too much ferruginous clay to make them of value as limestones, but selected portions are useful, and others would make good fertilizers if means could be found for grinding them cheaply.

The Inferior Oolite in North Yorkshire is so intercalated with shales as to be of minor importance.

¹ The Pea Grit is not a grit stone, but a pisolitic oolite.

Leckhampton Hill, near Cheltenham, offers one of the finest exposures of Oolitic limestone in the country, the average depth of the freestone face exceeding 100 feet. The stone was greatly appreciated for carved work, and the lime produced is exceptionally light and porous, so that it slakes readily, and is also well suited for chemical and metallurgical purposes.¹

Near by, on Cleeve Hill, the Pea Grit and Lower Freestone are worked for the same purposes.

The Lincolnshire limestone consists of a thick lenticular development of marine limestones, the beds varying greatly in character. Among the best known quarries in this limestone are the old Freestone quarries at Helmedon and the quarries at Great Weldon, Wakeley, and near Stamford.

The compact sub-crystalline limestone worked near Hustleton, Grantham, and Waltham, is most suitable for building, but part of it produces good lime.

The *Doultling*, *Dundry*, *Painswick*, *Haydor*, and *Ketton* stones are well-known members of this formation.

The *Doultling stone*, near Shepton Mallet, Somerset, is light brown or buff, and soft when freshly quarried, but becomes paler and harder on exposure. It has been extensively used as a building stone, and it may be regarded as consisting of about 96 per cent. of calcium carbonate and 4 per cent. of siliceous clay. It produces a rich lime, containing about 1.7 per cent. of iron oxide.

The *Dundry stone*, quarried and mined on Dundry Hill, near Bristol, is a buff, sub-oolitic limestone, which has been much used as a building stone.

The *Painswick stone*, from Avening near Stroud, is a strong stone, durable in interiors, but not suitable for exposed or damp situations.

Ball's Green stone from near Nailsworth, *Clipsham* stone from near Charlbury, Oxon., and the limestone from Bourton-on-the-Hill, Glos., resemble the Painswick stone, but are somewhat inferior for building purposes.

Casterton stone, from Casterton, Rutland—sometimes incorrectly described as "Stamford Marble"—is a good building stone, very suitable for carved work.

The *Ketton stone*, from Ketton, Rutland, is a strong and durable building stone, which is soft and very porous when fresh, but rapidly hardens on exposure. It may be said to consist of about 94 per cent. of pure calcium carbonate, 4 per cent. of magnesium carbonate, and 2 per cent. of clayey matter. It should not be confused with "Ketton Rag," which is denser, and contains more crystals of calcite.

The *Weldon stone*, from Weldon, Northants, consists of several beds, including the so-called "Weldon Marble." It has been extensively used for building purposes, but does not yield a specially good lime. It may be said to consist of 94 per cent. of pure calcium carbonate, 4 per cent. of magnesium carbonate, and about 2 per cent. of ferruginous clay.

The *Ancaster stone*, from near Sleaford, Lincs., has long been famous as a fine-grained oolitic building stone. It may be said to consist of about 94 per cent. of pure calcium carbonate, 3 per cent. of magnesium carbonate, and 3

¹ This stone is no longer quarried.

per cent. of clayey matter. The lime produced from it is very fat, but contains about 3 per cent. of magnesia.

The *Haydor stone*, from near Grantham, resembles the Ancaster stone.

The *Great Oolite* series of rocks extends from Somersetshire, in a north-easterly direction into Yorkshire, and includes the Cornbrash, Forest Marble, Great or Bath Oolite, and Fuller's Earth limestone. The Fuller's Earth limestone is a blue marly limestone of no commercial importance.

The Great Oolite consists of beds of hard shelly limestone, oolitic freestone, and various argillaceous limestone, and the most typical portions consist of :

Upper Ragstones (shelly limestone).

Oolitic Freestones.

Lower Ragstones (shelly and marly limestones).

The composition varies very greatly in different localities, but it usually corresponds to a mixture of 95 per cent. of pure calcium carbonate, 3 per cent. of magnesium carbonate and about 2 per cent. of limonite (a "hydrated iron oxide").

The *Corallian beds* yield limestones of small value as building stones, but some of them are useful for lime-burning. The most important stones in this series are :

Osmington Oolite, on the South Dorset coast and south-east of Abbotsbury, consists of oolitic grains in a calcite matrix.

Marnhull stone, a marly oolite.

Todbere stone, a shelly oolitic limestone.

Calne stone, a coarse, shelly oolite.

Headington stone or *Shotover limestone*, near Oxford, is very variable in composition, the hard grey limestone being the best.

Wheatley stone, at Wheatley, near Oxford, is a hard shelly limestone with pellets of calcareous mud and a matrix of crystalline calcite, very variable in composition.

The Corallian limestones in Yorkshire are highly siliceous and useless for lime-burning.

The Cornbrash extends from Dorset to Yorkshire and is a rubbly, iron-stained limestone suitable only for the roughest building work.

The *Forest marble* is a shelly limestone, not particularly suitable for building though used for that purpose. It derives its name from Wychwood Forest, between Banbury and Oxford, and from the use of the polished stone for mantelpieces.

The Forest marble is a very impure and irregular deposit of small commercial value, except for rough walling and pitching, but many small quarries exist, especially at Bothenhampton, Long Burton, Bowden Wincanton, and Frome, for lime-burning.

The *Great or Bath Oolite* (the source of all varieties of *Bath stone*) is found only in Wiltshire, Somerset, Gloucestershire, and Oxfordshire, its best development being near Bath, Minchinhampton, and Amberley Heath, in all of which

places it has been quarried for many years. Eastward of Bath it passes into the Great Oolite limestone. The fissile beds, near Stonesfield, Oxfordshire, and in the neighbouring parts of Gloucestershire, are known as Stonesfield Slates.

The *Box Ground stone* has been quarried for centuries on and about Box Hill, near Bath; most of it is now mined. It is somewhat finer in grain than many of the other Bath Stones, is moderately dense (127 lb. per cubic foot), and is very resistant to weather.

Corsham Down stone—found just below the true Bath Oolite at Corsham—is a good block stone.

Combe Down stone, which has been quarried for many centuries at Combe Down and Odd Down near Bath, has a relative weight of 128.6 lb. per cubic foot, and a crushing strength of 117 tons. It is pale brown in colour, of medium grain, and a good weather-resisting stone.

Bradford, Winsley Ground, Stoke Ground, and Westwood Ground stones are all light brown oolites of medium grain, and of considerable use for building purposes.

Baynton stone on Bathampton Down, has been largely quarried for building purposes.

The *Minchinhampton Weather stone* is hard, non-absorbent, and sometimes shelly.

At Windrush, near Taynton, and also near Barrington Park, the Great Oolite forms an excellent block stone.

Guiting stone at Temple Guiting, Glos., is a soft, shelly oolite, which hardens on exposure and then weathers well.

In Northamptonshire, Buckinghamshire, Bedfordshire, and Lincolnshire, the oolitic structure is rare, and it is difficult to distinguish its boundaries. In this area, no really good building-stone is found, but some portions are good for lime-burning and for agricultural purposes.

The *Portland Beds* are so-named from the Isle of Portland, but they extend from the Isle of Purbeck into Wiltshire, Oxfordshire, and Buckinghamshire, and lie beneath other rocks in Sussex, Kent, and Cambridgeshire.

The character of the beds varies greatly in different localities, and only in the upper beds are limestones found.

The *Portland stone* proper comprises four beds:

Roach—a pale buff oolite.

White bed—a fine-grained creamy oolite.

Curf—poor stone.

Best or Base bed—a fine-grained oolitic limestone which has been extensively employed for building purposes. It may be regarded as an irregular mixture of 96 per cent. of pure calcium carbonate, with about 1 per cent. of magnesium carbonate, and 3 per cent. of clayey matter.

The presence of fossil casts unfits the Roach stone for general employment in dressed work, though its strength and durability make it suitable for rough walling, docks and engineering works, where finish is not required. Similarly, minor irregularities, shells, etc., render the White bed unsuitable for elaborate

or delicate carved ornaments, but do not detract from its use for the bolder forms of sculpture, such as figures on the piers around the Victoria Memorial opposite Buckingham Palace. The Base bed—sometimes known under the names of Best bed, Lower Tier, and Bottom bed—is paler, softer, and more uniform in character, but by no means so durable in exposed situations. It is, therefore, most suitably employed in interiors and for finer carvings, for which purposes it is admirably adapted.

The *Seacombe stone* is harder and denser than the corresponding stone—the Isle of Portland—and is, therefore, more durable.

The *Chilmark*, *Wardour*, and *Tilsbury stones*, which have been quarried for hundreds of years, are often difficult to distinguish from each other. They are argillaceous limestones, and correspond to a mixture of 80 per cent. of pure calcium carbonate, 4 per cent. of magnesium carbonate, and 16 per cent. of siliceous clay.

Portland stone is also exposed near Swindon, and around Shotover Hill, Oxon., but in these localities it is too sandy for burning satisfactorily. The similar stone quarried at Thame, Brill, and Aylesbury is suitable for use as a rough building stone.

The *Purbeck limestone* occurs chiefly near Swanage, and consists of thin beds of grey shelly limestone with intercalated shales. These beds are known by many different local names. The stone is extensively used for building purposes and for paving.

The Upper Purbeck beds, near Swanage, yield the well-known "Purbeck Marble," with its characteristic *Paludina* shells.

The so-called marbles of various kinds obtained from the lower Wealdon beds in Sussex (known as "Sussex" or "Petworth" marble, and in Purbeck as "Purbeck marble") and from the coralline and shelly oolites, as at Wychwood Forest, in Oxfordshire ("Forest Marble"), are not true marbles, but shelly limestones which take a good polish and were formerly used extensively for decorative purposes.

Many oolitic limestones make excellent fat limes, but on account of their relatively high degree of purity they are of little use for making hydraulic lime. Some deposits, however, such as the beds intercalated between the marls of the Kimmeridge and Oxford clays, and the nodules of oolitic limestones found in other formations (see *Septaria*), yield good hydraulic limes. The chief use of these stones is for building purposes.

CHALK

The *Cretaceous Rocks* extend from the Isle of Wight, across the southern and eastern counties, and into Yorkshire. They form an almost continuous area from the South of Dorset to the sea coast of Norfolk, and eastwards to the coast between Dover and Deal in Kent. A second area extends from Spurn Head to Filey, in Yorkshire, and includes the Yorkshire Wolds.

The Cretaceous system is divisible into three main groups :

(i) *Upper chalk*—generally soft white chalk with flints, It is one of the purest forms of calcium carbonate, though usually containing 1–5 per cent. of clayey matter. It produces a rich or fat lime, which is only suitable for “ air ” mortar.

(ii) *Lower or Grey chalk*—harder and less white, with few flints except in the North of England. It is less pure than the upper chalk and usually contains 10–20 per cent. of clayey matter. This makes the lime slightly hydraulic, so that this variety of chalk is largely used for producing building lime, known locally as *greystone lime* or *flare lime* (the latter term being a reference to the type of kiln in which it is burned). The Dorking, Halling, and Medway limes are from this formation. They slake less readily than limes made from white chalk.

(iii) *Chalk marl*—a greyish or yellow mixture of chalk and clay. This is very impure, but is sometimes used for making *clunch lime*, which is uncertain in quality and liable to shrink in setting on account of the excess of clayey matter present.

Fine chalk is readily recognized under the microscope, as it is composed almost wholly of the remains of foraminifera shells, but some chalks have been subjected to such pressure that it is difficult to recognize the shells, as they have been crushed to such small particles. In addition to its use as a building material, chalk is used by bricklayers, plasterers, cement manufacturers, and farmers, as a flux in the blast-furnaces, and, when levigated, in the form of Whiting. It is also used as a source of lime and as an ingredient of Portland cement.

A serious disadvantage in using chalk for lime-burning is its great power of holding water. This absorbed water may easily be 20 per cent. of the weight of the chalk, and its evaporation whilst in the kiln involves a great waste of fuel. This may be avoided by keeping a sufficient store of air-dried chalk for use during wet weather.

Totternhoe stone and *Clunch stone*, near Dunstable, Beds., are phases of the Lower Chalk which are soft when quarried, but harden rapidly, though not suitable for exterior building purposes.

Beer stone occurs near Axminster, and is one of the best known chalk building stones ; it is soft and easily cut when fresh, but hardens on exposure, though not suitable for outside work.

Kentish Rag is an intercalated limestone which constitutes the main part of the Hythe beds in the Weald district, the associated materials being layers of sandstone and loamy clays. It is chiefly quarried near Maidstone. Some specimens of Kentish Rag contain over 90 per cent. of calcium carbonate ; others are merely calcareous sandstone. The better qualities are hard, imperious, and grey in colour, and weigh about 166 lb. per cubic foot. On exposure, it tends to flake gradually.

Hassock and *Calkstone* are more porous varieties of Kentish Rag. In Scotland and Ireland chalk beds occur in restricted areas, but are only worked to a small extent, notably in Antrim.

TERTIARY LIMESTONES

The Tertiary limestones are of small importance in the British Isles, the only one worth mentioning being the Bembridge limestone in the Isle of Wight, which was formerly used for building purposes. Limestones found in Tertiary strata, but actually of much greater age, are the nodules of *Septaria*, which are dredged round Sheppey and Harwich. They are presumably liassic and are used in the production of hydraulic limes and calcareous cements.

These *Septaria* consist essentially of a mixture of argillaceous and calcareous materials, together with various impurities, such as iron and manganese. On account of their high content of alumina and iron they are burnt at a relatively low temperature to produce a reddish cement. Abroad, Tertiary limestones are of more importance, one of the most interesting being the numulitic limestone used for building the Pyramids.

RECENT LIMESTONES

The Recent Limestones in the British Isles are of no commercial importance. They include *stalactites* and some *travertine*, *tufa* and fresh water deposits.

PROSPECTING FOR LIMESTONES

The prospector in search of limestone need not go far in the British Isles without finding an abundance of material, though whether it is suitable for his purpose is another matter.

The information given in the preceding section on the distribution of limestone indicates the chief localities where they are to be found, and with the aid of the excellent maps published by the Geological Survey, it is not difficult—even to those with only an elementary knowledge of geology—to trace out the boundaries of the limestone or chalk in any locality. Moreover, the outcrop of bands of limestone may frequently be followed, even from a distance, as the brighter green herbage which they yield contrasts strongly with the brown moorland often occurring on one or both sides of the outcrop. Over large areas, a limestone sub-soil may usually be traced by noting the greater greenness of the plants grown on it.

Some attempt should be made to ascertain the thickness of the deposit. In an unworked area this is by no means easy, and requires considerable skill and experience, but in many parts of England a sufficiently accurate idea may often be gained by a study of the memoirs of the Geological Survey, from a careful mapping of the area, and from a comparison with quarries in other parts of the same bed. Having located the area within which the limestone or other source of lime occurs, the next procedure should be to take a sufficient number

of suitable samples. It is essential that these shall be truly representative, or all later work will be useless. If there are sufficiently good exposures, samples may be collected from these, care being taken to remove the weathered rock to a sufficient depth to permit the samples to be taken from an unexposed face. Weathered limestones and chalk often have properties so different from that of the unexposed material that this precaution is important.

In many cases it is necessary to bore before taking the sample, and when this is the case a core-drill should be used. Samples taken by drilling with an ordinary chisel or "jumper" are of little value, and are often misleading. Sometimes a trench is better than a series of borings and may be no more expensive.

The samples should weigh about 10 lb. each—larger ones being still better when obtainable—and a sufficiently large number should be obtained to represent a fair proportion of the whole bed. Unless the stone is of exceptionally uniform quality its nature cannot be judged adequately from less than a dozen samples. These should be taken from a relatively large area, 50 feet apart and at every 5 feet in depth. Whilst samples from the same bed will resemble each other very closely if the deposit is uniform, they may differ very greatly in other cases.

In collecting samples, it is desirable to include some relating to the intervening layers of other materials. The latter are sometimes of value, and, occasionally, they are very detrimental. When two adjacent samples differ appreciably, a special investigation should be made, as the bed may be badly faulted.

In calculating the amount of limestone in a given area, some idea must first be obtained of the total volume. The weight may then be calculated, on the assumption that 1 cubic foot of the stone weighs 140–160 lb. Ample allowance must be made for cracks, faults, intercalated beds, and other materials.

The following observations should be made when collecting samples :

(i) The general position of the limestone and of any other strata associated with it.

(ii) Any obvious jointings, faults, stratification, etc.

(iii) The difference between the freshly exposed and the weathered material.

(iv) The relative hardness. A pocket knife easily marks a limestone composed of crystals of calcite ($H = 3$), but these substances resist the finger nail ($H = 2$). Rocks which cannot be scratched with a knife are usually siliceous (quartz has a hardness of 7). The hardness should always be tested on a fresh (not weathered) surface.

(v) The colour or colours.

(vi) The odour.

(vii) The "feel"—whether "soapy," etc.

(viii) The apparent structure and texture as revealed to the naked eye or by means of a pocket lens, revealing whether the material is crystalline, schistose, compact, or fragmental (elastic).

The further examination of the samples should deal with (*a*) the chemical composition of the stone, (*b*) the slaking and other properties of the lime produced from it, and, in some cases, (*c*) a complete micro-petrological examination, with determinations of (*d*) the porosity and water-absorption; (*e*) crushing strength; (*f*) resistance to abrasion; (*g*) relative weight, and specific gravity. A chemical analysis alone is not sufficient to show the quality of a limestone or similar materials, as the mechanical and other properties play an important part when such a material has to be heated to convert it into lime or if it is to be crushed or finely ground for other purposes.

Moreover, a microscopical examination of a limestone often shows more rapidly and more satisfactorily the faults in the material. The chemical analysis will show the percentage of impurities, but the microscope often shows the form in which they occur, and so permits a more certain conclusion being reached. For example, the total percentage of impurities in a shelly limestone, as shown by chemical analysis, may appear to be negligibly small, but a microscopic examination may show that it would be quite unwise to use the stone for lime-burning as it is of so fossiliferous a nature that it would slake slowly and irregularly.

PROPERTIES OF LIMESTONES

The nature of the various rocks known as limestones varies so greatly that it is difficult to summarize their properties.

Chemically, all these rocks are more or less impure forms of calcium carbonate, the chief impurities being those mentioned later. The lime-burner must, therefore, either select a limestone or other raw material with a chemical composition to suit his purpose, or—which is more usual—he must endeavour to find uses for the lime produced from his raw materials. To a considerable extent, the properties of the resultant lime may be altered by the presence of clay or sand, or by such selection and treatment of the stone that little or no foreign matter passes to the kiln when a pure lime is required.

The *chemical analysis* of a limestone is of greater or less importance according to the purpose for which the stone is required. If the stone is to be used for chemical purposes, its composition (as shown by analysis) is of very great importance. For the production of agricultural lime, a limited proportion of impurities matters less, and, for hydraulic lime, it is often better to make crushing tests rather than chemical analyses of the lime produced.

In any case, the analysis of a limestone, chalk, etc., is by no means easy, and it should only be attempted by those who have a sufficient training in chemistry; otherwise, serious errors—especially in the proportion of lime and magnesia—may occur.

The effect of various impurities in limestones and other natural forms of calcium carbonate are best considered in connection with the uses of these materials. It must suffice here to state that "fat" limes can only be made from the purest forms of calcium carbonate, but the stones from which grey

lime and the like are made are more complex in composition. The chief ingredient of importance in these limes, other than calcium carbonate, is silica, best known in the form of silver sand, but exceedingly abundant as forming nearly the whole of most sandstones, and also as quartz and other minerals. This silica is not readily distinguishable as such in limestones, but is present, at least partially, in a state of combination. When such "siliceous limestones" are burned at a suitable temperature, silicates of lime are formed, which, when in a fine state of division, set on the addition of water, hence the origin of the term "hydraulic." The amount of silica varies considerably, but in the best of these limes it reaches a high percentage; thus, Lyme Regis lime, which is one of the strongest in this country, contains about 24 per cent. of silica.

It must not be supposed, however, that the whole of the silica is brought into combination with the lime on burning; even the most careful treatment leaves a large proportion in a free or useless state so far as setting properties are concerned. The proportions which give the best hydraulic effect are found by experience to be about $2\frac{1}{2}$ parts of lime to 1 part of silica by weight. No exact formula can be given as so much of the silica and lime remains uncombined.

The most important of the other ingredients are alumina and iron oxide. Although these are present in very small quantities and do not appreciably affect the strength of the material, the former at least, if not the latter, also plays a most important part in the burning process, for, by combining with the silica, it produces a compound which enables the lime and silica to combine, and it is thus responsible for the development of hydraulic properties.

For most purposes, the impurities, other than silica, may be regarded in two ways: (i) either they are inert and do no harm except by reducing the total amount of true lime present in a given weight of the material, or (ii) they are actively harmful. For building and many other purposes for which limestone or lime is employed, the impurities may be regarded as inert and mere diluents; for the manufacture of lime for use in the chemical industries they may be harmful—by setting up undesirable reactions, staining the product, and so on—and the use of limestone or chalk containing such impurities should then be avoided. The nature and effect of the *impurities* in limestone are described later.

The *chemical properties* of pure calcium carbonate are those of a base, *i.e.* it combines with acids, forming salts, with the evolution of gas (carbon dioxide) and water. The impurities present in limestone or chalk are usually inert, but may stain the product. Limestone and chalk are powerful neutralizers of acids and where there is no objection to the evolution of gas they are the cheapest base available. Where the carbon dioxide creates difficulties, the calcined stone (lime) is used and forms a cheap and powerful base.

The *solubility* of calcium carbonate is more a chemical property than a physical one. In pure water it is only 18 mgms. per litre or $1\frac{1}{4}$ grains per gallon, but in water containing carbon dioxide (carbonic acid) it dissolves much more readily and appears to form calcium bicarbonate. In such water the solubility is:

TABLE II.—*Solubility*

Temperature	Solubility
0° C.	0.70 g. per litre
10	0.88 " "
22	0.57 " "
30	0.55 " "

A supersaturated solution of calcium carbonate in water containing carbonic acid may contain 2.29 g. of calcium carbonate per litre.

The *physical properties* of limestones are almost as important as the chemical composition, and, in this respect, limestones vary from the loosely consolidated marls, through chalk, to the hard, compact limestones and marbles. These variations in physical properties are of great importance, both economically and technically, as they largely determine the properties. Moreover, a highly porous chalk or oolitic limestone will absorb more water than a compact and more impervious limestone, and so may require more fuel to burn it.

The chief physical properties of limestones are the texture, colour, mechanical strength, porosity, specific gravity, hardness, the melting point (or its converse, the refractoriness), and the size (fineness) of the individual particles constituting the mass.

The *fineness* of the individual particles is important because the ordinary methods of crushing and grinding mainly separate the material into these individual grains, only a very small proportion of these particles being broken by such treatment. Hence, when a very fine powder is required it is important to use a material composed of extremely small particles, *i.e.* with a very fine texture.

Fineness is measured by standard testing sieves designated by numbers indicating the number of meshes or apertures per linear inch. The fineness of any material is measured by the percentage of it which will pass a certain test-sieve. For instance, a material with a fineness of 95 per cent. through a 100-mesh is such that 95 per cent. of it will pass through a 100-mesh test-sieve, or through one having 10,000 openings per square inch.

No matter what the fineness, a certain percentage of still finer powder will be present which will pass through still finer sieves, *e.g.* a 200, 300, or 350-mesh test-sieve. This percentage depends upon the grinding characteristics of the material and whether it reduces to a powder easily or not.

No ground material can be correctly designated as 100-mesh, 200-mesh, etc., without including in that designation the percentage of the material which will pass through that size of mesh.

The term *texture*, as applied to a rock, means the size, uniformity, and arrangement of its constituent mineral grains. In rubble, rip-rap, or crushed

stone, texture is of little moment, but in stone of ornamental grades it is of vital importance. Uniformity in size of grain and in distribution of minerals is demanded in monumental and the best structural stone. Fossiliferous limestones are subject to differential weathering, which destroys their originally uniform surfaces.

The *colour* of a limestone is sometimes important as indicating impurities, whilst for monumental work the colour may be one of the factors which is important commercially. Rocks are of many colours, and the choice of colour for a building stone depends on individual taste or prevailing fashion. For monumental stone there is a demand for rock of practically all colours. For building stone, red, grey, brown, or white rocks are used, and dark grey or black rocks are employed but little. The buff or yellow colours of many limestones and sandstones, and the red or pink shades of many granites, are due to the presence of minute grains of iron oxides. Surface stains are serious blemishes and are generally due to the presence of small crystals of pyrite, marcasite, or siderite, which oxidize by weathering, or to soluble iron salts in the quarry-water.

The *compressive or mechanical strength, or resistance to crushing* of a limestone is best determined by subjecting an accurately ground block—usually 4-in. cube though the precise dimensions and shape are not very important—to the action of a hydraulic press of special design, which registers the pressure applied to the sample. The block should have its upper and lower faces rubbed smooth and strictly parallel. No bedding material should be used.¹ The pressure should be applied very gradually and uniformly. A note is made of the pressure reached when the block is completely crushed.

At least six pieces should be tested, as the results often vary greatly and no single result can be regarded as satisfactory.

TABLE III—*Crushing Strength*

Material.	Mean crushing strength. Tons per sq. ft.
Ancaster freestone	192·0
Box Ground	101·0
Combe Down	119·1
Ketton	102·8
Portland Base Bed	243·6
Bath Oolite	71·0
Hopton Wood	184·0
Carrara Marble	289·0
Chalk	12·0

¹ If a piece of millboard be placed above and below the test-piece, this should be mentioned in any report of the test.

The importance of a high crushing strength is often greatly exaggerated and a consideration of the greatest loads to which stones are ever subjected in use will show that a crushing strength of 350 lb. per sq. in., or 23 tons per sq. ft. is ample, and includes a sufficiently high factor of safety. Yet, scarcely any limestone of repute has a crushing strength of less than 100 tons per sq. ft., and some marbles have a crushing strength of nearly 1,000 tons per sq. ft.

Table III shows the crushing strength of typical limestones.

Chatley has given the crushing strength of limestone as ranging from 100–600 tons per sq. ft. and marble about 600 tons per sq. ft. For safety, only $\frac{1}{10}$ of the above figures is assumed in actual working.

The *tensile strength* of limestone should be made on 8-shaped blocks with a cross-sectional area of 1 sq. in. at the centre. Blocks of precisely the same shape are used in testing Portland cement, and the same testing machine may be used. Unfortunately, the preparation of the test-pieces is difficult as the stone should be ground to the required shape (cutting with a hammer and chisel may affect its strength).

There are few results published of the tensile strength of limestone ; some, obtained by the author, are as follows :

TABLE IV.—*Tensile Strength*

Material.	Tons per sq. ft.
Buxton limestone	37
Ketton	31
Portland Base	24
Box Ground	62

The *elasticity* of a limestone is difficult to determine on account of its smallness, limestone not being visibly elastic.

The *transverse strength* or *modulus of rupture* is determined by placing a long rectangular block of stone on two triangular supports technically known as "knife-edges," whilst the load is suspended by means of a stirrup, supported on a third knife-edge, placed on the top of the block and equidistant between the other knife-edges. The modulus of rupture or cross-breaking strength (in lb. per sq. in.) is calculated from the formula :

$$M = \frac{3Wl}{2bd^2}$$

where W is the load in lb. which breaks the stone, l the distance between the lower knife-edges, b the breadth of the stone, and d its depth. Baldwin-Wiseman, using blocks 6 in. \times 1 in. \times 1 in. supported on steel knife-edges, 4 in. apart, obtained the following results :

TABLE V.—*Cross-Breaking Strain*

Material.	Pounds per sq. in.
Doubling limestone	320
Box Ground	404
Bradford Oolite	401
Bath Oolite	609
Hopton Wood	1003
Micheldeven chalk	168

Tests made of transverse strength show the adaptability of the stone for use as window-caps, door-caps, and the like. The number of broken caps that may be observed in buildings indicates that sufficient care has not been taken in selecting stones for such uses.

The *volume-weight* of a limestone is a term used to indicate the weight of exactly 1 cb. ft. of the material. It is useful to know this for any given stone, but a closely accurate figure for limestone cannot generally be given, owing to variations in the moisture or "sap" in the stone making variations in the weight from day to day. Limestones from different parts of the same quarry also differ in texture, and this, in turn, affects the volume-weight.

Under ordinary conditions, air-dried limestone has a volume-weight of 120–140 lb., *i.e.* 1 cb. ft. weighs 120–140 lb. Chalk has a volume-weight of 100–115, and marbles have a volume-weight of 140–160. The volume-weight of a limestone is ascertained by cutting a cube of the material as accurately to shape as possible, measuring its length, breadth, and thickness accurately, weighing it, multiplying the weight in *ounces* by 108, and dividing the product by the volume in cubic inches of the test-pieces.

The method which is commonly adopted of weighing a piece of the stone in the ordinary way and again when it is suspended from a thread and immersed in water is quite incorrect in the case of porous stones as it gives a result which is intermediate between the volume-weight and the specific gravity. Such an intermediate result is of very little value. In the case of wholly impervious stones this method does give the true specific gravity, but it is inapplicable to most limestones as they are porous.

A modification of it which may be applied to porous stones consists in painting a piece of stone with a waterproof material, such as melted paraffin wax or methylated collodion, so as to cover it with a very thin film which seals all the pores and yet has no appreciable weight. The stone so treated is weighed first in air and then suspended in water, when the volume-weight is :

$$\frac{\text{Weight in air}}{\text{Loss of weight in water}}$$

The volume-weight of a limestone gives a good indication of its porosity, as porous stones have a lower volume-weight than the impervious stones.

Sometimes, the term volume-weight is expressed by a number obtained by dividing the weight in grammes by the total volume measured in c.c., but the term "density" is then preferable. The volume-weight of limestones varies within wide limits.

The *specific gravity* of a limestone is the weight of an average small particle of the material divided by the weight of an equal volume of water. That is to say, it is a means of comparing the volume-weights of the solid material itself as distinct from larger masses of limestone which include the pores.

Much confusion has arisen from the application of the term "specific gravity," both to the powdered material and to the massive stone, whereas the term ought to be confined to the former and the term volume-weight (or, less satisfactorily, the term "*apparent density*,") to the latter.

The true specific gravity of a limestone is best determined by crushing it to powder and using a pycnometer or "specific gravity bottle." The bottle is weighed empty, and is then filled with water to a mark previously etched on the neck and re-weighed. The bottle is emptied, dried and a little of the powdered stone is placed in the bottle, and the bottle is again weighed. The bottle is then filled to the etched mark on the neck and connected to a vacuum pump so as to withdraw any air from the pores in the stone and adherent to the particles. The volume of water is then accurately adjusted to coincide with the etched mark and the pycnometer with its contents is weighed. If :

a = the weight of the empty pycnometer,

b = the weight of the pycnometer filled to the mark with water,

c = the weight of the pycnometer and the powdered stone,

d = the weight of the pycnometer containing the stone and filled to the mark with water, then

$$\text{Sp. gr.} = \frac{c - a}{b + c - d - a}$$

To obtain the most accurate results, the powder must be fine enough to sink to the bottom of the pycnometer, but not so fine as to form a floating scum.

The true specific gravity may also be determined by weighing a piece of the stone, then boiling it in water (preferably under a partial vacuum) for some time so that the water penetrates all the pores, and finally suspending the stone in water and weighing it whilst so suspended. The

$$\text{Sp. gr.} = \frac{\text{weight in air}}{\text{Loss of weight in water}}$$

The accuracy of the method depends on the extent to which the water penetrates the pores in the stone ; the results are usually rather low.

The *porosity* of a limestone is often important as indicating the quality of the lime which will be produced from it and the amount of time and fuel required for burning it. The porosity is best determined by immersing a weighed piece of the stone in water,¹ or, still better, by boiling it in water for some time,

¹Various organic liquids, such as paraffin or xylol, are sometimes preferred to water as they are able to penetrate pores into which water does not readily enter.

then withdrawing the stone, wiping its surface as dry as possible, and re-weighing the stone. Then, if the weights and volumes have been stated in grammes and c.c. respectively, the percentage of porosity by volume (P) is :

$$P = \frac{\text{weight of water absorbed} \times 100 \times \text{vol.-wt. of stone}}{\text{weight of dry stone}}$$

If the weight of the stone has been expressed in ounces and the volume-weight in lb. per cb. ft., the percentage of porosity by volume (P) is :

$$P = \frac{\text{weight of water absorbed (in oz.)} \times 100 \times \text{vol.-wt. in lb. per cub. ft.}}{\text{weight of stone (in oz.)} \times 62.4}$$

It is quite usual to express the porosity in terms of the weight of the water absorbed by a given weight of stone, but this is not satisfactory unless the term *water absorption* is used.

The accuracy of the result clearly depends on the extent to which the water enters the pores, and as some air is usually retained, the reported percentage of porosity is almost invariably low. This can only be avoided by determining the specific gravity (S) of the powdered stone, and the density (*d*) of the stone including the pores, when

$$P = \frac{(S - d) 100}{S}$$

There are many misconceptions respecting the porosity of limestones. For instance, it is quite a mistake to suppose that the harmful action of frost is proportional to the porosity, as this is not the case. The effect of frost, as well as of heat, on the stone depends on the *size* of the pores rather than on their number or the total porosity, large pores being much more easily penetrated than smaller ones. For this reason, the porosity-figure obtained after a short immersion in cold water may have a greater practical value than the much more accurate figure obtained by more elaborate methods.

A knowledge of the porosity of limestone is important, as highly porous stones are usually wetter and require more fuel to burn them into lime.

The *rate of absorption of water* depends chiefly on the size of the pores ; it is determined by immersing weighed pieces of stone in water for a suitable time, then withdrawing each piece, wiping it dry, re-weighing, and noting the increase in weight due to the water absorbed.

The *permeability*, or rate at which water or air can pass through a stone, must not be confused with the water absorption or porosity as the former depends solely on the character and size of the pores. Permeability to water is usually determined by cementing a tall glass tube on to the upper surface of the stone, filling the tube with water, and noting the rate at which water passes through the stone after the latter has once been saturated. Alternatively, the water may be supplied under a definite pressure, such as 14.5 lb. per sq. in. (*i.e.* one atmosphere) ; the test-piece is then clamped to the tube and not merely cemented to it.

Permeability to air is determined by fitting a thin slab of stone into a suitable funnel (the joint must be air-tight) and measuring the quantity of air which will pass through the specimen in a given time at a pre-arranged pressure.

Staining Test.—A very effective test of the permeability of a stone consists in immersing the stone in either red ink or an alcoholic solution of eosin, wiping it dry, and then sawing the stone in half and examining the sawn surface.

The *effect of frost* on stone is difficult to estimate accurately. What occurs under normal conditions is that the water in the wet stone expands on freezing and so tends to force the solid particles apart, the rupturing force extending outwards. As the pores are enlarged by this means, they can hold more water during the second frost, and, therefore, the intensity of the action rapidly increases. The commonest method of ascertaining the effect of frost is to have the wet stone stored in a refrigerator. The freezing, thawing, and re-saturation with water must be repeated several times before any effect can be observed. Sometimes, instead of freezing, the stone is soaked in a hot saturated solution of sodium sulphate which crystallizes on cooling and so exerts an effect similar to frost.

The *hardness* of limestone is usually tested by seeing which standard minerals it will scratch and which minerals scratch the limestone. Fluorite (No. 4 on Mohs' scale) scratches all limestones, calcite (No. 3) scratches many limestones, and gypsum or rock salt (No. 2) is usually scratched by the limestone. Hence, most limestones correspond in hardness to No. 2 or No. 3 on Mohs' scale.

In comparing the hardness of various stones, several tests should be made of each, as a single particle of impurities of exceptional hardness may give a misleading result.

Resistance to abrasion is important where the limestone is subject to such action. It is usually tested by pressing a weighed 3 in. cube of the stone under a constant pressure of about 180 lb. against a rotating iron disc which is supplied with emery, or preferably against an emery wheel of medium grit and grade. After five minutes, or other suitable interval, the stone is re-weighed and the loss taken as an indication of the abrasion. For some purposes, it is more convenient to measure the block before and after treatment and to note the depth of material worn away.

Many *weathering tests* have been devised, but none of them are really satisfactory when applied to limestones.

The *rattler test* is of great value in testing the durability of a stone for roadmaking. In the form usually adopted for this test the machine consists of a barrel, 20 in. long and 28 in. diameter, of polygonal cross-section, and made of grey cast iron, not chilled or case-hardened metal. Seven runners are fitted to each end, as in no case should the material pass through the barrel. The charge consists of 16 blocks (4 in. cubes), which are dried and weighed before testing, and 300 lb. of balls of grey cast-iron of two sizes, viz. 10 balls weighing 7 lb. each, and 245–246 smaller balls weighing $\frac{3}{4}$ lb. each. The barrel is revolved 1,800 times in one hour. The blocks are then removed from the machine,

all pieces less than 2 in. diameter are discarded, and the remainder is weighed. The loss in weight is regarded as a measure of the quality of the material tested.

This test is of little value for the comparison of building stones, but it is undoubtedly a satisfactory one for roadstones.

The *melting point* of pure calcium carbonate cannot be determined with accuracy, as the substance dissociates into lime and carbon dioxide at a bright red heat. If the gas is allowed to escape the residual lime melts at some temperature above 2,000° C., but if the gas is retained in contact with the material the pressure it produces depresses the melting point so that fusion occurs at about 1,060° C., or at about 1,000° C. with commercial limestones.

The *refractoriness* or resistance to heat of limestone is due to its conversion into lime under ordinary conditions of heating. Blocks of limestone spall (fly to pieces) when heated rapidly and the lumps of lime produced by slower heating have a low crushing strength, so that the commercial use of limestone as a refractory material is very restricted. Dolomite, which sinters at a high temperature, is superior to a pure calcium lime for this purpose and is largely used as a basic lining in steel-melting furnaces.

IMPURITIES IN LIMESTONES, ETC.

The chief impurities in limestones, chalk, and other forms of calcium carbonate are due to materials deposited simultaneously or to inclusions which have entered the material at a later stage.

The most important impurities are :

Clay, which, when present in appreciable proportions, converts a pure or calcic lime into a marl or argillaceous limestone. The former is a useful ingredient in the manufacture of Portland cement, and the latter, if burned, forms a hydraulic lime. The proportion of clay present may be judged roughly from the alumina and silica shown in an analysis of the material. For many purposes it is sufficiently accurate to assume that the percentage of alumina when multiplied by 2.5 gives the percentage of clay present. This assumes the absence of appreciable quantities of felspar, mica, and other aluminosilicates. A certain amount of silica is required to combine with the alumina, to form clay; this amount may be found approximately by multiplying the percentage of alumina by 1.15, any surplus silica found by analysis being regarded as existing in the free state—usually in the form of quartz. Owing to the assumptions involved in this method of calculation, a microscopic examination, or an examination of the residue left when the sample is treated with an excess of dilute hydrochloric acid, is desirable. Indeed, there is no better way of ascertaining the nature of the clayey and other siliceous impurity in a limestone, etc., than by carefully examining the residue left after treatment with cold dilute hydrochloric acid. Practically all the free silica, clays, felspars, micas, amphiboles, piroxenes, olivines, serpentine, and barytes will be found in this residue.

Siliceous matter, other than clay, may occur in a number of forms the chief

of which are: (a) in the free state, as sand, fragments of quartz or quartzose rock, flint, chert, or other variety of free silica, or (b) as feldspar, mica, olivine, serpentine, talc, or other siliceous materials. It occurs in variable—though usually small—proportions in limestones, chalk, etc. If the proportion of silica is very small it may usually be neglected, but when 5 per cent. or more siliceous matter (other than clay) is present it may be detrimental, owing to the formation of partially fused silicates during the burning. These products prevent the stone running properly through the kiln, as, when partly fused, they form a thick viscous mass which “glues” the lumps of stone together. Free silica in the form of particles of appreciable size, such as coarse grains of sand or larger particles, does not readily enter into combination with lime, and is, therefore, an inert and useless diluent. Gelatinous or amorphous silica, or extremely minute particles of silica, on the contrary, readily combine with the lime during the burning, and so produce a glassy slag which may be very objectionable for some purposes for which lime is used. Silica in the form of feldspar, mica, and other silicates is usually an inert constituent of limestone, but if the material is to be heated to a high temperature they will combine with the lime forming a molten glassy mass which is sometimes objectionable. In the burned lime, these silica compounds are objectionable (a) as forming undesirable impurities in the lime, and (b) on account of their hardness, which is detrimental when the lime or ground stone is used for polishes or when it has to be passed over fine screens.

Limestone or chalk which contains less than 5 per cent. of silica, alumina, iron oxide, and other impurities yields *rich* or *fat* limes; those containing 20 per cent. or more of free silica, iron oxide, and other impurities (except clay) yield *lean* or *feeble* limes. Clayey limestones, containing about 5 per cent. of silica and 2 to 4 per cent. of alumina, yield feeble hydraulic limes; those which contain 15–30 per cent. of clayey matter yield highly hydraulic limes.

The *iron compounds* most usually present in limestone are the minerals limonite (ferric hydroxide) and pyrite (ferric sulphide), but spathic iron ore (FeCO_3), hematite, magnetite, marcasite, and various iron-bearing silicates occur in smaller quantities in some limestones. When a very pure lime is required, such iron compounds are injurious, but otherwise they can do little or no harm.

On burning, these various compounds (except some of the silicates) are converted into red iron oxide (Fe_2O_3), unless the temperature exceeds $1200^\circ\text{C}.$, when the iron may combine with some of the lime and any silica present to form a complex silicate. Limonite and compounds forming red iron oxide on heating act as fluxes if the burned lime is used at sufficiently high temperatures; at lower temperatures they merely give a reddish or buff tinge to stone or lime.

Pyrites, on the contrary, form a black siliceous slag at a bright red heat, and are regarded as objectionable.

Magnesium compounds, especially magnesium carbonate, are scarcely regarded as an impurity, except in cases when even a small percentage of magnesia

is objectionable, as the magnesia compounds reduce the speed of slaking, rendering it irregular, and the product is liable to spall when the lime is in use. Dolomite and Magnesian limestone, are, however, extensively used in some industries.

Carbonaceous matter is sometimes present, but is usually of little importance. *Bituminous matter* occurs in some limestones and is objectionable if the stone is to be burned to make lime, because the bituminous matter is usually associated with an impure stone of irregular composition.

"*Alkalis*"—sodium and potassium compounds—are seldom present in large proportions; they are only objectionable when a very pure lime is required. Small proportions of alkalis are largely volatilized when lime is heated, but larger proportions (*e.g.* more than 5 per cent. of soda plus potash) are generally objectionable and may make a limestone of small value as a source of lime.

Acid compounds—especially sulphur trioxide (SO_3), phosphorous pentoxide (P_2O_5), and chlorine—are objectionable impurities in some limestones especially those used in iron and steel manufacture.

Sulphur is objectionable in lime used for some chemical purposes and in hydraulic lime. If less than $\frac{1}{4}$ per cent. of sulphur is present it may usually be disregarded.

Limestones which are highly fossiliferous do not, usually, produce high-grade lime, as the fossils generally contain sufficient silica and calcium phosphate to cause the lime to slake irregularly and slowly, so that it may be used before the slaking is complete and may then cause a disintegration of any masonry or brickwork in which it is employed.

When considering the amount of impurities in lime it must be remembered that the calcined quicklime will contain nearly twice the percentage of impurity in the limestone, as 1,000 lb. of limestone will produce only 560 lb. of lime, the same quantity of impurity occurring in the 560 lb. of lime as occurred in the 1,000 lb. of limestone. By "picking" or screening the lime some of the impurities may be eliminated; it is, therefore, preferable to determine the amount of impurities in the burned product and not in the raw limestone.

CHAPTER II

THE EXTRACTION, QUARRYING, AND MINING OF LIMESTONE

THE term *quarrying* is applied to all methods used for obtaining limestone and allied materials either from open excavations or quarries ; the term *mining* is used when the stone is removed through a sloping adit or by means of a vertical shaft or mine. By far the largest proportion of limestone and other forms of calcium carbonate are obtained by simple methods of open quarrying, but mining is used where a valuable stone lies at a considerable depth.

Mining is only employed for excavating limestone and similar materials when they occur under such a depth of overlying strata that open quarrying is impracticable. The methods used are precisely the same as in other branches of mining and are fully described in mining textbooks. As there is no risk of fire-damp and other explosive gases in a limestone mine, open lights may be employed and explosives used to facilitate the extraction of the stone. Moreover, as " a good roof " can usually be obtained, very little timbering is required. When the roof is weak, as at Ketton and Ancaster where it is composed solely of estuarine clays, mining would be impossible, notwithstanding the thickness of the overburden. With a great thickness of overburden and a good roof, as in the Bath stone quarries, mining is the best method. The roof and overlying strata are usually supported by large " pillars " of stone, left at intervals of 10-30 ft. according to the nature of the stone.

Limestone mines are usually worked in a plan somewhat resembling the " room and pillar " system in a colliery, and consist of a main entry and a series of parallel drifts, or chambers connected by cross-cuts. Supplementary air passages may be necessary to ensure adequate ventilation. In certain cases, the pillars are about 20 ft. square, and the drifts vary from 30-60 ft. in width, with a maximum height of 35 ft.

Vertical shafts are unusual in limestone mines, on account of the difficulty of raising large blocks through them.

Intermediate between mining by vertical shafts and open quarries is the use of a system of *adits*, or tunnels, extending in a sloping direction, usually the same inclination as the dip of the stone. Such an arrangement saves the cost of a vertical shaft, and yet has all the other advantages of mining.

Adits are specially used in localities where the thin workable beds with steep dip have been worked from the outcrop. Where possible, the adit should be inclined downwards towards its entrance, as this facilitates drainage ; it is not always possible to do this as the adit must, to a considerable extent, follow the dip of the limestone beds.

The most common method of opening a mine is by horizontal entry.

What is termed the "glory-hole" method is employed in some mountainous regions. A tunnel is driven into a ledge at its base end and at the inner end of the tunnel a large chamber is blasted and used for the rock to be removed from above. A slightly inclined shaft is then driven to the surface and the rock quarried round the opening in a circle of ever increasing size, so that the hole assumes the shape of a funnel, and the rock is gradually worked down into the chamber.

As the stone is removed, the "roof," if not strong enough, has to be supported by timber or concrete props, as in coal mining. Fortunately, extensive propping is seldom necessary, but sometimes pillars are built of useless pieces of the stone.

When working an adit, it is generally necessary to loosen the blocks by means of crowbars and wedges, explosives not being usually permissible. The loosened blocks are then hauled through the tunnel or adit to the open air.

Mining is so much more costly than open quarrying that the latter should always be used when possible. For this reason it is often cheaper to remove 30 ft. of overburden, and then to quarry the limestone by open working, than it is to excavate it by mining without removing the overburden.

Mining is advantageous (*a*) when the overburden is very thick and forms a good roof; (*b*) when the desired bed of stone is at a low level or steeply inclined; (*c*) when quarrying would result in a pure stone being mixed with other materials which would spoil it; and (*d*) where climatic conditions are unfavourable to open-air work. The yield of small stone is usually greater in mining than in quarrying and this increases the difficulty in finding a market for this material.

The most important of the limestones obtained by mining are some of the Bath stones, the Purbeck stone, and the Wenlock limestone near Walsall and near Dudley Castle.

Quarrying should always be used in preference to mining where quarrying is practicable as it is cheaper and offers much better facilities for inspection of the material *in situ*.

As illustrating two entirely different methods of getting limestone, the Keinton and Bath stone quarries may be mentioned. The Keinton stone occurs near the surface in well-defined horizontal beds with good natural joints, so that the blocks can be levered out with crowbars and then lifted about as required, the quarry being worked in benches or floors rather than faces. The Bath stones, on the contrary, occur in deep beds which rarely outcrop and have to be reached by long inclines or adits. A layer of rubbish between the free-stone and the roof is first removed by picks. The stone is then laboriously sawn into blocks, the saw cuts being taken down to natural joints, and the blocks are levered or lifted by cranes into trolleys and then hauled to the surface.

Selecting a Site.—It is of great importance, before actually opening out a quarry, that the site should be carefully and skilfully chosen, as a mistake in this preliminary work may eventually result in the failure of a quarry which ought to have been highly successful.

A considerable number of quarries have been started on the wrong side of a

hill, so that no advantage can be taken of the dip or lie of the strata. In other cases, the men work "straight ahead" into a hillside, when it would be much cheaper to "edge" the hill and to work at right angles to the present direction; this is especially the case where there is a thick covering of overburden or useless material.

Sometimes a site is chosen which is suitable in some respects, but is, on the whole, inferior to another possessing a single drawback which could be overcome by ingenuity.

Again, a site is sometimes selected near the top of a high hill and a long way from the railway or road, yet stone of the same quality is available much nearer to these facilities. In these and in many other ways, is the selection of a suitable site of paramount importance.

In selecting a site, special attention should be paid to (i) the overburden; (ii) the position of the dip and strike of the strata; (iii) the drainage possible; (iv) the water-supply; (v) the haulage grade to crushers or kilns and from thence to the railways; (vi) the position of the railway and the cost of a siding; (vii) suitable sites for power station, crushers, stone-dressing appliances, etc.; and (viii) the transportation facilities. All these items are of great importance, and if any one is wholly unsatisfactory the site should be abandoned.

The thickness of the overburden and the cost of removing and disposing of it very largely governs the value of a given limestone deposit, for it is obvious that an excessive thickness of useless material cannot be profitably removed to clear a comparatively thin bed of limestone. Hence, the site should be chosen so that a minimum of overburden may be moved. From this, it is clear that the maximum thickness of the overburden which can be removed economically depends on the thickness of the underlying stone and on local conditions respecting the disposal of the overburden.

The steepness or dip of the strata has a serious effect on the cost of haulage, especially if it is away from the face of the quarry so that all the stone has to be hauled up an incline. Such downward dipping strata also cause further trouble by acting as catch-pits for rain-water unless a suitable system of drainage is installed.

Selection of strata.—It is important to decide which strata are to be worked because some are usually more valuable than others, and if a system of working can be employed which leaves the less valuable or useless strata undisturbed it may be profitable to employ it.

The greatest uniformity in the quality of the material is usually obtained by working the selected strata separately in benches, taking care to avoid admixture with other material.

In some cases, uniformity of product is best secured by mixing material from several strata in prearranged proportions. The quantity of each in any one "lot" should be small, as uniformity will not be secured by tipping large wagon-loads of each material in succession into a bin.

The lay-out and planning of the quarry cannot receive too much skilled attention for much of the difference between success and failure in working

limestone depends on the efficiency of the system used. Each quarry or mine presents its own special problems, and unless these local considerations are duly taken into account there is likely to be failure.

Indeed, the many failures of firms engaged in working limestone show how foolish it is to re-start a quarry or mine without having first obtained the necessary skilled advice and properly-considered plan of working and development.

The site having been selected as skilfully as possible, the man in charge of the lay-out or working plan should exercise his skill and ingenuity in arranging that all the operations in the quarry shall be planned so as to avoid all methods that place an unnecessary burden on labour. Thus, excessive re-handling of material, complexity in transportation systems, and loss of time through the conflict of various operations should be avoided. In many cases this can be accomplished by modification of method, involving no heavy expense in the purchase of new equipment. In large quarries, hand methods are being largely superseded by mechanical means, not because of any shortage of labour, but because mechanical methods are cheaper, quicker, and promote a material and rapid increase in production.

When labour is cheap and plentiful, the advantages of mechanical equipment, particularly in small quarries, are questioned by many quarry-owners. In large quarries, the advantages of mechanical equipment are generally recognized. The adoption of such equipment has, however, been slow in many places. This is due to various causes, the chief of which are conservatism, lack of information on modern equipment, and lack of capital.

A fruitful source of waste is the undesirable handling of material owing to the rock being unloaded and reloaded unnecessarily, or dumped in places that require excessive labour for its subsequent removal. Such excessive rehandling may be due to lack of equipment, to faulty plant design, or to carelessness and oversight, but, whatever the cause, its effects on the profits are obvious. Such unnecessary handling is always costly, and in time of labour shortage, it is imperative that radical changes be made to remedy such faults.

In laying out a quarry, it is necessary to look well ahead, and to consider what will be the effect of the present arrangements when the quarry has been working 15-20 years. A further matter of importance is the "weight \times distance" factor of all material moved—a factor which must be kept at a minimum. Many men in planning quarries pay much attention to the weight of the material to be moved, but they overlook the distance which it has to be taken.

It is essential to ensure the stability of the quarry, and all necessary precautions to secure it must be taken; otherwise, there may, at some time, be a serious land-slip and lives may be lost. The precise precautions to be taken to ensure stability depend upon the locality, but, as a rule, the width of the bench or platform should be equal to the length between each bench, and at least half the height.

In quarrying limestone, it is always preferable to follow either the dip or the strike rather than work across them, as the latter tends to yield stone of maximum variation in composition and quality.

The loosened stones are moved more easily if the strata dip downwards away from the face, but in steeply inclined beds care must be taken to avoid serious slipping, which may cause accidents.

It is desirable to commence quarrying at a sufficient elevation so as to keep the floor of the quarry well above the drainage-level of the surrounding country. A high start also has the advantage that the stone can be delivered into the top of the kilns without the necessity of raising it by an elevator. For these reasons, wherever possible, the quarry should be made in the side of a hill rather than by excavating below ground-level though, in some cases, the latter is unavoidable.

In quarrying chalk, it is generally regarded as impracticable to work below the water-level in the chalk because of the enormous storage properties of this material. With modern methods of pumping, however, it ought to be possible to work below the water-level in those few cases where higher levels are impracticable.

The quarry-face should not usually be worked to a height of more than 25 ft. at a time, *i.e.* if a greater height of face is desired, it should be worked as two or more separate faces, each of which is not more than 20–25 ft. in height. Excessively high faces are not economical as they involve special precautions to ensure safety as well as the use of excessively large cranes, etc., which increase the cost of working. These objections are avoided by working in sections or benches of 20–25 ft. in height.

Whilst it is often the case that the present owner of a quarry can find far better methods of working than those actually adopted and is hampered by the manner in which his predecessors have worked, there are few quarry- or mine-owners who look sufficiently far ahead in regard to the development of the property. This is exceedingly important and should receive the fullest and most skilled consideration, particularly where there is a larger amount of overburden to be tipped or where expensive machinery or kilns are likely to be employed.

The other chief items requiring attention in planning any given site or quarry are : (i) the floor ; (ii) the drainage ; (iii) the removal of the overburden or stripping ; (iv) the methods of extracting the stone ; (v) the removal of the stone to the masons' yard or crushers ; and (vi) the position of the various accessories.

The *floor* of a quarry must not be too small in relation to the output, or working will become increasingly difficult, and must eventually stop.

The floor of the quarry, where possible, should slope away from the face ; where the nature of the strata permits it, an almost level floor is, in every way, preferable to a steeply sloping one. The arrangement of the floor of the quarry so as to ensure good drainage is very important, and failure in this respect is one of the commonest causes of loss in the limestone business. In one locality

where the limestone beds dip about 4 degrees a quarry was opened in such a manner that development took place down the dip. As a consequence, accumulation of water at the working-face after very heavy rain caused a temporary suspension of operations with consequent loss of labour. Had the quarry been opened in such a manner that development proceeded in the opposite direction, the water would have drained away and no accumulation of water at the face would have been possible. Where the limestone lies in horizontal beds, the utilization of an open bed plane for the quarry-floor, or a bench floor, not only makes blasting easier, but the smooth surface that results requires little or no grading or ballast for tracks, and track-laying may be accomplished with a minimum of labour. A smooth floor also facilitates loading.

The *drainage* of a quarry is a matter which should have more attention than is commonly paid to it. The wise quarry manager will always endeavour to secure natural drainage as far as possible, and even where some pumping is necessary, it is most economical to attempt to secure natural drainage for the quarry as a whole and to pump the water from a sump or well into which the quarry drains naturally. This can be secured with a little forethought and planning so that there is a slight slope in the floor of the quarry towards one definite sump or well. Unless this is done, there will be a series of delays, much slow working, and some accidents because the quarry-face and floor are too wet. It may seem to be an unnecessary expense to plan the quarrying so as to secure a well-drained face and floor, but it is well worth it. In some old quarries it has even been found profitable to abandon the existing face and to re-open the quarry at a different point so as to ensure efficient drainage. The lower costs of working the quarry under dry conditions rapidly paid for the cost of re-opening the stone at a different point. Where such a course would be regarded as too drastic, it is usually possible to work along the strike, *i.e.* at right angles to the dip of the strata, in order to secure natural drainage of the sections or benches.

Another matter of great importance is the position of the tramlines or tracks leading from the quarry-face to the works. If these are wrongly-placed, either the men will be hampered in their work or great expense may be incurred in putting the tracks in a suitable position. The ordinary method consists in arranging a series of tracks radiating from the main line, or pair of main lines, to various parts of the quarry-face (fig. 1). In many respects this is a good arrangement, but it has the minor drawback of compelling the men taking trucks or wagons to the face either to wait until the track is clear or to throw the empty wagon off the line and to re-instate it later—a process involving unnecessary labour, delay, and damage to the wagons. By using double tracks, this trouble may be largely avoided, though even then it is sometimes difficult to secure a wholly satisfactory method of delivering empty wagons and removing full ones.

Where conditions permit it is often better to arrange a track along the quarry-face and to have the material thrown into the wagons on this track.

Some quarrymen object to this because the tracks have so often to be altered, but in many cases this is less serious than is often supposed.

When a steam-navvy, grab, crane, or other mechanical loader is used, the arrangement of a track along the quarry-face is by far the simplest and the best (fig. 1).

No one method is equally satisfactory in all cases and the quarryman who would get the best results must exercise considerable ingenuity and skill.

The *position of the machinery* relative to the quarry-face and to the spoil-bank on which the overburden is tipped, requires careful consideration. The machinery ought obviously to be placed in a position where it is free from all danger from land-slips or explosions. It should also be placed in such a position as to be out of the way of development of the quarry-face, spoil-bank, or

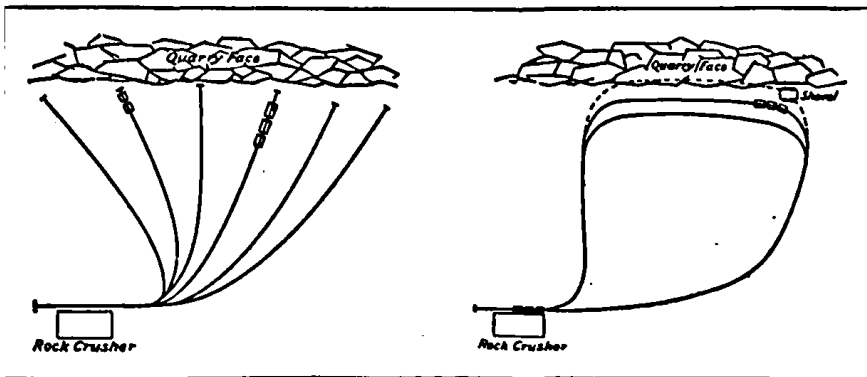


FIG. 1.—ARRANGEMENT OF TRACKS IN QUARRY FOR HAND AND MECHANICAL LOADING

railway-siding, and yet convenient for the supply of power and readily accessible from the works. Here again, no general rule can be applied to all cases, but it is usually wise to keep the machinery well in front of the quarry face, and somewhat below the quarry-floor so as to make full use of gravity. The distance between the quarry-face and the machinery ought to be sufficiently large to accommodate the spoil-bank unless there is some hollow somewhere which can be filled with overburden and can never be required for any other purpose. A serious mistake, which is often made in planning a quarry; is to place either the spoil-bank or the machinery on good stone which cannot, therefore, be quarried and is to all intents and purposes lost.

It is an excellent plan to allow space for machinery capable of five times the anticipated maximum output of the quarry, as this allows of ample development, keeps the plant well out of harm's way, and generally facilitates the working of the quarry. If worked stone is one of the products, the stoneyard should usually be situated alongside the machinery and the location of both may be considered together.

The chief *sources of power* in quarrying or mining and in working limestone, chalk, and marble are steam, producer gas, and electricity, with compressed air

or water (wave transmission) as secondary sources of power. The use of these in connection with drilling have already been described; the power required for crushing, transport, etc., is more conveniently described under these respective subjects, and it must here suffice to state that in planning a quarry or mine, ample power should be provided, even though it is not all required at first; as the output increases it is then easy to proceed, whereas in the absence of provision for ample power the whole future of the property may be jeopardized.

Stripping or ridding, i.e. the removal of overburden, such as clay, gravel, sand, sandstone, or useless superficial material, such as grass and soil. In some localities, this overburden is 30 ft. or more in thickness, and its removal involves problems in quarrying which are almost as great as those in connection with the removal of the limestone itself. In most cases, however, it is not profitable to remove more than 6 ft. of overburden.

The overburden to be "stripped" or "ridded" is usually of a relatively soft nature, and it can then be removed by digging either by hand or by excavating machines, or, if sufficiently thick or accessible, by means of a steam-navvy. Where the quarry is near a water-course, the ridding is sometimes effected by washing away the material hydraulically with powerful jets of water applied by fire-engines or similar appliances. In such cases, powerful hoses are used through which a stream of water $1\frac{1}{2}$ in.-2 in. diameter, at a pressure of 40-60 lb. per sq. in., is directed on to the material to be stripped and the latter is rapidly washed away. If water is rather scarce, it may be collected in settling ponds, and the clear water used over again, but this method of stripping gives the best results when the waste material can be discharged into a pit, a river, a deep lake, or into the sea.

This is a cheap method, but it can only be used where there is an abundant supply of water and a large dumping area at a suitable level.

The nature and amount of material to be moved governs to a great extent the methods to be used. The most expensive method of removing overburden is by pick, shovel, and wheel-barrow or wagon. These tools can only be applied economically where the overburden is very thin or the conditions such that other implements cannot be employed. Under average conditions a man may be expected to shovel into an ordinary wagon 40 cubic yards of light sandy soil or 25 cubic yards of heavy soil, well loosened, per day. In shovelling ordinary earth, a large number of experiments have shown that the most economical load for an average shovel is 21 lb. The size of the load and the shape of the spade or shovel vary with the material being handled, and if these matters are properly cared for, there is a possibility of increasing many a man's output by about 50 per cent. as most men lift about 15 lb. on each shovelful. This increase in output comes partly from experience and industry but chiefly by fitting the shovel to the work and seeing that the man is taught how to use it.

In loading wagons, a man working under normal conditions, and using a D-handled shovel, will throw the following amounts in ten minutes:

TABLE VI—Shovelling Earth

Height of wagon	Volume of earth thrown
3 ft.	1.4 cb. yd.
4 ft.	1.33 „ „
4 ft. 6 in.	1.2 „ „
5 ft.	1.1 „ „
5 ft. 6 in.	0.9 „ „
6 ft.	0.8 „ „

In casting ordinary earth through a horizontal distance not exceeding 10 ft. a man will average 18 shovelfuls per minute.

In loading wheel-barrows or low carts, without tall sides, not exceeding a height of 33 in., a man casting average earth will have an output of about 15 shovelfuls per minute.

The influence of several men on each other is important, and a good foreman with a gang of contented men will get more and larger shovelfuls than if the men are discontented or isolated.

As the number of shovellers to each wagon is increased, the average efficiency will decrease, and if ten shovellers were employed on one truck the average efficiency would not exceed 85 per cent.

As a correct position is essential in shovelling, it is well worth while to teach a man how to dig and shovel properly. Few labourers know how to handle their bodies or the shovels so as to make the work easy for themselves and rapid for their employers.

The men should be placed at their work according as they are right-hand or left-hand workers. The right-hand man casts his load from his right side while the left-hand man throws from his left. Where possible the men should be trained to shovel either right-handed or left-handed.

Standing close up to the material, the man should bend his back and his shoulders forward, not as in picking articles from the ground, but so that he is well balanced, one leg being well in front of the other. In digging, the spade should be pressed downwards, then lowered back, and lifted up horizontally with the load. In shovelling, on the contrary, the wrist of one arm should be laid on the knee of the front leg, and the other knee should rest against the end of the shovel. The shovel is thrust into the mass by the movement of the body, the object being to throw the weight of the body into the motion used in thrusting the shovel. When the shovel is full, the knees are straightened without straightening the back much and without altering the position of the hands. The load is then cast away by turning the body when the height and distance are not great. With longer throws, the arms must be used to give the shovel the necessary motion.

When conditions permit, and only a small outlay of capital is possible, a

plough and scraper are probably the most efficient implements which can be employed for a thin overburden on account of their adaptability and comparatively cheap working cost. The plough is necessary to loosen the earth before the scraper can be filled. A drag-scraper is more suitable for close work and short hauls, and a wheel-scraper for open work and long hauls. The latter should be used whenever possible, since it has a larger capacity than the former, and, being on wheels, is much easier for the horses. One plough moving fairly steadily can loosen about 300–400 cubic yards per day. Better results can usually be secured in very hard or tough ground by a scarifier drawn by a tractor or roller, but in ground of this nature blasting is usually more economical where the depth of material to be loosened exceeds 3–4 ft.

Drag-scrappers have a gross capacity of 3, 5, and 7 cubic feet, and a net effective capacity of about 60 per cent. of these quantities. Each scraper, when drawn by horses, will recover 50–65 cubic yards of material per day under average conditions, but a drag-line scraper has four times this output. Ploughs and similar appliances are only suitable where the overburden consists of relatively soft material, such as "soil," clay, sand, or gravel. For a thicker overburden some form of excavator is usually the cheapest means of removal, the type which is the most suitable in any one quarry depending on the nature of the overburden. Where this is relatively soft a drag-line excavator, or, sometimes, a grab, can be used, but for harder material a "navvy" or mechanical shovel must be used (fig. 2).

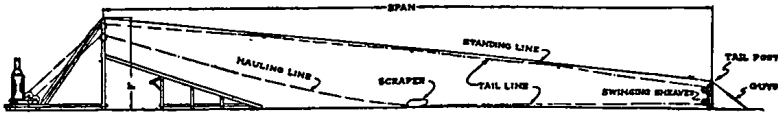


FIG. 2.—DRAG-LINE EXCAVATOR.

Drag-line excavators consist of a rectangular tray or skip with a cutting or scarifying device at the front. The tray is suspended from an elevated ropeway in such a manner that it can be drawn along the ground by a hauling-rope and can dig slightly into the ground and fill itself simultaneously. As the hauling-rope may be of any convenient length a drag-line excavator has a wide range of action, and can be used on slopes as well as on level ground.

Drag-line excavators are not seriously affected by water or floods, and they can often work under conditions which would be unsuitable for any other form of mechanical excavator.

Drag-line excavators are of two types: (i) those in which the skip is hung from the jib of a crane and is hauled towards the body of the crane, and (ii) those in which the skip is operated by a ropeway. The latter have far greater range, though a skilled man operating the first type can swing the skip 30 ft. or more beyond the end of the jib.

In both types of drag-line excavator speed of operation and ample digging are the most important factors; flimsy apparatus is useless in this type of excavator.

A *Mechanical Navvy* (fig. 3) is the cheapest means of excavating a thick

overburden ; it works most efficiently in loose material sufficiently thick to allow the shovel to make a cut throughout the greater part of its stroke, as steam-navvies are not usually economical when they cut or dig during only a small fraction of the stroke.



FIG. 3.—MECHANICAL NAVVY.
(By courtesy of Ruston-Bucyrus Ltd.)

Such a navy requires a small gang of men, and, when worked properly and well supplied with wagons, can load a great mass of material in a day. Efficient service depends on strong mechanical construction, and adequate care and management by a skilled worker. Inefficiency usually results from inadequate supply of wagons for the removal of the loaded material rather than from improper handling of the steam-navvy itself.

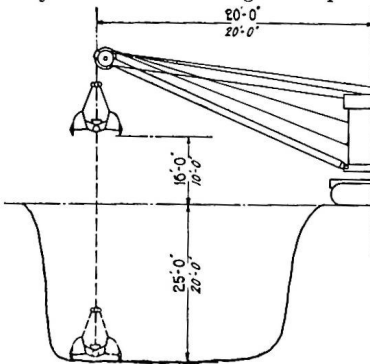
While the first cost of a mechanical navy is high, with proper care the cost of maintenance is not excessive, and where the rock surface is fairly uniform and level, a navy is probably the best device for removing any considerable thickness of overburden. In fact, four or five men with such a navy can load as much rock as forty-five men by hand methods.

For excavating rocky material a large and powerful navy is needed, the "railroad" type being preferable, but for softer material and for smaller outputs a revolving navy is often more advantageous, especially if it is mounted on wheels or "caterpillars" so as to travel forward under its own power. As the smaller navvies are not so strong as the larger ones, care should be taken to select a machine of ample strength for its intended purpose. Thus, it may be more profitable to purchase a machine of much greater strength than is needed for the stripping if it can be used later for loading the limestone.

Although usually known as steam-navvies, these machines may be driven by oil or electrically, and in many quarries oil or electricity is preferable as it saves the cost of hauling coal to the quarry-face.

The saving effected by using a mechanical navy depends on the proportion of the working day that it is actually digging, and this depends on having wagons or cars ready to receive the excavated material. The wagons or cars

may often be run along the top of the bank of a shallow cut and kept moving



NO 15 DIMENSIONS IN BOLD FIGURES
NO 10 DIMENSIONS IN ITALICS

FIG. 4.—GRAB-EXCAVATOR.
(By courtesy of Priestman Bros. Ltd.)

in a continuous line, saving the delay of turning and backing up to the navy which is necessary when they move over the quarry-floor.

For precautions regarding the use of steam-navvies see p. 74.

Grab-excavators (fig. 4) are similar in many respects to a "navvy," but instead of the bucket being forced into the material by means of a powerful arm or boom, a "grab" or "clam-shell" bucket is suspended from the end of the jib, and as it drops on to the ground it digs into it. On tightening the appropriate rope, the grab is filled, closed, and hauled up. The crane then revolves, and eventually the contents of the grab are discharged into a truck or wagon (see p. 73).

Ladder-excavators (figs. 5 and 6) are a modification of a well-known device known as a "Bucket-elevator" and consist essentially of an endless belt to which is attached a series of "buckets" each provided with a digging or cutting edge. The buckets are placed at a suitable angle to the surface of the material to be excavated and as the belt rotates each bucket digs into the material, is filled, carried forward, and eventually discharged into suitable wagons. If the

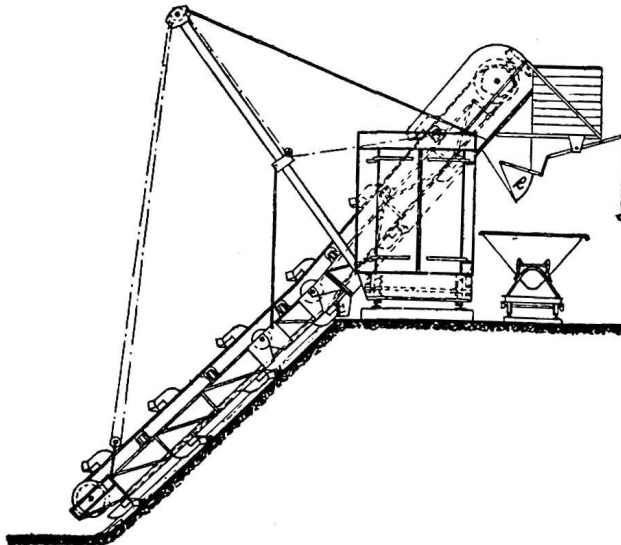


FIG. 5.—LADDER-EXCAVATOR AT HIGH LEVEL.

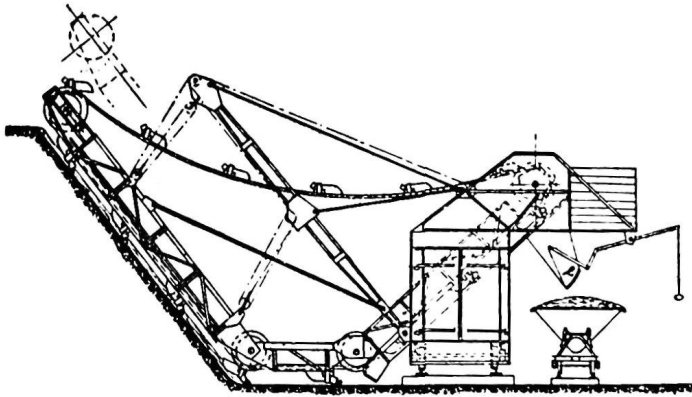


FIG. 6.—LADDER-EXCAVATOR AT LOW LEVEL.

belt is of sufficient length, the excavated material may be carried sufficiently far to be tipped at the back of the workings where it will do no harm and the expense of wagons may then be saved. Ladder-excavators are chiefly used on steeply sloping faces, but they can be worked satisfactorily on an almost horizontal surface when required. The driving and supporting machinery may be either above or below the material to be excavated, the former position being usually preferred. The overburden in limestone-quarries is seldom thick enough to enable a ladder-excavator to be used economically.

Explosives may be used for loosening rocky or other hard overburden ; they are employed in a manner similar to that used prior to excavating the limestone-rock. The loosened material is then loaded by one of the appliances described above.

The cost of removing overburden and delivering it into wagons may be estimated roughly from the following figures :

	Per cubic yard.
Hand-shovel and tipping-wagon method	15d.
Steam-navy and wagons hauled by small engine	8d.
Steam-navy and stripping-conveyor returning overburden to disused workings	1½d.
Drag-line scraper (to loading platform only)	1½d.
Hydraulic stripping	1½d.

These figures are quite general in character, and may have to be modified greatly before they can be applied to some quarries.

The disposal of the overburden is a matter to which thought should be given, because a second removal of the material at a later date will add unnecessarily to the cost of working. This is a precaution which ought obviously to be taken by all quarrymen, yet it is surprising to find how often the overburden is tipped on good stone which will be required at some future time.

In selecting a tip or dump, care should be taken that (i) the material

placed on it can do no harm, and (ii) it will not in any way interfere with the future development of the works.

Sometimes it pays to carry the "stripping" to a natural valley, hollow, or swamp, which will be more useful if filled, but usually the best place for the overburden is behind or well to one side of the works or between the works and the quarry-face.

For conveying the stripped material to the tip, wheel-barrows, wagons, or conveyor-belts are used, but, occasionally, an overhead ropeway is employed. Wheel-barrows are the slowest and most expensive, except for very small quantities; conveyor-belts are cheapest if the quantity to be conveyed is sufficient to justify their instalment and the distance is not too great. For longer distances, the choice between wagons and a ropeway must largely depend on local conditions.

Where a wide top is required to be made by means of a ropeway, the use of rocking towers at either end of the rope may be an advantage. An arrangement of this kind—known as the Harrington rocking cableway—is supplied by the Railway and Industrial Engineering Co., Greenburg, Pa., U.S.A. The other devices mentioned are so well known that no detailed description of them is necessary.

EXTRACTING THE STONE

The various methods used for removing the limestone and delivering it either to the works or to trucks, etc., for further conveyance, may be classified under two main heads: quarrying and mining. In the former, the overburden is removed by one of the methods previously described, and the stone is thus made accessible in an open working, whilst in mining the overburden remains *in situ*, and the stone is cut from beneath it, the only portions of the overburden to be removed being that which is necessary to secure a good "roof" to the mining galleries.

In order to remove the stone from an open quarry, the first step after the removal of the overburden consists in loosening the stone, so that it may be removed to the wagons, etc., used to convey it to its destination.

If it is desired to obtain the stone in very large blocks for masonry work and the like, it will be necessary to use crowbars, wedges (fig. 7), and similar appliances, which will separate the stone at the natural joints and enable it to be transferred to wagons or trucks.

The use of these simple tools is well known and need not be described in detail. They are essential when the largest blocks of stone are required without risk of shattering by explosives, but when smaller pieces of stone suffice—as is the case for all except wrought stone—such slow methods are too costly, and more rapid and powerful agents, such as explosives, must be used. The application of explosives is commonly known as *blasting* (see later).

In some quarries cutting-tools of such power are employed that blocks of almost any size can be cut from the parent mass. The more important of such power-driven machines are:

Channelling machines are practically reciprocating drills, so arranged that a steel bit or series of bits is made to cut a groove of any desired depth in the stone while the machine travels over the surface for any distance up to 50 ft. When these machines are used, the rock is cut into blocks of suitable size, which remain fast on their beds and have to be lifted with crowbars, wedges, or a light charge of explosive. Where the joints are horizontal the channelled blocks may be lifted off by means of a crane.

Channelling is by no means a cheap process, and great care should be taken in investigating the probable cost of operation before installing a channelling machine.



FIG. 7.—USE OF PLUGS-AND-FEATHERS IN QUARRYING.
(By courtesy of "The Stone Trades Journal.")

Sawing is largely used as a means of extracting large blocks, and a number of different kinds of saws are used. For many purposes, an ordinary toothed saw fitted with a single handle, the whole being about 7 ft. in length, is satisfactory, and is found to be cheaper than channelling machines for cutting the Bath limestone.

Hand-saws are of little use for horizontal cuts, and they are used to best advantage for making vertical cuts in stones having pronounced bedding planes.

The helicoidal *wire-saw*, on the contrary, can be used for both horizontal or vertical cuts. This saw is practically a taut, endless cord, $\frac{1}{8}$ – $\frac{1}{4}$ in. diameter, composed of three wires twisted together, the cord being made to travel continuously in one direction at the rate of 15–20 ft. per sec. by means of a grooved pulley of 20 in. diameter, over which it runs. The wire is fed with sand and water, which form the true cutting agent. Guide pulleys, which are lowered into pits at each end of the "cut," are used to keep the wire in contact with the stone. The wire cuts the stone quite cheaply, but the cost of making the pits at each end is always heavy, and often serious, especially as in limestone they

cannot usually be more than 30 ft. apart. If a penetrating pulley is used, the pits are not required, as the pulley cuts a way for itself. The wire-saw is so highly appreciated on the Continent that it is remarkable that it is seldom used in the United States and in Great Britain.

SOURCES OF POWER

The sources of power available in quarries are steam, oil, gas, compressed air, compressed liquid (wave transmission), and electricity.

Steam and gas are only used for driving fixed engines, compressors, and dynamos, as they cannot be carried for any great distance. At the quarry-face, or in underground workings, compressed air, compressed liquids, oil, or electricity are the chief sources of power, and all are convenient and satisfactory.

Compressed air is obtained by means of a compressor which may be driven by steam, oil, gas, or electricity. The compressed air is conveyed by pipes to whichever part of the quarry or works it is required. It is chiefly used for operating pneumatic boring tools at the quarry-face, but it is also used for pneumatic chisels or other tools used in dressing and carving the stone.

Air-compressors are of three chief types: (a) the horizontal slow-speed type; (b) the vertical quick-revolution type; and (c) the turbo-compressor type.

The durability of type (a) and its accessibility for repairs and adjustment make it popular, but it requires large foundations and buildings.

The vertical quick-revolution type (b) has the advantage over the horizontal type in the space occupied, but its general inaccessibility and its heavy upkeep are against its adoption.

The turbo-compressor type (c) is chiefly used for very large capacities and, owing to its high speed, motors of moderate dimensions can be fitted. The efficiency of turbo-compressors has been greatly improved, but it is even yet questionable whether they are as efficient as reciprocating compressors. Moreover, in actual work compressors often run much below full load, and the efficiency of the reciprocator under these conditions is much higher than the turbo. Full details of the construction of each type of compressor are to be had from the manufacturers.

In selecting a compressor, the following factors should be considered:

- (i) The primary power must be reliable and efficient.
- (ii) The suction stroke of the compressor should, throughout its length, fill with air at atmospheric pressure.
- (iii) On the compression stroke there should be no loss of air by too late closing of the inlet-valves, nor should there be any leakage back, but the whole contents of the cylinder, less the minimum of clearance, should be discharged through the outlet-valves.
- (iv) The outlet- or discharge-valves, should have ample area of opening, should open automatically on the pressure in the receiver being reached in the compression cylinder, and the air should be discharged at a pressure as little

above that in the receiver as possible, as excess pressure causes a rise in temperature with increase in volume, requiring a corresponding increase in the work necessary to compress and discharge the air.

(v) The discharge-valves should have sufficient width of seating to ensure their keeping quite tight, so that no loss by leakage back into the cylinder may take place.

(vi) The valves should be self-adjusting at all speeds and pressures.

(vii) All valves and the piston should be easily accessible for examination and removal.

(viii) The compressor should have full volumetric efficiency.

(ix) Wear and tear should be reduced to a minimum.

(x) An efficient unloader must be fitted.

(xi) A good fly-wheel and an efficient governor are essential.

(xii) In two-stage compression, efficiency depends upon the intercooler which should keep the high stage intake air at the same temperature as the lower stage intake air, and air-cooled to within 20° F. of the entering cold water temperature. The water supplied to the intercooler should be at least 2½ gal. per min. per 100 cu. ft. of free air.

(xiii) The receiver should be placed within 40–50 ft. of the compressors—its use being (1) to eliminate pulsation effect ; (2) to minimize the frictional loss attending the flow of air in the lines ; (3) to serve as a reservoir ; and (4) to cool the air and cause it to deposit its moisture.

(xiv) The receiver must be of ample size (one or more auxiliaries near to the face often effect a saving). By adopting a large receiver capacity, the compressors can run at a continuous speed—the pressure being retained a longer period at its maximum ; this allows the machines to work a longer period with greater power, and the periods of minimum demand are utilized by the compressors in filling up the receiver and increasing the efficiency of the plant.

Compressed liquids are chiefly used for the wave transmission method invented by G. Constaninesco, and used in the machines supplied by W. H. Dorman & Co. Ltd., Stafford. Wave transmission may be briefly described as a mode of conveying power by a series of impulses, imparted to a column or pipe line of fluid (usually water) by a very simple generator coupled to a steam-engine or other prime mover. These impulses, or waves, travel at the same speed as sound, and they can follow each other at any desired interval. The great advantage of wave transmission as compared with compressed air is its economy of power which in the end, of course, means a saving of cost. In working a rock-drill, for example, wave transmission delivers eight times as much power at the rock-face as compressed air, with the same input of power. The difference represents approximately a saving of 70 per cent. in power. There appears to be an enormous future for wave transmission ; at present it is only used to a small extent.

Oil (including *petrol*) is used for tractors and other locomotives and the small stationary engines employed for driving outlying plant. The various types are well known and need not be described in detail.

Electricity as a source of power is so well known as to need no description here. It is often the most convenient source of power on account of the simplicity of its use and the distance to which it can be carried. Electrical appliances are, however, rather sensitive, and often require more careful treatment than those operated by compressed air.

As an instance of the amount of power required, it may be mentioned that one firm with a daily output of 35,000 tons of stone, employs the following plant : Two five-drum Stirling boilers with superheaters, supplying steam at 140 lb. pressure per sq. in., superheated to 460° F., to two Belliss high-speed engines ; one electrical generating set of 250 kw., running at 375 revs. per min. and supplying a three-phase current at 550 volts and 50 periods ; a second generating set of 160 kw. running at 428 revs. per min. ; motors with a total capacity of 800 h.p. are used ; they are distributed over a length of about three miles. The motors are of the " Cascade " type, designed to give 100 per cent. overload, as these have been found to run exceptionally steadily under unavoidable variations of load.

SEPARATION OF USEFUL STONE AND RUBBISH

When stone is quarried for certain purposes it is necessary to separate the useful stone from the rubbish. This is mainly done by hand-sorting, but in some quarries a sloping grate is fixed at a suitable level so that when the mixed stone is tipped on to this, the larger sizes pass down into one set of wagons whilst the smaller pieces pass through the grating into other wagons (see also *Screening*, p. 148). The grates are moved as the quarry progresses, so as always to be in the best position to avoid waste of labour in loading. This device may also be used for separating small and large stones. The use of these grates is stated to have effected a saving of 32 per cent. in the cost of loading in one quarry.

Alternatively, both the rubbish and stone may be cleared away by separate continuous mechanical conveyors, such as oscillating shoots or conveyor-belts.

The ingenuity of some quarrymen using only hand-tools is so great that it is often doubtful whether the introduction of power-driven tools would effect an appreciable saving. In other quarries, on the contrary, there is ample scope for effecting great savings by the use of more modern appliances.

BLASTING

Blasting consists chiefly in boring or drilling one or more holes in the rock, inserting a suitable quantity of an appropriate explosive, and igniting the latter in such a manner as to loosen as much rock as possible and—in some cases—to reduce the larger blocks to smaller ones of convenient size.

If it is desired to loosen the natural blocks so that the stone may be used for monumental or similar purposes, the drilled holes must be few and far apart and should contain a small charge of mild explosive. If, on the contrary, the stone is to be broken into small pieces, the explosive should be more powerful

and the drilled holes should be fairly close together. Although the loosening of large stones requires a less powerful explosive, a relatively larger amount is required to break down defective blocks which have been loosened than would have sufficed to reduce the stone to small pieces before it had been loosened. For this reason, it is usually more economical to divide a quarry into two parts, one of which is worked for large blocks and the other in which the material is reduced to small pieces by more powerful blasting. As each quarry differs from others, the manager should carefully investigate the relative merits of these methods of blasting in the place under his control. It is equally important to remove the stone in a wisely systematic manner so as to keep the quarry and working face in a state convenient for working. Otherwise the future development of the quarry may be seriously hampered or even stopped.

Although many rules have been proposed in order to increase the efficiency of the blasting operations, it is still a fact that better results will be obtained by an experienced, intelligent quarryman working without any conscious adherence to rules than those which result from the efforts of less experienced men who follow rules closely. In deciding the best position for the charges of explosive as well as the amount of each charge, judgment is more important than any rules, though the latter are valuable as rough guides to general practice which ought not to be disregarded without reasons. The wise quarrymen in charge of the blasting operations will, in fact, regard rules as the summary of other men's experiences rather than as inflexible commands. In short, the precise method of working should depend on local conditions, and as these differ in each quarry only a general idea can be given here.

The *position of the bore-holes* should be selected in accordance with the natural joints or divisional planes of the stone as, in most cases, these will determine the limit of the effect of the explosive by providing a vent through which the explosive force will escape. For this reason, it is obviously wise to avoid drilling through horizontal or inclined joints or planes of fracture.

As the greatest effect will be obtained if the explosive meets with an equal resistance in every direction, the position should be chosen where such an effect is desired. Hence, the depth of the bore-hole should usually be equal to its horizontal distance from the face, though much will depend on the structure of the stone, the number, size, and position of the joints in the interior of the rock, and the tendency of the stone to break along particular lines of weakness.

When very large quantities of rock are to be shattered at once by means of a single, heavy charge, it is particularly necessary to find a part of the rock of great uniformity as if this is not done there will be a serious waste of explosive owing to much of its force being dissipated along joints, fissures, and cleavage planes.

It is often advantageous to prepare a number of bore-holes and to explode them all at the same time as the effect is thereby increased if the holes are not too far apart. It is often difficult to decide whether a single large charge—constituting a "chamber charge" or "mine"—is preferable to a series of bore-

holes fired simultaneously ; in limestone-quarrying it is often better to fire very few shots at a time so as to avoid undue shattering of the stone, but so much depends on local conditions and requirements that general rules are of little use.

The *size of the bore-holes* depends on the explosives used ; with gunpowder, holes 1 in. or $1\frac{1}{4}$ -in. diameter are usual, but smaller holes may be used for dynamite. Very narrow holes are not advisable, however, as they are difficult to charge properly. Bore-holes more than 3 ft. deep are usually 2 in. or more in diameter for the upper part and 1 in. diameter for the last 3 ft. The holes should be truly circular and cleanly bored. Their size and depth should be tested before use by inserting a suitable testing rod.

The depth of the bore-hole, as already stated, should not extend to a horizontal joint or plane of fracture. When there are two free faces to the rock to be blasted, a horizontal line from the bore-hole to the nearest face should be about two-thirds of the depth of the bore-hole ; in some (unusual) circumstances, very deep bore-holes relatively near the face would be justifiable.

Improper arrangement of the drill-holes, imperfect balancing of charges, or the use of too powerful or too weak an explosive may result in a very inefficient blast, and, as a consequence, the loading may be greatly hampered, particularly where many large charges are fired simultaneously in deep churn-drill holes, the mass of rock thrown down occupying the fillers for several weeks or even months. If the rock is imperfectly shattered, or improperly thrown down, excessive secondary blasting may be required and the filling of the wagons may be both slow and difficult. On this account it is false economy, both of money and of labour, to place inexperienced men in charge of the blasting.

The toughness of the rock is also an important factor in connection with secondary blasting, as tough rock with few seams or bed planes tends to break into large cubical pieces requiring maximum secondary blasting. The proper method of dealing with such rock can usually be determined only by experience. By varying the diameter, spacing, and burden of primary drill-holes, or by varying the amount or nature of the explosive the foreman may be able to arrive at a combination that will promote effective shattering during the primary explosion and thereby reduce the amount of secondary blasting required. It is evident that the amount of secondary blasting required in connection with unsound rock ledges is largely dependent on the skill employed in primary blasting.

Drilling the bore-holes is a matter requiring considerable skill and care as a faulty hole may cause a serious accident. These bore-holes may be made in several different ways : (i) by hand ; (ii) by augers turned by hand-power, with or without a mechanical feeding appliance ; (iii) rotary power-drills ; (iv) percussion power-drills ; and (v) well-drills. The height of the bank, depth and diameter of the holes, hardness of the rock, cleavage, wetness of strata, the necessity or advantage of speed in drilling, and other conditions, vary so much that there is no one universal system of digging or boring which has been found to outshadow the rest.

The cheapest method of drilling the holes is by means of a pneumatic hammer, a wave-transmission device, or other power-driven appliance, but where power is not available hand-drills are used. The old hand-drill or jumper will always be of service where it is difficult to supply air or steam, especially for small holes, and to depths not exceeding 15 ft. The tools required for this work are : 6 lb. sledge-hammer and three drills or spuds varying in length from 3-4 ft. up to 10-12 ft. It is necessary to have these lengths to suit the convenience of the men as the hole deepens. The drills are of tool steel $\frac{3}{8}$ -in.- $1\frac{1}{4}$ -in. diameter : the lower end is frequently drawn out to a fan-shaped bit or cutting point. A bucket of water, a dipper, a brush or "swab," and a scraper for cleaning are also needed. The drillers usually provide their own swab by cutting a young sapling (preferably of hickory) an inch or so in diameter and about 10 ft. long. Then by pounding or mashing the thick end with the sledge-hammer, they fray it for a length of 6 to 8 inches.

In drilling a vertical hole, one man uses the sledge-hammer, the other the shortest drill, which he holds plumb at the point selected for boring. The man with the sledge-hammer, called the striker, proceeds to strike the drill with quick sharp blows, while at the same time the driller between each blow of the sledge-hammer raises the drill a short distance and during the same interval twists the drill through an angle of from 30-40 degrees. Each four or six blows, therefore, cut the bottom of the hole over its entire area, creating numerous small chips of loosened rock.

The above procedure is continued until several inches to a foot of rock have been drilled. A little water is now poured down the hole, the brush end of the swab inserted, and after a short churning up and down is withdrawn laden with the newly made mud. On withdrawing, the swab is given a sharp blow or rap over a block of wood or a stone, thus freeing it of the accumulations ; possibly a little more water is added, and the work proceeds until the desired depth is reached, usually not exceeding 10-12 ft. The hole is now dried and cleaned out as carefully as possible by pouring down a handful or so of dry dust at a time and withdrawing it in a spoon or scraper. In wet rocks or those permeated by water-bearing seams, this drying is very difficult ; it may be avoided by using a cartridge of oiled or soaped paper, which will slip down the hole quickly and permit a shot to be fired before the water soaks through the paper.

The *auger drill* is not applicable to rocks of all degrees of hardness. It is limited to those of about the hardness of coal, gypsum, talc, and soft limestones, and it is inapplicable to really hard rocks, like sandstones, granites, etc. The simplest form of this drill is provided with a double brace or handle devised for rotating the auger, using both hands to maintain the motion and the chest to supply the pressure of the drill against the rock. This simple form is only applicable to soft rocks.

The forms commonly used for limestones consist of a frame fixed upright or inclined between the floor of the quarry or mine and some point above it in the face of the rock or in the roof of the mine and braced in position by screws

and guys. The auger is mounted on the end of a long screw or threaded steel bar, which is passed through a nut fastened in the frame. By turning the screw it feeds itself through the nut at the rate of about $\frac{1}{8}$ in. per revolution. The turning is effected by a crank or handle on the end of the screw or by the intervention of gears with two or three different rates of motion, if the rock to be drilled is fairly hard. The power is supplied by the driller himself. A man will make a 3 ft. hole $1\frac{3}{4}$ –2 in. diameter in ordinary rock in from twenty to thirty minutes and often much quicker.

These drills are of good service in mines, where the roof or floor offer facilities for fixing them in position readily. They will make holes at almost any angle, but most easily when horizontal. They are used, but not so easily, along the floor of a shale-bank, in an inclined position, and for making horizontal holes or holes inclined downwards. They are not successful in making vertical holes in open workings.

One plant using both the above types of drills at their pit reports that they have successfully brought down a 30 ft. bank by drilling 15–18 ft. horizontal holes at the bottom with a thread bar auger drill and 12–15 ft. holes at the top with a hand drill, and firing electrically both sets of holes at the same time.

Rotary power-drills (fig. 8) and *percussion power-drills* are only used on the larger plants, though a rotating drill driven by compressed air will bore small holes faster than any other drill. Under good conditions four holes have been drilled in less than four minutes. Part of the exhaust from these little machines can be turned down through the hollow drill to blow the cuttings from the hole. $1\frac{1}{2}$ in. holes and 6 ft. depths are the ordinary limits of the smaller size hammer rotating drills. For best results, these drills require about 50 ft. of free air per minute under a pressure of 80–100 lb. Rotating hammer-drills are specially valuable where there are many large pieces to be broken. Tripod drills driven by steam or air are adapted to vertical or horizontal holes up to 4 in. diameter; depths greater than 20 ft. can be reached, but the long steel rods required for deep holes are difficult to handle. Under good conditions, this type of drill will drill a vertical hole 60–80 ft. deep or 20–50 ft. in a horizontal hole per working day.

For drilling limestone, the end of the chisel or drill-bit should have a fairly acute angle, but if the stone is overlain by clay or other soft material a drill of wide angle should be used until the stone is entered. An acute-angled drill-bit will jam in soft rock because it penetrates faster than the loose material can be cleared away.

For rough ground which will not permit the use of a well-drill or ledge-blasting, the tripod drill is often very satisfactory.

Percussion-drills include those operated by counterpoise weights, electricity, or other simple source of power, pneumatic hammers and drills operated by compressed air and the drills operated by compressed liquid (wave transmission).

Impact drilling machines or well-drillers are used where very deep bore-holes are required. The power is transmitted through a cable to the drill, the

length of the bore being adjusted to the depth of the boring. In the Keystone Driller—which is largely used in the United States and is typical of this kind of drilling machine—a heavy drill is raised and lowered through a distance of about a yard once every second, and the flexibility of the cable is such that the drill rotates slightly after each blow. At suitable intervals the bore-hole may be cleaned by means of a sand-pump. These machines were originally used for

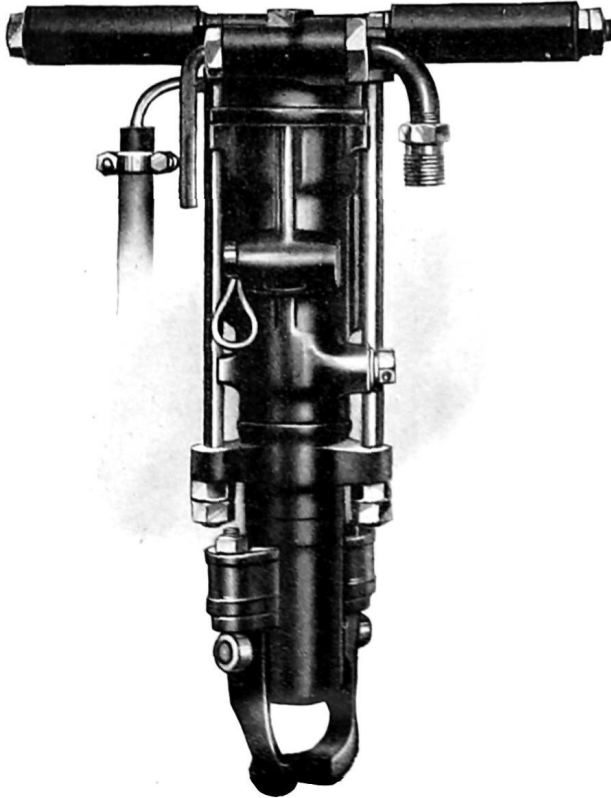


FIG. 8.—POWER-DRILL.
(By courtesy of Holman Bros. Ltd.)

oil-well and water-well drilling and can sink a hole to a depth exceeding 2,000 ft. They are self-contained machines, usually with a steam- or petrol-engine on wheels, and some of them are able to move from place to place by their own power. An impact drill is quite different from the ordinary air- or steam-tripod drill, where a comparatively light bit is driven by steam- or air-pressure against rock. With a tripod drill the depth of the hole is limited by the length of the bit and rod and it is not economical to have them longer than 25–40 ft. in length. With the well-drill, the bit is the same size for any depth required as it is

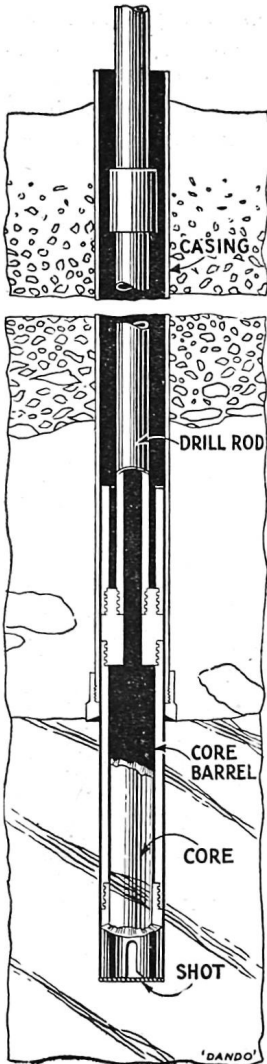


FIG. 9.—CORE-DRILL.

(By courtesy of Duke & Ockenden, Ltd.)

suspended by a rope or cable, the deeper holes merely requiring more rope to be paid out from the machine.

What is commonly called a well-drill hole is one driven to any depth desired and usually 2–6 in. diameter. Well-drill holes for blasting are not less than 30 ft. or more than 150 ft. in depth, although some plants have found that it pays to use a well- or a churn-drill for holes as shallow as 8 ft. in ground level enough to move from hole to hole without much difficulty.

Some of the advantages of using a well-drill are that a hole can be put down the entire depth of the quarry-face; it can be made of such a size as to contain very large charges of explosives without springing. The drilling machine can be run when operated by steam or petrol after the main power-plant and air-pressure are shut down. On account of the larger diameter of the well-drill holes, it is possible to place them farther apart and farther from the face than would be possible with the tripod-drill and to bring down a much larger quantity of rock. On the other hand, the tripod-drill is much more easily moved from place to place, can be easily put up in irregular places, and can drill a hole in any direction—up, down, straight in, or slanting downwards—whereas the well-drill or churn-drill is limited to vertical holes.

Core-drills (fig. 9) consist of a long tube, the lower end of which is fitted with a cutting edge, or preferably with diamonds, so arranged as to produce a core which can be removed either in the drill or separately. Such drills are invaluable when prospecting or investigating the nature of a bed of rock, etc., but they are usually too costly for boring prior to

the use of explosives. Core-drills are usually started by hand, but in the later stages of drilling they are rotated by machinery.

Tripod-drills require two men each, a runner and a helper, except that in some circumstances one helper is deemed sufficient for two drills. Hammer-drills require no helpers and are, therefore, more economical in labour than tripods. Wagon- or churn-drills usually require two men each,

though some electrically operated churn-drills employ only one man each.

The *churn-drill* is a comparatively recent type of equipment in limestone quarries, but it is rapidly gaining favour and is in successful use in many places. Whilst there are conditions where it is claimed that other types of drills render better service, the churn-drill has the advantage of accomplishing the work of four or five tripod- or hammer-drills with no greater labour than is required for a single tripod. Churn-drills not only effect a decided saving in labour in the actual drilling process, but their employment may also result in a marked saving in labour in other ways. When tripod-drills are employed in deep quarries the face must be worked down in a series of benches. Bench cleaning is, therefore, necessary and tracks must be moved frequently. These expenses are unnecessary when churn-drills are employed.



FIG. 10.—EFFECT OF EXPLOSION BY LIQUID OXYGEN.
(By courtesy of Liquid Oxygen Explosives Ltd.)

Each type of drill has its own particular advantages, but so much depends on the nature of the rock in any locality that no general comparison is of much value.

Most power-driven drills, when used for vertical holes of moderate depth, may be held by one man, but for drilling holes in an almost horizontal position some form of holder or quarry-bar is desirable.

The *explosives* used in quarrying limestones are of various kinds, and considerable care and skill are needed in their selection. For a very soft stone and for merely loosening large blocks, gunpowder or other weak explosive applied in fairly large quantities is the best, but for harder stone which is to

be reduced to small material an explosive containing a small proportion of dynamite or one of the modern safety explosives is more suitable.

On the whole, coarse grained gunpowder is usually preferable to dynamite and other high explosives except for those occasions where a very great shattering effect is required, as in clearing away rock and rubbish for which no use can be found, or where the stone is used in small pieces, as for fluxing purposes. For the production of lump lime or road-metal, on the contrary, a high explosive is not suitable as it unduly shatters the stone. Notwithstanding this serious drawback, high explosives (in the form of safety explosives) are often used in limestone quarries on account of the low cost of using them.

It is important to remember that a small charge of dynamite or a "safety explosive" in which the dynamite is diluted with some inert material has a different effect from a large charge of gunpowder or other slow-acting explosive, and in most limestone quarries the effect of gunpowder is the one desired. If gunpowder cannot be used, a diluted high explosive or safety explosive should be employed.

Liquid Oxygen (fig. 10) is being increasingly used in place of more orthodox explosives as it is free from the danger of misfires and poisonous fumes, requires no special regulations for storage or transport, can reproduce the effect of any existing explosive, and is much cheaper.

Each cartridge of the Weber type requires about 20 cb. in. of liquid oxygen the production of which, with the cartridge, costs about 2d. The liquid oxygen can be carried by road or rail for about 50 miles with an insignificant loss of material, but it is best to have the liquefying machine in or near the quarry.

The cartridges contain a metallic powder which is quite inert until the cartridge has been impregnated with liquid oxygen. They pass from the impregnator directly into the shot hole and may be fired either by a time-fuse or an electric detonator.

As soon as the oxygen from a mis-fired charge has evaporated (which it does automatically) the cartridge becomes inert and harmless so that it can safely be withdrawn. Any unexploded cartridges left in the rock can do no harm if struck by a pick or shovel.

To illustrate the effect of the explosive it may be said that, in one limestone quarry, one hole 15 ft. deep and three holes each 25 ft. deep were bored vertically. All the holes were 3 in. diameter. Six 18 in. Weber cartridges were placed in the short hole and ten in each of the others. About 1,500 tons of stone were blown down at a much less cost than if any other explosive had been used.

In all cases, the most suitable explosive for any particular quarry can be found by carefully conducted trials. The use of explosives is subject to stringent Regulations (see the Explosives Act, 1878, the Coal Mines Act, 1911, and later enactments). Full particulars of these can be obtained from H.M. Home Office, Whitehall, S.W.1.

The practice of drilling a hole, enlarging its base by first exploding in it a

charge of gunpowder, and then filling the enlarged hole with a more powerful explosive, is economical, as it reduces the number of holes required, but it is accompanied by serious risks, especially if the first charge has not been completely exploded.

The *amount of explosive required* is, roughly, inversely proportional to the number of free faces of the rock to be blasted. Thus, a rock with two free faces will require only half the explosive needed by a rock with only one free face, a rock with six free faces will require only one-sixth as much explosive, and so on. Another useful rule in calculating the amount of gunpowder required is to divide the cube of the depth of the bore-hole by 25; the quotient is equal to the number of pounds of gunpowder to be used in each charge. Thus, if the bore-hole is 2 ft. 11 in. deep, the cube of which is 25, which divided by 25 gives 1, so that 1 lb. of gunpowder should be used. For very large blasts, the maximum amount of gunpowder to be used is usually 1 lb. for each three tons of rock, but for some rocks as little as 2 oz. per ton may suffice. In many instances there is a serious waste of explosives, due partly to using too much in each charge and partly to wrong distribution of the bore-holes.

The object in quarrying is to rupture the rock, not to hurl it some distance. Hence, only enough explosive should be used to accomplish this. Where rock is thrown a great distance it is evident that the proper relation did not exist between the charge and the burden, and that too large a charge was used for the length of line of least resistance.

The amount of explosives required depends on (1) the kind of explosive used; (2) the depth of the bore-hole; (3) the line of least resistance; and (4) what the stone is to be used for.

The amount of 40 per cent. dynamite required by a cubic yard of rock excavated varies with the depth of the hole, decreasing as this increases. In open-cut work the formula $P = 3d$ in which P represents the number of pounds of dynamite required per cubic yard of rock, and d the depth of the bore-hole in feet, may be used.

The holes are generally spaced equal to their depth, but after 5 ft. in depth the formula $S = 2\frac{1}{2}\sqrt{d}$, where S represents the spacing and d the depth of the hole, may be used.

Another formula based on the estimated weight of rock to be moved by one charge of explosive is:

$$C = \frac{B \times S \times D \times W}{2240 \times E}$$

where C is the charge of explosive in lb., B the burden or distance in feet of the bore-hole from the face, S the distance in feet between the bore-holes, W the weight of 1 cb. ft. of limestone (often taken as 160 lb.), E the weight of rock (in tons) which will be loosened by 1 lb. of explosive.

It is convenient to make a first trial with 4 as the value of E and to judge from the result whether a larger or smaller number should be substituted in future work on the same rock.

The best results are obtained not only by varying the charge, but in changing the spacing or burden of the drill-holes. If the rock is very brittle, and is pulverized close to the explosive-charge, while insufficiently broken at a distance, it may be advisable to use smaller drills, and thus distribute small charges more generally throughout the rock.

Prior to loosening large blocks of dimensional stone by explosives, a series of bore-holes should be bored and then reamed with a reamer, having a diameter at least $1\frac{1}{2}$ times that of the bore-hole. The reamer must not be allowed to turn round or the cut will be spoiled. Very light charges are used.

Charging the bore-hole requires great care. The hole should first be tested as to diameter and depth; it should then be wiped clean and dry with a cloth. A little of the gunpowder is placed at the bottom of the hole by means of a zinc funnel, a piece of fuse with a blasting-cap inserted, the remainder of the charge poured into the hole and a paper wad pressed on top by means of a wooden rod. The hole is then filled gradually with air-dried clay or fine dry sand, inserted in small quantities at a time and tamped tight after each insertion. The length of fuse used must be sufficient for it to project a suitable distance from the hole to permit safe ignition and escape before the explosion occurs. Sand appears to be preferable to clay as a packing material as it requires less time to fill the borehole, avoids many accidents consequent on mis-firing, and does not require so much tamping; in fact, in most cases there is no need to tamp at all if fine dry sand is used.

Skilled tamping greatly increases the efficiency of the explosive.

Various other methods of charging gunpowder are used, but they are by no means free from danger.

When a high explosive or a safety explosive is used, it is supplied in the form of a cartridge, which is placed at the bottom of the bore-hole, the detonator is attached, and the hole filled with clay or sand as before. Dynamite charges are placed somewhat the same as powder, the first sticks being pressed into the bottom of the hole, then the primer or blasting-cap with the fuse attached as near to the centre as possible. The remainder of the charge is added and finally tamped with clay, sand, or ground brick. Many quarrymen contend that placing the primer on top or at the bottom gives just as good results. When firing electrically care should be taken to connect the lead wires to the fuse properly; the lead wires should not be connected to the battery until ready to fire. To prepare the primer when firing by safety fuse, the end of the fuse should be cut squarely across and placed in the cap, after first making sure that the fuse is perfectly dry. Care should be taken when pushing the fuse into the cap so that no twisting occurs. The fuse should just touch the fulminate or the varnish protecting it. With a pair of crimpers (and not with the teeth) the cap may then be fastened to the fuse. An opening is made in the dynamite stick with a wooden plug, and the fuse placed in this opening. The cap should touch the dynamite on all sides, since any space around it causes a cushion of air and lessens the effect of the detonation. The fuse is then firmly tied in place. The primer may be waterproofed by means of soap, tallow, or wax. The string

holding the fuse in place should be of sufficient length to lower the primer to the bottom of the hole. The charge should not be let down by the fuse.

Large blocks are sometimes reduced to smaller ones by a process known as *mud-capping*, which consists essentially in laying a high explosive on the block, covering it with clay, and exploding it. This method can only be used with explosives having an effect which is greater in a downward direction than in others. The charge should be placed on the spot which would be struck with a sledge if the rock were small enough to be broken in that way, and should be packed in a solid mass by slitting the paper cartridge shells and massing them together, taking care not to spread them more than is necessary. A blasting-cap, crimped into the fuse, should then be placed in the middle of the charge, and the whole covered with 6 in. of damp clay or sand, pressed firmly over the explosive, care being taken not to cover the outer end of the fuse. If the block is cracked, or seamy, the charge should be placed in a depression and covered with a quantity of clay or sand as described.

Mud-capping is very wasteful of explosives, as 1 oz. of explosive in a 1 in. hole, 12 in. deep, has practically the same effect as 1 lb. of unconfined explosive laid on the rock. On the other hand, drilling may cost as much as, or even more than, the additional explosive used in mud-capping.

Cartridges, containing dynamite, should be quite pliable. If hard, they may have been frozen, and will require to be thawed before use. This should be done by placing them for several hours in water at a temperature not exceeding 125° F. ; boiling water should not be used, nor should the dynamite be placed near a fire.

The storage of explosives must be in accordance with the Explosives Act of 1875 and subsequent orders issued under that Act. Particulars can be obtained from the Chief Inspector of Explosives, The Home Office, London, S.W.

The *fuses* used in limestone-quarrying are of two kinds—those ignited by a flame and those ignited electrically. Flame-ignition is much more risky and uncertain than the use of electricity, so that the latter should be employed whenever possible.

Ignition fuses are of different kinds, one of the best, invented by Wm. Bickford in 1831, consists of a tube of jute filled with fine gunpowder and provided with an outer casing of rubber where necessary.

The so-called “instantaneous fuses” consist of a series of wicks of compressed powder, the ends of which are fitted into a metal tube and connected to the slow fuse. These fuses are specially used for firing a number of shots simultaneously.

Electrical fuses are of two kinds with high and low tension respectively. In the high tension fuse the detonating mixture is ignited by a series of electric sparks, which pass between two copper wires in the fuse, whilst the low tension fuses contain a thin platinum wire which glows on the passage of the current and so ignites the priming. For limestone and allied materials, the low tension fuse is generally best, and is much more certain in action ; moreover, it can easily be tested, which is not the case with a high tension fuse.

A *blasting-cap*, or detonator, containing mercury fulminate or other suitable material, must be fastened to the end of the fuse which enters the bore-hole. The purpose of this cap is to transmit the spark from the fuse to the explosive in such a way as to start the explosion. When an electrical detonator is used, no fuse is needed, the detonator acting directly on the cap. The cap should be carefully crimped on to the end of the fuse so as to ensure the requisite contact.

Blasting-caps are dangerous and should be stored in a dry place where they can do no harm ; they are spoiled by dampness.

Detonators should comply with the following conditions :

1. They should contain a sufficient charge, equivalent to at least 1.5 gm., and preferably 1.75 gm. of pure fulminate (nitro-derivatives being taken as equal to double their own weight of fulminate).

2. The fulminate charge should be disposed in such a way as to detonate with the highest possible velocity, which should be about 3,300 m. per second for fulminate, and 4,500 for mixed detonators.

3. The length of the fulminate charge should not be too great in proportion to its diameter, otherwise defective propagation may ensue.

There are four methods by which the power of a detonator may be tested : (a) the lead block test ; (b) impact test on sheet lead ; (c) rate of detonation ; (d) practical tests on limit-density and -humidity. Of these tests, the second alone seems capable of being performed without special laboratories, but it has the disadvantage of not showing whether the detonation has been complete ; (d) appears the most reliable, though only comparative.

Since all cartridges are of approximately the same diameter, the detonator which will most easily produce complete detonation is the most powerful. Two of the chief causes of incomplete detonation are excessive density or humidity of the explosives, and two methods are, therefore, open for determining the practical power of detonators : ascertaining the limit-density of an explosive of given humidity they will completely detonate, or the limit-humidity, for a given density at which the same result is obtained.

The *exploder* (sometimes called a detonator, though this term is usually applied to the primer) is a device for producing an electric current which, in turn, may produce a spark or heat a wire to redness according to the kind of fuse used.

Of the various devices available for electrically igniting the charge a primary battery is uncertain, a magneto-machine requires periodical attention to keep the magneto in order, an accumulator is good but requires frequent charging, whilst a dynamo machine is quite permanent and satisfactory in every way.

The capacity of an exploder is defined by the maximum number of detonators it can fire simultaneously, without any misses, at the end of a line having a given resistance. This capacity depends essentially on the nature of the detonator used, and may vary within wide limits. It also depends on the velocity imparted to the mechanism by the shot-firer, but this cause of variation can be abolished by employing a spring that cannot be released until fully wound up.

The capacities stamped on exploders are only approximate, and their real value should be tested from time to time by connecting up a certain number of the detonators in series at the end of a line of known resistance, and finding how many can be fired at a time without any failures. If the exploder is of the variable velocity type, the operating member should be actuated moderately to allow for the personal equation of the short-firer. In order to establish a margin of safety, the resistance of the tested line should be greater than that of those actually used in practice (to allow for defective connections, etc.), and the number of shots fired in a volley should, in practice, be about 25 per cent. smaller than those successfully tried in the test.

The following are the chief reasons for preferring electrical exploders :

1. With an electrical exploder one to one hundred and fifty charges can be fired simultaneously.

2. An electrical exploder allows the bore-hole to be tamped better and gives the fullest confinement to the gases.

3. There is a fuller development of the explosive force with consequent greater effect.

4. An electrical exploder produces less smoke and fumes and permits a quicker return to the working face.

5. Better results are obtained with a smaller quantity of explosive, therefore, an electrical exploder costs less to use.

6. With a rheostat and galvanometer, the electrical connections can be tested to assure their being in order and to avoid misfires.

7. The shot-firer stands at a safe distance and does not operate the exploder until everyone is out of the danger zone. He has complete control of the entire blasting.

8. There is no need for matches, torches, or other type of open flame for the detonation of explosives where an electrical exploder is used.

The cable connecting the exploder to the charge should contain two separate copper wires, well taped, insulated, and covered with plaited cotton. The cable should be kept on a roll or drum, and special care should be taken to avoid the formation of kinks. The electrical conducting power of the cable should be tested occasionally, and any bare places covered with insulating tape.

Multiple blasting consists in boring many holes, charging them with explosives, and firing all simultaneously with an electric detonator. It is much cheaper than firing one hole at a time, especially if the whole depth of the quarry-face is blasted at once. If a face 1,000 ft. long, 70 ft. high, and 20 ft. thick can be blasted at once, the cost of explosive is about 1s. 2d. per ton. Strong detonators (No. 6 or No. 8) should be used—two or more in each hole—and their resistance to an electric current should be tested before use. All the detonators should have the same resistance or some will not be fired at the same time as the rest. In multiple blasting there is always a greater risk of misfires, which cause considerable expense and are very dangerous, and there are other disadvantages which have prevented multiple blasting from becoming very popular in this country, though it is largely used in the United States.

Secondary blasting is a term applied to the use of explosives to blast large blocks which have previously been loosened from their beds but require to be still further reduced ; such blocks are either drilled and again blasted as described on p. 57, or are mud-capped, as described on p. 67.

THE COST OF QUARRYING AND MINING

The cost of quarrying may vary from 6d. per ton for a soft chalk excavated and loaded with a mechanical navy, to 3s. 6d. per ton for blasted, hand-broken, and hand-filled small stone. The cost of mining, on the contrary, is seldom less than 2s. per ton, and sometimes rises to 10s. per ton of stone delivered into wagons at the surface.

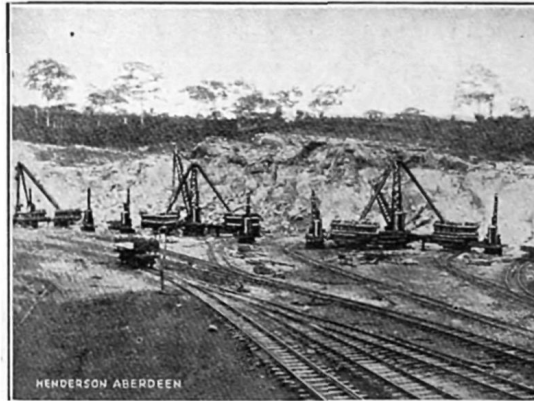


FIG. 11.—CRANES WORKING IN QUARRY.
(By courtesy of John M. Henderson and Co. Ltd.)

FILLING OR LOADING THE STONE

Before either large blocks or smaller pieces of stone can be removed from the quarry or mine, they must be placed on or in suitable wagons ; this process is known as “ filling ” when the pieces of stone are comparatively small, whilst the term “ loading ” is applied to all the material irrespective of the size of the pieces.

For *large blocks* of stone, some form of a crane is usually employed, though such blocks may be moved for short distances on rollers by means of crowbars. Occasionally, large blocks are allowed to travel down inclines or chutes, but unless these are at a very low angle they are distinctly dangerous.

The *cranes* (fig. 11) used in limestone quarries are invaluable for large blocks, and when fitted with a grab they can be used equally well for picking up small stones and “ rubbish ” and emptying it into wagons ; nor is their use confined to this, as, if well placed, a crane can be efficiently employed for haulage purposes and for moving large blocks horizontally or up an inclined plane. There is always some danger in using an ordinary crane as a haulage

device, and its use for this purpose cannot be recommended. Cranes may be of the simplest type, consisting of an upright "mast" properly supported by two or three "legs," and an inclined jib or boom, to the upper end of which is attached a pulley, over which the rope or chain is drawn by a simple hand-winch or winding gear. For very large blocks and where rapid working is important, a more suitable type of crane is that invented by Henderson in 1845, in which the inclination of the jib can be varied to suit the load, and the power is supplied mechanically instead of by hand. This type is known as a *derrick*. Both hand- and power-driven cranes are required in a well-equipped stone-quarry, the former, being semi-portable, are readily moved about as required, and facilitate the work of the larger cranes which are less mobile.

Steam- and oil- and electrically-driven cranes of various powers and excellent design are now supplied by a number of firms, each providing its cranes with some subsidiary advantage or "selling point."

Where the nature of the quarry permits a stationary crane to be used, this is an advantage, particularly where the crane has to work over a large radius, but portable or locomotive cranes, running on rails or "caterpillars" can now be obtained sufficiently powerful to do almost any work which may be required.

It is sometimes an advantage to use a crane with an extended jib, the normal portion being used for heavy loads and the extension for loads of five tons or less at a greater radius.

Locomotive cranes are self-propelling and can be used over a far greater distance than stationary cranes; they are specially used for "bank-winding," *i.e.* for lifting the material from a deep floor to the workings at a higher level and for haulage purposes.

It is a great convenience if a locomotive or travelling crane is fitted with a revolving mechanism so that the crane may be turned in every direction.

Electric cranes are in every way satisfactory when the cost of electric current is not too high; they are very rapid and very economical in regard to power, but they cost more in the first instance and for upkeep and repair. The motor on an electric crane must be of the best quality and of robust construction; a continuous current series wound motor is better than a shunt wound one, or one with an alternating current, though the latter are regarded with satisfaction in some quarries.

The stability of the crane in use is a matter of greatest importance, as more serious crane accidents are due to the crane being used outside its range of stability than any other cause. The necessary stability is obtained in stationary cranes by weighted, fixed sleepers, to which the masts and guys are attached and, in some cases, by a counterpoise so placed as to prevent the crane falling over in the direction of the load. In arranging the stability of such cranes, care must be taken to provide for sudden loads not strictly central to the crane, whereby the greater part of the load is thrown on to one "leg" or guy, or the stress is applied chiefly to one sleeper instead of equally to all. A common, and usually safe, practice is to use a ballast-weight on each sleeper equal to at least twice the load to be lifted.

In locomotive- and revolving-cranes, the engine and boiler are usually placed as a counterpoise, and in selecting a crane of either of these types care should be taken to see that the balance is properly maintained at all reasonable positions of the crane and maximum load. Wedges and rail-clamps are frequently used for locomotive-cranes and are quite satisfactory within their legitimate limits, but should not be relied upon for exceptionally heavy service.

In revolving a locomotive-crane, there is always a tendency to cause a fall by applying the crane to a load which is beyond its normal radius or on one side of the jib, or by swinging the crane round into such a position as to place the load outside the normal radius, namely the horizontal distance from the centre of gravity of the suspended load to the axis of rotation of the crane; as, for example, the horizontal distance between the centres of the hoisting hook and the centre pin of the crane.

Another common cause of mishaps is due to keeping the jib at a specified radius, but dragging the material from a point beyond this radius.

The capacities of the crane given on the identification plate apply only when the load is directly underneath the hoisting block. Moreover, they are maxima allowable and care must be taken not to overstrain the crane by exceeding them.

Many of the motions of hoisting, turning, travelling and varying the radius may be effected together and much time may be saved thereby. The following matters should also be considered in working locomotive-cranes:

- (a) Whether the load to be lifted is too great.
- (b) The possibility of loads being caught between other stones or held by them.
- (c) The radius at which the load is operated; the hoisting line should always be vertical when lifting a load. This fact explains the importance and advantages of a derrick-crane in which the jib can be raised or lowered so as to vary the radius to suit the positions of the load.
- (d) The proper distribution of the ballast or counterpoise.
- (e) The wedges or clamps must be properly placed.
- (f) The turning must be as rapid as possible so as not to waste time, yet must not be excessive or an accident may ensue.
- (g) Checking the load very suddenly by the brake is always dangerous.
- (h) The condition of the track—whether level, with a high elevation on one side, or curved—must be considered, as it has a great effect on the movement of the crane and on the loads which it is safe to move.
- (i) Whether the load is to be lifted with the main hoist-block or with a single line. This involves a careful consideration of the load and the radius throughout the whole movement.

The foregoing remarks must not be taken as indicating that the crane is a delicate or risky machine, for that is not the case; at the same time, much of the difference between efficient and inefficient working is usually due to a number of simple, yet often neglected, factors, such as those mentioned.

Carelessness in fixing and working cranes has been the prime cause of many

accidents, and, for this reason, care should be taken to employ only skilled crane-drivers and to give them every facility for doing their work properly.

Cranes are provided with either chains or wire ropes. Corrosion is not so serious with a chain as with a rope, and the durability is much greater, but as chains are both costly and heavy, wire ropes are extensively used and, if well cared-for, are quite satisfactory. In estimating the strength of a chain, it must be remembered that this depends chiefly on the thickness of the metal and not on the size of the link.

Whilst crane manufacturers can usually be relied upon to provide suitable pulleys, it sometimes happens that when a crane is purchased second-hand, or a broken pulley is replaced by a new one, the pulley or winding-drum is of too small a diameter, and so puts too severe a strain on the rope. This may appear a matter of small importance, but lack of attention to it has been the cause of several accidents.¹

Loose stones for crushing are often loaded by hand into wagons, but mechanical loading is often cheaper and preferable.

If hand loading is necessary care should be taken that the loader never requires to leave his place or touch a wagon and he should never be without an empty wagon.

It should be impossible to block the railway with wagons being loaded by slower men or men handling stone more difficult to load. Each loader should have his own working place, and be paid either on a piece-work or tonnage basis, or on fixed wages plus a bonus on everything produced over a pre-determined or fixed output.

Grabs (see p. 50) consist of a special device, which is hung from the rope or chain of a crane. The jaws of the grab are opened and the grab is lowered rapidly on to the stones to be lifted. By its impact, the grab penetrates into the stones, and when withdrawn its jaws close and the grab carries with it a load (up to about 15 cwt.) of stones. A pull on a rope reopens the jaws, and the grab discharges its contents.

Grabs will not remove the whole of the loose stone from a quarry-floor and leave the latter clean, but they are excellent for removing large quantities of loose material, the last portions being loaded by hand.

In moderately soft rock, such as chalk, a grab will excavate the virgin rock without requiring any blasting or other assistance.

In addition to suspending a grab from a crane, it may be suspended from a cable and be operated by a single winding drum. The grab digs into the material, picks up a load, is hoisted, conveyed along the cableway track, drops its load automatically, and returns to the starting point for the next load—always under control of the hoisting engineer.

When using a grab to lift limestone mixed with wet clay, or for wet chalk or calcareous mud, the effect of suction in increasing the amount of power

¹ For further information on the purchase and use of cranes see "Safety Pamphlet No. 15 (Derrick Cranes)," published by H.M. Stationery Office, price 6d. (1934.)

required must not be overlooked—especially when the grab is working at or near its maximum radius—or the crane may be “pulled over.”

Mechanical navvies (p. 49) cannot be used for the largest blocks, but they are very useful for picking up smaller stones of less than 2 cb. ft. volume and transporting them to trucks or wherever they may be required. Such navvies are also very useful where the stone is naturally very shattered, or when it is soft, like chalk, so that one navvy can be used both to excavate it and load it into wagons; the quarrying can then be effected at a minimum cost. For effective work with a navvy, however, the quarry must have a long face with a terrace or bench of sufficient width to accommodate the navvy and two sets of lines for the wagons and the whole of the material must be dealt with “as it comes.” If any sorting is necessary—as when fissures or intercalations filled with clay or other materials occur—a mechanical navvy is of little use.

For excavating or lifting shattered or broken stone, a navvy should be of suitable design and with a long range. Some of the most suitable ones will “clean up a quarry-floor” as well as load from a high bank. Unfortunately, in many limestone-mines, the breast is too small, and work is conducted in too many places to render navvy-loading practicable. Nevertheless, in a properly arranged quarry of sufficient size to keep a navvy fully occupied, this machine will be found to work remarkably cheaply either for excavating shattered rock or a soft rock like chalk, or for picking up the broken stone.

To work efficiently, a navvy must be able to work continuously for at least eight hours per day and four days per week, and, in most cases, it is essential that it should work during the greater part of its stroke.

To get the best work from a navvy, it must be supplied with sufficient trucks or wagons, into which it can discharge its contents, unless it is tipping the material for storage or other purposes. The lack of sufficient wagons is one of the commonest causes of navvies being less profitable than is expected; this difficulty is best overcome by frequent observations and detailed records of performance. Such records are invaluable as indicating irregular or other insufficient form of working.

One of the main sources of risk consists in failure to keep the road over which the machine must travel in the best condition. Frequently, in an effort of economy, light-weight or partly decayed sleepers, and second-hand, defective, or light rails have been used, resulting in an inconvenient and unsafe road-bed. Failure to keep the road-bed properly tamped and drained allows it to settle and become uneven, so that the navvy does not travel steadily, and is very likely to overturn. The use of caterpillars instead of wheels and rails is preferable.

Overturnings are not frequent with mechanical navvies, but they are so troublesome and dangerous when they do occur that all reasonable care should be taken to prevent them. In the smaller sizes of navvy the wheel-base is extremely small, and if the base is swung with a load beyond the safe capacity for an increased angle of elevation, the machine may be tipped on its side when this angle is increased very slightly, as a result of slight inequalities in the

rail-bed. Even when travelling on a straight track, and with the boom axis parallel to the axis of the track, slight obstructions on the track are sufficient to cause disaster if the navvy is at or near its ultimate lifting capacity and point of safe balance.

Inability to see towards the rear when the machine is moving forward, when it is turned on its table, or when it moves backwards frequently results in people being injured. A pair of reflecting mirrors, similar to those used on motor cars, help to eliminate this difficulty if the mirrors are of sufficient size to afford an ample view. It is still better if the driver, when standing in his usual place and turning his head, can see behind the navvy, though this cannot always be arranged.

Unless the makers or other equally skilled specialists in navvy-construction are employed, no important parts of the navvy—particularly the boom—should be changed. Thus, the lengthening of the boom immediately reduces the capacity of the navvy to handle safely the normal loads at a given elevation, whilst an increase of the strength or size of the cable or an increase of the steam-pressure to permit the lifting of heavier loads at greater boom elevations, introduces strains which may result in a sudden collapse. The failure of many crane-drivers to realize the tremendous reduction in the safe capacity of a crane due to any change in the elevation has resulted in the collapse of many cranes, and alterations to a navvy may have a similar result.

Speeding the navvy along its track, rotating it on its turn-table at a high speed, the load swung to the full length of the boom, and the sudden dropping of the bucket from a considerable height followed by a slight turning, may easily overthrow a steam-navvy.

Several devices have been attached to cranes and navvies to indicate when they are at the point of overturning and to give audible warning beforehand. The best devices of this kind are placed in the cabin, close to, or in full sight of, the driver; they are frequently supplemented by an indicator placed on the boom which shows by means of a pointer the maximum weight which can be safely picked up for any given boom elevation. This indicator may also indicate the safe overload clearance of the boom.

When a navvy is derailed, on no account should a leverage action be created by attaching the boom in an almost horizontal position to the track ahead, and by the application of power to lift the navvy so that it may be swung again onto the rails. Such treatment introduces the severest strains to which the navvy could be subjected, and in addition to the damage to the essential parts of the body, the housing of the hoisting mechanism and the anchorages of the turn-table may be torn apart in this procedure.

Mechanical navvies, like other apparatus, require occasional repair and continual maintenance and adequate platforms, steps, or ladders should be provided from which oiling, adjustments, or repairs may be safely performed so as to prevent the repair men from being exposed to unnecessary risks of falling no account of the lack of provision for this.

Most navvies are now fitted with an over-hoist or over-travel stop that

automatically arrests the upward travel of the boom and bucket if the operator fails to disconnect the power of the hoisting motor at the proper time when the machine is making a cut. Some drivers turn on the power and calmly wait for the load to come in contact with the over-travel release, thus disconnecting the motor. The danger of such an operation is evident, and it should be a matter of strict discipline.

Every mechanical navy requires to be lubricated in order to prevent wear from friction and destruction from rust. The lubrication of the cables is sometimes accomplished by a man standing on the trolley, who applies the grease as the cable is wound up. Sometimes, the cable is all wound up and the top half of the drum properly greased. The bottom half is then greased after the drum has made half a revolution to bring the ungreased cable into an upward position. Another greasing device attached to the top of the hoisting block consists of a brush or collar made of soft wicking, which surrounds the cable and is connected with the tank in such a way that the cable passing through the collar or bush becomes properly lubricated throughout its entire length.

Among the important precautions in working *steam* navvies are the following :

The boiler must be properly cared for and not fired too rapidly when it is full of cold water, or leaky tubes and seams will result. It is important to clean the flues once a week or the boiler will not steam properly, and to blow off sufficient water once a day when the boiler is about 60 lb. pressure. The boiler should be thoroughly cleaned once a fortnight. The cylinder-cocks on the engine must be opened before starting after standing for some time ; failure to do this will result in a loose piston or the knocking-out of the cylinder-head. When the engine is warm, the cocks are closed. It is desirable to open all the drain-cocks and drain the lubricator before leaving the engine for the night ; otherwise, in cold weather, the engine may be frozen solid by the morning.

To prevent accidents due to explosives being prematurely fired by sparks from a steam-navvy, the following additional precautions should be taken :

Before loading is begun, the steam-navvy and locomotives should be withdrawn from the face of the quarry to such a distance that no sparks from them could, under any circumstances, be carried to the explosive in the holes or on the ground above or around. If there is any danger from sparks or cinders, a canopy should be provided which will protect the explosive from flying sparks. A covered hopper may be used for black blasting powder.

Where an unexploded charge is uncovered by the steam-navvy, operations should cease until the explosive has been recovered and removed to a safe distance.

Ladder-excavators are not very suitable for moving stone.

Scoops are not used as extensively as they might be in limestone- and chalk-quarries because they are insufficiently known, particularly in Great Britain. As the work is very rough and heavy, the scoops must be correspondingly strong and the hauling or pushing mechanism must be sufficiently powerful.

The scoops, which may be moved satisfactorily in limestone- and chalk-

quarries and mines, are of two types : (i) scoops hauled by a rope and known as "drag-line excavators" ; (ii) scoops pushed into the material and either lifted and moved away or so arranged that the material is forced on to an endless belt at the back of the scoop and is thereby removed. The buckets or dippers attached to steam-navvies or ladder-excavators may, of course, be regarded as scoops.

Drag-line scoops may be attached to a ropeway, as described in the section on "Stripping" (though this is not often feasible for removing stones and chalk), or they may be attached to a navvy by replacing the customary dipper or



FIG. 12.—BUCKET-LOADER.

bucket and arranging ropes so that the scoop is thrown out some distance beyond the end of the jib and is hauled towards the base of the machine.

A useful type of scoop is one which is hauled and discharged mechanically, but is guided through the material by hand. This machine can be quickly moved about under its own power ; it has a reasonably long working range, and is equivalent to the work of 10–15 men.

Pusher-scoops are self-propelled and can work their way through a mass of broken stone at the rate of 70 ft. per minute, moving a maximum weight of a ton per minute and dealing with blocks up to 9 cwt. each. They have not been used to any great extent in England.

Bucket Loaders (fig. 12).—Where the material is in sufficiently small pieces (e.g. less than 3-in. diameter) and it is to be loaded into large trucks, it is often convenient to use a bucket-loader or similar device, consisting of an endless

belt on a portable framework, the belt being provided with buckets and driven with an electric or petrol motor. If the inclination is not very steep the buckets may be omitted and an endless belt used.

These loaders are so arranged that they can work at any suitable angle and a spout which can be moved radially is fitted to the delivery end of the machine.

Most of the earlier patterns of loaders required to have the materials shovelled into the buckets by hand, but the more modern ones are self-feeding. This great improvement is effected in two ways : (i) the machine is forced into the pile of material during the loading process, or (ii) a pair of rotary discs is fitted, which scoop the material automatically into the buckets.

A well-designed loader in good working order will deliver 1 cb. yd. of stone per minute as a fair working average, and will travel at the rate of about 60 ft. per minute in moving from one pile to another under its own power.

When desired, two or more of these loaders can work in series or with belt conveyors. Such an arrangement is particularly convenient where it is necessary to convey the stone or chalk over a pile of overburden or other material which it is not desired to move.

Pulley-blocks are used for lifting single blocks in a confined space or to a limited height. Various patterns are in use, the commonest consisting of a double pulley, from which hangs a chain carrying a smaller pulley, which, by means of a hook and chain, is attached to the load to be lifted. The principles upon which pulley-blocks operate are described in most books on applied mechanics. In using them, it should be remembered that the more numerous the pulleys, the slower the movement of the load, so that it is seldom advisable to use more than two pulleys.

Lifting-jacks or *screw-jacks* are used for raising blocks of stone a few inches in order to insert rollers or even a low truck. The jacks are commonly worked by hand, but electrically-driven jacks are used in some quarries.

A *hand-winch* or *crab* is often convenient for hauling wagons or for a variety of loading purposes. It consists of a drum round which a rope or chain is wound by means of a handle and simple gearing.

TRANSPORT AND HAULAGE

Various methods are used for conveying the stone from the quarry or mine to the masons' workshops, crushers, screens, kilns, etc. ; several methods are often used simultaneously.

The use of *wheel-barrows* and *horses and carts* is so familiar as to need no description. They are convenient and sometimes economical, but should usually be replaced by more mechanical appliances. All barrows should be built so that they are well balanced, the weight being thrown on the wheel and not on the man's hands, otherwise they will be difficult to drive and the output will be diminished. Barrows are preferably lined with sheet steel so as to increase the durability. The top edges should be similarly protected as these come in for considerable wear. Barrows with steel bodies and wooden frames

are very light and strong though more expensive than those made wholly of wood.

In connection with wheel-barrows a useful device known as the Ransome Tip-Cart may be mentioned. This consists of a peculiarly shaped body, holding 6 cb. ft. of material, or three ordinary wheel-barrowfuls, and made of welded steel plate, the body being mounted on a pair of steel wheels 3 ft. 6 in. diameter. Owing to its peculiar shape and construction, one of these carts when full can be pushed by a boy without undue fatigue.

The amount which can be hauled by a horse is greatly increased if the cart is replaced by a series of wagons running on rails.

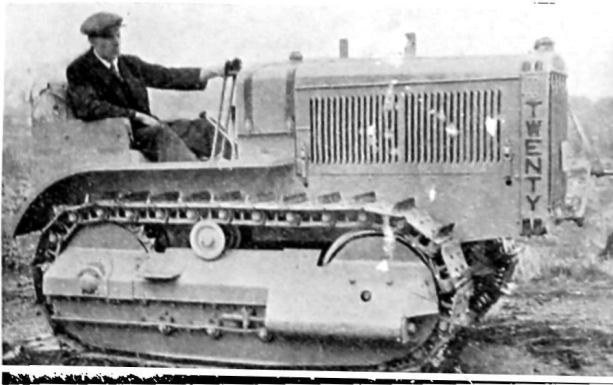


FIG. 13.—TRACTOR MOUNTED ON CATERPILLARS.

Tractors (fig. 13) with or without "caterpillars," are useful for hauling material about the quarry. They should be strongly built as they are subject to very rough usage, but with a "caterpillar" can go almost anywhere.

Tramways, with either horses or mechanical haulage, are very efficient, if well designed for the particular works in which they are used, but many tramways are quite inefficient on account of their being badly designed or the rails not being taken sufficiently close to the face; this is, however, a defect of planning the works rather than of the tramway method of transport.

Tramways are, in many respects, the most suitable means of transport for goods and material about the works, as they can be used in bad weather and under conditions where other appliances will fail to work. The original cost of construction is not excessive and the cost of maintenance is small if the road is well looked after. If allowed to get into a bad state, tramways may cause great losses through the excessive wear and tear on the wagons, as well as waste of power if the wagons are moved by rope haulage. If the wagons are to be moved by men, it is undesirable for them to hold more than three-quarters of a cubic yard of material, and rather less than this is preferable for most purposes, whilst about twice this capacity will be found convenient for pony traction on a

fairly level track. If the wagons are unnecessarily small, time will be wasted, but if they are too large additional men will be required to assist who at times are not needed, and hence cause waste of money. Tramways are not unduly expensive to construct, yet they greatly facilitate transport and are very adaptable, as almost any kind of power may be used to propel or draw the cars. The rails may be laid either temporarily or permanently, according to circumstances, or a combination of both temporary and permanent rails may be used. For very short distances men may push them, but where the distance is more than 300 yards, either horses or some form of mechanical haulage is preferable.

Mechanical haulage along rails is of four types :

- (a) Single-rope haulage.
- (b) Main-and-Tail haulage.
- (c) Endless-rope or chain haulage.
- (d) Loco- or Tractor- (including electrical) haulage.

The use of a rope or chain for this purpose is, to a large extent, a matter of choice ; in some cases, a combination of the two is used, part of the track being controlled by a chain, with rope terminals for the better winding of the drum. Rope is usually preferred on account of its cheapness, but for steep inclines a chain provides a better gripping power. Freshly discarded colliery ropes are usually satisfactory for haulage in quarries.

The *single-rope haulage* consists, as its name suggests, of a single rope, or chain, one end of which is attached to a wagon whilst the other is wound round the drum of a crab or winding device, so that the wagon is drawn along by the rope.

The rope or chain, which varies from $\frac{1}{8}$ – $1\frac{1}{4}$ in. diameter, may be *single* and wound on and off the drum according as the wagon is being drawn to or lowered from the machine. For this arrangement, the track (which is single) must slope sufficiently for the wagons to travel down it of their own accord. A single rope of this kind is only suitable for small outputs or for large wagons. It has the disadvantage of making the engine run more irregularly than when "endless haulage" is used.

A modification of the single rope haulage consists in the use of a double inclined track, along which the loaded and empty wagons travel simultaneously in opposite directions. This arrangement is particularly useful in gravity-haulage—the loaded cars going down the incline draw up the empty ones without any power being needed (see p. 82).

It is not always necessary to have a double track all the way ; provided it can be arranged that the descending and ascending cars or trucks always pass at the same point, it will suffice if the track is double at that point and for a short distance on either side of it.

In *main-and-tail* haulage, one end of the rope or chain is wound off one drum whilst the other end is wound on to another. This is the ordinary form of haulage for collieries and works where the endless system is not convenient. Either a single or double track may be used. The drums used for ordinary

purposes are about 12 in. diameter and 17 in. long, revolving at about 150 revolutions per minute. They may be driven by steam, oil, or electricity. The cable used is generally about $\frac{3}{8}$ -in. diameter, the above drum carrying 800 ft. The reversing is effected by means of a lever and gearing, the motive power working continually.

The cars usually carry about $1\frac{1}{2}$ cb. yd. of material and may be drawn up a gradient of 15° at 350 ft. per min., a power of about 10 h.p. being then required for each.

This method of haulage is suitable for relatively long distances over variable gradients, but it is wasteful in power, as there is no counterbalancing of ascending and descending loads, and the amount of rope required is very great. It is not largely used in surface quarrying.

In *endless haulage* (fig. 14) the ends of the rope or chain are joined, and the power is supplied by means of a horizontal pulley at one end. The wagons are attached to this endless band at approximately regular intervals, so that the load on the engine remains fairly constant. This, and the automatic nature of the driving, constitute the chief advantages of the endless system. A double track is essential. It is also wise to have some form of ratchet and clutch on the shaft of the driving pulley, so that in the event of a temporary stoppage of the engine the loaded cars will not travel backwards.

The rope is kept tight by a special tightening sheave, for which one of the terminal pulleys can be made to serve. To secure the necessary grip, the rope is coiled round two grooved driving pulleys, so placed that the rope wraps itself partly round each to secure the necessary grip.

The amount of material to be dealt with in an endless haulage system may be found by multiplying the number of wagons per minute by the average of material in each wagon. It is usual for the rope or chain to travel $1\frac{3}{4}$ – $2\frac{1}{2}$ miles per hour. The amount of power required varies from 5–40 h.p., according to the load, the incline, and the length of the track.

Which of these three systems is the best will depend on the number of wagons to be attached to the rope at once, and whether a

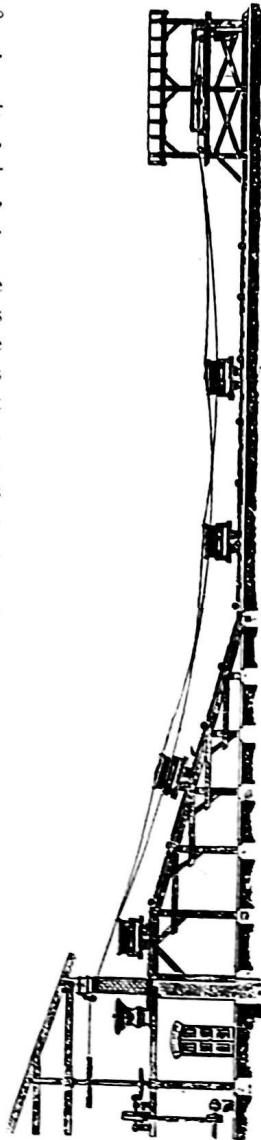


FIG. 14.—HAULING GEAR WITH ENDLESS ROPE OR CHAIN.

double track is possible, so that the empty wagons may be drawn up the "slack" part of the rope. Where two tracks are possible, the endless type is generally preferred when the loads are not excessive; the direct winding rope is, however, best suited for drawing the wagons over very uneven ground, as the engine-man is then able by watching the tightness of the hauling rope, to regulate his power to suit the changing levels of the track, whilst an endless rope, being run at one continuous speed, is not quite so suitable in such a case.

Where the track is in the form of a fairly steep incline, the use of a counterpoise will often effect a saving in the power required. This method is chiefly used for vertical lifts only, but it is equally efficient for steep slopes.

The rope or chain may be over or under the wagons according to circumstances. Suitable rollers must be provided for the rope to run on, and these must be well lubricated, or they will rapidly wear out the rope. For turning a curve, vertical rollers, with a large flange at the bottom to prevent the rope falling off, are used to replace the horizontal ones.

It is important to choose a good attachment for fastening the wagons to the chain or rope. The automatic clips for this purpose are not, as a rule, to be recommended. One of the best on the market at the present time consists of a clip which surrounds the rope, and which is opened and closed by a quick-acting screw. Catches to prevent run-away cars from doing any damage are almost essential, though too seldom used.

Gravity-haulage is that in which the movement of the wagons is effected by gravity instead of by mechanically applied power. Thus, the loaded wagons running down an incline may be made to draw up a corresponding number of empty wagons merely by connecting both sets to a rope running round a pulley at the top of the incline.

The applications of gravity to haulage are often very ingenious. Thus, by using one or more counterpoise wagons filled with water, a series of wagons loaded with stone, etc., may be raised to the top of an incline. The water may then be allowed to run out of the wagons at the bottom of the incline, whilst those at the top of the incline are filled with water. This arrangement is only practicable when the filling of the wagons with water is cheaper than the moving of the load by engine power. Occasionally, as at the Penrhyn slate quarries, the water tanks rise and fall vertically and transmit their motion in a more horizontal direction.

In some cases, where the force of gravity is not sufficient, a saving in engine power may be effected by making use of counterpoise wagons and other devices as far as these can be made available. Thus, in hauling material up a double inclined track, the empty wagons will act as a partial counterpoise to the loaded ones and will reduce the driving power accordingly. To obtain the best results, the number of these empty trucks should be at least equal to that of the filled ones, and as material of any kind, such as rubbish, can be carried in the opposite direction to the load an amount equal to half the useful load may be so carried with great advantage, provided it does not in any way interfere with the workings.

A powerful brake is essential in gravity-haulage as if the loaded cars are allowed to travel too rapidly at first, they may break the rope and cause a serious accident. A simple, yet strong form of band brake around the winding pulley is generally used.

The provision of some safety device—either in the form of catch-points or otherwise—to prevent runaway cars from doing damage, is very desirable.

Wherever possible, it is desirable to make much use of gravity as it is usually cheaper to lift the material to a single high point by applied power if, from thence, it can be distributed by gravity to the points where it is required, rather than to haul it to these various points by directly applied power. There is, indeed, a considerable saving to be effected by making much more use of gravity than is commonly done.

Chutes of various kinds are invaluable when they can be arranged. If properly designed and constructed, they convey materials very rapidly and require no power or attendance. More use might advantageously be made of them.

The *ropes* for haulage purposes in quarries and mines are usually of wire and are $\frac{3}{8}$ –1 $\frac{1}{4}$ in. diameter, but thicker ropes are used for heavy hauls. Table VII by Messrs. Bullivant, shows the breaking strain of various kinds of wire rope.

TABLE VII.—*Breaking Strain of Various Kinds of Ropes.*

Size		" Cru- cible "	Best Selected Improved "Cru- cible "	Best Selected " Mild Plough Steel "	Best Selected " Extra Plough Steel "	Approximate weight per fathom.
Circumference	Diameter					
Inches	Inches	B S. Tons	B S. Tons	B S. Tons	B.S. Tons	lb.
1 $\frac{1}{4}$	$\frac{11}{16}$	4 $\frac{1}{2}$	4 $\frac{3}{4}$	5 $\frac{1}{4}$	5 $\frac{3}{4}$	1 $\frac{3}{4}$
1 $\frac{1}{2}$	$\frac{1}{2}$	6	6 $\frac{1}{2}$	7 $\frac{1}{4}$	7 $\frac{3}{4}$	2 $\frac{1}{2}$
1 $\frac{3}{4}$	$\frac{3}{8}$	8	8 $\frac{3}{4}$	9 $\frac{1}{2}$	10 $\frac{1}{2}$	3 $\frac{1}{4}$
2	$\frac{7}{8}$	11	11 $\frac{3}{4}$	12 $\frac{3}{4}$	14 $\frac{1}{4}$	4
2 $\frac{1}{4}$	$\frac{11}{8}$	14 $\frac{1}{4}$	15	16 $\frac{1}{2}$	18	5 $\frac{1}{4}$
2 $\frac{1}{2}$	$\frac{13}{8}$	17 $\frac{1}{2}$	18 $\frac{1}{4}$	20	22 $\frac{1}{2}$	6 $\frac{1}{4}$
2 $\frac{3}{4}$	$\frac{7}{8}$	21 $\frac{1}{4}$	22 $\frac{1}{2}$	24 $\frac{3}{4}$	27 $\frac{1}{4}$	7 $\frac{1}{2}$
3	$\frac{15}{8}$	24 $\frac{3}{4}$	26 $\frac{1}{2}$	29	31 $\frac{3}{4}$	9
3 $\frac{1}{4}$	1	29 $\frac{3}{4}$	31 $\frac{3}{4}$	35	38	10 $\frac{1}{2}$
3 $\frac{1}{2}$	1 $\frac{1}{8}$	34 $\frac{1}{4}$	36 $\frac{3}{4}$	40 $\frac{1}{4}$	44 $\frac{1}{4}$	13
3 $\frac{3}{4}$	1 $\frac{13}{8}$	39 $\frac{1}{2}$	42	46	50 $\frac{3}{4}$	14 $\frac{1}{2}$
4	1 $\frac{1}{4}$	45 $\frac{1}{2}$	48 $\frac{1}{2}$	53	58	16 $\frac{1}{2}$
4 $\frac{1}{4}$	1 $\frac{3}{8}$	52 $\frac{1}{2}$	56	61 $\frac{1}{2}$	67	17 $\frac{3}{4}$
4 $\frac{1}{2}$	1 $\frac{7}{8}$	57 $\frac{1}{2}$	61	67	73	20
4 $\frac{3}{4}$	1 $\frac{1}{2}$	65	69	76	83	22
5	1 $\frac{5}{8}$	72	76	83	92	25

Wire ropes require frequent attention as they are subject to heavy wear and tear, and unless examined and repaired sufficiently often they may fail and cause a serious accident.

Bending the ropes round too small a sheave, pulley, or drum will cause strains which may easily damage it.

The effects of abrasion and of a cutting action are also serious, but may be kept within reasonable limits by efficiently lubricating the rope with a hot mixture of tar, linseed oil, and tallow.

Ropes used for hauling should never be overloaded, nor should they be applied to the load, or the load to them, with a jerk, as this has an equally detrimental effect. Similarly, the rope should not be allowed to strike any fixed posts or other objects which cause unnecessary rubbing, as these wear it away and soon reduce it to below its safe strength.

Electric haulage.—When the output is sufficiently large, it is economical to drive the quarry-wagons electrically, their movements being controlled from a central cabin in an elevated position. By this system of "remote control" only one man is needed for moving all the wagons. Special precautions are needed to ensure the contacts being kept clean. An average rate of 5 miles per hour for the greater part of the journey and 1 mile per hour near the primary crusher is satisfactory. Remote control is in use in some quarries.

The *rails* and *turn-tables* of a tramway should be skilfully selected, and it is essential that the track for tramways should be well laid on soundly bedded sleepers, to which the rails are securely fastened, preferably by means of bolts, which are cheaper in the long run than the more usual nails. Special care is needed in the case of points, particularly movable ones. In planning the tramway system of a works, care must be taken to avoid inserting too many points, as these affect the smoothness of the running. They also make it necessary for the wagons to run more slowly over the points in order to prevent them from being derailed. Points are, however, to be preferred to turn-tables, and the latter should only be used when really necessary. It will often be preferable to take the wagons several yards farther and use points than to have a shorter distance and use a turn-table. Much depends on circumstances, and, in some cases, turn-tables cannot be avoided. When used they should be kept in first-class condition so as (1) to turn easily; (2) be dirt-proof; and (3) need little attention. By using a ball-race for the turn-table most of the friction can be avoided. It is most important that the dirt should not gain access to the race, but if it should do so, the table ought to be designed so that it may be cleared in a minute or two.

In most cases, turn-tables are permanent structures, but a climbing turn-table is better for some purposes. The climbing turn-table, which is in itself a special form of large iron plate, can be laid over the rails, and is provided with sloping sides, so that wagons travelling over the track get on to the turn-table. They may then be turned in any direction desired, and led on by similar guides to another set of rails. Such a turn-table can be placed at any portion of the track, and so can be used as a temporary switch in places where permanent

points are undesirable. It is usually used to take wagons at right angles to the main track when forming a heap for weathering or in filling and emptying trucks. It has several other uses and its application in the works might usefully be extended.

The dimensions of the rails must be selected according to local requirements. For the lightest portable rails, a weight of 8 lb. per yard is usually satisfactory, but for permanent tracks it is better to use rails weighing about 22–30 lb. per yard.

When curves have to be traversed, the "outer" rail should be raised above the level of the inner. Although the amount of elevation can be calculated from a suitable formula, it is usually best to raise the rail much more than the calculated amount and an experienced rail-layer will usually produce a more satisfactory result than a less experienced man working to a formula. At the low rates of travel in stone working, the amount of elevation seldom exceeds 6 in.

It is highly advisable that the maintenance of the rails and turn-tables should be in the charge of one man, who should be compelled to keep all the tools, nails, bolts, etc., he requires for his work in a special box, which he should take with him to the place where repairs are needful. If this is done, great care being taken that the tools, etc., are not, on any pretext whatever, allowed to lie about, and the disused bolts, etc., carried away to their proper place, many annoying incidents which result from losing the tools, and much of the time lost in fetching them will be saved. These may appear small matters, but they are none the less important.

The *sleepers* should be arranged across the track as in a railway and not parallel to the rails as is sometimes the case, as the latter arrangement—though much cheaper—is not nearly so satisfactory. The sleepers may be of wood, steel, or concrete; it is very difficult to say which is the best material when price has to be considered, but most quarry managers prefer them in the order mentioned.

Wagons, tubs, or cars which run on rails and have a capacity of 5 cwt.—1½ tons are largely used in transporting limestone, chalk, etc., inside the works area, the ordinary railway trucks being employed for longer distances. Horse-drawn carts are only employed where other vehicles are less convenient. Motor lorries are being increasingly used for transport by road for distances up to 40 miles; beyond this they are not usually so cheap as railway transport.

The tramway wagons or "tubs" usually employed for single-rope haulage have a capacity of about 1 ton of limestone or ¾-ton of chalk. A particularly convenient form is that known as the "Jubilee" pattern supplied by several firms. These wagons may be made to tip sideways or endways.

The requirements of a car, wagon, tub, lorry, bogey, corve or whatever name these articles may be known by in different parts of the country, are: (1) strength; (2) lightness; (3) stability; (4) compactness; (5) easy running; ball-bearings are increasingly used in the construction of wagons, and it is, in any case, desirable to oil or grease them at very frequent intervals if they are

to run freely ; and (6) easy discharge ; this is particularly important in the case of " tipping wagons." Some of the more recent designs are particularly convenient in this respect and combine great natural stability with remarkable ease in emptying. At the same time, the body of such a wagon must be so fastened that it will not discharge its contents accidentally.

Wooden wagons were, at one time, exclusively used and some quarry-owners still prefer them. Most modern wagons are made of steel plate with ample angle irons and stout rims and a strong angle-steel frame. The wheels should be specially toughened and provided with ball-bearings for easier running. The body should be well balanced so as to tip easily when required, but should be provided with a simple and reliable fastener to keep it from

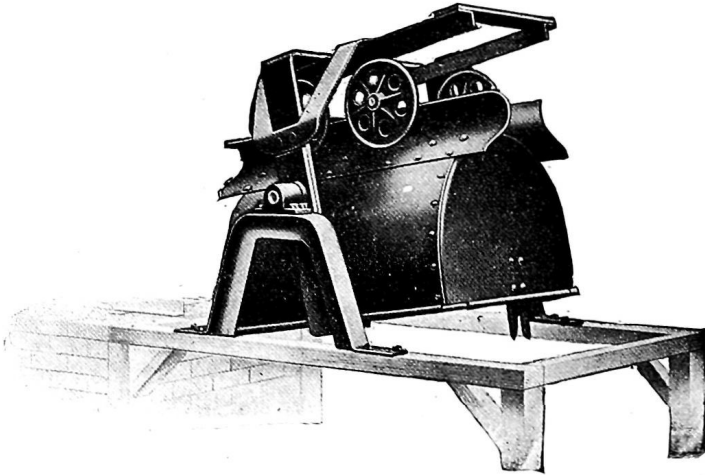


FIG. 15.—TIPPING-WAGON IN FRAME.
(By courtesy of C. Whittaker and Co. Ltd.)

tipping unexpectedly. Where several cars are to be fastened together, swivelled couplings are desirable.

Low trucks are used for moving large blocks of dimensional stone. These trucks must be of very great strength and should be provided with ball- or roller-bearings so as to run as smoothly as possible. A little investigation will show that the additional expense of these bearings is soon repaid by the smaller number of men required to move these trucks and the greater rapidity with which they work.

When endless haulage up a steep incline is necessary, small oblong wooden or steel wagons, each holding about 8 cb. ft., are very satisfactory. These are run into a tipping-frame (fig. 15) and so are emptied. These tipping-frames can only be used where the material has to fall to a lower level than the track, whereas side-tipping wagons can tip onto the level of the track.

The small wagons distribute the load more uniformly on an endless rope or

chain and feed crushers or other machinery more regularly, thereby effecting a saving in power as compared with large wagons. They are also easier for the men to handle at the quarry or in the mine.

The wagons used for endless chain-haulage should have a V-shaped fork which engages with the chain and forms the simplest and easiest method of connection. Where this device is used and the endless chain is made to rise slightly at the delivery end of the track, the wagon is automatically released as soon as it reaches the place where it is desired to stop it. This is done by taking the wagon to a rather greater height than is required and letting it run down a small incline at the last, the chain being raised well out of the way. Where a rope is used, a clip must be employed; this may also be released automatically.

In cases where the material might be stained by rust from steel or iron cars, wooden bodies mounted on steel frames may be used. Wooden cars should be built of well-seasoned oak, solidly braced and bolted, not nailed. They should be so constructed that any part can be renewed without damaging the remainder. The iron or steel framework should be stout, and the wheels heavy and sound. It is a great advantage if the cars are fitted with ball-bearings and self-oiling boxes.

The *bearings* used in the cars are of great importance, as upon them the ease or otherwise of the traction chiefly depends. There is a considerable difference of opinion as to which form of bearings is best, but there can be little doubt that ball- or roller-bearings, when well cased and properly looked after, afford the easiest running of the cars, though they are more costly in the first place. Quarry managers who have sufficient foresight to recognize that easy running cars do more work and require less traction almost invariably use cars with ball- or roller-bearings.

In each of these forms, the axle is surrounded by a ring of steel balls or rollers working in an outer steel ring which forms the lining of the "box" of the bearing. There are various types of ball-bearings on the market, and builders of cars will fit such bearings to any car if required to do so. The first cost of the car is of less importance, as cheapness usually means sacrifice of one or other desirable quality.

If the track crosses the public road it is desirable to have some form of brake attached to the wagon, or, if this is not thought desirable, the pony should be fitted into fixed shafts and not in the usual form of loose chain traces. For tracks entirely on the works, this precaution is not quite so necessary, though a brake or safety catch is still desirable.

Where the wagons have to be used on an incline of 1 in 2, they are liable to fall over and cannot be filled without some material falling out on the journey. To overcome this difficulty, the wagons may be mounted on a framework on wheels so that the wagons remain level whilst the frame-car passes up and down the incline. These special frame-cars can only be used on a uniform gradient.

To prevent the cars from slipping whilst dumping their contents, it is

often convenient to employ some simple form of catch. Unless this is done, the men engaged in unloading the cars may be injured, and, in any case, time is lost by the occasional derailing of the cars. There are various forms of tie and catch in use, but one of the best consists of a simple iron bar, the top being sufficiently high to clear the frame of the car without giving much play. Hence, when the car is tipped, the frame cannot move forward, but is held by the top bar and all slipping is prevented. So simple an appliance can be made from odd bars for a few pence.

Ropeways or *aerial ways* (fig. 16) are a modification of rope-haulage, in which the rope, instead of pulling the wagon along, actually carries it. To this end, the "wagon"—usually in the form of a box or large bucket—is

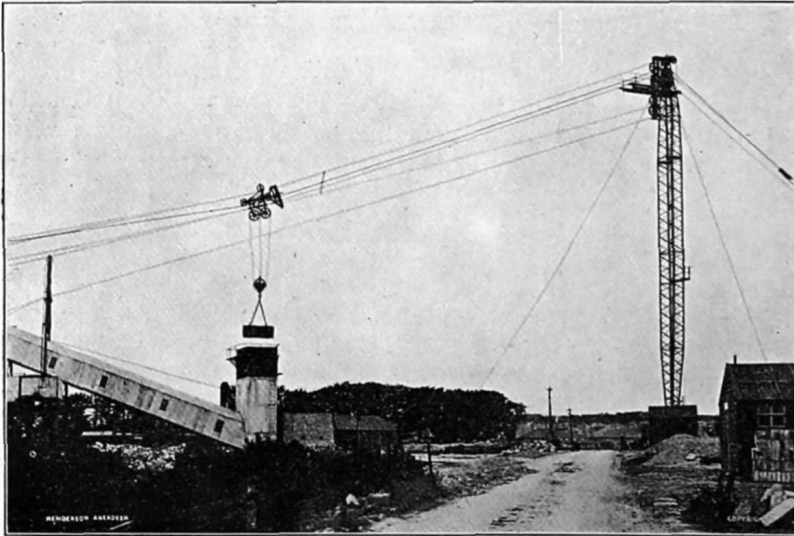


FIG. 16.—AERIAL CABLEWAY.

(By courtesy of John M. Henderson and Co. Ltd.)

permanently attached to the rope and the material is filled into it at one end of the track and emptied at the other by releasing a pin, which causes the bucket to tip over or allows one side of the bucket to fall out. Where the nature of the ground does not permit the construction of an ordinary tramway (as where a deep valley intervenes between the sources of supply and the destination of the material), this method of transport has the advantage of reasonable cost, small maintenance charges, and a high capacity. It also has the advantage that the space between the quarry and the destination of the material, instead of being occupied by a tramway, may be used for any other purpose for which it may be suitable. Unfortunately, the initial cost of overhead ropeways is so great that they can only be used for very large outputs or for abnormally long distances, and unless at least five tons per hour is to be transmitted, they are not

economical. A simple overhead ropeway may sometimes be made in quite a rough and homely fashion which is economical for short distances and loads of 1 ton per hour. Care should be taken to make it of ample strength.

Overhead ropeways are of three types : (i) those in which the buckets are fixed to a travelling rope and are carried by it from one end of the journey to the other ; (ii) those in which a fixed rope is used to carry the buckets which are provided with pulleys and are hauled along the rope ; and (iii) an endless ropeway of either of the foregoing types.

The second and third types are most economical where the output is

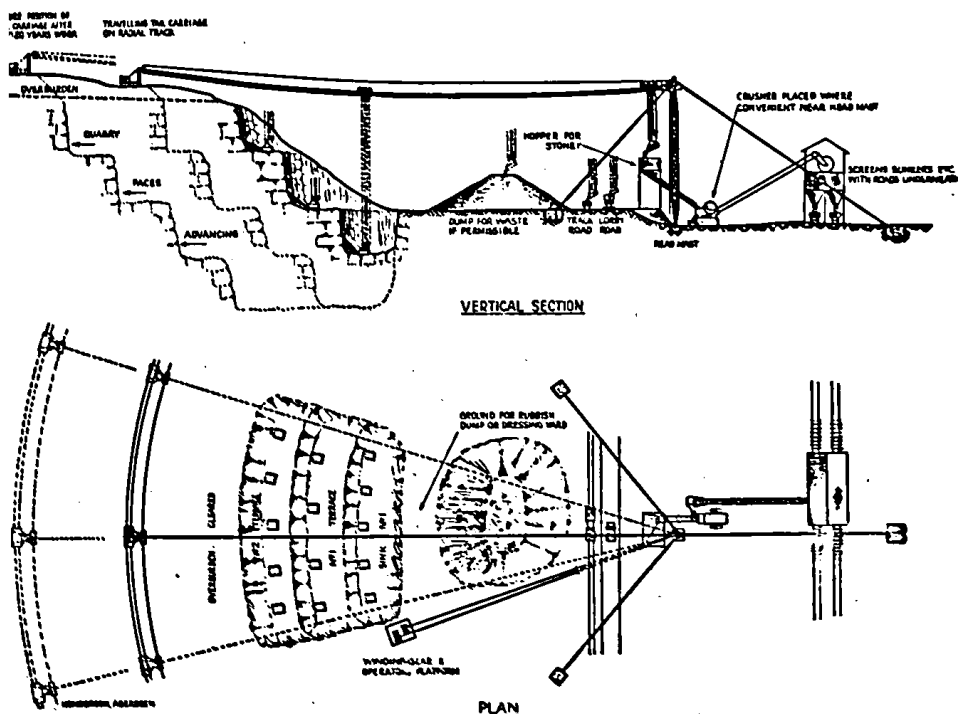


FIG. 17.—"BLONDIN" CONVEYOR.
(By courtesy of John M. Henderson and Co. Ltd.)

sufficiently large, the first type being used chiefly for small works. A typical example of a ropeway-used in a limestone quarry is that erected at the Steety Quarries, near Worksop. The total length of the ropeway is about 1,100 ft. and locked-coil carrying ropes are employed. The ropeway is driven by an electric motor which operates through a worm and worm-wheel gearing. The buckets are designed to carry 6 cwt. and the line is arranged to transport 30 tons per hour, but this capacity can be increased when required by adding more carriers. The carriers are loaded automatically by gravity from the breaker-hoppers and become automatically attached, by a special type of

gripper, to the hauling rope. Three automatic tippers are placed at various points on the carrying rope while three further tippers are placed at three of the standards. These various tippers are fitted with triggers of different lengths, so that any particular bucket on the line may be made to tip at any of the tippers by adjusting its tripping lever so that it will engage the triggers of the tippler at which it is intended to tip, but will pass the triggers of the remaining tippers. The adjustment of the tripping levers may be made by the man who is stationed at the loading station to fill buckets. The arrangement is very simple and works well in practice.

Many quarries use a *Blondin conveyor* (fig. 17) which consists of a combination of a hoisting device and an overhead ropeway. The load is lifted to a convenient height by hoisting tackle suspended from the ropeway and is then hauled along to the terminal, where it is lowered and the hoisting device returned to the quarry. An electric motor forms a convenient source of power ; it should be capable of sustaining 50 per cent. overload for at least 5 minutes each journey and 100 per cent. overload momentarily. The power required varies very greatly from almost zero to nearly double the normal load, short periods of high power occurring (*a*) during commencement of the hoisting, and (*b*) towards the end of the traverse or haulage of the load.

The difference between a modern, properly constructed plant and the inferior class of ropeway, may be seen, in the first place, in the structural work for the towers and stations. There is a choice of two alternatives, and in climates which are not exceptionally deteriorative to timber, there is much to be said for its use for ropeway plants. It will cost 20 per cent. to 30 per cent. less than steel construction, and while the latter is preferable it is not absolutely necessary. If timber is chosen as the material for the structural work, it should be creosoted, or at least those parts of the timber posts which go into the ground should be thoroughly tarred. Every few weeks, for the first two years, it will be necessary to go over the bolts which bind the timber together in order to tighten them, as the timber contracts considerably under outdoor influences. Upon inviting tenders, alternative quotations should be asked for, with structures in both timber and steel, so that a comparison can be made between the cost of the two. To assist in securing accurate tenders, the intending purchaser should obtain the prices of pine timber cut both round and half-round, from local dealers, and when sending his inquiry out he should state the price of this to the ropeway manufacturers as it generally is immaterial to them from whom the timber is bought, and many makers make it a firm condition that the purchaser must obtain the timber himself from whatever source he pleases providing that the same is up to a certain standard which any ordinary stock pine will meet. The necessary foundation work of these structures may be either of concrete or masonry work and most manufacturers will choose the latter if bricks are readily obtainable, and thus secure an economy. In most cases the towers may be erected without any foundation whatever provided they are of timber, but a foundation is an absolute necessity for steel work.

Next to the towers, the track or main carrying ropes are of greatest importance, and it is here that technical advice will be of great value. The quality of the steel used for making the ropes is of great importance, and it is strange to note that the builders of the poor class of plant mostly obtain inferior ropes from the manufacturers, whilst those firms which have a large connection are able to obtain from the best rope factories a grade of rope which their experience guides them in selecting. The chief factors in the cause of rope breakage are the brittleness of the steel used in the manufacture and the faulty design of the plant. In the first place, the rope-maker attempts to give his customer a rope with an extremely hard surface which will stand up to the wear and tear of the ropeway carrier wheels, and, in the second case, some designers have no sympathy whatever for the ropes and lay the cables irrespective of any sharp bends and kinks, which strain the individual strands of rope to such an extent that, if too brittle, they easily break, and once a break appears it does not take long for others to occur. In the larger firms of ropeway specialists the designers have an accurate technical knowledge of all the material they use in their designs, and are very careful to lay the cable so that little or no sharp bends are given to the rope. This, combined with the fact that the rope is also of a carefully selected quality, ensures the greatest possible length of life. There are many different opinions as to the length of time the carrying ropes or cables of a ropeway will last; this depends chiefly on the quality and the construction of the rope, but a fair average may be taken at six years, and many good ropes have lasted double this time, whilst others will, sometimes, give out in two years.

The most general form of rope used is what is known as *spiral rope* in which each individual wire or strand is round, and the whole of the wires composing the rope are spirally interwoven together in such a manner as to form a self-contained continuous rope. This type of rope is the cheapest on the market and serves as a good track cable, but, unfortunately, it has one or two serious disadvantages, as the outer surfaces do not present a continuous whole or smooth surface to the carrier wheel, and, consequently, a great amount of friction has to be overcome which wears out the rope, and, further, when one of the strands of the rope breaks it immediately springs out from the surface owing to its natural elasticity, and a rope jacket must be placed on the rope over the broken wire to bind it down again. Unless this is done, the protruding wire will catch against the wheel when the carrier comes along and will throw it from the track, and all successive carriers will be served in the same way. The rope jackets are of sheet steel, and only cost a few pence each, but sometimes the rope is high above the level of the ground, and it is not easy to obtain access to it. To remedy these disadvantages, several types of locked and semi-locked ropes have been designed with which it is practically impossible for any interruptions to occur in the traffic, such as happens with a spiral rope. Another advantage is that the whole outer surface is a smooth continuous whole, and presents a much better track to the carrier wheels. It consequently creates less friction, and thus reduces the wear on the rope.

On the towers, these cables should be supported on lengthy bearings or sideways, in order to avoid any sharp bends in the ropes.

Whatever form of rope is adopted, the same must be suitably anchored at one end-station and tensioned in the other. Many makers attach a telescopic spring to either end of the ropes, whilst others use pulley blocks or screw gear for taking up the slack of the ropes. The best method is to anchor the ropes at one end and tension them at the other by means of a large tension weight, hung so as to allow of it freely sliding up and down according to the variations in the tension of the rope, and keep it always at a fixed tension; this has considerable advantages over the other and more primitive methods mentioned. During the early hours of the morning, when sharp frost and very low temperatures may be experienced, the ropes will be extremely taut, should pulley blocks, springs, or other screw tackle be employed as a medium of tensioning the ropes, and in the middle of the day, when the air is hot, the ropes will be quite slack. It is not advisable to rely on the workmen attending to the screw-adjusting tackle every morning and midday in order to accommodate the tension of the rope to the prevailing temperatures. When a tension-weight is used, which is hung over a pulley to allow free sliding motion, the tension is always taken up quite automatically, and no attendance is required. In addition, practically no strain which has not been allowed for by the designers can be put upon the structures as may be the case with non-automatic tensioning devices.

The hauling rope should be carefully selected in order to obtain as smooth a working of the plant as possible. The end-sheaves round which this rope runs should be of large diameter so that the individual strands of the rope may not be injured in bending round it. A rope with a hemp core should be used. The grooves of the pulleys of the driving gear may be lined with leather or wood so as to give a better gripping action to the rope. The rope should also be suitably supported by rollers on the towers in order to obtain a proper clearance above ground-level. In the station opposite to the driving terminal, the traction rope should always be tensioned in a manner similar to the carrying rope, but a longer play for the weight must be allowed, as very considerable variations occur on the hauling rope. If these variations are not controlled automatically, the hauling rope becomes slack, and, consequently, the driving gear in the opposite station continues to revolve, but the traction rope remains still with disastrous effects to the wire strands of the rope.

The driving gear must be carefully designed, should have large leather or wooden grooved sheaves, and should, under no circumstances, be a single drum round which the traction rope is wound two or three times to give the necessary grip. The latter method, which is used by some makers, severely injures the traction rope, and in many cases reduces its life to one-half of what it would be if properly designed driving gear were used. The drive from the main sheave to the motor or engine is best effected through bevel gearing, although ordinary straight-toothed or spur-gearing may be used if desired.

The carriers or buckets usually consist of a two-wheeled trolley, the wheels

of which must be of good malleable iron or, preferably, of cast steel. Cast-iron wheels, after the hard chill of the outer surface has worn off, rapidly become very uneven and develop a bumpy irregular surface, with the consequence that when a worn part of the circumference of the wheel comes into contact with the surface of the track-cable it stops there and the traction rope hauls the carrier along with both wheels of the trolley locked fast. When this happens to several or possibly all the carriers on the line the friction is so great that the driving power may not be strong enough to overcome it, and the transport is, consequently, stopped.

The wheel of the carrier or trolley should be supported on axles fitted into steel side-plates; from this carrier the hanger which holds the bucket, and to which the hauling rope grip is fastened, should be hung.

The bucket should be made of sheet iron and supported on pivots to the hanger. When the buckets are to be automatically discharged, a tipping lever must be fitted and the pivot of the bucket must be placed below the centre of gravity. The pivots being so placed the bucket cannot retain its position unless it is held fast by the tipping lever; consequently, when a catch strikes the tipping lever and knocks it out of place, the bucket tips over and the whole of the stone is automatically shot out.

Fig. 18 shows an ordinary wagon, complete, hung from the carrier of a ropeway trolley. By this means it is not necessary to purchase new buckets for the ropeways, as the whole of the existing rolling stock can be utilized for the transport. In this case the two chain slings are merely slipped over the hooks of the tub and the carrier despatched from the ropeway terminal on to the ropeway track, a process to which an ordinary labourer or youth can easily attend.

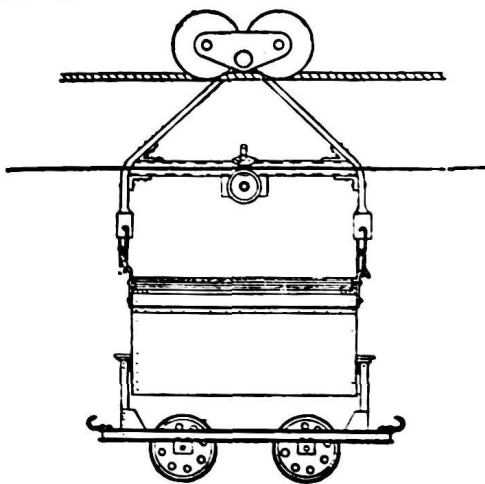


FIG. 18.—TUB HANGING FROM ROPE.

If a works has a number of ordinary tubs in use at the time of installing the ropeway, and if these are not too heavy, they should be used on the ropeway, but if no tubs are used, it may be advisable to take the ropeway manufacturers' standard carrier. Should the ropeway be replacing an inclined haulage system, where heavy wooden trucks are employed, it will be unwise to use these, as their great weight will necessitate very heavy carrying and traction ropes, with the consequent increase of the initial cost of the installation of the ropeway; the horse-power required would be unnecessarily great, and the maintenance

expenses would be unduly large on account of the heavy wear and tear on the ropes occasioned by the heavy tubs. If one of the standard types of carrier is used, and an ordinary loading station is placed on the working level of the quarry, the connection from this station to the quarry-face will be either a light-gauge rail track, if tubs are adopted, or an overhead railway, if standard buckets are used. The overhead track can be erected by ordinary labourers, and will consist of a rigid rail suitably supported or hung from iron trestles, these trestles being placed at correct intervals depending on the weight of the bucket and the strength of the rail. These trestles are quite simple to construct, and, for loads up to half a ton, can be made of light timber, 5 in. \times 5 in., with the cross beam 8 in. \times 4 in., whilst for buckets above this weight and up to one ton 7 in. \times 7 in. timber with an 8 in. \times 8 in. cross-beam, will be ample. The rail of this overhead track must end at exactly the same level as the station rails, so that the ropeway cars, when uncoupled from the traction rope, may run straight on to this track. The trestles and rails may be laid in any direction, will take short curves or wind about just as required, and the whole track is merely taken up and re-laid as circumstances demand. The rails can be made of ordinary flat or angle iron of a sufficient strength to bear the cars, which will travel over them. A simple fastening is required to attach the rails to the trestles.

The grip for the hauling rope to the hanger has been the subject of more study, patents, and discussions than any other part of a ropeway plant, and even to-day there are few good grips which can negotiate gradients of 1 in 1. The sharp rise from the quarry or pit will often require a gradient of this steepness and the purchaser should very carefully satisfy himself as to the efficiency of the particular grip he has under consideration. As so few grips will take a gradient of more than 45 degrees or 1 in 1 it is usual to excavate the ground, or so place the tower as to lessen the gradient.

Of the many types of grips on the market, such as friction-, screw-, and positive-grips, it is quite impossible to single out any particular one against the others. The purchaser may easily protect himself by seeing the grip in actual work under similar conditions to those which occur in his own plant.

It is often convenient to use carriers which can be lowered to the quarry floor and raised almost to the level of the rope during transport. Such a device is known as a Blondin Conveyor and is described on p. 90. Blondins are particularly suitable for raising loads of less than five tons out of deep quarries.

Unfortunately, overhead ropeways are not readily extended, and, consequently, some means must be found for taking the stone from the face of the quarry to the ropeway. This means a double handling or the use of tramway wagons which are fitted with hangers for suspension from the ropeway. Consequently, the cost of transport by a tramway is often as cheap as that by an overhead ropeway.

An automatic weigher and totalizer may be used to keep a record of the amount of material passed over the ropeway.

Where there is any risk of damage by material falling from the buckets, a stout network should be spread beneath the ropeway.

Mono-rails or Telfer-lines are rigid aerial ways in which the carriers are carried on a steel rail. Strictly, the term "telfer" should be confined to those devices in which the motor is attached to the moving bucket or carrier, but many mono-rails are now known as telfers. True telfers are seldom used in the limestone industry as the simple and less expensive mono-rails are usually sufficient, but telfers are always worth consideration where unusually large quantities of large stone have to be moved.

Mono-rails are commonly limited to short distances of 150 yards or less, as ropeways are preferable for longer distances. Mono-rails are, however, very useful at one or both ends of ropeways, where they form a more solid bearer during the loading and unloading. The rail usually consists of an ordinary I-girder.

Lifts in limestone- and marble-works are chiefly of the "cage" variety and are principally used for conveying goods from one storey of a building to another, but they are occasionally used in deep quarries.

Lifts are used in some quarries to lift the stone to the top of the kilns, a small tramway being provided to connect the kiln to the lift.

There is a considerable difference of opinion as to the desirability or otherwise of lifts, but their employment would seem to be unavoidable in some places.

The ordinary lift is similar to that used in collieries and consists of a box or cage raised or lowered by means of a rope working on a revolving drum, or reel, driven by a suitable engine or motor. Although, if carefully worked, such hoists may be run very smoothly, there is a great tendency to uneven running. Where there is a considerable amount of material to be raised, a double hoist is advisable. In this case, one end of the rope is secured to one cage and the other end to the other, after passing a number of times round the drum of the winch. In this way, when one of the cages is at the top of the hoist, the other is at the bottom. The drum is driven by two belts, an open and a crossed, one fast and two loose pulleys being keyed to the worm shaft. Should either belt break, the lift comes to a standstill and overwinding is rendered absolutely impossible, as the belt is automatically struck and the brake applied when the cage is at the top. Besides this, cages are provided with safety catches.

Where the difference between the level of the loading- and the level of the delivery-end is sufficiently great, an ordinary colliery hoist is one of the most suitable types. For much shorter distances, a simple type—preferably with counterbalance—may be used. For small loads and short lifts, a winding drum or self-sustaining hoist will meet requirements.

Electric lifts are excellent where the conditions are suitable, and are safe in the event of a brake failure when driven through a worm gear, though the efficiency is very low. The motors may be suitable for either direct or alternating current, but the former are more usual. Direct current motors are almost invariably compound wound, the series turns (20 per cent.) giving a good starting torque, the larger sizes above three horse-power having interpoles.

Table VIII gives the power for the most suitable motor for any given service, and shows the low powers necessary.

The motors and winding-drum are usually arranged at the top of the lift, but this is not essential. When placed at the bottom, a greater length of rope is needed because the ropes have to run from the top of the cage, over the guide-pulleys, down under the driving-sheave, up to the top again, and down to the balance-weight. This difficulty may be avoided by bringing the ropes from the top of the cage to the top of the balance-weight, then down under the driving-sheave, and up underneath the car, where is situated a device for maintaining

TABLE VIII.—Power required by Lifts

Load in cwts. (hoist weighs 2 cwt.)	Speed in ft. per min.	B.H.P.	Load in cwt. (hoist weighs 2 cwt.)	Speed in ft. per min.	B.H.P.
2	105	2	10	90	4
2	130	2	10	140	6
3	95	2	10	200	10
3	130	2	12	75 (R)	4
3	160	2	12	110	6
4½	105	2	12	190	10
4½	160	3	15	60 (R)	4
6	95	3	15	100	8
6	150	4	15	185	12
7½	95	3	20	70 (R)	6
7½	140	6	20	115	10
7½	200	8	20	175	15
9	90	4	25	50 (R)	6
9	120	6	25	90	10
9	150	6	30	45 (R)	6
9	200	8	30	120	15
10	70 (R)	3	40	90 (R)	15

(R) Spur gearing is employed to obtain the necessary reduction.

the tension of the rope. This has several disadvantages and still uses twice the length of rope that is needed when the drive is from the top, and good ropes are very expensive.

If alternating current supply only is available, induction motors must be used. They may either have wound or squirrel-cage rotors. Ordinary squirrel-cage rotors are of no use, as their starting torque is poor.

Hydraulic lifts are much steadier than others in their motion, but have the disadvantage of higher first cost, and are seldom used in quarries because water is not available.

Water-ballast lifts are occasionally met with, and, when water is cheap, are a convenient form of hoist. The principle of working is very simple—

two cages are used with one rope over a single pulley, and so arranged that when one cage is at the bottom of the lift, the other is at the top. Each cage contains a large tank (usually placed beneath its floor), which can be filled with water at will. When it is desired to lift the cage loaded with goods, water is run or pumped into the tank of the upper cage in sufficient quantity to more than balance the load of goods. The catch holding the cage is then released, and the loaded cage rises to the height required; a brake or catch is then applied to prevent its rising too far. When it is desired to lower the cage again, the water is run out of the tank, care being taken to leave sufficient in to prevent the cage from falling too rapidly. Though a primitive form of hoist, this plan is working satisfactorily in several places. The supply of water as well as the emptying of the tanks, when necessary, can be made almost automatic, and the water can be used over and over again, so that the actual working cost is extremely small. The chief point in construction is to provide sufficiently large pipes for the conveyance of water to and from the tanks on the cages.

All lifts, etc., should be fitted with safety appliances, so that, in the event of a breakdown, damage to life and limb may be prevented, or at least reduced to a minimum.

Capstans are seldom seen in quarries or mines for stone and marble, yet when available, they are often extremely useful for moving heavy loads for short distances. In many cases, their use would be unprofitable, but the owner of a works should, from time to time, consider whether the installation of a capstan would be worth while.

The most suitable form of capstan is a vertical rotating drum, driven from a motor or gearing below ground level. One end of a rope is attached to the block or other object to be moved, the rope is turned once or twice round the capstan head, and the latter set in motion. With very little assistance from the man in charge, the load can be moved quite easily.

Road traction, whether by horse-and-cart, or by the more modern tractor, traction-engine, or motor-van, is usually cheaper for local deliveries than the railway. The most convenient type of cart is an ordinary tip-cart of about two cubic yards capacity, but if the district is very hilly a somewhat smaller cart may be more convenient. Carts are not economical for distances above three miles.

Traction-engines and motor-lorries are much more suitable than horse wagons for limestone-quarries, etc.; the roads must, however, be suitable and kept in good condition, or the wear and tear on the machines is excessive. For loads over ten tons, steam-wagons are generally more economical than oil-engines. The wheels should be carefully selected or constant breakdowns will occur. They are preferably built of steel with riveted spokes. Oil-driven motor-lorries are unsuitable for weights over six tons, owing to the wear and tear on the wheels and engine.

The driver should be a skilled motor-mechanic, capable of telling from the beat of the engine whether anything is amiss and of repairing it at once. This means higher wages than a horse driver's, but the increased output of the

motor, as compared with that of a horse-and-cart, will compensate largely for this. It is strongly to be recommended that all motors and traction-engines in regular work should not be used more than five working days and should be thoroughly overhauled on the sixth. Including such repairs as re-boring cylinders, re-tubing boiler, and other more extensive repairs, it is not safe to reckon on more than 240 working days per year.

It is almost impossible, at the present time, to institute a really reliable comparison of working costs and standing charges of horses and carts with other forms of traction available, as so much depends on local conditions. The question of depreciation also complicates the problem. It is probably right to write off a quarter of the cost of a motor-wagon at the end of the first year, and each succeeding year to take off a quarter of what is left. Thus, a motor-wagon costing £800 would depreciate to £600 at the end of the first year, to £450 at the end of two years, to £190 at the end of five years, and after eight years' use it would have on the books only one-tenth of its original cost. This method of calculating depreciation is much safer and fairer all round than the more usual one for writing off 10 per cent. of the original cost each year. In estimating the costs of motors and engines with a view to comparing different types in actual use, errors of considerable magnitude often creep in owing to the careless way in which repairs are not charged to the transport, but to a general account for the whole works. The wisest course is to open a separate account for each motor-wagon or steam-engine with its attendant trailers, to pay all expenses in connection with them out of this account and to place to its credit all sums received for the delivery of the material.

It is generally found that for journeys of less than 20 miles the load multiplied by the journey must not be less than 60, so that the critical point is 5 tons for 12 miles, 6 tons for 10 miles, and so on, though with improved construction this may be reduced. For a number of journeys in quick succession and on good roads, a 6-ton lorry, when fully loaded, should be able to make at least 4 journeys of 10 miles each in a day, but much depends on the facility with which it is loaded and unloaded. The use of (a) additional bodies which can be lifted on and off the chassis by means of a crane; (b) a mechanical tipping device so that the stone slides out of the wagon; or (c) a movable floor on the principle of a belt-conveyor (as in the wagons supplied by The Principality Wagon Co. Ltd., Cardiff) greatly facilitates loading. Special care is required to ensure a minimum amount of time being spent in loading and unloading as during this time the driver's wages and the interest and depreciation charges on the lorry are earning nothing.

As regards the size and type of motor, it may be taken roughly that loads under 5 tons are most economically carried on the motor itself, but larger loads are best distributed between the motor and a trailer. The relative advantages of oil (petrol) over steam are most marked in the smaller loads—10 tons and under—and consist chiefly in economy of power production per ton-mile, in the rapidity of starting, and the smaller cost of attendance. For larger engines, the cost of petrol is too great for economy, but if an engine

burning heavy oil could be constructed, the adoption of a heavier type of motor wagon would make great progress. Steam-driven motor wagons are quite satisfactory.

In consequence of the expense of repairs, many firms now sub-let all their carting to other firms at a rate depending on the load and distance, and in this way save themselves the worry and responsibility of repairs and depreciation. For establishments of moderate size, this plan is to be commended.

Water carriage is deservedly popular where it is feasible, as it is cheap. The chief disadvantages of this means of transport are the low level at which the material must necessarily be delivered and the slowness of transit.

For loading into steamers it is usually necessary to have a full boat-load in stock and to load in the smallest possible time. The stock may be in wagons, but this is a costly form of storage and in most cases it is far better to build one or more large storage bins, fitted with belt-conveyors, which are more efficient and less noisy than other types. With suitably fitted bins and conveyors one man and a boy can load a thousand tons of stone a day into a boat.

Railways also form the chief means of transport over long distances, and for economical working it is, therefore, advisable to have a siding in the yard whenever possible.

Miniature railways are a feature of some stone quarries, the locomotives being driven by steam, oil or electricity according to local conditions. With the rapid increase in the general use of petrol-motors their wider application to quarry purposes is only a matter of time. They are excellent for loads up to about 5 tons, but for greater loads small steam-driven locomotives or electric-motors are usually cheaper in use though not in first cost. When the delays connected with arranging large numbers of wagons into trains and redistributing them are considered, it is often found that several tractors driven by youths will move the material about the works more rapidly, conveniently, and at less cost than a steam-locomotive of greater power.

DISPOSAL OF USELESS STONE

In some quarries, a considerable amount of useless stone has to be dislodged and taken to a tip. It is best to quarry it separately where possible, but otherwise the useless material should be picked out by hand (see *Sorting*) and so separated. The useless stone is best treated as overburden and should be disposed of in a similar manner, but with due regard to the quantity to be removed.

SUPPLIERS OF MACHINERY AND APPLIANCES

As it is impossible, in the space available, to illustrate or describe every machine or other article made by different firms, the following list is printed to facilitate further inquiries. It is not complete, because some firms may have been unintentionally omitted, nor does it mention suppliers of articles which can readily be obtained with a minimum of inquiry. The list is also limited to appliances of which the author has had personal experience.

AERIAL ROPEWAYS (*see* ROPEWAYS)

AIR-COMPRESSORS, PNEUMATIC DRILLS, AND PNEUMATIC SPADES

- Air Pumps, Ltd., Emerson Street, London, S.E.1.
 Alley & McLellan, Ltd., Glasgow.
 Armstrong, Whitworth, Sir W. G., & Co. (Engineers), Ltd., 22-26 Great Smith Street, London, S.W.1.
 Atlas Diesel Co. Ltd., New Oxford House, Hart Street, London, W.C.1.
 Bellis & Morcom, Ltd., Birmingham, 17.
 Bon-Accord Pneumatic Tool Co., St. Clair Street, Aberdeen.
 Bramley Engineering Co. Ltd., Stourton Works, Hunslet, Leeds.
 British Flottmann Drill Co. Ltd., Allensbank Works, Cardiff.
 Broom & Wade, Ltd., High Wycombe, Bucks.
 Climax Rock Drill & Engineering Works Ltd., 4 Broad Street Place, London, E.C.2.
 Consolidated Pneumatic Tool Co. Ltd., 170 Piccadilly, London, W.1.
 Davies, R. S., & Co. Ltd., Mold, Wales.
 Emso Engineering Co. Ltd., St. Albans.
 Fleming & Co., 31 Robertson Street, Glasgow.
 Garner-Denver Co. Ltd., 3 Wilson Street, Drury Lane, London, W.C.2.
 Globe Pneumatic Engineering Co. Ltd., 1 Victoria Street, London, S.W.1.
 Goodwin, Arnold, Ltd., Sumner Street, Southwark Bridge, London, S.E.1.
 Hardypick Ltd., Sheffield, 8.
 Harrison Bros. Ltd., Middlesborough.
 Holman Bros. Ltd., Camborne.
 Ingersoll Rand Co. Ltd., 165 Queen Victoria Street, London, E.C.4.
 Jones, Wm., Ltd., 154-5 Upper Thames Street, London, E.C.4.
 Lacy-Hulbert & Co. Ltd., Boreas Works, Croydon.
 Lead Wool Co. Ltd., Snodland, Kent.
 Macdonald, John, & Co. (Pneumatic Tools), Ltd., Pollokshaws, Glasgow.
 Makin, W., & Sons, Sheffield.
 Metal Union, Ltd., 66 Broad Street Avenue, London, E.C.3.
 Padley & Venables, Ltd., Hill Street, Sheffield.
 Pullen, F. A., & Co., 58 Harleyford Road, Vauxhall, London, S.E.11.
 Reavell & Co. Ltd., Ranelagh Road, Ipswich.
 Robey & Co. Ltd., Lincoln.
 Rotary Air Compressor Co. Ltd., 12 Victoria Street, London, S.W.1.
 Spiros, 66 Victoria Street, London, S.W.1.
 Sullivan Machinery Co., Salisbury House, London, E.C.2.
 Swift, Samuel, Owlerton, Sheffield, 6.
 Tilghmann's Air Compressor Co., Broadheath, Manchester.
 Wilson, Alexander (Aberdeen), Ltd., Ashgrove Road, Aberdeen.
 Worthington-Simpson, Ltd., Queen's House, Kingsway, London, W.C.2.

AIR-HOSE

- Whitby & Chandler, Ltd., Sheffield.

BARROWS

Allen, John, & Sons (Oxford), Ltd., Cowley, Oxford.
 Blacknell, H. & H., Farnborough, Hants.
 Bristowes Machinery, Ltd., Montagu Road, London, N.18.
 British Steel Piling Co. Ltd., 54a Parliament Street, London, S.W.1.
 British Timber & Wood Paving Co. Ltd., 57-58 Queen Anne's Chambers,
 London, S.W.1.
 Cowan, Hulbert, Ltd., New Oxford House, Hart Street, London, W.C.1.
 Croggon & Co. Ltd., 230 Upper Thames Street, London, E.C.4.
 Heath & Co., 63-65 Jackson Street, Manchester.
 Johnston Bros., London House, Crutched Friars, London, E.C.3.
 Kenyon, Alexander, & Co. Ltd., Victoria Bridge, Manchester.
 Lister, R. A., & Co. Ltd., Dursley.
 McDonald, David, & Son, Ltd., New Park Street, Hamilton.
 Millars Machinery Co. Ltd., Pinners Hall, London, E.C.2.
 Neal, R. H., & Co. Ltd., Plant House, Ealing, London, W.5.
 Parker, Frederick, Ltd., Catherine Street, Leicester.
 Pegson, Ltd., Coalville, Leicester.
 Phoenix Engineering Co. Ltd., Chard, Somerset.
 Ransomes & Rapier, Ltd., Ipswich.
 Rowland Bros., Fenny Stratford, Bucks.
 Scott, C. L., 46 William Edward Street, Birmingham.
 Slingsby, H. C., 89 Kingsway, London, W.C.2.
 Smith, Wm., & Sons, Grove Works, Barnard Castle.
 Stothert & Pitt, Ltd., Bath.
 Stubbs, W. B., & Son, Hawksworth, Notts.
 Swinney Bros., Morpeth.
 Theedam, E. C., Ltd., Dudley, Worcs.
 Townsend, A. P., Suffolk Street, Birmingham.
 Whittaker, C., & Co. Ltd., Accrington, Lancs.
 Winget, Ltd., Rochester.

BLONDINS (*see also* ROPEWAYS)

Henderson, John M., & Co. Ltd., Aberdeen.
 White, R., & Sons, Ltd., Widnes, Lancs.

BORING MACHINES (*see* AIR-COMPRESSORS)

CHAINS

Case, H., & Son, Cradley Heath, Staffs.
 Stringer & Son, Ltd., Cradley Heath, Staffs.

CONVEYORS (PORTABLE) AND LOADERS

Alexander, Herbert, & Co. Ltd., Charmouth Street, Leeds, 11.
 Chaseside Engineering Co., Enfield, London, N.
 Crone & Taylor, Ltd., Sutton Oak, St. Helens, Lancs.
 Hepburn Conveyor Co., Wakefield, Yorks.

Innes, Sons & King, Ltd., Hitchin, Herts.
 Johnson, C. H., & Sons, Ltd., Smedley, Manchester.
 Neal, R. H., & Co. Ltd., Plant House, Ealing, London, W.5.
 Pantin, W. & Co., 147 Upper Thames Street, London, E.C.4.
 Parker, Frederick, Ltd., Viaduct Works, Catherine Street (Extension),
 Leicester.
 Pegson, Ltd., Coalville, Leicester.
 Spencer (Melksham), Ltd., Melksham, Wilts.
 Stothert & Pitt, Ltd., Bath.

CONVEYORS AND ELEVATORS (BELT AND CHAIN)

Alexander, Herbert, & Co. Ltd., Charnmouth Street, Leeds.
 Allen, Edgar, & Co. Ltd., Sheffield, 9.
 Anderson-Grice Co. Ltd., Carnoustie, Scotland.
 Babcock & Wilcox, Ltd., Babcock House, Farringdon Street, London, E.C.4.
 Bagshaw & Co. Ltd., Dunstable, Beds.
 Bennett & Sayer, Ltd., Derby.
 Bennis, Ed., & Co. Ltd., Little Hulton, Bolton.
 Bobby, Robert, Ltd., Vickers House, Broadway, London, S.W.1.
 Bradley & Craven, Ltd., Wakefield.
 Bramley Engineering Co. Ltd., Stourton Works, Hunslet, Leeds.
 Bristowes Machinery, Ltd., Montagu Road, London, N.18.
 British Jeffrey Diamond, Ltd., Wakefield.
 British Ropeways, Ltd., 14-18 Holborn, London, E.C.1.
 Case, H., & Son, Foxoak Street, Cradley Heath.
 Chadderton Conveyor Co. Ltd., Radcliffe, Manchester.
 Cowan, Hulbert, Ltd., New Oxford House, Hart Street, London, W.C.1.
 Ewart Chain Belt Co., Derby.
 Fawcett, J. Dawson (Darlington), Ltd., Haughton Engineering Works,
 Darlington.
 Fawcett, Thos. C., Ltd., Hunslet, Leeds.
 Fletcher's Malleable Foundry, Ltd., Litchurch Lane, Derby.
 Fowler, John, & Co. (Leeds), Ltd., Leeds.
 Fraser & Chalmers, Erith, Kent.
 Fraser & Fraser, Ltd., Bromley-by-Bow, London, E.3.
 Glasgow Engineers, Ltd., 89 James Street, Glasgow, S.E.
 Goodwin, Barsby, & Co. Ltd., St. Margaret's Ironworks, Leicester.
 Greening, N., & Sons, Ltd., Britannia Works, Warrington.
 Hadfields, Ltd., East Hecla Works, Sheffield.
 Hardypick, Ltd., Sheffield.
 Head, Wrightson & Co. Ltd., Thornaby-on-Tees.
 Heenan & Froude, Ltd., 4 Chapel Walks, Manchester.
 Henderson, John M., & Co. Ltd., King's Works, Aberdeen.
 Hepburn Conveyor Co. Ltd., Wakefield.
 Hiscox, W., Ltd., Derby.

Johnson, Wm., & Sons, Ltd., Armley, Leeds.
 Kennedy-Van-Saun Manufacturing & Eng. Corporation, Room 442 Bush
 House, Aldwych, London, W.C.2.
 King, John, & Co. Ltd., Garnet Road, Leeds.
 Locker, Thos., & Co. Ltd., Warrington.
 Marsden, H. R., Ltd., Meadow Road, Leeds.
 Marshall, Sons, & Co. Ltd., Britannia Iron Works, Gainsborough.
 Mason Bros., Brandon Street, Leicester.
 Millars' Machinery Co. Ltd., Pinners Hall, London, E.C.2.
 Mining Engineering Co. Ltd., Worcester.
 Mitchell Conveyor & Transporter Co. Ltd., 45-50 Holborn Viaduct, W.C.1.
 Morris, Herbert, Ltd., Loughborough.
 Neal, R. H., & Co. Ltd., Plant House, Ealing, London, W.5.
 Newell, Ernest, & Co. Ltd., Misterton, Doncaster.
 Nortons (Tividale), Ltd., Tipton, Staffs.
 Parker, Frederick, Ltd., 100 Cannon Street, Leicester.
 Pegson, Ltd., Coalville, Leicestershire.
 Pneulec, Ltd., Mafeking Road, Smethwick, Birmingham.
 Pragos Engineering Co. Ltd., 351 Brixton Road, London, S.W.9.
 Ransomes & Rapier, Ltd., Ipswich.
 Reddaway, F., & Co. Ltd., Pendleton, Manchester.
 Redler Patents, Sharpness, Gloucestershire.
 Richter & Pickis, 6 Crescent, Minories, London, E.C.3.
 Robson, G., & Co., Hodgson Street, Sheffield.
 Ropeways, Ltd., Aldwych House, London, W.C.2.
 Royce, Ltd., Trafford Park, Manchester.
 Smith, Thomas, & Sons (Rodley), Ltd., Rodley, Leeds.
 Spencer (Melksham), Ltd., Melksham, Wilts.
 Steel Band Conveyor & Engineering Co. Ltd., Parade, Birmingham.
 Stothert & Pitt, Ltd., Bath.
 Stott, S. S., & Co., Haslingdon.
 Stringer & Son, Ltd., Cradley Heath, Staffs.
 Tullis, John, & Son, Ltd., Glasgow, S.E.
 Whitby & Chandler, Ltd., Sheffield.
 Wilson, Alexander (Aberdeen), Ltd., Ashgrove Road, Aberdeen.
 Wood, Hugh, & Co. Ltd., Newcastle-on-Tyne.

CONVEYORS (SPIRAL)

Bennett & Sayer, Ltd., Derby.
 Bradley & Craven, Ltd., Leeds.
 Fawcett, J. Dawson (Darlington), Ltd., Darlington.
 Fawcett, Thos. C., Ltd., Leeds.

CONVEYORS (STEEL BAND)

Steel Band Conveyor & Engineering Co. Ltd., Birmingham.

CRANES

Anderson-Grice, The, Co. Ltd., Carnoustie, Scotland.
 Henderson, John M., & Co. Ltd., Aberdeen.
 Ransomes & Rapier Ltd., Ipswich.
 Ruston-Bucyrus, Ltd., Excavator Works, Lincoln.
 Smith, Thomas, & Sons (Rodley), Ltd., Rodley, Leeds.
 Stothert & Pitt, Ltd., Bath.

DRAGLINES (*see* EXCAVATORS)DREDGES (*see* EXCAVATORS)DRILLS AND SHARPENERS (*see* AIR-COMPRESSORS)ELEVATORS (*see* CONVEYORS AND ELEVATORS)

ENGINES

Babcock & Wilcox, Ltd., Farringdon Street, London, E.C.4.
 Bellis & Morcom, Ltd., Birmingham.
 Blackstone & Co. Ltd., Stamford.
 Crossley Bros. Ltd., Openshaw, Manchester.
 Fielding & Platt, Ltd., Gloucester.
 Lister, R. A., & Co. Ltd., Dursley, Gloucestershire.
 National Gas Engine Co. Ltd., Ashton-under-Lyme.
 Petters, Ltd., Yeovil, Somerset.
 Tangyes, Ltd., Birmingham.

EXCAVATORS (SMALL) (*see also* SCOOPS)

Chaseside Engineering Co., Enfield, London, N.
 Denholm Contractors Machinery Co. Ltd., Astor House, Aldwych, London,
 W.C.2.
 Descamps, Georges, 29 King's Chambers, Angel Street, Sheffield.
 Jones, Wm., Ltd., 154 Upper Thames Street, London, E.C.4.
 Neal, R. H., & Co. Ltd., Plant House, Ealing, London, W.5.
 Pragos Engineering Co. Ltd., 351 Brixton Road, London, S.W.9.
 Priestman, Bros., Ltd., Hull.
 Ransomes & Rapier, Ltd., Ipswich.
 Rushton Tractor Co. Ltd., Walthamstow, London, E.17.
 Ruston-Bucyrus, Ltd., Lincoln.
 Spencer (Melksham), Ltd., Melksham, Wilts.

EXCAVATORS (LARGE) (*see also* SCOOPS)

Allen, John, & Sons, Ltd., Cowley, Oxford.
 Atlas Diesel Co. Ltd., New Oxford House, Hart Street, London, W.C.1.
 British-Jeffrey Diamond Co. Ltd., Stennard Works, Wakefield.
 Chaseside Engineering Co., Enfield, London, N.
 Descamps, Georges, 29 King's Chambers, Angel Street, Sheffield.
 Goodacre, Wm., & Sons, Ltd., Russell Road, Victoria Docks, London, E.16.

Jones, Wm., Ltd., 154-5 Upper Thames Street, London, E.C.4.
 Keystone Driller Co., Beaver Falls, Pennsylvania, U.S.A.
 Muir Hill (Engineers), Ltd., Elsinore Road, Old Trafford, Manchester.
 Neal, R. H., & Co. Ltd., Plant House, Ealing, London, W.5.
 Priestman, Bros., Ltd., Hull.
 Ransomes & Rapier, Ltd., Ipswich.
 Ropeways, Ltd., Aldwych House, Aldwych, London, W.C.2.
 Ruston-Bucyrus, Ltd., Lincoln.
 Smith, Thomas, & Sons (Rodley), Ltd., Rodley, Leeds.
 Steenbrugge, M., & Co., 17 Queen Victoria Street, London, E.C.4.
 Stothert & Pitt, Ltd., Bath.
 Taylor & Hubbard, Ltd., Kent Street, Leicester.
 Wellman Smith Owen Engineering Corporation, Ltd., Victoria Station House,
 Victoria Street, London, S.W.1.
 Wilson, John H., & Co. (1929), Ltd., Dock Road, Birkenhead.

EXPLOSIVES

Cooke's Explosive Factory, Penrhyndeudraeth, North Wales.
 Imperial Chemical Industries, Ltd., Imperial Chemical House, Millbank,
 London, S.W.1.
 Liquid Oxygen Explosives, Ltd., 1 Albemarle Street, Piccadilly, London, W.1.
 Northern Sabulite Explosives Co. Ltd., Darlington.

GRABS

Priestman Bros., Ltd., Hull.
 Ransomes & Rapier, Ltd., Ipswich.
 Ruston-Bucyrus, Ltd., Lincoln.
 Westwood, J., & Co. Ltd., Napier Yard, Millwall, London, E.14.

HAMMERS (*see SHOVELS, etc.*)

HAULAGE

Bennett & Sayer, Ltd., Derby.
 Bradley & Craven, Ltd., Wakefield.
 Brightside Foundry & Engineering Co. Ltd., Sheffield.
 Coventry Chain Co. Ltd., Spon End Works, Coventry.
 Ewart Chain Belt Co., Derby.
 Fawcett, J. Dawson (Darlington), Ltd., Darlington.
 Fawcett, Thos. C., Ltd., Hunslet Road, Leeds.
 Shaw, John, Ltd., Sheffield.
 Sheffield Wire Rope Co. Ltd., Darnall, Sheffield.
 Westinghouse Morse Chain Co. Ltd., The Chaineries, Letchworth, Herts.
 Wright's Ropes, Ltd., Universe Works, Birmingham.

HOISTS AND LIFTS

- Hardypick, Ltd., Heeley, Sheffield, 8.
 Holman Bros., Ltd., Camborne.
 Ingersoll Rand Co. Ltd., 165 Queen Victoria Street, London, E.C.4.
 Ransome Machinery Co. Ltd., Windsor House, 42-50 Victoria Street, London, S.W.1.
 Sandycroft, Ltd., 4 Broad Street Place, London, E.C.2.

LOADING APPLIANCES (*see* SCOOPS AND CONVEYORS)

LIGHTING, QUARRIES AND WORKS

- Barber & Coleman, Ltd., Brooklands, Manchester.
 Benjamin Electric, Ltd., Tariff Road, Tottenham, London, N.17.
 Carbic, Ltd., 51 Holborn Viaduct, London, E.C.1.
 Dargue Acetylene Gas Co. Ltd., 57-59 Grey Street, Newcastle.
 General Electric Co. Ltd., Magnet House, Kingsway, London, W.C.2.
 Horstmann Gear Co. Ltd., Newbridge Works, Bath.
 Korting & Mathieson Electrical, Ltd., 715 Fulham Road, London, S.W.6.
 Parkinson, W., & Co., Bell Barn Road, Birmingham.
 Tilley Lamp Co., Brant Works, Hendon, London, N.W.4.
 Wardle Engineering Co. Ltd., Elsinore Road, Old Trafford, Manchester.
 Wild, George, 22 Ropemaker Street, London, E.C.2.

LOCOMOTIVES (*see also* WAGONS AND TRACTORS)

- Blackmore, H. G., Windsor House, Victoria Street, London, S.W.1.
 Blackstone & Co. Ltd., Rutland Works, Stamford.
 Descamps, Georges, 29 King's Chambers, Angel Street, Sheffield.
 Drewry Car Co. Ltd., 13 River Plate House, South Place, London, E.C.2.
 Fowler, John, & Co. (Leeds), Ltd., Leeds.
 Greenwood & Batley, Ltd., Albion Works, Leeds.
 Hibberd, F. C., & Co. Ltd., 16 Northumberland Avenue, London, W.C.2.
 Holland, Bernard, & Co., 17 Victoria Street, Westminster, London, S.W.1.
 Hudson, Clarke & Co., Leeds.
 Hudson, Robert, Ltd., Meadow Lane, Leeds.
 Jones, Wm., Ltd., 154 Upper Thames Street, London, E.C.4.
 Kay, J. C., & Co. Ltd., Bury, Lancs.
 Kerr, Stuart, & Co. Ltd., Stoke-on-Trent.
 Motor, Rail, & Tram-Car Co. Ltd., Simplex Works, Bedford.
 Oliver, J. C., & Co., 7 Greek Street, Leeds.
 Peckett & Sons, Ltd., Bristol.
 Petrol Loco Hirers, 16 Elstow Road, Bedford.
 Ransomes & Rapier, Ltd., Ipswich.
 Ruston-Bucyrus, Ltd., Lincoln.
 Tractor Traders, Ltd., Thornycroft House, Smith Square, London, S.W.1.

Willett, Harold J., Ltd., Colchester.
Wingrove & Rodgers, Ltd., Old Swan, Liverpool.

MINING MACHINERY

Hardypick, Ltd., Heeley, Sheffield, 8.
Holman Bros. Ltd., Camborne.
Ingersoll-Rand Co. Ltd., 165 Queen Victoria Street, London, E.C.4.
Mossay & Co. Ltd., 200 High Holborn, London, W.C.1.

OVERHEAD ROPEWAYS (*see* ROPEWAYS)PICKAXES (*see* SHOVELS, SPADES, PICKS, AND HAMMERS)PNEUMATIC APPLIANCES (*see* AIR-COMPRESSORS)PORTABLE TRACK (*see* RAILS)

PUMPS

Anglo-American Rope & Oakum Co. Ltd., 12 Hopwood Street, Liverpool.
Bailey, Sir W. H., & Co. Ltd., Salford, Manchester.
Blackstone & Co. Ltd., Stamford.
Brooke Tool Manufacturing Co. Ltd., Greet, Birmingham.
Chalmers, Edina Co., 39 Assembly Street, Leith, Scotland.
Drum Engineering Co. Ltd., Bradford.
Erith's Engineering Co. Ltd., 83 Kingsway, London, W.C.2.
Fielding & Platt, Ltd., Gloucester.
Gilkes (Gilbert), & Co. Ltd., Kendal.
Goodwin, Arnold, Ltd., Sumner Street, Southwark Bridge, London, S.E.1.
Gunther & Sons, Oldham.
Gwynnes Pumps, Ltd., Hammersmith Works, Lincoln.
Hayward-Tyler & Co. Ltd., Luton, Beds.
Holden & Brooke, Ltd., West Gorton, Manchester.
Honig & Mock, Ltd., 7 Mark Lane, London, E.C.3.
Keystone Driller Co., Beaver Falls, Pennsylvania, U.S.A.
Kirkham, J. & W., Ltd., Lark Street Works, Bolton, Lancs.
Knight, J., & Hale, Ltd., Manchester.
Lacy-Hulbert & Co. Ltd., Boreas Works, Croydon.
Mather & Platt, Ltd., Manchester.
Millars' Machinery Co. Ltd., Pinners Hall, London, E.C.2.
Moorlands Engineering Co. Ltd., Leek, Staffs.
National Gas Engine Co. Ltd., Ashton-under-Lyne.
Newton, Bean & Mitchell, Bradford.
Phoenix Engineering Co. Ltd., Chard, Somerset.
Pullen, F. A., & Co., 58 Harleyford Road, Vauxhall, London, S.E.11.
Pulsometer Engineering Co. Ltd., Reading.
Richter Manufacturing Co., Richter Works, Bradford.

Ruston-Bucyrus, Ltd., Lincoln.
 Ruston & Hornsby, Ltd., Lincoln.
 Sihi Self-Priming Pump Co., Fallowfield, Manchester.
 Stothert & Pitt, Ltd., Bath.
 Sulzer Bros., 31 Bedford Square, London, W.C.1.
 Sykes, Henry, Ltd., Southwark Street, London, S.E.1.
 Tangyes, Ltd., Cornwall Works, Birmingham.
 Theedam, E. C., Ltd., Dudley, Worcs.
 Tuke & Bell, Ltd., Lichfield, Staffs.
 Warner, Robert (Pumps), Ltd., Pottery Lane, Newcastle-on-Tyne.
 Weir, G. & J., Ltd., Cathcart, Glasgow.
 Wellman Smith Owen Engineering Corporation, Ltd., Victoria Station House,
 Victoria Street, London, S.W.1.
 Willcox, W. H., & Co. Ltd., 32-38 Southwark Street, London, S.E.1.
 Winget, Ltd., Rochester.
 Worthington-Simpson, Ltd., Newark-on-Trent.

RAILS

Dorman, Long & Co. Ltd., Middlesbrough.
 Firth, W., & Co., Leeds.
 Hardypick, Ltd., Sheffield.
 Hudson, Robert, Ltd., Meadow Lane, Leeds.
 Oliver, J. C., & Co., 7 Greek Street, Leeds.
 Railway & General Engineering Co. Ltd., Midland Works, Nottingham.
 Summerston, Thomas, & Sons, Ltd., Albert Hill Foundry, Darlington.
 White, R., & Sons, Widnes, Lancs.

Good *second-hand* rails can usually be obtained from Thos. W. Ward, Ltd., Sheffield ; Charles D. Phillips, Ltd., Newport, Mon., and elsewhere.

ROPES (*see* HAULAGE)

ROPEWAYS (AERIAL)

British Ropeway Engineering Co. Ltd., 14 High Holborn, London, W.C.1.
 Dennis, W. F., & Co., 70 Queen Victoria Street, London, E.C.4.
 Heckel Co. Ltd., London, E.C.4.
 Henderson, J. M., & Co. Ltd., Aberdeen.
 Ropeways, Ltd., & R. H. Pearson, Ltd., Aldwych House, London, W.C.2.
 White, Rd., & Sons, Ltd., Widnes, Lancs.

SAFETY BELTS.

Hanley, A., 473 Queen's Road, Sheffield.

SCOOPS

Chaseside Engineering Co., Enfield, London, N.
 Ransomes & Rapier, Ltd., Ipswich.
 Robson, G., & Co., Hodgson Street, Sheffield.
 Sargeant, E. F., Skelton, York.
 Tractor Traders, Ltd., Thornycroft House, Smith Square, London, S.W.1.

SCRAPERS AND EXCAVATORS (*see also* EXCAVATORS AND SCOOPS)-

Wild, M. B., & Co. Ltd., Nechels, Birmingham.

SHARPENERS FOR DRILLS (*see* AIR-COMPRESSORS)

SHOVELS, SPADES, PICKS, AND HAMMERS

Brindley, F. J., & Sons, River Lane, Sheffield.
 Hardypick, Ltd., Sheffield.
 Lucas, E. & W., Ltd., Dronfield Forge and Shovel Works, Dronfield, Nr. Sheffield.
 Park, Wm., & Co., Clarington Forge, Wigan.
 Skelton, C. T., & Co. Ltd., Sheaf Bank, Sheffield.
 Stockton Heath Forge, Warrington.
 Warden, F. H., Ltd., Birmingham.

SPADES (*see* SHOVELS, etc.)TOOLS (*see also* SHOVELS, etc.)

Blyde, A., & Co., Wallace Steel Works, Sheffield.
 Bristowes Machinery, Ltd., Montagu Road, London, N.18.
 Caxton Wood Turnery Co., Market Harborough.
 Croggon & Co. Ltd., 230 Upper Thames Street, London, E.C.4.
 Descamps, Georges, 29 King's Chambers, Angel Street, Sheffield.
 English Tools, Ltd., 15 Wiend, Wigan.
 Hardypick, Ltd., Sheffield.
 Holman Bros., Ltd., Camborne.
 Jones, William, Ltd., 154-5 Upper Thames Street, London, E.C.4.
 Kenyon, Alexander, & Co. Ltd., Victoria Bridge, Manchester.
 Leedham & Heaton, Ltd., Atlas Forge, Britannia Bridge, Wigan.
 Lucas, E. & W., Ltd., Dronfield Forge and Shovel Works, Dronfield, Nr. Sheffield.
 Macdonald, John, & Co. (Pneumatic Tools), Ltd., 43 King Street, Pollokshaws, Glasgow.
 Makin, W., & Sons, Sheffield.
 Mountford, P., & Co. Ltd., Stourbridge, Worcs.
 Moyes, Wm., & Sons, 142 Waterloo Street, Glasgow, C.2.
 New Kent Brush Co., East Malling, Kent.

Padley & Venables, Ltd., Hill Street, Sheffield.
 Phoenix Engineering Co. Ltd., Chard, Somerset.
 Pike, George, Alma Street, Birmingham.
 Roadways Equipment, Ltd., 97 St. James' Road, Glasgow, C.4.
 Rowland Bros., Bletchley.
 Scott, C. L., 46 William Edward Street, Birmingham.
 Skelland, W., Kay Street, Ardwick Green, Manchester.
 Stockton Heath Forge, Warrington.
 Swift, Samuel, Livesey Street, Owlerton, Sheffield.
 Theedam, E. C., Ltd., Dudley, Worcestershire.
 Wells, A. C., & Co. Ltd., Carnarvon Street, Cheetham, Manchester.
 Wild, George, 22 Ropemaker Street, London, E.C.2.
 Wild, James & F. C., Sheffield.

TRACTORS (*see* LOCOMOTIVES AND WAGONS)

TURN-TABLES

Alexander, Herbert, & Co. Ltd., Hercules Engineering Works, Charmouth
 Street, Leeds.
 Firth, W., & Co. Ltd., Cavendish Road, Leeds.
 Hudson, R., Ltd., Meadow Lane, Leeds.
 Jones, William, Ltd., 154 Upper Thames Street, London, E.C.4.
 Oliver, J. C., & Co., 7 Greek Street, Leeds.
 Theakston, Francis, Ltd., London, S.W.1.
 White, R., & Sons, Ltd., Widnes, Lancs.

VEHICLES (*see* LOCOMOTIVES AND WAGONS)

WAGONS AND TRACTORS (*see also* LOCOMOTIVES)

Allen, A., & Son, Ltd., Lower Gornal, Near Dudley, Worcs.
 Allen, W. G., & Sons (Tipton), Ltd., Princes End, Tipton.
 Atkinson Walker Wagons, Ltd., Frenchwood Works, Preston.
 Aveling & Porter, Ltd., Rochester.
 Brindley, F. J., & Sons, River Lane, Sheffield.
 Burrell, Charles, & Sons, Ltd., Thetford, Norfolk.
 Cambrian Wagon Co. Ltd., Cardiff.
 Chenard-Walcker Tractors, Clapham Park Road, London, S.W.9.
 Easyloader, Ltd., 11 Tothill Street, London, S.W.1.
 Firth, W., & Co., Cavendish Road Works, Leeds.
 Fodens, Ltd., Elworth Works, Sandbach, Cheshire.
 Foster, Wm., & Co. Ltd., Lincoln.
 Fowler, John, & Co. (Leeds), Ltd., Steam Plough Works, Leeds.
 Garratt, R., & Sons, Ltd., Aldwych House, London, W.C.2.

Garner Motors, Ltd., Tyseley, Birmingham.
 Greenwood & Batley, Ltd., Albion Works, Leeds (Electric).
 Heath & Co., Diamond Works, Manchester.
 Hibberd, F. C., & Co. Ltd., 16 Northumberland Avenue, London, W.C.2.
 Howard, J. & F., Bedford.
 Hudson, Robert, Ltd., Meadow Lane, Leeds.
 International Harvester Co. of Great Britain, Ltd., 259 City Road, London, E.C.1.
 Jones, Wm., Ltd., 154 Upper Thames Street, London, E.C.4.
 Kerr, Stuart & Co. Ltd., California Works, Stoke-on-Trent.
 Latil Industrial Vehicles, Ltd., 11 Albert Embankment, London, S.E.11.
 Lister, R. A., & Co. Ltd., Dursley, Glos.
 Mann Steam & Motor Wagon Co. Ltd., Fashion Street, Spitalfields, London, E.1.
 Marple & Gillott, Ltd., Stevenson Road, Attercliffe, Sheffield.
 Marshall, Sons & Co. Ltd., Britannia Iron Works, Gainsborough (*Caterpillars*).
 McLaren, J. & H., Ltd., Midland Engineering Works, Leeds.
 Morris, R., Ltd., Farnworth, Bolton, Lancs.
 Oliver, J. C., & Co., 7 Greek Street, Leeds.
 Peace, Samuel, & Sons, Ltd., Wellmeadow Steelworks, Sheffield.
 Robey & Co. Ltd., Lincoln.
 Rowland Bros., Bletchley, Bucks.
 Rushton Tractor Co. (1929), Ltd., Forest Road, Walthamstow, London, E.11.
 Scammell Lorries, Ltd., High Holborn House, London, W.C.1.
 "Sentinel" Wagon Works, Ltd., Shrewsbury.
 Swift, Samuel, Livesey Street, Owlerton, Sheffield.
 Taskers of Andover, Ltd., Andover, Hants.
 Theakston, F., Ltd., 60 Tufton Street, London, S.W.1.
 Thorp & Son, Ltd., Derby.
 Wallis & Stevens, Ltd., Basingstoke.
 Warden, F. H., Ltd., Birmingham.
 Whitby & Chandler, Ltd., Wicker, Sheffield.
 Whitehead, John, & Co. Ltd., Albert Works, Preston.
 Whittaker, C., & Co. Ltd., Accrington, Lancs.
 Yorkshire Patent Steam Wagon Co., Hunslet, Leeds.

WEIGHING MACHINES (including AUTOMATIC)

Avery, W. & T., Ltd., Birmingham.
 Denison, Samuel, & Son, Ltd., Leeds.
 Simon, Richard, & Sons, Ltd., Phoenix Works, Nottingham.
 Winget, Ltd., Rochester.

WIRE ROPES (*see* HAULAGE)

CHAPTER III

THE PREPARATION OF THE STONE

THE preparation of the stone for various commercial purposes-consists essentially in :

(i) Recognizing portions of the stone as useful for one or more specific purposes, and separating them from the remainder. This operation is known as *Sorting*.

(ii) Treating the stone so as to facilitate further work on it, as by "Weathering," Drying, Dressing, Crushing, Grinding, Screening, Purifying, etc.

These various processes require careful consideration in order to obtain the best results in the most economical manner, as it is only too easy to waste both stone and money unless sufficient technical skill and business acumen are exercised. One of the most serious defects of many quarries at the present day is the excessive cost of working them, which is due to lack of skill or foresight in those who have worked them in the past. It may seem profitable to a lessee—an owner would scarcely be so foolish—to pick out some of the best stone, and leave the rest and all the inferior material, but if the quarry is worked for a sufficient length of time, the foolishness of this policy will soon manifest itself. It is, of course, undesirable to move unnecessarily any unsaleable material, but to obtain the greatest ultimate profit from a quarry an effort should be made to sell the whole of the material in some form or other. In most cases, by sufficiently skilled treatment, much of what is commonly regarded as "quarry waste" may be converted into products which produce an appreciable profit.

It is always desirable to arrange to tip the waste material in a suitable part of the estate and not to throw it in a haphazard fashion on to the floor of the quarry or into old workings. Many quarries have been spoiled by good stone being covered with tipped rubbish and later developments are often hindered because rubbish has been tipped into the old excavations. The cleaner a quarry-floor can be kept the easier will be the working, the smaller the risk of accident, and the better the impression created in the minds of prospective customers.

It is usually best to tip the rubbish to the farther side of a line drawn parallel to the quarry-face and at a convenient distance in front of it. This leaves the floor free for future developments.

SORTING

In only a few cases can the whole of the stone be used to the best advantage without any attempt at sorting, and whilst many quarry owners make feeble

efforts in this direction, they will find, on investigating the matter, that their policy is a short-sighted one.

Even where the stone is quarried for a single purpose, such as lime-burning or road-making, it should be carefully examined as to its quality and its suitability for the main purpose, as well as for others. Unless this precaution is taken there is likely to be much trouble later, especially if unsuitable stone is sent to the kilns. In several quarries, the quantity of inferior lime drawn from the kilns is so large as to warrant serious attention. The managers of these works contend that the cost of quarrying in such a manner as to avoid mixing the inferior stone with that of better quality and the cost of sorting the quarried stone prior to sending it to the kilns would be prohibitive. In each case which the author has fully examined, however, it was found that the cost of more careful quarrying and of sorting was far less than the loss on unsaleable lime or stone.

Sorting, when properly arranged and strictly supervised, is undoubtedly more profitable than is commonly supposed by quarry managers. The supervision must be good or the sorting will be useless. All highly discoloured pieces of stone should usually be rejected, the only exception being where the discoloration is due wholly to organic matter which is completely burnt out when the stone is converted into lime. If the stone is required for architectural or monumental purposes, any blocks with cracks, "shakes," or fissures should also be set aside unless the portions containing these defects can be cut off and a sufficiently good stone left. Any materials of an objectionable or useless character should at once be sent to a tip or other place where they can do no harm, for it is remarkable how much time is often spent in moving such materials two or three times, when once ought to suffice. A truck, skip, barrow, or even basket into which such materials can be thrown *at once* will save much trouble and expense later.

The rejected stone and rubbish should immediately be placed where it cannot be used for a wrong purpose. Several serious losses have been incurred through lack of this precaution.

The stone should also be sorted according to size, though in many quarries this can best be done automatically for all except the largest pieces by means of screens (see Screening).

When dimensional stone for building or monumental purposes is produced, special care is needed in selecting the stone.

The manner of sorting should largely depend on the nature of the materials. Thus, large blocks should usually be lifted to a convenient place and there carefully examined. If they are suitable for the intended purpose instructions are given accordingly, the rejected stones being disposed of according to their properties.

Where the conditions in the quarry do not admit of a sufficient examination of the stone being made therein, it may be necessary to make a rough selection at the quarry-face and a more careful one at the dressing- or masonry-shops. This course is open to the objection that it causes much useless stone to be

accumulated in the shops, which involves further expense—inasmuch as this waste material has to be handled by highly paid workmen. Whenever the selective sorting of the stone can be done at or near the face this expense is avoided. Where the seams of stone are thin or where there are many joints, seams, or erosion cavities filled with clay, sand, or gravel, the difficulty of removing the waste material before blasting may render it necessary to blast rock and waste material down together, and to separate the siliceous material from the good limestone at a later time, by either of the two following methods :

(a) The materials are carefully sorted, the useful rock being loaded into one set of wagons by hand, and accumulations of debris are loaded into another set of wagons in the same way. This method is too slow and laborious to be recommended for large quarries.

(b) The rock-fragments and waste material are loaded together with a steam-navvy or grab—a method that is economical of labour—and the good rock is afterwards separated from the waste, by screening or by washing in conjunction with screening. From the standpoint of labour saving, this method is greatly to be preferred, but much waste results from the finer rock fragments passing through the screens with the debris ; this loss may be partly prevented by screening the rock to various sizes and discarding only the finest grade material. Where any considerable amount of debris is originally separated from the rock, it is obviously a poor policy to mix them by blasting them down together, because their subsequent separation involves unnecessary handling of waste, and in rainy seasons the sticky clay in the rock impedes screening operations and renders separation difficult. For this reason it is usually better to remove the overburden as completely as possible before blasting the rock.

Although a stone is “ rejected ” for one purpose, it may be quite useful or even superior for another, and the skill of the manager as well as the profit on the undertaking will be indicated by the uses found for these “ rejected ” materials.

SEASONING OR WEATHERING

Many limestones and allied materials are soft when freshly quarried or mined, but harden rapidly on exposure. When such stones are to be dressed for use in building, or to be crushed for other purposes, it is desirable to treat them immediately, as power and labour are thereby saved. The dressed or crushed stone may then be exposed to the weather in order that it may harden. This is not always feasible, because some stones contain so much moisture, with various substances in solution and in a “ sol ” state (commonly known as “ *quarry sap* ”), that they cannot be dressed efficiently until they have become “ dry.”

When a freshly quarried block is allowed to dry the escaping water carries any mineral salts present in solution to the surface of the block and leaves them there or in the pores adjacent to the surface, forming a crust of variable thickness.

If some limestones are dressed a long time after they have been seasoned, the protective crust will be removed in the dressing and the finished stone may lack durability. With other limestones, the removal of the mineral salts during the dressing is an advantage. Which is the better method for any particular stone can only be found by experience.

Again, before dressing chalk to be used as a building stone, it is better to quarry the material in as large blocks as possible to allow them to weather for some months, as this treatment reveals irregular joints and bedding planes which are almost impossible to detect in the freshly quarried stone. The weathered blocks are then dressed as required.

Where a stone is to be burned for the production of lime, weathering is no advantage, but drying is sometimes economical.

Bath stone dislodged in the winter months is kept underground until the spring, so as not to expose the moist stone to frost, and all other stones may, with advantage, be kept under such conditions that they are not damaged by this very powerful disintegrating agent.

After the blocks have dried and hardened they should emit a clear ringing sound when struck; otherwise they contain a "vent" or unsound portion, which must be found and cut out.

DRYING BLOCKS OF STONE

Wet limestone and chalk are difficult to dress with accuracy as their surface is different from that of the same piece when dry. The process of drying does not merely remove the moisture in the material; it also effects other changes, some of which are very important.

Any free water in the stone will dissolve some, or all of the soluble salts present, according to their quantity. As the drying progresses, the water rises to the exposed surface of the stone or to those portions of the surface at which the drying occurs. The water then evaporates, leaving on the surface of the stone, or sometimes immediately below it, any salts which it may previously have held in solution, or any substances suspended in the water in that extremely finely-divided condition which is known as the colloidal sol state. If silica is in this state it forms a dry, thin and intensely hard "skin" on the surface of the stone, and makes it extremely resistant to weather. If this skin is broken by dressing or cutting the stone, or by accident, the exposed part of the stone will be less resistant than that which is covered by the "colloidal skin." Soluble silica in a stone is thus very advantageous in increasing its durability. Soluble salts, on the contrary, form a whitish "scum" of a crystalline nature which is unsightly. It is easily avoided by allowing the stone to dry thoroughly before dressing it, as the salts will be brought to the surface during the drying and will be removed, along with some of the stone in the subsequent dressing.

Large blocks of stone are usually dried by keeping them under cover in an open shed or even by piling them one above the other in the open air. The

latter is objectionable as the stone may be wetted by showers of rain, but, except in prolonged wet weather, this is not usually of importance as very little rain penetrates the stone and actual drying occurs on most days in the year. It is, however, better to keep the stone under cover where possible.

"Natural drying," as just described, is very slow, and a very large amount of space is required for this purpose in a works with a very large output. The drying may be effected far more rapidly by means of artificial heat, though this is much more costly than natural drying.

Drying chambers are of two chief types: (i) intermittent or batch dryers, which are filled with stone. This stone is then dried and afterwards removed; and (ii) continuous dryers through which a continuous series of trucks bearing stone is passed.

Intermittent dryers are good for small works as they can be accurately controlled and adjusted to the needs of the works, yet they are costly in fuel as no use can be made of waste heat. Dryers of this type may consist of a large chamber provided with a floor heated by steam, or with steam-pipes arranged so as to heat the chamber. Another form of intermittent dryer which is excellent and very economical consists of a long chamber with a bank of steam-heated vertical pipes at one end and an exhaust fan at the other. The fan draws a current of air past the steam pipes, which heat it, then past the stone, and finally discharges it from the chamber. The stone is, in this way, subjected to a current of air of any desired temperature and is rapidly dried. If waste heat is available, it may be used instead of steam in the heating pipes. This dryer is greatly improved if designed to accommodate trucks on which the stone remains during the drying, though this adds considerably to the cost.

In a *Continuous dryer*, trucks or cars bearing the stone pass slowly along a tunnel through which a current of heated air passes. The air may either travel in the same direction as the cars or in an opposite one, each arrangement having its own advantages. If the air travels in the same direction as the goods it must be heated at various points on its journey, or it would be cooled by the incoming stone and would cause moisture to condense thereon. If the air travels in the opposite direction to the stone, the outgoing cars are subjected to the hottest air, and are, therefore, thoroughly dried and warmed, but they carry out with them a certain amount of heat which is lost. Moreover, unless the air has a very high temperature on entering the dryer it will become so cool in reaching the further end that it will form condensation products on the incoming stone.

Stones behave so differently in drying that it is necessary to take their individual properties into consideration when designing a dryer if the best results are to be obtained in the most economical manner.

Time is an essential factor in drying stone, and this must be allowed for in every kind of dryer. Many misleading statements have been published with regard to the time required to dry blocks of various sizes. Even under the most advantageous conditions a medium-sized block containing about 12 cb.

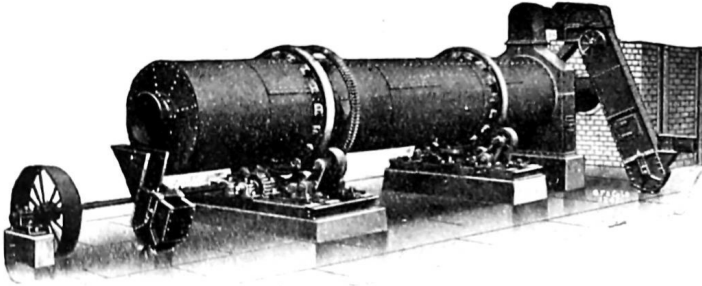


FIG. 19.—"NOTANOS" DRYER.
(By courtesy of Head, Wrightson and Co. Ltd.)

ft. of stone cannot be completely dried in less than three days, though it may be dried superficially, and so *appear* to be dry in half an hour. In proportion large blocks dry much slower than smaller ones on account of their very low thermal conductivity.

DRYING CRUSHED STONE

Crushed stone may be dried on shelves or racks in the same manner as blocks, but it is usually more convenient to employ a rotary or a vertical dryer.

For small and even medium outputs, a *rotary dryer* (fig. 19) is often the most efficient. This dryer consists of a cylinder about 20 ft. in length and 4 ft. or more in diameter, fitted with internal baffles, placed at a slight angle to the horizontal, and heated either by steam or waste gases or, more extravagantly,

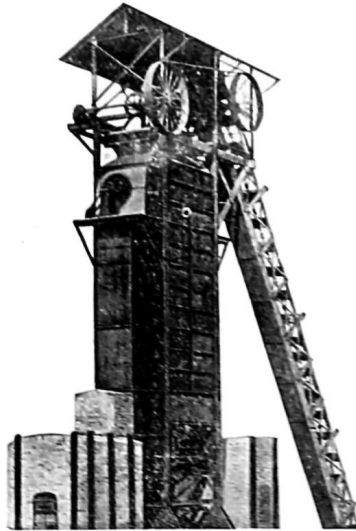


FIG. 20.—"SANGWIN" DRYER.
(By courtesy of J. Dawson Fawcett (Darlington) Ltd.)

by mounting it above a coke furnace. The cylinder is rotated slowly, and by this means stone fed into the upper end of the dryer gradually travels downwards and is discharged in a more or less dry state from the lower end. Such dryers are extravagant in fuel and the stone usually passes through them so rapidly that it is seldom dried completely, though often sufficiently so for the purposes for which it is required. It is more efficient with small stone than with larger pieces.

A convenient type of tower dryer (fig. 20) which is devoid of mechanical appliances is the "Sangwin" dryer supplied by J. Dawson Fawcett (Darlington), Ltd. It consists of a vertical tower fitted with sloping baffle-plates so arranged

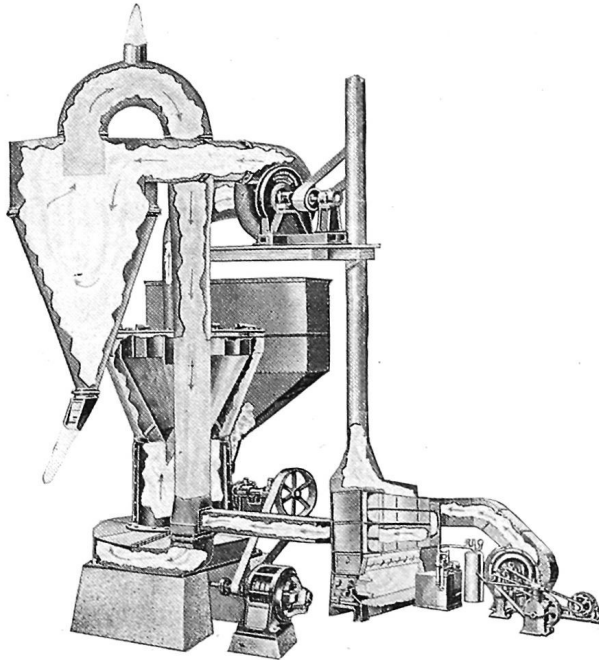


FIG. 21.—"RAYMOND" KILN-MILL.

(By courtesy of The Raymond Bros. Impact-Pulverizer Co.)

that the stone falls from one plate to another and is thereby brought into intimate contact with the hot gases rising through the tower. When the stone reaches the bottom of the dryer it is dry and can be removed by any suitable means.

Powdered stone, chalk, etc., may be dried economically either in a rotary dryer of the type just described, or in a vertical tower fitted with a slowly revolving screw propeller. The damp powder is fed into the top of the tower, and during its descent it is dried by an ascending current of air from an adjacent furnace. Auxiliary arms should be fitted so that the material is turned over repeatedly in passing through the dryer.

Various kinds of roasting furnaces may also be used, but are liable to overheat the material.

It is often convenient—especially when a stone has to be ground to powder—to combine the drying and grinding process in a closed circuit. The Raymond Kiln-mill (fig. 21) is a device of this kind. By this means the drying is effected by hot air much more economically and efficiently than by convection in an ordinary dryer. Waste heat, from kilns or other sources, may be used.

For smaller quantities, a steam-heated pugmill consisting of a closed horizontal cylinder fitted with revolving paddles, or a steam-heated ball-mill consisting of a similar cylinder partly filled with balls and kept in constant rotation may be used. If an exhaust pump is fitted so as to maintain a partial vacuum in these machines the drying will be much more effective.

A SUBSTITUTE FOR DRYING

Instead of drying crushed stone prior to coating it with tar or bitumen, the damp stone may be mixed mechanically with creosote or creosote-oil ($\frac{1}{4}$ gallon per ton of stone). The liquid will rapidly penetrate the moisture and form an emulsion to which the tar or bitumen will subsequently adhere (see Eng. Pat. 330,072 (April 1929), Berry, Wiggins and others).

DRESSING LIMESTONE

Most limestones are dressed or shaped by means of a hammer and chisel, the surface being finally scraped by means of a metal comb known as a *drag*, or by rubbing with blocks of sandstone or with sand.

An *axe*—a fairly heavy hammer with one or more axe-like edges—is sometimes used, and, to facilitate rapid working on ornamental work, special forms of hammers, picks, and chisels are available.

Hand-dressing is necessarily slow, and it is, therefore, preferable, to do as much of the preliminary shaping by machinery as possible. Thus, large blocks of limestone or chalk may be cut by power-driven saws, either of disc-shape (circular saws) or composed of one or more strips of steel, 6–15 ft. long and 3–5 in. wide, mounted in a frame which has a to-and-fro motion.

Frame-Saws (fig. 22).—A reciprocating frame-saw consists of a framework to which a to-and-fro motion is imparted mechanically. This frame carries a convenient number of strip-saws, so that a block may be sawn into several smaller ones simultaneously, or both sides may be sawn at the same time. The blades are arranged parallel to each other, their distance apart being adjusted to suit the required dimensions of the blocks.

It is not desirable to have a large number of the saws. If the number be excessive it would be cheaper to use fewer saws, even though this involved more labour in “setting” the blocks in their places on the saw-bench. In cutting thin slabs of marble it is often difficult to avoid using many blades.

The reciprocating frame which carries the saws is hung from supports by suspension rods in such a manner that a constant pressure is applied to the saws

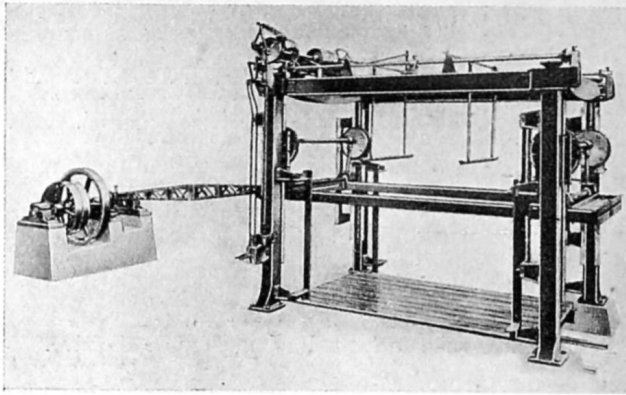


FIG. 22.—FRAME-SAW.

(By courtesy of The Anderson-Grice Co. Ltd.)

as they move to-and-fro at the rate of 100–200 strokes per minute. The strokes are quite short—seldom exceeding 1 ft. even for soft stones.

The cutting is aided by a mixture of abrasive and water which is fed into the saw-cuts. Sand is the abrasive most widely used on account of its low cost, but carborundum, carefully selected to suit the stone and the saw, will cut so much faster that it often proves cheaper in use than sand. Chilled steel shot (sometimes called “diamond grit”) is used for hard stone, but is seldom necessary for limestone. Many ingenious devices have been used for securing a variable velocity of the saws, or to make the path of the blades conform to a particular curve—usually a segment of a circle of several hundred feet radius—so that the ends of the saw are lifted at each stroke, thus permitting sand or other abrasive to pass beneath the blades and to ensure continuous cutting instead of the intermittent action which occurs with a straight to-and-fro motion.

The rate at which the blades descend depends partly upon the nature of the stone and the number of saws in the frame. The descent must be free from jerkiness or the cutting action will be badly impaired. Automatic methods are excellent when they operate with sufficient smoothness, two of the best being (i) ratchet and pawl, and (ii) eccentric and slotted lever.

The saw blades may consist of plain strips of tough steel (manganese steel has proved particularly serviceable) which must be hard, but not brittle, or they may be provided with teeth. The blades may also be ribbed, waved, recessed, or notched so as to direct the abrasive more effectively to the bottom of the saw-cut, provided such ribs, etc., do not spoil the appearance of the sawn face.

Circular saws (fig. 23).—The circular saws used for limestone, marble, etc., are of three types: (i) Those consisting of a steel disc with or without teeth cut in the rim and similar in many respects to those used for timber. These saws are of various sizes according to the work to be done. They are usually supplied with water and a loose abrasive, such as sand, carborundum, or chilled

shot ; (ii) Those provided with cutting points made of black diamonds, or other fixed cutters or abrasives ; and (iii) Those made throughout of abrasive material and known as abrasive- or grinding-wheels or made with a steel centre and a rim of abrasive material—usually carborundum,¹ whence the name *Carborundum Saws*.

Of these, the diamond-saws are by far the most powerful ; they have a remarkable output capacity and a cutting speed in limestone of about 6 in. per minute. The diamonds are fixed to the rim of the saw in two or three rows by means of sockets. The fitting is important, as unless the diamonds are

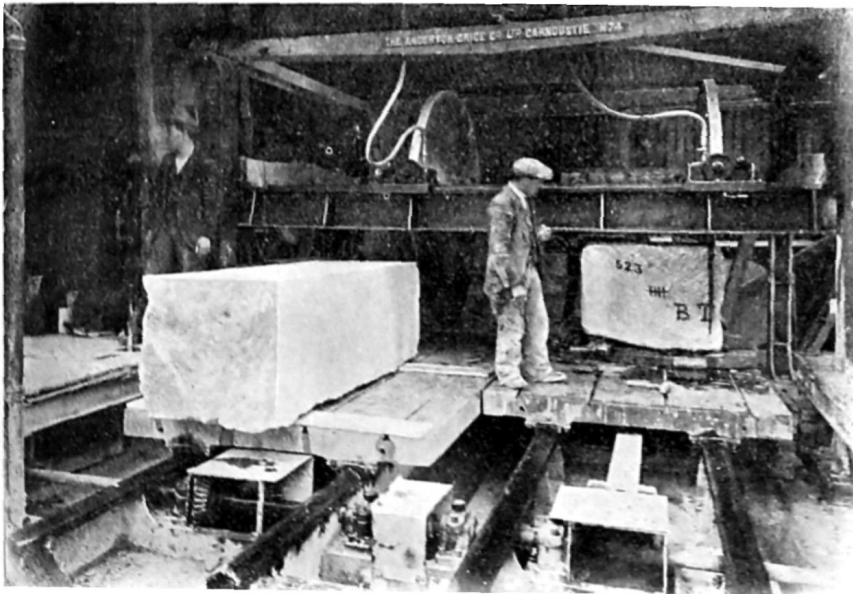


FIG. 23.—DIAMOND CIRCULAR SAW.
(By courtesy of The Anderson-Grice Co. Ltd.)

suitably fixed they will not cut properly. No abrasive is employed, but an ample supply of water is essential. A 5 ft. diamond-saw made by The Anderson-Grice Co. Ltd., fitted with 126 diamonds in three rows and making 150 revolutions per minute, will cut a block 26½ in. thick, using 5 h.p. A diamond-saw made by Edgar Allen and Co. Ltd., Sheffield, is 100½ in. diameter, about ¾-in. thick, and weighs about 8 cwt. Round its periphery are some 210 diamonds. The makers claim that when at work it travels at a peripheral speed of about

¹ The term *carborundum* is a proprietary one and strictly should only be applied to the products of one firm. The term *silicon carbide* refers to the same material without any restriction as to the manufacturer. The former term is, however, so widely used that strict insistence on its correct usage is troublesome. Other trade-names are *Alundum*, *Carbofrax*, and *Silundum*.

three miles per minute and will cut through a stone slab 6 ft. \times 3 ft. in fifteen minutes, as compared with six hours taken by a gang-saw.

The output of some diamond-saws may be increased by mounting two or more on the same spindle in such a manner that the distance between them can be adjusted as required. Either the frame carrying the saw or the bench carrying the stones may be moved mechanically. The travelling saw has the advantage (if fitted with a reversing gear) of cutting in both directions and so saves time, but the choice between a travelling saw and a travelling bench depends so much on local conditions that it is unwise to generalize upon it.

Carborundum saws, as previously explained, consist of a moulded rim of silicon carbide mounted on a steel centre. The proportions of the grains of carbide of various sizes must be chosen to suit the stone, such wheels being made with different "grits" and "grades" and of various binders. An ample supply of water under high pressure should be fed to the points of contact between the saw and the stone; three jets of water—one at the centre and one on each side—are advantageous. Carborundum saws usually have a peripheral speed of about 1,000 ft. per minute and when working on Portland stone they should cut 6 sq. in. of stone per horse-power per minute so that a 15 horse-power saw should cut 90 sq. in. per minute or 9 in. deep at 10 in. cut per minute.

Carborundum saws are being increasingly used on account of their rapid action, the cleanness and accuracy of the cutting, and the absence of the powdered abrasive used with other saws. They are, however, expensive in use and so are largely restricted to accurate work.

Abrasive-wheels made of carborundum or similar materials are excellent for sawing small pieces and for ornamental work, carving, etc. They require to be selected with skill, and it is usually advisable to obtain as much assistance as possible from the manufacturers. British stone-dressers are very slow in appreciating the use of abrasive-wheels as cutting tools; American firms are far more progressive in this respect.

Crosscut-saws (fig. 24) may be either the gang-saw or circular type, the latter being far more efficient. A crosscut made by The Anderson-Grice Co. Ltd., cuts and moulds in both directions of travel and is specially equipped to do repetition work, dimension stone, such as sills, lintels, cornices. It will go through 15 in. deep at one cut on limestone, with a feed of $9\frac{3}{4}$ in. per minute, using 15 h.p. The Rise-and-Fall gear has a movement of 15 in. vertically; this is of great importance in checking work and a great convenience in accommodating different sizes of cutting and moulding wheels. Six rates of feed are provided, from $2\frac{1}{4}$ in. to $26\frac{3}{4}$ in. per minute. The table may be fixed or power driven.

With a *gravity-saw* the table is drawn forward by means of weights so that no engine power is required to operate it.

Band-saws are occasionally used, but only to a small extent, as they seldom cut with sufficient accuracy.

Wire-saws worked on pulleys are sometimes used for cutting up blocks of

stone, but they are rapidly being replaced by the more precise diamond-saws or carborundum saws.

The efficiency and cost of sawing stone depend largely on attention to numerous small details, both in the design and construction of the saw and in the method of working. The best results with any particular stone can only be obtained as a result of continual observation and comparison. A skilled and observant sawyer will get far better results from a comparatively poor saw than an unobservant man with a good machine. Some quarries are unduly hindered by lack of foresight on the part of the owners who continue to use an old type of saw when a more modern one would be far more profitable.

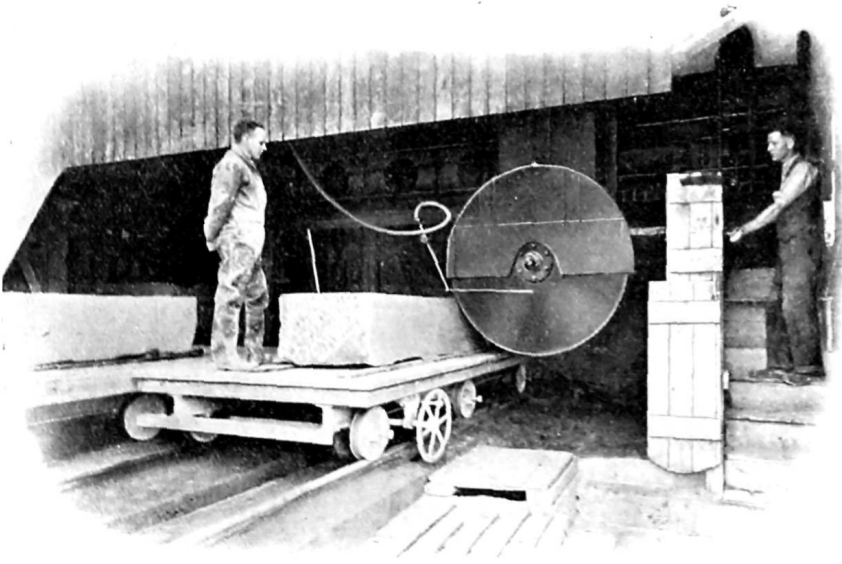


FIG. 24.—“SUPER-SIMPLEX” CROSSCUT SAW.
(By courtesy of The Anderson-Grice Co. Ltd.)

There is considerable scope for improvement in saws for cutting profiles, moulding, and other work which has, at present, to be done more laboriously by hand or by planing machines.

Lathes are used for turning columns, caps, pedestals, and other work. They must usually be of large size and very strongly built so as to possess the requisite rigidity. Apart from this they do not differ essentially from the large lathes used in other industries.

Planing machines (fig. 25) are used to smooth the surface of stones and also for carving mouldings of a kind suitable for this class of machinery. A planing machine consists essentially of a bed or table to support the stone, and a cutting tool which travels horizontally at a pre-arranged distance above the

bed. Either the table or the cutting tool may be moved, but in British practice the moving table is usually preferred, as the fixed holder enables the tools to be held more rigidly. As the stone comes into contact with the tool, the latter cuts off small chips and so planes the stones. For the preliminary "roughing" a double-nosed tool may be used, a finer tool being employed for finishing. The table or tool-holder should be capable of travelling equally well in either direction and additional tools should be fitted so that planing may be effected on both the outward and inward traverses.

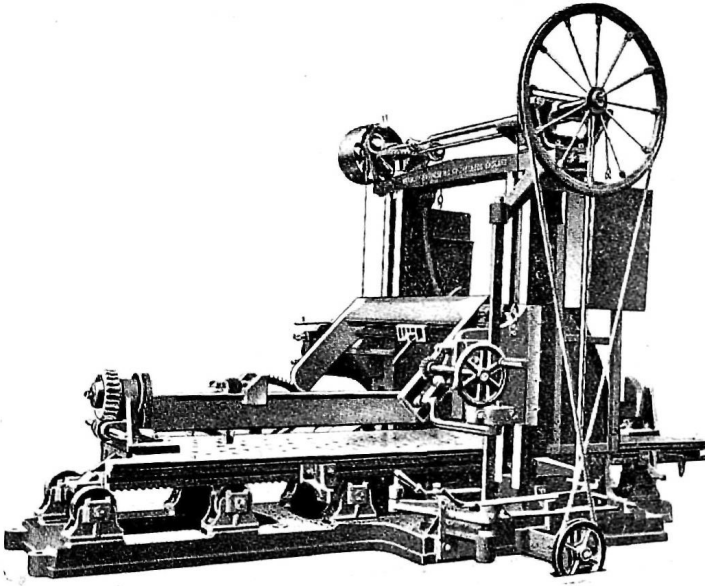


FIG. 25.—PLANING- AND MOULDING-MACHINE.
(By courtesy of Bramley Engineering Co. Ltd.)

Moulding and carving machines are used to a very small extent, as although quite successful they have not yet become popular. Pneumatically operated chisels are also used for carving stone.

Carving stone was formerly done wholly by hand and the best work is still done in the same way. For less important work pneumatic-hammers are used and much carved work is reproduced mechanically by means of planers and similar tools or by grinding.

The mechanical carving of stone is sometimes effected by very ingenious machinery, based on the pantograph. A machine invented by H. M. Edmunds¹ is operated photographically.

¹ *Stone Trades Journal*, p. 130, 1922 ; p. 262, 1923.

Smoothing and Polishing.—Limestone and marble are smoothed and polished by machines which rub the surface with a mixture of water and abrasive, such as sandstone, carborundum, etc., or scour it with blocks made of abrasive material.

Sometimes a little turpentine is added to the water used in the later stages of polishing.



FIG. 26.—POLISHING MACHINE.
(By courtesy of The Anderson-Grice Co. Ltd.)

Polishing-machines for flat surfaces are of the disc type, of which the well-known "Jenny Lind" pattern (fig. 26) is a good example. It can be run at two speeds, one suitable for smoothing and the other for glossing. The discs may be varied to suit the kind of material being polished.

For polishing more intricate surfaces which cannot be easily moved or worked by other means, a flexible shaft, with emery and other wheels to suit the stone, is now generally adopted. These can be brought to bear upon the stone at some distance from the source of power. The latter may be an electric-motor, or a power-turned lathe to which the shaft is attached. In using, the pressure on the stone has to be supplied by the man working the shaft; in this way it differs from the flat disc machine.

To obtain a final polish, the stone is rubbed mechanically with a pad which is kept supplied with a suitable powder and water. The most suitable powders for polishing are a series commencing with moderately coarse and fairly hard abrasives, such as emery, alundum, carborundum, etc., followed by finer ones, such as flour emery, or softer ones, such as tripoli, diatomite, pumice, and various sands, and ending with still softer materials, such as putty powder (tin oxide) or rouge if a very high polish is needed.

Detergents, such as potash or oxalic acid, are sometimes added to the polishing agent, and, occasionally, a coating of wax is applied to the finished surface.

Defects in a marble or other surface are made good by applying a stopping, which usually consists of mixture of stone dust (using the same stone as that of which the article is made) and resin, or white Portland cement. There are numerous "stoppings"—some of a secret nature—but none are completely satisfactory, and there is much scope for a really good, invisible, and permanent stopping.¹

CRUSHING

For many purposes, the stone, chalk, etc., must be crushed² before it is suitable for further treatment or use. Limestone may be broken into pieces of any desired size by means of hammers operated by hand. In this way a good man can break about three cubic yards per day into pieces less than 2½-in. diameter. The work is hard and the output uncertain, so that breaking by hand is gradually being displaced by the use of machinery.

Some users of crushed stone still maintain that crushing machines produce too many flashes and too few "cubic" pieces of stone.

Arrangement of Crushing Plant.—The several parts of the stone-crushing plant should be so placed that the stone travels by gravity through the crushers and screens to the trucks, even if this necessitates raising the unbroken stone in lifts or elevators to the crushers.

The bins should, as far as possible, be placed at such an elevation and in such a position that they can discharge their contents directly into railway trucks, and into motor-lorries or carts—two separate series of openings or discharge chutes being required for this purpose. Instead of bins the crushed stone is sometimes stored on the ground and lifted into railway trucks or motor-lorries by means of portable elevators.

Sometimes a bin is used to receive the stone direct from the quarry and to deliver it to the crushers and screens, but the charging platform is more frequently used for this purpose.

¹ Readers who require further information should see *Stone-Working Machinery* by M. Powis Bale (1884) and *Marble and Marble Working* by W. G. Renwick (1909). (Both published by Crosby Lockwood & Co. Ltd., London.)

² Where some of the material is of the same size as that which has been crushed, a saving in power may be effected by screening the material prior to crushing as well as afterwards.

Charging Platform.—A charging platform is usually essential. It should be large enough to hold a reasonable number of wagons loaded with stone, as well as the empty ones which accumulate before they can conveniently be taken away. A small charging platform is a continual source of annoyance and of some risk, and ought to be enlarged as soon as possible.

The platform should be sufficiently above the crushers to enable the latter to be easily fed, and yet it should not be so high as to be inconvenient. The most convenient height is for the floor or platform to be about 6 ft. above the first crusher so that the stone can be tipped from the quarry-wagons onto a sloping grate which will separate the smaller stones which need not be passed through the first crusher. If this distance is not available a conveyor screen (as supplied by Ross Patents, Ltd.) may be used.

Below the charging platform in regular order, so that the stone passes readily from one to the other, are crushers, screens, and storage bunkers. These should be sufficiently apart to admit of ready inspection and repairs, but not so much as to allow falling stones to damage them unduly.

Where the platform and breaker cannot be placed above the screens, it may be placed at a lower level and a belt conveyor used to raise the crushed stone to the screens. This should be avoided, where possible, as it is wasteful in power to elevate the stone in this manner; the elevation of the quarry-wagons up a gantry to a height above the crushers is usually much cheaper.

The crushing is usually effected in jaw-crushers, but gyratory-crushers, crushing rolls, and other kinds of preliminary crusher are used in some works, particularly where the material is to be reduced to very small pieces.

Stamp-mills consist of heavy weights attached to overhead rods, which are lifted up by a cam and allowed to fall on the material to be crushed. They have been used as rough crushers for limestone, but have now been entirely superseded by other forms of preliminary crushers, which require less attention and yield a larger output.

Jaw-crushers (fig. 27) consist essentially of a frame or casing, containing two plates or jaws set slightly apart at the bottom and more widely apart at the top; the spacing can be adjusted to suit the material to be crushed. One of these "jaws" is fixed, the other is moved to and fro by means of short and heavy cranks or toggles, so that very great pressure is exerted on any material placed between the jaws. In some machines, the movable jaw is given a rolling as well as a jobbling motion, thus aiding in drawing the material between the plates and reducing the slipping to a minimum. As this material is crushed, the smaller pieces are compressed repeatedly, until they, in turn, become sufficiently small to fall from the machine. In a very simple design of jaw-crusher used in Sweden, the power is transmitted from the crank shaft to the oscillating jaw through a lever and through a roller mounted between the lever and the jaw. The jaw has a concave face at the back, upon which the roller moves without any need of lubrication. The lever is made in two parts, bolted together, so that if an extra hard piece enters the mill and causes overloading, the bolt will break and stop the crusher. It is claimed that this

method of driving has a greater efficiency and requires less driving power than the ordinary jaw crusher, whilst the wear is reduced to a minimum on account of the smaller number of bearings and the smaller pressure upon each.

It is important to adjust the lower opening between the jaws to suit the material, as if the jaws are set too closely together they will produce too much powder and will waste a large amount of power in the process.

The jaw-crushers preferred in Great Britain are of two types :

(i) Those in which the jaw-stock hangs on a fixed or *dead* centre and swings to and fro as a pendulum. In these machines the movement of the jaw-stock may be derived from (a) an eccentric shaft ; (b) a rocking link or lever ; and (c)

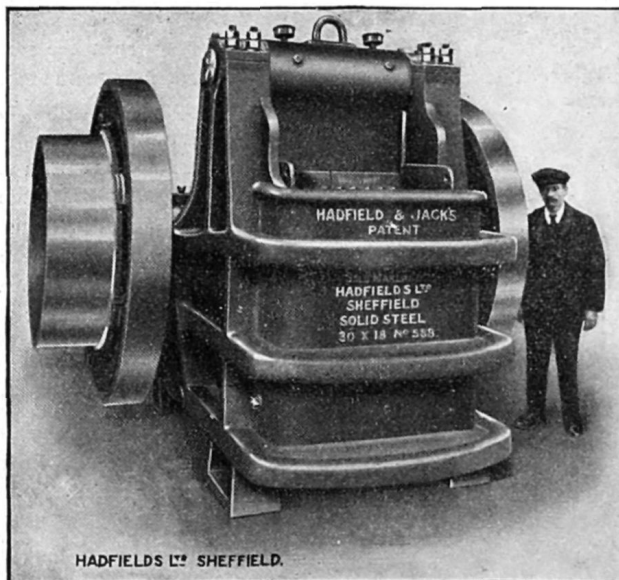


FIG. 27.—JAW-CRUSHER.
(By courtesy of Hadfields Ltd.)

a lever. If the same size and pattern of fly-wheel were used the mechanical efficiency of each would be the same, and if the machines are well designed there is little to choose between them. The angle between the jaw-faces must not exceed 20 degrees or there will be excessive slip.

(ii) Those in which the jaw-stock is carried on a *live* centre (eccentric) and has an upward and downward as well as a to-and-fro motion. If the to-and-fro motion at the bottom of the jaw-faces were the same as in machines of class (i) and the same fly-wheel is used, the leverage efficiency would be the same as in the other machines, but owing to the up-and-down movement of the jaw-stock the movement at the lower end can be less than in machines of the first class. When this is the case the machines of the second class have a

greater mechanical efficiency. A further advantage of machines with a live centre is that they exert a more oblique pressure on the stone and this has a greater crushing effect than a parallel or "straight" pressure.

American users prefer to have one swinging jaw and one toothed roll in their crushers and maintain that this arrangement is cheaper in power. The author has never been able to make an accurate comparison of the merits of these two types—double jaw and jaw-with-roll—of crusher.

Stones from various localities often behave differently in a jaw-crusher, so that it is necessary to make a sufficient trial of the most likely machines before deciding on any one of them. The chief difficulty is due to the formation of flakes rather than cubes.

It is often an advantage to have two sets of ribs on the faces of the jaws; one set of ribs projects out further than the others near the top of the jaws, and so applies the pressure earlier than when all the ribs are of the same size throughout. The result is crushed stone of a more uniform size.

The size of the stone-breakers varies greatly according to the output required. Hadfields, Ltd., Sheffield, have built machines with openings up to 4 ft. 6 in. long and 3 ft. wide, which will take pieces of stone weighing as much as $1\frac{1}{2}$ tons and produce about 150 tons of crushed stone per hour, but for most quarries a crusher which will deal with pieces about 12 in. cube is sufficiently large.

No crushers are remunerative unless kept fully employed, and the number of works which can keep a very large crusher continually in use is very small.

The size of the crushed stone may vary from about 6 in. diameter down to about $\frac{1}{2}$ -in. diameter. The governing factor is the angle between the jaw-faces, which should be as small as possible. To attempt to reduce large pieces to very small ones in one crusher is foolish.

For crushing below $\frac{1}{2}$ -in. diameter, stone-breakers and other coarse crushers are not economical on account of the power required. Where fine material is required it is preferable to crush down to about 1 in. or $1\frac{1}{2}$ in. in a coarse crusher, such as a stone-breaker, and then to reduce the material further in a fine grinding machine. Where a very large output is constantly required it is more economical in power to use several crushers of different sizes, rather than to reduce the material to small size at one operation. Thus, blocks 18 in. or more in diameter may be reduced to about 10 in. in the first crusher; to $4\frac{1}{2}$ in. in a second crusher, and to, say, 1 in. material in a third crusher.

A further saving in power may be effected by screening the material before it enters a crusher so as to by-pass all material which does not need to pass through that crusher.

All the wearing parts of a jaw- or jaw-and-roll crusher should be made of the toughest and most durable steel and all the fixed parts should be of ample strength with large and strong bearings. Such machines are subjected to sudden and violent shocks and unless they are thoroughly well designed and properly made they will break and cause a serious accident to the men engaged

near them. Spare parts should always be kept in stock so that if a breakdown occurs there will be no undue delay.

The power required by jaw-crushers or stone-breakers is shown in the following table :

TABLE IX.—*Horse-power required for jaw-crushers and stone-breakers.*

Upper opening between jaws (in inches) ...	24 × 16	20 × 9	16 × 8	12 × 8	8 × 5	8 × 4
Output (cubic feet per hour) ...	352	312	148	106	70	52
H.P. required	14	10	7	5	2	1½

Stone-breakers with cam and roll action require rather less power than the ordinary type for the same size of machine. The jaw usually moves from ¼–½ in. and the fly-wheel usually makes 250–300 revolutions per minute. An excessively high speed is undesirable owing to the bearings of the breaker becoming too hot and causing a great deal of wear and tear.

Some of the Sturtevant stone-breakers are run at speeds varying from 170 revolutions per minute in small breakers (8 in. × 12 in.) to 130 revolutions per minute in breakers 18 in. × 30 in. Greater speeds are undesirable.

It is most important that sufficient provision should be made in the power supplied in order to allow for the great strain to which the machines are subjected when large pieces of material are fed into the crushers. The figures given above are more than is actually required for ordinary working, but less power should not be provided; otherwise a man may have to be employed crushing large pieces of stone, so as not to damage the machines. Too little power may also cause a sudden breakdown which would be much more expensive in the long run than the provision of greater power for driving the machine.

The output obtained from jaw-crushers cannot be stated in general terms, as it depends on the size of the material charged into the hopper, the size to which it is to be crushed, and the nature of the material. For coarse crushing, the Table shown will give some idea of the output per horse-power. For crushing 6 in. material to pass through a ½ in. ring about 2 horse-power per ton is needed.

As a general rule, jaw-crushers have rather a lower output than that of a gyratory-crusher supplied with the same material.

Granulators resemble jaw-crushers, but have a slightly different motion so as to yield a more cubic product in pieces less than 1 in. diameter.

Gyratory Crushers (fig. 28) consist essentially of a cone, working on an eccentric, inside an inverted conical casing or shell, the object of the eccentric being to cause the cone repeatedly to approach and recede from the shell. The

stone is thereby subjected to a series of squeezes until it is crushed sufficiently small to fall out of the machine.

The main shaft carrying the inner cone should be of ample strength and not too long as this part of the machine is subjected to great stress.

The output of the machine depends on the size of the crusher, the size of the pieces put into the crusher, the size of the finished product, and the nature of the material. As a general rule it may be taken that about 1 ton of 8 in. material may be ground to pass through a ring $2\frac{1}{2}$ in. diameter per horse-power used in driving the machine. Machines with outputs of 200 tons per hour can be run even more economically, only about $\frac{1}{2}$ -horse-power being required per ton of finished product. This is rather greater than the output of a stone-breaker.

The size of gyratory crushers varies greatly, some having been made with an output up to 300 tons per hour. The largest gyratory crusher ever built in this country was made for crushing hard chalk for the Humber Portland Cement Co. Ltd., by Edgar Allen and Co. Ltd., Sheffield, and was designed to have an output of 250 tons per hour, crushing material 8 in. diameter down to pieces 4 in. diameter. The Allis-Chalmers Co. of America, make a Gates gyratory crusher to reduce 300 tons of material per hour to 4 in. mesh using 100-150 horse-power. Very large machines, however, are undesirable; where

a large output is required it is preferable to employ several machines each crushing about 50 tons per hour, rather than one large one, so that if one machine breaks down the whole plant is not held up thereby.

It is most important to the success of the machine that the lubrication should be satisfactory. Automatic lubrication is preferable as it is much safer than trusting to the men in charge lubricating at suitable intervals, as well as being more uniform and satisfactory in every way.

From its appearance, a gyratory-crusher might be thought to be a grinding machine, but this is not the case. The to-and-fro motion of the disc exerts a true crushing action; the product from the machine is largely cubical and free from an undue proportion of flat pieces, though with some stones the amount of "flake" is excessive.

The "mechanical advantage" of a gyratory-crusher is greater than that

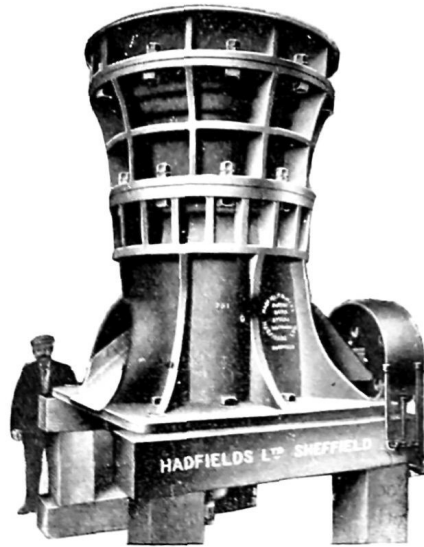


FIG. 28.—GYRATORY CRUSHER.
(By courtesy of Hadfields, Ltd.)

in a jaw-crusher, but no less power is required as the power expended depends on the resistance of the stone and not only on the mechanical advantage of the machine.

Gyratory crushers—like jaw-crushers—are preliminary breakers, and are not suitable for reducing stone to powder or even to “peas.” The largest crushers should not be expected to produce pieces less than 2 in. diameter, although there will always be a small proportion—up to 15 per cent.—less than this size. Smaller crushers can reduce 3 in. material to $\frac{3}{4}$ in. at a very low cost, but they must be fed to capacity or oversized pieces will pass through one side of the disc.

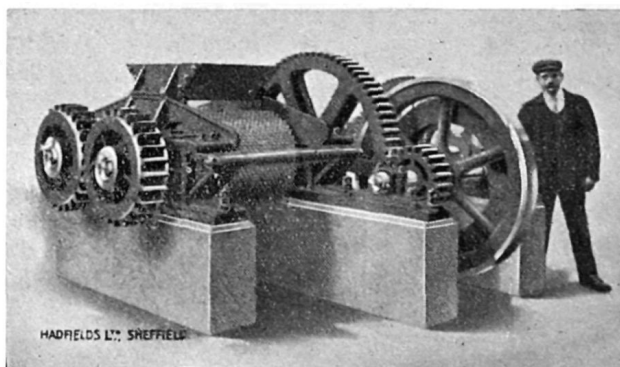


FIG. 29.—CRUSHING ROLLS.
(By courtesy of Hadfields, Ltd.)

Crushing Rolls (fig. 29) are chiefly used as intermediaries in order to give a product consisting largely of cubical pieces of moderate size. They are most effective when applied to stone from a widely-set jaw- or gyratory-crusher which has broken down the largest lumps to a size which enables the rolls to “cube” them rapidly. Where the output is not sufficiently large to justify two sets of machinery a pair of toothed rolls is preferable to a jaw-crusher where cubical stone is required, *e.g.* when crushing stone for roadways, macadam, etc.

Crushing rolls consist of a pair of horizontal cylinders or rolls placed side by side at a convenient distance apart and rotated, through gearing, by a belt-driven pulley. The size of the crushing rolls depends on the output required, and the size of pieces fed into the machine. It is important that the rolls should be sufficiently large to deal with the material, otherwise there will be an excessive amount of slipping with consequent loss of power. The best way of judging the size of rolls required is to measure the angle formed by tangents from the rolls at the points where the largest pieces to be fed into the mill touch the rolls. To ensure a minimum slip this angle should not be less than 30° , and an angle of 32° is better.¹ From this figure it will be found that

¹ For round pebbles an angle of only 10° is preferable.

the diameter of the rolls in inches (D) may be expressed by the formula :

$$D = 25(0.96d - a)$$

where d represents the size of the pieces of material supplied to the mill, and a the size of the crushed particles, *i.e.* the distance between the rolls.

Crushing rolls vary from 8 in. diameter up to about 36 in., according to the output required, whilst their length varies up to about 3 ft. Hadfields, Ltd., Sheffield, have built crushing rolls 5 ft. in diameter and 3 ft. 6 in. wide, which crush about 100 tons of material per hour to 6 in. or 8 in. pieces, the rolls revolving at 200 revolutions per minute, and requiring 100–150 horse-power to drive them.

The rolls are usually set at a distance apart equal to the diameter of the particles required. It is not wise to attempt to crush too finely on account of the excessive amount of power required. Usually, if fine grinding is necessary, two pairs of rolls should be used, one reducing say to 2 in. diameter, and the other down to, say, $\frac{1}{8}$ -in., any further grinding being done in a fine grinding mill. It is important that the crushing rolls should be built very strongly on account of the great strains to which they are subjected as, in some cases, pieces 8 in. or 9 in. diameter may be put into the machine. They should, therefore, be mounted in such a manner as to withstand very sudden and severe shocks, and should be provided with safety clutches or some other device to prevent accident in case a bolt or other article of exceptional hardness enters the machine.

Powerful springs which are compressed when an abnormally hard material enters between the rolls are sometimes used, but are not really satisfactory as they usually yield too readily and produce too coarse a product. They are better replaced by safety clutches fitted with a pin which breaks when a danger point is reached. Rubber buffers have been used to take up the strains, but they are unsatisfactory and should not be employed. The shafts carrying the rolls are also subjected to very great stresses, and should be made of the best quality axle steel. They should be of ample diameter so as to be sufficiently strong, and they should be properly balanced as accidents may occur when they are driven at high speeds. It is also necessary that they should be mounted in long bearings lined with phosphor-bronze brushes, as white metal wears too quickly in this class of machine unless it has a very large proportion of tin present.

The bearings should be kept in good condition, or the distance between the rolls may vary as they revolve thus giving a product of irregular size.

The fly-wheel should be large, as small ones are inefficient on account of their irregular working when large or hard pieces of material are supplied to the mill.

All parts of the machine must be properly lubricated, otherwise a great waste of power may occur and the bearings may require frequent renewal.

Crushing rolls can be used for either coarse or fine crushing ; for the former purpose they should be provided with specially toughened projections. These may be in the form of teeth or corrugations, and in some cases grooves are employed. These all aid in gripping the material when large particles are

charged to the rolls, so that they minimize the amount of slip and increase the output of the rolls. For fine crushing—reducing the particles to about $\frac{1}{8}$ -in. diameter—smooth rolls are employed.

On account of the great wear and tear on the surface of the rolls, it is necessary that they should be made of a very hard metal, such as chilled iron or manganese steel. In most cases, a rim of such material is fitted to a core of softer metal so that when worn the former may be renewed without the expense of obtaining an entirely new roll.

In one kind of crushing rolls supplied by Sutcliffe, Spéakman and Co., Ltd., the rims are composed of several rings, each about 4 in. wide. The reason for this is that the centre of the rolls wears faster, as it is subjected to the greatest wear and tear. By using rings instead of a single rim the worn part in the centre may be replaced by changing the position of the rings, so that the side pieces are in the centre and in this way the wear on the rim is kept uniform over the whole length of the rolls.

The uniformity of the surface of the rolls is specially important where the grinding is very fine as if the rolls are not properly maintained the size of the product will be very irregular.

The rolls may be dressed, when required, by means of a grinding-wheel. A special attachment should preferably be used so that the rotating grinding-wheel may be moved steadily across the surface of the roll. This may be done by using a long screw carrying the frame which supports the grinding-wheel, the transverse movement of the latter being accomplished by slowly turning the screw either by hand or by power. Fine emery- or corundum-wheels may be used with very satisfactory results.

When dressing a roll, the wheel is started at one end and is set so as to remove a thin "skin" at first. As the wheel reaches the centre of the roll it will not grind as the wheel is too hollow at that part, but it recommences grinding as soon as it has passed across the hollow. After reaching the other end of the roll the reversing of the screw enables the grinding-wheel to remove a further quantity from the roll. This is continued until all the hollows and depressions have been removed and a true cylinder is produced.

The speed of crushing rolls varies considerably. Toothed rolls may be driven at 200–300 ft. per min. (equivalent to 48–60 revolutions per min. with 16-in. rolls), but smooth rolls are sometimes driven at $2\frac{1}{2}$ –3 times this speed, speeds up to 1,000 ft. per minute being used. Higher peripheral speeds (up to 1,500 ft. per min.) are sometimes used, but though they yield a larger output there is much more slipping and less efficiency.

A good method of estimating the speed at which crushing rolls should be driven is by the use of the following formula :

$$S = \frac{1,000 - 300 \log. d}{100}$$

where S represents the peripheral speed of the rolls in feet per minute, and *d* the diameter of the pieces fed to the rolls in inches. This will give a suitable speed for any diameter of pieces.

In some cases, the two rolls in a pair are driven at different speeds. This increases the crushing power and reduces the amount of slip. The difference in speed should not be excessive or trouble will be caused by the rolls "bumping" and working irregularly. For low speeds one of the rolls may be driven by means of a belt and pulley, whilst the other is driven from the first roll by means of cog-wheels. For high speeds, however, this is impossible and the rolls must be driven separately by means of belts as geared rolls cannot be driven at very high speeds without their efficiency being much lower than when they are driven separately.

The output of crushing rolls depends on their spacing, their size and shape, the size of material supplied to the rolls and the size to which the material is to be crushed. If the space between the rolls were continuously filled with crushed material, the output would be AS cubic feet per minute, but as this condition is never fulfilled a more correct formula is :

$$A S (0.6f - 0.15)$$

where A is the area of the opening in square feet, S the speed of the rolls in feet per minute, and

$$f = \frac{\text{space between rolls (in inches)}}{\text{diameter of pieces fed on to rolls (in inches)}}$$

The power required for crushing rolls is rather great, about 3 h.p. being required for a pair of rolls 12 in. diameter and 10 in. wide. Rolls 21 in. diameter require 9-12 h.p., whilst those 32 in. diameter require about 15-16 h.p. to drive them. These figures are only approximate; when very hard pieces of stone are being crushed several times the amount of power mentioned may be required.

Crushing rolls are particularly useful for producing cubical pieces 2 in.- $\frac{1}{4}$ -in. diameter; they should not, as a rule, be used for finer crushing as they are then wasteful in power, though apart from this they may be employed for reducing stone to a coarse powder. Grinding rolls when driven separately at different speeds are excellent for producing a fine powder. They should only be used for finishing as they are useless when seriously worn and dressing the surface of the rolls is expensive.

Impact-Machines are also known as *Hammer-Mills* and *Disintegrators*. They consist of a casing in which rotates one or more "rolls" or "hammers" on a central shaft, the stones which have been crushed thereby being allowed

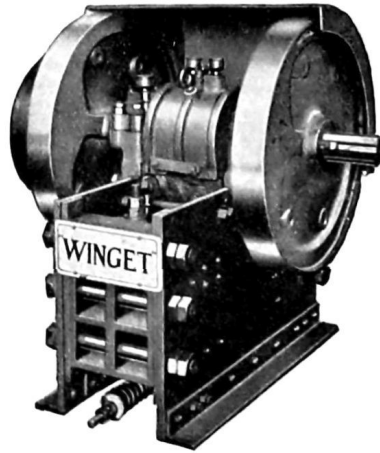


FIG. 30.—TOGGLELESS CRUSHER.
(By courtesy of Winget, Ltd.)

to fall between a series of grate-bars. A modification of this type is the *Cage-Disintegrator*.

The hammers may be rigidly attached to the roll or they may be mounted pivotally; the latter—known as *swing-hammers*—are usually to be preferred.

Impact machines are usually driven at very high speeds, but this is not always satisfactory. The lower the speed—provided the material is crushed—the more efficient and satisfactory will be the machine. Many machines now driven at high speeds could, with advantage, be reduced to 300–500 rev. per min.

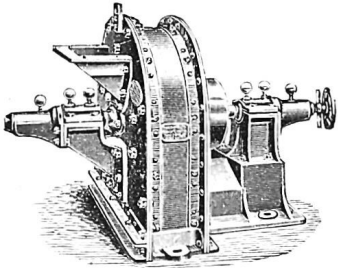


FIG. 31
"DEVIL" DISINTEGRATOR.
(By courtesy of Hardypick, Ltd.)

Single-Roll and Bar-Disintegrators.—Another type of disintegrator for coarse crushing which is much used—particularly in America—consists of a single roll fitted with hardened steel projecting pieces, the material to be ground being fed between the roll and the casing so that it is dashed to pieces by the projecting lugs. The peripheral speed of these machines is very high, sometimes attaining 3,000 ft. per minute.

This type of machine is able to take in pieces of material up to 36 in. in diameter and it has a large output (nearly three times as much as a jaw-crusher of equal size) whilst the power required is comparatively small.

The construction must be very rigid on account of the great strains to which the machine is subjected. It can only deal with material of moderate hardness and cannot for that reason replace jaw-crushers in many works.

Instead of having a solid casing against which the material is broken, a grating is sometimes used so that as soon as the pieces are reduced sufficiently small they fall through the grating. This avoids the excessive production of dust.

In the ring pulverizer, loose hardened steel rings are attached to the ends of the projecting bars and the centrifugal force of the rings is utilized in crushing the material. Such disintegrators are rotated at about 600 revolutions per minute and are very effective.

In some disintegrators of the single rolls type the projections are loose and act as loose hammers, as in the case of the "Devil" disintegrator (fig. 31) made by Hardypick, Ltd., Sheffield. A similar machine made by the Sturtevant Engineering Co. Ltd., is capable of crushing down to 10-mesh and requires about 5–10 horse-power per ton of material reduced to this size per hour. The hammers rotate at 1000 to 1500 rev. per minute.

For coarse to medium crushing, this type of disintegrator is very economical, rather less than 1 horse-power being required per ton of material crushed.

Single-roll and bar-disintegrators should be enclosed in a very strong casing which should be hinged so as to facilitate cleaning and also to enable any hard pieces which gain access to the mill to be removed.

As the machines are rotated at very high speeds, it is important that they should be very well balanced, otherwise the vibration may cause serious damage. The balance of the spindle and beaters may be tested by removing it from the machine and rolling it carefully on two bevelled knife-edges and filing or chipping the heavier parts until it will remain indifferently in any position.

Cage Disintegrators (fig. 32).—Another type of disintegrator consists of two or more concentric cages fitted with bars and rotating in opposite directions. The material to be ground is dropped between these cages and is broken by impact with the bars. The oldest type of this machine is the Carr disintegrator, but various modifications have been made.

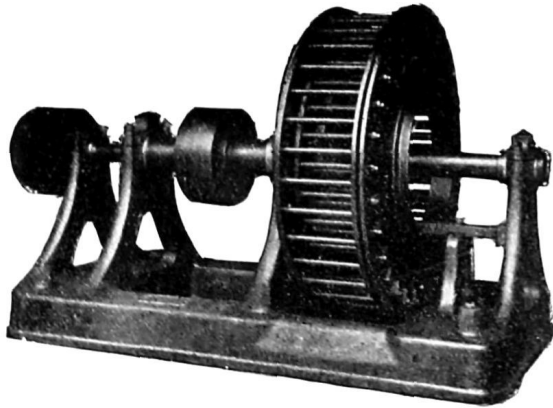


FIG. 32.—CARR'S DISINTEGRATOR.
(By courtesy of F. G. Tyler and Son.)

The output of machines of this kind depends on the kind of material to be ground and the number of bars in the cages. The cages are driven at very high speeds and are very effective.

A disintegrator of this type, 4 ft. 6 in. diameter, has an output of 25–30 tons per hour with chalk or other fairly soft material.

A modification of the Carr type of disintegrator, made by George Fletcher and Co. Ltd., Masson Works, Derby, has only one cage, and inside this are a number of beaters fitted to a revolving shaft so that they rotate in the opposite direction to the cage.

The material is crushed between the beaters and the bars of the cage. Disintegrators of the bar-and-cage type are particularly suitable for materials which are slightly damp as a large volume of air is passed through these machines by the rotation of the bars or cage and this air tends to dry the material to be ground.

Feeders for Crushers.—To secure a maximum output it is desirable to have some form of automatic feed so that the mills may not be overcharged. It is also desirable to exclude any fine material which may not need crushing as

(unless the mill is used as a mixer as well as a crusher) it is a waste of power to put small material through the machine. Feeders for preliminary crushers must be of very solid construction on account of the large pieces of material delivered to them. Rotary base-feeders, conveyor-belts, belt-elevators, etc., described later, for feeding fine grinding machines, may be adapted to feed preliminary crushers, but the wear and tear is very great. For most purposes the most useful method of feeding crushers, so as to secure a regular feed and not to put in any material which need not be crushed, consists of an inclined grid or grizzly with a reciprocating motion. The material is charged onto this,

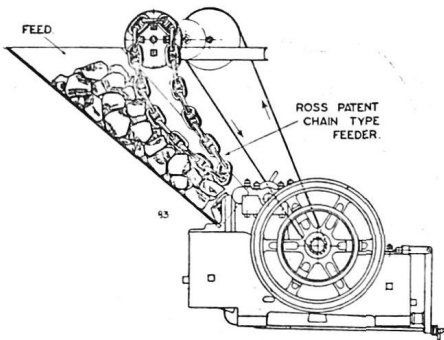


FIG. 33.—“ Ross ” CHAIN-FEEDER.
(By courtesy of Ross Patents, Ltd.)

the small pieces passing through whilst the large ones pass along and are discharged into the crusher.

Another method consists of a conveyor-belt composed of link-bars with convenient spaces between them. This belt allows the small material to pass through, but conveys the large stones to the crusher. It requires cleaning frequently or the wear and tear on it will be very great.

A third feeding device consists of a number of discs mounted on a shaft so as to form a sort of roller supported in an opening in the chute supplying the crushers. The material falls down the chute, the larger pieces passing over the rotating discs whilst the smaller ones fall between them and downwards into a suitable receiver.

The Ross Feeder (fig. 33) consists of several endless chains mounted on a shaft in such a way that the movement of the chain acts as a conveyor and at the same time prevents the material from travelling too rapidly and overloading the crusher. The Ross-feeder is extremely simple, very durable, and does not easily get out of order.

Grinding.—In the stone-working industries the term “ grinding ” is used rather loosely, but is chiefly intended to mean the reduction of a material to powder, as distinct from “ crushing ” which is the process of reducing large lumps to smaller pieces.

Most material in pieces larger than $\frac{1}{4}$ -in. would be “ crushed,” and material consisting of particles less than $\frac{1}{16}$ -in. diameter would be termed “ ground,” but in describing the production of pieces between these two sizes there is considerable laxity. It is, however, more convenient to make the distinction between crushing and grinding one of process, rather than product, so that the products from jaw and gyratory-crushers, stamps, and rolls are regarded as having been “ crushed,” whilst the smaller-sized pieces and powders from other machines are regarded as having been “ ground.”

In some cases, however, crushing machines are used for grinding. Thus, the "bar" type disintegrators may be used for crushing down to 25 or 50 mesh, but they are not economical for producing fine powders, though in grinding to 50-mesh a considerable proportion of finer material may be produced. Disintegrators are also very useful for mixing as well as grinding and are suitable for preparing poultry meals, fertilizers, etc., which contain other substances beside limestone and chalk. Disintegrators will deal readily with mixtures of stone and clay, stone and bone, or other organic materials which would not be ground so cheaply in any other form of machine.

Pan-Mills (fig. 34) used for grinding limestone, chalk, etc., are similar to those used for mortar. There are two chief types:

(i) *Chaser-Mills* in which a pair of rollers rotate one after the other on a fixed plate with a perforated grid.

(ii) *Revolving Pan-Mills* similar to chaser-mills except that the pan is rotated mechanically, the rollers merely turning on their axes as the result

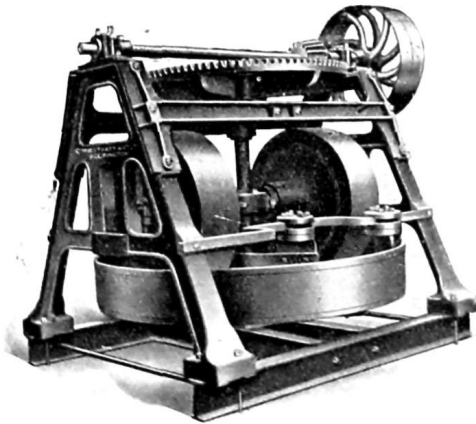


FIG. 34.—PAN-MILL.

of the friction between them and the material to be ground.

It is often considered that the fixed pan is stronger than the revolving type as a more solid foundation can be built, and there is less liability of damaging the pan when the rollers are raised several inches above the pan bottom on account of the introduction of a large piece of hard material. The mills may be either over- or under-driven, the over-driven type being most generally used as the gearing is more readily accessible. It also has the advantage that the gearing is kept more out of the way of the dust and there is more available space beneath the pan for the collection of the ground material.

For reducing large pieces, chaser-mills are better on account of their greater strength, but for pieces less than 3 in. diameter revolving pans are preferable.

The pan is made of either chilled metal or steel plates which are mounted on the pan proper, so as to form an easily renewable bed. These plates may conveniently be arranged in two concentric circles, the inner one—preferably made of tough manganese steel—being the grinding bed on which the material is subjected to pressure, whilst the outer one—which may be made of chilled metal as it is subject to less wear—serves for mixing the material and repassing it under the runners. The rim of the pan may be made of one or more pieces

as desired ; it should be vertical rather than sloping, though some grinders prefer the latter.

The pan may be solid, or it may be perforated with holes or slots as desired. The perforated pan is preferable for dry material as it is continuous in action ; when sufficiently finely ground the material falls through the perforated bottom of the pan and escapes. In the solid pan, however, the machine must be stopped at intervals, emptied, re-charged, and started again. This involves a waste of time which is undesirable whenever it can be avoided. Dry materials should never be ground in a solid pan, as much of the material is lost in the form of dust and there is a great waste of power. If a perforated pan is used the crushed material passes away as soon as it is reduced to a sufficiently fine state, and the formation of an excessive proportion of dust is avoided.

The number and size of the perforations or slots on the pan may be varied to suit local conditions, but if they are very numerous it is desirable to place them either inside or outside the track of the rollers, so that the rollers do not run directly over them. Otherwise the pan may break through inability to support the weight of the rollers. Circular perforations are preferable to slots as they prevent large flakes from passing out of the mill. If slots are used they should usually be at right angles to the track of the rollers.

Both perforations and slots wear somewhat rapidly—unless the pan is made of exceptionally hard metal—and should be renewed before the apertures become unduly large. It is seldom practicable to have perforations less than $\frac{1}{8}$ -in. diameter, and if a pan-mill is used to grind finer than this it is desirable to separate the finer particles by subsequent screening and to return the coarser material to be re-ground. It is by no means unusual to employ screens of 24-mesh in conjunction with $\frac{1}{8}$ in. perforations in the pan, with completely satisfactory results.

In both types of mill, scrapers should be provided so as to turn the material immediately beneath the rollers, as well as over the grate or perforated portion of the pan, so as to ensure the maximum crushing and screening effects. The smaller the perforations the nearer should the scrapers be to the bed of the pan.

The scrapers should be arranged to mix the material thoroughly and to pass it as often and as completely as possible beneath the runners. Each scraper should be capable of separate adjustment, both horizontally to ensure that it moves the material in the desired direction and vertically to enable it to be lowered as the metal wears away. Some firms on the Continent use hanging scrapers which rest on the material by their own weight and can move vertically without being adjusted. By fixing them to arms which are pivoted on a shaft at the back of the machine, the front of the pan may be left more free and accessible, and this greatly facilitates the emptying of the mill. There are, however, objections to the self-adjusting scrapers, and those which must be adjusted by hand are usually preferable. They remove the material which would otherwise adhere to the pan and so ensure a better mixture than is obtained with the loose scrapers.

The runners are best constructed of iron, fitted with renewable rims or tyres of steel or special hardened metal. The employment of these removable tyres has many advantages, one of the most important being the cheapness with which the working surface of the runner can be kept reasonably level.

Some firms prefer the runners to be made of stone, and where it is necessary to avoid the use of iron this material is excellent. For most purposes, however, it is better to fix a renewable tyre of manganese steel or chilled iron, as unprotected stone wears away rapidly. An excellent arrangement when transport charges are heavy is to make the main part of the runner of iron, and fit it with compartments into which concrete can be poured when the runners have reached their destination.

The runners must be so constructed as to allow of their movement to a distance of at least 6 in., so that in the event of a large mass too hard to be immediately crushed getting into the mill, the runners may get over it. If this cannot be done an excessive strain is placed on the driving gear and an accident may result. One excellent way is to suspend each roller by means of two chains, but a more usual way is to provide slots in the standards carrying the ends of the runner axles.

The size and weight of the runners must chiefly depend on the nature of the material to be ground; 5 cwt. for each runner is a good average, though some are more than twice this weight when a hard material is to be crushed.

The gearing, whether the pan be under- or over-driven, should consist of a horizontal crown-wheel of ample diameter and strength with well-cut teeth, driven by a pinion of corresponding strength and arranged to withstand many sudden and violent shocks. The drive should be through a belt on to a counter-shaft. It is not desirable to have several mills of this type all driven direct, though this is done in some works. The belt is able to absorb some of the shocks and avoids transmitting them to the driving shaft, whereas if no belts are used the shocks from one machine are transmitted to all the others on the same shaft. Either a loose pulley or a simple form of clutch should be provided so that the machine can be stopped rapidly when required.

The pulleys should be properly selected for the work they have to do. It is a serious mistake to use pulleys which are too narrow for the power to be transmitted, as a narrow pulley or a narrow belt causes more wear than one which is of ample width for the purpose. As the power transmissible by a belt is proportional to its width it is always wise to err on the side of too large rather than too small a belt. Owing to the dusty nature of the material, rubber and canvas or similar belts are preferable to those made of leather. The belt should be kept properly dressed.

The footstep bearing on which the lower end of the upright shaft carrying the pan is supported should be of ample size as it has a much heavier load than is commonly realized. It should be made in two parts so as to facilitate examination and replacement when required, and should be so designed that it will not be affected by the shocks to which the pan is subjected. It should be lubricated with a good quality of oil, supplied automatically as far as possible,

though the necessity of occasional inspection should not be overlooked as footstep bearings are costly to repair.

The output of pan mills—of either type—is largely dependent on the weight of the runners or rollers, the speed of rotation, and the amount of material on the pan. Light runners have a feeble crushing effect—but may be used where mixing is the chief factor—and a low speed of rotation causes a low output. The amount of material on the pan has a far greater influence on the output than is commonly supposed. If too little material is present the output will, clearly, be low ; if the mill is overloaded the excess of material will act as a cushion and reduce the crushing effect, thereby reducing the output. It is, therefore, necessary to find by actual trial what is the best amount of material to have in the mill at any one time. To control this effectively and to provide a regular supply of material to the mill, an automatic feeding device is desirable.

Automatic feeders for pan mills consist chiefly of five different types :

(a) A vertical drum with a loose base-plate, which is revolved by gearing beneath it. An opening is left on the side of the drum and a scraper is fitted, so that the material is charged on to the plate, and the latter revolved, the material being guided by the scraper through the opening at a regular rate. The amount of material passed through the hole in the drum may be varied to suit the requirements of the mill by altering the size of the hole by means of a movable damper, or by altering the speed of the base-plate or the position of the scraper.

(b) A continuous screw, either fully or partially enclosed in a casing. The material is supplied to one end of the screw, and by means of the revolution of the latter the material is conveyed along the tube or trough and discharged at a regular rate into the mill.

(c) An endless-belt, fitted with a bar at a certain distance above the surface of the belt, so that as the belt passes along it can only carry a certain amount of material which, on reaching the end of the belt, is discharged into the mill in a regular manner. If the belt is made of links, it will act as a preliminary screen and remove any material which does not need to be crushed.

(d) An endless belt fitted with buckets which are automatically filled and discharged into the mill. This type of feeder is not really continuous, but is much better than hand-feeding.

(e) A toothed-roller, or a roller provided with a series of discs, will act as a feeder and distributor if placed at the outlet of a hopper, but is only suitable for lumps of material.

The first two types of feeder are very satisfactory, but they require rather a large amount of power, whilst the use of the third is somewhat limited, though where it can be used it is very satisfactory. In order to prevent overfeeding it is often useful to attach a lever to an edge-runner mill, one end of the lever being placed above the runners, so that when they are raised too high above the level of the bed, on account of the introduction of too much material, the runners will automatically move the lever and ring a bell, thereby warning the man in charge.

The maximum output of a good pan-mill can only be secured by ensuring a regular supply of material at precisely the same rate as that at which the mill discharges the ground product.

Pan-mills should be fed with material which is not in unduly large pieces. No maximum can be applied to all cases, but as a general rule no pieces should be larger than 3 in. diameter, and if the largest size is only 1 in., so much the better. It is cheaper to reduce large pieces to 1 in. diameter in a stone-crusher than in a pan-mill, so that a crusher is an economical preliminary breaker for this purpose.

Ball-Mills (fig. 35) are used for reducing limestone, chalk, etc., to a fine powder and are the most efficient mills for this purpose. They consist of a drum or short cylinder about half filled with the material to be ground and steel balls of various sizes, according to the size of the mill. The mill is closed and rotated at a moderate rate, so that the contents are lifted and then allowed to fall in rapid succession, producing a hammering action on the material by the balls. In some mills the interior is arranged in the form of a number of steps, so that when the mill is rotated the balls fall from step to step and help to

crush the material charged into the mill. In this type of mill the surfaces on which the balls fall are set a short distance apart, leaving spaces through which the crushed material falls onto a screen below. Any material which will not pass through the screen is returned by the rotation of the mill into the grinding-chamber, to be subjected to further reduction. The material which passes through the screens falls into a hopper-shaped casing from which it is drawn by means of an opening in the base.

The grinding cylinder may be either perforated in this way or it may be solid, in which case the mill will be intermittent in action and must be stopped, emptied, re-charged, and started again at intervals. This may be avoided by connecting an air-separator to the ball mill, so that the whole forms one

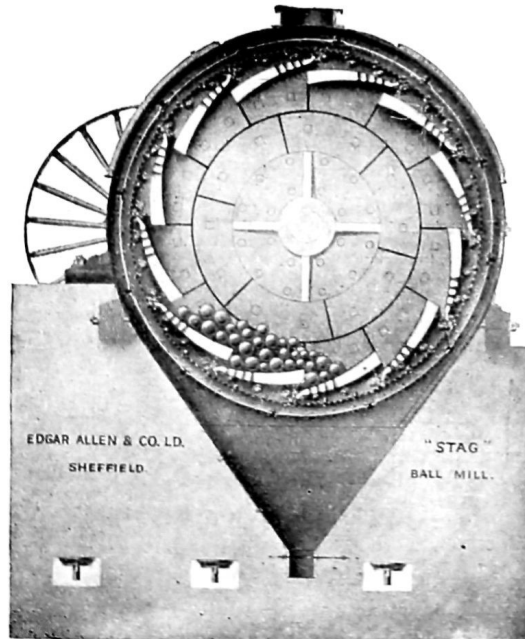


FIG. 35.—"STAG" BALL MILL.
(By courtesy of Edgar Allen and Co. Ltd.)

grinding unit, the coarse material from the separator being returned to the mill and re-ground. The small ball-mills of a wholly enclosed type, which work intermittently, are commonly known as Alsing cylinders. They are charged and run for a pre-arranged number of hours and then discharged. Very fine powders can be obtained in this manner, but the process is expensive.

The output of ball-mills depends to a very large extent on the use of the right proportion of balls to the size of the machine. The following Table gives some indication as to the weight required in relation to the width and diameter of the drum :

TABLE X.—*Weight required in relation to size of Ball-Mills*

Diameter of drum in inches ...	44	56	64	80	88	106
Width of drum in inches	36	38	45	52	58	68
Weight of balls in cwt.	3.5	7	12	24	36	50

For smaller mills, the Crossley Engineering Co. advise the use of 200 pebbles or balls about 2 in. diameter for a 20 in. diameter mill, and 40 pebbles or balls about 1½ in. diameter for a mill 10 in. diameter ; in the former case the weight of balls is about 26 pounds.

To secure the maximum grinding action the size of the balls is important. Where the stone to be ground is particularly hard and when the material fed into the mill is very coarse, it is desirable to use a large ball. For finer material or softer stone smaller balls may be employed, and it is a good plan to use balls of two sizes, one smaller than the other, so that the interstices between the larger ones are partially filled and the grinding is thereby rendered more effective.

The power required to drive ball mills depends to a large extent upon their size, but the following figures will give some idea of the power required :

TABLE XI.—*Power for ball-mills*

Length in feet	12	10	8	3
Diameter in feet	8	8	6	3
Horse-power required	12	8	4	1½

The power will also depend to some extent on the size of the material

charged into the mill. Where very fine grinding is required, it is undesirable to put large pieces into the mill, the greatest efficiency being attained when the particles are not more than $\frac{1}{4}$ -in. diameter. By supplying particles of this size the grinding is rapid and economical.

The amount of material put into the mill also has an important effect on the efficiency of the mill. Overloading must be carefully avoided, or the length of time occupied for grinding each charge will be greatly increased and the quality of the product lowered.

The quality of the product obtained from a ball mill is not always suitable, as it produces rounded grains. Ball mills cannot grind material to form angular particles, so that if this should be required ball-mills are unsuitable.

A ball-mill which has attracted much attention is known as the Hardinge mill (fig. 36). It consists of a double cone, one part being much larger than the other, the two cones being joined by a very short cylinder. The mill is supplied with balls varying from 5 in. diameter at the largest diameter of the mill to about 2 in. at the smallest diameter. Smaller mills have balls varying from $1\frac{1}{2}$ in.— $\frac{3}{4}$ in. diameter. The mill is rotated in the ordinary way by gearing, but as the mill varies in diameter, the portion having the greatest diameter will have the greatest peripheral speed, whilst the portions of progressively smaller diameter will have proportionately small peripheral speeds. The material to be ground is charged into the small cone and almost immediately comes into the zone of greatest speed and heaviest balls where it is roughly ground. As the particles become finer they travel in the second cone, coming in contact with smaller balls and lower speeds until finally the material reaches the smallest end of the second cone when it is sufficiently finely ground and passes out, through the end. The mill may be used for either wet or dry material. The advantages of this type of mill are that it is continuous in operation, and the fine material is removed from the coarse, so that less power is required and the grinding is more efficient. Mills supplied with material $\frac{3}{4}$ — $\frac{1}{2}$ -in. diameter will reduce it to 200-mesh quite readily, an air-separator being used for separating the fine product if necessary.

Tube-Mills (fig. 37) resemble ball-mills, but are of such a length that the material is completely reduced to powder before being discharged from the mill.

The cylinder is placed in a horizontal position, and is rotated at 25–30 revolutions per minute, the coarse material being fed into the tube at one end and withdrawn at the other end by gravitation. The balls used in tube-mills

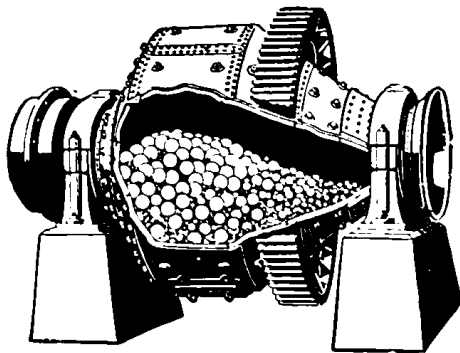


FIG. 36.—"HARDINGE" CONICAL MILL.
(By courtesy of Mining & Industrial Equipment Ltd.)

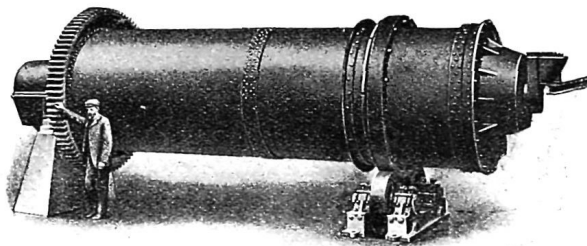


FIG. 37.—TUBE-MILL.
(By courtesy of Sutcliffe, Speakman and Co. Ltd.)

may be either in the form of flint pebbles or steel, the former being most commonly employed. Balls of four different sizes are preferable, as the working is then more efficient than when only one size is used. As the balls wear down it becomes necessary to add sufficient fresh ones to make up the deficiency. The replacement should always be made with the largest-sized balls.

The interior of the mills may be lined either with hard cast-iron or hard porcelain, the latter being preferable where iron contamination must be avoided. A durable lining is very desirable, as replacements are rather costly. Twelve months is the minimum length of service which can be regarded as satisfactory for a lining, and 18–24 months is by no means uncommon. Tube-mills have not a very large output; it depends on the length of the mill, the coarseness of the particles charged into the mill, and the size to which the material is reduced.

The quality of the product depends on the speed at which the material is charged into the tube, the slower the rate of feeding the finer the product. The maximum efficiency will be obtained when the feed is regulated so that the balls can effect a maximum amount of grinding in each particle before it passes further along the mill. The grains produced are round in shape. Tube-mills can be arranged to produce the finest possible powder and the product does not require to be screened or sieved. In the limestone industry, tube mills are used for producing limestone-flour which is used in the manufacture of asphalt and for other purposes.

Tube mills are expensive in first cost and to run; they are moderately but not highly efficient, and their chief recommendation is the certainty that the material is properly ground and requires no further treatment.

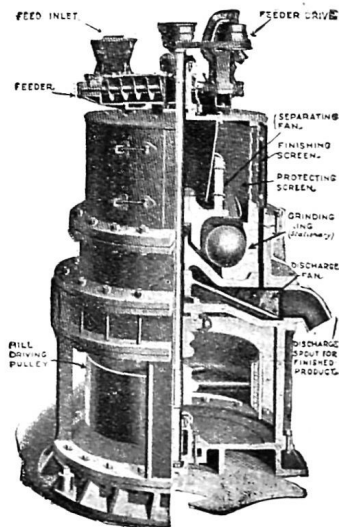


FIG. 38.
FULLER-LEHIGH PULVERIZER MILL.
(By courtesy of Fuller-Lehigh Co.)

Centrifugal Ball-Mills (fig. 38) are a type of mill in which the centrifugal force of the balls is used instead of their weight. The mill consists essentially of a hardened steel race, onto which the material to be ground is fed. In the race are a number of hardened steel balls which are driven round in the race by means of a rotary casting. Fans are arranged so as to cause air-currents to pass continually over the race, so that when the particles are sufficiently fine they are lifted up by the currents of air on to sieves which are placed round and above the race. The fine particles pass through whilst those which are too coarse fall back into the race to be re-crushed. This type of mill is very useful for fine grinding and material of 200-mesh fineness is readily obtainable.

A mill of this kind will crush 4-7 tons of limestone per hr. with a power of 50-70 horse-power.

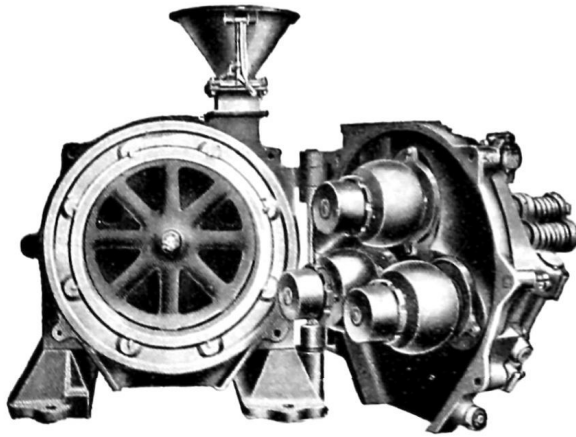


FIG. 39.—ROLL MILL, WITH DOOR OPEN.
(By courtesy of Sturtevant Engineering Co. Ltd.)

Roll Mills (fig. 39) consist of three rolls arranged in a horizontal shaft inside a casing, the interior of which consists of a hardened steel-ring. The ring and one of the rolls move in the same direction, whilst the other two rolls are loose and take their motion from the revolving ring. The material to be ground is fed between the driven roll and the ring and thus to the other rolls which complete the pulverization, the ground powder falling into a hopper-shaped receiver below. A machine of this type will grind about 3 tons per hour with about 25 horse-power, being fed with pieces 1 in. diameter, and the resultant product will leave a residue of only 8 per cent. on a 100-mesh sieve.

Pendulum Mills are similar in principle to the ordinary hand mortar and pestle, but they are much larger and are driven by power.

The Griffin mill (fig. 40) made by the Bradley Pulverizer Co., consists essentially of a pendulum suspended from a universal hardened steel-roll. The pendulum is driven by means of a pulley and is placed so that when rotating at a high speed the roll comes into contact with a hardened steel-ring fitted in

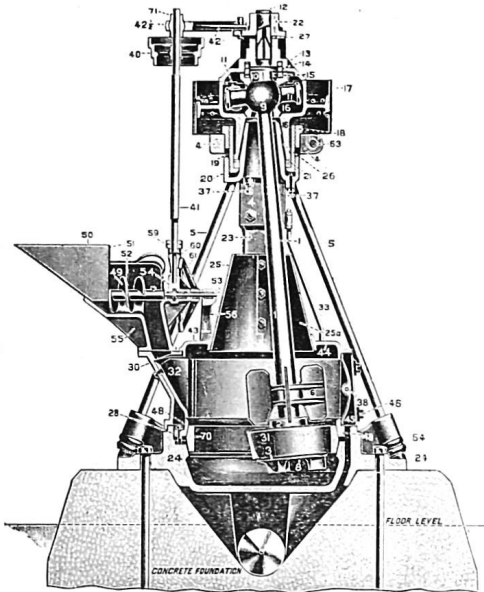


FIG. 40.—GRIFFIN PENDULUM MILL.
(By courtesy of Bradley Pulverizer Co.)

the side of a cast-iron pan. The material is charged into the pan and is stirred by stirrers fitted to the bottom of the pendulum, so that as the latter rotates it crushes, the stirred up material between the roll and the ring. The air currents cause the fine particles to rise on to screens arranged round the pan, so that the finest particles pass through whilst the coarser cones fall back for further treatment. These mills are driven at 150 to 200 revolutions per minute, and are very efficient fine grinders.

The Gus pendulum mill, made by George Fletcher & Co. Ltd., Masson Works, Derby, is of similar design to the Griffin Mill and is

capable of grinding from $\frac{1}{2}$ -in. pieces down to an impalpable powder. A special feature of this machine is that a number of fans are attached to the pendulum above the roll, and, in rotating, the pendulum operates these fans which drive the material against the screens.

Another modification of the ordinary type of pendulum mill is made by the Raymond Impact Pulverizer Co., Chicago, U.S.A., in which 2-5 pendulums are employed, each being suspended from a central casting, which carries all the moving parts. The action of the mill is the same as in the Griffin type, the material being stirred up by scrapers and ground between the grinding ring and the pendulums. In England it is known as the "Lopulco Mill."

Grindstones are occasionally used for fine grinding, but for large outputs they have largely been replaced by ball mills and pendulum mills which—in most cases—produce an equally satisfactory product in larger quantity and at a lower cost.

SCREENING

The object of screening stone, marble, chalk, etc., is two-fold :

- (i) It separates the material into pieces, the sizes of which are within predetermined limits. This is known as "Grading" or "Sizing."
- (ii) It effects a separation of clay, sand, and some other unwanted materials

which consist of such small particles as to pass through all the screens on which the stone is retained (see "Purifying the Stone").

Limestone is screened to various sizes; the extent to which the rock is graded depends chiefly on the number of screens or riddles employed and the sizes of the apertures in each. The apertures selected depend largely on the purposes for which the screened products are to be used, but the commonest apertures are 5 in., 4 in., 3 in., 2 in., 1 in., $\frac{3}{4}$ -in., $\frac{1}{2}$ -in., $\frac{1}{4}$ -in. and $\frac{1}{8}$ -in. diameter respectively, though intermediate sizes are used in some works.

Chalk.—especially in the form of *Whiting*—requires much finer screens or the use of an air-separator.

Some road-surveyors appear to find some special virtue in screens with perforations of an "odd" size; this would not matter if there was a general agreement, but it sometimes happens that several surveyors in adjacent districts insist on sizes differing only by a small fraction of an inch.

Smaller apertures are used in sieves where the material is required to be specially fine, as for ground limestone for agricultural purposes. For very fine particles, screening is not efficient, and classification by a current of air in an air-separator is far more satisfactory.

Screening may be employed for separating particles down to 200-mesh on a small scale, but for larger quantities it is cheaper and better to use an air-separator for material smaller than 100 mesh.

Screens or sieves are of various kinds, the principal being :

- (1) *Fixed screens*.
 - (a) Plane.
 - (b) Conical.
 - (c) Cylindrical.
- (2) *Movable screens*.
 - (a) Reciprocating.
 - (b) Rotary.
 - (c) Vibrating.
 - (d) Sieve conveyors or jiggling screens.

The terms used to describe screens are rather loosely applied. *Riddles* are very coarse screens. A *sieve* or *screen* is a riddle having moderately fine openings, whilst a *lawn* is a very fine screen—from 100—down to about 350-mesh. These terms are not standardized, however, and the term "sieve" may be applied to a "lawn" whilst the term "screen" is often used for a "riddle" and *vice versa*.

FIXED PLANE SCREENS

Fixed plane screens consist, usually, of a flat surface or sheet composed either of a meshwork of wires, a number of straight wires forming long slots, or a perforated or slotted metal plate. The term "plane screen" is used even when the screening surface is inclined so that the material supplied to it may travel down the incline and thus enable the screen to work continuously.

Horizontal screens are only used on a small scale ; they must be emptied periodically.

The crushed stone is supplied to the upper end of an inclined screen in a uniform manner across the whole width of the screen and slides down it, the finer particles passing through the meshes or perforations whilst the coarse particles, which will not pass through, fall off at the lower end as "tailings." It must be understood, of course, that if the screen is made of a perforated sheet, and is inclined, the largest particles passing through it will not correspond to the mesh or perforations of the screen, but will be the "projection" of such apertures on to a horizontal plane. Thus, if the screen were a sheet of steel with holes $\frac{1}{8}$ -in. diameter inclined at an angle of 45 degrees, the effective size of its perforations would be 0.0875 in. or about three-quarters of the apparent aperture. Owing, however, to the rate at which the particles slide over a sheet of metal inclined at such an angle, most of the particles will be about $\frac{1}{4}$ -in. diameter. Hence, the actual size of the particles can only be found by trial as it depends on the inclination of the sieve and the speed at which the material travels over the surface. In order to prevent the material from passing too rapidly over the sieve it is sometimes desirable to make the sieve in two parts—one sloping at a fairly steep angle, and the other at a smaller angle. By doing this, the speed of the material is lessened by the baffling action of the smaller slope. In other cases, the same effect is obtained by arranging small baffles across the surface of the sieve which arrests the speed of the material to some extent and so renders the screening more efficient.

The length of the screen also has an important effect on the sharpness of the separation. It is most important that the screen should be sufficiently long as, otherwise, much fine material will pass away in the tailings instead of going through the sieve.

The efficiency of a flat or inclined sieve also depends on the kind of material to be screened. Where this consists of a large variety of sizes, it is more difficult to obtain a good separation as the smaller particles become mixed with the larger ones and are not sufficiently separated during the short time in which the material passes over the screen. When most of the particles are of a size which will pass through the screen and only a small proportion are larger, the separation is much more efficient. Coarse material may be more efficiently screened than fine, as the holes, being larger, are not so likely to become clogged.

The kind of apertures employed is also very important ; they may be formed by (a) wire-gauze, (b) parallel wires, or (c) a perforated steel-plate.

Gauze or mesh-cloth is not usually satisfactory for a fixed sieve unless some means is employed for vibrating it to prevent the clogging of the holes. When a suitable vibrating arrangement is provided, gauze is very satisfactory for comparatively fine particles. It is unsuitable for very coarse screening on account of its lack of strength. Gauze-sieves are designated by numbers which, in this country, state the number of apertures per linear inch. Thus, a No. 24 sieve has 24 holes per linear inch, or 576 holes per square inch. On the Continent it is more usual to specify the number of holes per square centimetre.

Such Continental designations may be converted into the corresponding number by multiplying the square root of the Continental figure by $2\frac{1}{2}$. Thus, a Continental sieve designated as 4,900 mesh, *i.e.* having 4,900 holes per sq. cm., will correspond to $70 \times 2\frac{1}{2}$, or 175 in English standards, and will be equivalent to a No. 175 English sieve. Conversely, an English No. 25 sieve would correspond to a No. 100 Continental mesh.

NOTE.—Some Continental manufacturers designate their sieves by numbers, which correspond roughly, but not accurately, to the English ones.

The following Table gives various figures which may be used in comparing sieves designated in different ways :

TABLE XII.—*Comparison of Sieve Meshes*

No.	Meshes per linear inch.	Meshes per square inch.	Meshes per centimetre.	Meshes per sq. centimetre
30	30	900	12	144
60	60	3,600	24	576
90	90	8,100	36	1,296
100	100	10,000	40	1,600
120	120	14,400	48	2,304
150	150	22,500	60	3,600
200	200	40,000	80	6,400

A difficulty experienced in connection with sieves designated in one of the aforementioned ways, is that it is not possible to tell what size of aperture they contain, as this depends on the thickness of the wires used. To overcome this, a series of standard meshes have been prepared by the Institute of Mining and Metallurgy¹ in which all the apertures are the same diameter as the wires.

The British Standards Institution has issued a Standard Specification for Sieves. In the United States, a different standard is, unfortunately, used, and tends to cause confusion when British and American results are compared.

The Table on p. 152 shows the standards adopted by the Institute of Mining and Metallurgy with some extra information by J. W. Mellor :

¹ The sieves in accordance with the Institute of Mining and Metallurgy standards are made by N. Greening and Sons, Warrington.

TABLE XIII.—*I.M.M. Screen Apertures*

Mesh, <i>i.e.</i> apertures per linear inch.	Diameter of wires.		Diameter of apertures.		Screening area per cent. holes.
	inch.	mm.	inch.	mm.	
5	0.1	2.540	0.1	2.540	25.00
8	0.063	1.603	0.062	1.574	25.00
10	0.05	1.270	0.05	1.270	25.00
12	0.0417	1.059	0.0416	1.056	24.92
16	0.0313	0.783	0.0312	0.780	24.92
20	0.025	0.636	0.025	0.635	25.00
30	0.0167	0.424	0.0166	0.421	24.80
40	0.0125	0.317	0.0125	0.317	25.00
50	0.01	0.254	0.01	0.254	25.00
60	0.0083	0.211	0.0083	0.211	25.00
70	0.0071	0.180	0.0071	0.180	25.00
80	0.0063	0.160	0.0062	0.157	24.00
90	0.0055	0.139	0.0055	0.139	24.50
100	0.005	0.127	0.005	0.127	25.00
120	0.0041	0.104	0.0042	0.107	25.40
140	0.0036	0.091	0.0036	0.091	25.00
150	0.0033	0.084	0.0033	0.084	24.00
160	0.0031	0.078	0.0031	0.078	25.00
180	0.0026	0.071	0.0028	0.071	25.00
200	0.0025	0.063	0.0025	0.063	25.00

The English Standard Specification is too long to quote, but copies may be obtained from The British Standards Institution, 28 Victoria Street, London, S.W.1.

When gauze is used, the wires tend to stretch and to sag, and are liable to be forced apart, thus allowing larger particles to pass between them. It is, therefore, important that the size of the particles passing the sieve should be tested periodically, so as to ensure that the sieve is in proper working order. When larger particles are found, the mesh of the sieve should be carefully examined, and the defect repaired. The gauze may be made of iron, steel, brass, bronze, or, less frequently, copper.

The non-ferrous metals may be used for very fine screens, and where it is desired to avoid contamination by iron. Phosphor-bronze is largely used for the finer sieves, on account of its hardness and toughness. Small sieves may be made in one piece, but larger ones are usually in sections, each mounted on a suitable frame and fixed into the screen framework. By dividing the gauze into sections, repairs are facilitated, no unnecessary waste of gauze occurs, and replacements can readily be made. This is very important, as it reduces the time lost by the stoppage of the apparatus to a minimum.

Another reason for using small frames is that unless the gauze is tight it is impossible to vibrate it properly, and tight gauze cannot be obtained in a large frame owing to the tendency of the cloth to sag. Screen frames, measuring 6 ft. \times 4 ft., are about the maximum size which gives the most convenient handling with ease of replacement and low cost of repairs. The sieve or sections should be fitted in such a manner that it, or they, can readily be removed and replaced when necessary. Much time is often lost by lack of this precaution, and the consequent necessity of stopping the plant for an hour or more whilst a screen is repaired. If the screens are properly designed, a defective piece should be removed and replaced by a sound one in the course of two or three minutes. It is also desirable that the frames should be sufficiently small to enable the required tension in the gauze to be obtained without straining it. It is very important that the screening surface should be taut, in order to give a good separation; otherwise, 40 per cent. or more of fine material may be left in the tailings. As the wire is certain to stretch in use, some means should be provided for tightening the gauze from time to time.

Parallel bars and wires are used where the particles are cubical or globular, and free from flakes or long thin pieces. If the wires are fixed without any appreciable tension, they are satisfactory for light work and for hand-riddling, but not for continuous work. For the latter, the wires should be stretched by tension keys, as in a pianoforte—whence the name, "piano-wire" riddles or screens.

Parallel bars are used in the form of grids for separating moderately small pieces from larger ones. It is seldom desirable to have the bars less than $\frac{1}{4}$ -in. apart, and more usual to regard 1 in. spacing as a minimum for riddles of this kind. The maximum distance between the bars is usually about 6 in., though it could be much greater if required. Such riddles are often known as *grizzlies*; they are chiefly used to effect a preliminary separation of the small stone from that which requires to be crushed. Being very strong, they are not damaged by tipping a wagon- or truck-load of material on to them. By their use a considerable reduction may be effected in the amount of material which would otherwise pass through the crushers. Alternatively, one or more grizzlies may be used to separate pieces which are too large to be fed into the crushers or to other machines.

Bar-riddles or grids may be either flat or sloping, according to the conditions under which they are used. If sloping, the inclination should be slight—seldom exceeding 30 degrees, or the material will pass along too rapidly for it to be properly screened.

The bars may be made of iron, steel, or wood. They may be round, square, rectangular, or triangular in section, the latter form being best as regards preventing the particles becoming fixed between the bars, but it is not as durable as a grid with square or rectangular bars. Round bars are objectionable, as they are closer together about half-way down than they are on the surface of the grid, and thus tend to cause an excessive proportion of wedged pieces, which are often difficult to remove.

The bars may be of any convenient length. Such grids are often 8 or 12 ft. long, and usually about 4 ft. wide, though there is really no limit to either their length or width, as they can be built in section to ensure the requisite strength. The distance between the bars depends solely on the material to be separated. Parallel wires—arranged along the length of the sieve, and sometimes strengthened by a few cross wires—sieve more rapidly and more readily than gauze sieves. They have the disadvantage that if a long thin particle falls on to the screen, it may pass between the wires, whereas it could not pass a gauze screen of the same mesh, as the cross wires would stop it. This, however, does not often happen in screening a material such as limestone, chalk, etc., as the particles are in most cases fairly cubical.

A further difficulty encountered with parallel wire screens is that a large particle may force the wires apart, and then allow large particles to pass through the opening so created. This difficulty cannot be wholly avoided, but it can be minimized by keeping the wires taut so as to allow as little movement as possible; it does not occur with gauze screens.

Screens with parallel wires and no cross ones have a tendency to cause the material to race too rapidly over them, and thus prevent an efficient separation of the particles. This may be minimized by reducing the inclination or slope of the screen, or by arranging the wires across the screen instead of longitudinally, thus retarding the flow of the material, and effecting a sharper separation. Screens composed of parallel wires set closely together should usually be provided with some means of vibrating the wires sufficiently to keep them clean. If the wires are stretched sufficiently taut the movement of the particles may cause the requisite vibrations; otherwise, it may have to be applied mechanically.

Perforated steel plates are the most convenient form of screen where particles are between $\frac{3}{8}$ -in. and 4 in. Still larger perforations can be made, but the wear and tear are so great that it is cheaper to pass the coarse material over a grid or grizzly. The shape and size of the perforations vary according to circumstances. Sometimes the plates are corrugated as well as perforated, or they may be arranged in steps. Slots have the advantage of offering a larger screening surface than circular holes, but are very liable to pass long flaky pieces, which would be rejected by round holes. Consequently, it is usually better to employ the latter, though this may involve a large screen to produce the same area of apertures.

As most crushed stone is specified "to pass through a ring" of given diameter, it is clearly better to use circular holes in the screen, and thus ensure full compliance with the specification. Slots seldom produce so accurately graded a product. In the British Standard Specification for Chippings (p. 177) and in all perforated plates used for Standard Specification sieves (No. 410—1931) *square* holes are stipulated, but the Standard Specification for sieves for industrial purposes permits the use of round holes in plates! Square holes pass rather larger pieces than circular ones of the same diameter, because the diagonal of a square is 42 per cent. longer than its width (side).

Inclined perforated or slotted plates are so smooth that the material tends to race over the surface, with the result that some of the material fails to pass through the holes, and this must be allowed for in purchasing screens of this character. It is also very important that the angle at which they are placed should be very carefully considered, so as to allow for its effect on the material and on the rate at which it travels over the surface. Baffles, or the use of two or more screens at different angles, may be necessary to retard an excessive flow of material.

The thickness or "gauge" of the metal used for slotted and perforated screens should be sufficient to give ample strength. The following sizes give reasonable durability ; thinner sheets should not be used except under special circumstances.

TABLE XIV.—Perforated Sheets

Diameter of hole. inches.		Thickness of sheet. inches.		Centre to centre of Perforation. inches.	
$\frac{3}{16}$	·094	$\frac{3}{16}$	·037	$\frac{5}{16}$	·156
$\frac{7}{16}$	·109	$\frac{1}{8}$	·050	$\frac{3}{16}$	·187
$\frac{1}{8}$	·125	$\frac{1}{16}$	·062	$\frac{3}{16}$	·187
$\frac{5}{16}$	·156	$\frac{5}{16}$	·077	$\frac{1}{4}$	·250
$\frac{3}{16}$	·187	$\frac{7}{16}$	·109	$\frac{1}{8}$	·297
$\frac{1}{4}$	·250	$\frac{9}{16}$	·140	$\frac{3}{8}$	·375
$\frac{5}{16}$	·312	$\frac{11}{16}$	·172	$\frac{7}{16}$	·437
$\frac{3}{8}$	·344	$\frac{3}{8}$	·187	$\frac{1}{2}$	·468
$\frac{7}{16}$	·375	$\frac{1}{4}$	·250	$\frac{1}{2}$	·500
$\frac{1}{2}$	·500	$\frac{1}{8}$	·312	$\frac{1}{8}$	·688
$\frac{9}{16}$	·625	$\frac{3}{8}$	·375	$\frac{1}{4}$	·812
$\frac{3}{4}$	·750	$\frac{5}{8}$	·625	$1\frac{1}{8}$	1·125
1-4	—	$\frac{3}{4}$	·750	—	—

NOTE.—With holes 1-4 in. diameter, the total area of the holes should not exceed 43 per cent. of the total area of the sheet, and, preferably, should not exceed 36 per cent.

Too large a proportion of holes produces sheets which are too weak to be durable. If the holes are not the same diameter on both sides of the sheet, that on the lower side should be slightly the greater, so as to prevent the material from wedging in the holes.

EFFICIENCY OF FLAT AND INCLINED SCREENS

The efficiency of a fixed flat or inclined screen depends on several factors of which the most important are :

- (i) Its length ; many users employ screens which are far too short to ensure a good separation of the coarse and fine materials. This can best be ascertained by testing the tailings by means of a hand-sieve of the same aperture. In most

cases, a length of not less than 6 ft. is necessary, though 4 ft. is more usual. Where several screens are employed in series at different angles, each should be at least 4 ft. long.

(ii) The inclination or slope, which must vary according to the type of screen used, though an angle of 45° is generally satisfactory. If the screen is vibrated an angle of 30° is ample and a much smaller angle will often suffice.

(iii) Smoothness of surface ; a perforated sheet or screen with parallel wires will oppose less resistance to the flow of the material and so will tend to retain in the tailings a larger proportion of fine materials than will a gauze screen. This may usually be overcome by using a longer screen. The output of a gauze screen is often low because of the resistance caused by the cross wires, though this may be overcome by vibrating the screening surface.

(iv) Distribution of material on the screen ; thus, if the material is spread uniformly across the whole width of the screen and continues to be so distributed throughout its journey the efficiency of the screen will be high. Many users feed the screens carelessly, with the result that a large proportion of the available surface is not used at all ! For the effect of vibration see pp. 162 and 163.

(v) The nature of the material ; some materials are much more easily screened efficiently than others, as the proportion of material to be removed often exerts a notable influence on the process. Thus, it is extremely difficult to remove completely a small proportion of moderately fine material from a coarser one. A damp material will also be more difficult to deal with than a dry one.

TESTING TAILINGS

When a sieve or screen works perfectly, all the particles up to a certain desired size pass through it and the tailings will not contain any particles less than this size. Consequently, if the tailings were passed a second time over the sieve no further fine material would be separated. It is practically impossible to secure so perfect a result on a large scale, as no sieve in the market has a 100 per cent. efficiency. The only way to obtain the best possible result is to investigate several types of sieves or screens, and to test the tailings with a hand-sieve of the same mesh or aperture.

It is also a wise precaution to make similar hand-tests of both tailings and screened material to ensure a " clean " product.

SUPPORTS FOR SCREENS

Flat and inclined screens are often used for hand-sifting ; a flat screen is used, placed on an open support, such as a pair of rails or on top of a tub, box, or bin, and half-filled with the material to be sifted. The screen is then moved backwards and forwards on its supports or is lifted in the hands and shaken horizontally until it is judged that the whole of the fine material has been removed. With care a highly efficient separation may be effected.

An inclined screen or riddle is usually set up at about 75° or other suitable angle and the material is thrown against it; the finer particles pass through whilst the tailings fall down to the bottom of the screening surface.

The efficiency is low, but often sufficiently good for the purpose, especially when the coarse material has no value. An ordinary labourer kept supplied with material and working 10 hours a day will screen about 24 cubic yards of sand and gravel or similar material in this way. For larger outputs it is cheaper to support the inclined screen above the ground and at a slighter slope, and to feed the material on to the top of the screen, so that it slides down the surface, the smaller particles passing through the screen and being separated in this way. Much larger outputs can be obtained by this means. Inclined screens are made to screen 15–20 tons per hour of limestone ground to 40-mesh. The supports may be of timber or iron, the latter being preferable as it is stronger and more durable.

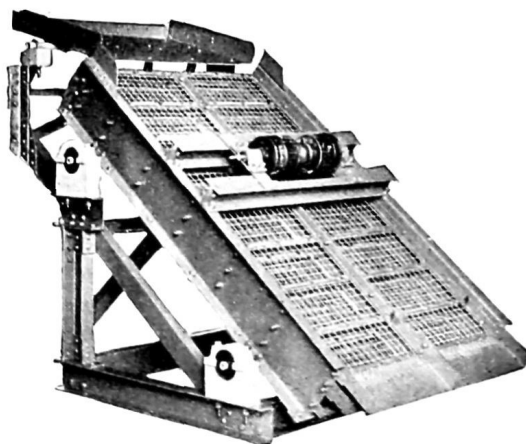


FIG. 41.—VIBRATING SCREEN.
(By courtesy of Huntington, Heberlein and Co. Ltd.)

DISTRIBUTION OF MATERIAL

To ensure a maximum output, the material must be uniformly distributed over the screen and, usually, the screen must be vibrated (fig. 41) either by hammers or magnets or by mounting it on an elliptical or eccentric shaft, the rotation of which creates the desired vibration (see p. 163).

Uniformity of distribution is secured on some screens by means of a screw-conveyor which discharges material over a weir on to the screen. In other screens baffles are used.

FIXED CONICAL SCREENS

A very useful kind of screen made by the Traylor Engineering Co., Allentown, Pa., U.S.A., consists of a shallow conical screen, the upper surface of which is swept by revolving scrapers. The material is introduced onto the screen and is moved by means of the scrapers, the finer particles passing through the screen, whilst the larger ones are gradually swept upwards until they scrape over the edge of the cone and are carried away as tailings.

A similar form of conical screen, made in this country, is the "Pulver"

blender, which consists of an inverted cone with an outlet at the bottom. Inside the cone is a rotary spreader-plate above which a number of beaters are mounted. The screen is surrounded by a conical casing with an exit pipe in the base. The material to be screened is fed on to the rotary spreader plate and broken by the beaters. The particles are then flung by centrifugal action on to the screen, the small ones passing through to the casing and escaping through the exit pipe in the base, whilst the larger particles pass down the screen and escape by the other outlet.

FIXED CYLINDRICAL SCREENS

Fixed cylindrical screens consist of a cylinder made of gauze or perforated plate mounted in an almost horizontal position ; the material is introduced at the higher end and is swept gradually through the cylinder by a cylindrical or spiral brush, mounted on a shaft which passes through the centre of the cylinder. The brush presses the material against the screen-surface and also gradually carries it along through the cylinder. Sometimes the brush is replaced by paddles or scrapers which serve the same purpose, but are less effective.

Occasionally a half-cylinder, forming a trough, is used in connection with a brush, but the disadvantage of this arrangement is that it is less effective than when a complete cylinder is used. The brushes wear away rapidly and are expensive, whilst with the finer screens the brushing causes a large amount of wear and tear on the screening surface.

MOVING SCREENS OR SIEVES

Moving screens or sieves include those having two kinds of motion ; (a) reciprocating, and (b) rotary.

RECIPROCATING SCREENS

The simplest form of reciprocating screen is an ordinary sieve, which is shaken to and fro by hand. This method is very tiring, and has so low an output that it can only be used for small quantities. For larger quantities, some form of mechanical power must be employed to create the motion.

Power-driven reciprocating screens are usually of the flat type, one of the commonest patterns consisting of a horizontal screen or sieve moved to and fro by means of a bar having one end attached to the sieve and the other to the edge of a disc mounted on a shaft so as to form a crank. It is sometimes more convenient, instead of using guides, to suspend the screen from the roof or from a framework erected over it, the motion being imparted in the same manner as before.

If desired, several sieves may be placed one above the other and reciprocated by a series of cranks. The finer particles from the upper sieves fall onto those below until they pass out into a suitable receiver. The sieves must then be emptied by hand unless they are made continuously acting by sloping them slightly and providing them with chutes.

Reciprocating sieves of this type may be of any convenient sizes. They are usually moved at the rate of 30–70 strokes per minute, according to the nature of the material.

The output of reciprocating sieves is rather smaller than that of rotary sieves (described later), but for many purposes they are useful if kept in good condition. The wear and tear on them is rather great on account of the reciprocal movement.

Grids or grizzlies may be given reciprocating movement—either as a whole or by constructing them of loose bars and attaching alternate bars to an eccentric or crank which then gives them the requisite to-and-fro motion.

Reciprocating Feeder Screens are often useful for effecting a rough separation of coarse and finer materials prior to delivery to another machine. They may be used for a variety of other purposes, of which only two are mentioned :

(a) When a mixture of coarse and fine material is fed from a bin or crusher on to a conveyor-belt, the durability of the belt may be greatly increased by causing the fine material to reach the belt first and so form a cushion which protects it from the abrasive action of the larger pieces. This is effected very ingeniously and cheaply in an arrangement, supplied by the Stephens-Adamson Manufacturing Co., Aurora, Ill., U.S.A., which consists of a belt-conveyor over which is mounted a hopper and a reciprocating grid or grizzly. The mixed material falls onto the grate and the finer particles pass through it to the belt, whilst the larger pieces pass along to the end of the grate and fall on to the cushion of finer material on the belt.

(b) When it is necessary to crush a material containing pieces of several different sizes, it is economical to screen it roughly, so that the smaller pieces (which do not require crushing) do not enter the crusher. This arrangement sometimes permits a smaller crusher to be used and it always effects a saving in power. One of the most effective screens for this purpose is a reciprocating grate which simultaneously acts as a feeder. The mixed material falls from a hopper on to the reciprocating grate, and the finer material which does not require crushing falls through into a chute, which delivers it below the crusher and it eventually joins that which has previously fallen through the grate.

REVOLVING OR ROTARY SCREENS

Revolving or rotary screens consist essentially of cylinders, polygons, or cones, made of longitudinal bars on end frames, perforated steel plates, or metal gauze. The screens are rotated at a moderate speed. The screens with longitudinal bars are specially suitable for very coarse screening, the bars being placed $\frac{1}{8}$ – $\frac{1}{4}$ -in. apart. They are particularly used for heavy work, which would cause excessive wear on other rotary-screens.

Rotary-screens with perforated plates are used for separating pieces from $\frac{1}{8}$ – $\frac{1}{4}$ -in. diameter, though they are not really satisfactory for pieces more than 2–2 $\frac{1}{2}$ -in. diameter.

Rotary-screens fitted with gauze are suitable for separating the finest particles and all those up to $\frac{1}{2}$ -in. diameter, though it is better not to use wire-gauze with holes more than $\frac{1}{8}$ -in. diameter, as perforated sheet is much stronger.

The material is supplied to one end of the screen, which is given a slight inclination so that as it rotates the coarser material is carried through it whilst the finer particles pass through the perforations or mesh.

The simplest form of revolving or rotary screen is a cylinder of perforated metal mounted on an internal shaft by means of ribs which form two or more "spiders." Nearly as simple, but having several important advantages, is a polygonal screen (fig. 42) with five, six, or eight sides (usually six) constructed

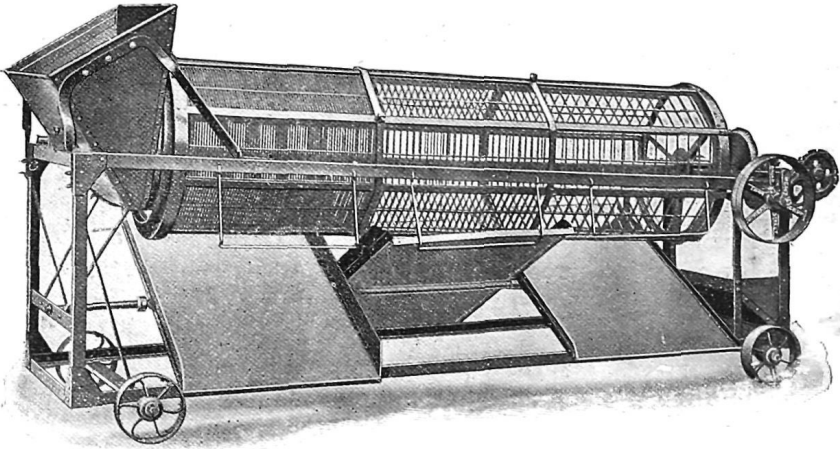


FIG. 42.—POLYGONAL ROTARY SIEVE.
(By courtesy of Parker, Winder and Achurch, Ltd.)

in a similar manner to the cylindrical screen. The hexagonal screens are rather more expensive in first cost, but they have a slightly larger screening surface for the same "diameter," the shape increases the "tumbling effect" on the material and so increases the output to a small extent, and repairs are made much more rapidly as well as much more cheaply. If a cylindrical screen is broken, the repair (apart from a "patch") is expensive, but with a polygonal sieve it is merely necessary to remove one side and replace it by a new one; this is effected much more rapidly than the repair of a cylindrical sieve, and is a matter of great importance on a busy day, as the sieve need only be stopped for a few minutes in order to attach a new frame, whereas a cylindrical sieve may be stopped for several hours in order that one section can be taken off and replaced by a new one.

Instead of mounting the cylinders or polygons, as described, on a shaft running through their centre, they may be fitted with a hardened steel ring

with a spur wheel gearing and rotated on external rollers. This method is better in several respects and enables the interior of the cylinder to be perfectly clear, thus giving more space, as well as avoiding the wear and tear on the shaft. External driving is used chiefly for the heaviest screens, the lighter ones being mounted on a central shaft.

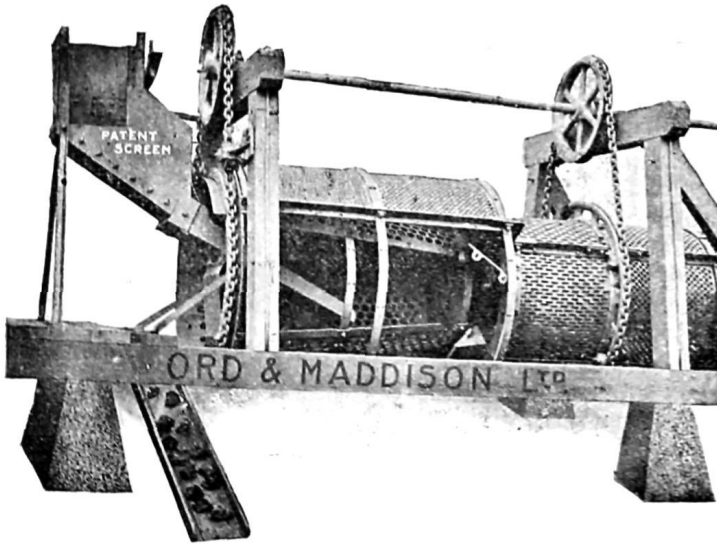


FIG. 43.—ROTARY SCREEN.
(By courtesy of Ord and Maddison, Ltd.)

In one type of rotary-screen (fig. 43) made by Ord and Maddison, Ltd., Darlington, the cylinder is suspended from several pulleys which, in revolving, turn the screen at the desired rate and ensure a very free and easy drive. A similar arrangement is employed in the screens supplied by W. A. Hiscox, Ltd., Derby.

Conical rotary screens (fig. 44) are similar to the ones just described, but are of a different shape and the drive is more easily arranged as the shaft is quite horizontal. The material is delivered through a chute to the small end of the screen and the tailings are discharged from the larger end. The greater perimeter of the larger end gives

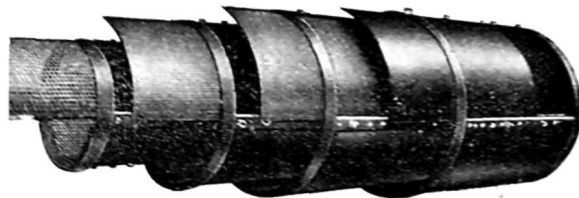


FIG. 44.
CONICAL ROTARY SCREEN (SHOWING EASE OF REPLACEMENT).
(By courtesy of J. and F. Pool, Ltd.)

a more rapid rate of travel to the coarser pieces, thus freeing them more readily from the smaller ones and ensuring a somewhat better separation.

The conical shape of the screen and the fact that a horizontal shaft is used, effects a saving in weight, reduces the amount of head-room and greatly simplifies the arrangement, especially if an elevator is used to feed the screens. In a cylindrical screen, the elevator-head must be mounted separately, but with a conical screen it can be mounted on the same shaft, thus simplifying the drive very considerably.

In some cases, in order to reduce the wear and tear caused by the fall of the material from the chute, a small screen may be placed inside the larger one, the material falling into this small receiver and then at a much lower velocity onto the screen itself. In other cases, several screens of different mesh can be arranged concentrically. In another type, a number of conical screens are fitted on one shaft, the small end of one screen projecting into the large end of the next one. The material is fed in at the upper end of the first screen and is discharged progressively through the narrow end of one sieve into the large end on the next and so on through the series.

A very useful screen made by Ord and Maddison, Ltd., Darlington, consists of a cylindrical screen with a conical screen inside it. As shown in fig. 43, the material is introduced into the cone by means of the chute, which is fitted with grid bars, taking out the smaller sizes and dust, these being instantly passed through the larger holes in the cone into the enlarged screen without mixing with the larger stones, thus ensuring perfect screening. All other stones are passed by gravitation towards the outer end; the largest stones are rejected to the elevator or breaker as desired. The remaining stones, after passing through the cone, are raised by means of elevator wing-plates, and may fall into a second cylindrical screen for further separation if required.

Tapering polygonal screens are also used, either singly or in series, those of hexagonal shape being generally preferred. They are preferable to conical screens for the same reasons that straight hexagonal screens are preferable to cylindrical ones. Hexagonal screens are mounted in the same manner as conical ones, on a central shaft, and are used for the same purpose.

When damp or adhesive materials, particularly those chiefly composed of particles of less than 20-mesh, are screened on a rotary screen, the latter may be vibrated by means similar to those employed for fixed screens. The most usual device is a pair of steel cams fixed on opposite sides of the screen and a horizontal hammer-bar hinged loosely so that it remains on a band surrounding the screen. As the screen revolves, the hammer-bar is lifted by the cams and then falls onto the screen-band, causing the screen to vibrate. This arrangement is very noisy in action, but is fairly effective. Several similar bars may be used on the same screen if desired.

Revolving- v. Vibrating-Screens.—The output of a revolving-screen is much less than that of a plane vibrating-screen of the same area and mesh, and can be as low as one-fifth of the output of the latter. Hence, the increasing popularity of vibrating-screens for many purposes.

VIBRATING SCREENS

In order that the small pieces of material may pass as readily as possible through the screens it is usually necessary to vibrate the screen in some convenient manner. With a hand-sieve, the customary method is to hit it against a stop or support—a method which is crude but very effective. Larger screens or coarse sieves are reciprocated mechanically, as described later, but those made of gauze are vibrated either by hammers or magnets.

The simplest form of vibrator consists of a series of short rotating bars which hit the frame of the screen at each rotation. The greater part of the vibration is absorbed by the frame, but sufficient movement is transmitted to the screening surface to ensure a reasonably high output.

A great improvement on this method is incorporated in the "Rolring" screen in which a series of strips of metal are placed, at regular intervals, on each side of the gauze; attached to these strips is a number of metal holders which project through the upper casing of the screen and carry wooden pegs which act as anvils when struck at frequent intervals by a number of loose hammer-bars attached to a series of rotating shafts fitted above the casing. In this way, the screen is vibrated by blows delivered almost directly to many points on its surface at a fairly rapid rate, and clogging is effectually prevented. The hammers and anvils should be arranged so as to give only a very small amplitude of motion to the screen—not enough to cause violent movement of the material, yet sufficient to free the particles and to present them with ample opportunities of escaping through the openings.

Two screens, one below the other, may be vibrated simultaneously, but in that case the upper sieve must not be finer than about 15-mesh.

In the "Hum-mer" screen a powerful electro-magnet is mounted above the gauze and attracts and releases the strips of steel attached to the screening surface at a very rapid rate, in a manner precisely similar to the vibrations of the hammer in an electric bell and keeps the gauze in a state of constant vibration. It is claimed that there is nothing to get out of order, the intensity of vibrations is far greater and more effective than with hammers, and can be varied at will in order to suit the material to be screened, and that very little power is required. By applying an intensely rapid vibration direct to the gauze, as in the "Hum-mer" screen, the particles are constantly separated from each other, the larger ones helping the smaller particles to pass more readily through the screen and enabling the screen to have a very large capacity and a very sharp separation. Rapid vibrations of small amplitude also prevent the material jumping or bouncing on the screen and enable a smaller angle of inclination to be used and a sharper separation to be effected. Whenever a vibratory mechanism is used, the screen should be fully enclosed in a dust-proof case, or the loss of the finest material will be serious.

The use of elliptical or unbalanced shafts, on which the screen is mounted, has become very popular. The amplitude of vibration is easily adjusted and "there is nothing to get out of order." *Rotary screens* may be vibrated in a similar manner.

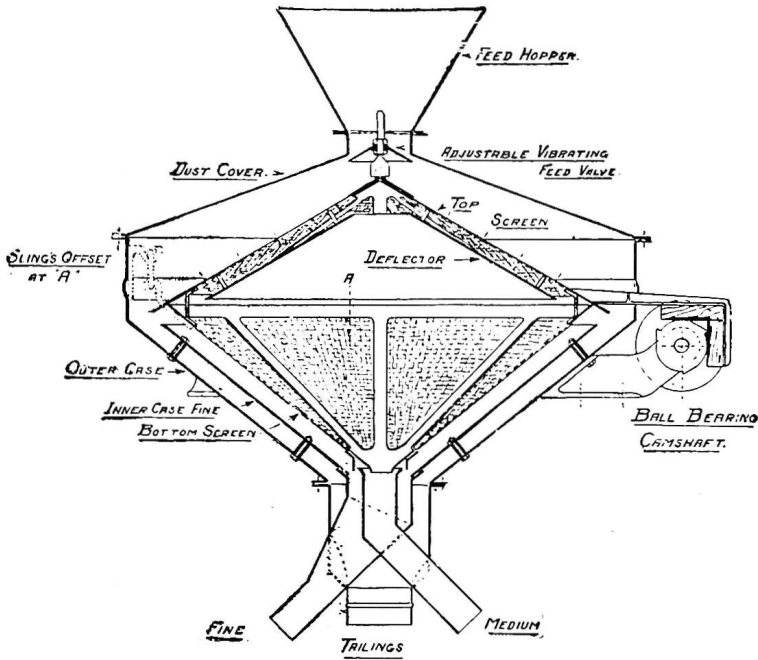


FIG. 45.—“VICONA” SEPARATOR.
(By courtesy of George Fletcher and Co. Ltd.)

A vibrating conical screen (fig. 45) made by George Fletcher and Co. Ltd., Masson Works, Derby, consists of a conical screen mounted above a similar, but inverted, screen, both being mounted in such a manner that they can be oscillated and vibrated by means of a shaft and cam. The material is fed through a hopper onto the upper conical screen, the small particles pass through it and fall on to a second inverted conical screen, which may be either the same or smaller mesh. In the former case, the material is separated into three different sizes, each passing into a different chute. The coarse material rejected by the first sieve passes down inside the casing to the tailings chute; the material which has passed through the first sieve, but is rejected by the second one, passes down an inner casing into the “medium” chute, and the material which has passed through the second sieve enters the “finest” chute. This type of sieve is very compact and yet has a specially large screening surface, whilst the oscillating motion is very effective for all materials between $\frac{1}{4}$ -in. and 200-mesh.

Ratio of Apertures to Product.—It is not sufficiently realized that revolving-screens must have larger holes than the particles they are intended to pass, because the inclination and the rotation of the screen both have the effect of making the effective size of the holes much smaller than their apparent size.

The following Table compiled by the Traylor Engineering Co., Allentown, Pa., U.S.A., shows the relationship between the sizes of the particles and the holes :

TABLE XV.—*Relationship between sizes of particles and apertures*

Size of Particles. Inches.	Size of Apertures. Inches.
$\frac{1}{4}$	$\frac{1}{2}$
$\frac{3}{8}$	$\frac{3}{4}$
$\frac{1}{2}$	$\frac{7}{8}$
$\frac{3}{4}$	$1\frac{1}{4}$
1	$1\frac{7}{8}$
$1\frac{1}{4}$	$2\frac{1}{4}$
$1\frac{1}{2}$	$2\frac{1}{2}$
$1\frac{3}{4}$	3
2	$3\frac{1}{2}$
$2\frac{1}{2}$	4
3	5
$3\frac{1}{2}$	6
4	$7\frac{1}{4}$

On account of the great difference between the sizes and effective sizes of the holes, it is important to check the sizes of the screened particles by actual measurement, or by hand screening, from time to time.

Speed of Rotation.—The speed at which cylindrical rotary-sieves are driven varies from 8–30 revolutions per minute, a speed of 16–20 revolutions per minute being most usual. Polygonal screens may be driven at a lower speed than cylindrical ones, as low as 4 revolutions per minute being sufficient in some cases. This avoids much of the wear and tear which occur in screens which are driven at higher speeds.

Dimensions of screens.—The dimensions of rotary-screens should depend on the extent of separation desired. Usually, each section of the cylinder is 4–6 ft. long and 2–4 ft. in diameter. Ample length is essential to secure a clean separation, but it is by no means unusual—especially in screens containing several sections in series—to find each section is much too short to do its work properly. This can best be ascertained by carefully examining the screened products.

MULTIPLE SCREENS

Multiple screens are those which can separate a mixed material into particles of several distinct grades or sizes. The simplest form is a long sloping sheet of metal composed of several sections, each perforated with holes of a

different size. The section with the smallest sized holes is at the lower end, the intermediate sections being arranged progressively according to the sizes of the holes. Thus, if there are six sections, the material would be separated into seven grades, viz. one for each section and the tailings which passed over the end of the screen.

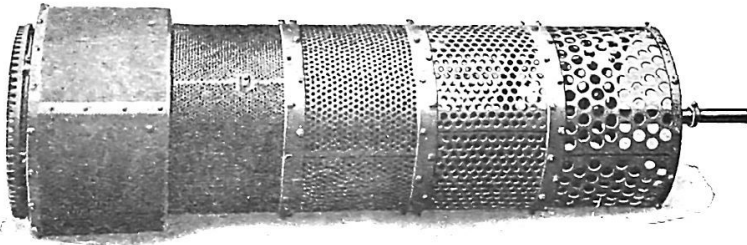


FIG. 46.—ROTARY MULTIPLE SCREEN.
(By courtesy of Goodwin, Barsby and Co. Ltd.)

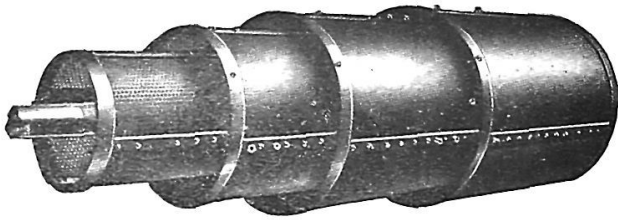


FIG. 47.—ROTARY MULTIPLE SCREEN.

It is more usual to employ cylindrical screens (figs. 46 and 47) than plane ones for multiple work on account of their larger output. It is even more important with multiple screens than with single ones that each section of the screen should be of sufficient length. It is a common mistake to have the sections too short, with the result that the materials are imperfectly separated. For all grades larger than $\frac{1}{8}$ -in. the most generally satisfactory length of each section is 6 ft.

Various other forms of multiple screens are also in regular use. For instance, the screens may be separated but so placed as to deliver their products to one another. This is the case when several conical screens are mounted on the same shaft. Another and very important form of multiple screen is described in the next section.

Concentric Screens.—Instead of employing a series of separate screens, it is often better to arrange them concentrically—inside one another—and to drive them by means of a common shaft. The coarsest screen is placed on the inside and the finest on the outside, the material being fed onto the coarsest screen first. The advantages of this arrangement are :

(i) Much of the wear and tear of the screens is on the coarsest one, whereas in most other arrangements it is on the finest screen which is least able to withstand it.

(ii) The arrangement is very compact and requires a minimum of space.

Another multiple screen which is very commonly used consists of an ordinary revolving cylinder with holes of the desired size surrounded by one with smaller holes to act as a separator for dust and very small particles. Thus, if it is desired to separate $\frac{3}{8}$ -in. material from coarse and fine, the former is removed by the main cylinder and the latter is separated by the dust screen. Such an additional screen is often attached to an ordinary multiple screen to remove the dust without unduly increasing the apparent length of the screen.

SCREEN-CONVEYORS

It is often convenient to combine a screen and conveyor in such a manner that a material is screened during transport. Most screens do this to some extent, but the term "screen-conveyor" or "conveyor-screen" is usually confined to those appliances which are primarily conveyors, but also act as screens. Such appliances are of several forms and considerable ingenuity is often exercised in adapting fresh combinations of screens and conveyors to a particular purpose.

One type of rotary screen-conveyor consists of a stout shaft on which is mounted a number of circular plates or discs set a pre-arranged distance apart. This shaft is fitted in a broad slot in an ordinary chute, so that when the material falls upon the edge of the discs the smaller pieces pass between them and so fall out of the chute whilst the coarser material is carried round the circumference of the revolving plates and into the lower portion of the chute. This appliance is chiefly of use as a feeder for crushing plants as it takes up very little space horizontally.

Another type of screen-conveyor consists of an endless belt composed of links spread a suitable distance apart and driven by a pair of sprocket pulleys. Between the upper and lower parts of the belt is a hopper which receives the small material passing between the links of the belt and conveys it to a suitable bin. The coarser material is carried to the end of the belt and is then discharged. As the belt can be of any convenient length, a very effective separation is made with the minimum amount of head-room. This arrangement also has the advantage of being self-cleaning as the links pass over the sprockets, whereas the spaces between the bars in an ordinary grate or grizzly are liable to choke. Below the belt, a brush should be fitted to remove any adherent particles so as to prevent them from being ground by and damaging the return pulleys. A screen-conveyor of this type with a total length of 6 ft. will have an actual screening length of about 3 ft. 6 in.

Another equally important type of screen-conveyor consists of an ordinary jigger-conveyor, the pan of which is perforated so that it also acts as a sieve

(fig. 48); the smaller particles falling through the perforations whilst the larger ones are "jigged" along the conveyor by a sharp to-and-fro motion imparted to the appliance. Such a jigger-sieve has the great advantage of moving the material uniformly over the surface, and, being horizontal, it removes a large percentage of fine material, thus giving cleaner tailings than a sloping screen. At the same time, it has the advantage over ordinary horizontal sieves of lifting the coarse material from the screen at each movement, instead of at longer intervals as in an ordinary to-and-fro sieve, and, as the tailings are automatically discharged, there is no stoppage of the sieve to remove "rappings." In both

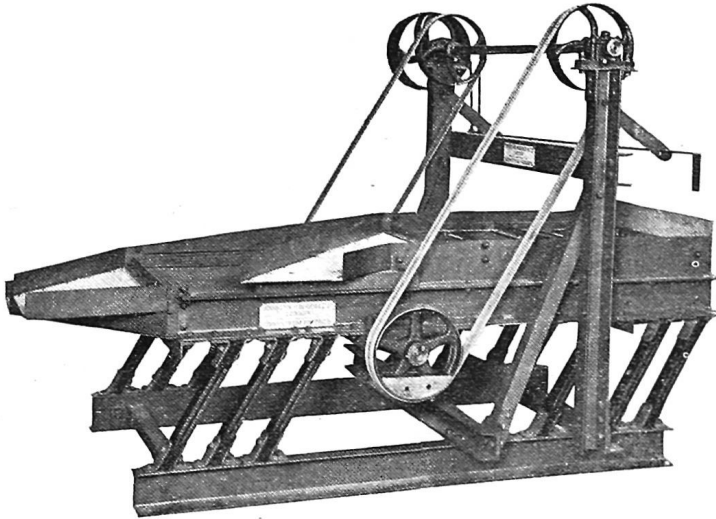


FIG. 48.—JIGGING SCREEN.

(By courtesy of Huntington, Heberlein and Co. Ltd.)

these respects it resembles a modern vibrating screen operated by an eccentric shaft.

The manner in which the sieve is moved ensures a greater "life" than in the ordinary to-and-fro sieve, and the screening surface is much greater than the latter in proportion to the power required. As the top of the trough is open, the material can be inspected at any time, and any damaged or defective part of the conveyor can easily be examined and repaired. Screens of this type are largely used for coal, and their use for limestone is well worth further attention. They have a very large capacity and require little power, but are not suitable for very small outputs or for very fine work.

AIR-SEPARATORS

For separating very fine particles, *i.e.* those below 100-mesh, on a large scale it is difficult to use screens effectively and air-separators (fig. 49) are

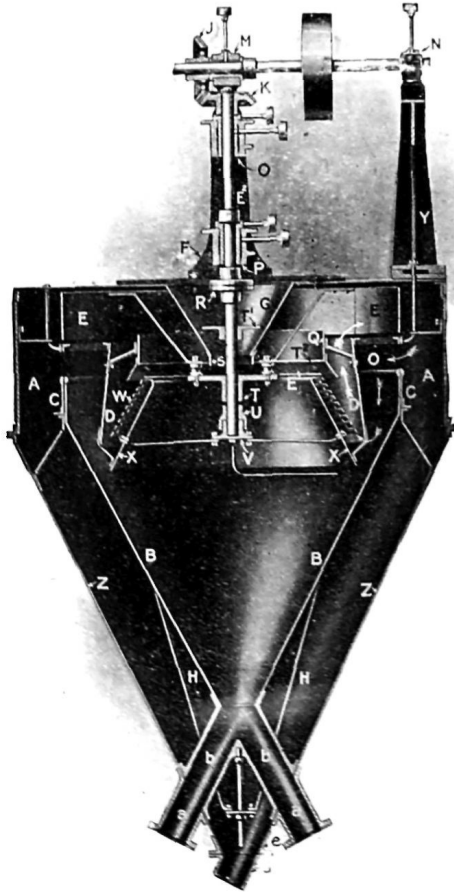


FIG. 49.—AIR-SEPARATOR.
(By courtesy of Edgar Allen and Co. Ltd.)

preferable. These appliances carry away the finer particles by means of a current of air, the size of the particles so carried depending on the speed of the current. The coarser particles are left behind and are usually transferred by some mechanical means to a chute and suitable receiver. The type of air-separator now generally used was invented by Mumford and Moodie, but it

is manufactured by several firms, and with various modifications (*e.g.* fig. 50), as the chief patents have long since expired.

The usual form consists of an inverted cone with a shallow cylinder above and a distributing device in the upper part of the appliance. The material is fed into the distributor, which usually consists of a horizontal disc rotating at so great a speed that the material is thrown from it by centrifugal force into a

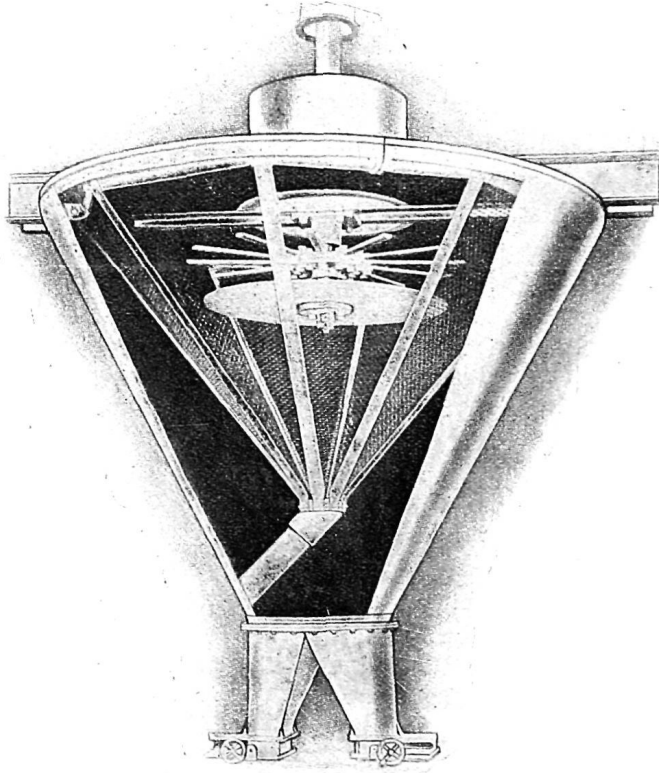


FIG. 50.—“PULVER-BLENDER.”
(By courtesy of The Bohle Engineering Co.)

current of air which passes through the separator. The disc may be surrounded by vanes or fitted with other devices which ensure a uniform distribution of the material in the air and so facilitate the separation. The distributor is only required when the particles have to be suspended in the air; if they have previously been suspended no moving parts are needed in the air-separator, but a series of fixed baffles is sometimes used to facilitate the separation. If necessary, two or more separators may be used in series, the final one being large enough to retain the whole of the powder and discharge clean air. With

extremely fine powder a *filter* is sometimes necessary to retain particles which are too fine to settle in the separator.

The particles travel at different velocities according to their size and specific gravity ; the coarse particles sink rapidly and fall into an inner vessel from which they are discharged, whilst the finer particles are carried by the air and pass to the outer casing which leads to a chute or discharge-pipe and are collected separately.

The speed of the current of air passing through the apparatus can be varied within wide limits, in order that particles of any desired size may be separated.

To obtain the best results, the material supplied to an air-separator should not contain any notable proportion of particles larger than $\frac{1}{8}$ -in. diameter, and the nearer the material approaches the nature of a powder the better will be the separation. The material must be supplied at a constant rate and special care is needed not to overload the separator. Hence, a mechanical feeding device is desirable.

It is often convenient, and quite satisfactory, to connect an air-separator to a ball mill, the product from the mill passing into the separator, and the "tailings" being returned to the mill for further grinding. The simplest means of delivery from the mill to the separator is a bucket-elevator, but if the whole of the product is sufficiently fine it may be drawn from the mill by a current of air moved by the fan in the separator.

SOME ESSENTIALS FOR PERFECT AIR-SEPARATION

The following requirements and conditions must be met in order to obtain satisfactory separation by air :

(i) The air must be expanded and rarefied or its velocity must be reduced so that the coarse particles will drop out of the current.

(ii) A sufficiently large volume of air must be used, in order to lift and suspend the material.

(iii) To carry off only the impalpable powder there must be ample room for the air to expand, or other means must be provided for its speed to be sufficiently reduced.

(iv) The nearer the air-space within the apparatus can be made to approach a vacuum, or the lower its velocity, the finer will be the separation.

(v) The mechanism for expanding the air must be such that the coarse particles will drop out of the current without carrying any of the fine powder with them.

(vi) The fineness of the finished product must at all times be under the absolute control of the operator.

(vii) In order to secure a large quantity of fine product, the material must first be ground to a proper fineness.

(viii) The material should be sufficiently dry, or the particles will adhere together and will not be properly separated by the current of air. To assist in the separation of damp materials the use of hot air is sometimes recommended, but it involves difficulties due to its feeble carrying power.

These conditions are usually secured by passing the air containing the particles in suspension through two or more conical vessels of the shape shown in fig. 49, but without any internal mechanism. Each vessel in the series should be considerably larger than the one preceding it, so as to secure the requisite reduction in the velocity of the air.

Where a dry material is required to be so fine that sieves are difficult to use, an air-separator is probably the best appliance for the purpose, especially if the particles larger than 0.02 in. diameter have previously been removed by screening. When air-separators do not furnish a sufficiently fine product, the process of levigation or elutriation may usually be employed, but is not applicable to lime on account of the solubility.

DUST-PROOF CASINGS

Where sieves are likely to produce much dust, as in fine screening, it is desirable to enclose them in a dust-proof casing, which prevents serious loss of material and avoids injuring the health of the workers. The shape of the casing depends on that of the screen; it may usually be of wood or sheet-iron plates, and should be fitted with doors, and give ready access to the interior.

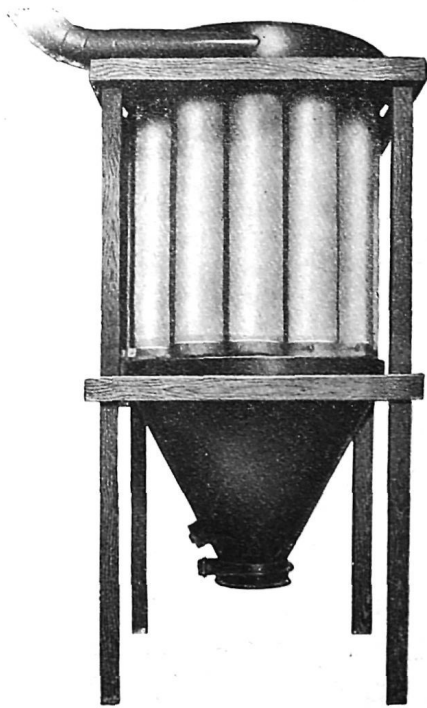


FIG. 51.—DUST-COLLECTOR.
(By courtesy of Spencer and Halstead, Ltd.)

DUST-COLLECTORS

The smallest particles of stone or lime (technically known as *dust*) constitute a saleable material and should not be allowed to escape into the atmosphere; in many localities, local by-laws impose penalties for their emission. Such particles should, therefore, be collected.

The most convenient method is to employ a fan to draw the dusty air into a dust-collector (fig. 51) from which the dust may be recovered without loss whilst the air is allowed to escape. These collectors are of two types: (a) *filters*, in which the dust-laden air is passed through clothes or into bags or "candles," which retain the dust, but not the air; and (b) *separators*, in which the speed of the air is reduced to such an extent that it cannot carry the

dust any further, but is obliged to deposit it. Such "cyclone-separators" closely resemble the air-separators described on p. 169, but have no moving parts. Filters, when in good order, are usually more efficient than cyclone-separators, but require frequent attention. The best results are obtained by passing the air first through a separator or depositing chamber, and then through a filter.

LEVIGATION AND ELUTRIATION

The term "levigation" is applied to the process of freeing chalk and other finely divided substances from coarser particles by means of water. A mixture of chalk and water is first passed through a fine sieve (say No. 80) to separate the coarser particles, and is then run into tanks and allowed to rest for a pre-determined length of time. The turbid liquid is then run off into another tank without disturbing the sediment. The material is allowed to remain for a suitable time in the second tank, when it is run off into a third tank; this process is very slow, and requires a large amount of space, but it is effective and not very costly if the tanks are arranged in a suitable manner, so that the liquid flows from one to another by gravitation. The time which must be allowed for particles of any given size to settle can be calculated from the formula

$$v = \frac{2gr^2(D-d)}{9c}$$

where v is the velocity in cm. per sec. of the sinking particles, D the specific gravity of the particles, r the radius of the particles in cm., d the density of the liquid, c the coefficient of viscosity of the liquid ($0.0114g. \text{ cm.}^{-1} \text{ sec.}^{-1}$ at 175° C.), and g the gravity coefficient (981).

In practice, a liberal allowance must be made for the fact that the particles are not true spheres (which must be the case if the formula is to apply strictly), and for the action of the water in flocculating or dispersing some of the particles; consequently, it is desirable to check the times allowed by measuring the sizes of the particles by means of a microscope.

In many works the process of levigation is not adequately controlled, so that much time is wasted without any improvement in the product. Moreover, the great effect of minute traces of impurities in the water and chalk is not fully appreciated. This can be minimized and the levigation improved, as well as hastened, by a detailed examination of the colloidal matter present, and by adopting proper means first for dispersing the chalk particles and afterwards deflocculating them. The levigation is often facilitated by crushing the chalk to pieces not more than $\frac{1}{8}$ -in. diameter and then stirring in a wash mill. The smaller particles are rapidly suspended and can be run off with the wash-water. The coarser particles are ground in an edge-runner mill (pan mill) with a deep pan. The product is then suspended in water and the coarse particles are separated. By this treatment a larger yield is obtained than when a simple wash mill is used.

Where an impalpable powder is not required a fine product can be obtained by *brushing* the chalk mechanically, but the product is much coarser than levigated chalk.

Elutriation is a process of separating particles by flowing water instead of in still water. A slurry composed of the materials and water is allowed to flow through a tall vessel in an upward direction at a very slow rate, so that all the desired fine particles are carried away to a receiving tank, whilst the coarser particles remain behind. The rate of flow and the pressure or head of water used affect the size of the particles carried away so that these two factors must be carefully adjusted. It is also important to use a sufficiently tall vessel in order that the particles may have ample time to adjust themselves in the water. An irregular flow, or eddies in the main stream, will give erroneous results and an imperfect separation. The various appliances used in the separation of heavy minerals and ores are not suitable for limestone products, as they require a much greater difference in the specific gravity of the desired product and the waste material.

After a lengthy experience, the author has found that the most efficient elutriating device consists of a metal pipe about 4 in. diameter and 8 ft. long, fitted with a suitable valve at its lower end, and connected to a supply of water delivered under a constant head. The material to be treated is supplied in the form of a slurry, and enters the pipe at some distance from the top by means of a vertical pipe. The particles of solid material are immediately set into violent motion by the conflict of the flow of water in an upward and downward direction, so that they are rapidly separated, and then travel either up or down, according to their size and specific gravity. Those which sink are removed by opening the valve, whilst the smaller particles flow up and out of the appliances into a collecting chamber. This device—which is a Schoene's elutriator modified so as to make it continuous in action—is very simple to use, requires a minimum of water, and is very accurate.

Elutriation, when properly carried out, effects a more accurate separation than levigation, as it is under better control, and with a suitable elutriating device it is easy to prevent any cohesion of particles and consequent waste of material, such as occurs with levigation.

The effects of traces of impurities, either in the water or the powder, require careful investigation, and much may be done to improve the sharpness of the separation by the careful use of suitable electrolytes as dispersing and deflocculating agents. Such an investigation requires special appliances and much knowledge of colloidal chemistry, so that it is best to consult an expert on the subject.

The results of such an examination are particularly well worth while, as they greatly improve the quality of the product as well as reducing the time required for collecting it.

SEDIMENTATION

The final stage in the process of levigation and elutriation is the collection of the desired product. The particles of such material are usually too small to

be recovered by filtration or centrifugal action, though one of these should be employed where possible—on account of their completeness and rapidity.

In many instances the material is collected in large tanks, in which it remains until it has completely settled. The clear water is then run off, and the sediment is dried in any convenient manner—usually on floors heated by flues beneath, or on trays passing in a continuous manner through a drying chamber. Hot-drying is slow and costly, but with some materials it is the only method available. Great care must usually be taken not to overheat the product, as this would cause it to agglutinate. There is an ample scope for an improved method of drying levigated chalk and similar materials which are obtained by sedimentation.

Where possible, the greater part of the levigated material should be separated by filtration or centrifugal action, leaving only the finest particles to be separated by sedimentation.

FILTRATION

Filters may be either intermittent or continuous.

In *Filter Presses* (fig. 52)—which consist of a series of twill cloths folded to form bags, and placed in frames—the liquid containing the chalk or other substance in suspension is forced into these bags by means of a plunger pump, until they are all filled.

The pump is then stopped, and pressure applied to the frames by means of a screw, so that the water is forced through the spaces between the threads in the cloths whilst the solid matter remains behind in the form of a series of slabs or “cakes.” When no more liquid can be expressed, the pressure is released, and the cakes removed. They may afterwards be dried in any convenient manner.

Filter presses do their work well and cheaply, but they require continuous attention, so that a *continuous filter* (fig. 53) is sometimes preferred. There

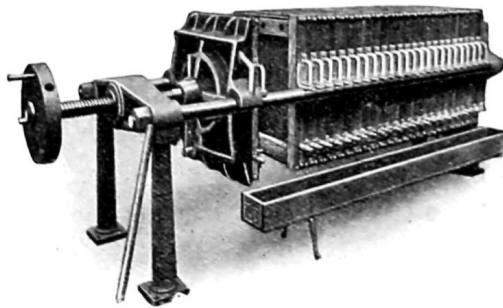


FIG. 52.—FILTER-PRESS.

(By courtesy of Manlove, Alliott and Co. Ltd.)

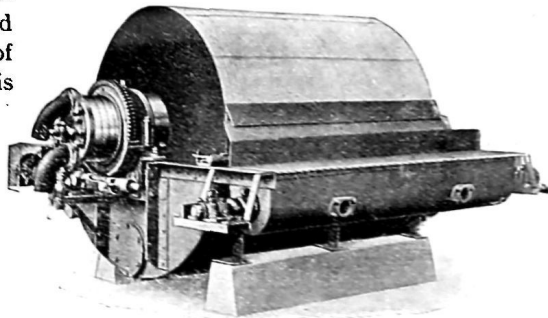


FIG. 53.—CONTINUOUS VACUUM FILTER.

(By courtesy of Dorr-Oliver Co. Ltd.)

are various forms, consisting essentially of a drum surrounded by filter-cloth, the slurry being applied to the outside of the drum so that the water passes through the cloths and drains away. The residual solid is automatically scraped off as the drum revolves, and at a further stage in the revolution the cloth is cleaned by the application of a spray of water. The action is continuous, and needs little attention.

CENTRIFUGAL SEPARATORS

Centrifugal separators consist essentially of a drum which rotates rapidly about a vertical axis. A charge of the slurry is run into the rapidly rotating drum, and, owing to the differential action of centrifugal force, the particles of solid matter fly to the lining of the drum and accumulate there whilst the water remains in its original position. When the separation is complete, the water is run off, the machine stopped, and the resultant paste removed. By combining a filter with a centrifugal separator, most of the smallest particles of solid can be retained.

If the drum is provided with suitable internal guides and an opening in the base (Gee's patent), it will be found that the charge—if admitted slowly—takes a long spiral path, and gradually parts with the solid matter, so that a grading or separation into particles of different sizes is automatically effected, the coarsest particles accumulating at the top of the drum and the finest at the bottom, with a complete set of gradations between. Hence, by using a loose lining in sections, a series of graded materials is obtained in an exceedingly simple manner.

To avoid this grading, the drum must be rotated more slowly, and no water must be liberated until the separation of the whole of the solid in the charge is complete.

Most centrifugal separators require to be filled, stopped, emptied, and re-charged, which makes their use expensive.

STORAGE OF GRADED MATERIAL

The screened and purified limestone, marble, chalk, etc., should be stored in such a manner that the material of each grade or "size" is kept separate from the others.

Bins should be used as far as possible, as if properly designed they can be emptied with a minimum of labour, but some of the larger grades may be stored on the ground in the open air and loaded into carts, trucks, or barges, by means of a portable bucket-elevator.

Storage is important to ensure prompt delivery, especially when lime is burned in continuous kilns and when loading steamships and other vessels.

It is also advantageous when stones from several different strata have to be mixed together in order to produce a mixture of uniform quality.

BROKEN STONE

Broken stone is a term applied to the material obtained by crushing larger pieces of stone. The British Standards Institution has issued a Standard Specification restricting the sizes to be described as broken stone as follows :

Broken Stone specified as 3-in. gauge shall all pass through a 3-in. ring and shall consist of the following sizes expressed as percentages by weight :

Not more than 15 per cent. passing through a $2\frac{1}{2}$ -in. ring in every direction.

Not less than 65 per cent. over $2\frac{1}{2}$ in. and not exceeding 4 in. in greatest length by measurement.

Not more than 20 per cent. over 4 in. in greatest length by measurement.

Broken Stone specified as 2½-in. gauge shall all pass through a $2\frac{1}{2}$ -in. ring, and shall consist of the following sizes expressed as percentages by weight :

Not more than 15 per cent. passing through a 2-in. ring in every direction.

Not less than 65 per cent. over 2 in. and not exceeding 3 in. in greatest length by measurement.

Not more than 20 per cent. over 3 in. in greatest length by measurement.

Broken Stone specified as 2-in. gauge shall pass through a 2-in. ring, and shall consist of the following sizes expressed as percentages by weight :

Not more than 15 per cent. passing through a $1\frac{1}{2}$ -in. ring in every direction.

Not less than 65 per cent. over $1\frac{1}{2}$ in. and not exceeding $2\frac{1}{2}$ in. in greatest length by measurement.

Not more than 20 per cent. over $2\frac{1}{2}$ in. in greatest length by measurement.

Broken Stone specified as 1½-in. gauge shall all pass through a $1\frac{1}{2}$ -in. ring, and shall consist of the following sizes expressed as percentages by weight :

Not more than 15 per cent. passing through a 1-in. ring in every direction.

Not less than 65 per cent. over 1 in. and not exceeding 2 in. in greatest length by measurement.

Not more than 20 per cent. over 2 in. in greatest length by measurement.

An average sample of not less than 100 lb. weight must be used for testing. The gauges should be made of metal and have cut in them holes and slots of the specified sizes.¹

Chippings is a term used for small pieces of stone applied to the surfaces of roads to prevent slipping. The British Standards Institution restricts the sizes of chippings to 1 in., $\frac{3}{4}$ -in., $\frac{1}{2}$ -in., $\frac{3}{8}$ -in., $\frac{1}{4}$ -in., and $\frac{1}{8}$ -in. and has issued the following specification :

1 in. chippings shall all be capable of passing through a square hole of 1-in. side and at least 70 per cent. by weight shall be retained on a sieve having square holes of $\frac{3}{4}$ -in. side.

$\frac{3}{4}$ -in. chippings shall all be capable of passing through a square hole of $\frac{3}{4}$ -in. side, and at least 70 per cent. by weight shall be retained on a sieve having square holes of $\frac{1}{2}$ -in. side.

¹ For further details see Specification No. 63 published by the British Standards Institution, 28 Victoria Street, London, S.W.1.

$\frac{1}{2}$ -in. chippings shall all be capable of passing through a square hole of $\frac{1}{2}$ -in. side, and at least 70 per cent. by weight shall be retained on a sieve having square holes of $\frac{3}{8}$ -in. side.

$\frac{3}{8}$ -in. chippings shall all be capable of passing through a square hole of $\frac{3}{8}$ -in. side, and at least 70 per cent. by weight shall be retained on a sieve having square holes of $\frac{1}{4}$ -in. side.

$\frac{1}{4}$ -in. chippings shall all be capable of passing through a square hole of $\frac{1}{4}$ -in. side, and at least 70 per cent. by weight shall be retained on a sieve having square holes of $\frac{1}{8}$ -in. side.

$\frac{1}{8}$ -in. chippings shall all be capable of passing through a square hole of $\frac{1}{8}$ -in. side, and at least 70 per cent. by weight shall be retained on a sieve having square holes of $\frac{1}{16}$ -in. side.

An average sample weighing not less than 100 lb. must be used for testing and the sieves used must have square holes formed by wires of the following dimensions.¹

TABLE XVI.—Dimensions of sieves for testing chippings.

Mesh.	Thickness of Wire.	
	S.W.G.	in.
1 × 1	9	0.144
$\frac{3}{4}$ × $\frac{3}{4}$	9	0.144
$\frac{1}{2}$ × $\frac{1}{2}$	11	0.116
$\frac{3}{8}$ × $\frac{3}{8}$	12	0.104
$\frac{1}{4}$ × $\frac{1}{4}$	13	0.092
$\frac{1}{8}$ × $\frac{1}{8}$	15	0.072
$\frac{1}{16}$ × $\frac{1}{16}$	17	0.056

Finely powdered chalk, marble, and limestone are used in the chemical industries, in the manufacture of casein paints, distempers, whitewashes, putty, etc., for agricultural purposes, as a base, filler, and polishing agent or mild abrasive, in medicine and pharmacy, in the manufacture of pottery and glass, as a metallurgical flux, for "stone dusting," in collieries, the manufacture of asphalt, linoleum, as a dressing for calico, etc. Their properties are in many respects similar to those of lime when used for the same purposes, as described later.

The chief difference is that finely powdered carbonate is more neutral in character (whereas lime is alkaline) and is quite insoluble in water, unless the latter contains carbon dioxide, when the powder is slowly dissolved, but is reprecipitated on boiling the solution.

The various sizes of stone produced are sometimes known by names which

¹ For further details see Specification No. 63 published by the British Standards Institution, 28 Victoria Street, London, S.W.1.

do not give any accurate idea of their nature. Thus, ground limestone may consist of particles of all sizes from those $\frac{1}{8}$ -in. diameter to the finest dust, unless the coarseness or fineness of the material is specified.

PREPARATION OF OTHER FORMS OF CALCIUM CARBONATE

Various well-known substances are obtained by the treatment of limestone, marble, chalk, or other forms of calcium carbonate so as to produce materials having certain desirable physical properties whilst still retaining the general chemical properties of calcium carbonate. When in a sufficiently pure state, calcium carbonate is a neutral white substance which, on reduction to powder, is useful for a large variety of purposes as described in Chapter IV. Some of the forms in which it is used may now be described.

WHITING, ETC.

Whiting, Whitening, Spanish White, Paris White, and Blanc Fixe are different terms for the same material. They are all prepared by reducing white limestone or chalk to a fine powder, usually by grinding the purest and whitest limestone or chalk. The *dry-ground* material—with or without the separation of the finer particles by means of a current of air—is regarded as the most crude form of whiting and sells for the lowest price.

Water-floated whiting is made by grinding the material with water, separating the finer particles with more water, and collecting and drying them. Several varieties of mill are used for the grinding :

(a) A *flint mill* is a form of wash mill, consisting of a pan, 9—16 ft. diameter, and a rotary framework carrying large masses of chert or other hard stone which grind the material as a result of their weight and movement. Sometimes the rotating framework is replaced by a single runner, about 4 ft. deep and 14 in. wide, mounted on a horizontal shaft. When this is used it is an advantage to pass the stone or chalk between a pair of Kibbler rolls before they enter the mill.

The mill is fed with a charge each morning and evening, and water is added as required, the mill working continuously, both day and night. The ground material is suspended in the water and flows out near the top of the mill as a slip, containing 11 parts of water to 1 of solid matter. Several mills are required and after the liquid has been run off they are emptied systematically to remove the ungrindable material (sand and flint) which accumulates in them. If the mill is properly controlled, the slip will not leave more than 10 per cent. of residue on a 200-mesh sieve.

(b) *Ball mills* are sometimes used to grind the limestone or chalk. They are usually of the Alsing type and consist of a rotating cylinder mounted horizontally and lined with porcelain or other hard material which will not contaminate the product. Steel-lined cylinders are sometimes used, but are liable to stain the material. These cylinders are charged with the material to be ground, water, and hard steel-balls or flint-pebbles, and are rotated continuously

until a sample withdrawn from the mill and examined shows that the grinding has proceeded sufficiently far. The mill is then emptied, and the fine particles separated by sedimentation as when other types of mill are used.

It has recently been found that a conical pebble mill (Hardinge-mill) is superior to a cylindrical one, as its shape effects a rapid separation of the smaller particles and so reduces the amount of power and time required for grinding a given quantity of material. It has the further advantage of being continuous in action (provided that it is supplied with a pure stone) and it is also claimed that it yields a smoother product.

For a cheap form of whitening the material from the ball-mill is sometimes dried without any separation of the coarser particles, but for better qualities the product is treated like that from the other mills.

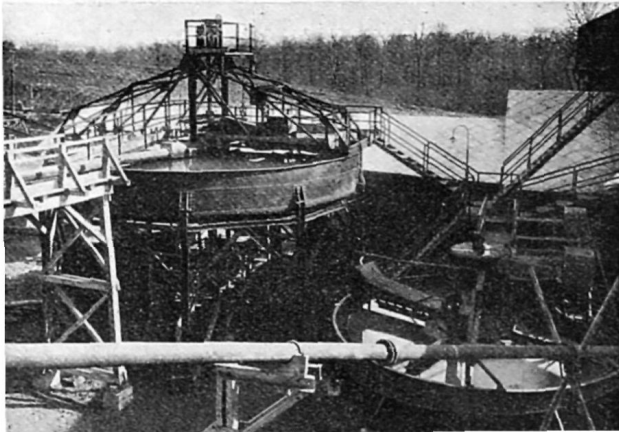


FIG. 54.—“DORR” HYDRO-SEPARATOR AND BOWL-CLASSIFIER.
(By courtesy of Dorr-Oliver Co. Ltd.)

The product from the flint mill is finer than that from a ball mill, and the particles are less granular, more colloidal, and more free from silica and other impurities, so that—notwithstanding the apparent crudeness of the machine—it continues to provide a product which is regarded as superior to that from ball or cylinder mills. The resulting slip—an opaque fluid—is run into a mixing tank where it is (if necessary) mixed with a large volume of water, and well stirred by mechanical agitators. The coarser particles are allowed to settle whilst the finer ones are run off and collected by a process of settling.

The old process consisted in the use of a series of 10–15 settling-tanks used in series, but this was slow and the product was variable. A better and much cheaper product is obtained by passing the slip through a Dorr hydro-separator (fig. 54) consisting of a circular tank with an overflow-weir just inside the circumference. The slip enters at the centre and flows to the circumference. A

central, slowly-revolving shaft, carrying four arms fitted with scrapers, sweeps any deposit towards the centre, from which it can be removed by a conveyor. This hydro-separator is really an elutriating device, the velocity of the slip being controlled so that only the fine particles are carried forward. The water carrying the fine particles in suspension contains 4 per cent. of solid matter. That flowing out at the centre contains all the grit with some fine material, and is passed into a bowl-classifier for re-treatment with more water, the fine particles being returned to the hydro-separator. The overflow from the hydro-separator is pumped to a rotating filter (fig. 53) which produces cakes containing 20-25 per cent. of moisture. These are passed through a rotary dryer. For some purposes, a rectangular classifier (fig. 55) is used instead of the circular one.

The use of a Dorr Separator and Classifier for this purpose has proved very satisfactory in the United States. By its means a continuous process is possible which, it is claimed, "improves the quality of the final product, reduces the floor-space required, eliminates waste, and reduces the cost of production by 17 per cent."

The thickened slip, consisting of almost equal proportions of chalk and water, or cakes containing about 20 per cent. of their weight of water, must usually be dried by artificial heat, either on shelves in hot chambers or in a rotary dryer.

In *drying* whiting the following precautions are necessary :

- (i) Heating above 250° F. must be avoided as it discolours the material.
- (ii) Drying to below 1½ per cent. of moisture causes the material to turn yellow if fresh heat is applied. The final product must contain less than 0.7 per cent. of moisture so that the last stage of drying must be done without new heat. The product leaves the dryer at 110° F.
- (iii) Contact with products of combustion must be avoided as they discolour the product.
- (iv) The heat should be applied at the feed-end of the dryer so as to ensure rapid drying at first as this prevents the formation of balls or lumps.
- (v) A regular feed is essential in a rotary-dryer. A screw-conveyor ensures this.
- (vi) The loss of dust must be kept at a minimum. This is best secured by working the dryer under slight vacuum at the feed-end and keeping both ends of the dryer closed.

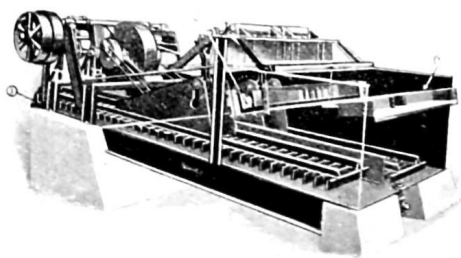


FIG. 55.—"DORR" RECTANGULAR CLASSIFIER.

(vii) Continuous operation (24 hours per day) is essential if the drying is to be done economically.

The drying is usually a slow process.

A form of "whiting" which may be used for most of the same purposes is that obtained as a precipitate in the production of various chemicals, etc., then drying and grading the product in an air-separator. It is better described as a "whiting substitute" (*below*).

Properties of Whiting.—The most important properties of whiting are : (a) its composition which should be that of commercially pure calcium carbonate ; (b) its whiteness (technically known as "colour"), even slightly tinted samples being of small value ; (c) its dryness, as moisture is objectionable in whiting of good quality and should seldom exceed 0.7 per cent. ; and (d) its fineness.

In some old-established works four or more qualities of whiting are sold, but in the modern works only one quality is produced. Of the four varieties, *commercial whiting* is the coarse product from the first settling-tank ; *gilder's whiting* is the product from a second series of tanks ; *extra gilder's* from a third series of tanks, and *Paris white* from the final classifier or collector.

When only one quality is made it is usually specified that it must leave less than 10 per cent. residue on a 300-mesh sieve though coarser whittings are used.

Fired trials of ground whiting sometimes produce rather misleading results as regards the surface colour of the fired samples, and different samples of the same material, fired in different parts of the same oven, have been known to give very variable results. Only when the fired product has been slaked by exposure to moist air, does the powder show its true quality, so that in the case of whiting the appearance of fired trials is quite unreliable as a guide to purity, and reliance can only be placed upon chemical composition.

In whiting of good quality the iron oxide should not exceed 0.04 per cent. nor the matter insoluble in acid more than 1.0 per cent.

Uses.—Whiting is used as a cheap base for neutralizing acids, as a filler for linoleum, rubber, asphalt, colours, in cigarette and other papers, in white ink, as a dressing for white shoes, in picture-frame mouldings, dolls, wire insulation, dyes, tooth pastes, fireworks, for facing-moulds and cores used in brass casting, and as a mild abrasive for polishing metals. It is also used in a small way in many industries, including structural iron, shipbuilding, locomotive works, file manufacture, explosives, medicines, printing, engraving, and the manufacture of shoes.

WHITING-SUBSTITUTE

The term *whiting-substitute* is applied to any substance which can be used for the same purpose as whiting made from chalk. The chief substitutes are finely-ground limestone, dolomite or marble, highly calcareous marls, and the calcium carbonate obtained as a by-product in the manufacture of alkali or in other chemical industries.

The particles of true whiting are spherical and have a high absorptive capacity, whereas those of whiting-substitute are angular, even when extremely finely pulverized, and have a low absorptive capacity. For many industrial uses, however, these particular properties are not of importance and the substitute can be used instead of true whiting.

The main requirements of a whiting-substitute suitable for the general trade are that it be white or light grey in colour, free from mica, consist principally of calcium carbonate, and preferably be fine-grained and free from grit. When pulverized it should yield a snow-white powder. Chemical purity is not essential, but is desirable. Each limestone-deposit or other source of whiting-substitute yields a product with individual characteristics, and it should not be assumed that because material from one deposit has proved satisfactory for any particular purpose that other whiting-substitutes will be equally suitable.

In the British Isles, whiting is relatively cheap and readily obtainable so that substitutes are not used extensively. In other countries where chalk is scarce there is a much greater demand for whiting-substitutes.

PREPARED CHALK

Prepared chalk (the *Creta Preparata* of the British Pharmacopœia) is native calcium carbonate (usually chalk), freed from most of its impurities by grinding, followed by elutriation, sedimentation and drying, and is practically the same as *Whiting*.

LEVIGATED CHALK

Levigated chalk is prepared by the process of levigation (p. 173), but as this is expensive some of the material sold as levigated is either "precipitated chalk" or finely-ground chalk, and is much coarser than the levigated product.

PRECIPITATED CHALK

"Precipitated chalk" is a medicinal preparation which is also used in industries where an exceptionally pure calcium carbonate is required.

The requirements of the British Pharmacopœia are met by a material produced by dissolving calcium chloride in water, adding rather more than an equal weight of sodium carbonate (which should previously have been dissolved in water), filtering off the precipitate, washing, and drying it. It will usually contain a variable proportion of soda, so that if a purer product is required ammonium carbonate should be substituted for the soda.

Precipitated chalk differs from ground chalk or ground limestone composed of particles of the same size in having a much smaller volume-weight (known in the trade as *density*, but not to be confused with the true specific gravity). For some reason which is not clearly understood, precipitated chalk tends to aggregate into small porous masses and thereby produce a very light powder, *i.e.* of large volume-weight in proportion to its weight. The crystalline form of the calcium carbonate has an important effect on the volume-weight and where a light product is required aragonite is the only suitable crystalline form.

Most of the lightest precipitated chalk now on the market is made by burning limestone, slaking it, converting it into milk-of-lime, and reconverting it into carbonate by passing pure carbon dioxide through the milk-of-lime in upright cylinders, about 18 ft. high and 6 ft. diameter, for 2-3 hours, with or without mechanical agitation. The process must be carried on under carefully controlled conditions with pure materials, phenolphthalein being used to indicate the completeness of the reaction. The precipitated-calcium carbonate is de-watered in filter-presses, and the filter-cakes are dried in hot-air tunnels at about 100° F. The dried cakes are ultimately pulverized and the finished article packed in paper-lined bags or barrels.

The quality of the product depends partly on that of the limestone from which it is made, that from chalk being inferior for some purposes to that from Carboniferous Limestone.

The product is almost pure, but where an exceptionally pure product is required a solution of calcium chloride should be first treated with sufficient ammonia or milk-of-lime to precipitate any iron, alumina, and earthy phosphates present. These should be filtered off and the solution so purified used for treatment with ammonium carbonate, as described on p. 183.

Waste solutions of calcium chloride obtained as a by-product can be used for the production of precipitated chalk for some commercial, but not for medicinal purposes, by carefully neutralizing them with any convenient alkali, chalk, or other forms of calcium carbonate, and then adding a slight excess of lime or even calcium carbonate to precipitate any iron salts as ferric oxide. The liquid must afterwards be filtered to remove the precipitated material. As the reaction between iron salts and calcium carbonate is slow, it is well to stir the liquid at frequent intervals during several days. The liquid is then made slightly alkaline with sodium carbonate (soda ash) which precipitates the calcium as carbonate. The precipitate is filtered, washed, and dried, and is then ready for use (as chalk) as a pigment or colour base, and for many other purposes for which a reasonably pure calcium carbonate in powdered form is suitable. It is often moulded into rough cakes or slabs, and sold in this form.

The precipitated calcium carbonate obtained as a by-product in several industries is seldom pure, but is sometimes sufficiently so to be saleable for industrial purposes. For instance, in the manufacture of caustic soda and in the neutralization of many acids a *lime-mud* is produced which consists almost wholly of calcium carbonate, though in some cases it contains various other substances which have been precipitated at the same time. Similarly the calcium carbonate obtained in softening water by Clark's lime-soda process and often known as *water works carbonate* is used for the neutralization of pickling solutions and other acid liquors, and for agricultural and other purposes where a very fine and pure calcium carbonate is not necessary. At the works of the Southend Waterworks Co., the carbonate is drained on a filter and burned in a rotary kiln, part of the resulting lime being used for softening further quantities of water and the remainder being hydrated and sold for agricultural, building, and other purposes. The purity of this form of carbonate depends on that of

the water from which it is obtained. If the hardness of the water is due solely to calcium carbonate, the product will be pure, but if derived from water containing calcium sulphate, magnesium compounds, or much suspended matter its purity will be correspondingly reduced.

The precipitated calcium carbonate must usually be dried and separated from coarse material before it is fit for use. Various methods of drying and grading are available, but one of the best is that patented by Stainer Hutchins,¹ the plant being supplied by the Fusion Corporation, Ltd., Cledford Bridge, Middlewich, Cheshire (fig. 56). Ordinary revolving dryers are useless as the wet calcium carbonate is slightly plastic, and adheres to the interior of the dryer and to any worms, scrapers, or other ordinary devices which are intended to remove it. In Hutchin's patent dryer, on the contrary, the rotating cylinder is provided with three or more loose bars of peculiar shape which extend almost the whole length of the dryer. These bars, which bear some resemblance to the paddles of a steamer and still more to the blade-carrying shaft of a pugmill, lie loosely in the dryer and are raised, along with the carbonate, as the dryer rotates. On reaching a height at which the adhesion of the contents and centrifugal force of the dryer can no longer hold it, each breaker falls onto the material on the bottom of the dryer, and pulverizes it as though it were in a ball mill. In its journeys, each breaker also rotates, and, consequently, acts as an efficient mixer, exposing fresh portions of the wet material to the warm air passing through the

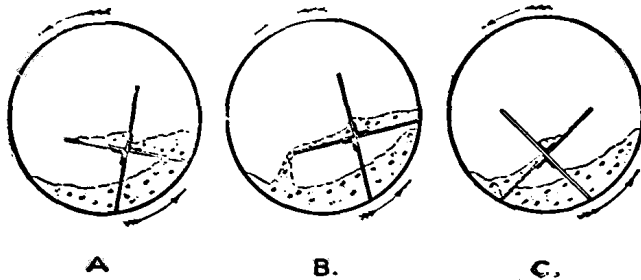


FIG. 56.—THREE POSITIONS OF BREAKER BARS IN HUTCHINS DRYER.

dryer. Three typical positions are shown in fig. 56. The combined action of the rotating drum and the breakers causes the dried material to pass gradually through the dryer and out into the grading device. The drying is effected by air, heated in a small furnace, and drawn by a fan through the rotating dryer. The dryer itself is not heated though external heating can easily be arranged if it were necessary.

The dry carbonate passing out of the rotating cylinder is taken to a bunker overhead by means of a simple bucket-elevator. The air drawn through the

¹ Instead of drying the wet slurry, it is often more economical to use a continuous rotary filter to remove the greater part of the water. The resultant cakes can then be dried completely or they can be taken direct to a rotary kiln and converted into lime.

dryer carries in suspension a large proportion of the finest particles of calcium carbonate, and delivers these into a series of cyclone dust-collectors, the sizes of which are designed to separate the coarse from the fine material. The very finest dust which cannot be caused to settle in a dust collector is delivered into a condensing tower, in which it is washed with sprays of water and converted into a mud. Only a very small proportion of dust enters this tower, yet if it were allowed to escape into the atmosphere it might create a nuisance.

This arrangement produces three grades of material, *viz.*, *coarse*, collected in the overhead bunker; *medium*, in the first collector, and *fine*, in the second dust collector. The small proportion of mud produced by the tower may be allowed to settle and then re-passed through the plant, or, as its amount is usually very small, it may be thrown away.

The arrangement will deal with carbonate containing 45 per cent. of moisture and will dry it so that the final product contains less than 1 per cent. of moisture and is in the form of a fine white powder, resembling whiting.

The fine powder obtained from the two cyclone collectors will pass almost completely through a 200-mesh sieve, and may be used for most purposes for which an extremely fine calcium carbonate is suitable.

The cost of drying and grading, using a plant producing approximately 60 tons per week, is only about 2s. per ton of dry product. If waste gases are available from some other source, the cost of drying and grading will only be about 9d. per ton.

Properties.—Four leading grades of precipitated chalk are recognized in the trade—extra light, light, medium, and heavy; the principal difference is in density. Most of the production is of the light grade, and its principal use is in the manufacture of toothpaste.

The trade term "density" when applied to precipitated chalk is a wholly arbitrary figure which must be divided by a factor (*e.g.* 130) to give the volume-weight of the sample. Thus, a 50-density chalk has a volume-weight of 0.384 gm. per cc., and a 100-density chalk a volume-weight of 0.770 gm. per cc.

The desired volume-weight of precipitated chalk should be secured by preparing the chalk under suitable conditions. Mixtures of dry samples of various densities do not give the same result.

The volume-weights (water = 1) of various grades of precipitated chalk are :

Extra light	...	0.285–0.345
Light	...	0.465–0.770
Medium dense	...	0.770
Dense	...	0.930
Waterworks chalk		1.280–1.300
Ground chalk	...	2.240–2.370

Unfortunately, individual manufacturers of precipitated chalk have their own standards of quality, and there are no exact or generally accepted specifications or methods of testing.

The following properties of "precipitated chalk" are important for various purposes, particularly in the manufacture of tooth pastes :

- (i) The sample should give no pink colour with phenolphthalein.
- (ii) It should be free from grit. An examination under the microscope will not only reveal grit, but the sizes and shapes of the particles of chalk.
- (iii) The proportion insoluble in hydrochloric acid should not exceed 0.025 per cent.
- (iv) No ultramarine or other blue colour (to compensate for a yellow tinge) should be present.
- (v) The volume-weight should be specified. Thus, for *dentifrices*, a precipitated chalk of low volume-weight should be used; the diameter of the particles should average 30,000 per linear inch, so as to have a maximum absorption. For *cosmetics*, a precipitated chalk of low volume-weight is preferable to zinc oxide and usually to china clay. For *polishing powders*, a precipitated chalk of medium volume-weight is used on account of its non-scratching power, though it is less abrasive than other powders and so polishes more slowly.

Tests.—The following tests for precipitated chalk of the best quality have been recommended by A. P. Wilson.¹

(i) The volume-weight may be measured by placing 40 gm. of the sample (previously sifted through a 30-mesh sieve onto a sheet of paper) in a 250 c.c. graduated cylinder, dropping the cylinder through a height of exactly 1 in. for fifty times at accurately measured intervals of 2 sec. and measuring the final volume. The test requires very careful attention to details, but is then accurate to ± 1 cc.

(ii) The *flow-point* or *absorption-value* is measured by the volume of water required to be mixed with a given weight of the chalk to form a paste of definite viscosity. A. P. Wilson determines it as follows: In a standard glass cylinder, measuring 154 m.m. by 20 m.m. internally, is placed about four-fifths of the requisite amount of water² and 10 g. of the chalk is then added, a little at a time from a spatula. After each addition, a stopper is placed in the cylinder and the whole is shaken vigorously. When the paste is too stiff to rattle, further water is added in portions of 1 cc. at a time from a burette, alternately with the remaining chalk, until all the chalk is in the cylinder. Water is then added in $\frac{1}{2}$ cc. increments with vigorous shakings between each addition (pounding on a rubber-pad is good). To test whether the end-point has been reached, the cylinder is tapped on the bench to shake the paste to the bottom of the cylinder and is then inverted at an angle of 15° from the vertical and slowly rotated. After an interval of not more than 5 sec. the paste should flow out in a quick succession of blobs. It should be quite natural and the blobs should not be slow to separate.

Concordant results should not differ by more than 0.25 cc. As the time-factor is important, the test should not take more than 3 min.

(iii) The "colour" is judged by placing 3 gm. of each sample on a piece

¹ *Precipitated Chalk* by A. P. Wilson (Birmingham: John & E. Sturge, Ltd., 1933.)

² This may require to be found by a series of preliminary tests.

of white paper and using daylight from a window with a north aspect, or "artificial daylight" from a properly corrected lamp.

(iv) *Solubility* is determined by pouring 50 c.c. of 40 per cent. hydrochloric acid onto 20 gm. of the chalk in a 400 c.c. conical beaker and, after one minute, a further 50 c.c. of the acid. No stirring or agitation is permissible. The object of adding the acid in two portions is to facilitate the observation of any dark, greasy film which would be formed if tar compounds are present. After all the chalk has dissolved, the liquid should be bright, sparkling, and free from suspended matter and dark particles.

(v) *Alkalinity (free lime)* is detected by pouring 20 c.c. of phenolphthalein solution onto a little of the chalk in a porcelain basin. If free lime is present a pink colour will be produced.

(vi) *Lead* may be determined on 2 gm. by adding hydrochloric acid in slight excess, boiling to remove carbon dioxide, cooling, adding sodium sulphide, and comparing the black colour (if any) with that produced by the same reagents and a standard solution of lead acetate. The test is improved if the acid solution is placed in a separating funnel, 0.5 c.c. of concentrated nitric acid, 5 c.c. of 20 per cent. solution of ammonium thiocyanate, and 30 c.c. of a mixture of equal volumes of amyl alcohol and methylated ether are added. The aqueous liquid is then run into a Nessler tube and tested with sodium sulphide.

ARTIFICIAL CHALK

The term "artificial chalk" is occasionally applied to calcium carbonate obtained as a by-product by one of the methods described in the preceding section.

BLACK CHALK OR SPANISH CHALK

Black chalk or Spanish chalk is not a lime compound, but a dark coloured shale rich in carbonaceous matter.

Artificial black chalk is made by mixing calcium carbonate with lamp-black, with an organic dye, or with a decoction of logwood, solution of ferrous sulphate (green vitriol) and sufficient glue to enable the mixture to be shaped.

ATOMIZED LIME

Atomized lime is a term used for lime which has been very finely ground, but it is also applied to limestone or chalk in a powdered form, though not so fine as might be supposed from the term "atomized." A mixture of limestone and lime both reduced to powder and corresponding to a basic carbonate is also sold as "atomized lime."

LIMESTONE FLOUR

Limestone-flour is the finest dust obtainable by grinding limestone. It ought to pass completely through a 100-mesh sieve, but sometimes includes coarser material. In general a limestone flour that will successfully meet the

requirements of fillers of a type like whiting or china clay should approximate 300-mesh size. Few limestone quarries have the equipment for grinding or sizing to this degree of fineness, and, therefore, have not been able to utilize this promising field of application.

TECHNICAL CARBONATE

Technical carbonate is a term applied to a basic magnesium carbonate prepared from dolomite or other magnesian limestone. The stone is mixed with coke and calcined so as to convert it into lime, the carbon dioxide gas being collected. The calcined material is then slaked in water and carbon dioxide gas is passed through it until almost-all the magnesia has been converted into basic carbonate and dissolved. The treatment must not be unduly prolonged or calcium bicarbonate will also be formed. The liquor is filtered and then consists chiefly of basic magnesium bicarbonate, which, on heating, loses carbon dioxide and is precipitated as the basic carbonate ($4\text{MgCO}_3 \cdot \text{Mg}(\text{OH})_2 \cdot 5\text{H}_2\text{O}$) which is separated and dried.

Technical carbonate is largely used for heat insulation and, when mixed with asbestos fibre, for this and other purposes. The asbestos mixture is known as "85 per cent. magnesia."

PRODUCTS WITH REGISTERED NAMES

Some manufacturers appear to find it preferable to employ registered names for the calcium carbonate they offer for sale, and this has the further advantage of ensuring the customer obtaining the material from a particular firm. Whether a user of calcium carbonate is wise in specifying a particular make of this substance by the use of a registered name instead of buying a similar material under its usual name of chalk, ground limestone, lime-mud, calcium carbonate, etc., is open to question. In any case, a user ought to know that some of the substances sold under various registered names are indistinguishable from calcium carbonate obtained in other ways, the latter being sometimes sold at a much lower price.

Probably the best purpose by which a registered name serves the user is to enable him to ensure getting a material of the nature he desires, whereas if he inquires for "calcium carbonate" or "chalk," he may receive a material which is unsuitable for his purpose.

LIMESTONE MIXTURES

Mixtures of limestone with other materials are used as poultry-meals, fertilizers, etc. The limestone (or chalk) is usually added in order to facilitate the grinding of bones, dried fish, or other materials which do not, alone, readily produce a uniform powder, though the neutralism and other properties possessed by the limestone are often valuable. Such mixtures are usually made in a bar- or hammer-disintegrator (p. 136) the grinding and mixing being effected simultaneously.

When ground materials have to be mixed a revolving pan mill (p. 139) with scrapers but no edge runners is very useful unless the material is very dusty; in that case a closed mixer, consisting of a horizontal cylinder with rotating blades, is preferable.

PURIFYING LIMESTONE AND CHALK

Sufficiently pure limestone is obtainable in such enormous quantities in various parts of the country that it seldom pays to attempt to purify low grade stone. In out-of-the-way localities, where the limestone beds are thin or where intrusions of foreign material are abundant, it sometimes pays to crush the stone and then wash it on a screen or in a contra-flow washer, in order to carry away earth and other foreign matter. Such treatment is costly (about 3s. per ton) if it is to be effective—otherwise it is useless—and it is, for that reason, seldom employed.

Where a limestone contains thin beds of clay or sand from which it cannot easily be separated during the quarrying, a simple method of cleaning consists in drying the mixture and then screening it so as to separate all the material less than $\frac{1}{8}$ -in. diameter. This fine material will contain practically all the clay and sand. If it cannot be sold, it must be tipped where it can do no harm. If there is a market for ground stone it may pay to wash the fine material in order to recover the stone, but usually it is cheaper to grind the coarser stone which has been freed from clay, etc., by screening.

Chalk is usually contaminated with flints, which can be separated by screening, though where a fine product is required it is better to wash the chalk. The wash mill usually consists of an annular tank, about 15 ft. wide and 3 ft.—4 ft. deep internally, made by excavating the ground, and lining with concrete, or preferably with blue engineering blocks. In the centre of the tank is an upright which supports a beam carrying at each end a broad-tyred spiked wheel, about 3 ft. diameter. The beam is rotated by means of a belt and pulley from an engine (formerly by a horse) so that when the mill is filled with equal quantities of chalk and water a slurry or cream is formed. It is necessary for the drive to be very elastic, as the wheels ride on top of the chalk and gradually sink as the latter is reduced to slurry.

An alternative method is to suspend a heavy spiked roller, by chains, from one end of the beam and to provide a harrow or agitator (consisting of a number of vertical blades, forming part of a square framework, and also suspended by chains) on the other end of the beam.

When the greater part of the chalk is suspended in the water a slide in the periphery of the tank is opened and the slurry is allowed to flow through a strainer or screen to a settling tank. The mill is then re-charged with chalk and water and the mixing operation repeated. After a sufficiently large quantity of flints and hard lumps of chalk has accumulated in the mill they are removed by digging.

Various attempts have been made to render these wash mills continuous in action, but they have not been satisfactory, and are usually very wasteful,

owing to the large quantity of chalk which adheres to the flints, etc., when automatic emptying devices—such as elevators—are employed.

In some works, the chalk is “washed” by treating it with water in a pan mill fitted with light runners and running the charge through a fine screen into a settling tank. This arrangement is the same in principle as the wash mill just described, but is liable to grind the flints and so to introduce silica into the chalk.

QUARRY WASTE

Some of the material which has to be removed in quarrying appears to have no commercial value, and when that is definitely the case it may rightly be regarded as *waste*. In most quarries, however, a large proportion of the material set aside as waste can be turned into a saleable product, thereby eliminating a serious amount of expense and bringing in a new source of revenue. The wasteful methods of quarrying which have been so plentiful in the past are no longer profitable, and with the advent of more machinery it is possible to make much more use of the various products. At the same time, the development on a very large scale increases the problem of the utilization of waste and demands closer supervision and greater ingenuity in creating a market for stone of sizes which are not in regular demand.

The term “quarry waste” is often applied to stone which is not used at the quarry where it occurs, but such material is not necessarily waste. On the contrary, much of it can be utilized after careful screening (sometimes accompanied by washing) and after inquiries as to purposes for which it can be used. Before a material is discarded an investigation should be made as to the profits to be derived from one or more of the following uses :

- (a) For filling and embankments—almost any kind of material except clay is suitable.
- (b) For coated limestone (roadstone) ; this only applies to pieces of stone of suitable size and hardness.
- (c) As a fluxing stone in blast-furnaces ; pieces larger than 1 in. diameter are required.
- (d) As an aggregate for concrete ; the pieces must be clean.
- (e) For agricultural purposes ; the material being ground to powder before use ; a fairly pure calcium carbonate is required.
- (f) As a filler and a substitute for whiting ; a very clean, white stone, ground to a very fine powder, is usually stipulated.
- (g) For making hydrated lime ; if the pieces are small a rotary kiln is essential.

Further particulars will be found in the next chapter.

Is it scarcely too much to expect that in a few years' time none of the quarried stone, now regarded as “waste,” will be sent to the spoil-banks, but that it will be made use of for various purposes? In some districts, even the clay-seams between the limestone-beds can be profitably converted into bricks!

COATED LIMESTONE

For several purposes, but particularly in the construction of roads and pavements, limestone coated with tar, bitumen, or equivalent material is extensively used. In order to secure adequate adhesion between the stone and the coating material it is essential that :

- (i) The stone must be dry and free from loose dust or clay.¹
- (ii) The coating material (or *Binder*) must be of suitable viscosity and adhesiveness and must be applied at a suitable temperature.
- (iii) When the stone is in use, the coating must not be brittle or it will break off, and it must not be too soft or it will wear away too rapidly.

Many artificially prepared materials are used for coating limestone, but tar and bitumen are the most extensively employed. They are heated sufficiently to render them fluid and mobile, the stone (previously crushed and graded to pieces of suitable size) is then added, and the whole mixed by prolonged mechanical stirring, the temperature being maintained as constant as possible. The best known of the coated limestones include *Tarmacadam*, *Asphalt*, *Asphalt Macadam*, and many products with registered names.

TARMACADAM

The term *tarmacadam* (*tarmac*) is applied to any road-stones which have been coated with tar, the proportions required depending partly on the nature of the stone and partly on the size of the pieces. Suitable proportions are :

TABLE XVII.—*Proportions of Limestone and Tar for Tarmacadam*

Limestone	Tar
2½-in. pieces	9 gall. per ton
1½-in. „	12 „ „ „
¾-in. „	14 „ „ „
⅜-in. „	16 „ „ „

The stone must be dry and preferably at a temperature of about 116° C. (240° F.) and the tar should be at the same temperature. Over-heated stone will be too thinly coated with tar.

ASPHALT

Natural Asphalt is a limestone impregnated with bitumen. It does not occur in the British Isles, but is imported from France, Italy, Sicily, etc. The rock is reduced to powder in a disintegrator and just previous to use the powder is heated, with constant stirring, to a temperature of 138–177° C. (280–350° F.) and can then be easily spread. It is afterwards compacted by heated tamping irons or *punners* and the surface is finished by hot smoothing irons.

¹ Instead of drying, an emulsifying agent, such as creosote, may be used (see p. 119).

Mastic Asphalt is made by mechanically mixing powdered limestone and bitumen in suitable proportions, the mixing being effected at a temperature of about 180° C. (356° F.) and casting the product into blocks of about 55 lb. each. The proportion of bitumen required varies with the stone and the purpose for which the material is to be used; about 10–20 per cent. of the weight of the limestone is generally employed.

ASPHALT MACADAM

Asphalt macadam is composed of

Limestone ($\frac{1}{4}$ – $1\frac{1}{2}$ in.)	...	...	80 per cent.
Sand ($\frac{1}{8}$ -in.-dust)	...	...	14 „ „
Bitumen	...	...	6 „ „

but the proportions may be varied to suit local conditions.

For “topping” the proportions may advantageously be:

Limestone passing 10 mesh	...	1 per cent.
„ „ 20 „	...	3 „ „
„ „ 30 „	...	3 „ „
„ „ 40 „	...	7 „ „
„ „ 50 „	...	31 „ „
„ „ 80 „	...	10 „ „
„ „ 100 „	...	15 „ „
„ „ 200 „	...	15 „ „
Bitumen	...	15 „ „

Both forms are made in a similar manner to Mastic Asphalt.

SUPPLIERS OF MACHINERY AND APPLIANCES

As it is impossible, in the space available, to illustrate or describe every machine or other article made by different firms, the following list is printed to facilitate further inquiries. It is not complete, because some firms may have been unintentionally omitted, nor does it mention suppliers of articles which can readily be obtained with a minimum of inquiry. The list is also limited to appliances of which the author has had personal experience.

ABRASIVES, STEEL GRIT, ETC. (*see also* DIAMONDS *and* SAWS)

Bramley Engineering Co. Ltd., Stourton Works, Hunslet, Leeds.

Harrison Bros. (England) Ltd., Atlas Foundry, Middlesbrough.

King, T. A., & Co., Hereford.

Lloyd, J. D., & Sons, Aberayron, Cardiganshire.

McEwan, Denby & Hart-Briggs, Ltd., Turret Works, Sunbury-on-Thames.

AIR-COMPRESSORS, PNEUMATIC DRILLS (*see* p. 100)

AIR HEATERS FOR DRYERS

Green, E., & Son, Ltd., Wakefield.
 Heenan & Froude, Ltd., 3 Chapel Walks, Manchester.
 Howden, James, & Co. Ltd., 195 Scotland Street, Glasgow.
 Howden-Ljungström Preheaters, Ltd., Caxton House, London, S.W.1.
 Incandescent Heat Co. Ltd., 16 Grosvenor Place, London, S.W.1.
 Musgrave & Co. Ltd., St. Ann's Ironworks, Belfast.
 Potter, F. W., & Soar, Ltd., Phipp Street, Great Eastern Street, London, E.C.2.
 Royles, Ltd., Irlam, near Manchester.
 Sturtevant Engineering Co. Ltd., 147 Queen Victoria Street, London, E.C.4.
 Sutcliffe, Speakman & Co. Ltd., Leigh, Lancs.
 Sutcliffe Ventilating & Drying Co. Ltd., Manchester.
 Visco Engineering Co. Ltd., Stafford Road, Croydon.

AIR SEPARATORS (*see also* DUST COLLECTORS)

Allen, Edgar, & Co. Ltd., Sheffield, 9.
 British, The, Rema Manufacturing Co. Ltd., Wellsby Works, Halifax.
 Mining & Industrial Equipment, Ltd., Aldwych House, Aldwych, London, W.C.2.
 Richardson & Co., Magnet Works, Walsall.
 Robinson, T., & Sons, Ltd., Rochdale.
 Standard & Pochin Bros. Ltd., Leicester.
 Sturtevant Engineering Co. Ltd., 147 Queen Victoria Street, London, E.C.4.

ASPHALT, BITUMINOUS AND ALLIED MATERIALS

ASPHALT AND BITUMINOUS MATERIALS :

A.B.C. Construction Co., 7-9 St. James's Street, London, S.W.1.
 Anglo-American Asphalte Co. Ltd., Windsor House, Kingsway, London, W.C.2.
 Anglo-Cuban Asphalt & Bitumen Ltd., 4 London Wall Buildings, London, E.C.2.
 Associated Asphalt Co. Ltd., St. Stephen's House, London, S.W.1.
 Baldry, Yerburch & Hutchinson (Roads) Ltd., 72-74 Victoria Street, London, S.W.1.
 Bannister, Ed., & Co. Ltd., Grimsby.
 Bathgate, A., & Sons, Ltd., 5 Castle Street, Liverpool.
 Berry, Wiggins & Co. Ltd., Tensulam House, Water Lane, London, E.15.
 Bimoid, Ltd., 324 Gray's Inn Road, London, W.C.1.
 Bitumen & Asphalt Co. Ltd., 36 Camomile Street, London, E.C.3.
 Bituminous Road Products, Borough Road East, Middlesbrough.
 Bradshaw & Co. (Asphalters) Ltd., 88 Fitzwarren Street, Manchester.
 Briggs, Wm., & Sons, Ltd., 5 Cowgate, Dundee.
 Bright's Asphalt Contractors, Ltd., 2 Norfolk Street, Strand, London, W.C.2.
 British Calol Asphalt Ltd., Victoria Station House, London, S.W.1.

- Brookes Chemicals Ltd., Lightcliffe Works, Halifax.
Chittenden & Simmons, Ltd., Bank Buildings, Maidstone, Kent.
Cleveland Slag Roads, Ltd., Grangetown, Yorks.
Colas Products, Ltd., Colas House, Buckingham Gate, London, S.W.1.
Colbit Road Spray, Ltd., Fairfield, Manchester.
Constable, Hart & Co. Ltd., Broadway Buildings, Broadway, Westminster,
London, S.W.1.
Dammanin Asphalt Co. (Great Britain) Ltd., 76 Victoria Street, London,
S.W.1.
Davies Bros. (Asphalters) Ltd., 36 Green Lane, Brook Street, Manchester.
Ebano Oil Co. Ltd., 15 Waterloo Place, London, S.W.1.
European Amiesite Ltd., St. Stephen's House, London, S.W.1.
Fox, Stockell & Co., 61 St. Mary Axe, London, E.C.3.
Gatty Saunt & Co., 36-38 Victoria Street, London, S.W.1.
Grimwood & De Geus Ltd., 24 Eastcheap, London, E.C.3.
Highways Construction Ltd., Iddesleigh House, Caxton Street, Westminster,
London, S.W.1.
Improved Road Construction, Ltd., 20 Saville Row, Newcastle-on-Tyne.
Keys, W. H., Ltd., Hall End Works, West Bromwich.
Limmer & Trinidad Lake Asphalt Co. Ltd., Victoria Street, London, S.W.1.
Locan & Rawlinson, Ltd., 89 Fountain Street, Manchester.
Mathews, Ernest, & Co., Clare House, Kingsway, London, S.W.1.
Neuchatel Asphalte Co. Ltd., 58 Victoria Street, London, S.W.1.
Pollard, Ravenscroft & Co. Ltd., 150 Southampton Row, London, W.C.1.
Premier Bitumen & Asphalte Co. Ltd., Stratford Market, London, E.15.
Previte (Trinidad Bitumen) Ltd., Winchester House, Old Broad Street, London,
E.C.2.
Prices Patent Candle Co. Ltd., Battersea, London, S.W.11.
Richards, A. H., Port Penrhyn, Bangor, North Wales.
Roberts, Thomas, & Co., 23 Queen Anne's Gate, London, S.W.1.
Rocmac, Ltd., Balm Road, Hunslet, Leeds.
Shell-Mex, Ltd., Shell Corner, Kingsway, London, W.C.2.
Shepherd, William, & Sons, Ltd., Milkstone, Rochdale.
Smith's Executors, Richard, Ltd., 182 West Street, Glasgow, C.5.
Steves' Emulsions, Ltd., St. Stephen's House, Westminster, London, S.W.1.
Stonehouse, M. J., Ltd., High Street, Cardiff.
Tar Distilleries, Ltd., 44 Grosvenor Place, London, S.W.1.
Tarfroid, Ltd., 69 Victoria Street, London, S.W.1.
Texas Oil Co. Ltd., 125-130 Strand, London, W.C.2.
Tunstalls Seyssel & Limmer Rock Asphalte Co. Ltd., Crown Point Bridge,
Leeds.
Unaphalte (Roads) Ltd., 20 Buckingham Street, London, W.C.2.
Val De Travers Asphalte Paving Co. Ltd., 106 Salisbury House, Finsbury Circus,
London, E.C.2.
Wimpey, George, & Co. Ltd., The Grove, Hammersmith, London, W.6.

TAR AND TAR COMPOUNDS :

- Anglo-American Asphalte Co. Ltd., Windsor House, Kingsway, London, W.C.2.
- Anglo-Scottish Chemical Co. Ltd., 20 Renfield Street, Glasgow, C.2.
- Ashton & Holmes, Ltd., Sutton Sidings, Macclesfield.
- Box, Norman E., Rusholme Road, Ardwick Green, Manchester.
- Briggs, William, & Sons, Ltd., 5 Cowgate, Dundee.
- Bristowes Tarvia Ltd., Thames House, Millbank, London, S.W.1.
- British Road Tar Association, 17 Grosvenor Gardens, London, S.W.1.
- British Tarspraying Ltd., Greek Street Chambers, Leeds.
- Brookes Ltd., 65 Victoria Street, London, S.W.1.
- Brookes Chemicals, Ltd., Lightcliffe Works, Halifax.
- Brotherton & Co. Ltd., City Chambers, Leeds.
- Burt, Boulton & Haywood Ltd., Salisbury House, London Wall, London, E.C.2.
- Clare, R. S., & Co. Ltd., Stanhope Street, Liverpool.
- Coal Products & Derivatives, Ltd., 301 Glossop Road, Sheffield.
- Crow, Catchpole & Co. Ltd., Aldwych House, Aldwych, London, W.C.2.
- Dorman, Long & Co. Ltd., Coke Oven and By-products Department, Middlesbrough.
- Gas Light & Coke Co. Ltd., Dauntsey House, Frederick's Place, Old Jewry, London, E.C.2.
- Hardman & Houlden, Ltd., Miles Platting, Manchester.
- Hartington Quarries, Ltd., 1 Exeter Street, Rochdale.
- Marley Hill Chemical Co. Ltd., Milburn House, Newcastle-on-Tyne.
- Mechanical Tar Spraying & Grouting Co. Ltd., 118 Victoria Street, London, S.W.1.
- Midland Tar Distillers, Ltd., Stephenson Place, Birmingham, 2.
- New Northern Quarries, Ltd., Grange-over-Sands, Lancs.
- Newton, Chambers & Co. Ltd., Thorncliffe, Nr. Sheffield.
- Peak, John, & Co. Ltd., Wigan.
- Phillips, J. Sadler, & Co. Ltd., 39 Victoria Street, London, S.W.1.
- Plascom (1909) Ltd., 246 Willenhall Road, Wolverhampton.
- Powell Duffryn Steam Coal Co. Ltd., Great Tower Street, London, E.C.2.
- Prestwich, Wm., & Sons, Ltd., Irlam, Nr. Manchester.
- Rainford Tar Products, Ltd., Rainford Works, Rainford, Lancs.
- Royse, Sir S. W., & Co. Ltd., 20 Albert Square, Manchester.
- Sadler & Co. Ltd., Middlesbrough.
- Scottish Tar Distillers, Ltd., Falkirk.
- Shepherd, Wm., & Sons, Ltd., 29 Milkstone, Rochdale.
- Smith, H. V., & Co. Ltd., 256 Westminster Bridge Road, London, S.E.1.
- Smithie, W. C., & Co., Farnworth, Nr. Bolton.
- South Metropolitan Gas Co., 709 Old Kent Road, London, S.E.15.
- South Western Tar Distilleries, 478 Salisbury House, London Wall, London, E.C.2.

Stonhouse, M. J., Ltd., High Street, Cardiff.
 Tar Distilleries, Ltd., 44 Grosvenor Place, London, S.W.1
 Tarfroid, Ltd., 69 Victoria Street, London, S.W.1.
 Tarmac, Ltd., Ettingshall, Wolverhampton.
 Tarphalte, Ltd., Brettenham House, Lancaster Place, London, W.C.2.
 Tarslag (1923) Ltd., 16 Queen Anne's Chambers, Wolverhampton.
 United Coke & Chemical Co. Ltd., Moss Bay, Workington.
 Wainwright, J., & Co. Ltd., 173 Marylebone Road, London, N.W.1.
 Welsh Navigation Steam Coal Co. Ltd., Coke Oven Offices, Ton-yr-Efail,
 Glamorgan.
 Yorkshire Road Tar Binders, Ltd., 26 Park Row, Leeds.
 Yorkshire Tar Distilleries, Ltd., Quebec House, Leeds.

EMULSIONS :

Bimoid, Ltd., 324 Gray's Inn Road, London, W.C.1.
 Bituloid Marketing Co., Southampton House, 317 High Holborn, London, W.C.1.
 British Taroleum Co. Ltd., 83 Bridge Street, Manchester.
 Brookes Chemicals, Ltd., Lightcliffe Works, Halifax.
 Clare, R. S., & Co. Ltd., Stanhope Street, Liverpool.
 Dorman, Long & Co. Ltd., Coke Oven and By-products Department, Middles-
 brough.
 Fox, Stockell & Co., St. Mary Axe, London, E.C.3.
 Hancock, C. C., & Co., 243 Abbey House, Victoria Street, London, S.W.1.
 Highways Colloidal, Ltd., 70 Victoria Street, London, S.W.1.
 Hockley, J. T., St. Peter's Hill, Grantham.
 Luxton, A. M., & Co. Ltd., 3 North Street, Wilton, Wilts.
 McCreath, Taylor & Co. Ltd., 30 Jamaica Street, Glasgow, C.1.
 Midland Tar Distillers, Ltd., Stephenson Place, Birmingham, 2.
 Newsome, Arthur, Ltd., Burley-in-Wharfedale.
 Peak, John, & Co. Ltd., Wigan.
 Phillips, J. Sadler, & Co. Ltd., 39 Victoria Street, London, S.W.1.
 Scottish Tar Distillers, Ltd., Falkirk.
 Smith's Executors, Richard, Ltd., 182 West Street, Glasgow, C.5.

ASPHALT-COATING PLANT (*see* STONE-COATING PLANT)BAGS (*see* SACKS)

BAGGING MACHINES

International Crushing & Grinding Equipment, Ltd., 34 Victoria Street,
 London, S.W.1.
 McEwan, James, & Co. Ltd., Evelyn House, 101 Finsbury Pavement, London,
 E.C.2.
 Paper Sacks, Ltd., Norwich House, Southampton Street, High Holborn,
 London, W.C.1.
 Pneumatic Scale Corporation, Ltd., Trafalgar Buildings, 1 Charing Cross,
 London, S.W.1.

- Rapid Packer, The, Co. Ltd., Shipham, Winscombe, Somerset.
 Sack-Filling & Sewing Machine Syndicate, The, Ltd., Kenmure Yard, London,
 E.8.
 Simon, Richard, & Sons, Ltd., Nottingham.
 Smidth, F. L., & Co. Ltd., Victoria Station House, Victoria Street, London,
 S.W.1.
 Valve Bag Co. of America, Toledo, Ohio, U.S.A.

BARROWS (*see* p. 101)

BELTS

- Angus, G., & Co. Ltd., Newcastle-on-Tyne.
 Attwater & Sons, Hopwood Street Mill, Preston.
 Barrow, Hepburn & Gale, Ltd., Grange Mills, Grange Road, Bermondsey,
 London, S.E.1.
 Dawson, James & Son, Ltd., Boultham Works, Lincoln.
 Dermatine Company, Ltd., Neate Street, London, S.E.5.
 Dexine, Ltd., 107 Abbey Lane, Stratford, London, E.15.
 Fleming, Birkby & Goodal, Ltd., Broad Street Place, London, E.C.2.
 Gandy Belt Manufacturing Co. Ltd., 97 Queen Victoria Street, London, E.C.4.
 Greening, N., & Sons, Ltd., Britannia Works, Warrington.
 Harris, Francis, & Co. Ltd., Burslem, Stoke-on-Trent.
 Hebblethwaite Bros. Ltd., Huddersfield.
 Hendry, James, Ltd., 252 Main Street, Bridgeton, Glasgow.
 Henley's W. T., Telegraph Works Co. Ltd., 11 Holborn Viaduct, London, E.C.1.
 India Rubber, Gutta Percha, & Telegraph Works Co. Ltd., 106 Cannon Street,
 London, E.C.4.
 Lewis & Tylor, Ltd., Gripoly Mills, Cardiff.
 Leyland & Birmingham Rubber Co. Ltd., Leyland, near Preston.
 Reddaway, F., & Co. Ltd., Pendleton, Manchester.
 Renton, Holdsworth & Co. Ltd., Sheffield.
 Tullis, John, & Son, Ltd., St. Ann's Leather Works, Glasgow.
 Walker, James, & Co. Ltd., Lion Works, Maybury Hill, Woking, Surrey.
 Walker, Wm., & Sons, Ltd., Bolton, Lancs.
 Watkinson, F., Ltd., Halifax.
 Willcox, W. H., & Co. Ltd., 32-38 Southwark Street, London, S.E.1.
 Woodite Company Ltd., Mitcham Common, Surrey.

BITUMEN AND ALLIED MATERIALS FOR COATING STONE

(*see* ASPHALT, BITUMINOUS AND ALLIED MATERIALS)

BITUMEN-COATING PLANT (*see* STONE-COATING PLANT)

BOILERS (TAR AND BITUMEN) (*see also* STONE-COATING PLANT)

Braham, Patterson & Benham, Ltd., Grenade Street, Limehouse, London, E.14.
 Bristowes Machinery Ltd., Montagu Road, London, N.18.
 Clarmac Engineering Co. Ltd., Port Dundas, Glasgow, C.4.
 Coleman, Thomas, & Sons, Alfreton Road, Derby.
 Croggon & Co. Ltd., 230 Upper Thames Street, London, E.C.4.
 F.W.D. Lorry Co. Ltd., 46 Charing Cross, London, S.W.1.
 Goodwin, Barsby & Co. Ltd., St. Margaret's Ironworks, Leicester.
 Johnston Bros., London House, Crutched Friars, London, E.C.3.
 Kilmarnock Engineering Co. Ltd., Britannia-Engineering Works, Kilmarnock.
 Marsden, H. R., Ltd., Meadow Road, Leeds.
 Marshall, Sons & Co. Ltd., Britannia Iron Works, Gainsborough.
 Municipal Appliances Co., Bamber Bridge, Preston, Lancashire.
 Phoenix Engineering Co. Ltd., Chard, Somerset.
 Shields & Whittaker, Ltd., Ffinch Street, Deptford, London, S.E.8.
 Smith, Wm., & Sons, Grove Works, Barnard Castle.
 Theedam, E. C., Ltd., Dudley, Worcs.
 Weeks, W., & Son, Ltd., Perseverance Iron Works, Maidstone.

BREAKERS (*see* CRUSHERS)

CARVING MACHINES (FOR STONE)

Anderson-Grice, The, Co. Ltd., Carnoustie, Scotland.
 Bramley Engineering Co. Ltd., Hunslet, Leeds.

CEMENT

Alpha Cement, Ltd., Shipton-on-Cherwell, Kidlington, Oxford.
 Barnstone Cement Co. Ltd., Barnstone, Nr. Nottingham.
 Beynon, T., & Co. Ltd., Merthyr House, Cardiff.
 Board, John, & Co. Ltd., Dunball, Bridgwater.
 British Standard Cement Co. Ltd., Grand Buildings, Northumberland Avenue,
 London, W.C.2.
 Broad & Co. Ltd., 4 South Wharf, Paddington, London, W.2.
 Casebourne & Co. (1926) Ltd., Billingham, Stockton-on-Tees.
 Cawood, G. R., & Co. Ltd., 1 Cavendish Road, Leeds.
 Cement Marketing Co. Ltd., Portland House, Tothill Street, London, S.W.1.
 Chinnor Cement & Lime Co., Chinnor, Oxfordshire.
 Contract & Works Supply Co., Sutton-on-Sea, Lincs.
 Corry, James P., & Co. Ltd., Talbot Street, Belfast.
 Earle, G. & T., Ltd., Hull.
 East Anglican Cement Co. Ltd., 4 Tenison Avenue, Cambridge.
 Eastwoods, Ltd., 47 Belvedere Road, London, S.E.1.
 Kaye & Co. Ltd., Southam Works, Rugby.
 Lafarge Aluminous Cement Co. Ltd., 296-302 High Holborn, London, W.C.1.

Portland Cement Selling & Distributing Co. Ltd., Grand Buildings, Northumberland Avenue, London, W.C.2.

Sankey, J. H., & Sons, Ltd., 7-8 Norfolk Street, Strand, London, W.C.2.

Sellars Cements, Ltd., Fairfield, Manchester.

COATING PLANTS (*see* STONE-COATING PLANTS)

CONTAINERS (*see* DRUMS AND CONTAINERS)

CONVEYORS (*see* p. 101)

CRUSHERS AND GRANULATORS (*see also* GRINDING MILLS)

Alexander, Herbert, & Co. Ltd., Charmouth Street, Leeds.

Allen, Edgar, & Co. Ltd., Imperial Steel Works, Sheffield.

Baxter, W. H., Ltd., Leeds.

Bradley Pulverizer Co., 37 Walbrook, London, E.C.4.

Bramley Engineering Co. Ltd., Stourton Works, Hunslet, Leeds.

Brealey, W., & Co. Ltd., Hawksley Avenue, Hillsborough, Sheffield.

Bristowes Machinery, Ltd., Montagu Road, London, N.18.

British & Foreign Machinery Co. Ltd., 148 Leadenhall Street, London, E.C.3.

British Jeffrey Diamond Ltd., Stennard Works, Wakefield.

Broadbent, R., & Son, Ltd., Stalybridge.

Christy & Norris, Ltd., Chelmsford.

End Runner Mills Co. Ltd., Ashbourne, Derbyshire.

Fawcett, J. Dawson (Darlington), Ltd. Darlington.

Fletcher, George, & Co. Ltd., Derby.

Fraser & Chalmers Engineering Works, Erith, Kent.

Goodwin, Barsby & Co. Ltd., St. Margaret's Iron Works, Leicester.

Hadfields, Ltd., East Hecla Works, Sheffield.

Head, Wrightson & Co. Ltd., Thornaby-on-Tees.

Henderson, J. M., & Co. Ltd., Aberdeen.

Johnson, Wm., & Sons (Leeds) Ltd., Armley, Leeds.

Kennedy-Van-Saun Manufacturing & Eng. Corporation, Room 442 Bush House, Aldwych, London, W.C.2.

Krupp, Fried., Grusonwerk, A-G, Magdeburg-Buckau.

Mansfield, Frank, & Co., 9 Redcross Street, Liverpool.

Marsden, H. R., Ltd., Soho Foundry, Leeds.

Mason Bros., Brandon Street, Leicester.

Mayhew, Ramsay & Co. Ltd., 90 Lots Road, London, S.W.10.

Millars' Machinery Co. Ltd., Pinners Hall, London, E.C.2.

Mining & Industrial Equipment Ltd., Aldwych House, Aldwych, London, W.C.2.

Newell, Ernest, & Co. Ltd., Misterton, via Doncaster.

Nordberg Manufacturing Co., Bush House, Strand, London, W.C.2.

Parker, F., Ltd., Viaduct Works, Catherine Street, Leicester.

Patent Lightning Crusher Co. Ltd., Rosebery Avenue, London, E.C.1.
 Pegson, Ltd., Coalville, Leicestershire.
 Pragos Engineering Co. Ltd., 351 Brixton Road, London, S.W.9.
 Rexman Mill Co. Ltd., 11 Queen Anne's Gate, London, S.W.1.
 Richter & Pickis, 6 Crescent, Minorities, London, E.C.3.
 Robey & Co. Ltd., Lincoln.
 Sandycroft Ltd., 4 Broad Street Place, London, E.C.2.
 Sawyer-Massey Ltd., Hamilton, Canada.
 Scholefield, R., Burley Vale Works, Kirkstall Road, Leeds.
 Sheepbridge Coal & Iron Co. Ltd., Chesterfield.
 Smidth, F. L., & Co. Ltd., Victoria Station House, Victoria Street, London
 S.W.1.
 Sturtevant Engineering Co. Ltd., 147 Queen Victoria Street, London, E.C.4.
 Sykes, Henry, Ltd., Southwark Street, London, S.E.1.
 Ward, Thos. W., Ltd., Savile Street, Sheffield.
 Winget, Ltd., Rochester.
 Wood, Hugh, & Co. Ltd., Newcastle-on-Tyne.

CRUSHING ROLLS

Alexander, H., & Co. Ltd., Charmouth Street, Leeds.
 Baker, Perkins, Ltd., Peterborough.
 Bennett & Sayer, Ltd., Derby.
 Bradley & Craven Ltd., Wakefield.
 Brightside Foundry & Engineering Co. Ltd., Sheffield.
 Buchanan, J. B., & Son (Liverpool), Ltd., Liverpool.
 Fawcett, J. Dawson (Darlington), Ltd., Haughton Engineering Works, Darlington
 Fawcett, Thos. C., Ltd., Hunslet Road, Leeds.
 Goodwin, Barsby, & Co. Ltd., Leicester.
 Hardypick Ltd., Sheffield.
 Johnson, Wm., & Sons (Leeds) Ltd., Armley, Leeds.
 Marshall, Sons & Co. Ltd., Gainsborough.
 Newell, Ernest, & Co. Ltd., Misterton, via Doncaster.
 Pragos Engineering Co. Ltd., 351 Brixton Road, London, S.W.9.
 Sandycroft Ltd., 4 Broad Street Place, London, E.C.2.
 Scholefield, Richard, Burley Vale Works, Kirkstall Road, Leeds.
 Sutcliffe, Speakman & Co. Ltd., Leigh, Lancs.
 Whitehead, John, & Co. Ltd., Preston.
 Whittaker, C., & Co. Ltd., Accrington.

CYCLONES (*see* AIR SEPARATORS and DUST COLLECTORS)

DIAMONDS

Anderson-Grice Co. Ltd., The, Carnoustie, Scotland.
 Bramley Engineering Co. Ltd., The, Stourton Works, Hunslet, Leeds.

DISINTEGRATORS

Alexander, Herbert, & Co. Ltd., Charmouth Street, Leeds.
 Allen, Edgar, & Co. Ltd., Imperial Steel Works, Sheffield, 9.
 Barrow, W. S., & Son, Ltd., Gloucester.
 Booth, J., & Son, Ltd., Congleton, Cheshire.¹
 Brealey, W., & Co. Ltd., Hawksley Avenue, Sheffield.
 British Jeffrey Diamond Ltd., Stennard Works, Wakefield.
 Campbell Tile Co. Ltd., Stoke-on-Trent.
 Carter, J. Harrison, Ltd., Dunstable.
 Christy & Norris, Ltd., Chelmsford.
 Crone & Taylor, Ltd., Sutton Oak, St. Helens, Lancs.
 Goodwin, Barsby, & Co. Ltd., Leicester.
 Hardypick Ltd., Sheffield.
 Mansfield, Frank, & Co., 9 Redcross Street, Liverpool.
 Mason Bros., Brandon Street, Leicester.
 Mayhew, Ramsay & Co. Ltd., 90 Lots Road, London, S.W.10.
 Parker, Frederick, Ltd., Leicester.
 Patent Lightning Crusher Co. Ltd., 14A Rosebery Avenue, London, E.C.1.
 Sturtevant Engineering Co. Ltd., 147 Queen Victoria Street, London, E.C.4.
 Wood, Hugh, & Co. Ltd., Newcastle-on-Tyne.

DRESSING MACHINES

(*see* AIR SEPARATORS, SCREENS, and STONE-WORKING MACHINERY)

DRUMS AND CONTAINERS

Drums, Ltd., 31-32 Grosvenor Place, London, S.W.1.
 Francis, F., & Sons, Ltd., Thames Ironworks, John Penn Street, London, S.E.13.
 Metal Containers, Ltd., Transport House, Smith Square, London, S.W.1.

DRYERS FOR LIMESTONE AND CHALK

Allen, John, & Sons (Oxford), Ltd., Cowley, Oxford.
 Baxter, W. H., Ltd., Gelderd Road, Leeds.
 Braham, Patterson & Benham, Ltd., Grenade Street, Limehouse, London, E.14.
 Bristowes Machinery, Ltd., Montagu Road, London, N.18.
 British Air Conditioners, Ltd., Harley Street, Blackburn.
 Bulmer, G. A., & Co., 103 Southwark Bridge Road, London, S.E.1.
 Carrier Engineering Co. Ltd., 24 Buckingham Gate, London, S.W.1.
 Fawcett, J. Dawson (Darlington) Ltd., Haughton Engineering Works, Darlington.
 Goodwin, Barsby, & Co. Ltd., St. Margaret's Ironworks, Leicester.
 Head, Wrightson, & Co. Ltd., Thornaby-on-Tees.

¹ Disintegrator and fine screen combined, Eng. Pat. 200,778.

Huntington, Heberlein & Co. Ltd., Bush House, Aldwych, London, W.C.2.
 Johnson, Wm., & Sons (Leeds) Ltd., Armley, Leeds.
 Keller (*see* Steenbrugge).
 Kilmarnock Engineering Co. Ltd., Britannia Engineering Works, Kilmarnock.
 Limmer & Trinidad Lake Asphalt Co. Ltd., Artillery House, Artillery Row,
 London, S.W.1.
 Marshall, Sons & Co. Ltd., Britannia Iron Works, Gainsborough.
 Matthews & Yates, Ltd., Swinton, Lancs.
 Millars' Machinery Co. Ltd., Pinner's Hall, London, E.C.2.
 Municipal Appliances Co., Bamber Bridge, Preston, Lancashire.
 Musgrave & Co. Ltd., Arkwright House, Manchester.
 Parker, Frederick, Ltd., Catherine Street, Leicester.
 Pegson, Ltd., Coalville, Leicestershire.
 Phoenix Engineering Co. Ltd., Chard, Somerset.
 Proctor & Schwartz (Agent : C. J. Fox & Sons, Ltd., 69 King's Cross Road,
 London, W.C.1.)
 Roadways Equipment, Ltd., 97 St. James' Road, Glasgow, C.4.
 Shields & Whittaker, Ltd., Finch Street, Deptford, London, S.E.8.
 Steenbrugge, M., & Co., 17 Queen Victoria Street, London, E.C.4.
 Stothert & Pitt, Ltd., Bath.
 Sturtevant Engineering Co. Ltd., 147 Queen Victoria Street, London, E.C.4.
 Sutcliffe Ventilating & Drying Co. Ltd., Manchester.
 Theedam, E. C., Ltd., Dudley, Worcestershire.
 Vickers, Thomas, Ltd., 14 New Street, Birmingham (*Cast-Iron Floor-Plates
 only*).
 Wake, John F., Darlington.
 Wolff (*see* Bulmer).

DUST-COLLECTORS

A. L. M. Engineering Co. Ltd., Hawthorne Road, Bootle, Liverpool.
 Dallow, Lambert & Co. Ltd., Leicester.
 Keith & Blackman, J., Co. Ltd., 27 Farringdon Avenue, London, E.C.4.
 Lodge-Cottrell, Ltd., Birmingham.
 Musgrave & Co. Ltd., Arkwright House, Manchester.
 Power-Gas Corporation, Stockton-on-Tees.
 Spencer & Halstead, Ltd., Ossett, Yorks.
 Standard & Pochin Bros. Ltd., Leicester.
 Visco Engineering Co. Ltd., Stafford Road, Croydon, Surrey.

DUST-SEPARATORS (*see* AIR-SEPARATORS)

ELEVATORS (*see* CONVEYORS AND ELEVATORS)

EMULSIONS (*see* ASPHALT AND BITUMINOUS MATERIALS)

ENGINES (*see* p. 104)

FANS

Davidson & Co. Ltd., Belfast.
 Keith & Blackman, J., Co. Ltd., 27 Farringdon Avenue, London, E.C.4.
 Matthews & Yates, Ltd., Swinton, Lancs.
 Musgrave & Co. Ltd., Arkwright House, Manchester.
 Sturtevant Engineering Co. Ltd., 147 Queen Victoria Street, London, E.C.4.

FEEDERS

Alexander, Herbert, & Co. Ltd., Charmouth Street, Leeds.
 Baker, Perkins, Ltd., Peterborough.
 Bennett & Sayer, Ltd., Derby.
 Berry & Son, St. Helens Road, Westcliff-on-Sea.
 Booth, J., & Son, Ltd., Congleton, Cheshire.
 Bradley & Craven, Ltd., Wakefield.
 Brightside Foundry & Engineering Co. Ltd., Sheffield.
 Buchanan, J. B., & Son (Liverpool) Ltd., Liverpool.
 Clayton, Goodfellow, & Co. Ltd., Blackburn.
 Farmer Bros., Castle Gresley, Burton-on-Trent.
 Fawcett, J. Dawson (Darlington) Ltd., Haughton Engineering Works,
 Darlington.
 Fawcett, Thos. C., Ltd., Hunslet Road, Leeds.
 Gardner & Sons, Ltd., Gloucester.
 Goodwin, Barsby & Co. Ltd., Leicester.
 Hardy, T., 111 Bolton Road, Edgworth.
 Herrmann, R., Ltd., 59 Marl Lane, London, E.C.3.
 Hole, E., & Son, Burgess Hill, Sussex.
 Horsham Engineering Works, Horsham, Sussex.
 International Clay Machinery Co., Dayton, Ohio, U.S.A.
 Johnson, S. H., & Co. Ltd., Stratford, London, E.15.
 Johnson, Wm., & Sons, Ltd., Armley, Leeds.
 Jones, John, & Sons, Ltd., Loughborough.
 Marsden, H. R., Ltd., Leeds.
 Monarch Co., 82 Victoria Street, London, S.W.1.
 Pragos Engineering Co. Ltd., 351 Brixton Road, London, S.W.9.
 Rawdon Foundry, Ltd., Moira, Leicestershire.
 Ross Patents, Ltd., 2 Victoria Street, London, S.W.1.
 Sampson, H., & Sons, Ltd., Malago Vale, Bristol.
 Scholefield, R., Burley Vale Works, Kirkstall Road, Leeds.
 Shenton, J. W., Edison Works, Great Bridge, Staffs.
 Société des Ateliers de Bondy, 75 Rue de la Liberté, Bondy (Seine). (Agent :
 G. Descamps, 27 King's Chambers, Angel Street, Sheffield.)
 Steenbrugge, M., & Co., 17 Queen Victoria Street, London, E.C.4.
 Swinney Bros. Ltd., Morpeth, Northumberland.
 Whitehead, John, & Co. Ltd., Albert Works, Preston.
 Whittaker, C., & Co. Ltd., Accrington.

Wills, W. & F., Ltd., Bridgwater, Somerset.
Wootton Bros. Ltd., Coalville, Nr. Leicester.

FILTERS AND FILTER CLOTHS (FOR AIR)

Harvey, G. A., & Co. (London), Ltd., Woolwich Road, London, S.E.7.
Mining & Industrial Equipment Ltd., Aldwych House, Aldwych, London,
W.C.2.
Spencer & Halstead, Ltd., Ossett, Yorks.
Visco Engineering Co. Ltd., Stafford Road, Croydon, Surrey.

FILTERS AND FILTER PRESSES (FOR LIQUIDS)

Daglish, R., & Co. Ltd., St. Helens, Lancs.
Dorr-Oliver Co. Ltd., Abford House, Wilton Road, London, S.W.1.
Johnson, S. H., & Co. Ltd., Carpenters Road, London, E.15.
Kestner Evaporator & Engineering Co. Ltd., 5 Grosvenor Gardens, London,
S.W.1.
Manlove, Alliot & Co. Ltd., Nottingham.
Premier Filter-press Co. Ltd., Finsbury Pavement House, London, E.C.2.

GRANULATORS (*see* CRUSHERS)

GRINDING MILLS

(*see also* DISINTEGRATORS, HAMMER MILLS, TUBE MILLS, etc.)

Alexander, Herbert, & Co. Ltd., Charmouth Street, Leeds.
Allen, Edgar, & Co. Ltd., Sheffield, 9.
Bennett & Sayer, Ltd., Derby.
Booth, J., & Son, Ltd., Congleton, Cheshire.
Boulton, W., Ltd., Burslem, Stoke-on-Trent.
Bradley & Craven, Ltd., Wakefield.
Bradley Pulverizer Co., 37 Walbrook, London, E.C.4.
Brealey, W., & Co. Ltd., Ecclesfield, Sheffield.
Brightside Foundry & Engineering Co. Ltd., Sheffield.
Buchanan, J. B., & Son (Liverpool), Ltd., Liverpool.
Christy & Norris, Ltd., Chelmsford.
Clayton, Goodfellow & Co. Ltd., Blackburn, Lancs.
End Runner Mills Co. Ltd., Ashbourne, Derbyshire.
Fawcett, J. Dawson (Darlington), Ltd., Haughton Engineering Works,
Darlington.
Fawcett, Thos. C., Ltd., Hunslet Road, Leeds.
Fraser & Chalmers Engineering Works, Erith, Kent.
Fuller Engineering Co., 25 Victoria Street, Westminster, London, S.W.1.
Hacfields, Ltd., Sheffield.
Johnson, Wm., & Sons (Leeds) Ltd., Armley, Leeds.

Marsden, H. R., Ltd., Leeds.

Rawdon Foundry Ltd., Moira, Leicestershire.

Rexman Mill Co. Ltd., 11 Queen Anne's Gate, London, S.W.1.

Saxon Iron & Steel Works, Stoke-on-Trent.

Sexton & R. E. Holding, Ampthill Road, Bedford.

Smedley Bros., Belper.

Sturtevant Engineering Co. Ltd., 147 Queen Victoria Street, London, E.C.4

Swinney Bros. Ltd., Morpeth, Northumberland.

Whitehead, John, & Co. Ltd., Albert Works, Preston.

Whittaker, C., & Co. Ltd., Accrington.

HAMMER MILLS (*see* DISTINTEGRATORS)

HEATERS FOR DRYERS (*see* AIR HEATERS)

HEATERS FOR TAR (*see* BOILERS FOR TAR)

JAW-BREAKERS (*see* CRUSHERS)

KNAPPERS (*see* CRUSHERS)

LIGHTING (*see* p. 106)

MACHINERY FOR WORKING STONE (*see* STONE-WORKING MACHINERY)

MIXERS (*see* STONE-COATING PLANT)

MOULDING MACHINES (*see* STONE-WORKING MACHINERY)

PERFORATED METAL AND WIRE GAUZE (for SIEVES, RIDDLES, and SCREENS)

British Wedge Wire Co. Ltd., Academy Street, Warrington.

Greening, N., & Sons, Ltd., Britannia Works, Warrington.

Hallen, A. G. A., & Co., Fulwood House, High Holborn, London, W.C.1.

Harvey, G. A., & Co. Ltd., Woolwich Road, London, S.E.7.

Locker, T., & Co. Ltd., Warrington.

Potter, F. W., & Soar, Ltd., 6 Phipp Street, London, E.C.2.

Proctor Brothers (Wireworks), Ltd., Leeds Wire Works, Call Lane, Leeds.

(*See also* SCREENS)

PLANING AND POLISHING MACHINES

(*see also* STONE-WORKING MACHINERY)

Sampson, H., & Sons, Ltd., Malago Vale, Bristol.

Willcocks & Son, Buckfastleigh, Devon.

PNEUMATIC APPLIANCES (*see* AIR COMPRESSORS)

PULVERIZERS (*see* DISINTEGRATORS)

RIDDLES (*see* SCREENS)

SACKS

Dowdings, Ltd., Little Eaton, Derby.
 Earle, G. & T., Ltd., Hull.
 Firmin & Co. Ltd., Ipswich.
 Kraft Sacks, Ltd., Clock House, Arundel Street, London, W.C.2.
 Medway Paper-Sacks, Ltd., Larkfield, Kent.
 Norwich Sack & Bag Co., Sprowston, Norwich.
 Paper Sacks, Ltd., Norwich House, Southampton Street, High Holborn,
 London, W.C.1 ; and Northfleet, Kent.
 Quilliam, Ltd., 12 College Lane, Liverpool.
 Thomas, W. K., & Co., 10 John Street, Adelphi, London, W.C.2.

SAWS (FOR STONE)

Ainley's, George E., Sons, Stocksmoor, Nr. Huddersfield.
 Anderson-Grice, The, Co. Ltd., Carnoustie, Scotland.
 Bramley Engineering, The, Co. Ltd., Hunslet, Leeds.
 Frost, Albert, & Co. Ltd., Park Grange Road, Sheffield, 2.
 Hardypick, Ltd., Heeley, Sheffield, 8.
 Harrison Bros. Ltd., Middlesbrough.
 Makin, Wm., & Sons, Attercliffe, Sheffield, 9.
 McEwan, Denby, & Hart-Briggs, Ltd., Turret Works, Sunbury-on-Thames.
 Provident Steel & Tool Co. Ltd., Brown Street, Sheffield.
 Willcocks & Son, Buckfastleigh, Devon.
 Wilson, Alex., (Aberdeen), Ltd., Aberdeen.

SCREENS, RIDDLES, AND SIEVES

Allen, Edgar, & Co. Ltd., Sheffield, 9.
 Alexander, H., & Co. Ltd., Charmouth Street, Leeds.
 Baker, Perkins, Ltd., Peterborough.
 Baxter, W. H., Ltd., Gelderd Road, Leeds.
 Bennett & Sayer, Ltd., Derby.
 Bramley Engineering, The, Co. Ltd., Stourton Works, Hunslet, Leeds.
 Brealey, W., & Co. Ltd., Hillsborough, Sheffield.
 Brightside Foundry & Engineering Co. Ltd., Sheffield.
 Bristowes Machinery, Ltd., Montagu Road, London, N.18.
 British & Foreign Machinery Co. Ltd., 149 Leadenhall Street, London, E.C.3.
 British Wedge Wire Co. Ltd., Academy Street, Warrington.
 Broadbent, Robert, & Son, Ltd., Phoenix Ironworks, Stalybridge.
 Clayton, Goodfellow & Co. Ltd., Blackburn.
 Cooch & Sons, Commercial Street, Northampton.
 Cort, Robert, & Son, Ltd., Reading Bridge Ironworks, Reading.
 Dressing & Screening Co. Ltd., 116 Victoria Street, London, S.W.1.

- Fawcett, J. Dawson (Darlington), Ltd., Haughton Engineering Works, Darlington.
- Fawcett, Thos. C., Ltd., Hunslet Road, Leeds.
- Fletcher, George, & Co., Derby.
- Fraser & Chalmers, Ltd., Erith, Kent.
- Gardner, Wm., & Sons, Ltd., Gloucester.
- Goodwin, Barsby, & Co. Ltd., St. Margaret's Iron Works, Leicester.
- Greening, N., & Sons, Ltd., Britannia Works, Warrington.
- Hadfields, Ltd., East Hecla Works, Sheffield.
- Hardy & Padmore, Ltd., Worcester.
- Harvey, G. A., & Co. (London), Ltd., Woolwich Road, London, S.E.7.
- Head, Wrightson & Co. Ltd., Thornaby-on-Tees.
- Heath & Co., 63-65 Great Jackson Street, Manchester.
- Hiscox, W. A., Ltd., Derby.
- Holman Bros., Ltd., Camborne.
- Horsmann, W. E., Sons & Co., Eveline Road, Figs Marsh, Mitcham, Surrey.
- Huntington, Heberlein & Co. Ltd., Bush House, Aldwych, London, W.C.2.
- International Combustion Ltd., Aldwych House, Aldwych, London, W.C.2.
- Johnson, C. H., & Sons (Leeds), Ltd., Smedley, Manchester.
- Johnson, Wm., & Sons, Ltd., Leeds.
- Kennedy-Van-Saun Manufacturing & Engineering Corporation, Room 442
Bush House, Aldwych, London, W.C.2.
- Liner Concrete Machinery Co., Glasshouse Bridge, Newcastle-on-Tyne.
- Locker, Thos., & Co. Ltd., Warrington.
- Marsden, H. R., Ltd., Leeds.
- Marshall, Sons, & Co. Ltd., Gainsborough.
- Millars' Machinery Co. Ltd., Pinners Hall, London, E.C.2.
- Mining and Industrial Equipment, Ltd., Aldwych House, Aldwych, London,
W.C.2.
- Newell, Ernest, & Co. Ltd., Misterton, via Doncaster.
- Nortons (Tividale) Ltd., Tipton, Staffs.
- Parker, F., Ltd., Leicester.
- Parker, Winder, & Achurch, Ltd., Broad Street, Birmingham.
- Pegson, Ltd., Coalville, Leicestershire.
- Pool, J. & F., Ltd., Hayle, Cornwall.
- Potter, F. W., & Soar, Ltd., 6 Phipp Street, London, E.C.2.
- Pragos Engineering Co. Ltd., 351 Brixton Road, London, S.W.9.
- Proctor Bros. (Wireworks) Ltd., Leeds Wire Works, Call Lane, Leeds.
- Robey & Co. Ltd., Lincoln.
- Ross Patents, Ltd., 435 Abbey House, Victoria Street, London, S.W.1.
- Sandycroft, Ltd., 4 Broad Street Place, London, E.C.2.
- Scholefield, R., Burley Vale Works, Kirkstall Road, Leeds.
- Stothert & Pitt, Ltd., Bath.
- Sunderland Engineering Co. Ltd., Pallion, Sunderland.
- Taylor, J. Darnley, & Co. Ltd., Cecil Chambers, Strand, London, W.C.2.

Whitehead, John, & Co. Ltd., Albert Works, Preston.
 Whittaker, C., & Co. Ltd., Accrington.
 Winget, Ltd., Rochester.
 Wood, Hugh, & Co. Ltd., Newcastle-on-Tyne.

SIEVES (*see* SCREENS, RIDDLES, AND SIEVES)

STONE-BREAKERS (*see* CRUSHERS)

STONE-COATING PLANT

Allen, Edgar, & Co. Ltd., Sheffield, 9.
 Aveling & Barford & Perkins (Sales) Ltd., Aldwych House, Aldwych, London,
 W.C.2.
 Aveling & Porter, Ltd., Rochester, Kent.
 Baxter, W. H., Ltd., Gelderd Road, Leeds.
 Braham, Patterson & Benham, Ltd., Grenade Street, Limehouse, London, E.14.
 British Steel Piling Co. Ltd., 54A Parliament Street, Westminster, London,
 S.W.1.
 Byrd, A. A., & Co., 11 Queen Victoria Street, London, E.C.4.
 Clarmac Engineering Co., Port Dundas, Glasgow.
 Coleman, Thomas, & Sons, Alfreton Road, Derby.
 Fawcett, J. Dawson (Darlington), Ltd., Haughton Engineering Works,
 Darlington.
 Fodens, Ltd., Elworth Works, Sandbach, Cheshire.
 Fowler, John, & Co. (Leeds), Ltd., Steam Plough Works, Leeds.
 Goodwin, Barsby & Co. Ltd., St. Margaret's Ironworks, Leicester.
 Johnson, Wm., & Sons (Leeds), Ltd., Armley, Leeds.
 Johnston Bros., London House, Crutched Friars, London, E.C.3.
 Liner Concrete Machinery Co., 30 Glasshouse Bridge, Newcastle-on-Tyne.
 Marsden, H. R., Ltd., Leeds.
 Marshall, Sons & Co. Ltd., Gainsborough.
 Mason Bros., Brandon Street, Leicester.
 Millars' Machinery Co. Ltd., Pinners Hall, London, E.C.2.
 Municipal Appliances Co., Bamber Bridge, Preston, Lancs.
 Newell, Ernest, & Co. Ltd., Misterton, via Doncaster.
 Parker, Frederick, Ltd., Catherine Street, Leicester.
 Pegson, Ltd., Coalville, Leicestershire.
 Perfect Concrete Mixer Co., Broxbourne, Herts.
 Phoenix Engineering Co. Ltd., Chard, Somerset.
 Ransomes & Rapier, Ltd., Waterside Iron Works, Ipswich.
 Road Plant Construction Co. Ltd., London House, Crutched Friars, London,
 E.C.3.
 Roadways Equipment, Ltd., 97 St. James' Road, Glasgow, C.4.
 Stothert & Pitt, Ltd., Bath.
 Taylor & Hubbard, Ltd., Kent Street, Leicester.

Wake, John F., Darlington.
Winget, Ltd., Rochester.

STONE-WORKING MACHINERY (*see also* AIR COMPRESSORS, CRANES, PLANING
AND POLISHING MACHINERY, SAWS. TOOLS).

Allen, Edgar, & Co. Ltd., Sheffield, 9.
Anderson-Grice, The, Co. Ltd., Carnoustie, Scotland.
Bramley Engineering, The, Co. Ltd., Stourton Works, Hunslet, Leeds.
Harrison Bros. (England) Ltd., Atlas Foundry, Middlesbrough.
Pinder, E. W., 212 Bermondsey Street, London, S.E.1.
Sampson, H., & Sons, Ltd., Malago Vale, Bristol.
Willcocks & Son, Dial Foundry, Buckfastleigh, Devon.
Wilson, Alex. (Aberdeen), Ltd., Ashgrove Road Engineering Works, Aberdeen.

TAR AND ALLIED MATERIALS FOR COATING STONE
(*see* ASPHALT, BITUMINOUS AND ALLIED MATERIALS)

TAR-COATING PLANTS (*see* STONE-COATING PLANTS)

THERMOMETERS (for DRYERS)

Accurate Recording Instrument Co. Ltd., Teddington, Middlesex.
Bailey, Sir W. H., & Co. Ltd., Salford, Manchester.
Cambridge Instrument Co. Ltd., 45 Grosvenor Place, London, S.W.1.
Elliott Bros. Ltd., Century Works, Lewisham, London, S.E.13.
Foster Instrument Co. Ltd., Letchworth, Herts.
Griffin & Tatlock, Ltd., Kemble Street, Kingsway, London, W.C.2.
Wright & Co. Ltd., Westminster Palace Gardens, Victoria Street, London,
S.W.1.

TOOLS (*see* p. 109)

TUBE MILLS

Allen, Edgar, & Co. Ltd., Imperial Steel Works, Sheffield, 9.
Newell, Ernest, & Co. Ltd., Misterton, via Doncaster.
Smidth, F. L., & Co. Ltd., Victoria Station House, Victoria Street, London,
S.W.1.

WASHERS (FOR STONE)

Dorr-Oliver Co. Ltd., Abford House, Wilton Road, London, S.W.1.
Fawcett, J. Dawson (Darlington), Ltd., Haughton Engineering Works,
Darlington.
Goodwin, Barsby & Co. Ltd., Leicester.
Head, Wrightson & Co. Ltd., Thornaby-on-Tees.
Parker, F., Ltd., Leicester.
Pegson, Ltd., Coalville, Leicestershire.

(Most of the firms making Screens and Riddles also supply Washers.)

WHEELS (*see* ABRASIVES *and* SAWS)

CHAPTER IV

THE USES OF LIMESTONE, CHALK AND OTHER FORMS OF CALCIUM CARBONATE

IN the commercial and other uses of calcium carbonate the physical properties of the material are often more important than the chemical composition. This will be readily recognized from the information in the current chapter, but many people, having only a restricted knowledge of the subject, often fail to realize the very great influence of the physical properties.

The uses of limestone and allied materials may be classified in two ways :

- (a) According to the nature of the materials.
- (b) According to their uses.

A classification according to nature is shown in the following Table. For further information, the later pages dealing with the uses of limestone and allied materials should be consulted.

TABLE XVIII.—*Uses of Limestone and Allied Materials*

Kinds of Stone	Chief Uses
Atomized lime	Agriculture.
Alabaster	Ornamental work.
Alkali waste	Lime, agriculture, crude filler.
Aragonite	—
Argillaceous limestones	Cement, hydraulic lime.
Calcite	Optical instruments.
Carboniferous limestone	Building, roads, lime, glass, metallurgy, chemical industries.
Chalk	Lime, whiting, medicine, agriculture, chemical industries, polishes, glass, paints, writing chalk, crayons, putty, filler for rubber, linoleum, roofing material, asphalt, etc., cosmetics, Tailor's chalk.
Clayey limestones	Cement, hydraulic lime.
Coral	Ornamental work, lime.
Crinoidal limestone	Small buildings, minor roads.
Crushed stone	Building, roads, concrete, rail-road ballast, stucco, poultry-grit, cement, lime, metallurgy (<i>See RUBBLE</i>).
Devonian limestone	Building, roads, lime.
Dolomite	Furnace-linings, lime, building, roads.

Kinds of Stone	Chief Uses
Foraminiferal limestone	Same as Chalk.
Liassic limestone	Paving stones, hydraulic lime, cement.
Lime spars	Lime
Magnesian limestone	Building, roads, furnace-linings, lime, paper, glass, agriculture, paints, metallurgy, chemical industries.
Magnesia Alba	Heat insulating and pharmacy.
Marble	Building (including ornamental), lime.
Marls	Agriculture, brickmaking.
Oolitic limestone	Building (including ornamental), lime.
Ordovician limestone	Building, road-stone, rubble, low-grade lime.
Paris White	Filler, paints.
Permian limestone	<i>see</i> Magnesian Limestone.
Pre-cambrian limestone	Small buildings, minor roads.
Rubble	Building, wharves, break-waters, banks of streams and canals, foundations, roads, concrete aggregate. The impure, siliceous varieties of limestones are utilized for these purposes. Chemical composition is immaterial, the chief requirements being that the limestone be relatively hard and tough and not subject to disintegration under the action of frost and weathering. A minor branch of the crushed-stone industry is engaged in the production of stucco-dash and poultry-grit from white crystalline limestones.
Shells	Lime.
Shell-limestone	Lime.
Silurian limestone	Building, roads, lime.
Spanish White	Paints, fillers, chemical industries.
Small stone	Roads, paths, railway and other platforms, concrete, ground stone.
Sludge (when dry)	Same as Chalk.
" Technical Carbonate "	Insulating coverings for boilers and pipes, accelerator in rubber industry, filler in paints, varnishes, cosmetics, etc.
Travertine	Crude ornaments, cement.
Tufa	Crude ornaments, cement.
Whiting	Filler, polishes, distempers, paints, chemical industries.

It should be clearly understood that the uses shown in this Table are only approximate and that some portions of any limestone strata may be quite unsuitable for the purpose named.

In some industries the lime used must have certain physical properties (such as rapid slaking) and to secure these only certain varieties of limestone can be used, so that whilst, for example, the carboniferous limestone as a whole is suitable for lime-burning, the quality of lime produced from some parts of it is unsuitable for chemical purposes though good for building.

Another method for classification is according to the size of the pieces, it being obvious that the larger sizes may, if required, be crushed or ground and then used for some of the purposes mentioned in connection with the smaller-sized pieces.

Pieces larger than 5 in. diameter are used for building purposes, rough walling, filling foundations, and sometimes for lime-burning.

Pieces 1½-in.-5 in. diameter may be sold as crushed stone or gravel, for road-making, concrete-aggregate, as a flux in metallurgy, and for lime-burning. It is usual for purchasers to specify the sizes of the stone by referring to the apertures of the screens through which the pieces must pass completely, and those of the screens on which they must be retained. For some purposes it is sufficient if all the material passes through an aperture of a specified size; this gives the maximum size of the largest pieces, but sets no limit to the size of the smallest particles.

Particles ½-1½ in. diameter are chiefly used as concrete-aggregate and road-filling. There is often only a limited demand for this grade of material, so that when a surplus accumulates it is usually ground.

Particles ⅓-½ in. diameter are chiefly used as gravel and concrete-aggregate. For concrete, the smaller pieces must usually be separated by a further process of screening, though when the material as a whole contains a suitable proportion of voids, the presence in it of small stone is an advantage.

Particles between ⅛-in. and ¼-in. are, if sufficiently angular, useful as poultry-grit and, to a small extent, as medium aggregate for concrete.

Note.—All the foregoing grades are purposely expressed in the widest terms and users should decide for themselves whether a closer grading is more suitable for their particular requirements.

Many users demand "clean" or "straight" grading, by which they appear to mean that all the pieces are of exactly the same size. This is quite unattainable by screening, as a material which has passed through one screen but has been retained by another will contain pieces of all sizes between those of the two sets of apertures in the screens. Thus, a stone which has passed through a screen with 2-in. holes and has been retained by one with ½-in. holes will contain pieces of all sizes between ½-in. and 2 in., and probably a small proportion of stones less than ½-in. diameter due to unavoidable defects in the screening.

Although ideally straight grading is impracticable, the following limits can be realized without serious difficulty in a modern plant :

TABLE XIX.—*Limits of Grading*

Grade.	Maximum size.	Minimum size.
D ¹	above 5 in.	5 in.
E	5	4½
F	4½	4
G	4	3½
H	3½	3
I	3	2½
J	2½	2
K	2	1½
L	1½	1
M	1	½
N	½	⅜
O	⅜	⅓ ₀ (24 mesh)
Z	0—	"dust"

Combinations, such as a maximum of 4 in. and a minimum of 1½ in., are also quite practicable, but if the apertures in the screens are larger than ½-in. and only differ by ¼-in. diameter, really accurate grading is scarcely practicable.

With screens having very small apertures a much closer grading is obtainable, though even with gauze screens it is scarcely feasible to use intermediate sizes to those shown in Table XIII. Thus, the product which has passed a 60-mesh and been retained by a 70-mesh sieve almost invariably contains an appreciable proportion of finer material and does not differ seriously from that which has been retained on an 80-mesh sieve. The letters used to indicate the various grades are not recognized as a standard by all firms, though it would be a great convenience, both to users and stone merchants, if these or some other equally definite limits of size were accepted as a standard.

When a user inquires for "¾ stone," he is presumed to mean that the material supplied will pass completely through an aperture or "ring" ¾-in. in diameter, but unless the minimum size is also specified, the seller is often at a loss to know exactly what is required. If, for example, "¼-¾-in. stone" were demanded this difficulty would not arise.

Not only the size, but the shape of the aperture in a screen or sieve should be specified. Apertures larger than ⅛-in. are usually assumed to be circular and smaller apertures to be square. In the British Standard Specifications for sieves and chippings, however, square apertures are stipulated (see pp. 154 and 177).

¹ Grades A, B, and C are used for various sizes of stones larger than 5 in. diameter. Similarly, grades P-Y are used for sizes between O and Z.

USES OF LIMESTONE AND ALLIED MATERIALS

(arranged according to Industries)

The more important uses of various forms of calcium carbonate may be conveniently arranged in the following groups, each of which is considered separately :

(a) USES OF LIMESTONE, ETC., IN AGRICULTURE AND HORTICULTURE.

Limestone, chalk, and other forms of calcium carbonate are used in agriculture for (i) improving the soil ; (ii) poultry ; (iii) pigs and other stock, and (iv) making rock gardens and garden paths.

The Use of Limestone, etc., in Soil is much more varied than is commonly supposed. To appreciate this it is necessary to realize that in order that a soil may be fertile it must fulfil the following conditions :

(a) It must contain enough calcium carbonate to ensure a permanent neutral reaction.

(b) It must contain reasonable proportions of essential plant foods—nitrogen, phosphorus, and potassium.

(c) It must contain bacteria which can ferment organic matter and others which can nitrify the ammonia produced.

(d) It must contain sufficient sand to ensure the requisite porosity and freedom in working as well as sufficient clay and silt to retain the humus in which the bacteria live.

In course of time soils tend to lose these essentials and, therefore, require to be " corrected " by the addition of the substances in which they are deficient. The materials which require to be added may be divided into two groups :

(a) Lime and calcium carbonate.

(b) Other plant-foods.

The necessity of adding lime or chalk has been known from ancient times, but its true purpose is still unappreciated by many farmers and horticulturists. It is commonly supposed that lime is more beneficial than calcium carbonate, but if the latter is in a sufficiently fine state of division, it will be better than lime for most agricultural and horticultural purposes.¹

The real reason why lime has been used so largely instead of calcium carbonate has nothing to do with the difference in their chemical composition, but is due solely to the ease with which lime, when slaked, falls to an extremely fine powder. It is the minuteness of the particles as produced which makes them valuable ; and as, on exposure, the lime becomes air-slaked or carbonated and is gradually reconverted into calcium carbonate, there is seldom any advantage in using free lime.

In most localities, the problem is one of cost, *i.e.* whether it is cheaper to use lime or finely ground calcium carbonate. At one time it was almost

¹ The fact that twice as much calcium carbonate as lime is required must not be overlooked.

impossible to obtain the carbonate in a sufficiently finely powdered state first making it into lime and then aerating it.

When in a sufficiently finely divided state, calcium carbonate added to a soil serves many purposes, of which the following are the most important :

(i) It separates the particles of dense clay and opens up the soil thereby making it easier for the plants to penetrate it and, therefore, more productive.

(ii) In the case of light land, it increases the power of the soil to retain moisture.

(iii) It renders the soil more porous and better aerated, so that desirable bacterial and other reactions proceed more regularly.

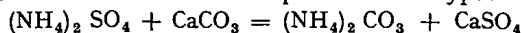
(iv) It neutralizes any acid material in the soil, thereby correcting "sourness" and facilitating plant-growth. In this connection, it is specially useful on freshly-drained swamp- or fen-land and on newly-cleared areas, as well as near large towns where the gases produced by burning coal introduce acid sulphur compounds into the soil.

Many plant diseases, like the slime fungus which causes "finger and toe" in turnips, etc., are only prevalent when the soil loses its neutral condition, and such diseases are not found when a sufficiency of calcium carbonate is present. The disease is caused by an organism (*Plasmodiophora, brassicae*) belonging to the slime fungi and forming spores which may remain dormant in the soil for some time—certainly for two or three years. It has long been known that the best remedy against finger-and-toe consists in the application of lime or calcium carbonate ; and as far back as 1859, Voelcker showed that soils in which this disease is prevalent are deficient in lime, and in many cases in potash also. Later researches have only served to emphasize the fact that the disease is associated with soils of an acid reaction, in which calcium carbonate is wanting or is present in too small proportions. The fungus, as is generally the case with fungi, refuses to grow in a neutral or slightly alkaline medium and the only way to get rid of the infection in the land is to restore its neutrality by repeated dressings of lime or calcium carbonate. At the same time, the land should be rested as long as possible from cruciferous crops.

The normal changes in a soil are brought about by bacteria which only flourish when the medium is neutral or very faintly alkaline ; as soon as the soil becomes acid the bacterial actions are largely suspended and in their place moulds and other micro-fungi become predominant.

(v) It provides a base, without which certain nitrifying organisms cannot act satisfactorily in the conversion of manure and albuminoid material into plant food. Bacteria do not thrive in a sour acid soil, the nitrifying organisms especially being adversely affected. There is a marked increase in the rates of production of nitrate and of decomposition of organic matter when a soil is properly limed.

(vi) It forms compounds with various chemicals necessary to plant growth and makes them available for the plant. Thus, when calcium carbonate is present in a soil it effects a double decomposition of the type :



such substances as ammonium sulphate, humic and zeolitic compounds of calcium, and though the proportion converted into ammonium carbonate is small it is constantly renewed, as the ammonium carbonate is nitrified, so that eventually the whole of the ammonium salt applied to the land undergoes this change.

In consequence, the continued use of ammonium salts as a fertilizer results in the depletion of the stores of calcium carbonate in the soil, and is a further indication of the need for frequent dressings with some form of calcium carbonate.

Without sufficient calcium carbonate in the soil no amount of fertilizing or manuring is of any avail, and there will come a time when the soil will no longer respond to such fertilizing until its deficiency in calcium carbonate is made good. The whole scheme of manuring should depend upon whether the soil is properly supplied with its calcareous base.

(vii) In dry weather, a properly limed clay-soil will not crack up and split as do the unlimed clay-soils, and in wet weather the reverse obtains, the limed clay-soils being drier and less sticky than the unlimed.

Clay soils are generally deficient in calcium carbonate—often to an extreme degree—so that the use of lime or calcium carbonate is of the utmost value to all clay-soils, improving the texture, making them drier, and, therefore, warmer and “earlier,” and rendering available the supplies of nitrogen and potash with which they are often liberally endowed.

All crops benefit by top dressing with fine calcium carbonate. Pastures are improved by a dressing of calcium carbonate, which not only does no harm to the cattle, but actually improves them.

Sir A. D. Hall has stated that “a large proportion of the soils of Great Britain are in serious need of lime (or calcium carbonate) by the lack of which their fertility is impaired, cultivation is rendered both more difficult and uncertain, and disease is more prevalent among the crops. On many of the sands and clays that cover much of England—as for example on the New Red Sandstone, the Lias, Oxford and London Clays, and the Tertiary Sands—the output of the soil might be enhanced and its value increased by from 10 to 20 per cent. by the proper use of lime or carbonate. A comparatively simple chemical determination, which can be obtained from the laboratory of any agricultural college, will provide the necessary information as to whether the soil needs lime or its equivalent. There are also several trustworthy natural indicators; thus, the presence among weeds of arable land of any quantity of spurrey (*Spergula arvensis* and *Spergularia rubra*) on sandy soils, of Sheep’s sorrel (*Rumex acetosella*) and of corn marigold (*Chrysanthemum segetum*), or of foxgloves in the hedgerows provides a sure indication of acidity in the soil that needs lime or some form of calcium carbonate for its correction.”

Among the chief reasons why ground limestone and chalk have not proved satisfactory are the following:

(a) The material used has often been too coarse; it has been found that particles of calcium carbonate which will not pass through a 100-mesh sieve

are of little value in a soil. As the greater part of chalk, shell-sand, and road-scrapings consist of larger particles than this, such materials are of much less value, agriculturally, than if they were very finely ground.

(b) Calcium carbonate obtained as a by-product from various industries often contains substances which are injurious to plant-life.

(c) Far too little material has been used. An analysis should be made of each soil and the requisite amount of calcium carbonate calculated and then added. In serious cases of deficiency it may be necessary to add as much as 5 tons per acre, but a more usual requirement is 1 ton per acre for fields and 1 lb. per square yard or about 2 tons per acre for gardens and lawns. It is obviously futile to expect good results when only a fraction of the needed calcium carbonate is added.

(d) An excessive price is often charged for a comparatively coarse and, therefore, indifferent quality of material.

(e) Calcium carbonate will not usually flocculate the colloidal matter in heavy clay-soils, nor that in soils over-rich in humus, so that its use in such soils effects very little improvement. At the same time, calcium carbonate does possess some flocculating power, and Sir A. D. Hall has gone so far as to state that "the flocculating action is really not due to the lime itself, but to the soluble calcium bicarbonate which arises from the action of water and carbonic acid upon the calcium carbonate formed from the lime."

As the soils mentioned in (e) are exceptional they may be dismissed from the present discussion. All the other objections to the use of calcium carbonate (as distinct from lime) can be overcome by the use of as sufficiently finely-ground material as is obtainable at a reasonable rate and applied in sufficiently large quantities to the land.

Calcium Carbonate v. Lime.—The foregoing reasons for adding calcium carbonate or lime to a soil may be expressed somewhat differently by stating that :

(i) A soil requires to be made neutral and to have sufficient calcium carbonate present to prevent it turning acid.

(ii) A soil may require to be partially sterilized so as to rid it of objectionable living organisms without damaging the valuable ones. The carbonate is useless for this purpose.

For the neutralization, calcium carbonate in a sufficiently finely divided state is equally as suitable as lime and, although more must be used (for 100 lb. of the carbonate has the same neutralizing power as 56 lb. of lime), it is usually much cheaper than lime. In any case, it is less risky as it is difficult to damage a soil with an excess of calcium carbonate and easy to do so with an overdressing of lime.

In rich soils the organic matter destroyed by the lime is alone worth far more than any difference in the cost of carbonate and lime (further information on the relative values of lime and calcium carbonate will be given in a later chapter on the use of lime in agriculture). Limestone or chalk which is in sufficiently minute particles is nearly as quick in action, is much pleasanter to

use, and is equally as efficacious as lime, provided that twice as much is used. For objections to chalk see p. 220.

How much Carbonate? The amount of calcium carbonate which should be added to a soil is best found by means of a chemical test. This is an operation of some delicacy and requires adequate training, and it is described here in order to show the means used for obtaining this invaluable information.

One of the most convenient methods for determining the calcium carbonate requirement of a soil is that devised by H. B. Hutchinson and K. MacLennan, as follows :

A solution of calcium bicarbonate is made by placing 10 g. of finely-powdered calcium carbonate in a syphon filled with water and fitted with a "sparklet" of carbon dioxide. The syphon with its contents is shaken mechanically for 15-20 minutes, and its contents diluted with distilled water so as to form a solution of about N/50 strength.

20 g. of the air-dried soil is placed in a bottle of 1000 c.c. capacity together with 300 c.c. of the roughly N/50 bicarbonate solution, and the air in the bottle is displaced by a current of carbon dioxide. The bottle, with its contents, is shaken mechanically for three hours, after which the liquid is filtered and a volume equal to exactly half that of the original solution added is titrated with N/10 acid, using methyl orange as indicator. The difference between double the result of this titration and that of 300 c.c. of the bicarbonate solution without any soil, represents the amount of calcium carbonate absorbed by each 1 c.c. of N/10 acid being equal to 5 mgm. of calcium carbonate.

Neutral soils show no absorption of carbonate. Soils containing free calcium carbonate increase the strength of the bicarbonate solution used, and so show negative results, *i.e.* no lime is needed.

Another test is based on the determination (electrically or chemically) of the H-ion concentration of the soil.

Forms of Calcium Carbonate Used.—Calcium carbonate has been used for agricultural and horticultural purposes in the following forms : chalk, road-scrapings and ditch-cleanings, marl, ground limestone, and as a by-product from various industries. Whatever form is used must conform to the requirements of the Fertilizer and Feeding Stuffs Act.¹

Chalk may, according to Sir A. D. Hall, often be used with advantage when it is readily accessible ; for example, on one side of the chalk-formation, the Gault and the upper beds of the Lower Greensand, and on the other side the London Clay and the Bagshot Sands are generally in need of lime and are never very remote from the outcrop of the Chalk. The superficial clays and sands lying on the Chalk itself are often deficient in lime and may be readily chalked by sinking shallow pits. It must be remembered that larger quantities of chalk than of lime are needed to produce a given effect ; not only is the chalk equivalent chemically to about half its weight of lime, but in practice it can never be reduced to so fine a state of division as lime obtains by careful slaking.

¹ *Statutory Rules and Orders, 1932, No. 658* (obtainable from H.M. Stationery Office, Adelphi House, Kingsway, London, W.C.2).

In chalking it is desirable to obtain the soft upper white chalk from a pit so that it is saturated with quarry-water ; if then spread over the land in the autumn it gets frozen while still full of water and becomes reduced to a comparatively fine powder which can be ploughed in an arable soil or spread with a harrow on the pastures. Very large quantities of chalk are used, up to 100 loads to the acre ; naturally the effect of such treatment is more permanent than the usual liming.

The custom of "chalking" was very extensively practised during the 17th and 18th centuries in Hertfordshire on the high plateau land on which the Rothamsted estate is situated. There the "clay with flints" and the "boulder clay," though not as a rule more than 10-12 ft. thick, and resting on the chalk-rock from which they have been largely derived, have been completely decalcified by the solvent action of the rain-water and no longer contain more than a trace of carbonate of lime. It was customary to sink bell pits through the clay until the chalk was reached, this was then dug out, hauled to the surface in baskets, and dragged to the fields in sledges. 60-100 or even 150 loads per acre were spread and from time to time the process was repeated. The amount of chalk thus spread upon the surface in the course of years was considerable ; the surface-soil of the arable fields on the Rothamsted estate now contains from 3-5 per cent. of carbonate of lime, which is equivalent to 30-50 tons per acre, and since none has been spread for the last 70 years at least, with solution in the rain-water constantly been going on, there must have been nearer 100 tons per acre at the beginning of the 19th century. The result of this use of chalk has been the creation of a soil fit for arable farming, for some of the Rothamsted fields which had never been so treated have had to be laid down to grass because their cultivation proved impossible in wet seasons.

A similar process with like results has been applied to the "red clay with flints" which occurs on the top of the chalk plateau in Kent, Surrey, Hampshire, and Dorset, as well as in the Chilterns and in Hertfordshire. In several cases where advice has been sought as to the reasons for the infertility or bad working quality of a specified field, it has been found that the particular field had escaped the chalking process and that the land could be brought into good order by a good chalking or liming.

The chief objections to chalk are (a) the silica present, which reduces its efficiency ; (b) the highly porous nature of the chalk, which makes it retain much water and so keeps it somewhat sticky and difficult to spread uniformly over the land ; (c) the size of the particles, which are often much too large to give the best results, although fine grinding is very difficult on stickiness of the chalk, unless it has previously been dried.

Road-scrapings can only be regarded as a makeshift, as their particles are too irregular and the size of the particles is often much too large for really valuable. The cost of collection also makes this material too expensive to be used on a very large scale.

Marl.—a naturally occurring mixture of calcium carbonate with clay and sand—is largely used in agriculture as a substitute for

especially in the Fens, the Lancashire Mosses, and in the sandy soils of Norfolk. It is valuable where no better material is readily obtainable, but its efficiency is greatly reduced by the amount of clay it contains. Consequently, a purer form of calcium carbonate is usually to be preferred.

Ground Limestone—when reduced to a sufficiently fine powder containing at least 96 per cent. of calcium carbonate—is almost ideal for agricultural and horticultural purposes. It is rapid in its action, easy to apply, and serves all the purposes reasonably required of it. It is superior to natural chalk on account of its greater fineness, dryness, and freedom from excessive silica. It can also be applied at any time, whereas chalk should usually be supplied to the land during the autumn or winter, so that it may be broken up by the frost, after which it can be spread evenly in the soil. Unless it is so exposed it is sometimes very difficult to distribute uniformly. Finely ground limestone or chalk is not affected by exposure to frost, but may be added when it is convenient to the farmer or horticulturist. Ground limestone has the advantage over lime that it can be kept in stock in bags for any length of time, whereas lime must be used quickly.

Magnesian limestone should not be used for agricultural purposes on light soils, though it has proved satisfactory on some very heavy ones.

The effect of ground limestone on a soil depends largely on its fineness. Badly ground limestone is of little use, and to be really effective for agricultural purposes any form of calcium carbonate should not leave a residue of more than 10 per cent.—preferably not more than 5 per cent.—on a sieve having 100 holes per linear inch. Extremely fine limestone-flour is difficult to distribute agriculturally so that the presence of a small proportion of coarser material is advantageous.

The machinery suitable for grinding limestone to such or even greater fineness has only been available for a few years, and this lack of machinery is probably the chief cause of lime being used. The lime, when slaked, falls to a very fine powder, which slowly changes, on exposure, into a very finely-divided carbonate.

Calcium carbonate obtained as a by-product is equally as good as any form of finely-divided calcium carbonate, provided no injurious materials are present. Where these are certain to be absent, there is nothing to choose between a well-screened, dry by-product carbonate and finely-ground chalk or limestone, so far as agricultural and horticultural purposes are concerned. Some of the by-product carbonate also contains ammonium sulphate—a valuable plant-food.

Preparation.—The only preparation which calcium carbonate requires very rarely is grinding. In order to make it fit for use in agriculture or horticulture it is necessary to grind it to a sufficiently finely-divided state, so that it is in the form of a very fine powder which “runs” easily.

The most suitable machines for this purpose are tube mills, but ball mills combined with air separators, pendulum mills, and other fine grinders may be used. Ordinary disintegrators are quite useless, as they do not produce a sufficiently fine powder.

The powder should be screened or air separated to remove all coarse material, and should preferably be supplied in bags, as this is the most convenient form of container.

As the demand for agricultural purposes is greatest in Spring and Autumn it is desirable to have a large storage capacity, so that the materials may be ground at a uniform rate throughout the year and kept in stock ready for rapid delivery in the busiest part of the season. Otherwise it will be impossible to cope with the demand, except by a wasteful expenditure of power and capital charges on a needlessly large plant.

The **Properties required** in calcium carbonate for agricultural and horticultural purposes are :

(i) The material must be so fine that it passes completely through a 60-mesh sieve and does not leave a residue of more than 10 per cent. (preferably 5 per cent.) on a 100-mesh sieve. Some agriculturists are satisfied with a limestone which passes completely through a 20-mesh sieve, 65 per cent. through a 60-mesh sieve and 50 per cent. on an 80-mesh sieve, but a finer material is always preferable. In the near future it will probably be necessary to grind the material to the same fineness as Portland cement, *i.e.* with not more than 10 per cent. of residue on a 180×180 mesh, because the value of calcium carbonate depends chiefly on its fineness. Soft porous stone, such as chalk or oolite, may be rather coarser than harder stone as the water in the soil attacks it more readily.

(ii) The material should contain at least 96 per cent. of calcium carbonate plus magnesium carbonate. It is now generally conceded that dolomite and high-calcium limestone will give equally satisfactory results.¹ Chemical purity is not essential, but the limestone with a high percentage of the carbonates of calcium and magnesium will prove more effective than will an equal weight of an impure stone.

(iii) No matter of a poisonous nature or otherwise injurious to plants or to human beings or animals who feed on the plants must be present. For this reason, if calcium carbonate obtained as a by-product from a chemical or other industry is used, it should be guaranteed free from deleterious substances. Otherwise ground chalk or limestone should be exclusively used (see also *Fertilizers*).

Calcium Carbonate v. Basic Slag.—Basic slag is a mixture of compounds of lime, silica, and phosphorus containing only about 5 per cent. free lime. It is almost wholly insoluble in water, but gives a slight alkali account of the presence of the small amount of free lime. Consequently, it is very inferior to calcium carbonate as regards neutralizing acids in soil. Basic slag is chiefly of value in incorporation of phosphates in the soil, and it is wrong to regard it as such for any other purpose. It is especially erroneous to regard it as such for either calcium carbonate or lime, for the greater part of the slag is combined in such a manner as to make it chemically useless

¹ See page 221.

Fertilizers.—Calcium carbonate is a regular constituent of many fertilizers to which it is added for the same purpose as it is used in agriculture and horticulture, with the additional advantage that it is a cheap filler or diluent and is also useful on the soil.

Many statements have been published to the effect that calcium carbonate is not a fertilizer, but merely a "soil neutralizer"; such statements are misleading. If a fertilizer is defined as a substance which makes a soil more fruitful, then calcium carbonate is undoubtedly a fertilizer, as can readily be ascertained by adding it to any soil which is deficient in this material.¹ It is a fact that every other fertilizing material, including farm-manure, depends for the full development of its value on the presence of sufficient calcium carbonate in the soil. Consequently, this substance is a valuable ingredient of fertilizers though in some cases it may be used alone with equally satisfactory results. Where a soil is rich in organic matter, yet slightly acid, or at least deficient in lime, the addition of calcium carbonate in a suitable form will—without any other addition—render such land more fruitful than is possible with an equal weight of any other substance (except lime) used as a fertilizer.

On the other hand, where a soil is deficient in ammonia, phosphorus, or other plant food, calcium carbonate will not supply it. The chief purpose of lime and calcium carbonate is to bring the soil into a fit state for the beneficial bacteria to convert the organic matter in the soil into plant-foods and to prevent the growth of harmful fungi.

Neither lime nor calcium carbonate replaces plant-food fertilizers; on the contrary, the more the latter are used the more necessary is it to employ calcium carbonate to get the soil into such a neutral and acid-free state that the best possible use can be made of the added fertilizer and to increase the effective manurial value of the soil.

Artificial fertilizers usually belong to one or more of the following classes :

(i) Comparatively pure salts, such as nitrate of soda, sulphate of ammonia, chloride of potash, sulphate of potash, "nitrate of lime," and kainite. The last is a natural mixture of the chlorides and sulphates of sodium, potassium, and magnesium.

(ii) Natural products, such as guano, bone, and mineral phosphate.

(iii) Chemically treated manures : superphosphates, dissolved bone, guano, bone flour, bone meal.

(iv) Manures produced as by-products : basic slag, shoddy, rape dust, and other organic residues.

Limestone, chalk, or any other form of calcium carbonates may be used in any of the above, except those containing soluble ammonium compounds, to destroy any acidity in the soil. Whether a farmer should buy the lime-compound mixed with the fertilizer, or separately, is a question which he must decide for himself.

As a fertilizer-filler, calcium carbonate has the advantage over silica flour,

as the nitrogenous compounds are essential constituents of many plants (especially clovers) and in this sense, also, calcium carbonate is a fertilizer.

slate dust, clay, and other inert materials, of being a useful addition to the soil.

For fertilizers the calcium carbonate should be in the form of a fine powder. It should pass completely through a 60-mesh sieve and not leave more than 10 per cent. on a 100-mesh sieve. The purity of the material is of minor importance so long as the impurities are not plant-poisons. If chalk or limestone is used, there need be no anxiety on this account; with the by-products from some industries, *e.g.* "alkali waste," much greater care is necessary, and for most agricultural purposes such a material is unsuitable.

Use in Poultry-Farming.—Limestone crushed to granular form and screened to uniform sizes may be sold as *chicken-grit*. The term is a general one, for the products included may be graded by size as *turkey-grit*, *pigeon-grit*, etc., the pieces ranging from $\frac{1}{8}$ -in. to those remaining on an 80-mesh sieve. No accurate definitions of the limits of size for each kind of grit have been made and poultry-farmers differ greatly in their ideas as to which are the best sizes. A disintegrator is the most convenient grinding machine for this material; as it produces little dust, it is seldom necessary to use a fine screen. A screen to separate pieces more than $\frac{1}{8}$ -in. diameter should, however, be used.

The use of finely-ground calcium carbonate on the ground in fowl-runs keeps them sweet and free from worms. It should be renewed fortnightly or even weekly if the runs are crowded. Its use is specially desirable in duck-runs as these birds quickly taint the land:

A liberal addition of calcium carbonate powder to the grain used for feeding poultry provides the necessary lime in a suitable form and increases the production of eggs. For this purpose ground limestone and chalk are quite satisfactory, provided they contain not less than 95 per cent. of calcium carbonate, and are ground so as to pass completely through a 60-mesh sieve. Powdered calcium carbonate from other sources may be equally satisfactory, but special care is then necessary to ensure the entire absence of injurious "chemicals" due to the materials from which it is derived as a by-product.

Pigs and other stock feed better and put on weight more quickly when a suitable form of calcium carbonate is added to their food. Experiments by J. M. Everard¹ showed that instead of calcium carbonate alone a mixture of several materials is preferable, and of many mixtures tried the best consists of common salt 20 lb., ground limestone 40 lb., and bone-meal 40 lb. The amount required is 9 lb. of the mixture to each 100 lb. of ordinary food.

Some breeders use a similar mixture containing other ingredients and composed of: salt 34.36 lb., bone-meal 28.64 lb., wood-ashes 18.75 lb., limestone 11.46 lb., flower of sulphur 11.45 lb., and potassium iodide 0.34 lb., and only 2 lb. of this mixture to each 1 cwt. of ordinary meal.

These mixtures may be fed to pigs and other stock of all ages and under all conditions, for either dry or wet feeding. The saving in cost of ordinary food, when such mixtures are used is very important.

Rock-Gardens and Garden-Paths.—As a decorative stone for rock-gardens, etc., rock limestone is used to a considerable extent, as many rock-pla

¹ Bull. Iowa Experiment. Station 1922, 1924.

thrive on it with the aid of a very small quantity of soil. The shape of the pieces of stone is the factor of chief importance. The magnesian limestone, near Cresswell Craggs and Shireoaks (both in Nottinghamshire) are excellent for rocks on account of the "styolite" structure which gives a pleasing irregular surface to the stone.

Garden-Paths.—See the section on *Road Construction*. Limestone slabs of irregular size and shape are particularly suitable for "crazy" or "random" paving. For "Crazy pavements," the stone should not be laid directly onto the soil or clay or sand but on a 4-in. bed of broken stone, bricks, or sand, well rammed, so as to afford a well-drained and level bed.

Ashes should not be used as they may produce a white "scum" on the pavement. With care, 10 sq. yd. of pavement should be obtained from a ton of stone, but much depends on the shape and thickness of the pieces. Quarried stone of varied tints and colours produces the prettiest effects.

(b) USES OF LIMESTONE, ETC., IN THE BUILDING AND ALLIED INDUSTRIES

Calcium carbonate is used in the building and allied industries as (i) building stone; (ii) monumental stone, including tomb stones and statuary; (iii) artificial stones; (iv) aggregate for concrete; (v) plastering; (vi) road stone, and (vii) for making Portland cement and various kinds of lime.

Building-stone.—Calcium carbonate in the form of chalk, limestone, and marble forms an extremely important building material.

The limestones which are of value as building stones are very numerous, over two hundred "large" quarries being worked for building stones in the British Isles, in addition to an unknown quantity of "small" quarries, most of which are only worked occasionally and solely for local use.

The Aymestry, Wenlock and Woolhope limestones in Shropshire, Staffordshire and Herefordshire are quarried for building purposes, though large blocks are seldom obtained.

The Devonian limestone has been largely quarried for building purposes in various parts of Devon, particularly near Plymouth, Newton Abbot, Totnes, and Torquay, where it is the predominant building stone. For ordinary structures it wears well, but is not very suitable for maritime work, though it has been largely used for that purpose.

The Carboniferous limestone has been extensively used as a building stone in many parts of the country, though it is now chiefly quarried for conversion into lime or for use as a flux. The best portions of this stone are usually greyish-blue in colour and are composed of small remains of organic life, though the whole is essentially crystalline. They are found near Wirksworth, Derbyshire, Prudhoe, near Hexham, Barton, near Darlington, Deganwy and Llysfaen in North Wales, near Wenvoe in South Wales, and in various parts of Ireland.

The Permian or Magnesian limestone is largely used as building stone, particularly that quarried at Mansfield, Bolsover, Steetly near Worksop, North Anston and Roche Abbey, near Sheffield, Brodsworth, near Doncaster, and at many other places. When freshly exposed, this limestone is cream

coloured, but soon turns grey. Magnesian limestone is a good and durable building-stone, but requires to be selected with care, as some portions are soft and do not weather well. In towns, magnesian limestone suffers from smoke and acid vapours from factory and domestic chimneys and is liable to flake: With skilful selection, the defects commonly attributed to magnesian limestone as a building stone are avoided.

The Liassic limestones are only used locally—notably in country districts—as they are unreliable in frosty weather. The Lower Liassic limestone at Sutton, near Bridgend, appears to be the most durable.

The Oolite limestone exhibits almost every variety of stratified rock, but in parts it forms one of the chief supplies of building stone, as Portland stone of Portland; the Great Oolite of Bath, Minchinhampton, and Milton, near Burford, in Oxfordshire; and the Inferior Oolite series at Ham Hill, Doulting, and Dundry, in Somerset, at Leckhampton, Painswick, and other places on the Cotswold Hills, and at Weldon, Ketton, Casterton, Stamford, Ponton, and Ancaster in the Midland Counties and Lincolnshire.

The chief building-stones in the Lower Oolite are Ham Hill stone, Dowdeswell stone from near Cheltenham, Doulting stone from near Shepton Mallet, Somerset, Dundry stone from near Bristol, Painswick stone from near Stroud, Ball's Green stone from near Nailsworth, Clipsham stone from near Charlbury (Oxon.), Bourton stone, Chipping Campden stone, Blockley stone, Casterton and Barnack stone from near Stamford, Waldon stone (Northants), Ancaster stone from near Sleaford (Lincs.), and Haydor stone from near Grantham.

All these stones have been used for important buildings, some of the quarries dating from the time of the Ancient Romans, and, in some cases, very large blocks have been obtained.

The chief building stones in the Great Oolite are the Bath freestones—including the Box Ground, Corn Grit, Corsham Down, Monks Park, Hartham Park, Farleigh Down, Combe Down, Bradford Winsley Ground, Stoke Ground, and Westwood Ground stones. All the Bath freestones are well esteemed as building stones and have been extensively used. Blocks weighing 10 tons and of good lengths have been quarried, and blocks of 5 or 6 tons are by no means unusual. Other well-known building-stones obtained from the Great Oolite include Baynton or Hampton stone from Bathampton Down, Windrush stone, Taynton stone, and Temple Guiting stone—all from Gloucestershire—Pudlicote and Charlbury stones from Oxfordshire, and Denton Blue and White stone from Northampton. Other building stones of less importance are quarried from the same formation at Tadmarton, Shalstone, Blisworth, Oundle, and elsewhere.

The Corallian limestones are not satisfactory for exterior work, though some of them have been used for this purpose, particularly the Osmington, Marnhull, Calne, Headington (or Shotover), and Wheatley stones. The Hildenley stone, near Malton, is particularly suitable for interior carvings, but not for exterior work.

The Portland stone from the island of that name, and from Purbeck (Dorset), Wiltshire, Oxfordshire, Buckinghamshire, and Kent are excellent, very well-known building-stones, and have been very extensively used.

Although a limestone, Portland stone appears to be peculiarly resistant to varied climatic conditions, as shown by its successful use in the damp, salty atmosphere of Cardiff, and the trying, smoky atmosphere of London—to mention only two out of the many where it has been used satisfactorily.

The Purbeck or Swanage stone from the hilly ground south of Swanage, is largely used as a building stone in the south-east of England, particularly for paving slabs, steps, setts, gate posts, window sills, sinks, etc.

The Chalk formation is not much used as a building stone, and the material is too soft and lacking in durability on exposure to weather. Some of the harder portions, as at Boynton, near Bridlington (Yorkshire), at Beer (Devon), and Totternhoe (Beds.), together with some of the Kentish rag stones, have been used extensively, particularly for cottages and for a few cathedrals, as well as for numerous churches.

Most of the chalk freestones harden on exposure, so that they should be dressed or carved soon after excavation. Though they often deteriorate badly when exposed to the weather, particularly in towns, they are excellent for interior work—especially for ecclesiastical purposes.

The limestones of more recent formation in the British Isles are of little commercial value for building purposes; the only one of importance is *travertine*, which occurs in small quantities near Matlock, in the base of the Tabular Hills, near Scarborough, near Osbournby in Lincolnshire, Dursley in Gloucestershire, and in the district around Llangollen and Wrexham in Wales. Travertine was, at one time, used for building houses in these districts, but its chief present use is for rock gardens.

The selection of a stone for building purposes is usually based on the architect's taste and experience, rather than on any scientifically measurable data. Tests of such stones are rarely called for by architects, whilst engineers rely on average figures for ultimate stresses rather than on tests of stones from any particular quarry. The following figures from Chatley's *Stresses in Masonry*, or similar wholly general figures, are used:

TABLE XX.—Crushing Strength of Various Stones

Ultimate Stresses (tons per square foot).					
	Crushing	Tension	Shearing	Bending	
Granite	900	30	50	100	
Basalt	800	80	40	—	
Slate	800	10	30	50	
Sandstone	500	10	30	50	
Sandstone (soft)...	200	5	10	20	
Marble	600	30	50	—	
Limesto.	500	25	40	60	
Limeston oft)...	100	9	35	50	
Chalk	10	—	—	—	

The usual factor of safety is 10.

The use of such figures assumes that the stone is of good average quality.

The physical properties, such as weather-resisting properties, hardness, evenness and thickness of bedding, ease of chiselling, colour, evenness and size of grain, and general appearance are the factors which take precedence over chemical purity.

It is very desirable to have regular tests made in order that more may be known of the ultimate stresses which can be withstood by stones from different localities, and to ascertain their behaviour when subjected to freezing and other conditions equivalent to "weathering."

The great reputation of limestone as a building stone is chiefly based on its use in localities where the quantity of acid gases in the atmosphere is very small and not on the conditions in many industrial areas to-day.

All limestones, when used for the exterior of buildings, especially in industrial areas, are very liable to decay as a result of the absorption of acid (sulphurous) gases from the atmosphere. The decay is less severe when the stone is frequently washed by rain. If limestone is placed above sandstone, water from the limestone passing to the sandstone may cause the latter to decay. As magnesian sulphate is readily soluble in water, magnesian limestones tend to be corroded more readily by industrial gases in the atmosphere than do wholly calcium limestones.

Limestone for Roofing and Paving.—A limestone rock which separates well along its surfaces of stratification into slabs two inches or so in thickness is useful for a flag-stone in paving; a rock that splits into still thinner slabs may be useful for roofing-stones or -tiles.

In the beautiful old villages built of local limestone in the Cotswolds, the roofs are commonly made of sandy limestone. Certain flaggy beds exist among the marine strata of the hills, one series of which is known as the "Stonesfield slate," from the village of Stonesfield, near Charlbury, Oxon.

The pleasant uniform grey tint of the old roofs in the Cotswolds, which marks out a village so naturally when we look down on it from the valley edge, has disappeared from modern buildings except where some landlord, loving the country, intervenes and insists on stone roofs.

Rough Walling is commonly made of limestone-blocks. Finely-ground limestone is largely used as a filler for asphalt-roofing and -paving. Either a high calcium or a magnesian limestone may be used.

Plastering.—Finely-divided calcium carbonate in the form of prepared chalk or whiting, is sometimes mixed with plaster of Paris to produce a plaster with a more stone-like finish and also to reduce the cost of the plaster as a whole.

Such a mixture is also very satisfactory for setting coats on Portland cement rendered or for floating coats. A variety of such materials commonly known as *Stuc* (see "Artificial Decorative Stones") is largely used for interior work. The proportion of carbonate used varies with the particular purpose for which it is employed, and with the quality of the plaster of Paris with which it is to be mixed. The materials are not accurately proportioned, it being left to the

workmen to use such quantities of each as they find gives good results, some men preferring a mixture which sets rapidly whilst others prefer a softer and slower setting one.

Ornamental work, such as that used on ceilings, etc., may be made of neat plaster of Paris, but for elaborate work it is usually better to employ a special form of putty. One good method of making this is to boil together 2 lb. of resin, 1 gill of Venice turpentine, and 1 lb. of boiled linseed oil. To the product is added 1 lb. of best glue previously dissolved in a gallon of water. The mixture is boiled with constant stirring, until all the water has been evaporated, after which whiting is added in sufficient quantity to give the mass the consistency of putty. This composition sets hard when cold, but if warmed it can be carved or moulded as required.

Stucco, *Pebble-dash* and *Rough-cast* are often made of crushed limestone, in pieces (a) $\frac{3}{4}$ -in. and less for "pebble-dash" and "rough-cast," and (b) in coarse powder ($\frac{1}{8}$ -in. to 60-mesh) for "stucco." For all three purposes, the limestone should be reasonably impervious to water and of uniform colour.

Decorative Building Stones.—Limestones are largely used as decorative building stones, both in the form of plain or carved stones for the interior of churches or other public buildings, and as polished "marble." For the former purpose, almost any limestone of pleasing appearance may be used, and some of those which weather badly prove exceedingly durable when used for interiors.

The essential characteristic of a stone to be used for carved work is great uniformity of texture. Some limestones and siliceous chalks are remarkable in this respect, whilst others—though not so uniform—produce a very pleasing effect when carved, as a result of the play of light on the small fragments of shells or cast which they contain. Some portions of the Leckhampton grit and of the Chalk freestones, previously mentioned, are particularly noteworthy in this respect.

Marble is a term used by architects and stone-workers to include a number of stones which would not be included by the mineralogist, so that almost any stone which will produce a high polish and show pleasing structural details may be regarded commercially as a marble. Hence, appearance, rather than structure or chemical composition, determines what is a marble in the commercial sense.

Among the more important English "marbles" used for decorative purposes are :

A fossil limestone quarried at Hopton Wood, Derbyshire, which is an excellent stone, takes a good polish, and is largely used in decorative features, such as columns, arches, ashlar, walks, staircases, pilasters, friezes, cornices, etc. It is grey to brown in colour with many gradations, and has been very largely used.

Other Derbyshire and Mendip marbles are polishable varieties of the carboniferous limestone ; so also are those of Kendal, Cleator near Egremont, and Bertham Fell, Westmorland ; those from Dent and Frosterly come from the Yoredale series.

The Devonian limestone at Newton Abbot, Ipplepen, and Torquay yields several varieties of stone which take a good polish.

The Stamford marble, and also the Weldon marble, quarried at Weldon (Northants) are blue shelly limestones which turn yellow or brown on exposure; the latter is very hard and capable of taking a good polish.

The Forest marble (including the Bowden marble) lies above the Great Oolite formation; it is chiefly quarried at Bothenhampton, Long Burton, Bowden, Wincanton, North Cheriton, Bratton, Wanstrow, and Frome, but its use as a polished stone is largely confined to the districts named.

Purbeck marble from the Upper Oolite beds near Swanage shows an abundance of *Paludina* shells. It was, at one time, extensively quarried at Purbeck, Dorset, but is now less popular than formerly. It is a medium, mottled grey, and takes a fine polish. Its principal uses are for internal church work and at one time it was greatly used for domestic mantelpieces.

Sussex or Betersden marble, a greenish-grey stone, full of a large species of *Paludina*, from the Weald Clay, was formerly much used in the perpendicular churches of the district, and is often confused with Purbeck Marble.

The Landscape (arborescent) marble of Cotham, near Bristol, is utilized for the manufacture of small ornaments.

In Scotland, the marble of Tiree is of Archean age, and that of Skye is Cambrian.

Artificial Decorative Stones.—In addition to the materials described in the section on “artificial stones,” mixtures of calcium carbonate and sulphate sold as *Stuc*, or under various registered names, are used for internal decoration to obtain the effect of worked limestone with the advantage of a plaster. The calcium carbonate is usually in the form of chalk or finely-ground limestone, whilst the sulphate is chiefly plaster of Paris which forms the binding agent. The mixtures are applied in the same manner as plaster (see “Plastering”).

Dense, compact limestones and marbles of attractive colour may be crushed to less than 1 in., screened free from material less than $\frac{1}{8}$ -in., and used for making *terrazo flooring*. Marble is preferred for this purpose, but other hard limestones often prove just as durable.

Monumental Stones.—Limestones used for monumental purposes must usually be fine-grained and very uniform in texture, though some marbles are admired on account of the “grain” or pattern due to irregular veins.

Such stones must be very durable and, therefore, require very skilful selection, for there is nothing more unsatisfactory than a monumental stone which has perished prematurely as a result of exposure.

The limestones and marbles which make good building-stones include all the good monumental limestones, and selections should, therefore, be limited to these. It should be particularly noted that some stones which are excellent for internal work are quite useless for exteriors.

In selecting a stone for monumental purposes, in addition to the durability and pleasing appearance, the effect of age on the appearance of the stone should be considered and also the fineness of the texture; the last-named is specially

important, in order that any lettering or other inscribed work may be clear and legible.

Artificial Stones made of limestone may be arranged in the following groups :

1. Blocks made of crushed and screened limestone united by Portland cement. Such blocks are really made of concrete.

2. Blocks made of crushed and screened limestone united by water-glass the blocks being baked at about 450° F.

3. Blocks made of crushed and screened limestone mixed with mortar (*i.e.* lime and sand). Such blocks are made of lime-concrete. According to Thom's patent, the sand is unnecessary, if the mixture of screenings, lime, and water is consolidated in moulds under great pressure, the resulting blocks dried at 120° F. and placed in a steel chamber from which the air is exhausted and replaced by carbon dioxide gas, to which the blocks are exposed until re-carbonization is complete. Oolite and magnesian limestones respond most readily to this treatment.

4. Blocks made of crushed and screened limestone united by a cement composed of silica-flour and lime ; the blocks are hardened by heating in contact with steam under pressure whereby the bond is converted into lime-silicate.

5. Blocks made of crushed and screened limestone and bitumen or tar. Such blocks are described under "Asphalte blocks" in the section on Road Construction.

Limestone (and marble) is used as an ingredient of artificial stones, for which purpose it is crushed partly to small-sized pieces and partly to powder, which are then screened and afterwards mixed in suitable proportions with one of the binding agents just mentioned. The product is made into a paste with water, shaped in moulds under pressure, and the resulting blocks set aside to harden or they may be hardened by heat.

The stone should be of pleasing appearance, hard, with a good crushing strength (depending largely on the purpose for which the blocks are to be used, but not less than 200 tons per square foot). Its purity is of minor importance. Chalk is usually too soft for this purpose.

The methods of manufacture are described in *Bricks and Artificial Stones of Non-plastic Materials* by A. B. Searle (Churchill).

The following British Standard Specifications are important :

No. 340—1928—Concrete Kerbs, Channels, and Quadrants.

No. 368—1929—Concrete Flags.

No. 187—1934—Sand-Lime Bricks.

Concrete Aggregate.—Hard limestone forms an excellent aggregate for the production of concrete. Marble is still better, but can seldom be obtained at a sufficiently low cost. Chalk is too soft for work of great importance, but may be used quite satisfactorily for two-storey cottages with suspended concrete-floors, and possibly for larger structures.

The most pleasing results are obtained with Oolitic limestone which produces a concrete closely resembling Portland stone, but any of the hard varieties are suitable.

The inclusion of limestone among the prohibited materials in the London County Council Regulations for Concrete (No. 149-151) appears to be based on some misunderstanding, as it has been repeatedly proved that most limestones produce aggregates of first-class quality with ample resistance to fire in conflagrations.

The stone should be hard and close-grained with a specific gravity of about 2.7, a volume-weight of above 108 lb. per square foot, and a compressive or crushing strength of not less than 3,000 lb. per sq. in. The pieces should vary in size as much as possible within the prescribed limit as an aggregate in which all the pieces are uniform in size produces a weak concrete. The usual limits are between $\frac{1}{8}$ -in. and $\frac{3}{4}$ -in. diameter for floors, beams, columns, piles, etc., but for massive concrete, lumps up to 8-in. diameter (termed "plums") are used and the limits—apart from these plums—may be from $2\frac{1}{2}$ -in.— $\frac{1}{4}$ -in. For very thin parts—*e.g.* walls less than 3 in. thick—the limits may be $\frac{1}{2}$ -in.— $\frac{1}{8}$ -in.

In all cases, the crushed stone should be screened free from sand and clay. It must be perfectly "clean" and the fragments should be angular and cubical, but not flaky.

Loam or "dirt" has a serious effect on concrete, and a very small amount of clay or earth adhering to the broken stone will greatly weaken the concrete, as well as make the cement set too slowly.

Sometimes it is necessary to remove earth and fine dust by washing the stone.

The effect of washing dusty limestone screenings is shown by making comparative tests of the strength of the concrete made from the washed and unwashed stone using three parts of screening to one part of Portland cement. In one instance, which may be cited as typical, the results were :

TABLE XXI.—*Strength of Concrete made from Washed and Unwashed Stone*

Limestone.	After 7 days.	After 21 days.
Unwashed	177 lb.	229 lb.
Washed	159 lb.	361 lb.

In this case, the strength of the concrete after 21 days was increased 50 per cent. by removing the fine dust.

To determine whether a sample of crushed stone should be washed before use, a tall glass cylinder, about 14 in. high and 2 in. diameter, should be half-filled with the aggregate and then nearly filled with water and corked securely. The cylinder with its contents is shaken violently to dislodge all the small particles, and then set aside. In a short time the larger pieces will have settled, whilst the smaller ones will settle more slowly on top of the larger ones. If the

proportion of fine particles is noteworthy, the stone should be washed before use.

As the result of an elaborate series of investigations, Fuller and Thompson found that :

1. The largest pieces of stone make the densest concrete.
2. As small a proportion of sand as is possible should be used, the stone being crushed so as to produce a minimum of voids or air-spaces between the particles.

The sizes of stone which will give the best result can only be found by trial as follows :

An iron drum, about 22 ft. long and 10-in. diameter, is carefully packed and filled to within exactly 1 in. of the top with the stone. Water is poured in from a measure until it just covers the stone, and the quantity of water so used is noted. The pipe is then emptied, and the process repeated with other samples of stone, crushed or screened to different sizes. The sample which requires the least water is the best for concrete, provided that it works well in mixing, and that when used as concrete all the stones are covered.

The percentage of voids or interstitial spaces varies with the shape and sizes of the pieces of stone, but is usually about 48 per cent. with stone which passes through a 3-in. aperture and is retained on one $\frac{3}{4}$ -in. diameter, and 43 per cent. with a stone which passes a $\frac{3}{4}$ -in. aperture and is retained on a $\frac{3}{8}$ -in. diameter. The percentage of voids also varies with the volume-weights and the true density of the stone thus :

TABLE XXII.—*Variation of Percentage of voids with Volume-weights of stones*

Weight per cu. ft. in lb.	Percentage of Voids	
	Limestone (soft).	Limestone (hard)
70	55	57
75	52	54
80	49	51
85	45	48
90	42	45
95	39	41
100	36	38
105	33	35
110	29	32
115	26	29
120	23	26
125	20	23
130	17	20
135	13	17
140	10	14

This Table does not apply to materials fine enough to pass a $\frac{1}{4}$ -in. mesh sieve, and, therefore, a material that contains fine particles cannot have its percentage of voids determined by the Table.

For concrete aggregate, the stone is crushed in a gyratory or jaw crusher and the product is passed over screens with apertures according to the desired sizes of the stone. Some users of concrete wisely prefer to try stones of several sizes which they mix in suitable proportions to obtain a material with a minimum of voids.

For concrete roads, see the section on "Road Construction."

The chief disadvantage of limestone as an aggregate is the shrinkage which it undergoes when subjected to the action of fire; this sometimes causes the concrete structure to collapse. As the decomposition which causes the shrinkage does not commence below a red heat, the danger is almost negligible, though it has been regarded as sufficiently serious to cause the use of limestone for concrete to be prohibited by the London County Council (see p. 232).

When a choice of several kinds of limestone is possible, preference should be given to Carboniferous Limestone or to a highly siliceous limestone, as these make a stronger concrete than Oolite; for many purposes, the latter is of ample strength.

British Standard Specifications No. 340—1928 (Kerbs and Channels) and 368—1929 (Concrete Flags) should not be overlooked.

The sale of crushed stone for concrete aggregate is commonly restricted by the cost of transport and the availability of other materials, but much may be done by good salesmanship and careful attention to user's requirements.

Limestone sand consisting of grains of 50–80 mesh (obtained by reducing larger pieces to this size) is sometimes used as a fine aggregate, but is generally inferior to true (silica) sand for this purpose.

Concrete blocks are sometimes faced with limestone-chippings ($\frac{1}{4}$ -in.— $\frac{3}{4}$ -in.) in order to produce a "rock-face."

Cements.—For the production of Portland cement, either a natural or an artificial mixture of calcium carbonate, clay or slag, and silica is used. The first of these is usually employed in the form of chalk or limestone, and in some localities an argillaceous limestone is employed which contains a suitable proportion of clay or is associated with a clay which can be added to it so as to produce a suitable mixture. The Lias limestones are particularly suitable for this purpose, though they usually require the addition of a considerable proportion of clay.

In Kent and Sussex, chalk is largely used and considerable quantities of it are sent to Northumberland.

The limestone generally used for cement is the blue Liassic stone occurring in the Midlands and South Wales, but some oolitic limestone is used in Northamptonshire, Rutland and Oxfordshire. The Cambridge marls—which are really argillaceous limestones—are also used.

The proportions in which the clay, or its equivalent, and the lime compounds are mixed to produce Portland cement depends on the precise

composition of the actual materials selected. The mixture (before burning) should contain 75–77 per cent. of calcium carbonate and 23–25 per cent. of real clay, the best proportions being found by trial and adhered to as closely as possible in the course of manufacture. It is clear that if the “clay” contains lime compounds (like the marls) less limestone or chalk will be needed than when a lime-free clay or shale is used.

The proportions of lime and clay are usually calculated from the equation

$$\frac{\text{molecules CaO}}{\text{molecules SiO}_2 + \text{molecules Al}_2\text{O}_3} = 2.85$$

so that the composition of Portland cement varies considerably as regards minor constituents, and frequently as regards the ratio of silica : alumina present in it. In the best Portland cement, however, this ratio is usually 1 : 2.5–3.0 or 1 molecule of alumina to each 4–5 molecules of silica. The proportion of lime in the finished cement is usually about 65 per cent.

The *properties* required in chalk or limestone for the manufacture of Portland cement depend almost wholly on its composition. The percentage of calcium carbonate should be as high as possible, the magnesia should not exceed 1½ per cent., and the silica and alumina may be high, provided they do not exceed the molecular ratio just mentioned.

Iron oxide is not objectionable, except in large proportions, and the proportion of soda, potash, etc., may usually be neglected. Dolomitic or other magnesian limestone should not be used for Portland cement, as the magnesia in it is regarded as deleterious to the cement.

Natural Cement.—When a limestone contains calcium carbonate, clay and silica in just the proportion required to make a hydraulic cement, the latter product is known as a *natural cement* or *rock cement*. Large quantities of cement of this character are produced annually in Belgium and America, but the troubles caused by irregularities in composition have been serious.

As the materials are used without any purification, rock and natural cements usually suffer from the presence of an excess of iron oxide (which colours them dark brown), and of inconvenient proportions of magnesia, etc.

These natural or rock cements are far less uniform in composition than are Portland cements, because no care is taken to adjust the composition of the raw materials used. They are also inferior because they are generally under-burned—the temperature in the kilns being insufficient to cause complete combination of the clay and lime or their equivalents as it is under 1200° C. instead of 1400° C., or above.

The great drawback to natural and rock cements is their unreliability. At the present time their chief purpose appears to be to form a cheap rival to Portland cement. The superiority of the latter is so great, however, that manufacturers are finding it will pay them better to take more pains to secure a uniform product of a composition and properties practically identical with those of Portland cement. Some of them have, therefore, installed arrangements for testing and adjusting the composition of the raw material and of

treating it in the same manner as in making Portland cement. The process is certainly more costly, but the better prices obtained fully warrant the additional expense. With natural materials so nearly correct in composition, it seems unfortunate that firms should continue to produce so inferior a product as natural cement, when they might so advantageously manufacture Portland cement. To do this it is essential that the materials should be ground to powder and thoroughly mixed before entering the kiln, as the direct calcination of relatively large lumps is one of the chief causes of irregular composition. The two chief constituents of the material are not in sufficiently intimate contact to produce a uniform product unless the raw material has first been reduced to powder or made into a fine suspension in water, *i.e.* into a slip or slurry.

Hydraulic limes are prepared by calcining an argillaceous limestone, the clay present entering into combination with a portion of the lime and forming what may be regarded as a mixture of Portland cement and quicklime.

The chief raw material in this country for hydraulic limes is the blue Liassic limestone of Warwickshire, South Wales, etc., but other argillaceous limestones may be used. As will be understood from the previous section on the raw materials used for Portland cement, a much superior cement is obtained when the composition of the material is adjusted so as to give a product of approximately the same composition as Portland cement.

The composition of the limestones used for making hydraulic limes must lie between (1) pure limes with 3 per cent. of clay, and (2) marls or mixtures of clay and chalk which contain no excess of lime. It has been found that argillaceous limestones with 70–80 per cent. of calcium carbonate, 10–17 per cent. of silica, and not more than 3 per cent. of iron and alumina are best, as, in the hydraulic limes made from these, most of the clay is combined with lime, yet there is sufficient free lime present to cause the material to slake satisfactorily. Hydraulic limes may also be produced by under-burning a rock which would, at a higher temperature, produce an excellent natural cement, but these are very inferior and unsatisfactory.

Lutes and Cements.—A considerable number of cements used for filling fissures and depressions, and for sealing purposes, are known technically as *lutes*. Other cements are in extensive use in which the calcium carbonate present is an essential constituent though it has not, in itself, cementitious properties; among the best known of such cements is putty and various other mixtures of similar or analogous composition.

Putty is a mixture of whiting (or other form of calcium carbonate) and a viscous oil, the proportions of the two substances being such as will form a paste which serves equally well the purpose of a lute and a cement. Common putty consists of a mixture of five or six parts of whiting and one part of linseed oil, but equally satisfactory mixtures can be made with powdered or precipitated calcium carbonate from other sources and with other oils, with or without other ingredients. It will usually be found, however, that a levigated material must usually be employed to produce a putty of really good quality. Finely powdered magnesian limestone is used abroad, but here a whiting from

white chalk is almost invariably used ; it must consist wholly of small particles and must produce a paste which neither shrinks nor swells on hardening. Old putty, which has become hard, can be made like new by adding a little oil and re-grinding, but the quality will be somewhat inferior as the best putty is that which has the least oil in it. The whiting or its equivalent should be quite dry and fine. It should be sifted immediately before use.

Road Construction.—Limestone is extensively used in the construction of roads. The harder limestone rocks are used (i) as road metal ; (ii) as an aggregate for concrete roads ; and (iii) as a constituent of asphalt roads and paths.

Road Metal must be hard and tough to resist the abrasive action of wheels and horses' feet and the crushing effect of pressure and repeated blows. A hard brittle stone will soon be ground to powder and rendered useless. Road metal, when ground to dust, should also have a considerable binding power, so as to retain the various materials in position. The harder limestones fulfil all these requirements satisfactorily and are, therefore, used very extensively as road metal.

The use of limestone for roads involves a paradox because limestone is easily abraded and reduced to powder and so is, apparently, inferior to much harder stones, such as granite. In practice, however, limestone receives and retains a coating of tar, bitumen, or similar material so much more effectively than do harder stones that coated limestone is considered by many highway engineers to be one of the best materials for modern roads !

The most suitable limestones for road making are those consisting of broken shells or foraminifera cemented with crystalline calcite, the best being in the Carboniferous Limestone. Limestones with large shells or crinoidal fragments are less suitable as they fracture easily. Fine-grained magnesian limestone is usually excellent for roads, and so are some highly siliceous limestones.

Limestones for road making should be selected in accordance with the results of tests of their hardness and crushing strength, and of their resistance to attrition. On no account should they be selected by their colour as this is sometimes most misleading. Some highway-engineers consider that even the hardest limestones are too soft to be satisfactory as a wearing surface on concrete-roads, and that when used as "chippings" they tend to become slippery under traffic.

Limestone for Telford Roads.—In the method of constructing roads which was originated by Telford, a paved foundation is first made and on it rough stones are laid to form a total thickness of 5-8 in. The size of the foundation stones is not of great importance, but they are usually 6-20 in. in length, and 3-10 in. in width, the most common size being 8-12 in. long and 3-6 in. wide. The foundation stones are laid separately, and are held by smaller chips or "spalls" placed below them, and consolidated by rolling. The lower stones should be set on their widest edge with their width across the road and the joints broken as much as possible. The stones must be angular so as to interlock

properly, and they should be laid "on their bed" so as to secure a maximum resistance to wear. The upper covering of smaller stones is similar to that of a macadam road.

Limestone for Macadam Roads.—The method of construction devised by J. L. Macadam requires comparatively small pieces of angular stone of various sizes in such proportions that when wetted and subjected to the pressure of a roller they will interlock and form a compact mass.

The sizes of the pieces of stone depend on the hardness and toughness of the stone and upon the weight of the traffic. The harder and tougher the material, the smaller it may be broken without danger of its crushing or shattering under the load of wheels and the impact of hooves; the harder and tougher a stone, the smaller it must be broken in order that it may compact well in the road. The stones in the top course should be larger for heavy traffic than for light traffic to prevent their being ground to powder. Larger stones can be used in the lower layers of a road than at the top.

One of Macadam's rules was to exclude any fragment weighing more than 6 ounces. A $1\frac{1}{2}$ -in. cube of compact limestone weighs about 6 ounces. Another of Macadam's rules was to exclude any stone that could not readily be put into a man's mouth. These rules are still frequently quoted, although improvements in road machinery have made them inappropriate with present methods.

The bottom course of a macadam road built of soft stones is often composed of fragments 3–4 in. in greatest dimensions; but if it is built of hard tough stones, the sizes are 2– $2\frac{1}{2}$ in. The size of the rock in the lower courses is not so important as that for the surface course. The top course of hard tough stones is usually 1–2 in. for heavy traffic and $\frac{1}{2}$ –1 in. for light traffic.

Some road-makers prefer to have the stones in one course all the same size, but a stronger and more compact road may often be built of stones of various sizes as the latter contain fewer interstices. The objection to most "mixed" stones is that if "natural" they usually contain too much dust and small material, whilst if various sizes are mixed artificially either the cost is increased unduly or the mixing is ineffective.

For most purposes, the stone is crushed in an ordinary jaw-crusher and separated by screens into four sizes— $\frac{1}{2}$ in., $1\frac{1}{4}$ in., $2\frac{1}{2}$ in., and "over 3 in." Where the road-makers can satisfactorily use the whole of the material from the crusher it is a great advantage. Usually limestones yield too much "smalls" when crushed; the excess should then be removed by screening, as a road made of properly graded material is much more durable than one in which there are more voids or interstices between the solid pieces. A properly graded road material is one in which the interstices between the largest pieces are filled with pieces of a smaller size, the interstices then remaining being filled with progressively smaller stones, without any excess of the latter being used.

It is a useful rule to insist that 95 per cent. of the material shall pass through a ring whose diameter is three-quarters of the thickness of the road-material when laid and rolled. Thus, if the road material is to be 3 in. thick when finished, 95 per cent. of the aggregate must pass through a ring $2\frac{1}{4}$ in. diameter,

and none of the aggregate must fail to pass through a 3-in. ring. Some engineers rightly consider this rule provides pieces of too large a size and they prefer all the aggregate to pass through a 1½-in. ring.

It is not enough, however, to stipulate a maximum diameter for the pieces of aggregate. If all the pieces were of the same size, any stone would be unsuitable for a first-class road. The pieces must be of several different sizes, in order that they may form a sufficiently compact and dense mass.

Although pieces 3 in. or more in diameter may suitably be used as a lowermost course or paving, it is not desirable to use them for the uppermost 3 in. of the road-bed; for this part of the road, and generally for tar—or bitumen—macadam, it is desirable to divide the stone into four sizes, namely:

(a) Pieces less than 1½ in. and greater than 1 in. diameter.

(b) Pieces between ½-in. and 1-in. diameter.

(c) Pieces between ¼-in. and ½ in. diameter.

(d) Pieces less than ¼-in. It is sometimes desirable to screen out this material, to reduce it to less than 24-mesh, and to mix it with the binder. Such treatment prevents the failure of some binders to adhere to coarse aggregate containing some "dust."

In the author's opinion, size (a) is much too large for the upper parts of the road-bed, and, in many cases, a more durable road-material is produced by discarding this size and using only (b), (c), and (d), except for the foundation, where larger stones, laid as paving, are preferable.

In order to produce a mixture of maximum density, either of two methods may be used. Each of these four sizes of stone may be mixed in definite proportions, so as to secure a uniform grading. Under some conditions this would be secured by using 40 per cent. of (a), 40 per cent. of (b), 10 per cent. of (c), and 10 per cent. of (d). These proportions would only be correct if the sizes of the pieces in each group were properly balanced, and, as this is very seldom the case, it is far better to proceed as follows:

A suitable quantity of stone of size (a) is placed in a large measuring vessel, until the latter is filled exactly to the brim, or to a fiduciary line. The vessel, with its contents, is then weighed, and water is poured in until it exactly reaches the top of the stones.¹ The vessel and its contents are again weighed and the quantity of water added thus ascertained. The stones are removed from the vessel and are mixed with a volume of stones of size (b), equal to the volume of water required to fill the voids or interstices in the stones, and the mixture is placed in a similar, but larger vessel, weighed, and the voids or interstices are again filled with water, the amount required being ascertained as before. The water is poured off, and the stones mixed with a quantity of stones of size (c), equal in volume to the second quantity of water added. The amount of spaces or voids which can be filled with water is again determined, and stone of size (d) is then added to correspond to this water. In other words, the voids or spaces between the particles of stone of a certain size are filled, as far as possible,

¹ If a suitable graduated vessel is available, the volume of water added may be measured instead of determined from its weight.

with the stones of the next smaller size, this process being repeated, until the smallest size is reached. In no other way can so dense and compact a mass of stone be produced.

It is not necessary to separate stones in this way on a large scale. All that is required is that the mixture should consist of suitable proportions of stones of the various sizes to produce a minimum of voids and a maximum of compact stone. In many instances it will suffice if large samples of the stone are tested periodically and the necessary corrections are made by adding suitable proportions of the sizes in which the mixture is deficient, or in adjusting the crushing or screening plant so as to produce the desired sizes in the required proportions.

Just as the best concrete is not ensured by mixing aggregate, sand, and cement in the ratio of 1 : 2 : 4, or in any other definite mathematical proportions, so is it equally irrational to expect the best road material without definitely ascertaining by trial that the mixed stone contains the maximum of stone and the minimum of voids, and that the grading is reasonably regular from the smallest to the largest pieces.

In connection with the sizes of the pieces of aggregate it is also essential to recognize the great importance of using two aggregates—a coarse one of stone, and a fine one of "sand" or rock powder which passes through a 24-mesh, but is retained on a 60-mesh sieve. Many engineers omit the "sand," because this material consists of small particles with a very high percentage of voids, and, consequently, requires more tar or bitumen than a coarser stone. In many cases, the increased amount of binder which is supposed to be required is wholly mythical, and actually more binder is used with some stones from which all the fine stone has previously been screened than would be used if 25–30 per cent. of sand were added.

The objection to the use of sand or stone powder is largely fallacious. The fact is that, provided there is not an excess of powder and that it is not in the form of "dust," the more compact and durable will be the road. Like the stone, the grading of the sand should be regular and should not contain an undue proportion of material consisting of grains of one size.

The shape of the pieces of stone should be what is known as sub-angular, *i.e.* they should have many angles, yet they should not be much greater in any one direction than in others. Long thin pieces are very undesirable, as they do not produce the most compact mass. For this reason, slotted screens should be avoided.

The most compact roads are formed by pieces which have their length, breadth, and thickness almost equal, but have more angles than a cube or sphere. It is obviously too costly to select the individual pieces of stone very carefully, but the shape just mentioned gives the maximum amount of interlocking and, therefore, affords the greatest strength to the mass apart from the binder.

The interlocking of the pieces of stone has a further notable influence, as it is of very great importance that when a tar or bitumen macadam road

is laid and finished, the stones of which it is made should be of such a shape and so firmly fixed that they will not move when the road is used. If any movement occurs, the surface of the road will be adversely affected, and its durability will be lessened. Not only so, but, if the stones are capable of being moved by the pressure of the traffic on the road, it is clear that the road does not possess the necessary resistance to pressure, and its durability, on this account, will be low. This is one reason why many macadam roads made with tar are so much less durable than those made with bitumen, the same stone being used in both cases. The fault is not always with the binder ; it is sometimes due to the shape of the pieces of stone, to too many pieces being of the same size, to an absence of pieces of stone of certain intermediate sizes, and to the use of too large a proportion of binder.

The importance of screening and mixing the aggregate in such a way as to secure a mass of maximum compactness, and of avoiding a larger proportion of binder than is absolutely essential, is seldom realized, yet failure to achieve these two essentials may halve the " life " of a road. The durability of a road is not the " average " wearing power, for the surface must be renewed as soon as the least durable portions are unduly worn. Moreover, when grooves or ruts are formed, the breaking down of the surface takes place more rapidly than the ordinary starting of grooves. No matter how hard or tough the aggregate, if holes, ruts, or other depressions are allowed to remain unrepaired, the surface will wear away with abnormally great rapidity.

Tests applied to the roadway, or to pieces of the mixed materials treated as though they were to form part of the road, rather than to the stone used as aggregate, show that a limestone aggregate, properly graded and saturated with just the requisite amount of binder, will produce a roadway which is equally as resistant to abrasion and to repeated impacts as many existing roadways made of granite, trap, and other much harder stones. The reason for this difference is probably to be found in the better grading of the limestone, whereby the separate pieces of aggregate, when once in position, are so interlocked that they do not slip, even under the heaviest traffic, whereas the harder and smoother pieces of granite and trap-rocks, when graded less skilfully, do not form so compact a mass, and so the surface of the road is more readily distorted, and, therefore, wears away more rapidly. With some harder rocks it is difficult to get enough fine material for use in the original construction.

The difficulties of the production of road stone are often needlessly increased by idiosyncrasies on the part of the surveyors, some of whom are unreasonable in their demands.

Objection is sometimes raised to stone shrinking unduly under the roller, the shrinkage being attributed to the stone being too readily crushed. It frequently happens, however, that the apparent shrinkage is much greater than the true shrinkage and is due to the softness of the sub-grade or earth on which the stone is laid. A shrinkage of 25 per cent. is not objectionable. An excessive shrinkage may be sometimes prevented by applying a layer of " hard core " (brick, rubbish, ashes, etc.) prior to laying the stone, whilst the Massachusetts

Highway Commission uses a cheap "cheese cloth" material for sandy sub-grades!

The interstices between the pieces of stone should be filled with a fine material or binder, which will act mechanically to keep out the rain water (thereby keeping the sub-grade dry), to support the fragments (so preventing them from being broken), and which will bind or cement the fragments into a single mass which is more or less solid. The proper binding of the stone is the most important part of the construction of a water-bound macadam road.

Fine screenings—the finest product of the stone crusher, say, from $\frac{1}{2}$ -in. or $\frac{3}{4}$ -in. to dust—from the stone used in the body of the course is the most desirable material for a binder, partly because of its high crushing strength, and partly because the stone is usually selected for the high cementing power of its dust.

Sometimes the detritus removed from the surface of a stone road during maintenance or preparatory to making repairs is employed as a binder. At best, such material is very poor for this purpose. It is worn out, has performed its duty, and is composed largely of manure and vegetable and earthy matter—all of which are very undesirable in a binder. Such detritus is more valuable as a fertilizer than as a road material.

Clay and loam are frequently used. Their merit is that they are cheap, are easily applied, and have a high cementing power, but they are easily affected by water and frost, and when wet act more as a lubricant than as a binder. Clay or loam binder will give a smooth road without much rolling, but such a road is liable to be very dusty in dry weather and muddy in wet weather.

Shale and slate are only hard and compact clay, and their only merit is that they give a smooth surface with little rolling. They are speedily reduced to dust, and then have all the disadvantages of clay. They have only fair cementing power.

Sand is often used as a filler and, if composed of fine, clean, hard grains, gives fair results, but sand which is resistant enough for a good binding material usually consists of silica or quartz, neither of which has a high cementing power.

The amount of binder required should be sufficient to fill the voids or interstices in the rolled stone and to form a thin coating on the surface of each piece of stone. It usually amounts to about 35 per cent. of the thickness of the rolled stone. A large excess of binder is undesirable as it separates the stones which ought to take the greater part of the wear and tear. For the same reason, the road should always be rolled before the binder is applied as well as afterwards.

Tarred Roads are surfaced satisfactorily by laying a $2\frac{1}{2}$ -in. coating of $1\frac{1}{4}$ - $2\frac{1}{4}$ -in. stone on the old surface and filling the interstices with bitumen or tar. If the stone contains too large a proportion of voids, the coarse stone should be laid and rolled, then covered with a layer of finer stone which is also rolled, and finally covered with the bitumen or tar. When desired, a final coating about $\frac{3}{8}$ -in. thick of $\frac{1}{4}$ -in. stone *chippings* may be applied and rolled.

A better result is obtained by the use of tar macadam instead of plain stone.

Tar Macadam consists of pieces of stone which have previously been heated with tar or bitumen (asphalt) and mixed whilst hot, so that the stone absorbs some of the binding agent as well as being coated with it. A similar material, consisting of stone and bitumen, is frequently known as *bituminous concrete*.

Road stone, which is to be coated with tar, bitumen, or analogous material, must be carefully screened, so as to be free from dust. For the best results, stones of various sizes should be used; the following has been repeatedly investigated and yields excellent results:

- (i) All the stone to pass through a $1\frac{1}{4}$ -in. ring.
- (ii) Not more than 10 per cent. nor less than 1 per cent. to be retained on a 1-in. ring.
- (iii) Not more than 10 per cent. nor less than 3 per cent. to pass through a $\frac{1}{4}$ -in. ring.

It is still better, however, if the stone is properly graded as described on p. 239.

The nature of the tar or bitumen used as a binder is almost as important as that of the stone, bitumen being superior to tar, but much more expensive. For this reason, an "improved tar" (consisting of a mixture of tar and bitumen) is sometimes used in order to combine some of the advantages of both these binding agents. An excess of binder must be avoided as many roads are unduly weakened thereby. It is also necessary that, if a tar, bituminous, or similar binder is used, the stone must be quite dry.¹

The stone and binder are usually heated separately just prior to mixing. Heating with steam is preferable, as an open flame is objectionable on account of the danger. Great care should be taken to avoid over-heating the materials, as this reduces the resistance of the finished material. The temperatures must be adjusted to suit both tar and stone when they are mixed together as, otherwise, adhesion may be imperfect.

The stone must be thoroughly dried before being coated or the moisture in it may prevent the tar or other binder from adhering properly. This drying is particularly important with a porous stone like limestone and carelessness with regard to it is certain to cause trouble.

The bituminous cement, if asphalt, is usually heated to about 135°–177° C. (275°–350° F.), and, if tar, from 93°–135° C. (200°–275° F.). The stone for the asphalt mixture is heated to about 150° C. (302° F.), and that for the tar mixture to about 100° C. (212° F.). Any asphalt or tar that is heated to more than about 180° C. should not be used. No tar should be heated in a kettle containing any asphalt, and no asphalt should be heated in a kettle containing any tar; any mixture resulting from this cause should be rejected, except under responsible expert advice.

When discharged, mixtures of asphalt, cement, and broken stone should have a temperature of not less than 93° nor more than 149° C. (200°–300° F.). When discharged, mixtures of tar and broken stones should have a temperature of not more than 131° C., nor less than 66° C. (250°–150° F.).

¹ See p. 119 for a means of avoiding drying.

Ordinary concrete mixers may be used, but specially designed mixers are preferable. The size of the stone for tar macadam should usually lie between $1\frac{1}{4}$ in. and $2\frac{1}{2}$ in., but many surveyors have their own ideas on the subject and specify other sizes.

The chief causes of failure with tar macadam are :

- (a) A dirty or wet aggregate.
- (b) A badly graded aggregate.
- (c) Too little binder (about 7–11 gallons of tar per ton of stone are usually needed).
- (d) Overheating of the stone or binder.

Asphalt Roads have been extensively used in three forms of asphalt :

- (i) street asphalt, (ii) asphalt concrete, and (iii) asphalt blocks.

True asphalt is a bituminous limestone occurring in France, Switzerland, America, etc., and corresponding to a mixture of 9 parts of pure limestone (*Epure*) with 1 part of bitumen or mineral tar. In the United States, the bitumen is termed "asphalt" and not the whole rock; the latter is termed "asphaltic limestone."

Artificial or "British" asphalt is made by mixing limestone, chalk, silica, or other mineral dust with bitumen or tar in the same proportions as they occur in natural asphalt. The materials must be mixed whilst hot.

It has generally been understood that calcareous fillers are superior to siliceous ones in asphalt, but Evans¹ has found that chalk and limestone-flour are inferior to a very fine silica-flour in raising the melting point of an asphalt, increasing the tensile strength, and decreasing the penetrability of the mixture. The differences are not great and may be without significance.

He has found that an asphaltic cement of maximum ductility and tensile strength is produced by using as hard a bitumen as possible with a minimum proportion of filler to produce the requisite tensile strength. The ratio of bitumen to filler must be correct within very narrow limits, as most failures in asphalts are due to unsuitable proportions of filler.

Limestone-filler has a great advantage over most others because it has less tendency to form objectionable emulsions of bitumen or tar in water.

A street-asphalt road consists of a wearing coat or surface $1\frac{1}{2}$ –2 in. thick, composed of about 15 per cent. of asphalt cement, 75 per cent. of sand, and 10 per cent. of limestone dust, overlying a binder course 1– $1\frac{1}{2}$ in. thick, composed of broken stone and asphalt cement, preferably on a concrete foundation. The limestone dust is mixed with the sand to fill the voids partially and so reduce the amount of asphalt required, and also to permit the use of a softer asphalt. The heavier the filler, per unit of volume, the better, since this usually indicates greater density; the denser the filler, the denser and more stable the wearing coat. The valuable part of the filler is the impalpable dust which is much finer than the particles just passing a 200-mesh sieve. A good filler should contain at least 60 per cent. by weight of actual dust, and preferably 80 per cent. should pass through a 200-mesh. Some highway-engineers prefer a much coarser

¹ *J. Inst. Petr. Tech.*, 18, 958, (1932).

filler and specify limestone ground so as to pass completely through a 30-mesh sieve, but to leave not more than 15 per cent. on a 100-mesh and 20 per cent. on a 200-mesh.

The amount of material in the wearing coat passing a 200-mesh sieve varies from 10-50 per cent., according to the grading of the sand, but usually from 12-20 per cent. Less filler is required with Trinidad asphalt than other kinds, since it naturally contains about 44 per cent. of finely divided mineral matter.

Asphalt concrete roads are made of a mixture of crushed stone and asphalt. The stone may be of all sizes from 3-in. to powder, but in most cases the largest pieces of stone do not exceed 1½-in., and in many instances no stone larger than ½-in. is used.

The hot asphalt may be applied direct to the road or pavement and consolidated by tamping, or it may be run into moulds and formed into blocks which are afterwards placed on the road and the joints sealed by pouring in tar.

Blocks of crushed limestone and dust bonded with 10 per cent. of asphalt 12 in. × 5 in. × 2½-3 in. deep are moulded under a considerable pressure at a temperature which will produce a mass with a specific gravity of not less than 2.35. The blocks are made in a works and delivered as any other form of stone, but require careful packing, as they easily break in transit.

A coarse product is largely used for roads; thus for a Bitulithic pavement the limestone may be graded as shown in column A (due to Agg), as in column B (the well-known "Topeka Mixture," used extensively in the United States), or as in column C, which shows the grading recommended by the American Society of Municipal Improvements.

TABLE XXIII.—*Grading of Limestone for Bitulithic Pavements.*

	A	B	C
Bitumen	7.6	7-11	7-9
Limestone passing 200-mesh ...	4.9	5-11	7-10
" " 100 " ...	4.6	—	—
" " 80 " ...	3.2	—	10-20
" " 50 " ...	7.3	—	—
" " 40 " ...	3.1	18-30	10-25
" " 30 " ...	2.4	—	—
" " 20 " ...	2.2	—	10-25
" " 10 " ...	5.1	25-55	—
" " 8 " ...	—	—	10-20
" " 4 " ...	—	8-22	15-20
" " 2 " ...	—	not over 10	5-10
" " ½ in. ...	9.1	—	—
" " ¾ in. ...	19.3	—	—
" " 1½ in. ...	31.2	—	—

When the traffic is very light, chalk may be substituted for limestone, sufficient chalk being used to enable a hot mixture of sufficient plasticity to be produced. According to M. Talbot Cosbie, equal parts of tar and chalk are satisfactory.

Mastic Flooring is chiefly composed of a mixture of bitumen or pitch and limestone-screenings the size of the latter depending on local circumstances. Usually the limestone is " $\frac{1}{4}$ -in. to dust," but sometimes a larger proportion of $\frac{1}{4}$ -in.- $\frac{1}{8}$ -in. stone is added. For the finer qualities a suitable dust is one of which 80 per cent. passes a 200-mesh sieve, and 50 per cent. consists of particles less than 25μ diameter.¹ Such a dust added to sand of uniform grading (equal proportions on all sieves between 10-mesh and 200-mesh) will produce a mixture of minimum voids, *i.e.* much lower voids than either the sand or the limestone. When used alone, about 9 parts of limestone dust may be added to each part of bitumen; pitch, though used, is not very satisfactory.

Concrete Roads are merely a special application of concrete. Limestone makes an excellent aggregate for this purpose. It should be crushed and screened so that it passes completely through a $1\frac{1}{2}$ -in. ring and not more than 5 per cent. through a $\frac{1}{4}$ -in. ring. The proportions of intermediate sizes should be regular, as a material consisting chiefly of fragments of one size is undesirable. Crusher-run stone or artificial mixtures of different sizes should, ordinarily, not be used.

Garden Paths and Drives.—Limestone is very suitable for garden paths, if the stone is properly crushed and screened so as to exclude all pieces larger than $\frac{3}{4}$ -in. diameter. With larger fragments, the path is difficult to maintain and it is unpleasant to walk or drive on it. An ample supply of fine stone must also be present to act as a binder; clay or loam is often used for the same purpose, but is not satisfactory.

Asphalt Paths are made, like asphalt roads, by heating a mixture of limestone and either asphalt or tar, stirring the mixture until it is uniform, and then laying it on the paths. More frequently, they are made by (i) placing a layer of stone-chips or screenings on the path and filling it with molten tar or asphalt which is rolled in, or (ii) by placing a layer of tar or asphalt on the ground, covering it with stone screenings, and these with more tar or asphalt, and then consolidating the materials by rolling.

In each case, the limestone chippings should not exceed $\frac{3}{4}$ -in. diameter, and the majority should be $\frac{1}{8}$ - $\frac{1}{2}$ -in. diameter. Finely-ground limestone may also be mixed with the binder in order to increase the wear-resisting power of the path and to reduce the amount of binder required.

Preparing Limestone for Roads.—The stone must be crushed and screened so as to reduce it to pieces of suitable size. The crushers should be of such a type as to produce as cubic a material as possible, flakes being very objectionable. For this reason, a jaw crusher is preferable to a rotary

¹ $1\mu = 0.001 \text{ mm.} = 0.00004 \text{ in.}$
 $25\mu = 0.025 \text{ mm.} = 0.001 \text{ in.}$

disintegrator for the larger sizes and crushing rolls or a granulating jaw crusher is preferable for the medium sizes. The product from crushing rolls is much more cubic than that of a jaw crusher, though granulating jaw crushers give good results. The angularity of the pieces is also important, as rounded stones do not "bind" well in the roads.

In screening limestone for roads it is important that the product should be as accurate as possible in size. In this connection it is well to remember that any shape may be passed as conforming to specification if it will pass through a ring of the stipulated diameter. Thus, a piece of stone about 3 in. \times $1\frac{7}{16}$ -in. \times $1\frac{7}{16}$ -in. must be accepted as "passing through" a $1\frac{1}{2}$ -in. ring. At the same time it is not desirable to supply such long pieces and the wise quarry owner will, for that reason, prefer to avoid *slots* in the screens which he employs.

It is most important when screening limestone, not to subject the stone to too much "hammering" in the screens, as this tends to round off the angles. If rotary screens or lifters are used they should be of such a pattern as to avoid excessive movement of the stone.

It is also important that all "fines" should pass through the perforations or mesh as soon as possible; otherwise, the various grades will not be properly separated and the stones will not be "clean."

The most satisfactory type of screen for road stone, so far as the product is concerned, is made of stout wires or rods woven to form a square mesh of suitable size. Such a screen has a much larger area than one made of perforated metal and it also produces a "cleaner" product, the pieces being separated more completely as they travel over the crossed wires than when they slide along a perforated sheet.

Cleanliness factor.—The "cleanliness" of a roadstone, *i.e.* its freedom from pieces of a larger or smaller size than specified, is very important. It can only be secured by working the screens under good conditions; if they are "forced" unduly, one or more of the products will be unsatisfactory.

Screens which do not cause an almost instantaneous separation of the smaller particles seldom yield a clean product. Woven screens are superior in regard to sharpness of grading and, therefore, to cleanliness of product, than are screens made of perforated sheet. Perforated sheets are much more durable and cost less per ton of stone screened: for most purposes they are sufficiently satisfactory.

Stone dust for roads may be made in any convenient type of disintegrator, as reduction to the finest dust is not essential except as a filler for asphalt. For the latter purpose, a material passing completely through a 40-mesh and of which 80 per cent. will pass through a 200-mesh sieve is often specified; a ball mill with air separator or a tube mill is required to produce it. For material intermediate in fineness between the product of a disintegrator and that of a tube-mill, a Griffin pendulum mill, or a Hall or Raymond mill are highly satisfactory. There is an increasing tendency to use material which corresponds to 300-mesh, for which purpose air separation must be employed. The cost of grinding to 200-mesh varies from 2s. 6d. to 8s. 6d. per ton. The

finished product usually realizes 15s.-25s. per ton for 200-mesh and 25s.-35s. for 300-mesh and finer dust.

For information on coating limestone with tar or bitumen see p. 243.

Ballast for railway embankments, harbour, dock, and reservoir-construction, etc., is frequently made of crushed limestone, when cheaper (waste) materials are not available. The stones required for this purpose may be of all sizes down to $\frac{1}{2}$ -in., according to the nature of the work and the requirements of the engineer.

(c) USES OF CHALK, LIMESTONE, ETC., IN THE CHEMICAL INDUSTRIES

In the chemical industries, calcium carbonate is chiefly used (in the form of finely-ground chalk or limestone) (*a*) as a base; (*b*) as a source of lime; (*c*) for the manufacture of carbon dioxide gas; and (*d*) for the manufacture of various calcium compounds, such as calcium sulphite.

As a base¹ it is used for neutralizing acids. Strictly speaking, the carbonate is a salt and not a base, but the carbon dioxide present is so easily displaced that for many purposes its presence may be neglected and limestone or chalk used equally as satisfactorily as lime, which is a true base.

The chief purposes for which calcium carbonate is used as a neutralizing agent will be realized from the following examples:

In the *manufacture of colours* from acid solutions of iron salts, finely divided calcium carbonate is added to the solution in order to neutralize the acid and so enable the base or colour to be precipitated. In some cases, the carbonate is used solely as a neutralizing agent, the colour being precipitated later by means of milk of lime.

Lactic acid is prepared by fermenting maltose with the lactic bacillus at about 50° C., chalk or other finely-divided calcium carbonate being stirred into the mixture to neutralize the lactic acid as fast as it is produced. The solution of calcium lactate is afterwards decomposed by sulphuric acid and the lactic acid separated and concentrated.

Tartaric acid is made by boiling argol—a crude bitartrate of potash obtained as a by-product in the manufacture of wine—with chalk to form insoluble calcium tartrate, which is filtered, washed, and then decomposed with sulphuric acid. It is better to neutralize the acid with calcium carbonate, but to use hydrated lime to precipitate the calcium tartrate. Another good method consists in adding enough hydrated lime to precipitate 90 per cent. of the total acid. Sufficient calcium carbonate is then added to neutralize the remaining 10 per cent. of acid, and leave a slight excess of calcium carbonate.

Experience has shown that if the juice is completely neutralized with calcium hydroxide, dark coloured compounds are formed which are difficult, if not impossible, to wash out, yet, if not removed, they cause the liquor pro-

¹ The term *base* cannot be defined exactly as it is used in a very loose manner. Probably the best definition for general purposes is that which describes a base as a substance (other than a salt) possessing the power of neutralizing acids by forming neutral compounds with them.

duced by the decomposition of the tartrate to be very dark coloured and increase the difficulty of securing satisfactory crystals.

It has also been shown that, however great the excess of calcium carbonate added to the juice, there is always a small residual acidity, varying from 0.08 to 0.20 per cent. depending on the acidity of the original juice. This slight acidity keeps the dark-coloured compounds in solution and enables a white precipitate to be produced.

Citric acid is made from lemon, lime, or bergamot juice in the same manner as tartaric acid; chalk, or other finely-divided calcium carbonate, being used for the same purpose.

Starch-sugar or *glucose* is made by heating starch with dilute sulphuric acid, the liquid being afterwards neutralized by chalk or its equivalent, and then filtered and concentrated.

Dextrin or *British Gum* is made in a similar manner to glucose, chalk or its equivalent being used to neutralize any excess of acid.

Refuse liquors, including *Pickling liquor*, may be made to yield the iron and some other metals in solution by adding limestone, chalk, or other form of calcium carbonate to neutralize the greater part of the acid, the precipitation of the metal being then effected by adding hydrated lime or milk of lime.

In the manufacture of *chlorine* and *bleaching powder*, one of the relatively expensive chemicals used is manganese chloride, which is left in the still after the free chlorine has been liberated. In the Weldon recovery process, the liquor is neutralized with ground chalk, limestone, or other form of calcium carbonate. The precipitated manganese is then separated and after being treated with milk of lime can be used again.

Properties required.—When used merely as a neutralizing agent, the chief property required in chalk or limestone is that it shall be reasonably pure and as rich as possible (consistent with the price) in true lime or calcium oxide. Other materials may be useless (as silica), of slower neutralizing action (as magnesium carbonate) or actually harmful to the material to be neutralized, as is the case with some iron compounds.

Of the various forms of calcium carbonate available as a cheap base, or neutralizing agent, those most used are chalk, whiting, recovered carbonate (such as the lime-mud produced in the manufacture of caustic soda), marble-chippings, and finely-ground limestone. The last-named is used where 6 per cent. or more of impurity is not regarded as harmful. The mountain limestone of Buxton and North Yorkshire (Skipton and Settle) is exceptionally pure and supplies most of the demand for limestone by chemical manufacturers in Lancashire and Cheshire.

The chief objections to any form of calcium carbonate as a neutralizing agent or base are the large quantity required (about half the weight of lime having an equal neutralizing power) and the amount of froth produced as a result of the evolution of carbon dioxide gas.

As a source of lime, the use of chalk, limestone, etc., is considered in the next Chapter.

For the production of carbon dioxide gas its use is considered in Chapter IX. A high calcium lime is required, and great chemical purity, though very desirable, is not essential.

As a Chemical Agent, limestone and white chalk are extensively used in the production of various substances, in addition to those previously mentioned. A material rich in calcium carbonate is usually preferred, though, for some purposes, magnesian limestone is equally suitable; it cannot be used where the resulting magnesium salts would have a deleterious effect on the substances being manufactured. Magnesian limestone has the advantage of having a greater neutralizing power than calcium carbonate, 84 parts of magnesium carbonate being equal in this respect to 100 parts of calcium carbonate.

Manufacture of Alkali.—The term *alkali* is applied commercially¹ to several substances, the most important of which are sodium carbonate, soda ash (which contains 98–99 per cent. of Na_2CO_3), caustic ash (which contains about 20 per cent. of NaOH), soda crystals or washing soda ($\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$) crystal carbonate ($\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$), bicarbonate of soda (NaHCO_3), sodium sesquicarbonate ($\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot 2\text{H}_2\text{O}$) and caustic soda (NaOH).

Alkali is made by two entirely different processes, known respectively as (i) the “Leblanc” or “Black ash,” and (ii) the “Solvay” or “Ammonia soda” process.

In the *Leblanc process*, common salt is converted into “salt cake” (sodium sulphate) which is then heated with calcium carbonate and small coal, the product being “black ash” (a mixture consisting chiefly of sodium carbonate and calcium sulphide) from which the various forms of sodium carbonate and caustic soda are afterwards prepared.

The calcium carbonate may be used in the form of chalk, limestone, “alkali waste,” or “lime sludge” (two by-products from the manufacture of alkali). The material employed should be as rich in calcium carbonate as possible, and should not contain less than 96 per cent. of this substance. It should be as free as possible from silica, alumina, and magnesia, as the two former cause a waste of soda as silicate and aluminate and the last is too feeble a base to do the work required of it. The calcium carbonate should be dry and in fragments about the size of peas. Bituminous matter is not harmful and may even reduce the amount of charcoal or coal required.

If chalk, alkali waste or any “recovered” calcium carbonate is employed, it must not be moist, or it will be necessary to dry it before use.

Preparation.—Free limestone or chalk used in the manufacture of black ash is crushed by means of an edge runner or pan mill or crushing rolls to the size of a pea or small bean. Powdered calcium carbonate is not usually so satisfactory as material in somewhat larger pieces.

In the *Solvay* or *Ammonia soda* process, limestone is not used directly, but it is required as a source of carbon dioxide, the manufacture of which is described in Chapter IX.

¹ In pure chemistry the term *alkali* is used for any base which is soluble in water and which will neutralize an acid to form a salt and water.

Potash is sometimes obtained from potash-bearing rocks (felspars) and from flue dusts by heating with finely ground limestone and ammonium sulphate, but the cost of production is usually greater than that of potash from other sources.

Calcium Carbide is made by mixing ground limestone with coke or coal and heating it in an electric furnace. A fairly pure calcium carbonate must be used; more than 2 per cent. of magnesia, 3 per cent. of silica, and 0.06 per cent. of phosphorous pentoxide and arsenic are objectionable. As electric heating is more costly than that by coal, it is now customary to use lime in preference to limestone when making calcium carbide.

Calcium Cyanamide is made by treating fused calcium carbide with nitrogen. It is used chiefly for nitrogenous fertilizers and as a source of cyanide. Impurities in limestone for the making of cyanamide are not of such great importance as for carbide manufacture, but, on account of the extra expense in fusing them, a pure high-calcium limestone is required.

Various chemicals are made by first forming the corresponding calcium compound with the aid of chalk, limestone, or its equivalent. The lime-compound being usually insoluble it may be filtered off, washed, and then decomposed so as to form the desired compound. As slaked lime or milk of lime is more active in forming compounds of the nature described it is usually preferred to chalk or limestone, though the latter are used when conditions are suitable.

Thus, chromates and bichromates are made by roasting a mixture of chrome iron ore with chalk or limestone and soda ash to form calcium chromate. This is decomposed by heating it with a solution of soda ash, which forms sodium chromate and calcium carbonate. The sodium chromate is afterwards converted into potassium chromate or a bichromate by methods which do not involve the use of lime.

Where a lime compound is used for a single industry, such as paper, glass, etc., its use is described in the section on that industry.

(d) USES OF LIMESTONE, ETC., IN EXPLOSIVES AND ALLIED INDUSTRIES

Calcium carbonate is used in the manufacture of various explosives, especially gun cotton and dynamite, to free the material from any acid which may be formed by the decomposition of the explosive. In each case, the calcium carbonate is merely required to neutralize the acid, so that its composition (provided it does not contain much silica, which is useless) is relatively unimportant. Consequently, limestones containing magnesium compounds may be used equally as well as pure calcium limestones and as magnesium carbonate. For this reason, chalk, limestone, dolomite, and artificially-prepared calcium carbonate, if sufficiently finely ground, are all equally satisfactory as anti-acids in explosives. One or other of these substances is usually the only anti-acid, but sometimes another anti-acid, such as zinc oxide, is used. Dynamite generally contains less than 1.5 per cent. of calcium carbonate, but special powders contain as much as 15 per cent. The impurities

in limestone, if they are less than about 5 per cent. in all, are of no practical importance in the manufacture of explosives.

(e) USES OF LIMESTONE, ETC., IN FURNACE CONSTRUCTION

Limestone is not extensively used as a refractory material in furnace-construction because of its softness when burned and of its active chemical properties. Dolomite and high-magnesian limestone are used extensively as substitutes for magnesite refractories in basic open-hearth steel furnaces, basic Bessemer converters, lead refining, reverberatory furnaces, lead cupelling furnaces, crucibles for lead blast furnaces, copper converters, copper reverberatory-furnaces, and in the form of crucibles for melting metals. Dead-burned material in various forms is commonly used, although raw dolomite may be employed for minor repairs. Raw magnesian limestone has also been used in the hearths and walls of some furnaces in which a basic slag is produced, but magnesia is so superior that it is now generally used (see *Metallurgy*, p. 254).

Many patents have been granted for the use of limestone as a refractory material, but most of them have proved to be impracticable.

The term *dolomite* is often used in furnace-construction; the substance referred to is not the raw stone but a highly calcined or "dead burned" material, which is really a magnesian lime, and, therefore, is included in Chapter XII.

(f) USES OF LIMESTONE, ETC. IN GLASS MANUFACTURE

Some glasses are made by melting a mixture of soda-ash (or salt-cake), lime, and silica in suitable proportions at a temperature approaching 1500° C. As calcium carbonate is converted into lime at about 700° C. it is obvious that any form of calcium carbonate which is sufficiently finely-ground to avoid the formation of insoluble "seeds" or "stones" may be used instead of lime. The only other objection to pure chalk, limestone, and other forms of calcium carbonate is the possibility of the carbon dioxide evolved by the action of heat failing to escape from the viscous molten glass and so remaining as minute bubbles when the glass congeals. As no gas is evolved when lime is used, it cannot cause this defect. Limestone is usually preferable to lime because its composition is more uniform and it is less disagreeable to handle. The gas evolved also exerts a stirring action which is advantageous. The relative rates of melting when lime and limestones are used cannot be ascertained directly as they are complicated by the action of the sodium compounds which also enter into the composition of the glass. As the limestone is decomposed before it can enter into combination with the silica a glass batch in which limestone is used ought to require a longer time than one in which lime is employed, but this is not always the case. Hodkin and Turner have found that mixtures of salt cake and limestone melt more rapidly than those of a salt cake and lime, but if soda ash replaces part of the salt cake the difference is less marked.

The chalk, marble, limestone, or equivalent used for the manufacture of glass should not contain more than 0.05 per cent. of iron oxide or 3 per cent.

each of alumina and silica, unless it is desired to include alumina as one constituent of the glass.

Most chalk contains calcium phosphate in varying proportions and is in that respect unsuitable for clear glass.

Magnesian limestone tends to make a rather tougher glass than pure calcium limestone, but the proportion of magnesia should not usually exceed 2 per cent., as it is liable to make the glass very viscous and "stringy." It is, therefore, obviously undesirable to use a chalk or similar material containing less than 95 per cent. of calcium carbonate (except in the case of very low-grade glass) and preference is usually given to a material containing 96 per cent. of this constituent.

The following alternative figures have been suggested according to the class of glass to be made, but they permit the use of limestones of far less purity than is generally desirable :

TABLE XXIV.—Analyses of Limestones, etc., for various kinds of glass

	Class I.	Class II.	Class III.
	per cent.	per cent.	per cent.
Calcium and magnesium carbonates	96.0 min.	91.0 min.	83.0 min.
Iron Oxide	0.2 max.	0.4 max.	0.8 max.
Sulphur dioxide and phosphorus pentoxide	1.0 max.	1.0 max.	1.0 max.
Silica	4.0 max.	9.0 max.	17.0 max.
Alumina	3.0 max.	5.0 max.	5.0 max.

The material should be sufficiently fine to pass completely through a 60-mesh sieve, though some glass-manufacturers are content if it passes completely through a 16-mesh sieve with openings 0.05 in. diameter. Dust should be avoided, as it reacts irregularly and much of it is carried over into the regenerators and is lost. The most suitable sizes of grains are obtained if 95 per cent. of the material passes through a 30-mesh sieve and 90 per cent. is retained on a 90-mesh sieve. As this material is generally regarded as too costly (notwithstanding its advantages) it is usual to accept material less than $\frac{1}{8}$ -in. diameter, especially if it is almost free from dust.

(g) USES OF CHALK, LIMESTONE, ETC., IN MEDICINAL AND PHARMACEUTICAL PREPARATIONS

The chief medicinal and pharmaceutical preparations (including tooth-powders and toilet preparations) for which calcium carbonate is used are *creta preparata* and *creta praecipitata*. These are used in the production of various pharmaceutical preparations, such as "grey powder," "camphorated chalk," etc.

The preparation of these materials has been described in Chapter III.

The properties required in chalk, etc., used for these purposes are :

- (i) The maximum proportion of calcium carbonate.
- (ii) Complete absence of harmful impurities and especially of traces of arsenic and other poisonous substances.
- (iii) Complete freedom from grit and other coarse particles. This is specially important when the material is to be used internally or in dentifrices.

Dentifrices.—Precipitated chalk (p. 183) is largely used in dentifrices, in which it (a) neutralizes acidity in the mouth ; (b) has a mildly abrasive action without scratching ; and (c) is an almost ideal absorbent and carrier for essential oils and other germicides. The “lightest” grades of precipitated chalk are the best for this purpose. They consist of a mixture of aragonite and calcite.

As crystals of aragonite and calcite differ appreciably in hardness, it is important in making dentifrices to maintain a constant proportion of each form. This is best controlled by comparing the relative intensities of the main lines in an X-ray spectrum photograph with those in similar photographs of calcite and aragonite respectively, as described by Cox and Goodwin in *Chemistry and Industry*, LII, 172 (1933).

(h) USES OF LIMESTONE, ETC., IN METALLURGY

In the production of various metals—especially iron, copper, and lead—from their ores, it is usually important to reduce both the metal and the other constituents of the ore to a molten state so that both may be drawn out of the furnace as fluids. For this reason, limestone is extensively used to combine with the silica and alumina contained in the ores to form a readily fusible slag, consisting chiefly of an orthosilicate $2\text{CaO} \cdot \text{SiO}_2$ or metasilicate $\text{CaO} \cdot \text{SiO}_2$ which also contains other silicates, aluminates, etc., which is drawn out of the furnace as required. Substances which combine with silica and alumina to form a molten product are known as *fluxes* and the various natural forms of calcium carbonate are particularly useful as fluxes on account of their cheapness.

The limestones used as fluxes in metallurgy are chiefly those of the Carboniferous and Oolitic formations, but Surrey Chalk has also been extensively employed.¹

The material is usually supplied in pieces 3-in.-6-in. cube ; very small pieces tend to lie too compactly and so spoil the draught of the furnace, whilst pieces which are more than about 6-in. cube usually require so long for the heat to penetrate them that they are unsatisfactory.

As the only constituent of value as a flux is the lime, the stone should contain as large a proportion of lime as possible and stones containing less than

¹ The relative merits of raw limestone and lime in basic electric steel furnaces have been studied by O. von Keil and E. Czermak (*Stahl und Eisen*, LII, 133 (1932)), who found that steel treated with lime contains more gas than that treated with limestone, but suffers less oxidation of the metal. In blast furnaces, the use of lime facilitates a larger output as it occupies less space than the corresponding quantity of stone.

90 per cent. of calcium carbonate are seldom worth using. The limestone or chalk should also be as free as possible from magnesia,¹ silica, sulphur, phosphates, etc. Carbonaceous and bituminous matter are difficult to burn and render the production of a thin fluid slag very difficult.

A noteworthy amount of *silica*, silicates, or alumina is objectionable, because it is useless as a flux, requires some of the lime to combine with it, and increases the amount of slag produced. Apart from these objections, silica and alumina do no harm, so that limestones containing them as impurities may be used if the cost of forming the slag and dealing with it is not greater than the difference in price (at the iron works) between purer and low grade stones. Wherever possible, however, the proportion of silica and alumina together should not exceed 5 per cent.

Magnesia is objectionable, as it makes the molten slag viscous, and prevents proper separation of the molten metal. This is particularly troublesome in lead and copper smelting (where 12 per cent. of magnesia in a stone makes working difficult), and it is also serious in the smelting of iron. Some iron-masters claim that the presence of a little magnesian limestone is an advantage in blast furnaces, as it produces a less fusible slag which, by increasing the working temperature, ensures a more complete removal of the sulphur in the iron. In most cases, however, the disadvantages of magnesia are greater than its advantages.

Sulphur is of minor importance, as it is retained by the slag, if the latter is sufficiently basic, but not more than 0·25 per cent. of sulphur is usually permitted as many metallurgists fear (erroneously) that it may contaminate the metal.

Phosphorus is detrimental, as it is withdrawn from the limestone into the metal, as shown by Berthier in 1838, and, later, by Lowthian Bell and others.

Although limestone or chalk is chiefly used as a flux in smelting metallic ores, it is sometimes found cheaper to use lime. The reasons for this are: (a) as the ironworks are usually some distance from the quarries, there is a saving of 44 per cent. on the weight of material transported when lime is used; (b) the cost of calcining the lime in a well-managed kiln of modern type is sufficiently close to the amount theoretically needed to balance any imaginary saving by calcining the stone in the blast-furnace; (c) the lime occupies little more than half the space required by the stone, and this space is, therefore, made available for more material to be smelted, thereby increasing the output of the kiln and reducing the waste of raw ironstone. The limestone travels much lower down the furnace than the lime, and so reduces the space in the "bosh" where the mixture of limestone and ore fuses and is converted into iron and slag. When lime is used, it breaks into small pieces much higher in the furnace, and becomes more intimately mixed with the ore, so that it reacts earlier and with less waste of ore; (d) the carbon dioxide tends to hinder the

¹ Magnesia tends to produce a viscous slag which is very troublesome, but limestone containing less than about 7 per cent. of magnesium carbonate is seldom objectionable in this respect. A slag containing magnesia is often preferred for road-metal so that a little magnesian limestone is sometimes used by metallurgists to ensure a better sale for the slag.

combustion of the coke in the blast furnace, and also wastes both coke and ore, and (e) the lesser amount of heat required when lime is used enables the material to be smelted more rapidly, so that a larger output is obtained. Hence, when a large amount of flux is required, the use of lime effects a notable saving in the cost of smelting the ore. It is not necessary that the whole of the stone should have been converted into lime, prior to use, so that a low grade of lime, containing 30 per cent. of unburned calcium carbonate, may be used, and still effect a considerable saving.

In smelting some ores, calcium carbonate will not form a slag unless some other flux is present. Thus, in smelting copper about twice as much (ferrous) iron oxide as lime is used as a flux, and in smelting lead more iron oxide (ferrous) than lead is sometimes used.

In addition to its use as a flux, magnesian limestone is used for patching the hearths and floors of basic furnaces, the calcined or dead burned stone being used.

(i) USES OF LIMESTONE, ETC., IN MINING

Calcium carbonate was not, until recently, used in the mining industries, but it is now extensively employed in the process of "stone dusting," to minimise the risk of explosions in coal mines. The fine dust is spread on shelves in the galleries of the mine in such a manner that, when an explosion occurs, the cloud of dust which will be raised will extinguish the flame and arrest the explosion. The best method of distributing the dust appears to be by means of a "blower" or injector nozzle fitted onto a small wagon, travelling at the rate of about three miles per hour, but some colliery managers claim that dust thrown by hand gives better results.

The material must be so fine that it rises readily into the air when an explosion occurs, otherwise it is useless. It must also be sufficiently free from grit to avoid damaging the eyes of the miners.

These properties are obtained if the material is ground so fine that the whole of it will pass through a standard I.M.M. sieve with 200 holes per linear inch, but as such fine grinding is costly, the present regulations are satisfied if 50 per cent. of the material will pass through such a sieve. As grinding facilities improve, the regulations will probably be made more stringent.

As precipitated calcium carbonate is exceptionally fine, and is a waste product from various chemical industries, its use for stone dusting in mines appears to be worth further investigation.¹

The fineness may be determined by sifting a weighed amount of the material through a standard 200-mesh sieve. The residue should be examined under the microscope to ascertain whether it consists of gritty particles injurious to the workers.

A siliceous limestone should not be used, nor any particles which do not pass readily through a 30-mesh sieve.

¹ For a lengthy paper on the superiority of precipitated calcium carbonate in mines see *Jour. Soc. Chem. Ind.*, 42, 197 T, (1923).

(j) USES OF LIMESTONE, ETC., IN PAINTS, DISTEMPER,
AND ALLIED MATERIALS

Various forms of calcium carbonate are used in the paint and allied industries in various ways, of which the most important are: (a) as a pigment; (b) as a diluent, reducer, or extender for other pigments; (c) as a primer, especially for gilding, and (d) in the production of putty.

In each case the calcium carbonate should be perfectly white, of low density, and of great fineness, so that limestone is seldom suitable and some form of chalk or precipitated calcium carbonate is usually employed.

Chalk—suitably freed from grit and other impurities by washing or levigation—is a valuable pigment, as it has a high covering power, can be mixed with the most sensitive colours, and, when used alone, does not change colour. It is extensively used as an indoor wash and by wall paper manufacturers. For many years only natural chalk was used, but during recent years, calcium carbonate, obtained as a by-product from various industries, has been largely used. The objection made by some users to ground limestone and “precipitated chalk” is that they have a poor covering power and low “strength.” Recent investigations have shown, however, that almost any form of calcium carbonate can be used if the particles are sufficiently fine, *e.g.* passing completely through a 300-mesh sieve.

The various forms of calcium carbonate used as a pigment include *artists' white*, *Paris chalk* and *Blanc minérale*, all of which consist of fine calcium carbonate in the form of either precipitated chalk or prepared chalk, though sometimes they are made of a very white marl, *i.e.* a mixture of white clay and chalk. The clay makes the chalk more adhesive, which is sometimes a convenience in distempers and water-paints.

Vienna white or *Vienna lime* is a cheap pigment, and extensively used for coarse painting. It is made by exposing a lime pulp on boards to air, and, when the pulpy character has disappeared (a basic carbonate being formed), the mass is kneaded with wooden paddles and made into small cakes, which are again exposed to the air. Alternatively, the paste can be made into bars (4 in. × 2 in. × 2 in.) by extruding them from a pugmill, and cutting with wires stretched on a frame a suitable distance apart. The absorption of carbon dioxide may be increased by filling the chambers with carbon dioxide gas instead of with air, but care must be taken to use clean gas made from limestone as the ordinary products of combustion of coke or coal contain hydrocarbons, smoke, soot, tar, etc., which would stain the pigment.

The lime used must be particularly free from ferric oxide, as this would stain it, and must be very porous, as a dense lime is useless and has a low covering power.

The free lime present in Vienna white makes it alkaline, and limits its use, as a colour-base or -extender, to very fast colour. Vienna white is used as a primer or foundation paint, but if a coloured surface is required, either lime-fast colours must be used or the material used for the ground coat may be mixed

with alum solution : a lime-alum compound is formed to which organic colours adhere well, and other coats of paint are not affected.

Other white pigments bearing special names are Cologne chalk, Bologna chalk, Briançon chalk, Champagne chalk, Blanc de Bougival, Blanc de Meudon, Spanish white, Blanc d'Orléans, Blanc de Troyes, etc. These are all natural chalk or marl which has been finely ground, or ground and levigated.¹

These and other forms of calcium carbonate may be improved and made whiter by adding a small proportion of blue "stain." Victoria blue, BR, Thionine blue, GO, and methylene blue are all suitable. They can also be used for Vienna white, and other materials containing free lime. Ultramarine and smalt were used at one time, but are much denser than aniline dyes, so that a given weight does not cover so well, and more stain is required.

The covering power of calcium carbonate as a pigment depends (*a*) on the special nature of the material, and (*b*) on the fineness of the particles. Hence, fine grinding, precipitation, or the natural occurrence of extremely fine particles, is essential.

Priming and distemper are largely made by exposing lime to air or carbon dioxide—see Vienna lime. If coloured, only those colours can be used which are resistant to lime.

By mixing with alum, or by washing the primary coat with soap and water or with milk and water, the harmful effect of the free lime is avoided.

Gilders use large quantities of chalk for priming picture frames, the chalk being mixed with size to bind it.

Preparation.—Properly prepared chalk, or its equivalent, should be as fine as the finest flour, so that unless the precipitated carbonate is used, the material must be finely ground. The machines used for this purpose include edge-runner mills (which may be enclosed to prevent loss of dust, unless wet mills are used), ball mills, and tube mills. The materials supplied to these mills may receive a preliminary reduction in crushers or disintegrators.

The ground material must usually be subjected to a process of elutriation or levigation. If wet processes are used, the material must be dried and must usually be graded by means of an air separator and collected in a cyclone dust collector.

Screens or sieves may be used, but the best qualities of calcium carbonate used in the paint industries are too fine to be effectively graded by screening. When whitening is used in paint, distemper, etc., its "covering power" is important. This property is very difficult to test accurately, the ordinary test of seeing how many square feet 1 lb. of paint (or a corresponding amount of distemper) will cover being subject to too many variable factors to be satisfactory. Unfortunately, no more reliable test has been devised, many which have been suggested being quite unsatisfactory. Whitewash and distemper vary greatly with regard to the proportion of size or glue required. It is, therefore, necessary to vary the quantity of this material with each new batch of whitewash or distemper to ensure the best results being obtained.

¹ *Terre blanche* is not composed of calcium carbonate, but is a white clay.

Whitewash is whitening suspended in water in which a little powdered glue or size has previously been dissolved in order to increase the adhesion of the whitewash to the walls, etc., to which it is applied.

Putty for glaziers' and painters' use, and for other purposes, is a mixture of whitening and oil (see p. 236).

(k) USES OF CHALK, LIMESTONE, ETC., IN THE MANUFACTURE OF PAPER

In the production of wood-pulp, which forms one of the early stages in the manufacture of paper, the wood, grass, or other raw material is cleaned and bleached by digestion with "bisulphite of lime." This substance is made by absorbing sulphurous acid gas (SO_2) in moist limestone. The gas is pumped up large towers containing blocks of limestone, which are moistened by a stream of water flowing from the top of the tower, the liquid drawn off at the bottom being a solution of calcium bisulphite, together with as large a proportion as possible of free sulphurous acid. The temperature of the towers, stone, and water must be carefully regulated; if it is too low the reaction will be feeble and the yield low, whilst if the temperature is too high, so much insoluble calcium monosulphite will be formed that none will be converted into the useful bisulphite. Under favourable conditions, the liquid discharged from the final tower contains 2.5 per cent. of free sulphur dioxide and 1.5 per cent. of sulphur dioxide as calcium bisulphite.

The limestone blocks should be shaped with a hammer into rough 3-in. cubes. The precise size is not important, provided that all the blocks are as uniform in size as possible, so as to expose a maximum of surface to the acid. If the towers are filled with pieces of stone of many sizes, their efficiency will be much less than if all the stones are uniform in size. Very small stones among larger ones are objectionable, as they fill the interstices, and reduce the amount of limestone surface exposed to the acid.

The purity of the limestone is of minor importance, provided not less than 95 per cent. of calcium carbonate is present. Some manufacturers prefer a magnesian limestone as they consider that magnesium bisulphite is more stable and more effective than calcium bisulphite. This is satisfactory if the stone is converted into lime before use; otherwise it should not contain more than 3 per cent. of magnesium carbonate or it will not readily form the desired quantity of bisulphite. Argillaceous limestones are unsuitable because of the clay present, which is not only useless, but tends to discolour the paper. Chalk is usually too soft, and too siliceous to be satisfactory, but can be used in the absence of a better stone. Finely ground calcium carbonate has not yet been used, but by employing an absorbent tower of different design it might be more economical to use powdered calcium carbonate obtained as a by-product from some other industry instead of lump limestone.

As the treatment of wood-pulp and similar materials is usually effected in the country where the raw materials are obtained, it is obviously desirable to obtain the limestone in the same country. Hence, very little limestone is exported for this purpose.

Limestone and other forms of finely divided calcium carbonate are also used as *fillers* for paper, *blanc fixe* being chiefly employed for the finest grades of coated paper, and *China clay* for cheaper grades. Onion skin or pelure paper is usually made without a filler, but when one is used it is generally some form of calcium carbonate. The paper employed for Bibles, and cheap cigarette papers is usually loaded with calcium carbonate to the extent of 15–30 per cent.

Calcium carbonate, when used as a filler, gives the paper a fine, matte surface, which is particularly suitable for printing from type.

(l) USES OF LIMESTONE, ETC., FOR POLISHING

Chalk, finely-ground limestone, and precipitated calcium carbonate are all used as mild abrasives in polishing silver and other articles. The chief characteristic required is that the grains must be sufficiently small and free from grit, and, consequently, a levigated material, such as whiting, is generally used. Calcium carbonate prepared in any other manner—if it is sufficiently fine and free from grit—is satisfactory. The grains should be sub-angular, because rounded grains produce a polish too slowly for them to be desirable.

The chief characteristic of “Vienna lime” is that it does not “smut” or “clog” the surface of the metal to which it is applied as a polish.

(m) USES OF CALCIUM CARBONATE, ETC., IN POTTERY MANUFACTURE

Calcium carbonate is used in the manufacture of pottery and allied material in three distinct ways :

(a) As a flux in the body of the ware, for which purpose it is mixed with the clay of which the articles are made (unless the latter is a marl and so naturally contains a notable proportion of calcium carbonate).

(b) As an opening agent to increase the porosity of the clay and to prevent articles made from it cracking during drying.

(c) As a flux in glaze.

Calcium carbonate can only act as a flux at temperatures above 650° C. ; in wares heated to this temperature it tends to combine with the silica present, forming calcium silicates which melt at temperatures above 1000° C., to form fluids which fill the pores in the clayey material and, on cooling, produce a strong vitrified mass.

When added to glaze calcium carbonate also combines with the silica forming a fusible glass or glaze which solidifies on cooling.

For both purposes the calcium carbonate should be fairly pure. Chalk may be used for bricks and somewhat low grades of pottery, but for the better classes of ware, whiting or other form of almost pure calcium carbonate should be used. For glazes, whiting is chiefly employed on account of its purity and the minuteness of the particles, a coarse material does not combine so readily with the silica and does not, therefore, produce so good a glaze.

For some potter a magnes an limestone may be used, but it is not satisfactory for glazes as it produces a vis ous melt which does not flow uniformly over the ware.

It is very important that whichever form of calcium carbonate is used in glazes, the particles shall be as uniform as possible in size. A glazer may modify the composition of the glaze or the heating of the ware in the kiln or oven to suit particles of any given size, but a carbonate composed of particles of many different sizes is always liable to cause trouble. When a sample is mixed with water and passed through a suitable sieve the residue should not exceed 1 per cent. on a 140-mesh sieve or 2 per cent. on a 200-mesh sieve. Alternatively, it should, when treated in a "Pearson air-separator,"¹ show at least 85 per cent. of material less than 0.02 mm. and at least 48 per cent. of material finer than 0.01 mm. in diameter. A simple specification which is sometimes used requires that $2\frac{1}{2}$ g. of the material, when shaken with 250 c.c. of water for ten minutes in a tall cylinder and then allowed to settle, shall require not less than twenty minutes for visible settling to cease.

Paris white is sometimes considered superior to whiting for ceramic purposes. It is made from a hard unweathered rock, is quite different from whiting in physical structure, and is often more uniform in size of grain. True whiting, which is made from soft weathered English chalk, is liable to contain particles of many sizes.

The total calcium and magnesium carbonates should not vary by more than 1 per cent. and the silica by more than $\frac{1}{2}$ per cent. from the standard, or the effect on the glaze may be serious. Iron compounds (expressed on analysis as ferric oxide) should be absent or should never exceed 0.25 per cent. except in dark-coloured glazes where their presence is less objectionable. For the most transparent glazes, and especially those used on white ware, the calcium carbonate should not be less than 96 per cent., the magnesium carbonate and silica should not each exceed 2 per cent., and the iron oxide 0.15 per cent. For dark-coloured glazes, a material containing only 90 per cent. of calcium carbonate may be used, but unless there is a very serious difference between the price of this and the purer material the latter should be preferred. It is easy to save a few shillings a ton by buying an inferior material, only to find that a still larger sum has to be spent on an increased amount of fuel or in other ways.

(ii) USES OF LIMESTONE, ETC., IN PRINTING

The stones employed for lithographic printing are usually composed of very fine-grained limestone of exceptionally uniform texture. A magnesian limestone is often used for this purpose, but some of the French lithographic stones contain 95-97 per cent. of calcium carbonate.

The chief sources of lithographic stones are the Jurassic limestones of France (Vigau, Jard) and Germany (Solenhofen, and Dichstadt, Bavaria), but smaller quantities have been supplied by Italy, Switzerland, India, and Algeria. Some of the finer lias limestones, when polished, may be used as

¹ The Pearson air separator as developed by Pearson and Hitchcock, at the U.S. Bureau of Standards, appears to be the only machine which can be used satisfactorily for testing dry powders, consisting of particles as small as 0.01 m.m. diameter.

lithographic stones, but the best natural stones for this purpose come from Solenhofen and Dichstadt.

The chemical composition of stone for lithographic work is of minor importance, but as the stone must be very uniform in texture and porosity it must usually be almost pure. The best lithographic stones contain only very small proportions—not exceeding 5 per cent. in all—of silica, alumina, and iron oxide. Nitric acid should dissolve the stone almost entirely, leaving only an insignificant residue. The stone should be free from calcareous crystallizations, vermiculations, siliceous specks, or conspicuous veins. The fracture should have a glossy surface free from grains; it is generally conchoidal.

The Vigau stone has a very dark tint, is very hard, and the texture is crystalline. This stone can be employed for transfers, but gives somewhat poor results in engraving. Its bluish tint is often a cause of its rejection by lithographers. Owing to its porosity, it cannot be used where a delicacy of the print is of importance, as its porosity, after treatment with acid, often causes difficulties in mechanical printing. The Montdardier stone is fairly satisfactory, but the blocks are often spotted blue, and a uniform colour of the mass is only found in small stones.

After being quarried, the stone must be freed from crust, *i.e.* various fossils, leaves, or skeletons of different petrified animals. The stone is afterwards planed and levelled, after which the blocks are cut to the most suitable dimensions, and then carefully dressed, polishing machines being used for this purpose.

The stones are then classified, according to the fineness of the grain, its mass or colour, and to its suitability for the different kinds of lithographic work.

In spite of the investigations made by French geologists and those of other countries with the object of putting an end to the German monopoly of lithographic stones, no stone from other quarries appears to possess a fineness of grain comparable with that of the Bavarian quarries, especially those at Solenhofen. Attempts to produce artificial lithographic stones have not been successful.

Indirectly, various forms of calcium carbonate are used in the formation of ink.

(o) USES OF LIMESTONE, ETC., IN RAILWAY ENGINEERING

The subject of railway engineering includes so many industries that almost every use of limestone might be included in it. The chief use of limestone in railway engineering is, however, as *ballast* (see Rubble, Crushed stone, p. 177, and end of section on Road stones, p. 248). In country stations, limestone screenings without a binder are used for the platforms, the loose pieces affording good drainage, while a firm, compact surface is formed by the footsteps of travellers and the wheels of luggage trucks.

(p) USE OF LIMESTONE, ETC., IN THE RUBBER INDUSTRIES

Whiting, and to a lesser extent, recovered calcium carbonate, is used as a

mineral filler in rubber goods. A coarse material is useless ; 98 per cent. of a suitable one will pass through a 300-mesh. Air-floated material is almost exclusively used ; it is prepared by grinding any convenient form of calcium carbonate in a closed ball mill circuit containing a large air separator. With a hard limestone the grinding will usually require about 50 h.p. per ton of dust produced ; dry whiting requires only about 30 h.p. and sometimes much less.

(g) USES OF LIMESTONE, ETC., IN THE SOAP AND ALLIED INDUSTRIES

Calcium carbonate is only used to a very limited extent in the soap making and allied industries, viz. as a filler or diluent. It cannot be used in the saponification of oil or fat.

(r) USE OF CALCIUM CARBONATE IN THE TEXTILE INDUSTRIES

Calcium carbonate in the form of chalk or whiting (more rarely as precipitated carbonate and seldom as ground limestone) is sometimes used as a fixing agent in dyeing cotton goods. The carbonate is suspended in water and the dye is "fixed" by immersing the dyed goods in the chalky water. The calcium carbonate should be in a very fine state of division so as to remain suspended as long as possible.

Calcium carbonate is also used in finishing "textile materials," for which purpose it is made into a paste with water, spread on the cloth, and rolled in.

For all purposes for which it is used in connection with textile materials, the calcium carbonate should be as fine as possible and should leave little or no residue on a 100-mesh sieve. Its purity is of minor importance, its physical and not its chemical properties being used.

(s) MISCELLANEOUS USES OF CALCIUM CARBONATE

Calcium carbonate in various forms is used in comparatively small quantities for many other purposes, among which may be mentioned :

In the *Brewing and Distilling Industries*, limestone and chalk are occasionally used to neutralize the acidity of the steeping liquors in brewing and malting. For example, the finely powdered material is sometimes sprinkled on the surface of barley in order to reduce the amount of matter extracted by water and the acidity of the liquor. Any finely ground chalk or limestone is suitable for this purpose.

Very finely grained limestones—especially some of the Bavarian beds from which lithographic stones (p. 261) are obtained—are used to pave the cellars of breweries, it having been found that this material, owing to its property of retaining moisture, favours perfect germination of barley, a very important condition for making good beer.

For Improving Wines.—The acidity of a wine may be reduced by shaking it with powdered calcium carbonate (produced by grinding limestone or marble) or by the addition of whiting. If the acid present is tartaric or citric, this treatment is quite successful, as the calcium salt formed is practically insoluble.

The method is less suitable for acetic acid as calcium acetate is readily soluble.

Writing or Blackboard Chalk, which is usually composed of whiting mixed with a little glue-water or dextrin and compressed into short rods or "sticks." The binding agent covers the grains and delays the action of acid, so that many specimens of blackboard-chalk do not effervesce readily with acid.

Other materials, including starch, and gypsum or plaster of Paris, are sometimes incorporated to produce a writing material which is easy and pleasant to use, but does not produce so much "dust" as simple compressed chalk.

Tailors' chalk is a mixture of pipeclay and washed chalk, tinted with ochre or ultramarine, and shaped by pressing in metal moulds. A little soap is sometimes added as a binder. For some years, a mixture of pipeclay and gum (without chalk) has been used extensively for tailors' chalk.

Cosmetics or toilet-powders and *tooth pastes* usually contain a large proportion of calcium carbonate, generally in the form of very finely ground chalk, or, preferably, the precipitated carbonate.

Patent Fuel is sometimes made with the aid of chalk, and some very extraordinary and extravagant claims have been made in this respect. If coal-dust, which does not burn readily because of its compactness, is mixed with chalk or other porous material, the mixture may burn more readily than the original coal-dust merely because the separation of the particles of coal gives a greater access of air.

The cost of manufacture and the very objectionable quantity of ash produced have the effect of making such a mixture more costly to use on a large scale than coal slack, so that it has very little commercial value. Yet, notwithstanding its objections, it has been exploited repeatedly in various ways as a new and important discovery of a valuable fuel. The suggestion that the ash left after the coal has burned away makes a valuable fertilizer usually accompanies other statements respecting the advantages of such a fuel!

The following quotation which went the rounds of the popular Press and deceived more than one editor of a technical journal may be regarded as typical of some of the worst rubbish published in this connection. As an example of "journalistic science" it is difficult to surpass!

"LIMESTONE AS A FUEL."

"Experiments are being made at the — Steel Works, according to a contemporary, which bid fair to settle the coal question by substituting limestone for the present black diamond. One of the employees, who is of an inventive turn of mind, tried out the experiment in his furnace at home before giving his knowledge to the officials of the big plant.

"A load of limestone, broken to about the size of No. 5 coal, was dumped on the floor of one of the departments where stoves are used extensively. A layer of fire on the bottom of the big heater was covered with broken limestone, this in turn was banked by fine buckwheat anthracite coal, and those in charge of the experiment say they secured the maximum heat with 50 per cent. less coal. Besides, they point out, the lime thus burned can be utilized as a by-product and scattered on the land as a fertilizer. This has been the practice for years in the burning of lime, also in securing a high degree of heat in open-hearth and blast furnaces."

As a *dusting agent*.—In many industries, small quantities of whiting are dusted over surfaces which must not be allowed to adhere. The same material

is also used when covering electrical detonators, etc., with pitch to prevent the latter adhering to the workers' fingers.

For "dusting," the chief characteristic required is extreme fineness of the particles, the purity of the material being of minor importance. Hence, precipitated calcium carbonate is often quite as good as whiting and is sometimes cheaper. Ground chalk or limestone may be used, but is generally rather too coarse. The finer portion separated by elutriation in air is, however, quite fine enough for the purpose.

As a *Gas Absorbent*.—Calcium carbonate is sometimes used to remove acid vapours from gases. It is cheaper than lime, but has the disadvantage of replacing the acid in the gas by carbon dioxide. Fortunately, in most cases, this substitution does no harm.

Lumps of limestone contained in a tower, up which the gases are passed, will absorb sulphurous, sulphuric, and hydrochloric acid and the resulting salts can be removed by washing the lumps with water, either at the same time as the gas is passing or later.

Towers of this kind are specially used where sulphurous acid is formed as a by-product of a reaction, to prevent the gas escaping into the atmosphere and damaging the surrounding vegetation.

In *Photography* very finely-divided calcium carbonate is sometimes added to the gold-toning bath to correct any tendency to acidity. Ammonia is usually preferable as it has less tendency to form spots on the prints.

In *Optical Instruments*, calcite crystals are used in the construction of prisms. For this purpose, the crystals should be large, perfectly clear, and as free as possible from all flaws or internal cracks. They require to be selected with extreme care and are relatively valuable.

For *Machinery Bearings*, slabs of very fine grained limestone, similar to lithographic stones, are sometimes employed. Such stones must be quite free from crystals of quartz—which will scratch the hardest steel. The purpose of such stones is to avoid the use of oil as a lubricant, but unless there are special reasons why oil should not be used, an ordinary well-designed and properly lubricated metal bearing will be more reliable as well as more economical.

If stone is used, it must be very fine grained, free from all gritty material, and of as uniform a texture as possible. It should not be too soft, or it will wear away too quickly, yet it must not be so hard that it wastes the metal of which the shaft is composed.

In *plastic compositions*, such as those used for phonograph records and many small articles, a considerable proportion of finely-divided calcium carbonate is used as a "filler" or "diluent." For this purpose it should be free from clay, and should be fine enough to leave little or no residue on a 100-mesh sieve. If still finer, so much the better. As great purity is usually of minor importance, finely precipitated calcium carbonate obtained as a by-product from various chemical processes is equally as useful and satisfactory as ground limestone or levigated chalk, and can sometimes be obtained much more cheaply.

The composition of many such plastic materials will be found in the Patent Abridgments (Class : Cements, etc.) and need not be given here. In very few cases are the properties of the calcium carbonate mentioned, but in each case the latter should be in as finely divided a state as possible, grit being very objectionable. Whiting is usually satisfactory, but some other forms of calcium carbonate obtained as by-products are often cheaper.

Coach-maker's Putty is a mixture of equal parts of dry white lead and whiting, to which sufficient gold size is added to form a stiff putty of suitable consistency. It is used for stopping holes, cracks, and other surface defects in wood which has to be painted and varnished.

CHAPTER V

THE MATERIALS USED IN LIME BURNING

THEORETICALLY, any form of calcium carbonate will, if heated in a suitable manner, be converted into lime and all the varieties of limestone mentioned on p. 211 are, therefore, potential sources of lime. Unfortunately, lime of commercial value cannot be made from all kinds of calcium carbonate, for various reasons. Some forms of limestone are too impure, some forms of chalk are too soft or in particles which are too small for use in ordinary lime kilns, and some forms possess other physical properties which render them unsuitable. It is for these reasons that the following materials are not used to any great extent in the preparation of lime :

Alkali waste, which is a residue left behind in the manufacture of sodium carbonate and caustic soda by the Leblanc method. The mixture contains about 85 per cent. of calcium carbonate, together with calcium sulphide (CaS), uncharged coal, and calcium carbonate. It is frequently treated by the Chance-Claus process for the recovery of sulphur, leaving nearly pure calcium carbonate behind, which may be used to produce quicklime or hydrated lime, if desired.

The alkali waste from the ammonia process is frequently much richer in calcium carbonate, 95 per cent. being sometimes present.

In either case, the soft "lime-mud" may be separated from the greater part of its contained water by means of a continuous rotary filter. It may afterwards be dried in a rotary dryer and burned in a rotary kiln. Some firms omit the filtration or the drying.

Shells, which have accumulated as an industrial by-product, sometimes form a raw material for the production of lime, and the shells of the oyster-canning factory near Baltimore are used for this purpose. Shells from the seashore are also used in some other countries when the cost of obtaining them is sufficiently low. The lime produced from these materials is said by some builders to be too pure to be used for building purposes unless some burned clayey matter is added.

Calcium sulphate, which occurs in nature as gypsum, selenite, anhydrite, and alabaster may be employed to produce lime by burning in the presence of an excess of oxygen at a temperature of 1200° C. Various attempts have been made to do this on a commercial scale, but as a source of lime it is unimportant.

The following materials form the chief sources of lime :

Limestone and chalk.—When a pure, or almost pure, lime is required the most suitable raw material is a limestone of moderate hardness containing not less than 99 per cent. of calcium carbonate. Where a somewhat inferior lime will serve a slightly less pure limestone may be used. It must be remembered,

however, that the proportion of impurities in the lime, even under ideal conditions of burning, will be almost double that in the raw stone, so that even a small proportion of impurities in the raw material is often highly objectionable. Fortunately, there is an abundance of hard limestone in the British Isles capable of supplying lime of almost any desired degree of purity.

For many purposes, lime is mixed with other materials and it is then unnecessary to use a pure stone. Limestone or chalk containing 10 per cent. or more of silica produces a lime which is excellent for mortar and plaster, but the same lime is quite unsuitable for industries in which its chemical properties are of prime importance.

Some forms of chalk which are too soft to be burned in very tall kilns, produce excellent lime if shorter kilns are used, but the fuel consumption is higher than for tall kilns. Forms of calcium carbonate obtained as by-products from other industries do not usually produce good lime because they are very difficult to burn economically on account of the small size of the particles.

For the best results, a material suitable for lime burning should be in moderately large pieces—not less than 3 in. in diameter—fairly hard, so as to resist any tendency to crushing in the kiln, and sufficiently pure to serve the required purpose after being burned.

None of the kilns in use on a large scale can deal profitably with small pieces of stone or with powdered calcium carbonate. This is particularly unfortunate as the supply of small stone and powder is very much greater than the demand. Under special circumstances these two forms of calcium carbonate can be burned successfully, but under normal conditions the cost of burning is greater than that of larger pieces. A further objection is that in the British Isles lump lime in large pieces is regarded as being much superior in quality to small lime and the latter has, therefore, to be sold at an unprofitable price. If a really satisfactory method of burning small stone or powder could be devised and used, the resulting lime could be hydrated and sold in that form; at present, however, no kiln or burning appliance which is really commercially satisfactory is available for the purpose. Hence many sources of lime are lying idle because they consist of pieces less than 3 in. in diameter.

The most suitable limestones for lime burning are those in the Carboniferous Limestone Formation, but other limestones (including Chalk and Magnesian Limestone) are satisfactory for mortar and agricultural purposes. For hydraulic limes and cements an argillaceous limestone is usually preferred; those in the Lias Formation are extensively used for this purpose.

When considering the suitability or otherwise of erecting plant for converting any particular mass of limestone into lime it is necessary to make very full and careful enquiries as to the purposes for which such lime would be suitable, the prospective sales during a period of ten years or more, and the prices which can be obtained. Lime cannot be transported cheaply over long distances and there are so many lime kilns in various parts of the country that "a sound market" is essential if any lime-burning business is to be successful.

It is not sufficient to chip a few pieces of stone from a projecting mass;

the site should be carefully surveyed, bored under skilled supervision, and a sufficiently large number of samples from various parts of the site and at various depths tested. The money spent on such a preliminary investigation is never wasted in comparison with the loss that will be sustained if a plant is erected on an unsuitable site as has so often been done in the past. Some limestone-deposits are exceedingly irregular in composition, and to erect a works on them without ample previous investigation is to court almost certain failure. Among these "uncertain" limestones the most important are those in the Devonian, Triassic, Liassic, and Oolitic Formations and great care is, therefore, necessary before attempting to use any of these for lime-burning.

When considering the suitability of a limestone for producing burned lime, the chief data required are :

1. The chemical composition—the proportion of impurities in the lime will be roughly double that in the stone.

2. The temperature required to burn the stone and convert all the calcium carbonate into lime.

3. The tendency or otherwise of the lime to fall to pieces during the burning. This is usually judged from a determination of the crushing strength of a 2-in. cube sawn from a lump of the lime. It may also be estimated by determining the porosity of the lime, using paraffin instead of water. A paraffin-absorption of 25 per cent. by weight should not be exceeded ; many good limes will only absorb 18 per cent. of their weight of paraffin.¹

4. The quantity of putty produced. 1 lb. of good lime should produce 85 cu. in. (nearly 1 quart) of putty (equivalent to 3 litres per kilo).

¹ Incidentally, a "temperature-absorption" graph showing the increase in the weight of paraffin absorbed as the temperature used in burning is increased, is useful for indicating the best burning temperature.

CHAPTER VI

LIME KILNS

LIME is produced commercially by heating limestone or chalk to a bright red heat in a kiln (Fig. 57), the temperature being regulated in such a manner that the conversion of the carbonate into lime is as complete as possible without the product being spoiled by overheating.

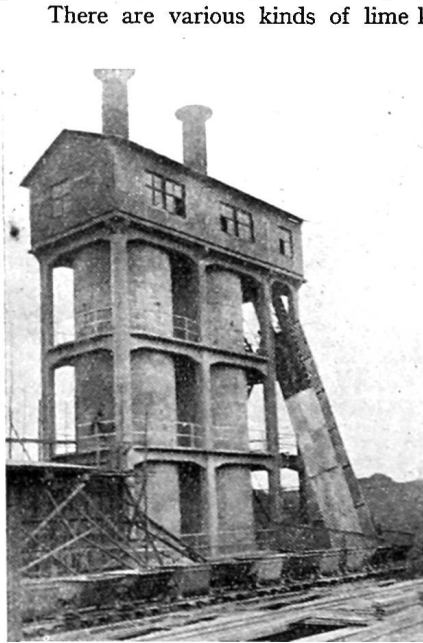


FIG. 57.—TYPICAL MODERN LIME KILNS.

There are various kinds of lime kilns, each suited to some particular purpose, and in order to decide which is the best for any given works or locality, it is necessary to bear in mind the principles which control the burning of lime in an efficient manner, and, at the same time, not to overlook the various local conditions which may have an important influence. For example, a farmer in an isolated area who wished to apply a few tons of lime to his land might produce it much more cheaply in an intermittent kiln of low efficiency than he could purchase and deliver on his land lime burned in a much more economical manner in a highly efficient plant situated fifty or more miles away.

In comparing the different types of kilns described in the following pages, the varying importance of different factors must be adequately considered, as it

may easily happen that a kiln which would be the best in one locality would be ridiculous in another. For this reason, some exceedingly primitive types of kiln are described fairly fully; they are still the most suitable in some situations, and must not be despised because others are capable of producing purer lime with a smaller consumption of fuel.

The earliest method of burning lime appears to consist in stacking alternate layers of wood and limestone in the open air to a height of about 10 ft., plastering the sides of the structure with clay paste, except near the ground, where holes are left to admit air, and leaving an opening at the top through which the products of combustion can escape. In more recent times, coal has replaced the

wood formerly used, except in the lowermost part of the structure. Such an arrangement can produce only a low grade of lime, as it does not permit of uniform combustion, so that the burning is very irregular and a large proportion of unburned stone is mixed with the lime. The waste of fuel is very excessive, but, notwithstanding the disadvantages, the method is still employed satisfactorily in some localities where lime cannot be obtained as cheaply by any other means.

Lime kilns may be arranged in two chief groups of "intermittent" and "continuous" kilns respectively.

Intermittent kilns are those in which a quantity of stone is placed, converted into lime, and allowed to cool, and the lime is then removed. Before any more lime can be produced, the kiln must be refilled as before.

The chief types of intermittent lime kilns are (i) the "flare kiln," in which the fuel and stone are kept separate, and (ii) the "mixed-feed intermittent kiln," in which alternate layers of fuel and stone are used.

In a *flare kiln* (fig. 58) or *pot kiln*, a rough cylindrical or similar structure is built of stone at the side of a hill or embankment, so as to permit of easy access to the top, whilst an arched opening; about 4 ft. high, in the front of the kiln enables the fire to be replenished and the burned lime to be withdrawn. The height of such a kiln is usually twice its greatest diameter, the opening in the top being one-third the greatest internal diameter of the kiln, and the opening for the fire about one quarter the greatest diameter.

Some flare-kilns are conical in shape; others have the shape of two truncated cones placed base on base. Both these types may be built independently of any embankment and may be filled and emptied from the surrounding ground-level through openings in one side of the kiln which are built up before the kiln is lighted.

Some flare-kilns are rectangular in plan and are surmounted by an arch (fig. 58). They may have two parallel grates, each about 18 in. wide, running right across the kiln, each grate being fed through a separate opening or mouth in front of the kiln. A very large kiln may have three or more grates. The use of several grates effects a better distribution of the heat and a saving in fuel.

The shapes of kiln mentioned and other special shapes are supposed to improve the quality or to increase the quantity of lime produced from a given quantity of fuel, but are usually of minor importance.

At one time, in many parts of the country each large farm had its own kiln, which was usually a solid stone structure built against a hill so that a cart could fill the stone into the top of the kiln. These kilns were usually 20 ft.

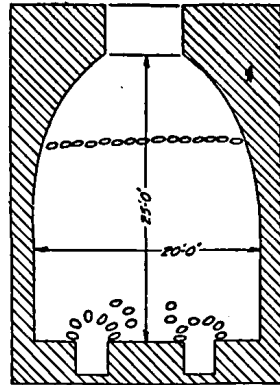


FIG. 58.—FLARE KILN.

deep, round inside, about 6 ft. diameter at the top, widening out for about 6 ft. until 7 ft. diameter and then contracting to about 2 ft. \times 18 in. at the bottom where there is an opening in the side about 18 in. square (the "eye" or draw-hole).

The kilns were usually lined with a local refractory stone. In the simpler types no grate was used, but a quantity of brush-wood was laid on a bed of peat, coal, or coke, then a thin layer of stone, and then alternate layers of coke and stone until the kiln was full. The brush-wood was lighted, the lime drawn out, and the kiln refilled at intervals.

In the more modern type of flare-kiln, with grates, the first stage in filling or charging the kiln consists in placing a suitable amount of wood and coke or coal on the grates or in the lower part of the kiln, and building a dome or arch of large pieces of stone above the lower opening in the kiln, no mortar being used, and considerable spaces being left between the stones. This dome or arch is used to support the remainder of the stone to be burned, and with which the kiln is then filled. In flare-kilns the stone must be stacked carefully and in such a manner as to produce as uniform a draught as possible. No precise directions can be given as the pieces of stone are irregular in size. The proper charging of flare-kilns can only be learned by actual experience. Slabs of stone may be placed partly across the top of the kiln, so as to regulate the draught, and to ensure the fire burning steadily and heating the stone uniformly. When the kiln is full the wood is set on fire. The heat of the fire is then gradually increased by the use of more wood or, usually, by coke or coal, the finishing of the firing being usually with long-flame coal. The heating is continued by replenishing the fire with more fuel, until it is judged that the lime is completely burned, after which the fire is allowed to die out, the ashes cleaned out when the kiln is cool, and, afterwards, the lime is withdrawn.

In all flare-kilns, the chief heating agent is the flames from the fuel, so that a long-flaming fuel, such as wood, bituminous coal, or oil, is necessary, though coke may be used in the early stages of firing if desired.

There is no satisfactory means of ascertaining when to stop heating the lime, as the construction of the kiln does not admit of trials being drawn. A simple method which is often used consists of inserting a poker into the burning stone. If the poker enters readily, and meets with only a feeble resistance, the lime is probably well burned, as the incompletely burned stone offers a much greater resistance. This method, though useful, is by no means always reliable, especially when applied to very pure limestones which yield a hard, dense lime. More often a lime-burner will continue the heating for 48 hours after the fire has reached its maximum temperature (making about 72 hours in all), and trust to a heating of this duration to convert all the stone into lime.

The gradual shrinkage of the stone during the burning also aids a skilled burner in judging the progress of the production of lime.

A *Field-Kiln* is very similar to a "pot kiln" though it is sometimes rectangular in shape and may have fires on two or more sides.

Intermittent mixed-feed kilns or *Draw kilns* are so similar in construction to short "continuous" mixed-feed kilns (see later) that there is no need to distinguish between them. The difference is in the mode of working: for intermittent use, the kilns are filled, lighted, allowed to cool, and then emptied, whereas when used continuously, the lime drawn out at the bottom of the kiln is replaced by fresh stone and fuel supplied through the top. As intermittent mixed-feed kilns are very wasteful, they are only used to a very small extent.

Although many attempts have been made to improve intermittent kilns, the great loss of heat caused by allowing the kiln to cool down each time it is used renders these kilns wasteful in fuel, so that they can only be employed satisfactorily in isolated places where it is cheaper to produce the lime *in situ*, even wastefully, than to purchase it at a distance and have to pay heavy transport charges.

In many country districts, intermittent kilns have been invaluable to farmers who understand the great benefits to be derived from the application of lime to their land. In more recent years, most farmers have largely overlooked these benefits, and many of those who have not done so have purchased lime instead of burning it for themselves. In some cases, the purchased lime is cheaper, but in the more isolated districts where limestone is available, it is usually cheaper to burn the lime than to buy it as the heavy transport costs are thereby saved. The purchaser of lime has, however, no anxiety as to the failure of his men to burn the lime properly, but can usually rely on obtaining lime of good quality. The present trend is, therefore, to look to large lime works to supply the lime and, consequently, the small, intermittent kilns have largely fallen into disuse.

Intermittent kilns can never be economical in fuel because so much heat is required to raise the temperature of the kiln-walls to that at which the lime is burned and this heat is wholly lost each time the kiln is allowed to cool. In flare-kilns there is also a serious risk of the stone nearest the fire being overburned before the stones in the upper part of the kiln have been properly calcined.

Continuous kilns are of three types :

(i) *Vertical* or *shaft kilns*, sometimes known as *running kilns* or *draw kilns*, into which the stone is fed at the top, and from which the lime is withdrawn at the bottom. Some of the earliest—known as *bell pits*—consisted of a shaft, 30–40 ft. deep, and widened at the bottom like a bell, excavated in the rock. Some of these were worked continuously, others intermittently.

(ii) *Horizontal kilns*, consisting of a series of chambers arranged in a "ring," which are heated and cooled in succession, the fire travelling "round the kiln."

(iii) *Rotary* or *inclined kilns*, which consist of a sloping rotating cylinder, through which the stone passes, and is gradually converted into lime.

VERTICAL CONTINUOUS KILNS

In vertical or shaft kilns, the stone enters at the top, and is withdrawn at the bottom. Such kilns may be heated by :

- (a) Coal or coke mixed with the stone.
- (b) Coal burned in external fireplaces on the circumference of circular or elliptical kilns or on opposite sides of rectangular kilns.
- (c) Gas obtained from any suitable and convenient source, such as producer-gas, natural gas, or the gas obtained as a by-product from coke-ovens or other plant.
- (d) Oil.

The efficiency of continuous vertical lime-kilns depends largely on the following factors :

1. The manner in which the heat is introduced into the kiln.
2. The efficiency of the combustion and the amount of air in excess of that actually required.
3. The distribution of heat in the hottest part of the kiln.
4. The distribution of the heat through the portion of the kiln above the hottest zone (*i.e.* the pre-heating zone).
5. The extent to which the heat is utilized before it escapes from the kiln.
6. The amount of heat left in the lime drawn from the kiln.
7. The amount of heat lost by radiation and in other ways.

Taking these factors in turn, the *introduction of the heat* depends chiefly on the form of fuel used and on the required purity of the lime. Where small coal or coke is cheap, and a very pure lime is not required, the introduction of the fuel along with the stone in alternate layers (in what is commonly known as *mixed feeding*) is often the cheapest method. It has two very serious disadvantages : (a) all the ash in the coal or coke used as fuel becomes mixed with the lime, and it is often difficult to separate it, and (b) there is no control of the burning other than by varying the proportion of fuel to stone or by varying the thickness of the layer of fuel in different parts of the kiln. Notwithstanding these drawbacks, mixed-feed kilns are extensively used in many parts of the world as they are comparatively cheap to build, can be made of any diameter and, therefore, of any output ; they can make use of cheap forms of fuel, require no attention at night, and are easy to manage. These advantages are important, where the quality of the lime is of secondary consideration, or where subsequent treatment or use of the lime is such as to prevent the presence of fuel-ash being harmful.

When lime of great purity is required, gas or oil must be used, and these are introduced through burners on the exterior of the kiln.

In some annular types of kiln, the fuel may also be introduced centrally, but these are unusual. The chief drawback to the user of producer or by-product gas (so far as its introduction is concerned) is the loss of heat which

occurs between the source and the kiln. With producer gas, the loss of heat in the producer, added to the loss of heat in transmission to the kiln, is sometimes as much as 35 per cent. of the total heating value of the fuel, and is then so serious as to demand a careful consideration as to whether the additional gain in the purity of the lime is worth the added cost. In many industries, the lime is slaked prior to use, and if the slaking can be effected under conditions which ensure the removal of all ash from the lime, it is often cheaper and equally effective to employ "mixed feeding" with a subsequent hydration and separation of the lime, than to use gas as the fuel.

Intermediate between gas firing and "mixed feed" is the use of a series of fireplaces on the exterior of the kiln. They are far less efficient than gas-producers, but are cheaper in first cost. If, however, the fireplaces are made so deep as to become small gas producers, they have the advantage over larger separate producers of preventing the loss of heat in transmitting the gas to the kiln; they also facilitate the control of the temperature in the kiln, and are often easier to manage than large producers. To be fully effective, these small producers must be properly designed; it is not sufficient to make them in the form of ordinary fireplaces with an unusually deep bed of fuel.

Vertical lime-kilns are preferably symmetrical in shape, being usually circular, elliptical, or rectangular in plan. As they require to be heated as uniformly as possible over the whole cross-sectional area at every part of the kiln, it is necessary that the heat should be introduced as uniformly as possible. Thus, in a gas- or oil-fired kiln, the burners are usually placed at equal distances apart all round the kiln. With an idea of saving fuel, however, in some elliptical and rectangular kilns, the burners are only placed on two opposite sides. This tends to allow unburned stone to pass down the sides without burners, but, in actual practice, the amount of stone which passes is not serious unless the kiln is exceptionally wide.

The pressure at which the gas or oil enters the kiln must be sufficient to ensure the centre of the kiln being fully heated or a "core" of insufficiently burned stone will pass down the centre of the kiln along with the lime.

The *completeness or otherwise of the combustion* of the fuel in the kiln depends on the manner in which the fuel and air are brought into contact with each other and on the temperature of the air and the fuel. If solid fuel is used, part of the air is required to convert the fuel into gas and the remainder is then used in burning the gas so produced. If the fuel is burned on a grate, the two portions of air can be kept quite separate—one (the *primary* air) entering into the ashpit and rising up through the grate and the fuel lying thereon, whilst the other (known as *secondary* air) enters above the fuel on the grate. If too much air enters through the grate or over it, the combustion will not be as efficient as it should be, and heat will be wasted. The proportion of primary and secondary air required varies with the composition of the fuel and must be regulated accordingly. In lime kilns, an excess of air is much less harmful than a deficiency as most of the heat in the superfluous air can be removed if the kiln is properly designed. In oil-firing, the primary air is used to atomize

the oil and break it up into such small particles that it practically becomes a gas. The amount of air used for this purpose is often sufficient to supply all that is required for the complete combustion of the oil. Hence, no secondary air is usually required.

In a gas-fired kiln, on the contrary, no primary air is needed, all the air being "secondary air." Its quantity is much more easily regulated than with solid fuel. This is one reason why gas- and oil-firing are often cheaper than solid fuel.

To ensure the efficient combustion of gas, oil, or the gaseous products produced by burning solid fuel, each particle of fuel should be surrounded by just that amount of air which will suffice for its combustion and no more. If the particles of fuel are too large, some of the air surrounding them will escape before they are properly burned—which means imperfect combustion and waste. As the particles of fuel cannot be too small, gas in this respect is ideal.

Perfect combustion with no excess of air requires an intimate mixture of gas and air to be burned in a sufficiently large space to prevent the products of combustion from cooling too rapidly. The ideal is met by the continuous supply of a properly-made mixture of air and gas to a large combustion chamber from which the products of combustion pass to the material which it is required to heat. For various reasons, no lime kilns can work on this principle with the result that the combustion in lime kilns is often very imperfect and almost always inefficient because too much air has to be admitted under the peculiar conditions of burning.

Instead of the empty space which is necessary for the perfect combustion of a gas—and, as already pointed out, even solid fuel must be gasified before complete combustion can occur—the gas in a lime-kiln must usually enter between pieces of broken stone or partly-burned lime and only there does it meet with the air needed for its combustion.¹ In the case of mixed feeding, the "hit-or-miss" action is still more pronounced, though in all cases, if the kiln is tall enough, the drawbacks of imperfect combustion can be largely overcome. If a kiln is too short, the smoke and other imperfectly burned products pass on too quickly and are lost.

Quite apart from all other considerations, such as the temperature attainable and its effects on the stone, the greatest efficiency of combustion will be realized by gasifying the solid fuel or atomizing oil, burning the gas or oil spray in contact with a suitable proportion of air in an empty space or combustion chamber, and passing the products of combustion to the material to be heated by them. This is recognized as essential by all who have sufficient knowledge of the subject, yet it seems impracticable to apply it to lime kilns.

One reason for the usual, serious departure from what is recognized as the proper practice in combustion is the idea that because air rises up through the kiln it is in a good condition for burning the gas efficiently. Such a supply of

¹ The Bone-Court process of surface combustion has not been used in burning lime; it may be too dangerous, as the air-gas mixture is explosive.

air, if sufficiently large, may eventually ensure the gas being completely burned, but it cannot ensure its being burned in the most efficient manner. As to how far more efficient combustion is possible will be seen later.

In mixed feeding the conditions favour complete, but not efficient, combustion, because the solid pieces of fuel are too large and too concentrated for the latter; in gas- and oil-fired kilns the combustion can be made much more efficient and the supply can be kept under better control, but it is much more difficult to ensure the uniform distribution of heat throughout the kiln without some of the lime being seriously overheated. In lime-kilns in which coal is burned in external fireplaces, the efficiency of the combustion is usually low, because of the faulty design of the fireplaces; if these are made into small producers, the efficiency of the combustion may be as great as that in gas-fired kilns.

The *distribution of the heat* must be as uniform as possible, particularly in the hottest part of the kiln—commonly known as the “hot zone” or “fire zone.” At first sight it would appear that the principle of feeding the kiln with alternate layers of fuel and stone would ensure a uniform distribution of heat, but in practice this is not the case. The layers of fuel do not fall uniformly and, consequently, do not heat each part of the cross-sectional area to an equal extent. In addition, the hot gases tend to creep up the sides of the kiln more than up the centre so that great irregularities in heating are possible. To a large extent, these irregularities neutralize each other under normal conditions, the excess of fuel gathering towards the centre counteracting the lesser draught at that part.

The pieces of stone and lime also exert a baffling action on the upward movement of the hot gases and so tend to distribute the heat more uniformly. In this connection, the relative sizes of the various pieces of stone play an important part; if the pieces were all the same size and were true spheres the total volume of the spaces between them would be 47 per cent. of the volume of that part of the kiln. When pieces of different sizes are present, or when angular or flaky pieces of stone are used, there is a smaller proportion of space between the stones and the ability of the hot gases to rise through the kiln is correspondingly reduced. This matter requires careful consideration when deciding the size of pieces of stone to admit to the kiln. It is mentioned here only to emphasize its important effect on the distribution of heat.

The most efficient heating will occur when all the pieces of stone are the same size and are as nearly spherical as possible. The actual size is of much less importance than the fact that the pieces are all the same size, because the proportion of spaces or “voids” is the same in a mass of spheres of 6-in. diameter as in the same volume of spheres $\frac{1}{2}$ -in. in diameter. The objections to small stone in a kiln are two: (a) the voids are individually so small that they impede the draught, though their total volume is the same as that between larger spheres, and (b) if the pieces of stone are of different sizes the small ones enter the voids and so reduce the extent to which the stone can be burned.

The baffling action of the stone on the products of combustion makes it

possible for intensely hot flames to enter the kiln, without the stone near the burners being seriously spoiled by overheating. It, consequently, minimizes some of the adverse effects which would otherwise be produced if streams of hot gas and flame entered through opposite sides of the kiln and met in the middle. The baffling action of the stone on the flames tends to cause incomplete combustion with the result that flames are produced in other parts of the kiln and the control of the temperature is not nearly so good as might appear at first sight.

The distribution of heat in the hot zones is effected by :

(i) Admitting the fuel and stone at the top of the kiln in layers and hoping that the kiln will be heated uniformly over the whole cross-sectional area.

(ii) Admitting the fuel at several points on the exterior of the kiln, these points being so arranged as to admit the same (or an adjustable quantity of) heat to each part of the kiln at the level of the burners. Such an arrangement, in an empty kiln, would probably result in a much higher temperature being reached in the middle (where the flames overlapped) than at the sides, but in actual work this is not the case, as the baffling action of the stone in the kiln largely prevents it and keeps the heat fairly uniform, though there is a tendency for the stone near the wall to be heated more than that in the centre.

The great advantage of gas- and oil-firing over external fireplaces of the usual shallow type is the greater ease with which one part of the kiln can be supplied with more gas or oil and its temperature regulated accordingly, though the actual control of the heat by this means is very limited.

The distribution of heat in the preheating zone which lies above the hot zone is wholly automatic in character. The gases from the hot zone rise through the preheating zone, their course being baffled by the stone in the latter. No valves or other appliances are employed for regulating the temperature or distribution of heat in the preheating zone with the exception of those kilns which have a central chimney capable of moving up or down (fig. 59) as required and so varying the " cone of hot gases " which is formed by the drawing action of the chimney. If the chimney is mounted on wheels so as to be able to travel horizontally as well as vertically, a further variation in the distribution of heat in the preheating zone can be effected. The latter device is not easy to use and can seldom be recommended. The central dipping chimney is an excellent device and is an important feature of several types of French kilns.

It is generally considered that if the preheating zone is sufficiently long, no special care is needed to ensure an even distribution of the heat in it. An unduly short preheating zone, on the other hand, can never be efficient, as much of the heat escapes before it can be used. Too long a preheating zone is almost impossible except where the stone is so soft that it is crushed by the weight of the stone above it in the kiln. Soft limestone is rare, and for most chalk and soft stone a preheating zone 30 ft. in height would do no harm though seldom practicable for other reasons which have nothing to do with the actual burning.

The *Utilization of Waste Heat* is very important when competition is keen or fuel costly. The hot gases which escape from the kiln carry with them a large amount of heat, which is usually lost. It can only be recovered in kilns with a closed top, in which the draught is created by an induced fan or "exhauster." When such an appliance is provided, the waste heat in the hot gases can be converted into steam in a waste heat boiler or heat exchanger and the steam thus produced can be used for the gas producers or for other purposes for which steam at a low pressure is suitable.

If the kiln is sufficiently tall to utilize most of the heat in the gases in the preheating zone, that which escapes to the boiler will be very small. Hence, in designing a kiln heated by producer gas, it is necessary to decide how much heat must be drawn from the kiln in order to produce the steam required by the producer. If no steam is required—as when the kilns are heated by natural or by-product gas—the preheating zone should be made high enough to reduce the escaping gases to as low a temperature as they can have whilst producing sufficient draught in the kiln.

The lime which has just left the burning-zone has a temperature of 900° – $1,100^{\circ}$ C., and has to be cooled until it can be handled (about 80° C.) before it leaves the kiln. This cooling is effected most advantageously by having the bottom of the burning zone at such a height above the outlet of the kiln that the lime is cooled by air which rises through the bottom of the kiln to the burning zone. This air is heated by the lime which it cools and, therefore, whilst cooling the lime is made more valuable for burning the fuel.

The height of the cooling zone varies in different kilns; it should seldom be less than 6 ft. and may, with advantage, be as much as 15–20 ft. The only drawback to an unnecessarily long cooling zone is the additional cost when building the kiln and that expended (if any) in taking the stone to a greater height than would otherwise be the case. Too short a cooling zone is inconvenient because it does not cool the lime sufficiently, and wasteful because it does not make use of all the heat available in the hot lime.

The loss of heat from lime-kilns by radiation and other causes is sometimes very serious, and whilst it is almost impossible to reduce it below 10 per cent., it is by no means unusual to find the actual loss is 45–50 per cent. of that supplied by the fuel.

Leakages can be found and stopped, loss by radiation can be reduced by

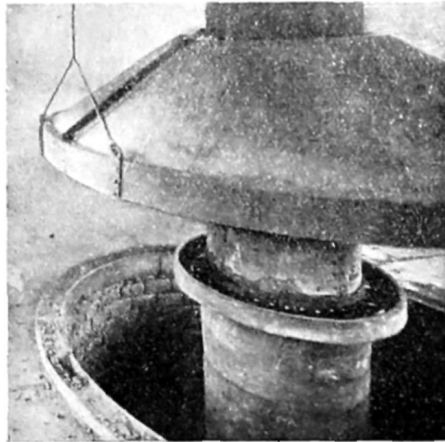


FIG. 59.—DIPPING CHIMNEY.

means of highly porous bricks which are better than sand or kieselguhr, and by building a steel casing round the kiln much may be done to ensure its durability as well as to reduce unnecessary loss of heat.

The chief sources of loss of heat are :

(i) Gases leaving the kiln at too high a temperature, due either to the kiln being too short or not being supplied with sufficient stone.

(ii) Too much air entering the kiln and so absorbing too much heat from the fuel. This can only be stopped by careful investigation of the amount of air admitted relative to that required by the fuel.

(iii) Hot lime leaving the kiln because the cooling zone is too short or too much lime is drawn out at a time.

(iv) Loss of heat due to inefficient combustion can only be avoided by so designing the kiln that the combustion of the fuel is complete, but occurs without the use of an undue excess of air. The importance of this having once been realized, it is a comparatively simple matter to pay special attention to it in comparing the merits of different kilns.

(v) Loss by radiation can only be avoided by the use of insulating material round the kiln—or preferably by the use of such material as part of the structure of the kiln. The various methods of insulation will be dealt with in greater detail in connection with structure of the kilns used for burning limestone.

Vertical shaft kilns may be divided into two main classes :

(a) *Mixed Feed Kilns*, in which the fuel and limestone are placed in alternate layers in the shaft.

(b) *Separate Feed Kilns* in which the limestone enters at the top of the shaft, whilst the fuel is burned in external fireplaces, or is converted into gas in an external gas-producer. Kilns heated by natural gas or by oil may be conveniently included in this group.

The chief distinction between “mixed feed” and “separate feed” kilns is that the latter have the advantage of avoiding the contamination of the lime by ashes from the fuel, and, for this reason, when pure lime is required, it should usually be burned in a kiln of the second type. Mixed feed kilns are only used where the lime need not be so pure or where the lime is afterwards subjected to a process of purification; when properly designed, they require less fuel and are largely used for burning material containing less than 97 per cent. of calcium carbonate, in which the small increase in the amount of impurity caused by the ash from the fuel is not so serious.

MIXED-FEED KILNS

One of the simplest forms of continuous mixed feed kilns consists of a circular or oval vertical shaft, open at the top, through which the stone and fuel are charged into the kiln in alternate layers, and one or more openings at or near the base, through which the burned lime is withdrawn. Poke-holes and inspection-holes should be provided at suitable heights in the kiln so that the

progress of the burning may be watched, and any material which may "stick" or "hang-up" in the shaft may be released by using a poker. The kiln may be sufficiently high to create the necessary draught, or it may be comparatively short and surmounted by a chimney.

The *advantages* of kilns with mixed feed are :

- (i) They are relatively cheap to construct.
- (ii) They are the most economical in fuel.
- (iii) They give a maximum output for the size of the kiln.
- (iv) Working expenses are very low.

The *disadvantages* of kilns with mixed feed are :

- (a) The lime is discoloured by contact with the fuel.
- (b) The ashes from the fuel cannot readily be separated from the lime.
- (c) Part of the ash may combine with some of the lime forming a clinker and preventing the lime from burning properly.
- (d) The lime is often unevenly burned.

Provided a kiln of this simple type is rightly proportioned and is skilfully managed, it is almost ideal when the purest lime is not required. Most of the existing kilns of this type are, however, badly designed, so that they are very wasteful in fuel, and some are extravagant in labour. Moreover, many attempts have been made to "improve" this type of kiln by the addition of various appliances which are introduced in order to reduce the amount of labour required or to enable the kilns to be used by men with little or no skill in management. To understand the value or otherwise of these modifications it is necessary to have some standard with which they may be compared.

An Ideal Mixed Feed Kiln is sufficiently high to make the fullest possible use of the heat from the fuel and to cool the lime to such an extent that it can be handled with ease. It must be of such a shape that the stone and lime will pass easily down through the kiln without any poking or other attention being necessary, and, at the same time, the lime must be burned uniformly, none of it being spoiled by overheating and none being incompletely burned.

The manner in which the stone and fuel are supplied to the kiln should require the minimum of labour, and the withdrawal of the burned lime should be effected in the simplest possible manner.

If the stone and fuel do not present unusual difficulties, a plain cylindrical shaft, not less than 50 ft. in height from the discharge outlet to the top of the kiln, will be found to approach very closely to this ideal, but where the stone is difficult to burn, where a fuel must be used which is not very suitable, or where, for some reason, a very short kiln must be used, it may be necessary to modify the shape and dimensions of the kiln in order that good lime may be produced cheaply.¹ In most cases, however, the variations in the shape and dimensions

¹ Many mixed-feed kilns are only 22 ft. high, 9 ft. diameter at the top, and tapering to 6 ft. at the bottom, with two eyes or outlets about 5 ft. high and 3 ft. wide in the lower part of the wall, but no grate. Such a kiln holds about 16 tons of stone and produces 5-8 tons of lime per day. It requires about twice as much fuel as a modern cylindrical kiln 50 ft. high with a chimney on top and grate bars in the base.

of mixed feed kilns have not been made as the result of a careful study by men with adequate knowledge of the subject, but are the result of casual ideas which various people thought may be improvements and, in some cases, owing to the balancing of various errors, some of these modifications have actually given better results than were obtained before they were used. In the majority of cases, however, the result of such improvements is not compared with an ideal kiln, but with a very imperfect kiln previously in use. This is a wrong basis of comparison which has led to many erroneous conclusions as to the merits of various "patents" in connection with mixed feed kilns:

Bearing in mind what has just been stated with regard to an ideal mixed feed kiln, the various deviations from a simple cylindrical shaft may now be described and their respective advantages and disadvantages considered.

Horizontal Cross Section.—Most mixed feed kilns are circular in plan, and as this shape is cheapest as regards the cost of erection relative to the capacity of the kiln, and as it usually ensures the most uniform burning and the easiest descent of the stone and lime with a minimum of "sticking," it is, in most cases, the most suitable shape. Where very large kilns are required and no form of chimney or fan draught is used, the circular shape is sometimes inconvenient as the men cannot work comfortably in the centre of the top of such a kiln. There are three methods of avoiding this difficulty: (a) to withdraw the gases from the kiln in such a manner that they do not interfere with the men's work in spreading the stone and fuel properly in the kiln; (b) to alter the shape of the kiln so that the spreading may be effected from the sides of the kiln; and (c) to use a mechanical device for spreading the stone and fuel. In most cases, the author prefers the first method and has found, by experience, that this is usually the best, but some lime burners use the second and third methods—possibly because they have never considered the first!

Oval mixed feed kilns are sometimes used. Unless the kiln has an output of more than 30 tons of lime per day, they are in no way better than circular kilns. The only advantage of the oval shape occurs in the case of very large kilns in which it enables the men to distribute the stone and fuel without the men stepping inside the kiln, as with a sufficiently charged elongated oval, no part of the surface of the stone or fuel is at a greater distance from the sides than half the smallest diameter of the kiln, and, consequently, the workmen can rake and distribute the stone and fuel quite uniformly without leaving the sides of the kiln. In this way, they are less exposed to the gases from the kiln, though with a side wind the advantage so gained usually disappears.

Oval kilns are more advantageous when fired externally or with gas or oil; this is considered in greater detail in a later section.

Kilns which are circular at the top and oval at the burning-zone are sometimes used, as they are supposed to cause the pieces of stone to turn over in their passage through the kiln and so be more uniformly burned.

Square and Rectangular Kilns are seldom used as the stone in the angles is imperfectly burned and the average quality of the lime from kilns of these shapes is, therefore, low.

Some mixed feed kilns with a *cruciform cross section* have been used, but they contain so large an amount of wall-surface compared with the output that any roughness of the walls increases the friction between the contents and the kiln, which increases the liability of the stone and lime to "stick," and greatly increases the cost of repairs. Kilns which are cruciform in plan are now seldom used, the simpler shapes being preferred.

Vertical Section.—There is great diversity in the shape of the vertical sections of mixed feed kilns. The simplest—and usually the best—form is that of a perfectly straight vertical cylinder or shaft of uniform diameter from top to bottom, as kilns of this shape are easily and cheaply built and the absence of any great irregularities in the surface facilitates the descent of the materials down the shaft and reduces the tendency to "stick." Many mixed feed kilns are constructed with a simple shaft of this type and work perfectly satisfactorily; it is, indeed, being increasingly realized that complicated shapes are more likely to introduce difficulties than advantages.

A permissible departure from the true cylinder is to make the *shaft taper slightly towards the top*, thus forming a steep-sided cone. The advantage of this mode of construction is that sticking is less likely to occur than in a kiln with vertical sides, though this is not always the case, as some limestones "stick" equally as much in a conical kiln as in one with vertical sides. It is sometimes suggested that, as the cross-sectional area of the stone and lime is greatest at the bottom of a kiln of the shape just mentioned, the pressure on the lime is less than in a cylindrical kiln; in actual working the difference is so small that it need not be considered, as the pressure on the base is not proportional to the area. A difference of 2 ft. between the top and bottom diameters is ample.

In some vertical kilns the *shaft may be tapered towards the bottom*, forming an inverted cone. The use of this shape is based on the idea that as the lime occupies only half the volume of the stone from which it was made, the cross-sectional area at the base need only be half that at the top (see p. 281).

It is sometimes claimed as a further advantage possessed by a shaft which is wider at the top than at the base that, in descending, the stone is rolled over and over, thus exposing fresh surfaces to the action of the hot gases, whereas in a straight sided kiln the charge sinks steadily downward. If the maximum amount of rolling which can occur in both types of kiln is calculated it will be seen that the greatest possible gain from the inverted conical shape is so small as to be negligible.

As too much air is liable to enter a kiln with wholly vertical sides, and so cause a waste of fuel, it is usually advantageous to make the lower part of the kiln in the form of an inverted cone, but this should not extend to a height of more than about 8 ft. so as to be well below the point at which "sticking" is likely to occur. The walls of such an inverted cone should slope at an angle of 60° – 70° so that the lime will flow freely downwards.

In actual practice, other matters, such as the extent to which the lime is cooled before leaving the kiln, have to be taken into consideration, and when this is done, the apparent advantages of an inverted cone are found to be

illusory, especially as "sticking" is more likely to occur than in a vertical or conical shaft.

The discharge-opening should be not less than 2 ft. diameter or it will be difficult to remove the lime, which will tend to "hang" over the opening instead of falling through it.

In some kilns—especially those of oval cross sections—two of the "sides" are vertical, whilst the other two are tapered so as to produce a circular cross-section in the lower part of the kiln.

Some vertical kilns are in the form of a *cone resting on an inverted cone* or of a *barrel*, the greatest diameter of the kiln being rather below the centre,

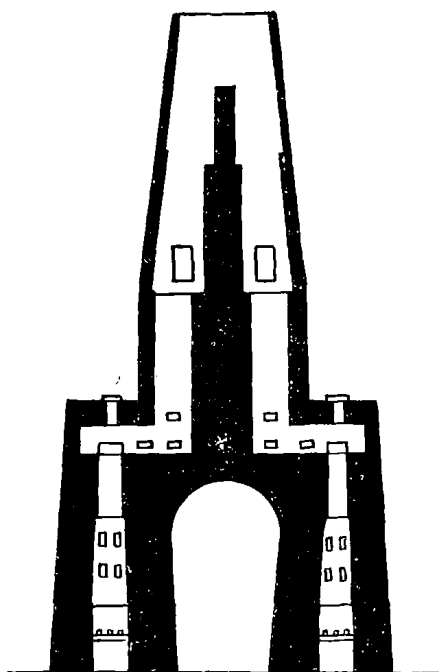


FIG. 60.—DIETZSCH KILN.

cylinder than in a wider one, and such uniformity of heating is particularly desirable in the hottest part of the kiln.

(c) The required temperature is more readily obtained in the narrow part than in a wider one, as the constriction increases the intensity of the draught and so causes the fuel to burn more rapidly.

Against these advantages are the following disadvantages:

(i) A greatly increased tendency of the stone to "hang" above the constricted portion instead of passing through it, thereby necessitating extensive poking at intervals which tends to produce irregular burning.

i.e. at the burning zone. This shape tends to irregular distribution of the heat and to the production of a minimum draught at the part where a strong draught is most needed for the development of the maximum heat from the fuel. If the requisite draught is obtained, the long time occupied by the lime in passing through the burning zone tends to produce over-burned lime.

Some vertical kilns are *constricted in the burning zone* and are much wider at the top and bottom, their shape corresponding roughly to that of an inverted cone mounted on the apex of another cone. The purposes of such a shape are:

(a) To cause the limestone to pass more rapidly through the burning zone so that it is not kept too long at the highest temperature of the kiln, and is not over burned.

(b) The stone tends to be heated more uniformly in a narrow

(ii) Much greater wear and tear on the lining of the constricted portion. These disadvantages are most serious in kilns of small diameter.

When a kiln is constricted in any part, it is most important that the taper should be very steep, the angle not being less than 60° , and preferably greater. If the angle is small, "sticking" is almost certain to occur; it will cause much trouble, and will yield a product of irregular composition. Notwithstanding these disadvantages, such well-known and widely-used kilns as the Aalborg, Smidth, and Spencer kilns all have a constricted burning zone.

Kilns with two shafts are sometimes used for very soft stone, or lime which is easily spoiled by being crushed, as in the *Dietzsch* kiln and other "Etageofen" or Stage kilns, in which the shaft consists of two separate parts, connected by one or more horizontal portions.

In the *Dietzsch* kilns (fig. 60) there are two vertical shafts joined by a horizontal or slightly sloping chamber, so that the vertical downward pressure is less than half that in a plain shaft kiln of equal total height, and there is, consequently, far less tendency to crushing. "Hanging" is also reduced to some extent, as this is partly due to the lateral effect of the great vertical pressure in a straight shaft. The chief disadvantage of the *Dietzsch* kiln and similar types is that it is necessary to push or rake the stone along

the nearly horizontal portion and the descending material tends to "hang" at the "bends," where it changes its direction of travel. For material which cannot be burned in a tall single shaft, the *Dietzsch* and similar kilns are excellent.

In the "R" kiln (fig. 61) are two inclined shafts which discharge their contents into the top of a lower vertical shaft, so that the pressure on the burned lime is less than when a single shaft is used, but the friction caused by the two uniting columns, and the change in the direction of travel of the material tend to cause "hanging," unless the material is frequently poked down. Hence,

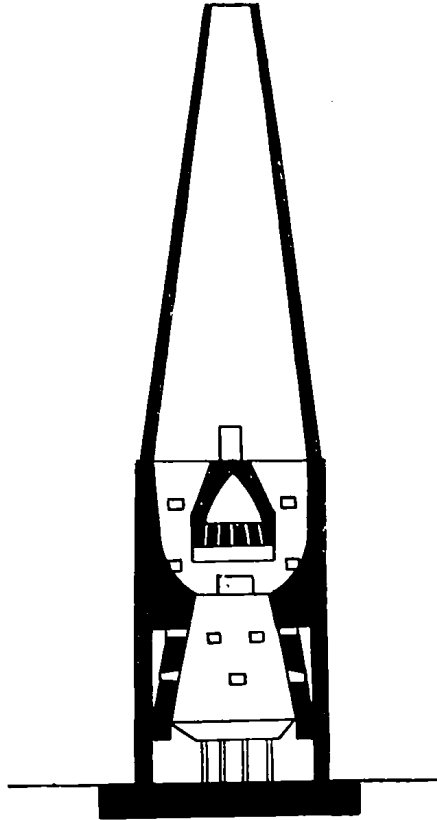


FIG. 61.—"R" KILN.

this type of kiln involves more labour than kilns with a single shaft.

Kilns with one shaft.—In the *Aalborg*, *Brockham*, and *Smidth* kilns, the lime is fed with some of the fuel through the top of the kiln, but part, and, sometimes, the whole of the fuel is supplied through three or more inclined shafts, so that it enters the main shaft at the burning zone. It is claimed that this arrangement ensures a more effective combustion of the coal.

The *Brockham* kiln (fig. 62) is largely used for burning chalk and particularly for *greystone chalk*. Its fuel consumption is intermediate between that of a flare kiln and a draw kiln.

The *Aalborg* kiln and some of the *Smidth* kilns are alike in principle, differing only in details of secondary importance. They are described on pp. 295, 296.

Various special modifications of the shapes of shaft feed kilns have been patented, which are supposed to avoid serious defects, but most of them are unimportant and few have been adopted in modern kilns. Thus, one patentee has claimed the use of a spiral shaft, being under the impression that by this means the stone will travel much further than in a simple vertical shaft. Unfortunately, the "spiral" is so slight that only the stone in contact with the walls of the kiln can be subjected to its action, whilst the greater part of the stone descends vertically downward, as in a plain shaft. Consequently, the cost of erecting the kiln is greatly increased, but no adequate advantage is gained.

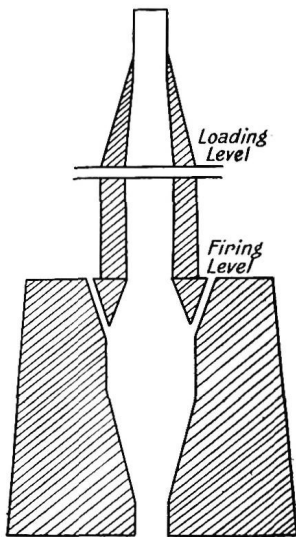


FIG. 62.—BROCKHAM KILN.

Equally useless are various arrangements of grids placed at various heights in a kiln so as to support the contents and to prevent undue crushing of the lime. Such grids wear away rapidly, necessitating complete stoppage of the kiln; even when they remain intact they greatly impede the progress of the descending column, so unduly reducing the output of the kiln.

The shape of the outer walls of a vertical kiln is largely a matter of convenience, provided the structure, as a whole, possesses the necessary strength. If the kiln is to be cased with steel—which is usually desirable, as ensuring much less risk of leakage—the exterior and interior of the kiln may be similar in shape, with the exception of the base, which may most conveniently be in the form of four massive piers or pillars, about 10 ft. high.

Many old kilns are built of rough hewn stones from the quarry, as these could be obtained very cheaply, and in such kilns, the exterior walls are square, or rectangular, with a good slope or "batter," so that each wall is really a buttress, the shape being irrespective of that of the shaft. Such "masonry" kilns were often built against the side of the cliff, the latter forming the "back

wall" of the kiln, and avoiding the necessity of building a gantry from the quarry to the kiln. Since 1914, the cost of masonry has increased so enormously that it does not now pay to build kilns of hewn stone except under unusual conditions, so that for new kilns—at any rate in Great Britain—steel-cased shafts are almost invariably used; they are usually circular or oval in cross section, as this appears to be the most convenient and economical form. The construction of the kiln walls is described later.

The *height of the kiln* should be determined after a consideration of the best use of the fuel, and of the nature of the stone to be burned. Soft materials, such as chalk and marl, cannot be burned in very tall kilns, as they crush so readily, so that very short kilns—often not exceeding 15 ft. from the charging opening to the draw-holes—are often used. These are very wasteful in fuel, but are unavoidable if taller kilns cannot be used on account of the softness of the lime, and the consequent reduction of the draught by crushing. Such exceedingly short kilns are seldom required, and, in most cases where they are used, they could, with great advantage, be replaced by taller kilns of better design. As the tall kilns are much more economical in fuel, it is important not to reduce the height more than is absolutely necessary. Where the stone and lime are sufficiently hard not to be crushed in the kilns, the height of the kiln should be adjusted to obtain the maximum economy of fuel. Thus, some kilns are as much as 120 ft. high, though an internal height (from the top to the bottom of the contents of the kiln) of 45–60 ft. is usually ample, and 43 ft. may be regarded as the minimum for really economical working. The height of the chimney, if one is employed, is not included in the figures just mentioned.

Some builders of lime kilns assume that vertical shaft kilns for hard stone should be four to five times as high as they are wide, but this is based on a misunderstanding, as there is no direct relationship between the width and height of a mixed feed kiln. The *height* should be determined in accordance with the nature of the stone and fuel, but the *width* should depend almost entirely on the output required. In other words, for a given stone, the height should not be appreciably different in three kilns the first of which has an output of 20 tons, the second 50 tons, and the third 70 tons per day, but the cross sectional areas should be in almost direct proportion to the square root of their respective outputs.

The author has examined a large number of vertical kilns in several different countries, and has reached the conclusion that the dimensions of most of them are largely based on those of pre-existing kilns, rather than on any fundamental principles of design. Only a few of these kilns appear to be correctly dimensioned; most of them are much too short, and so waste fuel.

The *diameters of mixed feed kilns* can be of any convenient dimensions, though circular kilns of more than 25 ft. internal diameter are very difficult to manage. An internal diameter of 15 ft. is usually quite satisfactory, and with a stone presenting no special difficulties should produce an output of about 50 tons of lime per 24 hours.

Limestones vary in the rate at which they can be burned, but an output

of 26 lb. of stone per hour per square foot of cross sectional area is obtained from well-designed mixed feed kilns, 8 ft. or more in internal diameter. Mixed-feed kilns of less than 8 ft. internal diameter are seldom desirable, as they are costly to build in proportion to their output; it is, however, possible to work kilns of only 4 ft. internal diameter in a wholly satisfactory manner; though they require a rather larger proportion of fuel per ton of lime burned than when a kiln of greater diameter is employed.

Manufacturers are increasingly realizing the desirability of using mixed feed kilns of as large a diameter as possible consistent with the output required, as a single large kiln is much cheaper—both to build and manipulate—in proportion to its output than two or more smaller kilns having the same output. This statement does not apply to gas- or oil-fired kilns.

Where a kiln is constricted at any part of its diameter, the area of the constricted portion should seldom, if ever, be less than half that of the wider part, and so great a constriction is generally undesirable. Only in very exceptional cases should the angle of the interior walls of the inverted cone from the wider to the narrower part of the kiln be less than 60°. The much greater angle of slope shown in some drawings of kilns, especially those illustrating patent specifications, is undesirable and liable to cause serious trouble when the kiln is in use, unless the stone and fuel are unusually easy to burn.

The *base of the kiln* should be strong enough to support the pressure of the superimposed structure and the contents of the kiln. This pressure will seldom be less than 6 tons per sq. ft. of the smallest area of the base, and may be much greater. The shape of the base should be such as to give the necessary strength and at the same time facilitate the discharging of the kiln.

Three methods are commonly used to support the shafts of vertical mixed feed kilns:

(a) *Cast-iron pillars* on a concrete base are very strong, the permissible working stress for compression being 8 tons per square inch, and have the advantage of not occupying much space, so that ample room is available for discharging the kiln. Such pillars are only occasionally used for lime-kilns, but they are commonly employed for the blast furnaces used in the metallurgical industry. Where the kiln is narrower at the base than higher up, the wider part may sometimes be conveniently supported on such pillars, the conical portion being dependent from it, or supported on a separate foundation. Small shaft kilns are sometimes supported on steel girders bolted to a concrete foundation.

(b) *Brickwork, masonry, or concrete pillars* are not so strong as cast-iron pillars, unless more bulky, but they are often much cheaper, and so are more commonly employed. The pillars or walls should be arranged so as not to interfere with the discharge of lime from the base of the shaft, and must be of ample strength to support the superstructure and its contents.

(c) A *rectangular tunnelled base* of brickwork, masonry, or concrete is very strong, secures a better distribution of the load and a larger base area than pillars, and is also very convenient for discharging as the trucks may be run into the tunnel, filled, and then pushed through and out at the other end,

instead of discharging the lime into smaller wagons which are afterwards emptied into trucks. If required, a series of screens and sorting planes may be arranged between the outlet of the kiln and the opening in the top of the tunnel.

The *outer walls of the kiln* are required to :

- (a) Support the weight of the kiln and the charging house at the top.
- (b) Resist the outward pressure of the contents of the kiln.
- (c) Protect the refractory lining of the kiln from sudden changes of temperature, mechanical damage, and the weather.
- (d) Reduce the loss of heat from the kiln due to radiation.

For these purposes, they should be substantially built and of ample thickness, especially if there is a heavy superstructure. When these walls are of masonry or brickwork they are usually thicker at the base than at the top of the kiln, but in no case should the lower part of the walls of the shaft be less than 2 ft. thick, and preferably they should be 3 ft. thick, exclusive of the refractory lining, unless the kiln is encased in steel, when a thickness of 3 ft.—3 ft. 6 in. including the lining will be usually satisfactory. If the kiln shaft tapers towards the top, the outside walls should correspond so as to avoid an excessive thickness of brickwork.

The chief materials used for the outside walls of mixed feed kilns are masonry, brickwork or concrete, with or without a steel casing on the outside.

Limestone was, formerly, the chief material, as it was readily available at a low cost, and could be roughly hewn to shape in the quarry where it was to be used. For this reason, it was very convenient. Since 1914 it has become too costly when brickwork is available. Other stones are seldom used, as they are generally more difficult to obtain and have none of the advantages of limestone.

Brickwork is also used to a considerable extent for the outer walls of kilns, but unless enclosed in a steel-casing so large a number of bricks is required that their use becomes as costly as masonry.

Concrete, suitably reinforced, has been used for the outside walls of lime kilns on account of its convenience, but it has proved to be more expensive than brickwork in a steel casing, except in remote localities, and it is difficult to avoid the formation of cracks, which cause leaks.

Casings of sheet steel are now largely employed for the external covering of lime kilns, particularly those using mechanical draught, as such kilns remain gas-tight much longer than those made of brickwork, masonry, or concrete. The casings are built of sheets of steel about 5 ft. square, $\frac{5}{16}$ — $\frac{3}{8}$ in. thick, and fastened together by means of rivets. For very large kilns, the lower plates should be $\frac{1}{2}$ -in. thick to ensure the requisite strength. The casing is first erected on the base or foundation of the kiln and the interior walls are then built inside it. One ring, about 9 in. thick, of good red bricks, is placed next the steel work ; inside this there should be a 2 in. ring of insulating material, and inside the latter the lining, consisting of two or more rings of fireclay bricks. The thickness of the wall and lining must not be reduced unduly, or the loss of heat by radiation will be excessive. When kilns are steel cased, all the doors needed for poking,

inspection, etc., are attached to the casing, and when closed should be perfectly gas-tight.

The *insulation of the kiln walls* to minimize the loss of heat by radiation is very important, but it is often overlooked. Without insulation, this loss is usually about 10–15 per cent. of the total heating power of the fuel used. With insulating material properly applied this loss may be reduced to about 5 per cent. The most suitable insulating material is kieselguhr in the form of bricks; these are sold under various proprietary names, but are generally known as *insulating bricks*.

The *lining of the kiln* is one of the most important parts, as unless it is carefully selected and properly constructed, the wear and tear may be very heavy and the consequent repairs very costly; to obtain the maximum durability, suitable lining bricks or blocks must be chosen.

The chief actions to which the refractory lining of a lime kiln is subjected, are :

- (1) The abrasive action of the descending charge of stone and lime.
- (2) The sudden changes of temperature occasioned by draughts of cold air entering the kiln, especially after poking the charge.
- (3) The chemical action of the fuel, dust, ashes, and gases on the lining.
- (4) The chemical action of the lime on the lining at high temperatures.

The results of these various actions are most severe when a very pure lime has to be burned, as this requires the highest temperature and one at which the lime is most corrosive. Impure limes (such as those from the Lias formation) and magnesian limes are burned at lower temperatures and have a much smaller corrosive action on the lining, magnesia being a much less powerful flux than lime, and the slag it produces being much more viscous and less penetrative.

The upper part of the lining of a vertical kiln does not present much difficulty, as the temperature is not high and the chief actions to be resisted are the abrasion of the descending charge and the deposition of carbon from the waste gases which tend to accumulate in the pores of the bricks, and disintegrate them. (Hard blue bricks, such as those used for paving and structural work, are very suitable for the upper portion of lime kilns, as they are very strong and resistant to abrasion, and are not affected by heat up to about 900° C.) Fireclay bricks are suitable if hard and of fine texture; they need not be highly refractory. (Other suitable materials are granite and hard sandstone, though these are not usually available at a sufficiently low price and are seldom used. A lining of steel-plate, $\frac{1}{4}$ -in. thick, is used in the uppermost 6 ft. of some tall kilns and is very effective.)

Some limestones are so little affected by a moderate rise in temperature that the upper part of the kiln may be built and lined with blocks of this material, but most limestones flake and spall when heated irregularly, and a kiln built of such stone would rapidly “wear away.”

These materials (with the exception of fireclay bricks) should not be used too far down the shaft or they may be damaged if the fire rises a little too high,

The thickness of the lining in the upper part of the kiln need not be more than 9-in. and it may be backed with 9 in., 14 in., or 19 in. of common red brick or second grade fire-bricks with or without a ring of porous bricks to reduce the loss of heat by radiation.)

(*Fireclay bricks* are most generally used for lining the hottest zones of lime-kilns, the best bricks being those which are very high in alumina (about equal proportions of silica and alumina being most satisfactory), as highly aluminous bricks are less readily attacked by lime than are ordinary fireclay bricks. It is theoretically incorrect to use an acid lining in contact with a basic material, such as lime, but if aluminous bricks are employed, the chemical action is reduced to a minimum. Siliceous fireclay or fireclay-grog bricks are less satisfactory, but are very largely used.)

The temperature in the hottest zone of a lime kiln seldom exceeds about 1300° C. and 1000°–1200° C. is more usual, so that the refractoriness of the bricks need not be very great, provided they will withstand continued heating at the maximum temperature of use. The bricks must not be highly vitrified and dense, or they will not be resistant to sudden changes in temperatures, but it is very desirable that the superficial skin should be dense in order that it may be as resistant as possible to abrasive and chemical action. Soft, porous-faced bricks are quite useless, no matter how heat-resisting may be the clay from which they are made. It is well known, that a No. 2 grade of firebrick may, by reason of its great hardness and strength, often be better able to withstand the abrasive action of lime than more refractory, yet softer, bricks. Second-grade firebricks usually have the further advantage of a smoother and closer face, which reduces the intensity of the action of the lime (see also "Aluminous Bricks").

Theoretically, the use of firebricks is unsound, because they are of an acid character and at a sufficiently high temperature react with the lime and form a fusible silicate resulting in severe corrosion of the brickwork. As the limestone and lime are in relatively large pieces the total amount of combination which occurs is relatively small until the kiln lining becomes so worn that the stone or lime lodges in the cavities in the brickwork; the corrosion may then be serious.

For general use no material has been found which is superior to good well-burned fireclay bricks rich in alumina, of fine, uniform texture, and with a smooth surface.

Silica bricks are sometimes used for lining lime kilns, but they are seldom so satisfactory as fireclay bricks, as they are more rapidly attacked by the lime, are friable, and not resistant to sudden changes in temperature. It is not correct to state that good silica bricks are not suitable for lime kilns. The bad results noted are more frequently due to mistakes in the management of the kiln. Some silica bricks "spall" badly and so are unsuitable.

Sandstones and schists have been used with fair satisfaction for lining lime kilns, provided they are placed so that the laminations are horizontal and not vertical; if placed in the latter position, they will readily spall in use.

Gritstone was used until about thirty years ago, but the higher temperatures due to using better coal have compelled the use of firebricks. Linings made of natural stone are not constant in volume and the strains to which they are subjected are very liable to disintegrate them, so that such linings are not really economical, even when they are cheaper in first cost. Brick linings are invariably preferable.

Aluminous bricks are usually made by mixing fireclay with calcined bauxite or other form of free alumina, but the name is sometimes applied erroneously to ordinary fireclay bricks. The added alumina, if properly incorporated, increases the resistance of the bricks to corrosion by limestone and lime, but a porous aluminous brick with a coarse texture may be much less resistant than a denser fireclay brick with a fine texture and a smooth surface to which the lime cannot adhere. When aluminous bricks are used they should contain at least 60 per cent. of alumina, almost all of which should be combined with silica, but many of the aluminous bricks contain less than 40 per cent. of alumina. What appears to be an ideal mixture is one containing alumina and silica in the same proportions as in mullite, *viz.* : 71.8 per cent. of alumina and 28.2 per cent. of silica, or 1 part of silica to 2.55 parts of alumina. This mixture is only useful when the bricks made of it have been burned so intensely as to produce a large proportion of mullite ; otherwise, the bricks are of much inferior quality to good fireclay bricks.

Magnesia bricks are unsuitable for lining lime kilns, as although they are basic and not likely to be corroded by the lime, they are not resistant to abrasion at high temperatures, and they are very susceptible to sudden changes of temperature. Moreover, the presence of magnesia in lime used for fluxing purposes is very objectionable. Magnesia bricks are also very costly, so that other less resistant bricks are more economical at present, though if a sufficiently hard and strong magnesia brick could be produced at a reasonable cost it would form an almost ideal lining for many lime kilns.

Rammed or tamped linings have been used to some extent for lime kilns, but they are unsuitable on account of their low durability.

Blocks are preferable to bricks for lining kilns, as there are fewer joints, and, as the joints are more easily abraded and corroded than the solid bricks or blocks, the durability of a lining built of blocks is greater than one of bricks. Blocks are more costly to buy, but are well worth the extra cost on account of the lesser cost of repairs. Blocks of convenient size are 9, 12, 18, or 24 in. in length, the ends being 9 in. square ; they are set as " headers " in the kiln. Larger blocks are inconvenient to handle and so are undesirable. The blocks should also be tapered to suit the diameter of the shaft, so as to ensure their joints being as thin as possible. It is also an advantage to use bricks or blocks with faces curved to suit the cylindrical or oval interior of the kiln ; ordinary firebricks, being straight, form a series of projections or hollows which are one cause of the rapid wear and tear of the lining. The small additional cost of properly shaped blocks or bricks is more than counterbalanced by the greater durability of the lining in which they are used.

It is important not to use bricks which have been subjected to an excessive pressure during manufacture as such bricks tend to flake or chip when in use. The pressure should only be just sufficient to ensure an accurate shape.

Whichever kind of bricks or blocks are used for the lining, it is important that they should be accurate in size and shape as thin joints are imperative. No bricks or blocks—no matter how refractory—will remain long in use in a lime kiln if they have been laid with wide joints, for the lime readily attacks the jointing material and, a short time after, the firebricks fall out in consequence of the abrasive action of the descending charge.

The refractory lining of the hot zone should not be less than 9 in. thick and, in some cases, it is 24 in. thick, though this is not generally necessary. It should be backed by inferior firebricks and common building bricks so as to make a total wall thickness of 3 ft. or 3 ft. 6 in. if a steel casing is employed, or by a greater thickness of firebricks with concrete or masonry if no steel is used.

The refractory lining of the kiln should extend about four-fifths of the distance from the bottom of the burning zone and about half-way down the cooling zone. Too long a refractory lining is preferable to one which is too short, as, in the latter, corrosion will be excessive. For this reason, some lime burners line the kilns throughout with refractory bricks or blocks.

Metal linings are sometimes used in lime kilns, as in the Stein kiln, which is built of cast-iron sections, each 18 in. high, fitted with projections so as to increase the strength of the shaft and the radiation of heat in order to obtain a cool kiln in which the descending column will not be likely to "stick." Such kilns are very wasteful in fuel, and very costly to repair, so that they are now very seldom used.

Other linings are sometimes used. Thus, in the Schneider kiln a layer of crushed limestone mixed with tar is used to protect the lining of the kiln, but it is not entirely satisfactory.

Insulating the kiln.—In order to prevent excessive loss of heat by radiation, it is often desirable to insert a ring of insulating bricks (made of kieselguhr) between the lining and the outside walls of the kiln. Some kiln builders prefer a ring of loose kieselguhr, or even an empty (air) space between the brickwork and the steel casing, or between the inner and outer brickwork. It has been found in America that a ring of insulating bricks ($4\frac{1}{2}$ in. thick) between the lining and the outer wall of a kiln will effect a saving of 60–70 per cent. of the heat which would otherwise be lost by radiation, or 8–9 per cent. of the total fuel consumption of the kiln, as well as providing an elastic backing to take up the strains due to changes in the volume of the lining.

The insulation of a kiln reduces the durability of the refractory lining because the lining of the kiln is much hotter than when no provision is made for preventing losses by radiation, and, consequently, the chemical action between the lime and the lining is increased. It is, therefore, necessary to take special care to use a more refractory lining in insulated kilns, or the saving effected by the insulation will be counterbalanced by the extra cost of repairs to the lining.

Metal bands are sometimes fitted round the walls of lime-kilns so as to strengthen the walls and reduce the tendency to crack. It is far better, however, to build the walls of the kiln sufficiently strong to render such bracing unnecessary and merely of a precautionary character. If bands are to be used, the ends should be attached to shackles on a screw movement; the latter must be tightened at intervals until the band emits a "singing" note when struck. When a steel-casing is used, metal bands are, of course, unnecessary.

Poke holes should be left at suitable positions in the walls of the kiln. They are chiefly necessary in the burning zone, and at any part of the shaft which is constricted, but they are also desirable in the upper part of the cooling zone, so that if the lime is contaminated with clay or is accidentally overburned—both of which cause it to "stick" in the kiln—the sticky mass may be broken down by the application of pokers. In a well-designed kiln, every part of the interior where "sticking" can possibly occur is readily accessible to a poker. To ensure this an ample number of poke holes should be left in building a kiln; if this is not done, much difficulty will ensue in working the kiln. The poke holes should be fitted with air-tight covers to prevent air entering the kiln through the poke holes.

Inspection-holes should be provided in the burning zone and above it, so that the temperature of the contents of the kiln can be ascertained. Poke holes may be used for this purpose if desired, but additional inspection holes, 2 in. diameter and covered with glass or mica, are desirable. Some of these may also be used as *pyrometer holes*.

Air holes and flues must also be provided at suitable places, the location of which are more conveniently considered in connection with the air supply to the kiln. Inspection and poke holes may in some cases be used to admit air if necessary, though properly designed air inlets are preferable.

Roofs are always desirable over kilns, as, in their absence, the water which enters the kiln in rainy weather involves a serious waste of fuel. Many mixed feed kilns are not provided with roofs, but this "saving" has very serious disadvantages. Moreover, the space between the roof and the kiln should be enclosed by light side walls, the whole forming a proper housing which prevents rain and wind from interfering with the working of the kiln and protects the workmen from the weather. The most convenient and cheapest form of housing consists of a steel girder framework, supported on horizontal girders attached to the top of the kiln and covered with corrugated iron or similar material. There should be ample lighting and ventilation. The latter is especially important if any gases are likely to get into the exit flue. Plenty of space should be provided inside the housing; a mistake which is commonly made is to make the housing so narrow that the charging of the kiln is a matter of great inconvenience and serious accidents sometimes occur on account of the space provided being insufficient to prevent them. Where the rails run round the top of the kiln there should be a space of at least 3 ft. between the inside rail and the wall of the housing so as to enable a workman to stand on one side

whilst a wagon passes without risk of him being knocked into the shaft of the kiln or crushed between the wagon and the wall of the housing.

When the kiln has a conical top leading to a chimney a housing is not necessary, but in kilns with submerged chimneys it is highly desirable. Indeed, to obtain the best results, some form of cover is almost essential. The chief reason why so many existing kilns have no cover is that the owners do not know how to cover them without suffocating the men! Such ignorance ought not to be permitted when it can so easily be avoided with great advantage to all concerned. In some kilns with a submerged chimney, a cover is provided which fits over the top of the kiln and surrounds the chimney; this cover can be raised when it is desired to charge the kiln and is then lowered. This method is quite satisfactory and prevents kiln gases from entering the housing as well as increasing the draught of the kiln, but most of the firms which have these covers do not use them except when the kilns are being "shut down" for the week-end or are being worked below normal capacity. The advantages of this form of cover are realised, but well-designed kilns, work so well without it, if they are properly housed, that the cover is seldom used (see fig. 59).

Fuel supply.—The usual method of adding fuel to mixed feed kilns is to put it into the kiln in the same manner as the stone, alternate layers of stone and fuel being formed. This method has a very serious drawback with some coals, for as the coal descends the shaft, some of the more volatile hydrocarbons are distilled off before the coal reaches the burning zone, this portion of the fuel being wasted, as it is carried off in an unburned state with the other gases leaving the kiln. In most mixed feed kilns where such coal is used, the loss is very noticeable. It may be avoided by using coke or a coal which is very low in volatile matter, such as anthracite and some "smokeless steam coals," but these are often regarded as being too expensive.

In order that the cheaper coals may be used, various methods have been adopted for putting the fuel into the shaft at the point where the volatile matter can be burned and the heat from it utilized instead of being wasted. Thus, in the *Aalborg* kiln (fig. 63) there are two barrel-shaped zones superimposed on one another, the junction between them forming the burning-zone. Inclined passages or chutes are arranged so as to supply some or all of the fuel direct to the

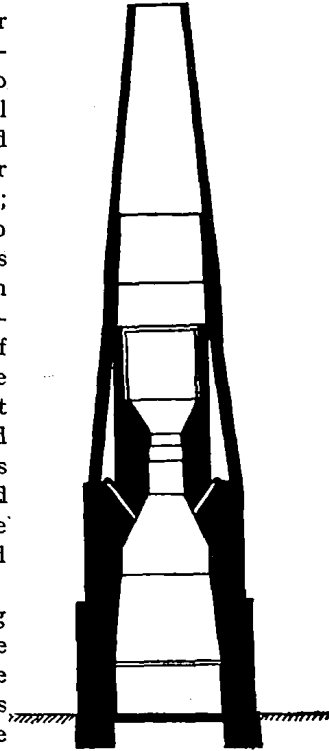


FIG. 63.—AALBORG KILN.

burning zone, so that any hydrocarbons liberated are burned along with the solid fuel. Iron covers are placed over the fuel chutes so as to prevent the escape of gases when the kiln is not being charged with fuel (see also the Brockham kiln—fig. 62).

The kilns erected by *F. L. Smidth and Co. Ltd.*, are of the Aalborg type, part of the fuel (preferably coke or anthracite) being mixed with the stone and put into the top of the kiln, whilst the remainder of the fuel, which may be rich in volatile or gas-forming material, is dropped through the fuel-chutes into the burning zone of the kiln. The proportion of each kind of fuel varies according to the nature of the stone and other circumstances, but, as far as possible, the larger proportion of the fuel is fed to the burning zone direct, and only sufficient is mixed with the stone to ensure the proper burning of the lime.

The fuel consumption of this type of kiln is by no means low, being normally about 18–20 per cent. of the lime produced, whereas with a well-designed mixed feed kiln, using coke or anthracite the fuel-consumption is only 10–15 per cent. The Aalborg kiln does, however, make good use of coals high in volatile matter, and may, therefore, cost less to burn than when a smaller quantity of much more expensive fuel is used. Kilns of this design are usually small, having an output of about $\frac{1}{2}$ ton per hour, or 15 tons per 24 hours. Much larger kilns of this pattern are difficult to work.

The *Spencer* and *Ryan* mixed feed kilns resemble the Aalborg kiln inasmuch as the fuel is introduced at a point some distance below that at which the stone enters the kiln.

In the *Dietzsch* kiln (fig. 60) is a connecting chamber, in the roof of which are holes through which the fuel is dropped amongst the stone. The pre-heated stone and the fuel are raked along the connecting chamber and fall into a second shaft in which the fuel is burned and the stone is calcined.

In the "R" kiln (fig. 61), which is very similar to the *Dietzsch* kiln, is a passage with a perforated floor directly over the lower shaft so that fuel can be dropped through into the burning zone of the kiln.

In the *Hauenschild* kiln all the fuel is dropped down cast-iron tubes which extend some distance down the kiln. These tubes are closed when no fuel is being charged, so that the gases from the fuel evolved must pass through the spaces between the lumps of limestone instead of escaping by way of the fuel-column.

In another type of kiln, the fuel is intended to form a hollow column with the limestone inside and outside, but it is almost impossible, in practice, to maintain it in this position, the final result being similar to that of an ordinary mixed feed kiln. If the strict columnar structure could be maintained it would have the advantage of keeping the fuel out of contact with the walls of the kiln, thereby lessening the tendency to sticking.

Air supply.—The arrangements for supplying air to mixed feed kilns are generally of a simple character.

The simplest method consists in supplying the air through one or more openings in the base of the kiln, through which the burned lime is discharged.

This air passes through the burned lime, cools it, and enters the burning zone where it assists in the combustion of the fuel; the waste gases formed then pass upwards, heating the stone in the preheating zone and finally pass out at the top of the shaft.

As it is not easy for the air to pass readily and uniformly through the openings used for discharging the lime, vertical or sloping grates are provided in the *Cornet*, *Perpignani-Candlot*, *Duchez* and many other kilns, to facilitate the supply of air to the base of the shaft and its uniform rise through the freshly-burned lime.

The arrangement used in small *Cornet* kilns (fig. 64), consists of grates on two or four sides of the kiln, the grates being inclined at an angle of about 60° . These grates allow the requisite amount of air to pass through and also reduce the width of the kiln down to a convenient size for discharging the lime, which is effected through a flat grate below the air-grates. A similar arrangement is used in the *Duchez* kiln (fig. 65).

The *Candlot* kiln and the larger *Cornet* kilns have vertical grids placed inside the walls of the kiln (fig. 64) about 3 ft. above the discharge openings and the *Cornet* kilns also have a series of openings into the kiln at the burning zone, these openings being connected to and surrounded by an annular flue which admits air to them.

In the *Campbell* kiln, the cooling zone is an inverted frustum of a cone which is slotted so as to form a grate; it rests on a vertical slotted drum,

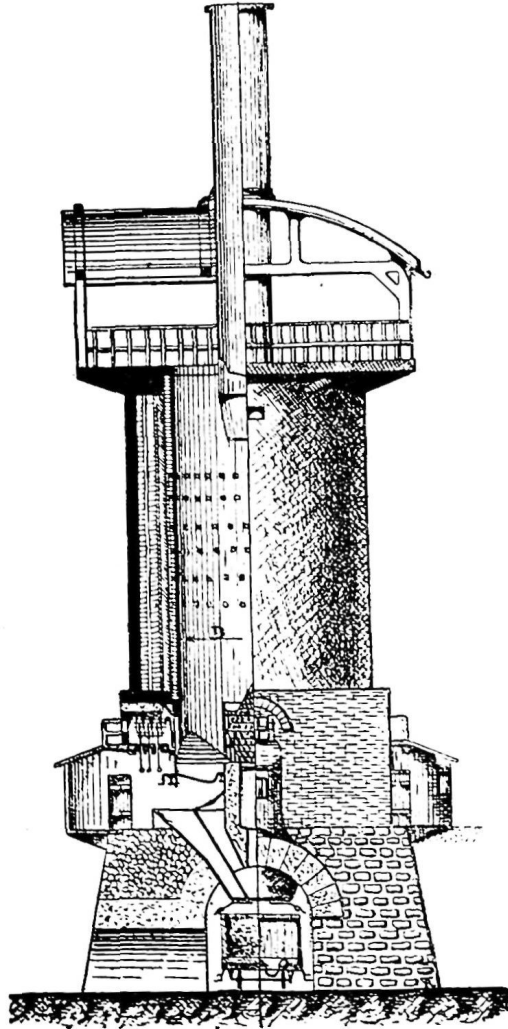


FIG. 64.—CORNET KILN.

built of bars, the former being about 4 ft. 6 in. and the latter 3 ft. in height. There is an open space all around the cone and drum so as to allow ample access of air to the kiln and to give the drawer access to the lime.

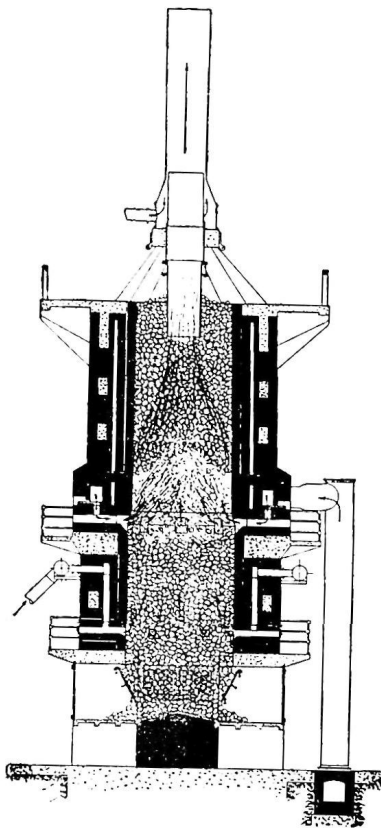


FIG. 65.—DUCHEZ KILN.

or in the burning zone to enable a more accurate control of the burning to be maintained. An arrangement of vertical air flues discharging into three or four rows of horizontal air flues, controlled by dampers with handles near the base of the kiln is a special feature of the Cornet kiln (fig. 64).

The *DucheZ* kiln (fig. 65) has a more complex system of damper-controlled flues in the walls, through which air is forced by a fan and discharged through openings in the burning zone, whilst other flues are provided for supplying cold air if necessary near the base of the kiln. It is claimed that this dual system of flues greatly reduces the amount of heat lost by radiation, but the author has yet to hear of a kiln at work in which it is actually used.

An alternative supply of hot air to the burning zone is obtainable by

The *Steiger* kiln has a vertical grating placed at the base of the straight sided portion of the kiln and a short distance above the cooling zone, so that the air is partly supplied directly through this and partly through the base and the cooling lime.

In a recently-built *Cornet* kiln of 50 tons output per day, a central perforated cone is fitted at the base of the kiln so as to supply additional air to the centre of the shaft and the vertical outside air grids then form a continuation of the wall of the kiln.

In the *Polysius* kiln (Ger. Pat. 328,320, 1918) the cooling zone is surrounded by a hollow space down which the gases are drawn before they enter the bottom of the kiln. This still further utilizes the heat from the cooling lime, though it is doubtful whether it is really worth while and the risk of "carbonating" some of the lime is serious.

The great disadvantages of admitting air solely through openings in the base of the kiln is that the supply of air to the burning zone cannot readily be controlled. For this reason, some kilns have additional air flues operated by dampers which supply air just below

constructing flues in the walls which descend from the top of the kiln to the burning zone where they allow the air to enter into the kiln ; these flues are heated by radiation from the kiln walls.

The object of the various rows of inlets from the vertical air flues is to supply air at the height at which it is required and to withdraw it when it will serve no useful purpose. This is the more important as the height of a burning zone varies within several feet, and it is necessary to have air inlets at different heights in the kiln, so that the air may be admitted at whatever height the burning zone may be in the kiln.

Only one row of air inlets is used at a time, namely, the one which is just below the burning zone and in the uppermost part of the cooling zone.

The advantage of preheated air over cold air in the burning zone is obvious as heat which would otherwise be lost is utilized and the hot air does not require to be raised in temperature so much when it reaches the burning zone as it would if it were admitted in a cold state to that zone.

There is no doubt that by suitably controlling the position at which the hot air is introduced into the kiln, the position of the burning zone can be kept at any desired height in the kiln shaft, whereas without any secondary air flues very little control of the position of the burning zone is possible in a mixed feed kiln.

The inspection and poke holes may, on occasion, be used to admit air, but they do not compare with flues properly constructed for this purpose. Moreover, they can only admit cold air whereas a proper flue arrangement can be designed so as to utilize the heat which would otherwise be wasted by passing through the walls of the kiln.

In most shaft kilns, the air required for cooling the burned lime is considerably in excess of that required to burn the fuel used in the kiln, and, consequently, it is difficult to work the kiln efficiently. If a given quantity of coal is supplied with only a slight excess of air, the temperature of the flame and gases will be very high, whereas if a large excess of air is provided the temperature attained will be much lower and, consequently, the burning of the lime may be very imperfect, unless more fuel is used in order to raise the temperature sufficiently.

The amount of cold air required to cool a ton of lime may be calculated by assuming that 1 lb. of fuel requires 10 lb. of air and that 1 lb. of fuel produces 5 lb. of lime, so that the air required to burn the fuel is equal to twice the weight of the lime produced. This is a serious understatement because an excess of air is almost invariably required for the effective combustion of the fuel under the conditions appertaining to lime burning and, in practice, the amount of air required by the fuel is usually about four times the weight of the lime.

The amount of air which would cool a given weight of lime dust is theoretically the product of the temperature and the specific heat of the lime, but as the lime in the kiln is in the form of lumps, a very much larger quantity of air is needed, and no calculation will show the amount actually required. A series of careful experiments has shown that in an ordinary mixed feed kiln, about

10 tons of air are required to cool 1 ton of lime, and if only 2 tons of air were required for the combustion of the fuel, $\frac{2}{8}$ ths of the air needed for cooling the lime would pass from the cooling zone into the burning zone of the kiln. This air would not only be useless but harmful, as such air absorbs heat in being

raised from the temperature imparted by the cooling lime to the highest temperature reached in the kiln. Provided the temperature attained in the latter is sufficient to ensure the lime being properly burned, the actual loss need not be serious if a sufficiently tall kiln is used, as the hot air and gases passing up the kiln can be made to preheat the stone in the upper part of the kiln. In this way, much of the heat is recovered in tall kilns, but is lost in short ones.

In the *Chaudière* kiln (fig. 66) an ingenious arrangement is used whereby the excess of air used in cooling the lime is not passed up through the burning zone, but through a central tube extending right down the shaft and communicating at its upper end with the kiln chimney.

The air entering the base of the kiln rises through the cooling lime and just below the burning zone, all the air which is not required for burning the fuel is diverted through openings controlled by dampers into the central tube; the remainder rises upwards through the kiln in the usual manner. The proportion of air passing up the central tube can be varied as desired.

The tendency of most vertical kilns to be cooler at the centre than elsewhere has led to the insertion of a central core or *acorn* of firebricks in the lower part of the kiln. This

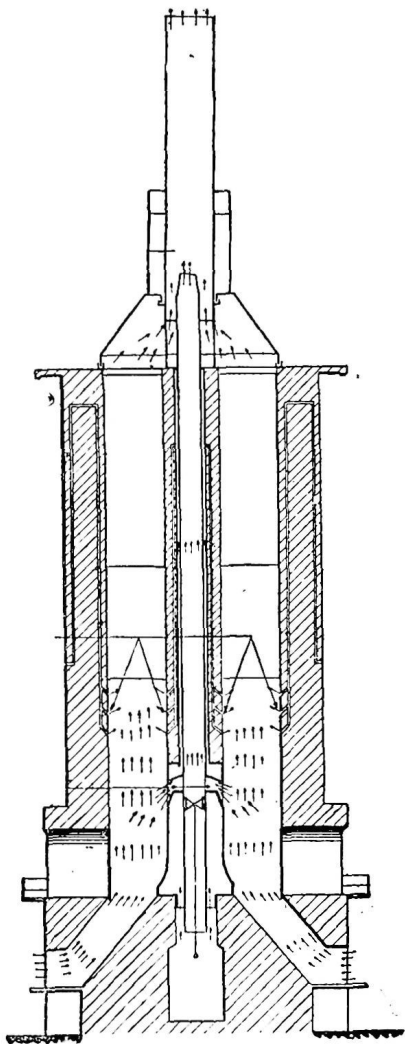


FIG. 66.—CHAUDIÈRE KILN.

device reduces the amount of under-burned stone, but it also tends to cause the delivery of hot lime. The central core has the advantage of supporting much of the stone in the upper part of the kiln, but it also offers a large surface

to be attacked by the lime and is liable to increase the "sticking" or "hanging" of the lime in the kiln. It reduces the capacity of the kiln, but it facilitates drawing and reduces the amount of underburned lime.

Instead of a solid core, a hollow shaft is used in the Chaudière kiln ; this shaft enables an unlimited amount of air to be used for cooling the lime.

FURNACE-FIRED KILNS

Furnace-fired lime-kilns—long known as "Patent" kilns—may be heated with either coal, gas, or oil. They differ from the *mixed fuel* kilns previously described, in the fuel being burned in a furnace or fireplace and not mixed with the stone.

Furnace-fired kilns are chiefly of the vertical shaft type, though external coal fires have been applied to rotary kilns (Schaffer & Crow's patent, U.S.A.) and to horizontal kilns of a modified Hoffman type.

The chief purpose of furnace-fired kilns is to keep the solid portion of the fuel and all the ash out of contact with the lime, in the expectation of obtaining a purer lime. This is only obtained by a slightly greater expenditure of fuel than in mixed feed kilns, because the fuel in an externally-fired kiln is not in such close contact with the stone and the loss of heat by radiation is much greater. Fortunately, the increase in the fuel consumption need not be great—it is usually 1–1½ cwt. of coal per ton of lime—and in many cases it is more than counterbalanced by other savings effected when an externally fired kiln is used and by the increased saleability of the lime.

Such vertical kilns with external fires resemble mixed-feed kilns in every respect except the external fireplaces which prevent the ashes from the fuel becoming mixed with the lime. They have most of the advantages of the mixed-feed kiln and are under better control. Furnace-fired kilns may be of any shape. Those of the vertical type consist of a vertical shaft 30–50 ft. high and 5–8 ft. inside diameter, similar to the mixed-feed kilns previously described, but fitted with external fireplaces or burners, so that no fuel ashes enter the kiln and the lime and limestone do not come into contact with any solid fuel.

The limestone is fed in at the top and gradually passes down through the kiln. As it descends, it is heated by flames from the external fireplaces or burners, the waste heat being used to preheat the stone and the cooling lime being used to heat the air required for combustion. When draw-bars or grates are opened at the lower end of the kiln, some of the lime falls through and so makes way for a fresh supply of stone. In some cases, the removal of lime is effected continuously by means of a mechanically-operated device. The draught may be either natural or created by a fan. Kilns of this type are necessarily less economical in fuel than kilns of similar shape with a mixed feed, but the greater purity of the lime when a separate feed is used should enable it to fetch a higher price and so more than counterbalance the difference in the cost of production.

The *advantages* of a vertical kiln with separate feed are :

(i) The general ease of working and the efficiency of the vertical shaft kilns of similar shape, less a slight loss in fuel due to the use of separate fireplaces or burners.

(ii) The lime is not discoloured by contact with the fuel.

(iii) The lime is free from fuel ash and clinker.

(iv) The heating is under better control which should result in a very low percentage of over- or under-burned stone. At least 90 per cent. of the product should be well-burned, clean, white lime, as compared with 75-90 per cent. from kilns with mixed feed.

The *disadvantages* of vertical kilns with separate feed are :

(a) A higher fuel consumption than in kilns with mixed feed.

(b) A higher cost of construction though less than that of rotary kilns.

(c) An inability to burn small pieces of stone.

(d) An inability to burn stone of a soft nature except by the use of kilns which are so short that the fuel-consumption is correspondingly high.

(e) The flames tend to rise up the walls of the kiln, leaving the stone in the centre much cooler than that nearer the walls and necessitating great care and skill in drawing the kiln, if under-burned stone is to be avoided.

(f) A higher labour cost due to the additional stoking. By replacing the hand-stoked fires with two or more gas producers of ample size, a cheaper grade of fuel can be used, the amount of labour required is reduced, and a much more constant or uniform burning results. Even under the most expert firing, the hand-stoking of external fires is a wasteful means of supplying heat to kilns.

(g) There is always a tendency for lime to roll into the furnaces, blocking them and affecting the burning adversely, unless the furnaces are cleaned frequently.

Wood-fired kilns are among the oldest of the furnace-fired or "patent" kilns and the many modifications subsequently made in order that coal may be used show how strongly experience of wood firing has influenced later designs. There are usually four furnaces, placed in pairs on opposite sides of the kiln and about 12 ft. above the ground. The furnaces are very large, as wood is bulky fuel, but in all other respects these kilns resemble the coal-fired ones described later.

The great advantage of wood is its "mild," moist heat, which effects the decomposition of the stone at a relatively low temperature with little risk of overfiring, so that wood-fired lime is still regarded as the best in quality. Unfortunately, the cost of wood and the uncertainty of supplies almost prohibit its use and many ingenious devices have been invented for securing the same advantages whilst using cheaper or more convenient fuels.

In coal-fired kilns of the vertical shaft type, the fuel is burned in fireplaces either disposed uniformly around the circumference of the shaft or, if only two fireplaces are used, they are placed on opposite sides of the kilns.

The *Broomell* kiln (fig. 67) consists of a vertical cylinder 45 ft. high, supported on a concrete foundation capable of supporting a load of about 200 tons. On this foundation are two parallel concrete piers, about 11 ft. high, and on these the kiln proper is erected. The cylindrical portion consists of a steel shell with a fire-brick lining, 13½ in. thick for a height of 13 ft. and 9 in. thick for the remainder, and an outer cylinder (between the fire bricks and the steel) built of red bricks laid in fireclay. Directly above the furnaces the fire-brick lining is 18 in. thick.

The inside diameter of the lining is 6 ft. 6 in. except at the furnace-openings, where it is only 5 ft. ; the overall diameter is 11 ft.

Below the cylinder is a steel cooling-cone, 5 ft. 8 in. high, 6 ft. 6 in. diameter at the top, and 2 ft. diameter at the bottom. This cone is supported on two 10 in. girders, the ends of which rest in pockets in the concrete piers, as it is undesirable (on account of expansion) to bolt the cone to the bottom of the cylinder.

Two sliding discharge-gates are fitted to the bottom of the cone, and are operated by racks and pinions.

The two furnaces are built on a heavy cast-iron sole plate, which rests on the piers, and on brackets attached thereto. The furnaces are built of red brick and lined with firebrick. Each furnace is 54 × 36 × 36 in. The fireholes are 18 in. wide and 25½ in. high, and are fitted with heavy firebrick sliding doors, worked with a counterpoise. The sides and front of each furnace are further strengthened by eight brickstays of 8 in. channel iron, the bottoms of which are bolted to the sole plates and the tops are fastened with heavy tie rods. Each furnace has eight sections of grate bars, each section being 28½ in. by 6 in., and containing five bars. For half their length, the front bars are made with pockets fitted with firebrick to provide a large coking space.

A kiln of these dimensions has a rated output of 8–12 tons of lime per day of 24 hours, and the fuel-consumption is 5–7 cwt. of coal per ton of lime ; this is due to the shallowness of the fires, the shortness of the kiln above the furnaces, and the open top of the kiln.

The stone is fed into the top of the kiln from small wagons, which run along an upper platform. A steel lining ring prevents the stone from damaging the brickwork.

The *Keystone* kiln (fig. 68) very closely resembles the *Broomell* kiln, but the cylinder is continued to the ground-level and the concrete-piers are not used ; this enables the cooling-zone to be surrounded by a cylinder which lessens the escape of hot air and dust. The four furnaces have hinged doors

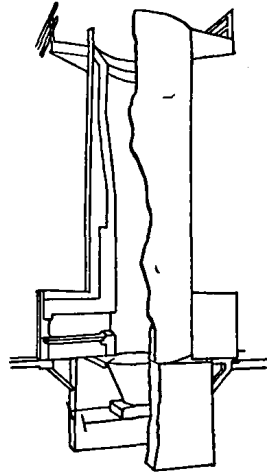


FIG. 67.—BROOMELL KILN
(CUT AWAY TO SHOW INTERIOR).

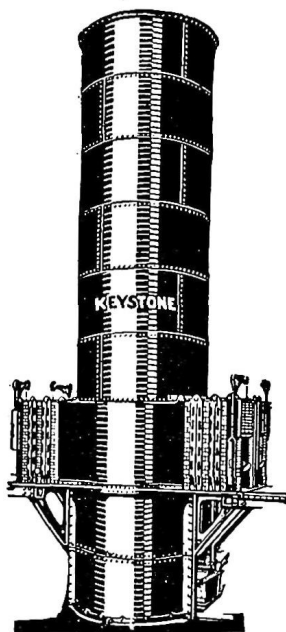


FIG. 68.—KEYSTONE KILN.

instead of sliding ones; the inside of the kiln is cylindrical throughout and several minor details are slightly different.

When the fuel used makes a forced draught desirable, this is readily applied by slightly modifying the furnaces.

The *Arnold* kiln (fig. 69), like the *Keystone*, is extensively used in the United States, and differs from the latter chiefly in the shape of the interior, which the makers claim gives an output 40–60 per cent. greater than can be obtained with a wholly cylindrical interior; this does not appear to be borne out by the published statements of output, which rate *Arnold* kilns, 38 ft. high and 11 ft. in diameter, at 10–11 tons per day of 24 hours. The constriction of the lining is to enable the heat from the furnaces to pass more certainly into the kiln, as there is a maximum distance (about 7 ft. 6 in.) beyond which it is difficult to get the heat through the stone, so that an internal diameter of 7 ft. or 7 ft. 6 in. appears to be a maximum for furnace-fired kilns. Whether an elliptical section is preferable to a circular one is a matter about

which there is much difference of opinion.

Among other differences in detail, the cooler is suspended from the bottom of the kiln instead of being supported independently, the firing floor is about 4 ft. further from the ground, and the four furnaces are provided with shaking and dumping grates.

The *Doherty-Eldred* kiln (fig. 70), whilst of the same general type, introduces as a special feature an arrangement for withdrawing some of the gases from the upper part of the kiln and re-introducing them, mixed with fresh air, below the fire. The effect is to produce longer flames of larger volume and lower temperature, which behave more like the flames from burning wood and tend to lessen the risk of over burning. It is claimed that the increase in output is 80 per cent., the decrease in fuel consumption is 18 per cent., and the decrease in under- and over-burned lime is 5 per cent. These kilns work by induced draught, created by a fan, and a portion of the gases are tapped off through a separate pipe and blower and so forced to re-enter the kiln. The *Eldred* kiln has not become popular in this country, but it has created great interest in the United States.

Many other kilns of the same general type have been designed and a few have been erected. They differ from each other mainly in such details as the shape of the interior of the kiln, the type of grates used, and the number, size, and shape of the fireboxes.

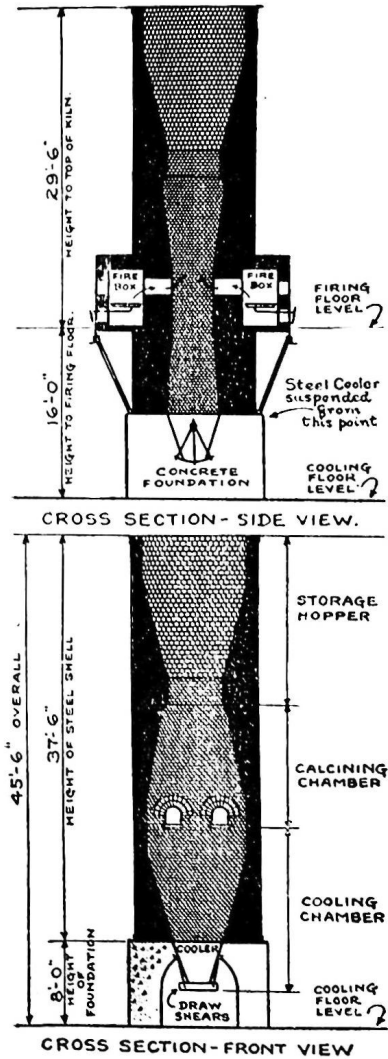


FIG. 69.—ARNOLD KILN.

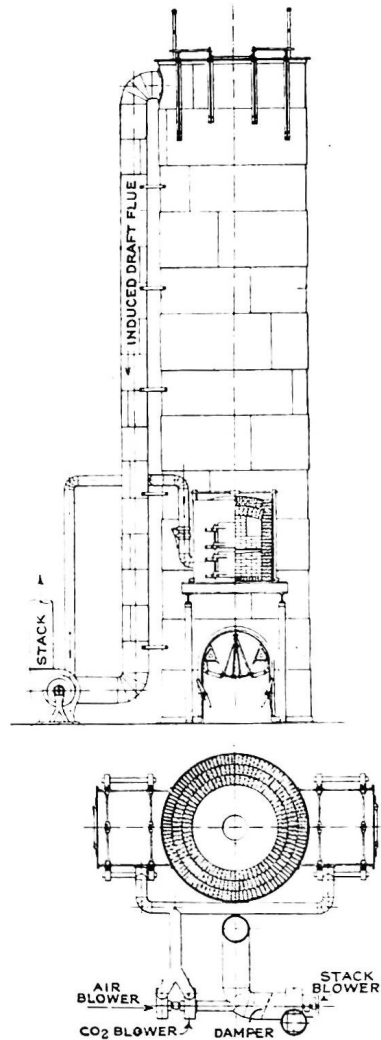


FIG. 70.—VERTICAL SECTION AND PLAN OF DOHERTY-ELDRED LIME-KILN.

In all important essentials all furnace-fired vertical lime kilns using coal are extraordinarily similar, and they nearly all have one fundamental error, namely, a shallow bed of fuel on the grate, which is chiefly the reason for the low fuel efficiency of this type of kiln; the heat is almost wholly generated in the furnace instead of amongst the pieces of stone.

There is a direct means of overcoming this objection, but in only one make of kiln does this appear to have been done.

In the *Priest* kiln, the furnaces are so designed that, instead of a shallow bed of fuel in which the coal is fully burned, a deep bed is used, and the furnace is thereby converted into a gas producer of a type which combines the advantages of the ordinary gas producer with the simplicity of an ordinary fire-box. The furnaces are, in fact, gas-producers and not merely fires, but being part of the structure of the kiln, they avoid the loss of heat which is inseparable from the use of an independent gas producer.

To avoid some of the waste of heat by radiation from coal-fired furnaces, O'Connell has patented the erection of a boiler over each furnace, the steam produced being used to create power. This arrangement has never become popular.

The injection of steam into the furnaces has the same effect of reducing the temperature at which the lime is decomposed as when it is injected into mixed-feed kilns, but in furnace-fired kilns (especially those with deep fires) it has the further advantages of producing long, mild flames, regulating the production of gas from the fuel, and generally facilitating the working of the kiln. The use of exhaust gases from the kiln (as in Eldred's process just described), has a somewhat similar effect so far as the nature of the flame is concerned.

As most furnace-fired kilns have open tops the full diameter of the kiln (some are even of enlarged diameter to increase their storage capacity), the draught is often irregular and uncertain and the loss of heat is often very great. The irregularities in the draught may be reduced or even avoided by the use of a dipping chimney (fig. 59) as used on some mixed-feed kilns or by means of mechanically produced draught.

Forced draught is not usually satisfactory as it renders inspection and discharging difficult. Moreover, its effect is soon dissipated. It may be applied with a steam-injector, a small jet of steam at high pressure carrying in with it a large volume of air, or a blower-fan may be used. The air may be drawn direct from the atmosphere or it may be passed through flues in the kiln-wall and heated before entering the furnace.

Induced draught is much more satisfactory, but cannot in any sense be regarded as necessary; its chief advantage is that a fan enables a constant draught to be maintained, whereas a chimney is dependent on the weather.

Notwithstanding their great popularity, furnace-fired kilns are by no means easy to work satisfactorily, though, with a "skilled" man, they are capable of much more accurate control than mixed-feed kilns. The most successful ones are those with deep beds of fuel, which operate as small gas producers; those with shallower beds of fuel necessarily waste a large amount of heat by burning the fuel in the furnace instead of in the kiln. For the same reason, the arches over the furnaces need frequent repairs when the depth of the fuel is small.

OIL-FIRED KILNS

Oil-fired lime kilns are usually of the vertical type and resemble the coal-fired kilns just described in every respect except that the furnaces must be modified so as to burn oil instead of coal.

For the successful use of oil, the furnace must be sufficiently large to ensure the production of a suitable flame, which must be fully developed before it leaves the combustion chamber, or it will be cooled and will choke the pores in the stone with soot.

The oil is admitted through specially designed burners in which it is mixed with the air necessary for its combustion. The intensity of the combustion is so great that it is often difficult to obtain firebricks which will endure it for more than a few weeks, but by using a combustion chamber of ample size and bricks of good quality this difficulty may be avoided.

Some firemen using oil prefer an empty combustion chamber, but others build a small " wall " against which the flame can impinge. This wall becomes so hot that no soot can form on it and by radiation it greatly assists combustion.

Many " trade " illustrations show oil-fired furnaces for burning lime which are quite unsuitable for the purpose, and care should be taken to avoid them. Most of them produce an intensely hot flame, but it does not " carry well " into the kiln and so is almost useless ; others produce a flame of such length that it merely " soots up " the kiln and extinguishes itself.

This is not the place for a discussion of the relative merits of different oil burners, or of air blowers and steam injectors for atomizing the oil. Most of the better-known oil-burners can be used for lime burning and the particular method of atomizing the oil is of minor importance. It is the method of disposing of the flame rather than of producing it which is the chief cause of difficulty when burning lime kilns with oil.

The oil must be heated to such a temperature that it flows readily and atomizes rapidly without any charring. If steam is used, an excess should be avoided.

The burner should be mounted so that it can be moved to any position, vertically, horizontally, and backwards or forwards, as well as pointed at any angle, because small adjustments are of very great importance. The means of controlling the size and nature of the flame will depend on the particular type of burner used. Their precise design matters little provided they allow of ample variation and accurate adjustment.

On account of its cost and the supposed uncertainty of deliveries, oil is not used in this country for burning lime, but in several localities in the Far East, and in the Western States of America, it is successfully used on an extensive scale.

As oil-fired lime kilns do not differ from other furnace-fired kilns, except in the design of the furnace, there is no need to repeat the descriptions of the other parts of the kilns, but an exception may be made as regards the *Gillette* kiln, which consists of a series of vertical tubes, each 24 ft. \times 20 in. \times 3 in., made of silicon carbide and heated in an oil-fired furnace. The crushed stone (freed from dust) is charged into the top of the tube and the lime is removed by a rotary device. A claim is made that this kiln produces purer lime and purer gas more cheaply than any other. Each tube produces $2\frac{1}{2}$ tons of lime per 24 hours using 9 gallons of oil per hour or 86 gallons per ton of lime.

KILNS WITH POWDERED FUEL

The use of finely-powdered fuel blown into the kiln (as in oil-firing) is a feature of *Otto and Co.*'s (Bochum) kiln. Its chief advantage is that low-grade fuel can be used efficiently, but the ash adheres tightly to the lime. For this reason, and the consequent impurity in the lime, the use of powdered fuel is not likely to become so popular as that of oil which is practically free from this disadvantage, though, like powdered fuel, it tends to overburn the lime.

GAS-FIRED KILNS

The chief disadvantage of solid fuel for burning lime is the contamination of the lime by fuel ash. Even when fuel is fired on external grates some of the ash is carried into the kiln in the form of dust and contaminates the lime. Hence, when the lime is to be kept as clean and pure as possible, the kiln must be gas- or oil-fired.

Other advantages of gas-firing are :

- (i) A better control of the heating.
- (ii) A saving in fuel as compared with externally-fired kilns using coal. Gas-fired kilns can also use fuel of more varied composition and of lower quality than the coke, anthracite, or coal used in mixed-feed kilns or direct-fired kilns, though where the fuel is of inferior quality, a very large gas producer may be required and it will probably be necessary to have a highly skilled man in charge. With a suitable producer, a skilled man can burn lime with peat, lignite, waste wood, coke, coal, or briquettes, whereas a less able man would only be able to use a suitable coal.

Under ordinary circumstances the coal should not be in very small pieces, slack being much more difficult to gasify regularly than nut coal. The more uniform in size are the pieces of coal the more easily will they produce a regular supply of gas ; a very evenly graded coal consisting of pieces all $\frac{1}{2}$ -in. diameter is usually preferable to an irregular coal containing both lumps and dust.

- (iii) A saving in labour when several kilns are in use at the same time.
- (iv) Ease of filling.
- (v) Ease of discharging.
- (vi) Efficient use of the heat in the fuel as a result of the preheating of the stone in the upper part of the kiln and the heating of the air by the lime in the cooling zone.
- (vii) Simple construction.
- (viii) Low labour costs.
- (ix) The chief object in using gas-fired kilns is the superior quality of the product.

The most serious disadvantages of gas-fired kilns are :

- (a) They must be worked continuously day and night if they are to be used to the best advantage. Some firms shut off the gas from Saturday noon to Monday morning, but such a practice is far from economical and is better avoided. When once lighted, a gas-fired kiln should work day and night continuously until it is shut down for repairs or lack of trade.

(b) They require constant attention, and as they are chiefly used to produce lime of the greatest attainable purity and best quality they require more skill to manage them. If gas-fired kilns were used to produce lime of the quality obtained from most mixed-feed kilns they would not require any more skill than the latter. Most of the lime burners who have experience of kilns fired with solid fuel and gas-fired kilns agree that the latter are much easier to manage when once the necessary skill has been obtained.

(c) The *capacity* of a gas-fired kiln is about 17 per cent. greater than that of a mixed-feed kiln of the same dimensions because no space is occupied by solid fuel. It is not wise, however, to build gas-fired kilns any smaller than mixed-feed kilns of the same output because the distribution of heat in a gas-fired kiln is less favourable than in a mixed-feed one.

(d) The output of a gas-fired kiln is less than that of a mixed-feed kiln of the same diameter. There is no necessary limit to the output of a gas-fired kiln if properly designed, and some of the kilns built by Schmatolla have an output of 100 tons of lime per day without reaching the limit. These large kilns are necessarily of the rectangular or annular type; for cylindrical shaft kilns heated by gas, the maximum internal diameter is about 8 ft., which corresponds to a maximum output of about 30 tons of lime per day of 24 hours when a pure calcium carbonate is burned.

(e) A cylindrical kiln is limited to a maximum inside diameter of about 7 ft. 6 in. or 8 ft., as the gas flames cannot travel across a kiln of much larger diameter. When small pieces of stone are being burned the maximum internal diameter may be as low as 5 ft. 6 in. on account of the greater compactness of small stone. By making a kiln rectangular or oval in plan, its size may be increased to almost any desired extent, provided the gas travels across the smaller diameter, which should not exceed 8 ft. and should preferably be much less. Rectangular and oval kilns are difficult to heat uniformly and usually have at least two "cool spots" which the hottest gases do not reach; these are more easily avoided in cylindrical kilns.

All vertical gas-fired kilns closely resemble externally-fired kilns using coal, except that the grates are replaced by pipes or flues conveying the gas from a gas producer or other source to the kiln.

The gas employed in gas-fired kilns is almost invariably producer gas, though coke-oven gas and natural gas have been employed where they were sufficiently cheap. Town's gas or illuminating gas is too costly.

Various types of gas producer are used in connection with lime kilns, but some of the more elaborate ones do not offer any great advantage as there is no purpose in preparing a specially clean or pure gas. The simpler the gas producer the less likely is it to get out of order; mechanically operated gas producers are quite satisfactory, but usually require more skilled attention than can be afforded by lime burners. Hence, a simple type of gas producer with an injector which blows steam and air in suitable proportions through the fuel bed is usually the most generally suitable. In selecting a gas producer for a lime kiln, the following should be borne in mind:

(i) The bed of fuel should be as deep as possible ; if there are several small producers built onto the kiln a fuel depth of 3 ft. is satisfactory, but if one separate producer is used, the fuel should be at least 4 ft. 6 in. deep and preferably 6 ft. deep.

(ii) The supply of steam and air should be capable of accurate regulation.

(iii) The grate supporting the fuel should be easily cleaned and of such a pattern that the apertures are not easily clogged.

(iv) The outlet main should be fitted with a dust trap which can easily be cleaned, and with a main gas valve.

(v) The size of the producer or battery of producers should be sufficiently large to provide more gas than is ever required by the kiln or kilns, without any "forcing," as it is essential to successful working to have an ample supply of gas. Some lime kilns have been seriously hampered by producers of insufficient power.

(vi) Mechanical devices for feeding fuel to the producer or for removing ash are not essential ; they add considerably to the cost and some of them easily get out of order. Where a skilled mechanic is available, they are excellent and labour saving, but many lime kilns are in isolated districts where the requisite skilled labour is not available ; for such kilns, a simple, hand-operated producer is preferable.

Four or more small producers built onto the kiln have the advantage of avoiding the loss of heat which is inevitable when a single large producer is placed some distance from the kilns. The small producers are easier to clean and deliver the hot gases more directly to the kiln. They avoid the troublesome weekly "burning out" of the gas ducts, which is often inevitable when a single producer is used with bituminous coal, but in regular daily work they require more attention than a single larger producer. When each kiln has its separate producers it can be worked independently of the others ; this is often a matter of great importance as the loss of output when a single large producer has to be stopped for repairs or cleaning is sometimes very serious. If each kiln has its separate producer any one kiln may be stopped for repairs or because of shortage of orders without interfering with the others. When a single producer, large enough to supply several kilns, is only used to supply one kiln (the other kilns being stopped for commercial or other reasons) the cost of the gas supplied to the one kiln is increased, and the burning will probably be made unprofitable.

The chief difficulty associated with several small gas producers grouped around the kiln is that they complicate the construction of the latter, and also they must be comparatively narrow and are, therefore, liable to work irregularly. This latter objection is overcome by using only four producers—two on opposite sides of the kiln, though, unless they are well designed, they may leave the other sides of the kiln insufficiently heated. In a properly-designed kiln none of these disadvantages are serious, and the saving in fuel which is effected by them—especially in times of restricted output—is sufficiently important to justify their use in some works.

Whether several small producers or one large one is used, the *gas* is intro-

duced at a height of not more than one-third of the height of the kiln, and usually about 8-10 ft. above the draw eye or lime exit, the number of gas inlets or ports depending partly on the size of the kiln and partly on the wishes of the designer.

The number of gas inlets varies greatly in different kilns; some (which work quite satisfactorily with some limestones) have only four inlets—two on opposite sides of the kiln—whilst others have inlets uniformly spaced all round the circumference of the kiln, as many as twenty being sometimes used on a kiln only 7 ft. 6 in. internal diameter. Theoretically, it is better to have a large number of gas inlets uniformly distributed, but practical considerations often

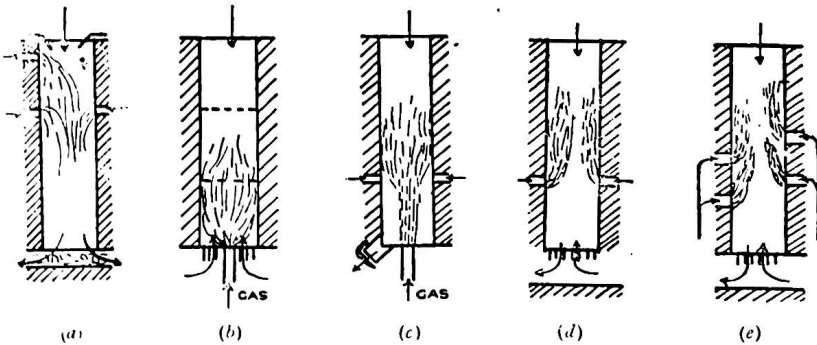


FIG. 71.—VARIOUS ARRANGEMENTS OF AIR- AND GAS-INLETS.

make a smaller number preferable as where there are many outlets they must be small, are very liable to choke, and are difficult to clean. Where these disadvantages can be overcome or at least minimized, the larger the number of gas inlets the better, though many kilns work quite satisfactorily with few inlets.

Although the gas may enter a kiln at any desired point, some are much better than others. If, for instance, the gas were to enter near the top of the shaft and to be drawn downwards and off at the base (fig. 71 (a)), there would be a great waste of fuel, and the lime would be very hot when drawn. Less fuel would be wasted if both gas and air entered at the base of the kiln (fig. 71 (b)), but there would still be a waste and the lime would be inconveniently hot when drawn.

The gas is often delivered through ports without any admixture with air because it is difficult to maintain the correct proportion of air and gas in a burner unless both are delivered under constant pressure. This difficulty can be partially overcome by applying some of the air under pressure and causing the flame to induce a further supply of (secondary) air but even this is not wholly satisfactory. Back-firing and explosions must be prevented by ensuring that the mixture has a velocity at least equal to the velocity of flame propagation. If the gas is supplied without any admixed air, combustion will be irregular and under-burned lime will be drawn from the kiln.

If all the air required is mixed with the gas the flames will be short and intense local heating will be produced. Hence, the best arrangement is a partial admixture of gas and air arranged so as to suit local conditions.

Less satisfactory are lime-kilns with the gas entering at the base and the air about one-third of the way up the shaft (fig 71 (c)), as if air leaks in among the gas—and it is very difficult to prevent it from doing so—there is a serious risk of explosion. In addition, the lime is usually discoloured by smoke in the gas.

A very common arrangement is to admit the gas at the sides of the kiln and the air at the base (fig. 71 (d)), and this is fairly satisfactory though it enables some gas to escape unburned from the kiln.

Whether the gas should enter through a series of ports at one level or through two or more ports at different levels (fig. 71 (e)) depends partly on the quality of the gas and partly on that of the stone; usually one series of gas ports is sufficient, though several series have the obvious advantage of lengthening the burning zone and may be preferable when a stone is difficult to burn.

The air¹ required to burn the gas may be introduced in two ways :

- (i) *Primary air* which is mixed with the gas previous to ignition.
- (ii) *Secondary air* with which the gas comes in contact after ignition.

Some gas-fired kilns use both primary and secondary air, but many of those of the older type use only secondary air which rises up through the exit or draw eye and is heated by the lime in the cooling zone of the kiln.

Some limestones—particularly those containing magnesia—are better burned if some primary air (*i.e.* air mixed with the gas before the ignition of the latter) is used. Various patterns of gas burner have been suggested for this purpose, one of the oldest being the Bunsen burner in which gas and air are both introduced into a mixing pipe and the mixture is ignited at the end of the pipe. Where the air and gas are under sufficient pressure, a blow-pipe burner

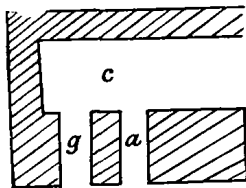


FIG. 72.
BURNER FOR GAS-FIRED KILN.

may be suitable. A burner which has been used successfully is shown in fig. 72; the gas from a producer rises vertically up the gas duct *g* and into the horizontal duct *c*, whilst the air rises up the duct *a* into the same duct *c*, the two mixing together before they are ignited. The distance of the ducts *g* and *a* from each other and the length of the mixing duct *c* determine the character of the flame; the arrangement shown gives a long flame, but if greater

mixing of gas and air were permitted a shorter flame would be produced. Theoretically, the use of some primary air is desirable, but in practice it is found that it is not essential and few kilns use it.

Many ingenious devices for providing hot air have been proposed, but most

¹ V. Sokolov (*Kemistroi*, V, 1979, 1933) states that it is profitable to use air enriched with oxygen so as to obtain exit gases with a high proportion of carbon dioxide which can then be recovered and utilized.

of them are of small practical value. Some of the more important ones are described later.

The *efficiency* of combustion in a vertical gas-fired kiln can be made almost perfect if the kiln is properly designed, as the air and gas can be mixed in almost any desired proportions and flames of any character and length can be produced.

The *distribution of the heat* in a vertical gas-fired kiln can be controlled to a much greater extent than in any other type of vertical kiln. Full advantage may be taken of the hot products of combustion for preheating the stone and of the heat in the lime for heating the secondary air. Flues may also be arranged in the walls of the kiln to preheat the gas and the primary air, if desired.

In short, well-designed gas-fired vertical kilns possess all the best characteristics of vertical kilns so far as the control of combustion and the distribution of heat is concerned. Unfortunately, some gas-fired kilns are badly-designed.

The simplest gas-fired kiln, as previously suggested, is a vertical cylinder of brickwork, preferably enclosed in a steel-casing so as to reduce the leakage of hot gases and to strengthen the structure. As previously explained, the diameter of such a kiln is limited by the distance which the flames will travel horizontally when the kiln is filled with stone. Many of the earlier gas-fired kilns had an internal diameter of 6–10 ft., and whilst those less than 7 ft. 6 in. might attain a sufficiently high temperature, those of larger diameter could only do so with the greatest difficulty, as there is a well defined distance beyond which the flames cannot penetrate horizontally into the kiln and for most purposes the maximum internal diameter of a gas-fired kiln may be fixed at 7 ft. 6 in. The upper and lower parts of the kiln (*i.e.* those outside the burning zone) may be of any convenient width, though it is not usually desirable to have them of much greater diameter than the burning zone. Kilns of other than a plain cylindrical shape are considered later.

One of the earlier *Schmatolla* gas-fired kilns is about 42 ft. high, 30 ft. from the lime outlet to the stone inlet, and the gas ports are 6–10 ft. above the lime outlet. It has one gas producer, with a gas main running all round the kiln, from which three (or more) gas ducts lead radially to the kiln shaft. The burning zone is conical to a height of 10–14 ft. above the gas ports, but above this the shaft may widen, as shown by zone, so as to increase the capacity of the kiln. No primary air is used in this kiln, the whole of the secondary air enters through the three draw-eyes near the base, and rising through the lime cools it, but is itself heated so that it readily ignites the gas entering the kiln from the three gas ducts. This simple arrangement is excellent in many ways, but has one disadvantage—the gas immediately above the ducts may rise up the kilns without coming into contact with any hot air. To prevent this, *Schmatolla*, in more recent kilns, has provided a second set of flues which introduce a small proportion of hot secondary air just above the gas ports. He has also introduced a little air into the gas ducts so as to secure earlier ignition and the combustion of tarry matters which might otherwise condense on the lime or on the walls of the kiln; the importance of this use of primary air is by no means sufficiently understood.

One of the more recent of Schmatolla's kilns is shown in fig. 73. The gas enters the kiln through four ports *C*, at a height of about 7 ft. above the draw-eyes. Each gas-port is surrounded by an air flue through which air can enter the gas-port from the air flues *f.f.* Above these is a series of secondary air flues *g.g.*, connected with a series of secondary air flues *h* in the walls of the

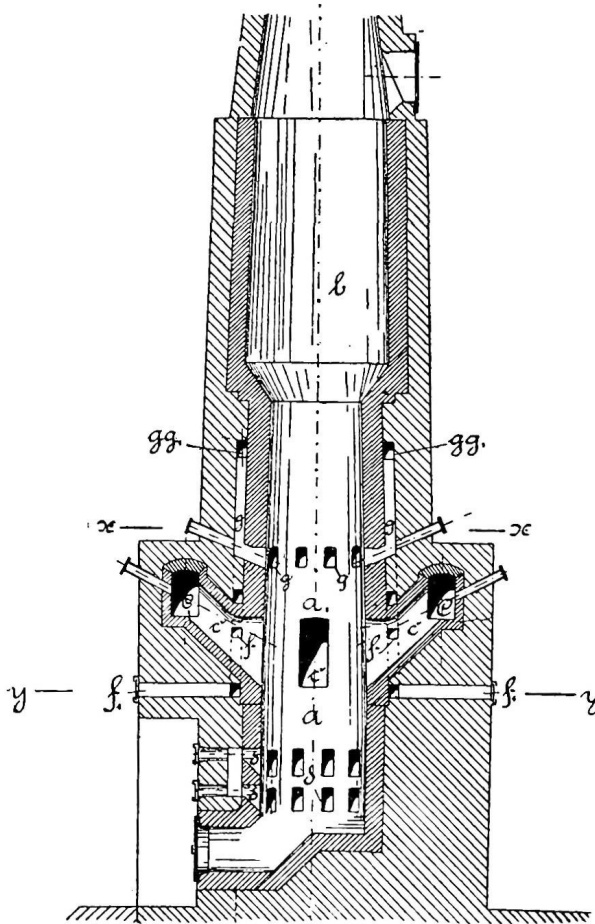


FIG. 73.—SCHMATOLLA GAS-FIRED KILN.

lower part of the kiln and serving as recuperators for heating air and delivering it to the kiln above the gas-ports. When required, the air flues *g.g.* can also be connected to the air flues *f.f.* Below these gas-ports are the air inlets *d*, controlled by dampers, through which the greater part of the secondary air enters the kiln.

Schmatolla's kilns, though well designed, have had a most unfortunate history in England, chiefly because they were not built strictly in accordance with his designs ; in at least one instance, several important flues were omitted and in another, the gas ducts were improperly constructed. For these defects Schmatolla is by no means wholly to be blamed, but the results, both to his reputation and to the builders, have been unfortunate. It is important to mention this as, when properly built, Schmatolla's gas-fired kilns are quite satisfactory and their failure in this country is due to causes quite apart from their design ; the fact that in other countries Schmatolla kilns have been working satisfactorily for more than 25 years shows the danger of condemning a design for a particular kiln without a full knowledge of the facts. Incidentally, it should act as a warning to those who incline to purchase drawings of kilns and to build kilns themselves without having sufficient knowledge to be able to ascertain whether the details shown in the drawings are sufficiently complete to enable a satisfactory kiln to be built from them.

Schmatolla's kilns, just described, contain the most important essentials of a gas-fired kiln, but kilns of other designs, in which the same essentials are also provided, not only produce equally good lime, but have various characteristics of their own which are well worth consideration. Moreover, the cost of construction of lime kilns plays so important a part at the present time that a very careful and detailed study of kilns of a similar general design is necessary before the relative importance of the various details can be properly appreciated and a sound conclusion reached as to the best kiln for a particular quarry or site. Among the many modern gas-fired lime kilns there is none which is so outstandingly superior to all the rest that it alone can be regarded as " unquestionably the best." The nature of the stone, the direction and force of the prevailing winds, the climatic conditions, the output and the manner in which a kiln is worked all have an important bearing on the output and quality of the product and on the details of construction of the kiln, and it frequently happens that a gas-fired kiln which is excellent in every respect for one firm may be quite unsuitable for another. Hence, in the foregoing and following descriptions of gas-fired kilns, attention is confined to the salient features which distinguish them from one another.

The *Fahnehjelm* kiln, which, with various small modifications, has been in use for over 20 years, exists in two types (i) with small producers built onto the kiln, and (ii) with a single separate producer. In both types there is a large central core of brickwork to reduce or avoid the formation of an unburned core of stone. This arrangement has several objections, but it exists in a number of kilns of different patterns which work satisfactorily.

Priests Furnaces, Ltd. (fig. 74), have erected several gas-fired kilns which have attracted much attention, partly because gas-fired lime kilns are by no means common in this country, and partly because of their characteristic features and the consistent high quality of the lime produced. The general shape of these kilns is cylindrical, care being taken to build them sufficiently high to ensure adequate pre-heating of the stone by the products of combustion.

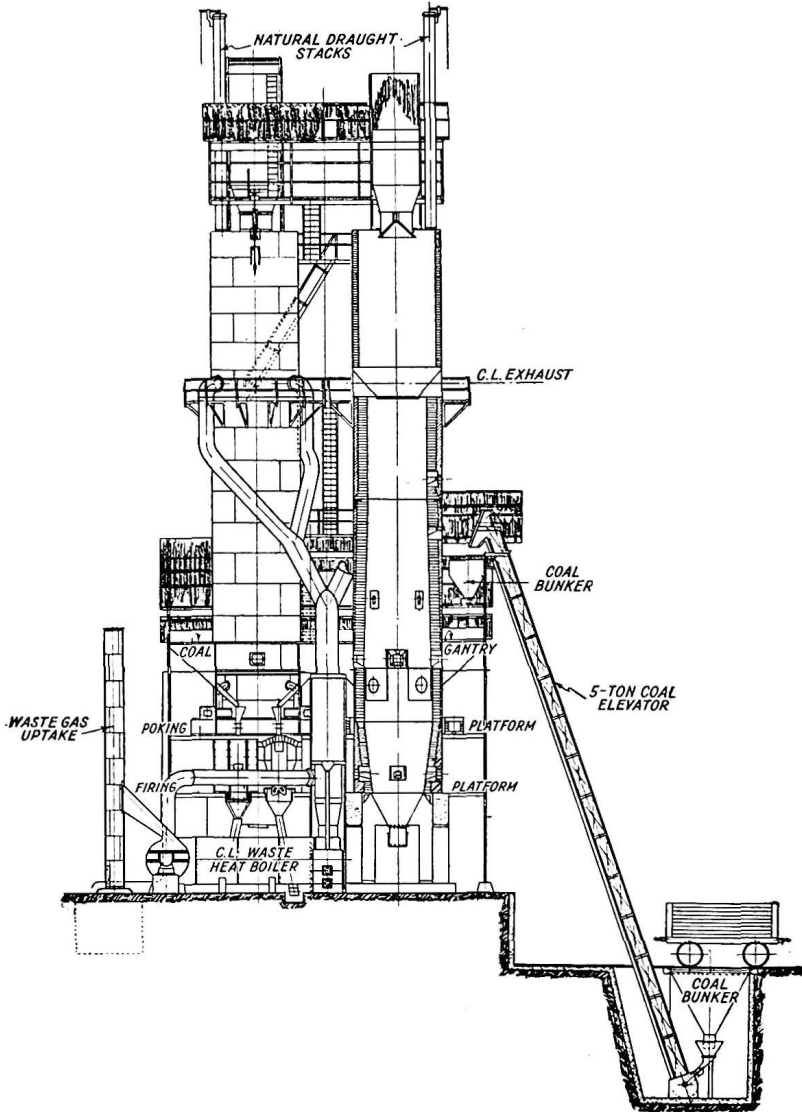


FIG. 74.—ARRANGEMENT OF PRIEST'S PATENT GAS-FIRED LIME-BURNING PLANT.

The gas in some of these kilns is supplied by a single producer to a main which surrounds the kiln, and delivers gas through several inlets to the interior of the shaft ; in other kilns erected by this firm there are four producers built directly onto each kiln on opposite sides, the gas from these entering the kiln through large ports. The choice of producer depends partly on local conditions, and

on the nature of the stone; one large producer requires more fuel on account of the heat lost in transmitting the gas to the kiln, but this may be counter-balanced by the ability of a larger producer to use a cheaper grade of fuel, so that the actual cost of fuel may be reduced by its use.

An important feature of the most recent of the Priest kilns is a series of water-cooled burners with downward outlets. These ensure a better distribution of the burned gas in the kiln and also protect the brickwork just above the burners from the excessive heating to which it is subjected in other kilns. The tendency of the flames to rise vertically up the sides of the kiln is reduced and the centre of the kiln is more uniformly heated.

In most of the Priest kilns no primary air is supplied to the gas burners, but in the more recent ones this can be supplied when required. Otherwise, all the air required for combustion rises through the cooling lime.

The draught is created by a fan connected by a large duct to near the top of the kiln, the gases being drawn off through several openings in the kiln, so as to ensure as uniform a draught as possible. The gases are passed through a waste-heat boiler which supplies the steam needed to operate the producer, and also any additional steam injected into the kiln in order to lower the dissociation point of the calcium carbonate. The gas inlets are large and easily cleaned out, but present no other special features. The low fuel-consumption of these kilns, compared with some other English gas-fired kilns, appears to depend chiefly on (i) a producer or producers particularly suitable for lime kilns; (ii) the use of heat in the

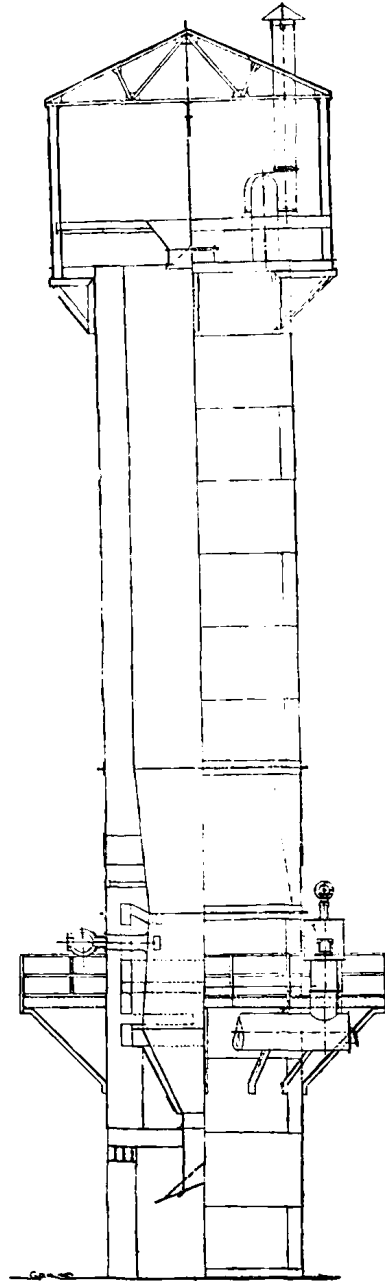


FIG. 75.
DOWSON AND MASON GAS-FIRED KILN.

discharged gases; (iii) the improved means of projecting the gas from the burners towards the centre of the kiln; (iv) the uniform withdrawal of the hot gases under adequate control by means of a fan; and (v) the general care taken in the construction of the kilns to ensure durability and to avoid leakage. These may not appear to be very striking characteristics, but to anyone familiar with some of the flimsy Continental and American kilns, they are at once recognized as of great importance. Simplicity in design combined with durability, due to good construction, is far more important in a gas-fired kiln than the inclusion of many ingenious devices which tend to weaken the structure, demand increased attention and skill, and (except in the hands of men of unusual ability) do not compensate for the complications they introduce.

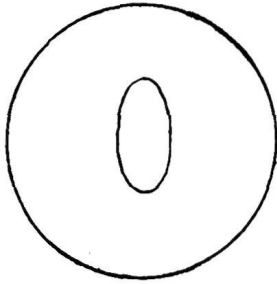
The *Dowson and Mason* gas-fired kiln (fig. 75) has a gas main surrounding the kiln, with numerous gas inlets uniformly distributed. It has no primary air, but admits the secondary air in two ways: (a) that which rises through the cooling lime, and (b) that which rises through the space between the double cooling zone, up flues in the brickwork, and is discharged through downward-sloping ports immediately over each gas inlet. The object of this second supply of air is to protect the brickwork immediately above the gas ports by blowing the flame towards the centre of the kiln. A Duff producer with a dog kennel grate is usually supplied with this kiln.

Ashmore, Benson, Pease and Co. Ltd., in association with the Power Gas Corporation, Ltd., have built several gas-fired lime-kilns, but "are unable to publish any particulars."

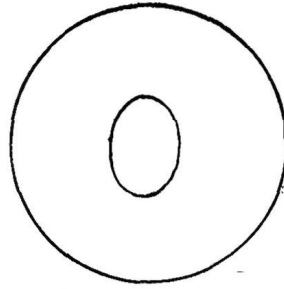
F. Crosland's first kiln (fig. 76) (patented in 1904) is designed to ensure the stone being turned over repeatedly in its passage through the kiln. For this purpose, the shape of the kiln is changed four times. It is claimed that this form of construction imparts a slow, twisting action to the stone, so that each piece is exposed on all sides to the action of the hot gases. The gas burners in this kiln consist of a series of ports, five being arranged on each major side of the ellipse, and one at each end. There are no gas burners in the strict sense, but only gas ports, no primary air being used.

In a later form of this kiln, the upper part is sloped instead of being vertical, and a combustion chamber is provided over each burner. The sight holes leading to the combustion chamber can, if desired, be used to supply primary air, and the nature of the flames can be thereby varied to suit local requirements. The shape of the combustion chambers is not satisfactory as the flames will tend to wear away the overhanging brickwork, but this is easily overcome.

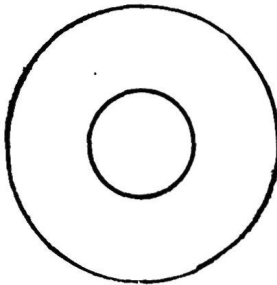
The *Mount* kiln (fig. 77)—used in the Rockland-Rochport works, one of the largest and most up-to-date lime plants in the United States—is oval in section 6 ft. 6 in. greatest diameter, and 5 ft. least inside diameter, widening out to 7 ft. 6 in. at 11 ft., above the gas inlets. The kiln is 75 ft. high above foundations, the brickwork stopping at a height of 55 ft., *i.e.* where the gases are drawn off through a main to the fans, the top 20 ft. being unlined and serving solely as a store of stone.



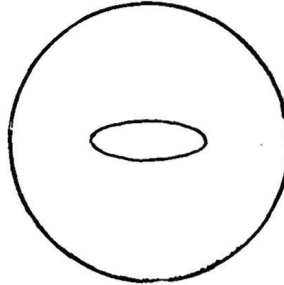
SECTION ON 3-3.



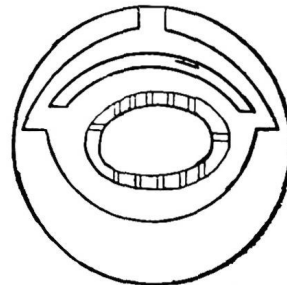
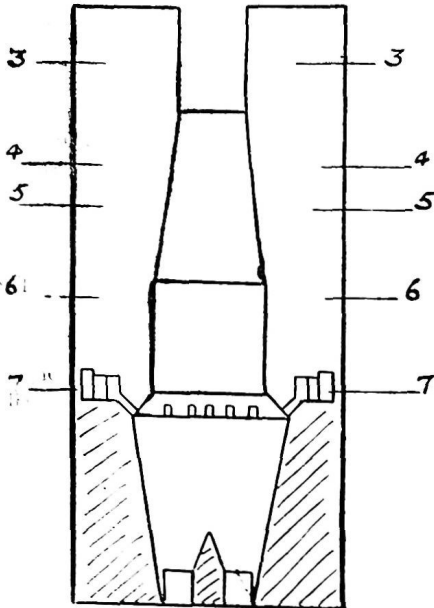
SECTION ON 4-4.



SECTION ON 5-5.



SECTION ON 6-6.



SECTION ON 7-7.

FIG. 76.—CROSLAND KILN.

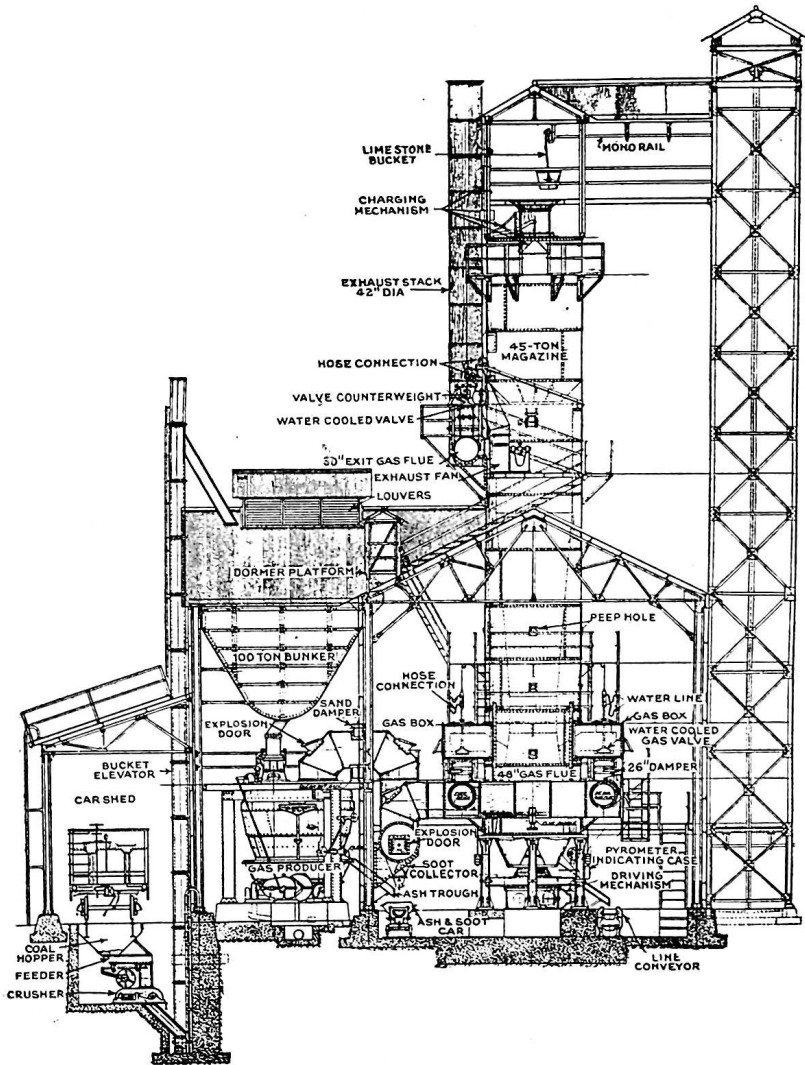


FIG. 77.—MOUNT KILN AND ACCESSORIES.

The gas is made in a Morgan producer, which is automatically poked, and is delivered under constant pressure to burners arranged on opposite sides of the kiln. The burners are so designed that primary air can be admitted and mixed with the gas before ignition, but, in practice, no primary air is used, all the air being drawn through the cooling lime. The kiln is discharged automatically through a revolving table, something like a Trump feeder, which

operates with a minimum grinding effect. At Rockland-Rochport each of these kilns produces 30 tons of lime per day of 24 hours.

The gas-fired kilns which are ordinarily supplied by *F. L. Smidth & Co. Ltd.*, are of the *Aalborg* type. The gas from a single producer passes into a main surrounding the kiln and thence through several gas inlets into the shaft. Much importance is attached to the kiln not being more than 4 ft. 6 in. diameter at its narrowest part, the designers of this kiln being of opinion that with a greater diameter some of the lime will be imperfectly burned. This small diameter limits the output of the kiln to 15-20 tons of lime per day. There is no primary air, all the air required for combustion rising through the cooling lime. This kiln, though widely used, possesses no special features so far as gas-firing is concerned; it is, in fact, a mixed-feed kiln to which a supply of gas has been added, all the special features—important in a mixed-feed kiln but of little significance in a gas-fired kiln—being retained.

Fig. 78 shows a section and plan of a pair of gas-fired lime kilns by *Peretti & Funck* of Magdeburg; the interior of the shaft is oval, the gas duct runs all round it with 24 gas inlets uniformly distributed, and there are three gas producers—all on one side of the shaft. When only one kiln is built the producers may be arranged symmetrically so as to ensure a uniform distribution of heat.

This kiln has no primary air, all the air used for combustion rising up through the cooling lime.

The gas-fired kiln designed by *Gilbert and Whittaker* has a surrounding gas main with ten inlets, uniformly distributed. All the air required for combustion

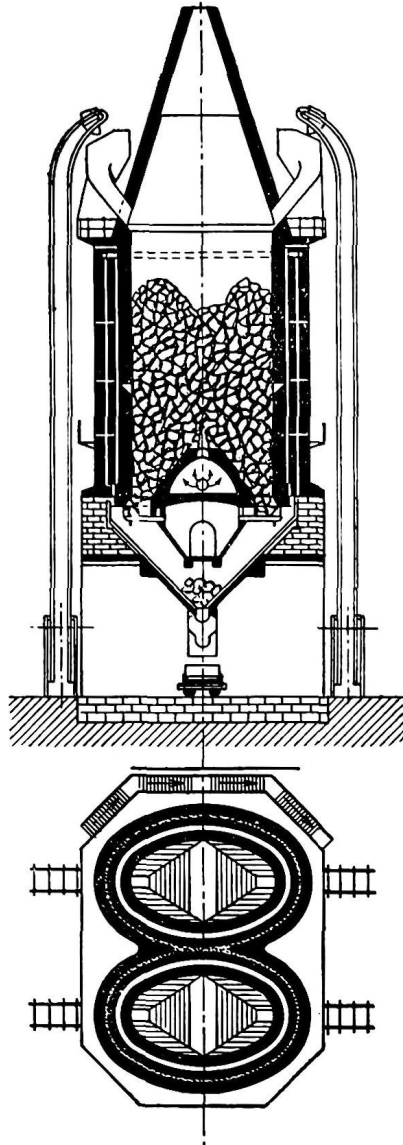


FIG. 78.
PERETTI AND FUNCK LIME-KILN.

rises through the cooling lime. The chief feature of this kiln is not the mode of heating, but the series of tooth rollers mounted on a shaft near the base of the kiln which are intended to ensure a regular and continuous discharge. Such a device appears to work quite satisfactorily with hydraulic limes, but the author has never been able to obtain satisfactory results when burning high calcium limes containing little or no clay.

The *Duchez* gas-fired kiln only differs from the mixed-feed kilns designed by J. E. Duchez and previously described in using gas instead of solid fuel mixed with the stone. The gas main and burners possess no unusual features of any importance, but the introduction of air under pressure into the lower part of the kiln is a special feature, the value of which is extremely difficult to estimate.

In the *Lengersdorff* kiln the burning zone is narrower than the cooling zone, so that air rises from the upper part of the latter into flues in the brickwork and thence into a series of small flues arranged in pairs, one on each side of each gas burner. By causing a strong draught in these air flues and limiting the amount of air rising through the cooling lime, some of the flames and hot gases are drawn downward and into the air flue, where they dilute the air and increase the length of the flame, thereby tending to reduce the amount of core and to prevent overburning the lime. This is one of the few kilns fitted with complete gas burners, *i.e.* gas burners which comprise a separate air supply for each.

Many arrangements of hot-air flues, other than those previously described, have been proposed, but they do not appear to offer any real advantage over those described. For instance, in the kilns built by *Franz Meiser* part of the air rising through the cooling lime is drawn up vertical flues in the masonry and delivered a short distance above the gas ports. Unless a fan or other device is used the movement of the air through these flues is very slight and their use is correspondingly small.

A combination of induced and forced draught is sometimes very effective, air being blown in at the base of the kiln and the gases being drawn out of the top either by a fan or by natural draught. In most cases, however, the air required is best drawn through the kiln and not blown in under pressure as the latter tends to irregular burning of the lime.

When the limited diameter of a circular gas-fired kiln is objectionable the shape may be altered in several ways :

(i) Mendheim, about forty years ago, built a number of kilns which are oval in plan, the gas being projected across the smaller diameter of the oval. The objection to this design is that the ends of the kiln are insufficiently heated and tend to deliver imperfectly burned lime, though with skilful designing and management this need not be serious. Several kilns of this shape are in use in this country and abroad, they differ in details, but the more successful ones are characterized by the shorter diameter, not exceeding 7 ft., and by the burners extending as close to the ends of the longer diameter as possible. In one pattern, the burners are also placed in the ends of the longer diameter.

(ii) Isserlis combined several kilns into one (fig. 79) the upper part being separated by partitions, and the lower part being quite open. These kilns work

satisfactorily but they are much more difficult to build than round kilns, because the long rectangular shape necessitates special constructional work or the kilns would be weak in the walls. Repairs to such large kilns are difficult and it is generally better to have several separate kilns than a combined one of the same capacity.

(iii) F. Meiser and K. Meiser (G.P. 345,226—1920) have patented a kiln with a central shaft, the contents of which are burned by the mixed-feed process whilst the contents of the outer annular column are burned by gas-firing. The kiln is suggested for situations where good fuel for mixed-feed purposes

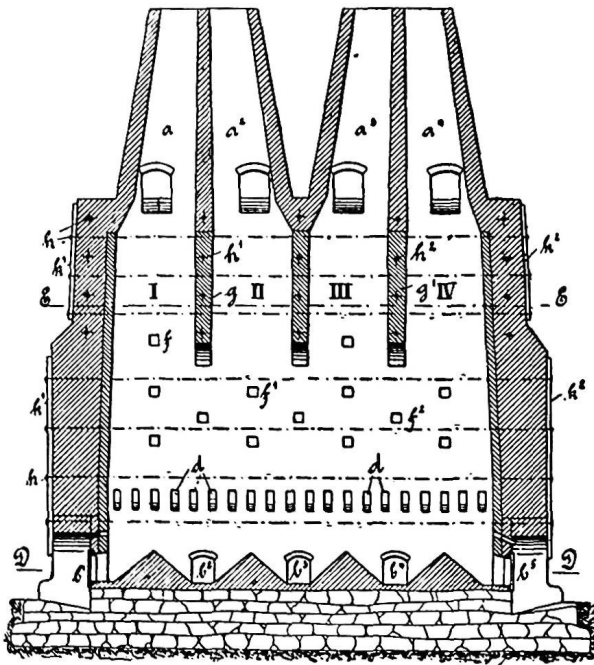


FIG. 79.—ISSERLIS' GAS-FIRED KILN.

is not available in sufficient quantities, the remainder of the fuel, which is inferior, being converted into gas before use.

It is obvious that many variations in detail are possible, but there is no need to describe these. Mention should, however, be made of a modification in which the central air shaft is very narrow and with no gas burners on the inner side of the kiln, because such a modification (though the subject of a recent English patent) can scarcely be expected to produce uniformly heated lime unless the annulus is so narrow as to be almost useless.

The *general dimensions and chief features* of vertical gas-fired kilns are the same as those of other vertical kilns of good design. The stone is supplied

through the top of the kiln and the lime is drawn out at the bottom, many of the devices for charging and discharging other vertical kilns being equally applicable to gas-fired ones and so do not need to be described here.

A quick acting draw is essential so as to reduce to a minimum the air entering the kiln during the drawing period. The various methods used for charging and discharging mixed-feed kilns are equally applicable to gas and oil-fired kilns.

A *cooling cone* is provided in most of the better kilns. It is made of steel plate and the cooling is chiefly by radiation. It would be better to cool by passing sufficient air through the lime and to use all the air for combustion, but this cannot be done because the amount of air required to cool the lime is much greater than that required for the combustion and a great excess of air would cool the flames unduly and would result in too much underburned lime or "core" being produced. By constructing the cooling zone of sheet steel the loss of heat by radiation is increased and the lime is cooled rapidly, although no use can be made of most of the radiated heat. Some designers have proposed a double cooling zone, to draw a current of air between them, and to pass it into the kiln above the burners; this is useful for other reasons, but only a very small proportion of the air which could be heated can be used in this way.

Most of the newer gas-fired kilns have accommodation for stone in the upper part of the kiln so as to reduce the quantity of stone to be charged at night.

The adaptation of coal-fired kilns to some patterns of gas-fired kilns is difficult when once a kiln has been built because of the extensive flues and ducts which should be in the brickwork unless a large loss of heat by radiation is unimportant, but some direct-fired kilns can be altered to gas-firing. It is also comparatively easy to alter the drawings of almost any type of vertical kiln so as to heat it by gas, provided the diameter of the kiln is not too great. For this reason, several well-known types of mixed-feed kilns have been adapted to gas-firing; the necessary modifications are usually so obvious that no description of them is needed. They retain their chief characteristics, but are gas-fired instead of being fired by solid fuel.

The lining of a gas-fired kiln should be of similar material to that used for mixed-feed kilns (p. 290), but as the hottest zone is at a higher temperature it is usually best to use for it bricks with a high alumina-content, preferably amorphous, though, with suitable burners which do not allow the flames to rise immediately up the walls of the kiln, good fireclay bricks are satisfactory. Above the hottest zone, bricks with 35-40 per cent. of alumina are usually satisfactory, and, in many cases, good fireclay bricks are used to within 15 ft. of the top of the kiln. For the uppermost 15 ft. the firebricks should be chosen for strength and hardness rather than for refractoriness. For the cooling zone high-grade firebricks are best.

KILN DRAUGHT

Most vertical kilns are worked by natural draught. The kilns themselves behave as chimneys, and, if sufficiently tall, will create ample draught, as a

result of the upward movement of the hot gases passing out at the top of the shaft, without any other appliance being necessary. There are, however, serious objections to wide open-top kilns as draught producers because of the great effect of the wind on them, creating irregular draughts and faulty burning. Moreover, such kilns are very unpleasant for the workmen engaged in filling them, especially in stormy weather.

Such kilns produce a much more steady natural draught if they are (i) covered with either a cone provided with a charging door and surmounted by a chimney-stack of suitable dimensions; (ii) covered and fitted with a side chimney; or (iii) provided with a partly submerged chimney and covered with a suitable housing as described on p. 278. The use of a chimney greatly reduces the effect of winds, hinders down-draughts and greatly improves the working of the kiln.

The diameter of the chimney-stack for lime-kilns may be calculated from the following formula¹ :—

$$D = 0.0847 \sqrt{\frac{c(t + 460)(r + 18.65)}{r}}$$

where D is the diameter of the stack in inches, c the kiln-capacity in tons of lime per 24 hours, t the temperature of the escaping gases in °F., and r the weight of lime burned to each pound of coal used.

Thus, using a lime : coal ratio of 5 : 1 and with the gases escaping at a temperature of 570° F., the chimney would require to be about 3 ft. 6 in. in diameter for a kiln producing 50 tons of lime per 24 hours, 2 ft. 6 in. for a kiln producing 25 tons of lime per 24 hours, and 1 ft. 6 in. for a kiln producing 10 tons of lime per 24 hours.

The output of a kiln is almost proportional to the square of the draught.

The draught may be induced by a chimney, fan, or by air under pressure blown into the kiln. Owing to the effect of the stone and the lime in the kiln it is sometimes necessary to use both induced and forced draught, as forced draught alone will not always pass up the kiln. In a kiln working with induced draught there should be no suction at the eyes or fire holes of the kiln, but preferably, a slight pressure.

Induced draught is chiefly created by chimneys, but fans are being increasingly used.

A convenient height for the chimney is 20–40 ft. above the top of the shaft though so high a chimney is not always necessary. It will depend largely on the location of the kiln. If the kiln is at the bottom of a deep quarry with a high and possibly overhanging face, it is desirable to have a high chimney to create the necessary draught, but if the kiln is in an open situation a much lower chimney may be quite satisfactory.

When a kiln is surmounted by a cone and chimney, an opening, provided with a door, must be left in the side of the cone through which to charge in the stone to be burned. When the door of this charging hole is opened it will

¹ U.S. Bur. Stand. Tech. Paper, No. 16, p. 33, 1913.

interfere with the draught on the kiln, and the escape of gases through it may also be unpleasant to the workmen.

The *Schneider* kiln is closed at the top by a truncated conical cover surmounted by a chimney, or (if several kilns are side by side) connected to a

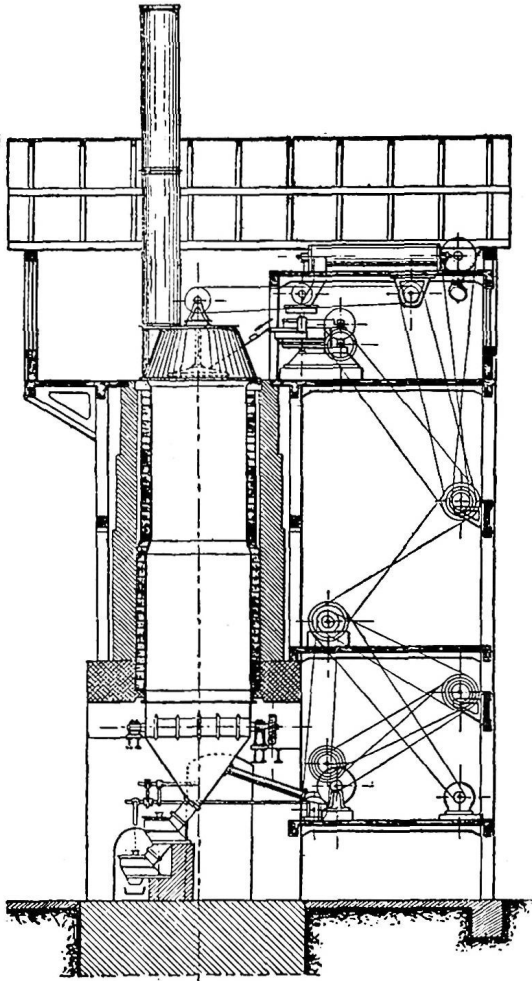


FIG. 80.—MANNSTAEDT KILN.

pipe or flue, which discharges the gases into a chimney so placed that it can serve all the kilns. A similar method is adopted in the *Hauenschild* and *Stein* kilns.

In the *Mannstaedt* kiln (fig. 80) the chimney is not placed centrally over the shaft, but to one side so that a central charging hopper with a cone damper can be used. By this method, the charging can be effected without the workmen being enveloped by the kiln gases.

The *Anker* kiln also has a central charging hopper and a chimney leading from one side of the shaft.

The *submerged chimney* is a feature of several of the best type of French kilns, including the *Candlot*, *Cornet*, and *Duchez* kilns, and is a remarkably ingenious device. Although it was used as far back as 1820, and is mentioned in a French book on lime kilns published in 1847, it

has scarcely been used in other countries until quite recently. This is the more remarkable as it is as effective and convenient as it is ingenious. A submerged chimney consists of a metal pipe, 30–40 ft. high, and of suitable diameter, according to the diameter of the kiln. The upper two-thirds are constructed of $\frac{3}{8}$ -in. steel-plates, rivetted together, but the lowermost third is much

stronger, and is usually of cast-iron about 1 in. thick. The chimney is slightly tapered at the base, and is submerged 3 ft. or more below the top of the stone in the kiln. If the chimney is rightly proportioned, the kiln gases do not pass out of the top of the shaft, but enter the chimney below the top of the stone, and so avoid the inconvenience of charging material into a shaft out of which dense fumes are pouring. If desired, a light conical cover may be lowered onto the top of the kiln at night and at other times when no charging is taking place. This cover should be supported by counterpoised ropes so that it may be raised and lowered easily. The advantages of a submerged chimney are :

(a) The gases are drawn towards the centre of the shaft, thus overcoming their natural tendency to creep up the sides and ensuring a more even burning.

(b) The kiln lining is subject to less wear and tear as a result of the drawing of the gases to the centre of the kiln.

(c) The workmen charging the stone into the top of the shaft are protected from being enveloped by the kiln gases and can work in comfort.

(d) The draught is much steadier than in open-top kilns.

(e) There is no interference with the draught during charging, as in kilns with conical tops or mechanical draught.

In the *Duchez* kiln, the draught in the submerged chimney is supposed to be increased by an outer chimney so that air can be admitted round the submerged pipe, thus increasing the velocity of the rising gases, but whether such increase occurs has yet to be proved.

Various other methods of withdrawing the waste gases by natural draught have been devised, but most of them (even though patented) are of very little value, and some overlook important facts. Thus, P. Dumont (Eng. Pat. 169,786) has patented the use of a number of bifurcated flues around the top of the kiln, with the object of drawing off the gases uniformly from all parts of the periphery of the shaft. This is precisely the opposite of what is required, for in any kiln the gases tend to creep up the walls and not up the centre of the kiln, so that any device which increases this will do more harm than good.

Mechanical Draught has considerable advantages over natural draught, and it is being increasingly used in modern kilns of the external-fired type, but it is not much used in mixed-feed kilns, most of these employing natural draught for their operation. Nevertheless, mechanical draught can be almost as easily applied to mixed-feed kilns as to other types. Only its application to mixed-feed kilns is dealt with in the present section.

Mechanical draught is of two different kinds, according as air is forced into the kiln under pressure (*Forced draught*) and is allowed to escape naturally at the top of the shaft, or as the gases are drawn out of the kiln by the suction of a fan (*Induced draught*).

A combination of both forced and induced draughts is sometimes, though not often, used, air, steam, or other gas being blown into the base of the kiln and suction being simultaneously applied to a pipe connected with the top of the shaft. The author has made numerous investigations of both forced and induced draught applied to lime kilns, and has found that, on the whole, forced

draught is not to be recommended for introducing air into shaft kilns as (i) it renders discharging and inspection very difficult, and necessitates special forms of discharging apparatus (see a later section on methods of discharging kilns); (ii) it is very liable to cause irregular heating, as the air tends to force its way through certain parts or "channels" of the kiln and not uniformly upwards. This gives rise to excessive "hot spots" where the lime is overburned and to other "dark spots" where the burning is incomplete; and (iii) more power is required with forced than with induced draught.

Notwithstanding these serious objections, forced draught is, in some kilns, used as the sole means of introducing air into the kiln, and in other kilns it is used to supplement the natural draught. For instance, in the *Mannstaedt* kiln (fig. 80) all the air used for cooling and combustion is forced by means of a fan connected to a horizontal air flue below the discharging apparatus. This necessitates the latter being closed so that no air can escape by the outlet through which the burned lime passes.

Several other mixed-feed kilns have forced draught supplementing the natural draught of the kiln. Thus, the hot-air flues in the *Duchez* kiln (fig. 65) are operated by forced draught, and the draught of the *Steiger* mixed-feed kiln is sometimes assisted by means of forced draught. This is usually unnecessary for lime, being more desirable when burning cement. Kilns of the *Hauenschild-Schneider* type are also operated by forced draught.

In one of the kilns devised by *A. Hauenschild*, air is injected into a mixed-feed kiln about half-way up the shaft through a number of jets or tuyères arranged round the kiln and fitted so that the blast is directed upwards at an angle of about 45 degrees.

Mechanically *induced* or *suction draught* is seldom used in mixed-feed kilns, though it has several important advantages, the chief of which are:

(i) The kilns can be worked under any climatic conditions. This is a considerable advantage, especially where the climate is unfavourable or where surrounding hills or the sides of a deep quarry may prevent the creation of a steady natural draught.

(ii) Smaller pieces of stone may be burned in the kiln than with natural draught, as with the latter the spaces between the stones must be large, so as not to offer a high resistance to the draught. This is only possible when large stones are used in the kiln.

(iii) As the output of a kiln is largely dependent upon the draught, the output may be considerably increased by increasing the draught by mechanical means; a practical limit is reached when the cost of power to create the draught is equal to the saving effected by increasing the output of the kiln. Very strong suction is not always economical, for the reason given above, and also because it tends to draw too much air through cracks and other accidental openings in the kiln. When working with an induced draught it should not usually exceed 4 in. when measured by a water-gauge, and, for most purposes, a gauge reading of 2 in. at the fan is ample.

The fan used to draw off the exhaust gases must be suitable for dealing with hot gases (up to 300° C.) ; otherwise, the wear and tear will be very great. The gases from the kiln should not exceed this temperature if it is working efficiently, but if gases at a higher temperature need to be passed through the fan it is advisable to mix cold air with them after they leave the kiln, or to pass them through a waste heat boiler, or use some other means of cooling them sufficiently to prevent them from damaging the fan.

The types of fans and other appliances used for producing mechanical draught are more conveniently considered in connection with gas-fired kilns.

As it is usually very difficult to make use of the heat contained in the waste gases from mixed-feed lime kilns it is generally best to employ it in creating a natural draught, except in those few localities where the conditions prevent a satisfactory natural draught from being created.

✓When burning small pieces of stone, a very high draught is required, and forced draught under a pressure of 12-16-in. water-gauge is needed. To use this effectively, a special discharging device is necessary which will allow lime to be withdrawn from the kiln without any loss in air-pressure. In the *Mannstaedt* kiln (fig. 80) this is effected by the use of two large sealed vessels placed in series and provided with dampers so that the lime falls first into one and then into the other vessel, the air being prevented from escaping with the lime by the manipulation of the valves.

Several arrangements for supplying air under pressure are in use abroad in vertical kilns, but they have not become popular in the British Isles where kilns of simple type are chiefly used. When the air is admitted under pressure in a suitable manner, it enables a much larger output of lime to be secured and smaller stone can be burned successfully. In some kilns of only 10 ft. internal diameter, an average output of 150 tons per day is secured as compared with about 40 tons per day with natural draught. It is difficult, however, to ensure a uniform distribution of the air in the kiln as there is a great tendency for the air to pass mainly through channels in the mass of stone and not to rise uniformly through the kiln.

✓*Supplementary Chimney.*—Even when mechanical draught is employed a small chimney should always be fitted to each kiln for use when the mechanical appliances are not available. The height of this chimney must be sufficient to keep the kiln burning, though not at its full capacity ; if the kiln is sufficiently high to work without artificial draught (*e.g.* 40 ft. or more in height) a chimney 10-15 ft. and 10 in. internal diameter should suffice, but if the shape of the kiln is such that the natural draught in it is poor, the supplementary chimney may require to be 30 ft. high and 18 in. internal diameter.

The chimney should be fitted with a flap damper made of cast-iron ; this is usually placed on top of the chimney and worked by means of a chain and lever, but it may be placed inside the chimney if preferred. Valve and rotary dampers are seldom satisfactory, as they are destroyed too rapidly by the kiln gases.

The supplementary chimney is usually of cast-iron. It should be attached to an elbow piece projecting from the side of the kiln, or to a branch from the

pipe leading to the inducing fan, but not to the top of the kiln, as it would then interfere with the charging.

Kilns of the Hoffman type usually have a separate chimney; this must usually be about 150 ft. high. A fan with a much shorter chimney can be used and is equally satisfactory, the cost of the power required being compensated by the greater use made of the heat in the kiln, and the better control of the burning.

The draught of a vertical gas-fired kiln, like that of other vertical lime kilns, may be natural or artificial, but adequate control and regular working are far better secured by creating the draught by means of a fan or exhauster, though natural draught may be used to keep the kiln alight when the fan is out of order or when the kiln is "damped down" owing to shortage of orders.

In the *Dowson-Mason* kiln, the fan is usually placed on top of the kiln, but this arrangement, though very simple, prevents any use being made of the heat in the gases discharged by the fan. Some other kiln builders (including *Priests Furnaces Ltd.*) place the fan near or at ground-level and pass the gases into a waste heat boiler which provides all the steam required by the producer under normal conditions of working and in this way reduces the fuel consumption. Such a boiler should be fitted with a grate on which coal can be burned or it may be difficult to obtain sufficient steam when relighting the kiln.

CONVEYING STONE AND FUEL TO VERTICAL KILNS

The method of conveying material to the top of a shaft kiln depends largely on its location.

(1) If the kiln is built on the side of a hill, it is often possible and very convenient to have the working bench on a level with the top of the kiln, so that an almost horizontal gantry or bridge may be run from the quarry floor to the top of the kiln, and the stone conveyed along this in small trucks on a narrow gauge of tramway. If possible, the track should run right round the kiln, so that the trucks may be discharged at any point and the empty ones taken back on the return line; turntables may be used, but they are slower and more troublesome. The track may slope very slightly (about 1 in 100) towards the kiln, so as to facilitate pushing the trucks, but the slope must not be very great or they would move too rapidly, get out of control and be more difficult to return. If the quarry floor is much higher than the kilns an inclined track operated by rope haulage may be used, but it is not to be recommended as very serious accidents may happen, because the top of a high kiln is not a suitable place for the end of a steep haulage track.

When the stone has to be crushed to 6-12 in. pieces, before putting into the kiln, the quarry floor may conveniently be several feet higher than the top of the kiln, so that the material discharged from the crusher or grids may fall straight into the trucks used for filling the kiln.

(2) Where the quarry floor is much below the top of the kiln, the stone may be conveyed up an incline, a tramway track being used if the incline is very long; for shorter distances a skip running on rails, and a belt conveyor, bucket-

elevator, or similar appliance may be employed, though belt conveyors are not very satisfactory for large and heavy stones, as the wear and tear on the belt is so great; where the inclination of the belt is not very steep, belt conveyors are satisfactory. Bucket elevators are satisfactory for small stones and fuel in pieces not larger than 2-in. diameter, but they are noisy and troublesome when dealing with larger pieces.

Small skips with wheels, which are hauled up a track by a rope, are very satisfactory, and may be used for inclines up to 60–70°. Owing to the lack of space on top of a kiln, a single skip of special shape is preferable to several; it is filled, hauled to the top of steeply inclined rails, tipped, and then returned to be refilled. Such *basicules* are very largely in use on the Continent. Suitable provision should be made to prevent damage to the workmen if the skip breaks away from the rope.

(It is more often convenient and very satisfactory, especially where space is cramped, to use a vertical hoist. The same hoist may be used for elevating the fuel to the top of the kiln.)

(3) Aerial ropeways are sometimes used to supply stone and fuel to the top of the kiln, especially when the quarry is at some distance from the kiln and the surface of the land between is very uneven, but owing to its cost, an aerial ropeway is of little use for a single kiln. It is, however, excellent for a battery of kilns, with an output of not less than 5 tons per hour.

(4) In some cases, cranes are used for lifting the material to the top of the kiln, and some very large kilns are filled by travelling cranes fitted with grabs, which work on top of the kilns, though these are very unusual.

Flare kilns and those of the Hoffman or similar types are usually supplied by small trucks which run on rails on the ground, but it is sometimes cheaper and more satisfactory to employ a travelling crane and to fill the kiln from the top. The great drawback to the use of such a crane is the care which must be taken to avoid all risks of accident by dropping the stone on men at work in the kiln.

COOLING THE LIME

In order to facilitate the handling of the lime discharged from the kiln and to prevent an undue loss of heat, the lime should be as cool as possible when it leaves the kiln. To ensure this it is usually necessary to employ a *cooling zone* which, in the case of a vertical kiln, is generally the lowest part of the structure proper (as distinct from the supports), and, in such kilns, it is usually in the form of an inverted cone, though in a few cases it may be of the same diameter as the rest of the kiln or it may even be slightly larger (*i.e.* a simple cone). It may be constructed of stone, brickwork, steel plates (the last-named being very popular in some modern kilns), or a series of bars which allow air to pass between them and yet retain the lime in its place.

The lime is generally cooled by air entering the kiln at the base of the cooling zone and passing up into the shaft, where it mixes with the fuel and assists combustion. The lime, whilst cooling, yields up most of its heat to the

air, warming the latter and so reducing the amount of fuel compared with what would be required if no use were made of the heat in the lime. In some kilns, little or no air passes through the cooling zone and in these the cooling zone is constructed of sheet iron or steel plates, so that the cooling lime loses its heat solely by radiation. This is much less effective than when air is passed through the lime, but with some types of coal-fired kilns and of kilns with forced draught it is necessary to keep the bottom of the kiln tightly closed, and cooling by radiation is then the simplest mode of cooling.

In kilns of the *Hoffman type*, each chamber is used in turn as a cooler, this being part of the routine procedure in burning.

In *rotary kilns* the lower end acts as a partial cooler, but for effective cooling a separate appliance—roughly equivalent to an extension of the kiln—is necessary. In some plants, particularly in the United States, the lime is so hot when drawn that it has to be stored in large bins until cool, but in the British Isles the lime is drawn at more frequent intervals and is much cooler.

The hot lime is usually carried in large iron or steel trucks which hold up to 6 tons each (so as to accommodate the whole of the lime drawn at once from a kiln). The trucks are hauled up an incline and discharged automatically into the cooling bins.

The cool lime is afterwards screened and any underburned (core) or overburned pieces are picked out by hand; the remainder is then taken to a store or loaded directly into trucks. For this purpose drag conveyors, belts, bucket conveyors, and elevators are extensively used.

Many vertical kilns have much too short a cooling zone, with the result that the lime is very difficult to handle. The best procedure with such kilns is to draw the lime into steel cars which are then hauled up an incline and discharged into large metal bins with a capacity of four or five days' output of lime.

Some firms endeavour to cool the lime quickly by drawing large quantities of air through the kiln. This is objectionable for two reasons: (a) the carbon dioxide and moisture unavoidably present in the air cause air slaking and so spoil some of the lime, and (b) the excess of air carries away a large amount of heat which cannot be properly utilized in the kiln and so involves a serious waste of fuel. Chaudière has designed a kiln with a central vertical shaft with its lower end level with the top of the cooling zone. This shaft carries away the greater part of the air used for cooling the lime and also (by occupying the centre of the kiln) reduces the amount of underburned lime (see p. 300).

In a vertical kiln the cooling zone should not be rigidly fixed to the kiln structure, but should be arranged so as to allow fully for the great changes due to its varying expansion and contraction.

The shape of the cooling zone has an important effect on the working of the kiln (see the section on "Discharging the kiln.")

THE USE OF STEAM

If steam is introduced along with the air into a lime kiln the limestone will be decomposed at a lower temperature than with air alone. As any other

inert gas produces the same result it is clearly due to the physical properties and not to the chemical properties of steam.

Steam introduced below the fuel in externally-fired kilns or gas-fired kilns will prevent clinkering and will supply combustible gases (carbon monoxide and hydrogen) from the decomposition of the water by the red hot fuel. These gases tend to lengthen the flame in the kiln, which is very desirable, but it can equally well be obtained in a gas-fired kiln without steam. Apart from this and the reduction in the amount of clinker formed on the grate bars the use of steam does not save fuel. The heat required to decompose the steam is not "waste heat" and must be provided by the fuel.

The use of more steam than is needed to prevent clinkering is a source of much loss of heat in lime kilns and should be avoided.

The introduction of steam seems to be particularly desirable in rotary kilns, as it mellows the heating of the flames which, in the absence of steam, is liable to be too fierce. It also assists in diluting the carbon dioxide produced from the stone and by thus lowering its vapour pressure it facilitates the decomposition of more stone.

DISCHARGING THE KILN

A shaft kiln is discharged through one or more openings near the base, these openings being closed by doors or other device (such as "shears") which must be very close fitting, and provision should be made for taking up wear and tear and other adjustments by lock-nuts or other means so as to ensure a constant fit at all times.

The doors or shears should be opened and closed by a single push or pull on the operating levers outside the kiln, so that the workers are well away from the dust and heat. In the *Arnold and Wiegall* kiln, a pair of sliding horizontal plates is used; they are operated either by hand, mechanical power, or air-pressure controlled by a three-way valve from any convenient part of the kiln.

If shears or horizontal discharge doors are used, they must be very strong, so as to withstand the weight of the lime and stone above them, and they must be capable of being quickly closed so as to prevent an excessive amount of lime passing out of the kiln.

The cooling zone and discharging device should not be attached rigidly to the kiln base, but should be kept sufficiently separate to allow for the expansion and contraction of the zone.

Two very different kinds of material have to be removed from a lime kiln, namely, (i) the waste gases, and (ii) the solid matter, which includes the lime, fuel, ash, and any imperfectly burned stone which may be present. The removal of the gases has been considered in the section on "Draught"; the removal of the lime and ashes is considered in the present section. In most kilns, the ashes are removed along with the lime—the two being mixed together. In gas-fired kilns and those with external fireplaces the ashes are removed separately, but their removal presents no special problem.

For removing the lime, several methods are in use :

The oldest means of discharging lime kilns was from one or more horizontal openings in the side of the kiln, but most modern steel cased kilns are discharged from the centre, the cooling zone being in the form of an inverted cone, though, as previously explained, this method of discharging increases the natural tendency of the lime to travel more rapidly down the centre than down the sides.

Instead of one opening in the centre many kilns have one or more openings at the side. The effect of such openings depends very largely on the shape of that part of the cooling zone in which they occur and on the manner in which the kiln is drawn. If the stone "hangs" in the cylindrical part of the kiln at a short distance above the top of the opening, it is possible to poke it in such a manner that the stone falls as from a cylinder into the open air and in a perfectly uniform manner. If, on the other hand, the lime does not hang, but falls slowly, a kiln with an opening at the side will tend to draw more lime from that side than from the others. When there are several openings in the side of the cooling zone, there is a tendency to increase the rate of fall down the sides which neutralizes the tendency to hanging, caused by the friction of the descending charges against the walls and by clinkering. When openings in the side of the cooling zone are used, they should be arranged at a suitable height above the ground, so as to avoid unnecessary stooping on the part of the men discharging the kiln. (The use of holes almost on the ground in many old kilns so as to have "height" is the result of a very short-sighted policy; it greatly increases the labour of shovelling the material as compared with that when the bottom of the outlets is sufficiently high for the trucks to be filled by raking)

The simplest method is by leaving the bottom of the kiln open with a space of several feet between it and the ground. In such a kiln the shape of the cooling zone is of great importance as it affects the manner in which the material falls as it descends through the kiln. This has been carefully investigated by B. Bloch, who used a mixture of white and coloured stone in alternate layers and found that :

(i) If the cooling zone is in the form of an inverted cone or funnel, the sides of which are more steeply inclined than those of the portion of the kiln above it, the middle of the layer sinks much more than the sides, so that too much lime is drawn from the centre and too little from the sides of the kiln. A uniform flow of material through the kiln is then impossible.

(ii) If the cooling zone is conical, with the wider opening below, the reverse is the case, more lime being drawn from the sides than from the centre of the kiln.

(iii) If the cooling zone is cylindrical the flow will be uniform. As the lime shrinks slightly in cooling there is no need to impede the flow, and there is, therefore, no need to use a cooling zone which is slightly conical; one which is quite cylindrical will produce better results.

Bloch's investigations show quite clearly that the customary double-cone

shape for a vertical lime-kiln is fundamentally wrong and that the proper shape is either wholly cylindrical or very slightly conical throughout, the conicity being only sufficient, however, to reduce the friction between the stone and the walls of the kiln. Many of the ingenious devices—such as a core of solid brickwork or concrete in the centre of the kiln—are used to avoid the drawback of an error in the shape of the cooling zone, though the use of such devices is a clumsy means of overcoming the results of such a simple error.

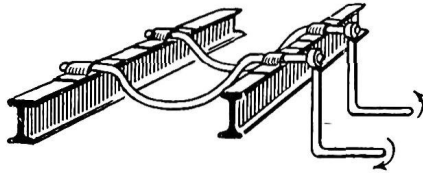


FIG. 81.—CURVED BARS (CLOSED).

In order to prevent the lime from falling prematurely, some kilns are provided with grates at the bottom of the cooling zone. These grates may be arranged peripherally with a solid centre (or an air-cone as in some gas producers) or the grate may occupy the whole area of that part of the kiln. As fixed bars are inconvenient, movable ones are usually employed. If the bars are straight, one or more may be pushed aside as required, but bars of special shape are used in the Cornet kiln.

In the Cornet kiln, the lower part of the cooling zone consists of four grates sloping at an angle of about 60 degrees, so that at their base the opening is about two yards square. Below this opening are a number of curved bars (fig. 81) which ordinarily are about 2 in. apart.

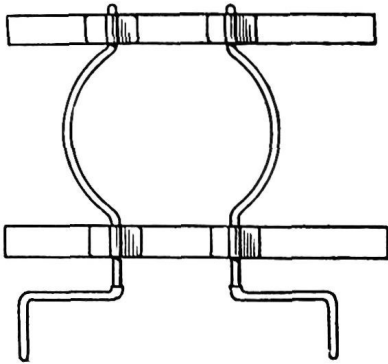


FIG. 82.
CURVED BARS (DISCHARGING POSITION).

When it is desired to discharge the kiln the bars are turned (fig. 82) so that the two concave faces of a pair of bars are turned opposite to each other, thus leaving a large opening between them through which the burned lime can pass. This is repeated with different bars so as to discharge the kiln uniformly. When the bars are released, they fall back into their normal position and prevent the fall of further lumps of lime until they are again turned aside. This method is very convenient and satisfactory, and at the same time it allows air to pass through to cool the lime and burn the fuel.

In kilns of large diameter which are fitted with a central cone to supply air to this part of the shaft (fig. 83), the curved grate bars are arranged around a cast iron cone with numerous holes in it; this central cone is intended to supply air to the centre of the kiln and to assist in directing the burned lime to the discharge openings on the circumference of the kiln.

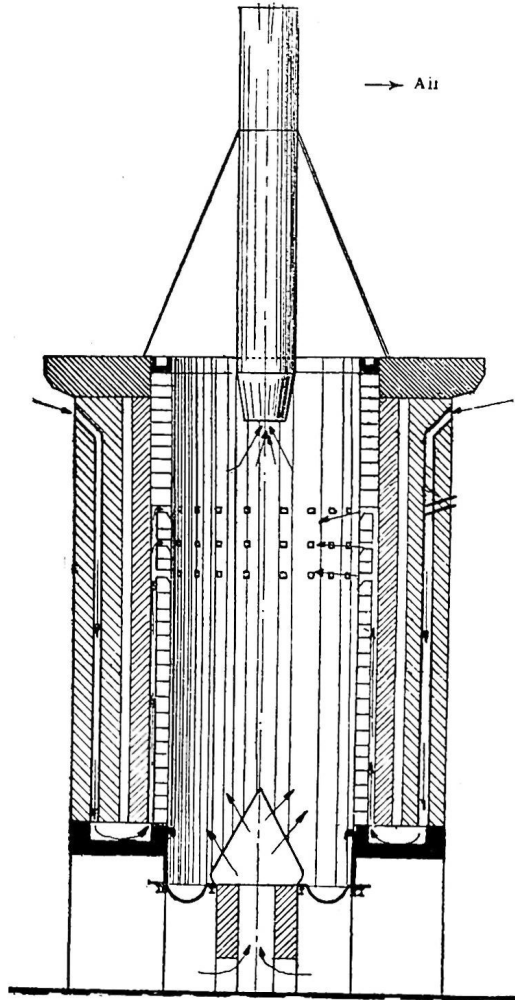


FIG. 83.—KILN WITH CENTRAL CONE NEAR BASE.

Bars, forming the sides and base of the cooling zone, are also used in the *Candlot*, *Campbell* and other kilns.

In order to overcome the disadvantages of drawing wholly from either the centre or the periphery, the "*Anker*" kiln is fitted with a double discharging-device (fig. 84). The benefit of this, when properly adjusted, is shown in figs. 85, 86 and 87, in which fig. 85 shows the inaccessible core of material which is produced when the discharge is peripheral, fig. 86 shows an annulus or "ring" of residual material which remains in the kiln when the discharge is central,

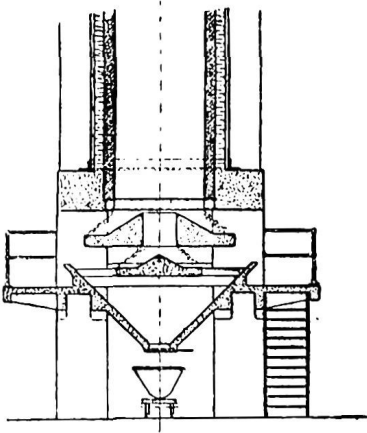


FIG. 84.—"ANKER" DISCHARGING DEVICE.

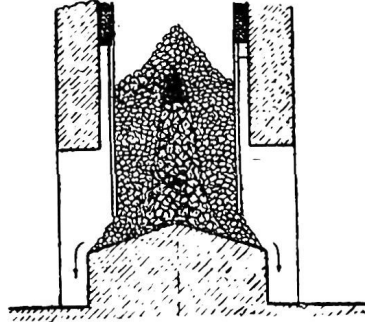


FIG. 85.—EFFECT OF PERIPHERAL DISCHARGE.

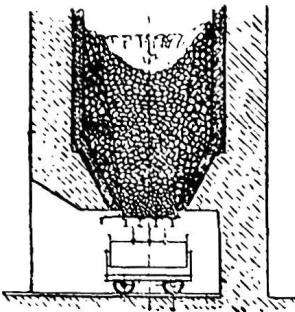


FIG. 86.—EFFECT OF CENTRAL DISCHARGE.

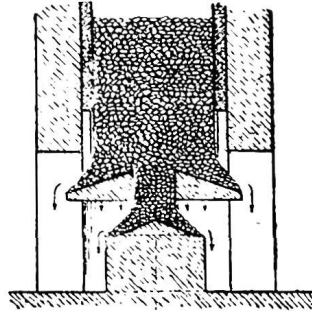


FIG. 87.—EFFECT OF "ANKER" DISCHARGE.

Fig. 87 shows the arrangement in the "Anker" kiln whereby both a peripheral and central discharge are obtained. The relative amounts of material withdrawn from each can be controlled by circular bands (not shown) which regulate amount of lime which can pass out of either opening at any one time. The regular automatic discharge ensures the gradual downward movement over whole sectional area of the kiln. In most other cases the lime is withdrawn from the periphery, the centre column remaining "dead" and gradually crushing so that it does not permit uniform distribution of the air through the kiln. Although the "Anker" device is very ingenious, it has not been used so largely as might be expected.

All the foregoing discharging devices work intermittently, as and when it is desired to discharge lime from the kiln, but it has long been the aim of some engineers to construct kilns with an automatic, continuous discharge, and devices for this purpose have been fitted with fairly satisfactory results.

Automatic discharging devices consist essentially of mechanically operated appliances for continuous removal of lime from the bottom of the kiln. They all tend to reduce the lime to small pieces, and are, therefore, inapplicable where lump lime is required. Such appliances consist of (a) a rotary grate with spirally arranged bars; (b) a series of screw conveyors; (c) a series of ribbed or toothed rolls arranged in parallel; (d) a rotating cone; (e) a series of rotating blades mounted, like a propeller, over a hollow dish with an opening in the centre (Sobek, Vienna); (f) reciprocating bars; (g) reciprocating pushers, which push the lime over the edge of the platform on which it rests (von Grueber); or (h) a combination of two or more of these devices.

Such appliances have the advantage of removing the lime in small quantities continuously and so are readily adaptable to the use of mechanical conveyors to transport the lime to bins or trucks, but their great disadvantage is that they reduce the lime to small pieces and prevent it from being sold as "lump" lime. The ever increasing use of hydrated lime makes this objection less serious than formerly, and it does not apply to hydraulic limes which have to be ground to powder before they can be used. Another serious disadvantage of automatic drawing devices is that they cannot adjust themselves automatically for varying conditions in the kiln. Hence, a skilled man is always superior to an automatic drawing device.

In the Steger automatic discharging device, there are two cones fixed one above the other and rotated by means of a crown wheel. The upper cone has a circular opening in its apex through which lime can fall to the lower cone to ensure both central and peripheral discharge. Scrapers are fitted to the cones which bring down the lime as they rotate. The drawback to this arrangement is the liability of large pieces to rest over the centre of the upper cone and stopping the central discharge.

The "Anker" automatic discharging device breaks up lumps of lime less than some others; it consists of a slowly rotating base which can discharge fairly large lumps, though it is liable to break up the lime by the cutting action of the projections on the cone.

Sometimes the breaking up of the lime is considered desirable and the discharging device is designed to effect it, as in C. Candlot's patent (Eng. Pat. 150,994, 1920) consisting of a revolving grate having a planetary movement and provided with teeth of lance-like shape to break up the descending column to facilitate its discharge. Equally vigorous is the action of a pair of toothed rolls *d.d.*, with vertical grates *e.e.*, at the base of the cooling-zone (fig. 88); the ground lime falls into the hopper *f*, and is removed by the conveyor *g*. An analogous device is used in some *Mannstaedt* kilns.

A device patented by A. Hauenschild (E.P. 170,764) has a rotary grate which moves alternately in opposite directions and is also raised and lowered at intervals, so that it travels in a vertical helix. This device is intended to be specially useful if the charge is likely to clog or "stick," as the peculiar motion of the grate tends to break up the material; there is always the risk that it may break up the material excessively and produce too much fine lime.

When kilns are operated by forced draught near the base it is important that the opening of the discharging apparatus must not allow air to enter or escape and so affect the draught of the kiln. This is avoided in the *Mannstaedt* kiln by causing the lime to fall successively into two sealed vessels, each controlled by a bell damper. The upper damper is opened and the lime then falls into the upper vessel. The upper damper is then closed and the damper of the lower hopper is opened to allow the lime which has accumulated in the upper vessel to fall into the lower one. The middle damper is then closed and a lower damper is opened to allow the lime to fall into a truck or other receiver.

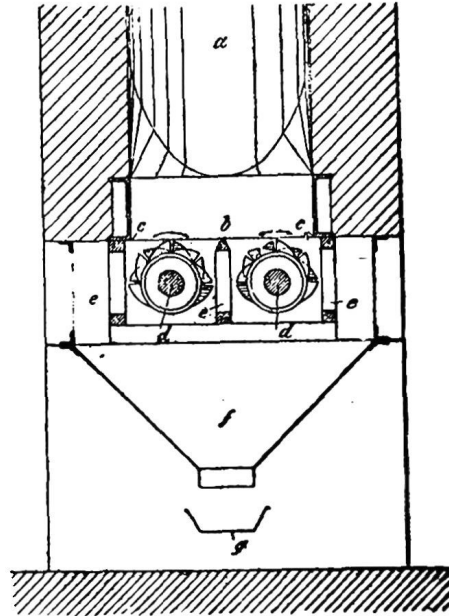


FIG. 88.—LÖHNERT'S DISCHARGING DEVICE.

Many other discharging devices have been patented, but none of them have gained popularity in the British Isles, chiefly because they reduce the lime to pieces which are too small to be sold readily in this country. For hydraulic lime and lime which is to be hydrated, this objection does not apply and an automatic discharging apparatus can then be advantageous.

Discharge chutes.—It is sometimes convenient to arrange some device below the outlet of the kiln, so as either to allow the lime to run into a truck immediately below the outlet or well to one side of it. This can be effected with a hopper of suitable shape, but where it is desired to fill two or more trucks simultaneously a cone should be used to divide the stream of lime (fig. 89).

Even more important than the mere delivery of the lime to trucks or wagons is the provision of means for separating the small lime from the large without any unnecessary handling. Several arrangements for this purpose are now in use.

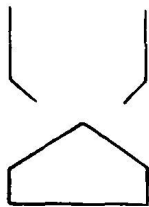


FIG. 89.
DISCHARGING CONE.

In fig. 90 two screens are arranged like a roof of a house, so that any small lime will fall through them; the larger pieces will remain on the screen for a short time, but will eventually fall into one of the chutes on either

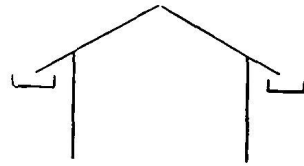


FIG. 90.
SCREENS AT BASE OF KILN.

side. The angle at which the screens are fixed should be adjustable so that the large stone neither travels down too rapidly nor remains motionless on the screens.

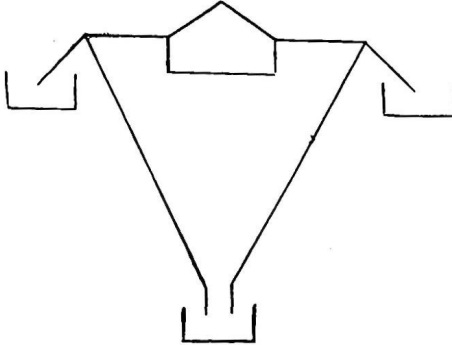


FIG. 91.—SCREENS WITH EXTENSION.

In fig. 91, two similar screens are used, together with a horizontal extension to each so as to provide a greater screening area.

The arrangement shown in fig. 92 is only suitable where the proportion of small lime is small, so that it can be retained in the inner bin until sufficient has been accumulated for it to be discharged into a truck.

When designing screens for lime as much use as possible should be made of gravity.

Where the relative positions of the kilns and railway trucks permit, the chutes used for delivery of the lime may be in the form of screens which separate the small and large lime. These chutes must be sufficiently inclined not to require much raking, but not too steep, or the lime will slide past so rapidly that picking out the pieces of unburned stone will be impracticable.

Wherever possible, a screen or its equivalent should be used, as if lump lime is sold the screen automatically separates the small lime, whilst if the lime is to be hydrated the separation of the small lime is equally useful.

The *sorting* of lime in order to remove under-burned or over-burned stone is usually effected in a very casual and inefficient manner. The lump lime is discharged into small wagons, or into a railway truck, and one or more men casually pick out what pieces they consider to be "stone" or "core." Not infrequently they throw aside a lump of good lime and disregard pieces of true core, and in most instances the sorting is far from complete.

Much better results would be obtained if the methods adopted at collieries were adopted, and the lump lime were to be dropped on to a belt-conveyor of such a length as to allow ample time for each piece of stone to be picked out before the lime falls into the trucks, bin, or other receiver.

Unfortunately, no wholly satisfactory method of separating "core" from lump lime has yet been found. "Picking" is too speculative and depends too much on the conscientiousness and skill of the men employed. Where a lime free from core is required, the most satisfactory method is to hydrate it, when the lime

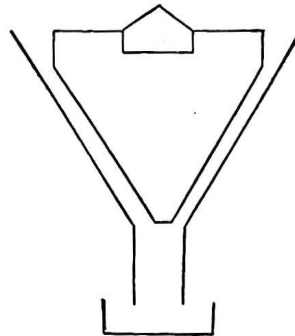


FIG. 92.
SCREENS FOR "LARGE" LIME.

will be reduced to powder whilst the "core" will remain in its original state and can be separated by screening, or, still better, by means of an air separator.

The sorted lime is then ready for dispatch to its destination, and, where possible, it should be sent off at once, as it will rapidly slake if exposed to moist air. As there are very few works in which—with the kilns working to full capacity—all the lime can be put straight into railway trucks or on to road motors and sent off immediately, most works must either provide storage for the lime produced in periods of slack trade and during week-ends and holidays, or else work the kilns slowly or even allow them to go out until they are again required. To avoid other troubles—including delays in loading and the risk of setting trucks or motors on fire with hot lime—it is in many ways preferable to put all the lime from the kilns into bins which are placed at a convenient height so that they will discharge directly into railway trucks or motor wagons. If this is done the wagons can be loaded in a few minutes from the bins and need not wait until lime is taken from the kilns.

If the kilns are situated on a hillside it may be possible to fill the bins by gravity. The burned lime may fall on to a screen, chute, or screen conveyor and, after sorting, direct into the bins. Kilns less happily situated may require an elevator to raise the lime to the bins.

The bins for storing lump lime should be shallow so as not to break up the lumps unduly. A height of 10–15 ft. is generally the most suitable, though shallower bins may be necessary for very soft limes. The sides of the hopper at the base should slope at an angle of not less than 60° so as to enable the bins to be self-discharging as lump lime does not flow readily.

The shape of the bins will depend to some extent on the space available and on the relative position of the railway. They may be made to discharge centrally directly into railway trucks beneath them, or into trucks along one side or both sides. Motors and carts are more easily loaded from bins with side or front outlets, whilst for trucks a central discharge is often more convenient.

Ample space should be provided for bringing several trucks or wagons simultaneously to the kiln or bins. This is a matter which is often neglected with the result that a horse or shunting engine is required every time a truck is filled. It is the best plan to arrange, if space permits, for sufficient trucks to be shunted into place alongside or beneath the bins for a whole day's work, and to use a mechanical pusher or puller to move them forward as required. Then when the whole of the trucks have been filled the shunting engine can take them all to the sidings for despatch to their destinations.

Forethought and planning are very necessary, or the discharging and despatching arrangements may prove to be a "bottle neck" to the whole plant, thus causing inconvenience and loss.

CHARGING THE KILN

In order to secure the maximum output and the minimum fuel consumption shaft kilns must be charged continuously day and night, though the quarrymen

usually work only 8–9 hours per day. It is, therefore, necessary to secure these conditions, to provide ample storage for the stone to be placed in the kiln during the night. One means of ensuring this is to load sufficient trucks during the day and to place them in a position where the men in charge of the kiln at night can easily discharge the contents of the trucks into the kiln. If the trucks are not too large and they are placed near the top of the kiln, this is a simple matter, but if the quarry floor is much higher than the top of the kilns it may be more convenient to tip the stone into a bin, the bottom of which discharges into small trucks on a track at the level of the top of the kiln, so that the kiln-fillers may draw supplies of stone from the bin at intervals as they require them.

When the material has to be elevated from the base of the kiln, one of three arrangements may be used (i) a large storage bin may be constructed below ground level; the material from the quarry is tipped into this and afterwards can be conveyed to the top of the shaft as required by means of a skip or bucket elevator; (ii) a bin may be built above the ground level, at a convenient height to permit its being readily filled from the quarry and discharged into small trucks which can be elevated in a hoist—this arrangement being more convenient than the previous one where several kilns have to be filled; and (iii) the height of the kiln may be increased so as to form a bin for stone on top of the kiln so that the material in it can fall into the kiln as required. Such a bin should be large enough to enable the burning to be carried on at the normal daily rate during week ends and holidays. Which of these arrangements is best in any particular case will depend on local conditions.

Storage of Fuel.—The fuel is generally stored at the base of the kiln in a bin below ground level, from which it is elevated by means of a hoist, skip or bucket elevator to the top of the kiln or to such other convenient position for it to be used. In cases where the coal can conveniently be taken in railway trucks to a point on a level with the top of the kiln, it will be cheaper to do so, but this is seldom practicable.

Charging.—Much expense may be necessitated as a result of inefficient methods of charging the stone and fuel into the kiln, so that it is very desirable that great care and skill should be exercised in selecting the method to be used to enable the operation to be carried out with as little handling and labour as possible, always bearing in mind that, in some instances, hand-labour may be cheaper than mechanical appliances, especially in small plants.

The selection of a really efficient method of charging shaft kilns with fuel and stone is very important, though little attention is usually paid to it in this country. There are two important methods of charging mixed-feed kilns:

(a) Through one or more openings at the side of the kiln (peripheral charging) (fig. 93).

(b) Through the top of the kiln (fig. 94).

The first method is generally used in kilns surmounted by a conical chimney, the charging doors being in the sides of the cone. This method is largely used—chiefly because it is almost inevitable with a conical top to the kiln—but it has the great disadvantages of:

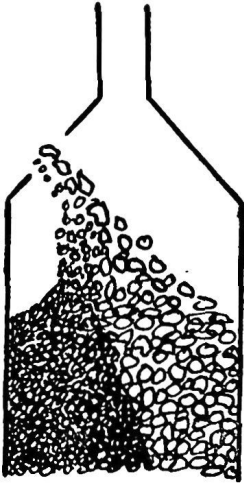


FIG. 93. —PERIPHERAL CHARGING.

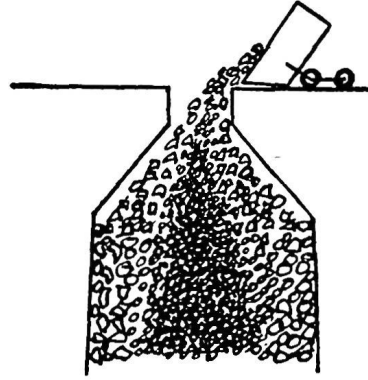


FIG. 94.—CHARGING THROUGH TOP OF KILN.

(i) Not distributing the stone evenly over the whole cross-section of the kiln, particularly if—as is often the case—there is only one charging door. The stone then tends to accumulate near to this door, and some of the small stones are separated from the larger ones so that the side of the kiln nearest the door is more tightly packed than the opposite side (fig. 93). Raking will level the stones in the kiln, but it will not overcome the bad packing due to separation of the larger stones from the smaller ones.

(ii) Being very unpleasant for the men filling the kiln, as gases which should go up the chimney may escape through the chimney door.

(iii) Drawing air through the charging door and stopping the draught of the kiln. For this reason it is necessary to fill as rapidly as possible so as not to keep the door open too long. To facilitate this, a tipping wagon of large size is very convenient, especially if the charging door is sufficiently large. The wagon may be pushed through the door and the whole of the contents of the wagon shot in a few seconds into the kiln; the wagon is then withdrawn and the door closed. Such an arrangement is less practicable when there are several doors, but the latter are seldom used as they must be small, and small doors are undesirable as they prevent rapid charging and are also liable to become jammed with stone and require frequent poking to cause the lumps to pass through.

The charging doors should fit well, so as not to interfere with the draught of the kiln when the doors are closed.

In the second method of charging—through the top of the kiln—the shape of the kiln is important.

In the simplest types of vertical shaft kilns, the top of the kiln is quite open, and the charging is effected by running a truck on to rails carried by the

outer walls of the kiln, tipping it into the open top of the shaft, and distributing it uniformly by means of long pokers or rakes. This method is very unpleasant, and even dangerous, especially in windy weather, on account of the objectionable and mildly poisonous nature of the gases passing out of the kiln. This objection is avoided in kilns provided with a submerged chimney as are the Candlot, Cornet, and some other kilns; these kilns may be charged with comparative comfort as the submerged chimney draws off most of the gases before they reach the top of the shaft. For this reason the men are able to walk about on top of the stone and fuel, and can arrange these materials to the best advantage. There is a slight movement of the materials towards the centre of the kiln, when they reach the bottom of the chimney, but this does not seriously disturb their arrangement.

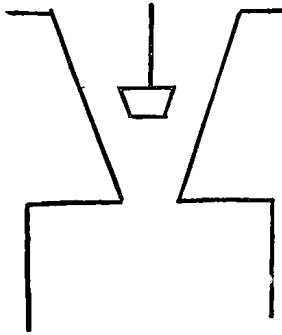


FIG. 95.—BELL IN WRONG POSITION.

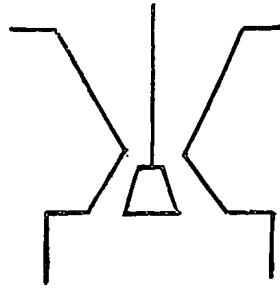


FIG. 96.—BELL IN RIGHT POSITION.

In admitting stone through the top of a kiln, care must be taken that it is distributed uniformly, and that no undue separation of large and small stone can occur. If the mouth of the kiln is very narrow (fig. 94), the stone will form a cone down which the large stones will roll, leaving the smaller ones in the centre, so that the centre of the kiln will be more closely packed than the periphery. This objection is largely avoided by using a bell or cone of cast iron, which distributes the stone uniformly around it, and if the bell or cone is of suitable size the subsequent slip of the material towards the centre of the kiln is insignificant. The position of the bell has a great influence on the distribution of the stone; if the bell is above the opening (fig. 95) it is of little value, whereas if the bell is below the opening (fig. 96) the best distribution is obtained.

The objection is sometimes raised that the bell below the hopper is exposed to the hot acid gases, and so is rapidly corroded. This corrosion can only occur if the kiln is too short, so that the gases leave it at too high a temperature, or if the cone is made of unsuitable material. With a kiln of reasonable and sufficient height, and a cone made of cast iron, no serious trouble is experienced.

A further objection sometimes urged against the conical bell below the hopper is that it projects the stone too violently against the lining of the kiln. This can only occur when the cone is too large in proportion to the diameter of

the kiln. In any case, this is a much less serious objection than those associated with cones above the hopper.

The operation of the cone is made much easier if it is fitted with a counterpoise which will cause it to return when all the stone in a charge has entered the kiln. Care should be taken that the cone fits "gas tight" when closed.

An exceptionally good charging device (fig. 97) (Ger. Pat. 478,532 and 565,095) consists of a hopper *a* which is normally closed by a conical damper *b* mounted on a vertical rod, and having a second small hopper *d* and a spreader *e* just below it. When the hopper *a* has been filled with stone, the cone *b* is lowered and the stone enters the kiln. Much of it falls on the circular grate *c*, through which

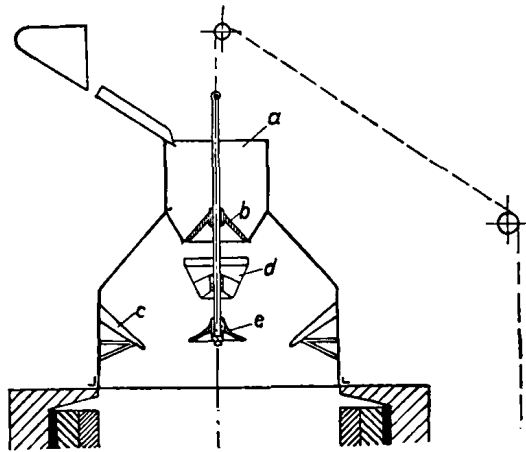


FIG. 97.—CHARGING DEVICE.

the smallest pieces fall to the periphery of the kiln and so prevent undue "creeping" of the rising gases; the larger stones fall towards the centre of the kiln. The cone *b* is then replaced and a charge of fuel fed into the hopper *a*. The cone *b* is then raised so that the coke falls into the hopper *d*, from which it is distributed uniformly over the whole area of the stone.

Many ingenious charging devices have been patented, but the best of them are simple in design, and correspond very closely to a hopper with a cone sealing it from below. Before installing any such device, it should be carefully examined so as to see whether (i) it is simple in action and not likely to get out of order; (ii) it is not likely to be damaged by heat; (iii) it effectively seals the hopper and prevents all leakage of gas when closed, (iv) it is easy to manipulate; (v) it does not cause a separation of the large and small stones; and (vi) it distributes the stone as uniformly as possible in the kiln.

Automatic charging devices which open when a charge of stone is fed into the hopper are sometimes useful, but most lime burners prefer a hand operated device as being more positive in action, less liable to leak when closed, and having the advantage that the hopper can be filled with stone, only a portion of which need enter the kiln at any one time.

The use of a hopper and bell is seldom applicable to mixed-feed kilns, but is largely confined to gas-fired kilns.

Automatic appliances for measuring and charging both stone and fuel in pre-arranged proportions are in use on the Continent, but none of them have proved to be sufficiently satisfactory to be used in Great Britain. The best

consist of two rotating hoppers—one for the fuel and the other for the stone—with an adjustable outlet to each. Their chief disadvantage is that the fuel is so scattered that it does not burn well.

Lime kilns of the intermittent type (flare kilns) and continuous kilns of the Hoffman or similar types require the stone to be carefully stacked in each chamber in such a manner as to produce as uniform a draught as possible. No directions can be given for this as the pieces of stone are irregular in size. The proper filling of such kilns can only be learned by actual practice, accompanied by keen observation of the results.

CONSTRUCTIONAL DEFECTS IN GAS-FIRED KILNS

Notwithstanding the fact that the design of a vertical gas-fired lime kiln is a comparatively simple matter so far as the chief features are concerned, great difficulties have been experienced in various countries in working gas-fired kilns successfully because of inherent constructional defects. It is, therefore, useful to mention some of the more important defects and to indicate what remedies are possible or how such defects can best be avoided.

1. *The kiln may be too short*; this will necessitate a larger fuel consumption than in a well-designed kiln because the hot gases will escape before they have given up all their useful heat to the stone. There are practical limits to the height of such kilns, but to ensure economy in fuel it ought not to be less than 30 ft. from the draw eye or lime outlet to the point at which the hot gases escape from the kiln. Shorter kilns can usually be improved by increasing their height, though before this is done due attention must be paid to the manner in which the kiln is to be filled.

2. *The kiln may be too high*, this may cause several defects of which the most important are :

(a) It may impose too severe a pressure on the foundations and so endanger the stability of the kiln.

(b) It may not be able to withstand the wind pressure unless specially designed for this purpose, though tie ropes may assist it.

(c) The lime may be crushed by the excessive pressure of the stone and lime above it, this being specially serious when chalk or other soft stone is used.

(d) Only large pieces of stone can be burned, as the pressure would force small ones into so compact a mass that there would be insufficient draught and great difficulty in withdrawing the lime.

(e) The great height to which the stone must be raised will increase the cost, though this is usually insignificant.

Some of these objections do not apply to a serious extent in very tall kilns in which there is a large storage hopper above the point at which the waste gases are drawn from the kiln, provided a suitable valve is inserted at the base of the hopper. By this means the height of the kiln may sometimes be greatly increased so as to permit loading from a high level which would otherwise not be available.

3. *The preheating zone may be too short* and the fuel consumption thereby increased (see 1).

4. *The gas may be unsuitable* in quality ; this may be due to the use of an unsuitable producer or producers, or to the faulty management of the producer. A clean gas is not required for lime burning, as it would have too short and too hot a flame ; an excessively dirty gas, on the contrary, will choke up the gas ports and ducts, and may discolour the lime. Most of the pressure gas producers on the market, if sufficiently large, will produce suitable gas for lime burning, but the gas scrubbers with which some producers are provided should not be used. Suction gas producers are quite useless for burning lime. The simpler the producer the more likely is it to be satisfactory ; mechanically operated producers appear to save labour, but the labour required to keep them in order is of a costly type, so that they are only remunerative when one producer supplies several kilns simultaneously. One reason why small producers built onto the kiln are so popular is that they are easy to manage.

In most cases, the quality of the gas depends on the manner in which the producer is worked (see " Operation " later).

The use of steam in producing gas is advantageous, but not essential. The admission of steam into the lime kiln through the gas ports slightly lowers the temperature at which the lime is burned.

5. *The gas may be too cool* as a result of the producer being too far from the kiln. This is a common defect. The gas should be led direct to the kiln by the shortest and most direct route. Producer gas carries certain heavy gases and smoke, which easily settle out as soot or tar if given the least opportunity. Anything that tends to slow up the velocity of the gas or cool it in its course between the producer and kiln furnishes an opportunity for it to deposit tar or soot, the accumulation of which not only hinders operation, but is a waste of usable fuel.

The use of needless elbows, bends, and rises in the gas main should be avoided as they tend to cool the gas, even when the distance between the kiln and producer is short.

6. *There may not be sufficient gas* ; this defect is usually one of management, but it is occasionally due to the producer being too small or to the admission of the gas being wrongly arranged.

The gas producing power of some producers under average working conditions in a lime works is greatly exaggerated by those engaged in selling them. No single producer can be considered sufficiently large if it cannot gasify 6 cwt. of coal or coke of a calorific power of at least 12,000 B.T.U. for each ton of lime produced. As most vertical gas-fired kilns are designed to burn 24 tons of lime per day, the producer should be able to gasify at least 6 cwt. of fuel per hour for each kiln to be heated. If several small producers are used their total gas producing power should be at least 7 cwt. of fuel per hour per kiln, as it is not wise to work them continuously at their full capacity.

7. *The gas may enter in an unsuitable part of the kiln.*—This was a common fault in some of the early attempts to heat lime kilns by gas. The most suitable

place of entry is 6–10 ft. above the draw eye or lime outlet and the gas should enter at as many points as possible at this height, the ports being uniformly distributed around the kiln when a single gas producer is used or arranged in such a manner as to ensure uniform heating if several small producers are used. The number, size and disposition of the gas ports depend so much on the shape of the kiln, the nature of the stone and of the gas used, that detailed rules are of little value ; the designer must use his discretion so as to secure as uniform heating as possible.

8. *The distribution of the gas in the kiln is unsatisfactory.*—This may be due to the faulty position of the gas ports (see 7), to the ports being too small or of an unsuitable shape, or to the diameter of the kiln being too great.

The flames should pass right into the middle of the kiln or a cool central column of imperfectly-burned stone will be formed. To drive the gas into the middle of the kiln it must be under sufficient pressure, otherwise the flame will merely creep up the walls of the kiln. A pressure of 10 in. water gauge is necessary for some gas-fired kilns, and when mixed sized stone is used the gas must sometimes be under a still greater pressure. By supplying the kiln with pieces of stone 4 in. or more in diameter, the necessity for a high gas pressure is largely avoided.

If too much air is mixed with the gas prior to ignition, the flames will be short and may not extend far enough into the kiln. On the other hand, if the gas is ignited in the presence of too little air the flame will lack intensity and, though long, may be too feeble to be of any use. These defects may be due to the use of unsuitable gas burners or to improper management of the kiln.

The friction caused by the passage of gas through ports which are too small, has the effect of preventing the gas travelling far enough into the kiln. Hence, whilst it is desirable to have a fairly large number of gas ports, these must not be too small. It is better to have a few ports of moderate or large size than many very small ones.

In a cylindrical kiln the gas ports should be distributed uniformly and should direct the flames towards the centre of the kiln. When producers are built in the kiln itself, however, it is sometimes advantageous to have the burning zone square in section with the internal corners rounded and the gas ports opposite each other ; the same arrangement is preferable in an oval or rectangular gas-fired kiln.

Great care is needed in designing the gas ports or burners to ensure that the amount of gas passing through each is suitable for the corresponding part of the kiln. Owing to the cooling effect of wind, etc., it may be necessary to pass more gas through some ports than through others ; it is by no means always desirable—even when all the burners are the same size—to pass the same amount of gas through each, and a skilled designer will sometimes vary the size to suit local requirements.

9. *The air may be supplied improperly.*—This is a very common defect, though the damage done by it is often far less than would generally be supposed. The chief errors in the supply of air are :

(a) Too little air reaches the gas at the moment of ignition ; this makes a flame of low temperature, though it may be of great length. There is no single remedy ; a suitable one must be found by carefully investigating the kiln or kilns in which this defect occurs. In most gas-fired kilns the air is supplied through the lower part of the kiln so that it is heated by the cooling lime before being used for burning the gas. If the amount so introduced is sufficient and is well distributed, it ought to do its work properly, though the influence of the size of the stone in the kiln must not be overlooked.

(b) Too little or too much primary air may be used. This will have the effect of producing soot and smoke which may discolour the lime as well as involve a waste of fuel. It is a curious fact that no primary air at all is used in many gas-fired kilns, which nevertheless, produce good lime. Primary air mixed with the gas prior to ignition ensures a clean hot flame, but if too much primary air is used the flame will be so short and intense that it will fail to reach the centre of the kiln and may overburn the lime with which it comes into contact.

A suitable proportion of primary air is unquestionably an advantage, but the behaviour of many lime kilns shows that this proportion may be very small indeed when burning some tender limestones.

(c) The air may be at too low a temperature to ignite the gas properly. This is an unusual defect, and can only occur in a badly-designed or ill-managed kiln. When it occurs, unburned gas will escape from the kiln—usually with the evolution of smoke.

(d) The air may be badly distributed through the kiln. This defect is usually due to the employment of too many air ducts which easily get out of order and do not function properly. For most stones, the bulk of the air should pass through the cooling lime. No air flues are needed for this, and the fewer that are used for any other purposes the more easily will the kiln be managed.

10. *The cooling zone may be defective ;* it is always one of the weak spots of a kiln and unless carefully designed is liable to be very troublesome. It is preferably made of iron or mild steel, mounted separately, so as to permit of expansion, and exposed sufficiently to allow of the maximum loss of heat by radiation. Its durability may be increased by making part of it in the form of grates, as in the Cornet, Candlot, and Duchez kilns, as when a plain cone is used the air near the top is often stagnant and hot. The use of a double cone with a current of air drawn between them is sometimes an advantage. The use of a water jacket is good, but seldom necessary.

There is no essential difference between the cooling zone of a gas-fired kiln and any other vertical kiln, except that care must be taken that the air, when it comes into contact with the gas, is hot enough to ignite it. The level of the fuel in a mixed-feed kiln can be raised to a point at which the air is sufficiently hot to ignite the fuel properly, but in a gas-fired kiln this is impracticable as the gas inlets are fixed. Consequently, an excess of air of low temperature is far less serious in a mixed-feed kiln than in a gas-fired one.

11. *The flames may creep up the walls of the kiln leaving a cold centre ;* this

defect is usually due to the gas not being under sufficient pressure or to the ports being of an unsuitable shape. It can largely be prevented by introducing a small supply of air above the gas ports so as to drive the gas downwards instead of letting it rise immediately it leaves the ports. If the waste gases are drawn from the periphery of the kiln instead of the centre, a similar "creeping" may occur.

12. *The waste gases may be too hot*; this indicates either bad management or too short a kiln. The result is a wastage of fuel.

13. *The waste gases may rise irregularly up the kiln*; this is usually due to bad management, but it may be due to faulty design whereby more of the gases are drawn from one part than from another.

14. *The waste may be drawn off improperly*, and so may interfere with the draught and the pre-heating of the stone. The commonest cause of this defect is when the gases are drawn off by a fan through a single outlet in the kiln instead of several. When chimney draught is used, this defect is rare.

15. *The lime may be too hot when discharged*; so far as this is due to faulty design or construction, it is usually due to the cooling zone being too short or of too thick a material. As previously explained, the greater part of the cooling of the lime is the result of loss of heat by radiation. For this purpose, a steel cooling zone is preferable. It should be separate from the kiln proper so as to allow for its different expansion.

16. *The stone and lime "stick" in the kiln*; there are several causes of this defect, including:

(a) A very impure stone which undergoes partial fusion in the burning zone, and then cools, binding the material into a large mass which does not "fall" when lime is drawn from the kiln.

(b) The kiln is of an unsuitable shape, so that any sticking which may occur is increased in importance. The plainer the kiln, the less likely is the stone or lime to "stick." Most of the unusual shapes of kiln—including those in which the stone is supposed to roll over and over as it passes through the kiln—are of little value so far as their shape is concerned. Fortunately, in many such kilns the stone takes the shortest route, and does not travel in the manner anticipated by the designer.

Any projections from the brickwork or masonry in the interior of the kiln, particularly in the burning zone, may cause excessive sticking.

(c) The "sticking" may be caused by too high a temperature in the kiln, by the supply of unsuitable material, and other results of careless or unskilled management.

(d) The bricks or other materials used for lining the kiln may be unsuitable. Theoretically, a neutral or basic material should be used for lining lime kilns, whereas the firebricks commonly used are acid in character, and combine chemically with lime at high temperatures, forming a molten glassy slag which acts as a cement and causes the lime to adhere to the walls of the kiln. Neutral and basic materials are costly and have other serious defects, so that fireclay bricks are, in practice, the most suitable material. They should be well

shaped, smooth, and of close texture, so as to offer as little resistance as possible to the lime and stones.

17. *The abrasion and corrosion of the kiln lining may be excessive;* this may be due to :

(a) The use of firebricks of poor quality, and particularly those rough and irregular in shape, coarse in texture, and soft, through being insufficiently burned.

(b) Bad workmanship, the bricks being laid irregularly, and with thick joints, so that a series of small ledges is formed, which offer considerable resistance to the stone and lime in its passage through the kiln.

(c) Bad design, especially with regard to the shape of the interior of the kiln, as all projections offer resistance to the flames, and are a cause of abrasion and corrosion.

The manner in which some of the arches forming the top of the ports or gas inlets project into the kiln is a constant source of trouble because of the resistance they offer to the rising flames, and to descending stone and lime.

18. *Unnecessary loss of heat by radiation may occur* through the walls being too thin, or through the absence of a heat insulating material. This is particularly the case with some modern steel cased kilns, in which the brickwork is only 18 in. thick. The most suitable preventative is to use thin bricks made of kieselguhr, diatomite, or similar matter to surround the lining of the kiln. Such bricks need only be 1-2 in. thick, but as they can halve the loss of heat in thin walled kilns their use is important.

19. *The workmen are not properly protected from the fumes and hot gases.* This defect occurs chiefly in kilns with open tops, working by natural draught. A partly submerged chimney is the simplest means of avoiding it ; at the same time the draught of the kiln is increased.

20. *The kiln works irregularly* as a result of insufficient draught due to the kiln having an open top, too small a fan, or too small a chimney. The remedy in each case is obvious.

One great drawback to natural draught is its dependence on climatic conditions with the result that a kiln will work well on some days and badly on others. With artificial draught this is avoided, though other difficulties peculiar to artificial draught may be experienced.

21. *The means of feeding or charging* the kilns may be inadequate or unsuitable.

22. *The storage capacity in the upper part of the kiln may be insufficient.* Limestones from different sources vary greatly in the time required to preheat and burn them economically, but it is seldom safe to allow less than 72 hours. Hence, for an output of one ton per hour, a limestone measuring 14 cu. ft. per ton and burned in a gas-fired kiln 6 ft. 6 in. in diameter would require a minimum height of 30 ft. between the burning zone and the top of the stone, whilst a chalk measuring 16 cu. ft. per ton would require a minimum of 34 ft. These figures are necessarily approximate, as a porous limestone will burn more rapidly than a dense one, and so need not be so long in the kiln. The rate at which the

stone passes through the kiln can be shown by dropping a firebrick into the top of the kiln at a given time, and noting the time when it is withdrawn along with the lime.

23. *Lack of means of access* or difficulty of access to different parts of the kiln is a constant source of trouble. Stairways and platforms of convenient shape and size should always be provided, as men cannot be expected to work a kiln to the best advantage when they have to climb steep or long ladders or walk along narrow and unprotected gangways in the night. The easier it is for the men to work, the more likely are they to work properly.

Equally important is the provision of numerous and rightly-placed poke holes and spy holes, as otherwise the kiln cannot be worked to the best advantage. Yet, how few kilns are properly provided in this respect and what gargantuan labour is often involved when a little sticking occurs! Some kilns have poke holes worked from platforms which are so narrow that it is impossible to use the pokers properly!

24. *Costly or excessive repairs* may be due to (a) bad design; (b) poor or unsuitable materials used in building the kiln; and (c) bad workmanship either in the construction or use of the kiln. A comparison of any kiln with some of the illustrations of others of well-known design will usually show any serious defects which may exist, but in case of doubt an expert adviser who is independent of all kiln builders and patentees should be consulted.

25. The *leakage* of heat and gases is a frequent cause of loss in gas-fired lime kilns and is often more serious with them than with mixed-feed kilns because of the manner in which gas-fired kilns must be heated and controlled. One great advantage of a properly constructed steel casing is that it largely prevents the serious leakage of air and gases which is so common in other lime kilns. Concrete is equally suitable, is more permanent if the lining is sufficiently thick, and has the further advantage that it has no joints and that any cracks which may develop are easily seen and repaired. Moreover, concrete radiates less heat than steel.

Flues in the kiln-walls are always liable to leak without this being recognized and then fail to act without their failure being known. For this reason, they should be avoided wherever possible, because, whilst they are advantageous when they function properly, they are a great nuisance when they cease to do so.

The *fuel consumption* of vertical gas-fired kilns depends on the nature of the fuel used and on that of the stone. A well-designed kiln of this type burning an almost pure calcium carbonate will usually require about 5 cwt. of good coal (with a calorific power of 13,000 B.T.U. per lb. of coal) for each ton of lime produced. This figure is far above the amount theoretically required and also exceeds by about 100 lb. per ton of lime the coal or coke required for burning a similar limestone in a mixed-feed kiln. The difference is due chiefly to (i) the serious loss of heat which occurs in converting coal or coke into producer gas, the loss usually equalling at least one-fifth of the total heating power of the fuel; (ii) the loss of heat which occurs in transferring the gas from the producer to the kiln; (iii) the loss of heat due to the gas which passes unburned through

the kiln ; (iv) the loss of gas by leakage ; and (v) various losses due to mismanagement of the kiln, as a gas-fired kiln requires more skill than a mixed-feed kiln.

Under normal conditions these losses are not serious (being about 1s. 6d. per ton of lime produced) and, in practice, may be more than counterbalanced by the superior quality of the lime produced, so that gas-fired kilns are increasing in popularity where a pure, or almost pure, lime is required. Where lime containing 10 per cent. or more of impurities sells readily and satisfactorily, it would be cheaper to use mixed-feed kilns.

ADVANTAGES OF VERTICAL SHAFT KILNS

Where labour is costly, vertical shaft kilns are usually the best for burning limestone and similar materials, the pieces of which are irregular in shape. The chief advantages of vertical kilns are as follows :

(1) *Simple Construction and Capital Outlay.*—The simplest form of continuous shaft kiln consists of a long shaft or straight tube of brickwork or other suitable material ; the stone or other material to be heated is put into the top of this shaft and passes out through an opening at the bottom of it. No simpler design for a kiln could be conceived, and for this reason, and because such kilns are inexpensive to build, they can be erected quite rapidly. Vertical kilns have long been popular for burning limestone, as they are so simple and are easy to understand, and, apart from certain inherent drawbacks, they are not difficult to manage. Many improvements made in these kilns render them somewhat more complicated both in construction and use, but the general principles concerned are easily understood and the simpler forms of vertical kiln require a comparatively small capital outlay.

The initial cost of a rotary-kiln is nearly three times that of a simple vertical shaft kiln for the same output, so that the capital charges per ton of lime or in material burned in a rotary kiln is very much higher. A kiln of the Hoffman type involves an initial capital outlay almost midway between that of a rotary and vertical shaft kiln.

(2) *High Output.*—In proportion to its size and cost, the output of a vertical kiln is high. The ground space required by such a kiln is comparatively small ; a mixed-feed kiln with a shaft 15 ft. diameter internally and 40–50 ft. high will produce about 50 tons of burned lime per 24 hours, but the base of the kiln is only about 30 ft. × 30 ft. A kiln of the Hoffman type for the same output will require a floor-space about 200 ft. by 25 ft. A batch of vertical kilns may be placed in a row in a comparatively restricted area and yet may be operated quite efficiently. This is very desirable where the kilns are placed in a quarry, as in such a location only a limited amount of floor space is available.

(3) *Low Labour Charges.*—As a vertical kiln works by gravity the operation of the kiln is very simple and cheap. It is merely necessary to tip the raw stone properly into the kiln or into a hopper above it ; gravity will afterwards ensure the material passing through the kiln to the point at which the lime is withdrawn. In a kiln of the Hoffman type, on the contrary, the lumps of stone must be

carefully stacked in the kiln and the corresponding pieces of lime must be removed by hand from the kiln, both the operations necessitating a large amount of labour and the former requiring considerable skill, which increases the cost of burning the stone. In a rotary kiln no hand labour is needed, but power is required to rotate the kiln and convey the material along it; this expense is avoided in vertical shaft kilns.

The discharging of vertical kilns is very simple, the burned lime falling by its own weight into the bottom of the kiln or into a wagon placed there to receive it. In a Hoffman kiln, the cost of discharging is almost as great as that of charging the kiln. In rotary kilns, there is the cost of the power employed in rotating the kiln and cooler. The low labour charges involved in working a vertical kiln are particularly important where wages are high and where suitable labour is difficult to secure.

(4) *Low Cost of Repairs.*—As vertical kilns are simple in construction the repairs are not usually costly and are easily made, only moderately skilled labour being needed. Hoffman and rotary kilns are much more complicated in design, the latter requiring the attention of an engineer to supervise the maintenance of the mechanical parts of the kiln and the flue arrangements of a Hoffman kiln being so much more elaborate than in vertical shaft kilns that repairs are usually more costly.

(5) *Continuous Discharge.*—Vertical shaft kilns are generally discharged at comparatively small intervals of time. Some burners withdraw lime every hour and few kilns of this type should be drawn at longer intervals than 3–4 hours under normal conditions of working; if, however, the kiln has to work below its normal output, the intervals between the drawing of each ton of lime may be increased to 10 or even 16 hours with some shaft kilns, though only by increasing the fuel consumption per ton of lime produced. This great difference in the intervals between successive drawings of lime is not to be recommended where it can be avoided, but it is often very convenient, especially where trade is irregular. Rotary kilns have a much smaller range of output and must be worked at a uniform speed if lime of good quality is to be produced. In kilns of the Hoffman type, the chambers must be emptied only once, or at the most twice, each day, so that it is less easy to take the lime direct to the trucks, carts, or motor lorries, and if the lime is not to be spoiled by exposure it should be stored in suitable bins. Even with shaft-kilns the provision of bins for storage is generally desirable—especially for night work and holidays—as such bins enable lime to be dispatched quickly in large quantities—a matter of great importance to some users of lime.

(6) *Low Fuel Consumption.*—Vertical shaft kilns of the mixed-feed type are—when fuel is costly—the most economical of all lime kilns as the fuel is burned in direct contact with the material to be heated, so that there is very little loss of heat. Apart from the cost of labour, Hoffman kilns are even more economical than vertical kilns, as better use is made of the heat evolved by the fuel. The most efficient Hoffman kilns may, under favourable conditions, require as little as 3·7–4·0 million B.T.U. per ton of lime burned, or

about 8 tons of lime per ton of coal used. Some of the best mixed-feed shaft kilns, under favourable conditions, require 4–5 million B.T.U. per ton of lime produced corresponding to 6–8 tons of lime per ton of coal or coke burned. The best gas-fired vertical kilns average 5–6 million B.T.U. per ton of lime, corresponding to 5–6 tons of lime per ton of coal burned, whilst less efficient ones may require 8–10 million B.T.U. per ton of lime, corresponding to about 3–4 tons of lime per ton of coal burned. Vertical kilns with external fires require 10–15 million B.T.U. per ton of lime burned, corresponding to 2–3 tons of lime for each ton of coal consumed.

The most economical of the other types of lime kilns is the rotary kiln, but this never requires less than about 5 million B.T.U. per ton of lime, corresponding to 5–6 tons of lime per ton of coal.

The thermal efficiency of lime kilns will be dealt with in greater detail in connection with their operation, but attention may here be drawn to the fact that in all properly designed kilns, most of the heat in the finished lime is withdrawn and used in burning the fuel before the lime leaves the kiln, and also that most of the heat in the gases forming the products of combustion is used for preheating the stone and so is withdrawn from the gases before they leave the kiln ; this is especially the case if an induced fan draught is employed, as it enables the temperature of the gases leaving the kiln to be much lower than when " natural draught " is utilized.

It will be observed that the advantages of vertical shaft kilns are very great, but before selecting a kiln of this type the advantages of other types must not be overlooked, and attention should also be paid to the disadvantages.

FAULTS IN VERTICAL SHAFT KILNS

In addition to the advantages which have just been mentioned as possessed by vertical shaft kilns, there are certain disadvantages or faults which restrict their use and make preferable the employment of other types of kilns for special purposes for which shaft kilns are less satisfactory, or are useless. These faults may be considered under two headings (*a*) inherent faults which are inevitable in this type of kiln, and (*b*) faults of individual kilns, due to errors either in design or construction which may be avoided if the kilns are properly designed for the work they are expected to perform, and to adapt them to the special requirements of the particular stone for which they are used. The distinction is important, because a kiln having certain dimensions may be entirely satisfactory for one kind of stone, and wholly unsuitable for a different kind of limestone ; yet, by suitably altering some of the dimensions—preferably before building the kiln—it may be made to give complete satisfaction with the second kind of stone. Many lime burners do not appreciate the importance of designing the kiln so that it suits the material they require to burn, and, for this reason, many existing kilns use more fuel than they should for each ton of lime produced.

A disadvantage of vertical shaft kilns is the great *height* which is necessary in order to secure efficient working, a low fuel consumption, and satisfactory

facilities for the discharge of lime from the base of the kilns. The extent to which the height of the kiln is a disadvantage depends chiefly on the nature of the site. In some quarries, it is a definite advantage, as, when the kiln can be built on the side of a hill or at the base of a high quarry face, it may be possible to supply the limestone to the level of the top of the kiln. Even in such cases, however, the fuel may have to be raised to a considerable height. This is particularly the case in mixed-feed kilns in which the fuel must generally be supplied through the top of the kiln.

The adverse effect of the height of a vertical kiln is usually exaggerated, under the worst conditions, it is only equivalent to the cost of raising the stone and fuel from the ground level to the top of the kiln. This cost is much less than is commonly imagined by those who have not estimated it very carefully, and when it is compared with the cost of filling a Hoffman kiln, it will be found that the latter is much greater. Even with the tallest vertical kilns yet built, having a total height of 120 ft., the cost of lifting the stone and fuel should not exceed 1s. 6d. per ton of lime produced, and, in many instances, it is only one-third of this sum.

Tall kilns are occasionally unsuitable because the stone or the lime produced from them is crushed by the overlying material. This is a very rare fault, and can only occur with the weakest stones and limes. It is a simple matter to have the crushing strengths of the stone and lime tested, and from this it is easy to calculate what height of kiln would be necessary before either of these materials were to be damaged by crushing. This simple test usually shows that the idea that a tall kiln will unduly crush the stone or lime is often only a delusion.

With a limestone weighing 150 lb. per cubic foot, and a kiln 100 ft. high internally, the total pressure on the lime near the bottom of the kiln cannot exceed 15,000 lb., or 7 tons per square foot, which is far below the average crushing strength of either lime or stone, though some forms of lime will not resist this pressure. With weak stone or lime, the falling of the material when in the kiln is liable to do more damage than the weight of the overlying stone, especially if the lime is withdrawn at long intervals and in large quantities. Thus, a fall of 1 or 2 ft. of a column of material 50–60 ft. high above puts a severe strain on the lime near the base of the kiln. Even with moderately strong lime, such as is common in this country, an appreciable proportion is broken into small pieces in passing through the kilns; usually up to about 15 per cent. of such small material is produced.

The pressure of a vertical kiln and its contents on its foundation is relatively much greater than that of kilns of other types, so that a vertical kiln should be erected on a sufficiently firm rock foundation. This is usually an easy matter, as quarry floors are generally of solid rock, but in other cases—as where clay or shale beds are interstratified with the limestone—care is necessary in selecting a site for the kiln. Where there is any doubt as to the strength of the foundation, a reinforced concrete platform should be built, and the kiln erected upon this.

The pressure of the loaded kiln on its foundation is not distributed over the whole area, but is concentrated on the piers or walls supporting the structure, which are not more than about half the total cross sectional area of the base, so that a load of 4–6 tons, or even more, per square foot is quite common. Ample provision in the foundation to resist this pressure is necessary to ensure the stability of the kiln.

Vertical kilns offer a very large area to wind pressure, and so must be very strongly constructed to ensure their stability, particularly if the walls are thin, as in steel cased kilns. Secure anchorage to the foundation is very necessary for such thin walled kilns.

A serious disadvantage of vertical shaft kilns is their inability to burn small pieces of limestone. No pieces of stone which are less than 4–6 in. diameter should be supplied to the kiln, or they will fill the interstices between the larger pieces and so prevent the hot gases rising uniformly at a suitable speed through the kiln, so as to secure good draught and to maintain the heat in the hottest zone of the kiln.

This disadvantage is made less serious by the use of a mechanical forced or induced draught, as it has been found that the volume of the air spaces between pieces of stone 1 in. or 2 in. in diameter is substantially the same as that between 6 in. or 8 in. pieces, the only difference being that the resistance to the passage of air is greater with small spaces than with large ones. By using mechanical means to create a draught of sufficient intensity it is often possible to work such a kiln satisfactorily, provided the pieces are sufficiently uniform in size. If the pieces are of numerous different sizes, the small ones will fill the interstices between the larger ones and so will reduce the total volume of air spaces so that it becomes impossible to force or draw sufficient air or gas between the pieces to burn them properly. For this reason it is seldom wise to put small stones into vertical shaft kilns, and when small stones have to be burned, it is usually better to use a rotary kiln, which is specially suitable for burning small pieces and even powdered materials.

When a vertical shaft kiln is used, in most well-organised works, the small stone is separated by means of a grating, and is used in other ways, such as fluxing stone, road stone, tar macadam, ground limestone, etc., so that no loss is occasioned as a result of the small pieces not being passed through the kilns.

The only other serious defect inherent in all vertical shaft kilns—and it is shared by all continuous kilns—is the necessity of keeping the kiln full, and maintaining a reasonably constant output. It is scarcely right to regard this as a “defect,” though it is often inconvenient when the demand for lime is small, and it is undesirable to continue to produce the full output of which the kiln is capable.

Some gas-fired and externally-fired vertical kilns can be worked at as low as one-tenth of their normal capacity—though with great waste of fuel relative to the amount of lime produced—but mixed-feed kilns and kilns of the Hoffman type cannot usually be worked satisfactorily at less than half their rated capacity. A rotary kiln, on the contrary, can be worked at one-quarter of its

normal output, or even less, where the fuel consumption is not considered.

Some defects are only inherent in particular types of vertical shaft kilns, but they should be carefully considered before any particular design is adopted. Thus :

Mixed-feed kilns suffer from the inherent defect of having the ashes from the fuel mixed with the stone, and, consequently, the finished lime contains a larger proportion of impurity than if it had been burned (i) in an externally-fired shaft kiln in which the ashes from the fuel remain in the fireboxes ; or (ii) in a gas or oil-fired kiln in which the amount of ash which becomes mixed with the lime is negligible. For this reason, mixed-feed kilns can only be used where impurity added by the fuel will not be harmful. Where very pure lime is required, it is almost essential to employ an externally-fired or gas-fired kiln.

The effect of an admixture of ashes is not really so bad as it appears to be at first sight, because, unless the ash is fused, it will be in the form of very fine particles, most of which can be removed by passing the lime over a screen or grating, or even by using a fork instead of a shovel. The proportion of ash which finally remains is usually too small to be objectionable, though it may spoil the " colour " of the lime. As the ashes from the fuel seldom introduce more than 3-4 per cent. of impurity, this is of far less importance than the lime spoiled by irregular firing which is inevitable in gas-fired kilns, especially when burning a relatively soft oolite or chalk. Consequently, mixed-feed kilns are generally satisfactory, except when very pure lime is required, and even then, when slaked lime is used, it is often possible to separate the ash during the process of slaking or hydrating.

An excess of ash may be avoided in lime produced in mixed-feed kilns by the use of a fuel containing only a very small proportion of ash. Unless they are exceptionally tall, mixed-feed kilns cannot efficiently use fuel containing much volatile or gas-forming matter, because the fuel must usually be introduced through the top of the kiln, and is not volatilized until it reaches the part of the kiln where the temperature is raised to the ignition point of the fuel. Long before this temperature is reached, however, the more volatile hydrocarbons are evolved from the fuel and pass away, incompletely burned, with the waste gases from the kiln, being entirely wasted so far as the heating of the kiln is concerned, though they are included in the amount of the fuel consumed per ton of lime produced. This defect is reduced, though not wholly avoided, in some mixed-feed kilns by introducing the fuel some distance below the top of the kiln, so that it enters the kiln at a point where it can at once ignite. Such a device is adopted in the Aalborg, Dietzsch, and similar kilns (pp. 284, 295). This defect does not, of course, occur in externally-fired or gas-fired kilns (unless very badly designed), as in such kilns the gases from the fuel enter the kiln at the point where they can be properly burned, so that no loss of hydrocarbons by volatilization is occasioned.

Vertical kilns operated by natural draught suffer from the inherent defect of being dependent for their working upon climatic conditions. Thus in stormy weather or when the wind is either too feeble or too fierce, it may be very

difficult to secure a satisfactory draught, with the result that the kiln will work slowly or, in an extreme case, make no progress at all! This defect applies not only to vertical kilns, but to all kilns operated by natural draught, and it occurs equally in Hoffman or continuous chamber kilns. Most lime-manufacturers do not regard this defect as a serious one, though in this they are mistaken, as can readily be seen if recording draught gauges are applied to the kiln and are carefully studied. The irregularities and other defects due to natural draught may be entirely avoided by creating a mechanically produced forced or induced draught in the kiln, as by this means a perfectly steady and fully controlled draught may be obtained; many modern kilns—especially gas-fired ones—are intended to be used with such an artificial draught.

An inherent, though not usually serious, defect of some externally-fired and gas-fired vertical shaft kilns is the tendency of the gases to pass up the sides of the kiln instead of rising uniformly through the whole of the interior. In a well-designed kiln, the draught is sufficiently uniform to burn all the lime properly, but in some types of shaft kiln, a central shaft (Chaudière) or a submerged chimney (Cornet, Candlot, etc.) is employed to draw the gases towards the centre of the kiln and thus secure a more uniform burning of the lime. These devices are considered in greater detail in connection with the construction of various types of shaft kilns. This defect is less marked in mixed-feed kilns, in which the fuel is spread over the whole cross-section of the kiln.

In most types of vertical shaft kiln, a much larger volume of air is passed through the kiln than is needed for heating the lime, most of the excess being used in cooling the lime. This causes a serious waste of fuel, because the amount of air required for cooling the lime is greatly in excess of that required for burning the fuel efficiently. This defect has not been overcome in most vertical kilns, though some lime burners effect a saving by discharging hot lime through the base of the kiln. Patents have been granted for kilns in which only sufficient air is admitted to burn the fuel efficiently, the air used for cooling the hot lime being withdrawn at a point below the centre of the kiln. So far as the author is aware, none of these arrangements are in regular use with the exception of one works in which the hot lime is withdrawn from the kiln at a temperature of about 600° C., and is passed at once into a special bin in which it is cooled by a separate supply of air. The saving in fuel, whilst appreciable, is not as great as could be desired.

In some gas-fired kilns it appears to be necessary to keep the discharge doors closed when not actually drawing lime from the kiln, as if they are kept open there is not sufficient draught through the kiln. Unless the kiln leaks badly, the use of closed doors reduces the extent to which the lime can be cooled before being discharged. This defect is chiefly noticeable where a kiln is too short to create a sufficient draught and where air enters the gas ports in much greater amount than is needed to burn the gas.

In the previous pages, those faults have been considered which are inherent, and, therefore, unavoidable, and due to an error in design or construction of a

particular kiln. At the same time it should be noted that a defect which appears to be due to a constructional error may actually be a kiln incorrectly working a correctly designed kiln.

(a) *The shape of the shaft may be unsuitable*, and may cause various troubles such as (i) sticking of the materials in the shaft ; (ii) inconvenience in working the kiln, *i.e.* in filling, firing, and emptying it ; and (iii) insufficient draught. It is generally desirable to have a shaft of as simple a shape as possible, a cylindrical shaft with perfectly vertical sides being usually the best, though a slight taper is sometimes an advantage. Any deviation from this simple shape tends to cause one or more of the troubles just mentioned, and is undesirable unless it is required to effect some special improvement which will counter-balance any small inconvenience.

Some designers of kilns favour an oval or elliptical cross-section, others prefer to form a spiral in the interior of the shaft, and still others consider it desirable to have one part of the shaft at one side of, instead of directly above, the remainder of the shaft. Thus, in the Dietzsch kiln, two shafts are used and are connected to each other by a horizontal portion into which the fuel is fed. This arrangement has the advantage of using less fuel than kilns in which the fuel is charged in at the top, but it necessitates raking the stone along the horizontal portion of the shaft, and so increases the labour cost of burning. Most of these departures from a simple shape are more ingenious than practicable, and the most efficient modern kilns have shafts of quite simple shapes.

(b) *The diameter of the kiln may be excessive*. This is a very serious fault in externally-fired and gas-fired kilns, but it is occasionally found in mixed-feed kilns. It is most important that the hot gases should penetrate right to the centre of the stone in the kiln, as, otherwise, there will be a core of imperfectly-burned stone which will become mixed with and will spoil the lime. Consequently, the diameter should not be so great that any part of the contents of the kiln cannot be properly heated, especially when external fires or gas is used. The author has found that an internal diameter of about 7–8 ft. is a maximum for vertical kilns fired by gas or by external fires, and about 20 ft. for a mixed-feed kiln. The importance of this fact does not appear to have been realized by many patentees and builders of lime kilns, with the result that a large number of kilns have been erected which, for this reason alone, can never be efficient.

The only means whereby uniform heating can be secured in gas or externally-fired kilns of large diameter is to construct the kiln in the form of an annulus, and even to this arrangement there are serious objections.

(c) *The kiln may not be properly insulated*. This will, of course, result in a serious loss of heat by radiation which can best be avoided by putting a course of insulating bricks between the lining and the outer wall or casing of the kiln. In the past very little attention has been paid to insulating lime kilns, but the value of this procedure is being increasingly realized, especially in America, where insulating bricks are largely employed as a backing to the refractory

kilns. When it is considered that the loss by radiation may be 20% or even more of the available heat in the fuel used, it will readily be seen that the insulation of the kiln may effect a very considerable saving

(d) *The preheating zone may be too short*, so that the gases escape from the kiln at too high a temperature. Consequently, there is a wastage of fuel and full use is not made of the heat produced. The remedy clearly consists in increasing the height of the preheating zone until the escaping gases are only sufficiently hot to create the necessary draught in the kiln. If an artificial (fan) draught is used, the preheating zone may be of still greater height, being then only limited by the crushing strength of the lime in the burning zone of the kiln.

This is a very common defect in vertical kilns, and is one of the chief reasons why many of these kilns are so extravagant in fuel. It is not always possible to increase the height of existing kilns, but where the distance from the point where the lime leaves the kiln to that at which the hot gases pass out is less than 40 ft. some attempt should be made to increase it. To obtain the maximum efficiency from the fuel, a vertical kiln should not be less than 200 ft. high, but this is rightly regarded as impracticable and a net height of 60 ft. for the stone and lime in the kiln may be regarded as the maximum which can be considered under normal conditions.

The effect of the length of the preheating zone upon fuel economy is further considered in connection with the operation of the kiln.

(e) *The high cost of repairs* in some vertical kilns is generally due to faulty construction and materials. It always pays to use good materials, even though they are expensive in first cost, and to employ skilled workmen to erect and repair the kiln rather than local bricklayers, because, otherwise, the cost of repairs will be very high, and, in addition, there will be the loss entailed by frequent stoppages, as well as that due to loss of trade following the failure to fulfil standing orders and contracts. The high cost of repairs is sometimes due to the unskilful working of the kiln, as described later.

(f) *Unsuitable charging appliances* are sometimes fitted to vertical shaft kilns and are a source of difficulty and loss. It is necessary that the materials should enter the kiln in such a manner that they will distribute themselves uniformly over the whole of the cross-sectional area of the kiln in their descent. Unless this is done, the burning will be irregular. Charging appliances are considered in detail later, but a good workman with a rake and poker will often produce a better result than an unskilled man with an elaborate mechanical or automatic device.

(g) *The temperature may be difficult to regulate* in the various zones of the kiln with the result that the lime is burned irregularly. This difficulty occurs to some extent in all vertical shaft kilns, but is greatest in mixed-feed kilns as in these there is practically no control over the burning of the fuel. Externally-fired and gas-fired kilns can be controlled to a much greater extent, but not so effectively as continuous and rotary kilns, though in well-designed

vertical kilns, the difficulty is not generally serious. It can be reduced to a minimum in a well-designed kiln, by the use of gas as a fuel and by means of pyrometers and draught-gauges at different heights in order to register the progress of the burning, but in some badly-designed kilns uniform burning is impossible. The various appliances used are described later.

(h) *The fuel may be incompletely burned*, as a result of a constructional defect in the kiln, though more often it is due to improper working. Incomplete combustion may be shown by (i) the smoke passing out of the kiln; (ii) pieces of fuel occurring in the lime; (iii) an analysis of the waste gases from the kiln showing the presence of gases, hydrocarbons, or of carbon monoxide. Incomplete combustion may be due to an insufficient quantity of air passing through the kiln, but in most cases it is due to the air not being admitted at the right time and place, so that it cannot be used to advantage.

Thus, if the preheating-zone of the kiln is too short or if a fuel unduly rich in volatile matter is used, a large amount of incomplete combustion may occur simultaneously with a large excess of air. The only remedy in such a case is to use a more suitable fuel and/or to increase the height of the kiln.

Sometimes incomplete combustion is due to too little air being supplied to the gas burners for it is much more difficult to burn gas completely if once the gas has been lighted than if the air and gas are mixed before ignition. The difference is easily seen if a Bunsen burner is used (a) with its air ports open, and (b) with its air ports closed. In the first case the flame is colourless and on placing a cold saucer on it no deposit (other than water) is formed, but when the air ports are closed the flame is smoky and luminous, and will readily deposit soot on any cold articles immersed in it. The difference is due to the gas not being able to obtain sufficient air to burn it completely unless that air is mixed with gas before the latter is lighted. For the same reason, it is extremely difficult to secure perfect combustion in a gas-fired kiln unless sufficient air is mixed with the gas before it passes out of the burners. Several gas-fired kilns now in use suffer from this defect and, consequently, are more wasteful in fuel than they need to be.

In a well-designed and well-managed vertical kiln, there should be no emission of smoke and the waste gases should contain neither hydrocarbons nor carbon monoxide. Exactly what must be done to enable existing kilns to reach this ideal can only be ascertained after a thorough and minute examination of such kilns when at work.

(i) *An excess of air may pass through the kiln* as a result of defective construction, such as the apertures in the base of the kiln being too large and not capable of adjustment by suitable dampers. Mixed-feed kilns seldom have proper facilities for controlling the air supply, but in gas and externally fired kilns, if the air is supplied at the right places, its quantity can generally be adjusted to suit the requirements of the stone and fuel. As already explained, too much air usually involves a wasteful expenditure of fuel, though this may be reduced by increasing the height and cooling it apart from the kiln, the former method being preferable where practicable.

(j) *The air may be admitted improperly, i.e. at an unsuitable part of the shaft, as a result of faulty designing.* In certain types of kiln, it is difficult to admit the air to the best advantage; thus, in mixed-feed kilns, almost all the air passes up through the bottom of the kiln. By restricting the amount which enters in this manner and adding a supplementary supply of hot air at or near the top of the burning zone, as in Cornet's kiln (p. 297), a greater efficiency is obtained. Even this arrangement is necessarily crude, as the inaccessibility of the fuel in mixed-feed kilns prevents it being burned under the most efficient conditions. At the same time the efficiency in such kilns, if properly designed, is sufficient, in combination with their advantages, to make them serious competitors of oil and gas-fired kilns, and, under favourable conditions, they cost less in fuel than the latter.

In gas and oil-fired kilns, a large proportion of the air should be mixed with the fuel prior to ignition as this ensures the most efficient combustion. It is often impracticable to supply all the air in this manner, but as much as can be rightly used should be so introduced.

It is most interesting to observe that some gas-fired kilns which have been in use for many years appear to work satisfactorily in apparently complete contradiction to what has been stated above. In these kilns, so far as can be seen, no air is introduced to the gas before ignition and the outlet for the lime is kept closed except when lime is being drawn! Yet, these kilns continue to produce good lime with a fuel consumption of only 6 cwt. per ton of lime and occasionally with a still smaller fuel consumption! Such a state of affairs appears to be impossible to understand, but it can probably be explained by air gaining access to the kiln in ways which are not obvious, *i.e.* by leakage. That serious leakage does occur in such kilns is shown by the fact that the lime is comparatively cool when discharged.

In many gas-fired kilns, the gas enters without any admixture to air prior to ignition. This is incorrect but if the gas is low in hydro-carbons—such as most producer gas—the consequences may not be serious, and as the length of flame is increased by this treatment it is sometimes advantageous—especially if the gas is of low quality, and the lime is easily overburned.

The only method of ascertaining the best practical method of introducing air into a particular lime kiln—and kilns differ greatly in this respect—is to make an exhaustive examination of the kiln under various conditions, and thus find what conditions yield the best and most economical result. The available conditions in some kilns are so abnormal that ordinary considerations can scarcely be applied to them, a multiplicity of errors reacting on each other and the final result is economical, even though, from a theoretical point of view, it is far from satisfactory. If, however, one of these errors is remedied, it may so destroy the balance as to make the working of the kiln unprofitable. In such a case, either the working of the kiln must be continued until it requires to be shut down for repairs, or it may be stopped and the necessary alterations made in the kiln. Sometimes the latter are so extensive as to necessitate rebuilding.

(k) *The draught may be insufficient* to produce the requisite quantity of lime. This defect is usually the result of bad designing, the kiln being too low in proportion to its diameter, but it may also be caused by feeding the kiln with pieces of stone of too many different sizes. Some lime burners endeavour to increase the draught by means of a chimney, fan, or blower, but this will not be efficient, unless the relative dimensions of the kiln (and particularly the height) are correct. If the kiln is unsuitable in shape, the use of a chimney or an artificial draught will do little good, but if the wrong dimensions of the kiln are corrected, as far as possible, the use of a suitable chimney, or, in some cases, an artificial means of creating draught, will be satisfactory. The increased cost of working the kiln when artificial draught is used will then be more than counterbalanced by the advantages gained, namely (i) the increased output of the kiln ; (ii) the relatively smaller fuel consumption ; (iii) the non-dependence of the kiln upon climatic conditions ; and (iv) the possibility of producing steam by the use of a waste-heat boiler, heated by the kiln gases.

(l) *The output of the kiln may be too low*, either through one or more errors in design, or because of one of the defects previously mentioned. The output of a kiln depends on so many factors that no simple rule can be found which shows the ratio of the dimensions of a kiln to its maximum output of lime, but under normal conditions, a well-designed mixed-feed kiln 35 ft. or more in height and 15 ft. internal diameter should produce 50 tons per day of 24 hours, which corresponds to nearly 0.3 tons of lime per square foot of kiln area.

A well-designed gas-fired kiln of $7\frac{1}{2}$ ft. internal diameter should produce 30 tons of lime per day of 24 hours, corresponding to 0.67 tons of lime per sq. ft. of kiln-area or more than twice the throughput of a mixed-feed kiln.

Kilns which have much smaller throughputs than those just mentioned will usually be found to be needlessly inefficient, though their height, the nature of the stone, and other considerations must not be overlooked.

To increase the output of a kiln to that corresponding to its diameter is often an impossible task, as many kilns are so badly designed that they would have to be pulled down and rebuilt. The extent to which any existing kiln can be altered so as to yield an efficient output must usually be decided by an expert who has devoted special attention to this subject. Curiously enough, few kiln builders appear to have studied the fundamental principles upon which the output of vertical lime kilns depends.

(m) *The stone and lime may stick in the shaft* either as a result of faulty design or bad working. The chief causes are :

(i) The shape of the kiln may be such as to facilitate the holding up of the material. Thus, constrictions in the kiln-shaft, or any departures from vertical walls, are very likely to prevent the material from descending uniformly, especially if it has any tendency to clinker, for it is obviously difficult for lumps of stone or lime to move over a horizontal or inclined surface or to pass through a constricted opening. Although most limestones are reduced to about half their bulk during the burning, it is undesirable to reduce the diameter of the kiln very much, or sticking is very likely to occur. This troublesome behaviour

of the material is not entirely avoided, even when the shape of the kiln is suitable, and in some cases in conical shafts, the sticking is as serious as in cylindrical ones. On the whole, however, it is least in kilns with vertical walls and greatest in those in which the material has to pass around "bends" or over inclined surfaces in its passage through the kiln.

Where the sticking is due to the excessive pressure of the stone on the burned lime, due to the great height of the kiln, a Dietzsch kiln may be preferable as it has two shafts united by a short horizontal passage. It is seldom that this arrangement has much effect on the sticking and it necessitates much additional labour in raking the stone along the horizontal portion of the shaft.

The effect of various shapes of shafts of lime kilns is more fully considered in dealing with the various types of shaft kilns.

(ii) Hauenschild has attributed the sticking of materials to the cooling of the kiln walls and tried to overcome it by the use of thinner (and, therefore, hotter) walls in a steel casing and by a double-walled kiln with a space of 2 ft. 6 in. between each wall, but this does not remedy the defect. Stein Wetzlar used an iron kiln without any lining and avoided all sticking, but the kiln was very wasteful in fuel owing to the great loss of heat by radiation, and the iron was so badly corroded in the burning zone that the cost of repairs and renewals prevented its continued use.

(iii) Schneider considered that sticking was largely due to the fuel coming in contact with the walls of the kiln, and tried to overcome it by using partitions so placed as to feed small stones between the kiln walls and the fuel. He also arranged the fuel in a mass so that the resulting clinker "hung together," but did not touch the walls. Although these arrangements overcome the defect to some extent, they introduced another difficulty—the removal of the clinker—which so reduced the output of the kiln as to make its use almost impracticable.

(iv) Sticking may also be due to the use of an unsuitable lining for the kiln. If the lining is not sufficiently refractory combination may take place between the lime and the lining and partial fusion may occur, causing adhesion and so preventing the regular descent of the stone. This can only be remedied by using suitable materials for the lining. As the lime is basic and silica or fireclay bricks are acid in character, some combination is certain to occur, though this need not be serious if the bricks have a fine texture, are accurate in shape, and are laid with thin joints. Basic lining materials cannot be used satisfactorily, either on account of their prohibitive cost, excessive sensitiveness to sudden changes in temperature, or to their introducing an objectionable impurity, such as magnesia, into the lime.

(v) Sticking may be caused by the charging appliance being incorrectly designed, so that the material is not distributed uniformly in the kiln, but accumulates in one or more parts and later, falls suddenly.

(vi) Quite apart from incorrect design or faulty materials, sticking may also be caused by the faulty manipulation of the kiln, whereby the lime is overheated and partial fusion occurs, or by the introduction of clay with the limestone supplied to the kiln. The mixture of clay and limestone undergoes partial

fusion and so acts as a cementing material which causes the pieces of lime to adhere to each other.

(n) *Excessive abrasion and corrosion of the lining of the kiln* may be due to incorrect design, or faulty materials. Thus, excessive wear may be the result of the shaft being unnecessarily constricted in one or more portions, which naturally increases the amount of abrasion and, consequently, the cost of repairs to the lining. Cheap lining materials usually have a coarse texture, are irregular in shape, and have to be laid with thick joints so that they may facilitate abrasion and corrosion by the limestone as it passes through the kiln.

(o) *The gases may pass out of the kiln at too high a temperature* as a result of faulty design, *i.e.* the preheating zone being too short to cool the gases, as described in (a), or it may be due to faulty management of the kiln.

(p) *Lack of arrangements to protect the workmen* engaged in charging the kiln from the waste gases evolved from it is a common fault with vertical shaft kilns. If the men are enveloped by the gases, they not only suffer inconvenience and so work badly, but the gases may have serious consequences on account of the carbon monoxide present in them. Various methods may be adopted in different types of kilns to safeguard the workmen, the commonest being (i) some form of chimney, the lower end of which is submerged in the stone to a depth of several feet, as in the Cornet and Candlot kilns and (ii) some form of closed hopper into which the stone can be tipped and the hopper opened when the men are some distance away (see pp. 278 and 344).

(q) *The cooling zone* of a vertical kiln should generally be separate from the kiln base, so as to allow for expansion; otherwise, some other means of allowing for expansion should be provided or this part of the kiln may crack. As the loss of heat by radiation from the cooling zone is not serious, it is often convenient to construct the lower part of this zone of steel without any brickwork lining. By this means, the lime may be cooled with a smaller quantity of air than is required when the cooling zone is built wholly of brickwork.

(r) *The discharge of hot lime* is often due to the faulty construction of the kiln in one of the following ways:

(i) The cooling zone may be too short.

(ii) Insufficient provision may have been made for passing air through the cooling lime.

(iii) The bottom doors may have to be almost closed so as to enable sufficient draught to be maintained.

The remedy obviously consists in having a sufficiently long cooling zone and in making ample provision for cooling the lime before its discharge, but this cannot always be arranged in an existing kiln. In that case, the hot lime should, if possible, be taken by a conveyor to a separate cooling and storage bin.

Hot lime may also be discharged as a result of endeavouring to pass the stone too quickly through the kiln in order to obtain a greater output of lime.

(s) *Improper removal of lime from the base* is often due to a defect in the design of the discharge device. Sometimes the doors are too low and the whole of the

arrangements for discharging are cramped into as low and small a space as possible in order to save on the height of the kiln. This is a very bad policy, as it involves a waste of labour in placing the material in trucks, bins, etc., or taking it to the screens. A much better plan is to build the kiln on a higher base so as to allow ample room for screening and discharging the lime into trucks or bins by gravity. It is often advantageous to build the kiln over a tunnel through which full-size railway trucks can pass, instead of having only sufficient space for a small wagon of 1 ton capacity or less to pass-under it, as the small wagon will have to be filled and then discharged into the larger trucks for transport at an additional cost of labour. It is still better if the kilns can be arranged to discharge the lime into bins placed over the railway lines as by this means several trucks can be filled at a time and need not be kept waiting until the kiln is discharged. The bins also ensure ample storage capacity for week-ends, holidays, and times of slack trade. The various methods of arranging the discharging appliances are considered in detail on pp. 333-341, but it will be seen that defective planning of this important part of the plant may result in a serious increase in the cost of producing and handling the lime.

Not only is insufficient height and space a source of loss, but the use of hand labour instead of automatic methods is also costly and may often be very profitably replaced by mechanical methods of handling.

Apart from faulty designing, the inefficient removal of lime from the base may be due to bad management.

(t) *The finished lime contains too much unburned stone.* This may be due to faulty management of the kiln, but it is occasionally caused by faults in the kiln itself, such as too short a burning zone, insufficient supply of air to the fuel, or, in the case of gas or externally-fired kilns, to defects in the burners or fireplaces.

(u) *The fuel consumption may be excessive,* either as a result of bad management, or, more commonly, because the kiln has been badly proportioned, the chief errors being insufficient height, and inadequate control of the air supply and the draught. Many of the defects previously mentioned will cause an excessive consumption of fuel, so that the remedy for the former will reduce the amount of fuel burned.

The amounts of fuel required for different types of vertical kilns have already been stated, but it must be understood that these figures are only approximate and individual kilns of any one type may differ greatly as regards fuel consumption.

(v) *The rate of calcination may be too low.* There is very little useful information on the rate of calcination under normal conditions, but according to C. C. Furnas¹

$$\log_{10}R = 0.0031415t - 3.3085$$

where R is the rate of penetration in the lime of calcination in centimetres per hour, and t the temperature in degrees Centigrade.

¹U.S. Bureau of Mines per *Indust. and Eng. Chem.*, XXIII, 534 (1931).

Fig. 98 shows the time required for pieces of limestone of different sizes at various temperatures, the size being defined as the greatest thickness of a piece of stone, where thickness is defined as the smallest of the three dimensions of length, breadth, and thickness.¹

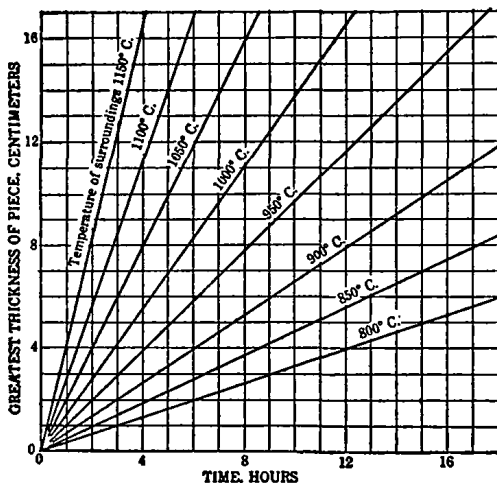


FIG. 98.—TIME REQUIRED FOR BURNING LIMESTONE.

adequate for the satisfactory management of the kiln. Unless substantial stairways and ample platforms are erected wherever they are likely to be required, the men engaged in working the kiln cannot be expected to do their best. With the inadequate provision for inspection and poking and for passing from one part of the kiln to another which is usually provided, the men cannot be expected to give enthusiastic and devoted attention to their work.

HORIZONTAL LIME KILNS

The term *horizontal lime kilns* is used as a contrast to kilns in which the stone descends vertically during its conversion into lime. They are almost all of the continuous type as an intermittent kiln with a horizontal draught would be very wasteful in fuel and would produce too large a proportion of imperfectly burned stone.

Horizontal lime kilns are of two chief types (a) those in which the fire travels continuously through the kiln, the stone being stationary (*Ring kilns*), and (b) those in which the stone is moved through the kiln either by gravity (*Rotary kilns*) or by being carried on trucks or plates, the fire remaining stationary (*Tunnel kilns*).

Horizontal kilns of the first type were originally termed *Ring kilns* because of their shape, but this term is seldom used in the British Isles where such kilns are generally known as *Hoffman Kilns*, from the inventor of the earliest kilns

¹ This chart bears no relation to the time required in a commercial kiln.

The calcination appears to advance in definite straight lines from the exterior to the centre of each piece of stone, but much more slowly than the increase in the temperature of various parts of the piece. The latter appears to be due to the centre of a piece of stone remaining at a constant temperature until calcination is complete.

(w) *The arrangements for ascending and descending the kiln* are often very unsatisfactory and quite inadequate

of this type, though many modifications have since been introduced which render other names more appropriate.

Friedrich Hoffman's first patent kiln was designed in 1857 for burning building bricks, but its use was extended in 1864 for burning lime for which purpose it is still largely employed.

The earliest Hoffman kilns were circular, later ones were more elliptical in shape, and the modern modifications of Hoffman's kilns are rectangular.

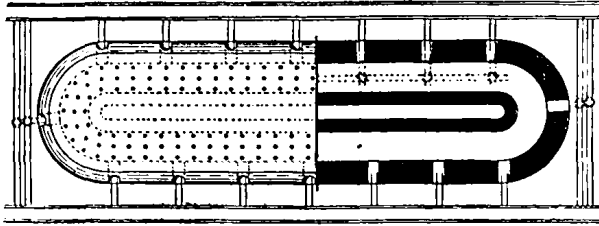


FIG. 99.—PLAN OF HOFFMAN KILN.

The essential feature of Hoffman's kiln (fig. 99) is that the limestone is contained in an annular or ring-shaped tunnel and the hot gases from the fuel travel through this tunnel, heating the stone and converting it into lime. Simultaneously, air enters at another part of the tunnel and is heated by passing it through the lime and so ensures more perfect combustion than if cold air were used, whilst the hot lime is cooled in a simple and certain manner.

The "tunnel" in a Hoffman kiln is assumed to be divided into twelve or more "chambers" and partition walls are built for this purpose in some modern modifications, though they are not necessary for burning lime and are only a cause of waste of heat; for bricks and other articles, such partition walls are often very advantageous.

In describing the operation of a Hoffman or similar kiln, the existence of "chambers" is always assumed, even when they do not actually exist.

The total length of the tunnel when used for burning lime should not be less than 168 ft. and 240 ft. is preferable. The latter length will allow of 20 (imaginary) chambers, each 12 ft. in length.

In such a kiln at any time, under ideal conditions :

1 chamber will be empty.

1 chamber will be filling.

7 chambers will be preheating by hot gases from the fuel.

4 chambers will be under fire, fuel being burned in them.

6 chambers will be cooling, and at the same time heating the air required for the combustion of the fuel.

1 chamber will be emptying.

20 chambers in all.

If a kiln has a small number of chambers, the number in each stage of heating or cooling must be reduced, but the general principle is retained. At

week-ends and holidays, the number of chambers in any stage of heating or cooling may alter, but the correct number in each stage should be restored as the week's work progresses; in this respect a kiln with a large number (20) of chambers has a great advantage over one with a small number (12 or 16) because variations in the number of chambers at any given range of temperature is much less serious. The larger the number of chambers, the more slowly will the material be heated or cooled and the greater should be the certainty of its efficient treatment in the kiln.

In the original Hoffman kiln, the limestone was carefully stacked in the chambers by hand, vertical shafts or "pillars" being left about 3 ft. apart and immediately below a series of "feed holes" in the arch of the tunnel. Small coal was fed through these holes and lodged on projecting pieces of stone forming the pillars and were burned by the very hot air passing horizontally through the tunnel. As the products of combustion pass forward they heat the limestone in successive chambers, and, when the temperature of the gases is so low that it is not worth attempting to recover any more heat from them, they are drawn through one of a series of openings into the main flue and so away to the chimney.

The fire pillars must be exactly under the feed holes in the arch, but if no arch is used, iron "feed holes" and caps are laid on top of the "pillars" and the whole of the limestone is covered with a 6 in. layer of stone-dust which serves to keep in the heat and to prevent any rain from damaging the burnt lime. Such a covering is not so efficient as a properly constructed arch, as it does not retain the heat so well, but it is popular because it is cheaper as regards first cost and because the kiln can be emptied by a crane and grab.

The necessary draught is created by means of a fan or chimney.

When the lime in one "chamber" is sufficiently burned, fuel is fed into the next succeeding chamber, the opening into the main flue is closed, and the next succeeding one is opened; by these means the hot gases and fire are advanced "one chamber" and as this usually takes place either once or twice daily, according to the rate at which the stone can be burned, the fire gradually travels round the kiln.

Limestones vary very greatly in the rate at which they can be burned, but with a sufficiently long tunnel and a hard, clean stone, a rate of 3 ft. per hour for the fire travel can often be obtained; most lime kilns of this type have much shorter tunnels and in them the fire cannot usually travel forward more than 1 ft. per hour. To work a Hoffman kiln to the best advantage there must be no stoppage in filling and emptying on Sundays and other holidays, as such stoppages greatly reduce the rate of fire travel. Under these conditions a Hoffmann Kiln with a fire-travel of 1 ft. per hour should produce 5 tons of lime per day per sq. yd. of cross-sectional area, so that a chamber 12 ft. wide and 8 ft. 6 in. high internally (*i.e.* 9 sq. yd.) should yield 45 tons of lime per day of 24 hours.

On opening a chamber and removing some of the lime, the ash from the fuel will be found adhering to some of the lumps, but the greater part of the lime

will be quite clean and well burned. Indeed, if the burner is reasonably skilled, the proportion of under or over burned stone (including that spoiled by the ash) should not exceed 5 per cent. To ensure this, each chamber must be thoroughly cleaned before being refilled and care must be taken to avoid introducing small stone into the kiln.

The chief improvements in the Hoffman kiln are concerned with :

(a) Keeping the fuel separate from the lime by burning it in troughs or grates across the tunnel and about 10 ft. apart. Such kilns are often known as "Belgian" kilns. They embody an important improvement, but the fuel consumption is increased by about 12-25 per cent. of the total fuel burned.

(b) Providing drop arches which project below the arch of the tunnel and are intended to prevent the hot gases from travelling over the stone and lime in the kilns instead of through them. This defect is a serious one as most limestones shrink greatly during the burning and so enable the gases to pass too readily along the upper part of the tunnel. The use of drop arches is a great improvement, but does not wholly avoid this defect.

(c) Providing permanent partitions and sub-floor flues, the former dividing the kiln into an appropriate number of chambers and the latter enabling the hot gases to have an up-and-down movement instead of a wholly horizontal one, and thereby greatly reducing the adverse effect of the shrinkage of the stone when converted into lime.

(d) Greatly increasing the length of the tunnel by arranging portions of it parallel to each other, and connecting them by short lengths of tunnel so that the whole kiln is almost square in plan. This is known as the Bühler or zig-zag kiln (fig. 100). It has the advantage of a very high rate of fire travel and a very low fuel-consumption owing to the great length of the tunnel and the use of a fan instead of a chimney to create the draught, so that all the available heat in the kiln gases is used.

Gas-fired kilns of the Hoffman type can be used satisfactorily for burning lime, but as they consume more fuel than coal-fired kilns of the same type and have no great advantage over the latter, they are seldom used. Moreover, the cost of labour in setting and drawing these

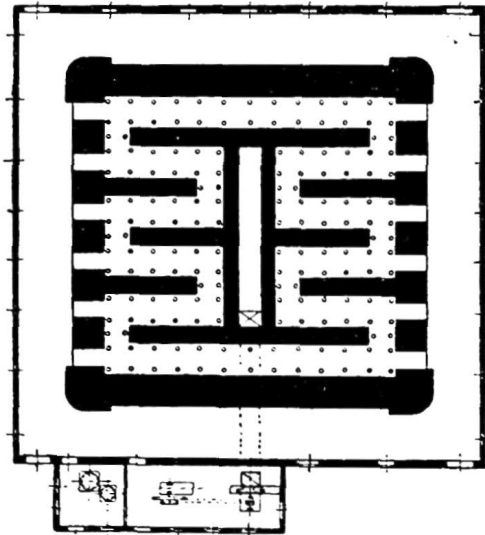


FIG. 100.—PLAN OF BÜHLER KILN.

kilns is so much greater than that of vertical gas-fired kilns that few gas-fired Hoffman kilns are likely to be built for burning lime in the future.

Archless kilns are a modified form of Hoffman kiln from which the permanent arch or crown which protects the lime from the rain has been omitted; its place is taken by a double layer of bricks laid close together and covered with a thick layer of ashes. This alteration greatly reduces the cost of construction or of filling and emptying as the kiln can be filled and emptied by means of a crane with grab or skip very much more easily than when all the material has to be wheeled through the wickets or doorways. The absence of an arch causes the loss of a considerable amount of heat by radiation and a further wastage of fuel and lime occurs during rain, but these losses are often less than the saving in the cost of labour in filling and emptying the kiln.

O. Bock proposed that instead of building a kiln of brickwork it should be constructed by excavation, and several kilns so built are still in use on the Continent; the principle involved is precisely the same as in the Hoffman kiln, the only difference being that one is above ground and the other excavated in it. If the ground is of suitable material, Bock's "sunken kiln" is satisfactory; it is, however, more liable to be affected by moisture than a well-built kiln of similar shape and size.

The *efficiency* of kilns of the Hoffman type and their various modifications is fairly high; these kilns are almost perfect in theory, so far as the utilization of the heat from the fuel is concerned, but they fall short of what is anticipated because of the irregularity of the burning, due to the shrinkage of the stone, which causes the gases to take a "short circuit" over the top of the stone and lime instead of through them. Yet, a well-designed "improved" Hoffman kiln will burn a pure hard limestone using only 3 cwt. of good coal per ton of lime produced.

The quality of the lime from a Hoffman kiln is intermediate between that of a vertical kiln with mixed feed and one with external fires or gas firing. In the true Hoffman kiln, the ash from the fuel is concentrated in the fire pillars at intervals of 3-4 ft., and immediately around these pillars and the longitudinal flues the lime is mixed with ash and is impure; in the other portions of the kiln it should be as pure as the stone from which it is derived.

Owing to the number and closeness of the fire pillars, the lime, as sold, tends to be variable according to the ash content, but this defect is largely avoided by using grates instead of the fire pillars just described, so that almost all the ash is confined to the grates.

The *advantages* of kilns of the Hoffman type and its modifications are:

(a) Its low fuel consumption, which is at least $\frac{1}{2}$ cwt. less per ton of lime than that required by tall vertical shaft kilns, and with some kilns there is a difference of 8 cwt. per ton of lime in favour of the Hoffman type.

(b) The lime is cleaner than that from mixed-feed kilns, and when a Hoffman kiln with grates is used the lime may be quite as clean as that from a gas-fired kiln.

The chief *disadvantages* of kilns of this class are:

(a) The cost of filling and drawing is excessive, as the stone has to be carefully packed and (in the true Hoffman kiln) vertical fire pillars have to be built for the fuel. A Hoffman kiln with an output of 24 tons a day will normally require 13-14 men as compared with 5 men for a shaft kiln of the same output; the additional men are employed in placing the stone in the kiln, in building up the brickwork doors or wickets, and in emptying and cleaning the kiln. Many attempts to fill Hoffman and similar kilns mechanically have largely failed, because such a procedure does not place the stones with regularity to ensure uniform burning, whereas a conscientious and skilled filler can do this quite well.

(b) The burning is liable to be irregular as the stones are of many different sizes and require very skilful placing in order that the draught through them may be uniform. "Flues" must be arranged so that the hot gases will travel properly along the lower part of the kiln, as, otherwise, this part will be insufficiently heated.

Part of the irregularity is due to the shrinkage of the stone when converted into lime. This leaves a large opening between the top of the burned stone and the arch of the kiln, so that air and hot gases rush along this opening instead of uniformly through the kiln. The only means of counteracting this is to construct sufficiently large flues in the lower part of the kiln so that the hot gases will travel uniformly both above and below the stone. An archless kiln. (p. 372) suffers less from this defect as the "topping" sinks as the stone shrinks.

(c) The kiln requires more skilled attention in firing than a tall shaft kiln.

(d) In the original Hoffman type some of the lime is spoiled by contact with fuel ash, but this is avoided by using grates.

(e) A complete Hoffman kiln is costly to construct; by omitting the arches, the construction is greatly cheapened and filling and drawing facilitated, but an increase of about $\frac{1}{3}$ cwt. of coal per ton of lime is involved owing to the loss of heat by radiation, etc.

(f) Another great disadvantage of Hoffman kilns is the enormous amount of air which passes over the burned lime—it averages three times as much as the useless air in a shaft kiln. The moisture and carbon dioxide in this air cause *air slaking*.

The heat balance of a typical Hoffman kiln is shown in Table XXV.

TABLE XXV.—*Heat balance of Hoffman kiln.*

Heat used in lime	...	...	...	...	49.0
Loss in outgoing gases	...	...	...	...	25.2
Loss through incomplete combustion	...	...	...	...	—
Loss in drawn lime	...	...	...	...	0.5
Loss in unburnt fuel	...	...	...	...	4.6
Loss by convection and radiation	...	...	...	...	20.7
					100.0

Notwithstanding these disadvantages, the Hoffman kiln and its modifications are well suited to localities where a tall kiln would be inconvenient and where labour is sufficiently cheap, though in most places a vertical shaft kiln would produce lime more cheaply.

The *chief constructional defects* in Hoffman and allied kilns when used for burning lime are :

(i) The walls and flues tend to leak and so cause irregular burning to a greater extent than with steel cased vertical kilns.

(ii) It is impossible to avoid using a large excess of air, and this tends to cause loss of heat and to re-carbonate the lime.

(iii) The kilns are frequently too short, so that they are not so economical in fuel as they should be.

(iv) These kilns require constant attention in supplying the fuel, and though " automatic fuel feeders " are in use, they do not save as much labour as might be supposed. Their chief value is in saving fuel.

The chief constitutional defects of shaft kilns do not occur in kilns of the Hoffman type, and unless such a kiln is unduly short, very badly designed, or carelessly built, there is little wrong with it. This was for long one of the great advantages of kilns of this type. They would be as popular to-day as ever, but for the cost of labour for filling and emptying being now prohibitive in many places.

TUNNEL KILNS

Instead of an annular tunnel and a travelling fire, as in the Hoffman and allied kilns, a straight or circular tunnel may be used and the stone may travel through it on trucks or plates whilst the temperature of each part of the tunnel is kept constant. The utilization of heat is the same as in a Hoffman or similar kiln, but for some purposes the use of cars is more convenient.

In a tunnel kiln, the stone to be burned is placed on trucks which are pushed through the tunnel at a speed of about 5 ft. per hour, though it is sometimes preferable to advance trucks 5 ft. in the course of a few seconds and to leave them stationary for the remainder of the hour. The tunnel is hottest near the centre, and as the limestone passes forward it is gradually heated by the waste gases from the fuel which travel in the opposite direction. The fully-burned lime passes on and is cooled by the incoming air which later aids the combustion of the fuel.

The fuel may be coal, gas, or oil and it may be applied in any convenient manner, the heating of tunnel kilns not offering any serious difficulties. Gas—especially producer-gas—is the most convenient fuel, though not always the cheapest.

The great *advantages* of a tunnel kiln are the ease with which it is discharged, and the facility with which the temperatures can be controlled.

The chief *disadvantages* are :

(i) The difficulty of obtaining cars which will withstand the action of the lime and heat.

(ii) The necessity of placing each piece of stone on the trucks so that it will not fall off and so as to produce a uniform distribution of air spaces or voids. The same difficulty is experienced in Hoffman and allied kilns, but with them it is less serious as the walls of the Hoffman kiln can support the stone, but those of a tunnel kiln must not do so.

(iii) A minor objection is the cost of power for pushing the cars, though this is seldom serious.

Tunnel kilns for lime are, as yet, in an experimental state, but the reasons just mentioned appear sufficient to prevent them being used extensively in the near future.

If, however, the cars could be fitted with suitable cages to contain the stone and burned lime, the use of a tunnel kiln would be advantageous in works where a vertical kiln is inconvenient and in those where a greater control over the burning of the stone is desirable.

ROTARY KILNS

The great success which attended the use of rotary-kilns in the manufacture of Portland cement has led to their employment to a small extent for burning lime, especially when that material is to be hydrated.

Rotary kilns were first used for lime in 1885, but the earliest one to attain commercial success was erected in this country at the Beckton works of the Gas, Light and Coke Co. in 1893—some time prior to the date (1906) in which the first rotary kiln for lime was built in the United States, at Carthage, N.Y. Since then rotary kilns have greatly increased in numbers, particularly in the United States, where one firm (The Eastern Potash Corporation) has 10 rotary kilns, each 125 ft. by 8 ft., burning lime.

A rotary lime kiln (fig. 101) consists of a long steel cylinder, 20–260 ft. in length, and 2–12 ft. in diameter, lined with firebricks, and mounted in an almost horizontal position on trunnions so that it can make 5 or 6 revolutions per minute. The stone is fed in

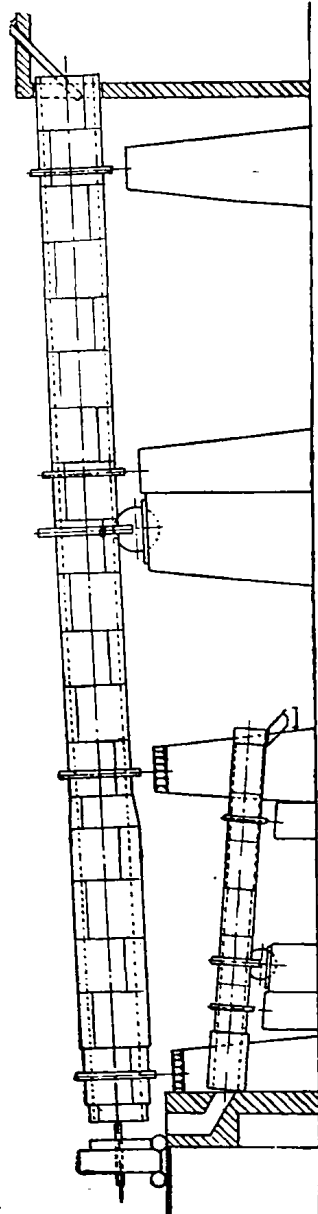


FIG. 101.—ROTARY KILN AND COOLER.

at the upper end of the cylinder and gas or powdered coal is blown in (along with a blast of air) at the other end and heats the stone to any desired temperature as it passes slowly through the kiln and out at the lower end into a second rotating cylinder, where it is cooled by a current of air before being discharged.

The dimensions of rotary kilns, when used for lime, vary greatly; the smallest successfully in use is 60 ft. long and 6 ft. inside diameter, and produces 20 tons of lime per day of 24 hours. Smaller kilns cost too much in proportion to the lime produced and the fuel consumption is too high. Large kilns similar to those used for Portland cement are also in use in America, but only to a very small extent in Europe; one at Polgardy in Czecho-Slovakia produces 120 tons of lime in 24 hours and requires 45 h.p. to drive it, but several in the United States in successful operation are 130-150 ft. long, 6-6½ ft. inside diameter, and produce 80-125 tons of lime per day.

The present tendency is to make the rotary kilns for lime almost as long as those used for cement, *i.e.* 130-200 ft. as this tends to reduce the fuel consumption.

The approximate outputs of rotary kilns of various sizes are shown in Table XXVI:

TABLE XXVI.—*Outputs of Rotary-kilns*

External Diameter ft.	Length ft.	Output per 24 hours tons
5	60	18-20
6	60	26-30
6	100	40-50
7	80	55-60
7	100	70-80
8	125	90-100
9	175	150-200
10	200	200-250

Rotary kilns are heated by injecting fuel and air at the lower end, the products of combustion passing through the kiln to a chimney near the upper end.

Producer gas, natural gas, oil, or pulverized coal may be used, but pulverized coal is not advisable where the highest grades of commercial lime are required because any small particles of incompletely burned coal and ash mix with the lime, produce black or brown spots in the latter and spoil it for plastering. This may largely be overcome by the use of an air separator after hydration.

Oil tends to produce a short flame with the heat concentrated at one point, and this is not satisfactory, especially where the stone is easily over-burned.

Producer gas is excellent, though expensive, as 6-7 cwt. of coal are required to produce 1 ton of lime. This is due to the heat lost on conversion into gas in an external producer. Natural gas (where available) is also excellent, but town's gas is far too costly.

As they break down the lime passing through them, rotary-kilns are not suitable for producing lump lime, but are excellent where the lime is subsequently to be ground or hydrated. Consequently, they are gaining popularity for use in situations where a large amount of stone in small pieces is available and as an auxiliary to other types of kilns; the latter produce the lump lime and the rotary kiln deals with the small stone.

The temperature reached in the hot end of a rotary kiln burning lime is usually 1200-1350° C., which is 300-400° C. above that needed to dissociate the stone, but it is necessary to make up for the great loss of heat through radiation and up the chimney. A considerable saving in fuel could be realized if use could be made of this wasted heat for other purposes, such as a waste-heat boiler, which could supply steam or power for use in other industries.

The *size of the stone* used in rotary kilns should not exceed 2 in. diameter, nor be less than $\frac{1}{2}$ -in. diameter, and it is preferable that the largest pieces should not be more than twice the diameter of the smallest ones, the most generally convenient range being that retained on a $\frac{5}{8}$ -in. screen, but passing through a $1\frac{1}{4}$ -in. one. If the stone is crushed much smaller than $\frac{1}{2}$ -in. the proportion of unusable fines will be so great as to defeat the purpose for which the kiln was built. Wherever it is practicable, the stone should be graded so that the pieces are as nearly of one size as possible, as large and small pieces are not decomposed at the same rate. Flat pieces of stone should be avoided as they burn very slowly in rotary kilns.

The *speed* of a rotary kiln is varied, so as to control the burning, the material being heated more intensely when the kiln revolves very slowly and *vice versa*. The most convenient method of changing speed is by a variable speed electric motor, but other simple devices are equally satisfactory. It is found that the best results are obtained by keeping a constant feed of stone and varying the speed of the kiln so as to control the burning.

The slope of the kiln should usually be $\frac{1}{2}$ -in. or $\frac{3}{8}$ -in. per linear foot; too steep a slope causes the material to pass too rapidly through the kiln, so that it is not heated properly.

The *rate of passage* of the stone and lime through a rotary kiln is far greater than that in a shaft kiln, and seldom exceeds 6 hours. This has a marked effect on the slaking power of the lime.

The *cooler* should be provided with some device which will cause the lime to come more closely into contact with the air. Lifting irons which raise the material and drop it are worse than useless, for they create a lot of fine dust, which goes up through the kiln to the chimney and is lost. A much better way is to divide the cooler into four quadrants by means of four partition plates. These should allow for expansion, but must not have open clearance spaces, or they will merely pass the dust through these and back into the kiln. At the

discharge end of the cooler, end plates should be fastened so that the lime does not slide off the quadrant plates, but off the cylinder.

Means should be provided at the lower end of the kiln where the lime drops into the cooler, and when it drops off the end of the cooler, to prevent the inrushing air picking up the dust. At both such points, great care must be used to keep the air deflected from the flow of lime as far as possible.

Steam may usefully be injected along with the fuel in a rotary kiln, as Herzfield and others have shown that calcium carbonate is decomposed in the presence of steam at 790° C., which is nearly 150° C. lower than the temperature required for the dry material. The same principle is used in Schaffer and Crow's *wet process* of lime burning (U.S.P. 1,337,367 and 1,337,401), in which the limestone or chalk is ground with water and the resulting paste is supplied to the (rotary) kiln. The mass breaks up into convenient sized nodules, and is burned in an atmosphere saturated with steam.

The great advantage of steam is that it lessens the risk of overburning the lime, and so enables a larger proportion of the material to be hydrated at a later stage of the manufacture.

The *advantages* claimed for rotary kilns for lime are :

- (a) A very uniformly burned product.
- (b) A low cost for repairs.
- (c) Low labour costs.
- (d) Quicker results.
- (e) A lower cost for stone, due to the utilization of all the clean stone in a quarry independently of its size.

A more uniform product is certainly obtained from the rotary kiln, as the revolving of the kiln mixes the material and any underburned or overburned material is mixed and distributed uniformly through the correctly burned material. Furthermore, because of the small size of the material being calcined, there is less danger of the heat not penetrating to the interior and of underburned material being produced. A uniform quality is, therefore, produced from the rotary kiln, as all the qualities produced during the calcination are averaged out. The average quality of lime produced from a shaft kiln runs about the same as that produced from a rotary kiln, but the lump material from a shaft kiln may be picked to yield a material of higher quality.

A rotary kiln installation may be made to give the utmost possible efficiency by installing a waste-heat boiler, through which the flue gases from the kiln are passed. The waste gases leave the kiln at about 700° C., and, consequently, a considerable amount of heat may be recovered by installing a waste-heat boiler.

In the Austro-American Magnesite Co.'s plant at Radentheim, Carinthia, a very large output is obtained by working the rotary kilns in connection with a cyclone dust-arrester and a fan having a suction of 18-in. water-gauge. This is necessary to prevent the creation of a dust nuisance in a popular tourist centre, but it is very costly as a 100 h.p. motor is used to create the requisite draught.

For preparing lime from waste products, and especially for those formed in the alkali, sugar, and wood pulp industries, the rotary kiln offers exceptional advantages, as it is not only peculiarly adapted to deal with materials in a small form, or even in a pasty state, but it can be connected with a dryer so readily as to make the dryer and kiln practically one piece of mechanism. This cannot be done with any other form of lime kiln with anything like the same degree of ease.

The chief *drawbacks* are :

(i) The very high cost of installation, which renders rotary kilns unsuitable for very small works. This is more important in Europe than in the United States, and is the chief reason so few rotary kilns are used for lime in Europe.

(ii) The cost of power to drive the kiln and cooler and, if powdered coal is used, the cost of grinding it.

(iii) The lime is all "small" and not saleable where lump lime is preferred; it is, however, in a better form for hydrating.

(iv) The high fuel cost (it being seldom possible to use less than 8 cwt. of fuel per ton of lime) due to the great loss of heat by radiation and up the chimney, which is about 60 per cent. of the total heat supplied to the kiln. This is due to the gases entering the chimney at a temperature of 500°–700° C., unless special means are used to reduce their temperature. In a works with only one rotary kiln, it does not pay to instal heat recovery plant for use in the lime-works itself, though it may do so if there is some other industry requiring heat or steam. With a single rotary kiln, the interest on investment, the depreciation charges, the labour charges, the possibilities of paying break-down service to the electric company, or maintaining a separate boiler, or separately firing the same boiler, practically eat up any saving obtainable. If there are two rotary kilns it usually pays to attempt to recover the waste heat.

Heat may be saved by the use of kilns of special design, such as the Polysius Solo kiln, which is built on the principle that "the best place to utilize waste furnace heat is in the furnace itself," and in which the burning cylinder is so prolonged on either side of the widened sintering zone that the flue gases escape at little above the temperature necessary to maintain the draught, and the lime leaves the kiln in a condition permitting immediate storage and needing no cooling in a special low-level drum. The kiln can thus be installed at ground-level, and cost of stairs and staging saved. The Pfeiffer Recuperator Kiln has the same advantage, using 4–6 cooling tubes joined by bonds to the furnace interior.

The Fellner and Ziegler kiln has an extended calcination zone, and the coal dust inlet has been divided into 2 or 3 branches, giving better combustion.

(v) A matter of small moment in a well-designed works, but which may be serious in others, is the amount of lime dust which is drawn back into the kiln with the incoming air, and deposited in the chimney. This dust is useless for most purposes and is a dead loss. Moreover, it deadens the flame, and increases the difficulty in burning. It can only be avoided by carefully deflecting the air so that its speed at entry is too low for it to carry much dust.

(vi) The burned and unburned limestone are thoroughly mixed by the rotation of the kiln, so that it is almost impossible to separate them. This is of small importance when the lime is hydrated before being sold as the separation occurs automatically in the hydrating plant.

(vii) There is very little control of the burning, so that the quality of the burned lime is largely a matter of chance, though skilled burners do obtain a remarkably uniform product merely by varying the speed of rotation of the kiln.

(viii) Builders and other users who desire lime in lump form will not readily purchase lime burned in a rotary kiln, as they are afraid it is air slaked lime under another name. When they realize its advantages, they buy it readily, but it is often difficult to convince them because of the conservative attitude they adopt. For the chemical trades and industries where the lime can be used in a small state, or in a slaked condition, the rotary kiln will provide the cheapest means of burning the small stone now wasted.

The *physical properties* of lime produced in the rotary kiln are in several respects different from lime made from the same stone in a shaft kiln. The most pronounced difference is the extreme rapidity with which lime from the rotary kiln will slake; this is probably due to its porous nature. In the rotary kiln, the total time between the introduction of the stone to the kiln and the discharge of the lime is so short that the sudden removal of the carbon dioxide seems to leave the lime more porous than the slowly calcined lime from a shaft kiln. Some difference in the binding power or sand carrying capacity and in the plasticity of lime from rotary kilns has also been noted.

The *future prospects* of rotary kilns for lime are uncertain, notwithstanding the almost universal use of such kilns for Portland cement.

The long-established preference for lump lime, and the prejudice which still exists against small material, has hampered the sale of quicklime from the rotary kiln. At the time when lime was made in pot kilns and other of the earlier types, the prejudice against small material was established on good grounds, for the impurities tended to concentrate in the fines. Lime produced in rotary kilns from small clean stone is just as pure as the lump material, and as this fact is better realized the prejudice against small lime from rotary kilns is rapidly disappearing.

The outstanding advantage of the rotary kiln is that it successfully converts small stone into lime, a more valuable product than the raw limestone. Hitherto, it has been used primarily to calcine the small stone left after the larger material has been removed for calcination in shaft kilns, but it is being considered more and more as a primary producer of lime to take all the quarry output directly, and not merely utilize the by-product of small stone, because it has one great advantage in that all the limestone may be crushed, sized, and calcined immediately after it is taken from the quarry, avoiding expensive hand sledging and picking out the one-man stone and subsequent rehandling. Thus, considerable economy in operation is possible where fuel is sufficiently cheap.

Its use is, at present, restricted by its high cost of installation, its

unsuitability for small outputs, and its high fuel consumption. In very large works, it enables other savings to be effected which more than neutralize these drawbacks, but for the medium and small works, which best seem to meet requirements in Europe, the rotary kiln is of very limited usefulness in burning lime.

ELECTRIC KILNS

Several attempts have been made to use electricity for burning lime, because electric furnaces are capable of a very accurate control and are free from some of the variations in temperature which necessarily occur when fuel is used. Such furnaces are of two types :

(a) Those in which the " arc " is formed with two electrodes and the material to be heated is passed through the arc in a steady stream. Such furnaces are exceedingly powerful and readily attain extraordinarily high temperatures, but they are not suitable for burning ordinary lime.

(b) Those in which the heat is produced by passing an electric current through a *resistance* which thereby becomes heated. For lime burning such furnaces are very effective, but extremely costly in running expenses.

Under ordinary circumstances, electric furnaces are not suitable for lime burning as the cost of current is much greater than that of fuel except in those localities where fuel is almost unobtainable. The cost of installation is also very high.

For the production of " fused lime " electric arc furnaces may be employed satisfactorily and they are also used extensively in the manufacture of various lime products, such as calcium carbide, where very high temperatures are required, but these require conditions very different from those needed in burning ordinary lime.

Electric kilns of the direct type are particularly suitable for producing dead burned dolomite. As electricity is dearer than fuel at temperatures below 1200° C., it is best to burn the dolomite in an ordinary kiln so as to convert it into lime and magnesia and to heat that product in an electric kiln.

Electric resistance furnaces are of little use for lime burning as they require about 9000 kwh. per ton of lime. To compete with coal or coke at 20s. per ton, electricity must not cost more than 0.027d. per kwh.

Electrically fused lime has attracted some interest as a refractory material suitable for lining furnaces used in the basic process of steel manufacture. The fused material behaves very differently from quicklime ; it hydrates with extreme slowness even when boiled with water. At present it is too costly for extended use.

RETORTS FOR LIME.

Many attempts have been made to heat limestone in retorts so as to obtain the carbon dioxide with a minimum of air. Most of these attempts have failed because the cross-sectional area of the retorts was too large to permit the whole of the stone to be converted into lime, but the Gillette retort (p. 308) appears

to have overcome this difficulty when only a small output is required. The use of a retort is unprofitable when lime is the sole product ; when the carbon dioxide can be utilized for " dry ice " (p. 459) or some other purpose, retorts may be profitable.

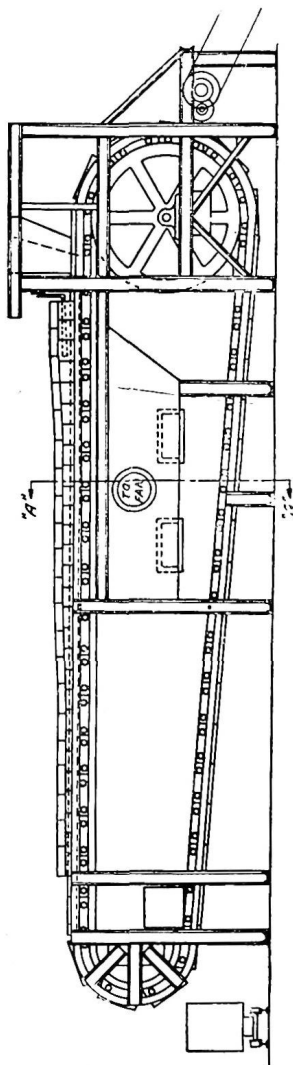


FIG. 102.—SINTERING MACHINE.

OTHER APPLIANCES FOR BURNING

Many ingenious devices have been proposed for burning lime, but they have not been adopted on a commercial scale—chiefly because they cost more to use than the types of kilns previously described.

One of the most promising of these devices is the Dwight-Lloyd *Sintering Machine*¹ (fig. 102) which resembles an endless chain stoker travelling over an exhaust chamber and beneath a low arch or cover of firebrick. The crushed stone or by-product is mixed with 5 per cent. of coal and is fed uniformly into the chain grate. It is carried beneath an oil flame which heats it sufficiently for the coal to ignite, and the air drawn down through the mixture and into the exhaust chamber completes the burning both of the fuel and the lime. As the lime is carried along on the chain grate it gradually cools and is discharged at the end of the machine.

The fuel consumption is $3\frac{1}{2}$ cwt. of paraffin and 2 cwt. of coal per ton of lime so that it is much more costly than a lime kiln, but it does enable small lime and by-product carbonate to be burned.

The metal of the pallets must be coated with lime dust so as to prevent the stone from being chilled by the metal and the pieces of stone should be as uniform as possible in size, though stone of two sizes can be used if the large pieces ride on the small ones.

The lime produced air slakes so rapidly that it cannot be sold as quicklime, but it is in an excellent condition for producing hydrated lime.

The largest output of sintered lime (dead burned dolomite) is that of the

¹ Made by Dwight and Lloyd Metallurgical Co. Inc., and supplied in England by Huntington, Heberlein and Co. Ltd., London.

Rhenisch Westphalischen Kalkwerke which produces 400 tons of dead burned dolomite per day. The kilns are of the vertical mixed-feed type with under pressure. The effective height is 40 ft. and the internal diameter is 7 ft. 3 in. at the top and 8 ft. 2 in. at the bottom. The normal output is 75–80 tons gross, but from this the “fines” have to be screened out and the saleable product is 55–60 tons per day. This exceedingly high output is due partly to the fact that overheating a dead burned material is impossible so that the kiln can be “forced,” and partly to the effective use of air under pressure. The fuel is coke and the fuel-consumption ratio is 5 : 1 on the gross product. A characteristic of this kiln is the high proportion of carbon dioxide in the gas (36–40 per cent.)—due to the limited amount of air used.

The rotary kilns used in Germany and Austria for dead burned dolomite are much less efficient than the vertical kilns, but they are largely free from the “sticking” or “hanging” of the charge in the kiln which is so troublesome with vertical kilns.

For dead burned dolomite the electric arc is probably the most suitable heating appliance, but in most localities the cost of electricity is prohibitive. A considerable reduction in cost is effected if the dolomite is first calcined in an ordinary kiln and afterwards dead burned in an electric arc.

SELECTING A KILN

From the foregoing description of kilns of various types it will be realized that in designing a lime kiln there is great difficulty in securing all the desirable elements in a single kiln. For example, small sized stone may interfere with good draught, or good draught may spoil uniform heating. Economy, too, imposes a limit on the cost of installation of the kiln and its eventual operation. A kiln suitable for high magnesian stone may prove a failure for a high calcium rock, and one suitable for a hard stone may be quite unsuitable for chalk.

No matter what the shape or size of the kiln, it must consist essentially of five parts or zones, namely :

- (1) A feeding or charging zone.
- (2) A preheating zone in which the stone or chalk is slowly heated by the waste gases from the burning fuel.
- (3) A zone of combustion where the fuel is burning and creating the heat necessary to complete the conversion into lime.
- (4) A cooling zone in which the temperature of the lime is reduced to that of the atmosphere, or as near to it as possible.
- (5) A discharging zone.

If any of these zones is too small to do the work required of it, the kiln will not be so economical in fuel as it should be, and consequently, it is of the highest importance that these zones should be studied both as to their size and to their position in the kiln.

In a Hoffman or tunnel kiln a total length of at least 168 ft. appears to be necessary ; the lowest effective height of a vertical kiln should be at least

43 ft. quite apart from any chimney or any means of delivering the discharged lime into trucks or bins. This figure is a minimum if the fuel is to be used to the best advantage; shorter kilns will burn equally good lime, but will waste fuel.

In designing or recommending a kiln, the relative importance of the different elements must be determined from a study of the local conditions as regards stone, fuel, power supply, market, etc.

The first essential is that the kiln shall heat the stone or other material to the requisite temperature as uniformly as possible. The temperature required will depend on the nature of the stone and must be found by trial. In the case of dolomite which has to be sintered, a very much higher temperature will be needed than for ordinary limestone or chalk, and the kiln must be selected accordingly.

Again, the requisite temperature cannot be obtained in a very tall kiln loaded with chalk because the latter would be crushed and the draught reduced so much that the fuel would not burn properly. A short kiln or rotary kiln must, therefore, be used.¹ Similarly with "small stone" the draught would be inadequate and a rotary kiln may be required.

A further essential in selecting a kiln for burning large quantities of stone or chalk is to see that it provides for the prompt removal of the gas as soon as it is formed. This may be effected by means of an exhauster, but unless the gas is required in a concentrated form for some other purpose, it is much better to pass air through the kiln in order that the carbon dioxide may be carried off with the air through a chimney.

The next factor to be considered is the amount of fuel required to burn the stone or chalk. This varies with the material to be converted into lime, as more fuel is needed for loose powdery chalk than for pieces of limestone above 2 in. in diameter. The difference is almost wholly due to the extent to which the hot gases produced by the fuel can rise among the pieces of material. If the latter is in the form of powder, it is much more difficult to pass the hot gases through it than if small lumps of stone are to be burned. If the stone or chalk is in very large lumps, the outside of them may be well burned, but so much time is required before the heat can penetrate to the centre of a large lump that it is very difficult to burn them completely.

The amount of fuel required also depends on the extent to which use is made of what are sometimes called the waste gases, *i.e.* the hot gases produced by burning the fuel, and what proportion of the heat contained in the hot lime can be recovered and used. If, as in the older type of lime kilns, the gases pass out of the top of the kiln at a high temperature, the waste of heat must necessarily be great. For a kiln to be effective with natural draught (*i.e.* without a fan or exhauster) the gases passing out of it must have a temperature

¹ An ingenious means of increasing the thermal efficiency of chalk kilns has been devised by Priests, Furnaces Ltd., who have built four vertical mixed-feed kilns close together, each kiln having an effective height of 28 ft. The waste gases from each kiln enter the next one and so preheats the chalk in the succeeding kilns. The fuel so effected enables the four kilns working together to have a lime : fuel ratio of 6 : 1 or 374 lb. of coal per ton of lime—an extraordinarily good figure. This ingenious combination of the principles in a Hoffman and a vertical kiln appears to have great possibilities.

of at least 400° F., and as the creation of a draught by means of a fan is about equally costly in fuel as a chimney working at the temperature just mentioned, it may be taken for granted that the flue gases must pass out of the kiln at as near that temperature as possible.

An old-fashioned flare kiln, working on the batch system, will require about 10 cwt. of fuel for each ton of lime produced. A good, yet short, vertical shaft kiln will require about 8 cwt. of fuel per ton of lime produced, but a really well-designed vertical shaft kiln should require less than 4 cwt. of fuel per ton of lime produced, though in many vertical kilns the fuel consumption averages 4-5 cwt. per ton of lime produced. A good rotary kiln will usually require 6 cwt. of fuel per ton of lime, but this extravagance is counterbalanced by the facility with which small stone and even powder can be burned.

Gas-fired kilns require more fuel than mixed-feed kilns owing to the loss of heat due to conversion into gas; a good gas-fired vertical kiln should not require more than 5 cwt. of coal or coke per ton of lime.

It is sometimes more convenient to quote the fuel consumption as a simple numerical ratio; thus 5 : 1 indicates that 5 tons of lime are produced by 1 ton of fuel. To convert such a ratio into "cwt. of fuel per ton of lime" the first figure should be divided into 20; thus, with a ratio of 4 : 1, 5 cwt. of fuel is required per ton of lime.

The following ratios are interesting :

TABLE XXVII.—*Fuel Consumption of various kilns.*

Kind of kiln.	Lime : Fuel.
Flare	2-3 : 1
Hoffman	5-6 : 1
Short Vertical (mixed feed)	2½-4 : 1
Tall Vertical (mixed feed)	4-6½ : 1
„ „ (externally fired)	4-6 : 1
„ „ (gas fired)	5-6 : 1
Rotary	2½-4 : 1

In comparing them with others, due regard must be paid to the effect of local circumstances.

In each case, the lime produced must not contain more than 5 per cent. of under or over-burned material or these improperly burned materials must be separated before the amount of lime produced is determined. This precaution is necessary, as otherwise a close comparison is impossible.

Moreover, it may be stated that any kiln which is burning more than 5 cwt. of good fuel per ton of fat lime produced is needlessly extravagant, and a really modern kiln should use only 3-4 cwt.

If hydraulic or lias lime (which is rich in clay) is being burned, the proportion of fuel required will be much lower, as clay requires so much less heat to burn it than limestone. Without going into details, it may be stated that for each ton of "clay" in the hydraulic lime, only $\frac{3}{4}$ cwt. of coal would be required in a well-designed vertical kiln, so that a hydraulic lime containing 66.6 per cent. of lime and 33.3 per cent. of burned clay should not require more than 3 cwt. of good fuel for each ton of hydraulic lime produced, and in a really well-designed kiln this would be reduced to about $2\frac{1}{4}$ cwt.

The greatest efficiency in fuel can only be obtained when the fuel is burned in intimate contact with the stone. If this is done, the ash from the fuel will become mixed with the lime and will reduce its purity to a corresponding extent. If this ash is objectionable and the purest lime attainable is required, it is necessary to permit a corresponding waste of fuel, as the latter must be burned separately, and only the products of its combustion be brought into contact with the stone; kilns which permit of this are known as "gas-fired" and "semi-fired" kilns respectively.

If the fuel is first gasified in a producer, there will be an inevitable loss of about 30 per cent. of its total heating power in the producer, and for this reason alone gas firing can never be so cheap as direct firing, as the gasification of the fuel prior to its combustion is more wasteful in heat than direct combustion. In a semi-gas-fired kiln the loss is not so great, but it is appreciable, and must be carefully considered in selecting a kiln.

On the other hand, the use of gas or semi-gas, with secondary air, enables a greater control to be exercised over the air admitted to the kiln, and this is a distinct advantage. As a result, gas-fired kilns often prove to be much more economical in fuel than might be supposed. A well-designed gas-fired kiln should not require more than 5 cwt. of good fuel per ton of fat lime produced, or a somewhat smaller amount if hydraulic lime is being burned. This assumes that there is ample power available to drive the fan needed to supply the secondary air free of charge; otherwise the additional fuel (or its equivalent) needed for this purpose must be added. It will not be less than 6d. per ton of lime produced.

The chief drawback to a gas-fired or semi-gas-fired kiln is the additional skill required on the part of the fireman. A badly-managed producer will easily double the fuel consumption, and thus turn what should have been a profit into a serious loss. In any case, additional time is required to attend to the producer or fires.

In selecting a kiln, it is seldom that sufficient attention is paid to the supply of air to it. This, as previously explained, is needed for three purposes: (a) to ventilate the kiln, and to remove the carbon dioxide before its pressure becomes so great as to hinder the burning; (b) to ensure the complete combustion of the fuel; and (c) to cool the lime in order that it may be handled safely as soon as it is discharged from the kiln.

The importance of the first of these purposes must not be overlooked, or the proportion of unburned stone will be too high. On the other hand, an

excessive amount of air cannot be used for this purpose, or the loss of heat will be serious. It might be possible to introduce air just above the zone of combustion, but this would have a serious cooling effect on the stone in the preheating zone, and cannot be recommended. On the other hand, a large excess of air, introduced just below the zone of combustion, would necessitate an increased supply of fuel. On the whole, the best method is to provide an efficient draught, and to allow the waste gases to pass out of the kiln at such a temperature as will ensure the carbon dioxide rising upwards and away from the zone of combustion without the necessity of introducing a larger proportion of air. In short, a good draught producer—either a chimney or fan—is essential. It is equally important that the draught shall not be interrupted by the feeding or discharging of the kiln, and the avoidance of this offers ample scope to ingenious inventors.

The supply of air required for the combustion of the fuel is a comparatively simple matter, as it is analogous in every way to that required for kilns and furnaces in other industries. At the point of combustion the air should be at the same temperature as the fuel, so that provision must be made either for heating it directly in recuperator flues or indirectly by using it for cooling freshly burned lime, or by making use of both these methods.

If no attention is paid to the amount of air required to cool the lime, it is possible to pass a quantity of air through a mixed-feed kiln as will just ensure the complete combustion of the fuel, but this will produce very hot lime and so is very wasteful of heat. On the other hand, if sufficient air is used to cool the lime rapidly it will eventually have to be raised to the highest temperature of the kiln and this—though often done—is very wasteful of fuel. For that reason, the air required for cooling should be limited as far as possible.

To ensure proper control of the air supply and the best use of the fuel, all false draughts, due to cracks in the kiln structure, etc., must be avoided. To secure this, the constructional work must be well done, and all skimmed work must be avoided. A steel casing is also advantageous.

Overheating of the lime must be avoided when the lime has, afterwards, to be slaked. It is far preferable to pass some stone incompletely burned through the kiln than to produce any over-burned lime.

Loss of heat by radiation through the kiln walls may be reduced by the use of a vertical insulating layer of kieselguhr, or of insulating bricks. Sand is often used for this purpose, but is much inferior, though it is sometimes useful inasmuch as it flows into cracks in the masonry and so prevents air leaking through them.

The arrangements for emptying the kiln require careful study. Most of the elaborate automatic devices are useless for lump lime, as they exert a grinding action. Other arrangements require too much labour, and are difficult to control. Some excellent discharge devices are available, but the selection of one for any particular works should be made under expert advice.

The location of the kiln with respect to fuel may also affect the selection; for example, a lime plant located near a coal mine need pay less attention to the

cost of fuel than one at a distance, but might, on the other hand, be compelled to consider labour costs carefully because of the competition of the mine for men.

It has been clearly shown that a lime kiln to be efficient must be designed and operated to conform to the characteristics of the stone to be burned and the fuel available. The raw material and fuel will determine to some extent the size and style of kiln. The size of the fire places or gas burners depends on the heating requirements of the stone, and their design on the kind of fuel. The heating-chamber of the kiln must conform as fully as possible to conditions which will secure uniform heating with good draught.

At the present time, the greatest advance to be made in kiln design has to do with combustion and the application of present-day knowledge of heating to lime kilns. Radiation and other heat losses vary in magnitude and relative importance in different kilns, and each type should be strengthened where it is weak. While fuel is the largest item in the cost of kiln operation, the cost of labour, repairs, and fixed charges should not be overlooked. In erecting a new limeworks, or enlarging an existing one, the kiln used should be decided upon by the combined judgment of the works' manager and an experienced technical adviser. The magnitude of the savings which may thus be effected makes expert advice very cheap in this connection, provided that the adviser is really independent, and is not merely a salesman acting as a consultant.

A lime burner who endeavours to make such selection without calling in an independent and impartial adviser, is almost certain to make a serious error. He may easily select a kiln which will produce a lime of good quality, but, unless he takes into consideration all the foregoing statements, as well as many other matters for which no space can be found in this volume, the kiln may cost so much as to be unremunerative and it may waste as much fuel as would otherwise have paid a respectable dividend on the capital involved.

Where such advice is not available, it will generally be found that :

(a) A tall shaft kiln with mixed feed is the most economical in fuel, but the ashes in the fuel contaminate the lime.

(b) When the purest lump lime is required, a vertical gas-fired or semi-gas-fired kiln is essential.

(c) When small stone is to be burned, a suitably designed vertical kiln or a rotary kiln will be necessary ; the latter is wasteful in fuel, but can burn smaller pieces of stone than any other types of kiln ; it can even burn lime sludge.

(d) When dead burned dolomite is required a vertical mixed-feed kiln with a supply of air under pressure is usually the best, but a gas-fired kiln with a central gas burner as well as peripheral ones is sometimes satisfactory, and in some Continental works rotary kilns are used. An electric arc is probably the ideal means of producing dead burned dolomite, but is only practicable where electricity is very cheap.

The following Table, showing briefly the chief features of the various types of kiln, is useful when selecting a kiln for producing lime :

TABLE XXVIII.—*Chief features of various kilns*

Type.	Pot or Flare Kiln (Intermittent).	Draw-Kiln (Intermittent).	Vertical Mixed-Feed Kiln (Continuous).	Vertical Externally-fired Kiln (Continuous).	Vertical Gas-fired Kiln (Continuous).	Hoffman Kiln (Continuous).	Rotary Kiln (Continuous).
Stone required	any kind if large	any kind if large	hard, large	hard, large	hard, large	large or hard or soft	any kind if small
Fuel	coke, coal, or oil	coke, coal, or oil	coke or coal	coke or coal	gas	coal or coke	coal, oil, or gas
Fuel-ash in lime	none	all	all	little	none	all	all
Capital cost	low	low	low	medium	high	high	high
Repairs cost	low	low	low	medium to low	high	low	high
Labour cost	high	medium	low to medium	medium	medium	high	medium
Draught	low	low	low	low	medium	low	high
State of lime	not uniformly cool	not uniformly cool	not uniformly cool	not uniformly warm	not uniformly cool	fairly uniformly cool	uniformly hot
Output	low	low	high	medium to high	high	high	high
Quality of lime	good	fair to good	good	good	good	good	medium
Charging	laborious	easy	easy	easy	easy	laborious	easy
Discharging	laborious	laborious	easy to hard ¹	easy to hard ¹	easy	laborious	easy
Fuel(cwt.) per ton of lime	7-10	6-9	3½-8	4-7	4-5	3-4	6-8

The *thermal efficiency* of a kiln is the ratio of the total heat supplied by the fuel to that required to decompose the stone completely under ideal conditions ; it is usually expressed as a fraction or as a percentage. Thus, if the heat needed to decompose 1 lb. of pure calcium carbonate under ideal conditions is 776 B.T.U. and the heat required in a certain kiln is 1,552 B.T.U., the thermal efficiency of that kiln is $776/1552 = 0.5$ or 50 per cent. In a "heat balance sheet" or statement of the distribution of the heat supplied to a kiln (p. 391), the total heat being represented by 100, the efficiency is the same as the figure which represents the heat required to heat and decompose the stone.

¹ Depends on kind of discharging device (if any).

The thermal efficiency of lime kilns is very difficult to determine with accuracy because the rate at which the calcium carbonate is decomposed varies with the temperature and with the size of the particles. Whiting and Turner¹ found that, *in vacuo*, decomposition can be detected at 500° C., but the rate is exceedingly low. With finely-ground carbonate in very small quantities, the rate of decomposition increases rapidly with the temperature. At normal atmospheric pressure, the minimum temperature at which the conversion into lime is complete is 897° C.² and is influenced by the size of the particles or pieces of lime.

According to Dyckerhof, the time-temperature curve of calcium carbonate at normal atmospheric pressure shows a marked endothermal reaction at 880–910° C. This corresponds closely with the 897–900° C. found by other investigators using different methods. For commercial lime burning, a rather higher temperature must be regarded as the minimum because the rate of decomposition must not be too low; 915° C. may be regarded as the practicable minimum under working conditions.³

Careful measurements under critical laboratory conditions show that at 900° C. 425 calories are required to decompose 1 gm. of calcium carbonate. This corresponds to 776 B.T.U. per 1 lb. of calcium carbonate, or 1386 B.T.U. per 1 lb. of lime, but these figures only apply to finely-ground calcium carbonate heated in small quantities. For larger masses and for more rapid decomposition more heat is required.

At 915° C., which is the minimum temperature at which the decomposition occurs sufficiently rapidly to suit commercial conditions, the amount of heat required to convert 1 lb. of calcium carbonate into lime may be assumed to be 1105 B.T.U. which is made up of :

Heat to raise the carbonate to the required temperature ...	329 B.T.U.
Heat for decomposition	776 B.T.U.
	1105 B.T.U.

Of this heat, 329 B.T.U. remain in the products (carbon dioxide gas and lime), and should be available for heating more calcium carbonate so that the net amount of heat required under ideal conditions is only 776 B.T.U. per lb. of carbonate.

Hence, if c is the calorific power of the fuel, f the weight of fuel burned (in pounds), s the weight of stone burned (in pounds), and e the efficiency factor :

$$ecf = 776s, \text{ or } e = \frac{776s}{cf}$$

¹ *J. Soc. Glass Tech.*, 14, 409–24 (1930). A paper by Smyth and Adams (*J. Amer. Chem. Soc.*, 45, 1167, 1923) shows that the pressure of the gas produced increases with the temperature and that to ensure complete decomposition the temperature must be greater than corresponds to the gas pressure.

² Smyth and Adams, *loc. cit.*

³ The corresponding temperature for magnesium carbonate is 756°C. Dolomite dissociates smoothly between these temperatures.

Under ideal conditions, $e = 1$, but under others it is a fraction which, when multiplied by 100, gives the percentage efficiency of the kiln. Thus, if 20 lb. of coke with a calorific power of 12500 B.T.U. are required to burn 100 lb. of limestone :

$$e = \frac{776 \times 100}{12500 \times 20} = 0.31 \text{ or } 31 \text{ per cent.}$$

If a pure carbon fuel with a calorific power of 14544 B.T.U. could be used without any loss, the fuel consumption would be only 0.05 lb. per lb. of calcium carbonate, or 5 per cent. of the weight of stone burned.

The distribution of the heat used for burning lime differs with the type of kiln and the working conditions. In a vertical or shaft kiln of good design, using external fireplaces for the coal, R. R. Meade found (in 1921) that the heat was utilized as follows :

Heat used to decompose the stone	...	...	...	39 per cent.
Loss of heat in outgoing gases	...	...	...	22 " "
Loss of heat by radiation	...	...	...	17 " "
Loss of heat by incomplete combustion of fuel	...	...	...	11 " "
Loss of heat in lime when drawn	...	...	...	11 " "
Total heat in fuel	...	...	...	100

This corresponds to :

Heat utilized	...	...	39 per cent.
Heat lost	...	...	61 " "

This kiln required 639 lb. of fuel per ton of lime produced, or a lime : fuel ratio of $3\frac{1}{2} : 1$, which is poor, the loss of heat by radiation and incomplete combustion being very high.

In a well-designed mixed-feed kiln using 450 lb. of fuel per ton of lime produced the distribution of the heat is approximately :

Heat used to decompose the stone	...	...	...	55 per cent.
Loss of heat in outgoing gases	...	...	...	22 " "
Loss of heat by radiation	...	...	...	10 " "
Loss of heat by incomplete combustion of fuel	...	...	...	3 " "
Loss of heat in lime when drawn	...	...	...	10 " "
				100

Vertical kilns differ greatly in their efficiency, and fuel consumptions of 400-640 lb. of coal or coke per ton of lime are common.

In mixed-feed kilns of great height in proportion to their output, the loss of heat in the outgoing gases and lime may be reduced still further and the thermal efficiency increased to about 64 per cent., which appears to be the maximum attainable in commercial kilns.

The thermal efficiencies of several types of kiln were found by Emley¹ to be

TABLE XXIX.—*Thermal efficiency of lime kilns.*

Type of kiln.	Thermal efficiency.
Vertical kiln with natural draught ...	30.9 per cent.
" " " forced and induced draught	44.1 " "
" " " producer gas	35.3 " "
" " (Schmatolla)	54.0 " "
" " (Eldred)	38.3 " "
Rotary kiln	38.2 " "

those shown in Table XXIX, but some of the data on which these figures are based appears to be erroneous and so render those in the Table uncertain. Unfortunately, no other corresponding series is available.

Instead of using the normal method for calculating efficiency, it is often advantageous to assume that the theoretical minimum fuel-requirement (using pure carbon of calorific power 14544 B.T.U.) is 13.4 per cent. of the lime producible or 300 lb. per ton of lime. On this basis, a kiln with a fuel ratio of 5 : 1 or 448 lb. per ton of lime will have an efficiency of 67 per cent.

For further information on the fuel-consumption of various kilns see pp. 385, 389 and 436.

THE EFFECT OF IMPROVEMENTS IN KILNS

It should be noted that each improvement in a lime kiln usually adds considerably to the cost of erection, so that all modern types of lime kilns are far more costly than the primitive kilns formerly used. This is largely inevitable, as it is partly due to the necessity of using some fuel other than wood, whereas wood is, in many ways, the simplest and best fuel to employ. Unfortunately, it is no longer available in sufficiently large quantities in those localities where the largest quantities of lime are required.

This increased cost is only beneficial when it confers some distinct advantage, such as a saving in labour or fuel, the value of which is greater than the cost. It is, therefore, very important when selecting a kiln, or when considering the utilization of some improvement, to consider its cost in relation to the value of its advantage. To take an extreme case as an example, it is useless to erect a kiln which is very costly if the saving in fuel to be realized from its use is less than the increased cost of the kiln. A common mistake is to over-estimate the amount of lime which will actually be produced by a kiln, with the result that a cheaper though inefficient kiln may sometimes prove to be more economical than a more efficient kiln.

No kiln is perfect, so that in selecting a kiln for any particular work, it is usually necessary to attach more importance to one characteristic than another.

¹ U.S. Bureau of Standards, Tech. Paper No. 16 (1913).

This is well indicated in the following Table, originally drawn up by A. E. Truesdell :

TABLE XXX.—*Desirable features in Lime Kilns*

<i>For Universality.</i>
(a) Ability to burn either hard or soft stone.
<i>For High Quality.</i>
(b) Absence of ash in the lime.
(c) Uniform heating.
(d) Low temperature operation.
<i>For High Output.</i>
(e) Good draught.
(c) Uniform heating.
(f) Steam in combustion gases.
(g) Small-sized stone.
<i>For Low Fuel Cost.</i>
(h) Minimum discharge gases.
(i) Cool discharge gases.
(j) Cool lime.
(k) Low radiation.
(l) Easy lime discharge.
(g) Small-sized stone.
<i>For Low Labour Cost.</i>
(m) Easy kiln charging.
(l) Easy kiln discharging.
(n) Easy fuel and ash handling.
<i>For Low Repair Cost.</i>
(d) Low temperature operation.
(i) Cool discharge gases.
(j) Cool lime.
(g) Small-sized stone.
<i>For Low Fixed Charges.</i>
(o) Low first cost of kiln.

SUNDRY KILN APPLIANCES

In addition to the main structure of the kiln and the various appliances used for charging and discharging it, various other appliances are required for efficiency.

The *shovels* used for handling the fuel should be as large as a man can conveniently use as coal is a relatively bulky material and it is foolish to use as small a shovel for coal as for stone.

The *spades* for loading stone usually have pointed blades ; they should be only about half the area of the shovels used for coal.

Several large *forks* with about 9 prongs each, 1½-in. apart, should be provided, and two or three rakes with three wide prongs nearly at right angles to the shaft are often convenient for drawing the lime from the kiln at the discharge end and for distributing the stone at the top of the kiln.

Pokers, fire irons, and crowbars of various lengths up to 15 ft. are also required, as well as sundry tools, such as *hammers, chisels, coal skips, etc.*

For controlling the burning of the kiln, *gas analysis-apparatus, pyrometers, draught gauges, etc.*, are useful and desirable, and are considered more fully in connection with the operation of the various types of kilns.

SUPPLIERS OF KILNS AND APPLIANCES

As it is impossible, in the space available, to illustrate or describe every machine or other article made by different firms, the following list is printed to facilitate further enquiries. It is not complete, because some firms may have been unintentionally omitted, nor does it mention suppliers of articles which can readily be obtained with a minimum of enquiry. The list is also limited to appliances of which the author has had personal experience.

CONVEYORS AND ELEVATORS (*see p. 102*)

KILNS (*see LIME KILNS*)

LIME KILNS

Allen, Edgar, & Co. Ltd., Imperial Steel Works, Sheffield, 9.

Dean, Hetherington, & Co., Accrington.

Priest's Furnaces Ltd., Albert Road, Middlesbrough.

Stourbridge Gas Construction & Engineers Ltd., Brierley Hill, Staffs.

There are no firms in the British Isles who make a speciality of building mixed-feed kilns. Several steeple-jacks (chimney-builders) can build such kilns efficiently if supplied with suitable plans.

PYROMETERS

Cambridge Instrument Co. Ltd., 45 Grosvenor Place, London, S.W.1.

Foster Instrument Co. Ltd., Letchworth, Herts.

Siemens Bros. & Co. Ltd., Woolwich, London, S.E.18.

CHAPTER VII

FUEL FOR LIME KILNS

AMONG the various kinds of fuel available for lime burning, there is a fairly wide choice—coal, coke, anthracite, lignite, peat, wood, grass, rice-husks and other vegetable matter, oil and gas, all being used satisfactorily for this purpose. Where a high-class coal is available, it is the best fuel, its only rival being natural gas, but as the choice of fuel usually depends on its cost the following information should be carefully considered:

Coal.—If the fuel is to be burned in intimate contact with the stone a coal of low volatile content, such as anthracite or smokeless steam coal, is the best, as the greater part of the volatile matter either escapes unburned or is burned under conditions where it is of little or no value and so is practically useless. Moreover, coal with a large proportion of volatile matter creates irregular heating and “sticking” in the kiln. When coal is used in external fire places or as a source of producer gas, a coal which is moderately rich in volatile matter is an advantage, as it produces gas which burns with a longer and hotter flame. An excess of volatile matter should be avoided, as it tends to decompose and form soot which necessitates “blowing out the flues” once a week or even oftener, unless semi-producers are used which are built on to the walls of the kiln.

It is a great mistake to use a long flame coal in direct contact with the stone; such a fuel should be gasified prior to use. On the other hand, almost any coal can be used in a gas producer though it is not wise to use too fine a “slack” on account of the difficulties in using it. “Small nuts” is the form of coal which usually gives the best results in gas-producers, large lumps and slack being equally objectionable though for different reasons.

Powdered coal is not desirable where high-grade lime is concerned as the ash from the fuel is blown on to the lime; otherwise, it would be an excellent fuel.

The objectionable impurities in coal used for lime burning are *volatile sulphur* (which should be as low as possible and certainly less than 1 per cent.), *ash* (which should, if possible, be less than 6 per cent.), and *water* (which should not exceed 6 per cent.). The sulphur and ash spoil any lime with which they may come in contact, whilst the water requires heat to expel it and so causes a wastage of fuel.

Coal is largely used because of its availability, and, when properly employed, it is a satisfactory fuel. Its chief disadvantage is the great tendency to produce too short and too hot a flame which tends to deposit finely divided carbon in the lime (with consequent discoloration), as well as tending to overburn the lime. This disadvantage may be overcome by converting the coal

into producer gas, the flame of which can be made to resemble that of wood more closely than any other fuel.

Some coals contain too much sulphur, which spoils the lime for chemical purposes, though not for the building trade and for agriculture. For the purest lime the coal should contain less than 1 per cent. of sulphur unless the coal is converted into gas before entering the kiln. Sulphur in the fuel also appears to discolour the lime, imparting an unpleasant brownish tinge, the precise cause of which is not known.

It is important to distinguish between (a) the sulphur which burns to sulphur dioxide and absorbed by the lime, and (b) the sulphur combined with the ash as sulphates. The latter is harmless unless it is decomposed by an excessive temperature in the burning when it may form sulphur dioxide. The total percentage of sulphur in a lime is not a reliable guide to its effect on metals smelted with the aid of lime.

Very poor coal containing 10 per cent. or more of ash, is not very suitable for lime burning on account of its low heating power, though much of it is used for this purpose. Many English lime burners would be astonished if they were to visit some of the lime works in France and Germany, and observe what excellent lime is produced with coal of so poor a quality that no English lime burner would attempt to use it. The use of such low-grade fuel is not economical, but the fact that it can be used when required shows that many lime burners might, with advantage, use a cheaper fuel than they employ at present; if the kilns are suitable for it. The best fuel for lime kilns is a good quality of small coal, anthracite, or coke. "Dust" should be avoided as it burns away too rapidly and much of the heat produced is lost. If none of the fuel is small enough to pass through a $\frac{1}{4}$ -in. hole, or so large that it remains on $1\frac{1}{2}$ -in. hole, it will usually be satisfactory. Gas coal and cannel coal are not very satisfactory fuels for lime kilns unless they are used in producers.

Pulverized coal has been used for burning lime in vertical (*Otto*) and rotary kilns. It has several important advantages over larger pieces, inasmuch as combustion is more perfect and is under better control. It is inferior to gas firing, because the ash from the fuel becomes mixed with the lime, and also because the flame tends to be much too hot. Pulverized coal is burned in a manner similar to oil, which it closely resembles. It may be applied to Hoffman and similar chamber kilns if automatic stokers are employed.

The chief advantages of pulverized fuel over gas when a specially pure lime is not required, are :

(i) Pulverized fuel can be burned with less excess of air than is needed for producer gas and the products of combustion are much less voluminous because there is so large a proportion of useless and inert nitrogen in producer gas.

(ii) The serious loss of heat due to gasification (which may easily exceed 20 per cent. of the total heating power in the fuel) is avoided when powdered fuel is used. Against this must, however, be set the cost of drying and grinding the fuel which may be expensive.

(iii) The flame from pulverized fuel is more regular than that from producer gas.

The advantages of pulverized fuel over the ordinary form are (a) combustion is almost perfect, so that there is no waste due to smoke and soot; (b) the heating is much more regular and is under much better control.

The essentials when powdered fuel is used, are:

(1) The fuel must be sufficiently dry for each particle to remain suspended separately in the air. Damp fuel tends to segregate into masses composed of numerous particles and the burning is then very irregular.

(2) The fuel must be sufficiently finely powdered for each particle to burn away completely in the air with which it is surrounded; otherwise burning will be irregular and the fuel will be wasted.

(3) Ample space must be provided in which the combustion of the fuel can be completed before it comes into contact with the lime; this is easily arranged in long rotary kilns, but is a very difficult matter with vertical kilns and then involves the use of very large combustion chambers.

Coke is an excellent fuel for lime burning, either in direct contact with the stone or for the production of gas. If a pure lime is required, "furnace coke" should be used as this contains a minimum proportion of sulphur and ash. Coke can only be used satisfactorily when kilns are burning properly, and it is then almost an ideal solid fuel, the only other approaching it being anthracite "nuts" or "large peas."

As coke has little or no volatile matter in it, a difficulty is sometimes experienced in lighting it, but a skilful burner will usually find in good coke a wholly satisfactory fuel. From the lime manufacturer's point of view the chief disadvantage of coke is its cost, but when considering this it should be remembered that if the effective heating value of good furnace coke be represented by 95, that of most small coal and slack must be represented by 70-77, so that good coke costing $1\frac{1}{4}$ - $1\frac{1}{2}$ times as much per ton as coal may not prove any more costly in use than poor coal, and will produce a better burned as well as purer lime.

The impurities in coke which are objectionable in lime burning are the same as those in coal. Coke from gas works can seldom be employed for first-class lime on account of the sulphur present; this is of little importance in lime used solely for agricultural purposes.

As previously stated, furnace coke is usually more free from sulphur than gas coke, but it burns less freely and so a considerable part of it tends to pass through the kiln unburned. For these reasons, gas coke, or only the soft coke from coke ovens, is often preferred.

The efficiency of coke in a mixed-feed lime kiln is often greatly improved by mixing it with about one-fifth of its weight of coal. The coke used for burning limestone should be as pure as possible. Gas-works coke is not so satisfactory as oven coke, as the latter is made from fuel low in sulphur and is, therefore, less liable to contaminate the lime. For building and agricultural lime, this impurity is of no importance, and gas coke, which is usually obtainable at a smaller cost, may then be used.

Anthracite may be regarded as a coal which has lost most of its volatile matter and, therefore, resembles coke in composition but not in appearance. It ignites more easily than coke and burns with a rather longer flame. For mixed-feed kilns it is an excellent fuel when not too costly.

Peat is not a satisfactory fuel for burning lime as its heating power is too low. It is, however, used in small kilns for burning lime for agricultural purposes in localities not ordinarily supplied by the larger lime kilns. Peat can also be used to produce gas for gas-fired kilns. It must be dry.

Lignite or *Brown Coal*, in its crude state, is almost as unsatisfactory as peat, and for the same reason. If dried and made into briquettes it is more

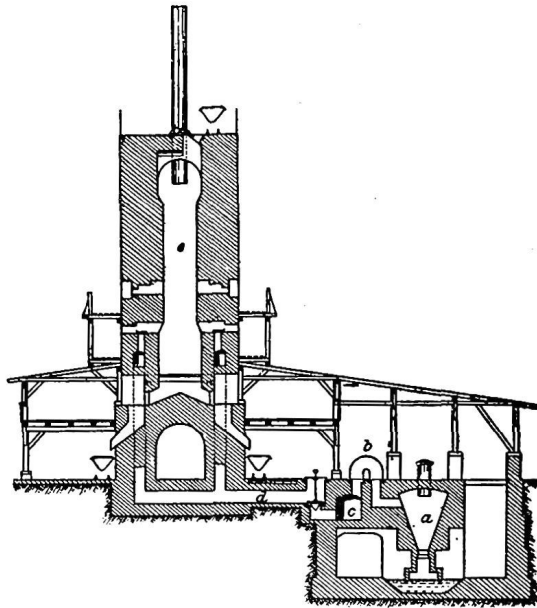


FIG. 103.—HERMAN'S KILN WITH GAS PRODUCER USING LIGNITE.

satisfactory, but much inferior to coal or coke. It may be used in a gas producer when these other fuels are not available, or are too costly, but is not satisfactory if mixed with the stone. As lignite contains a large proportion of water, it is desirable to cool the gas made from it to about 180° F., thereby removing the excess of water and producing a gas of suitable heating power. The producers must be much larger than for coal, but are, otherwise, similar. Fig. 103 shows a Herman's gas-fired kiln in which the long and rather narrow producer *a* is supplied with lignite, the gas from which passes through one or more bends *b* in which the water vapour is condensed, the cooled and purified gas passing through the duct *d* into the kiln. It is seldom necessary to use any special cooling device; the gas will usually be cooled sufficiently by passing through one or more bends made of sheet iron, as shown.

Weight for weight, lignite is very inferior to coal, but as it often occurs in very large quantities close to limestone, and in localities where coal or coke are very expensive, the possible use of lignite as a fuel should not be overlooked.

Wood is specially suitable where obtainable as it burns with a long mild flame which does its work readily without much risk of overburning. Wood has the great advantage of producing flames of a suitable temperature so that it is easier to obtain lime of high quality with wood than with any other fuel.

Wood was used in all ancient lime kilns, but is now too costly except in a few localities. It throws off its heat slowly and very uniformly, producing long flames of fairly constant volume, so that whilst it is far from efficient so far as the consumption of fuel is concerned, lime burning is very easy when wood is used in an intermittent kiln.

Grass and other vegetable matter is only used for burning lime in countries where other fuel is scarce or where an abundance of waste vegetable matter has to be burned to destroy it. Such material is best burned in special fire-places, preferably of the gas-producer and semi gas-producer type, and not in direct contact with the stone. With the exception of wood, the use of these materials is much more troublesome than any other fuel, and is not economical except under special conditions.

Oil is an excellent fuel for burning lime, especially in those countries where suitable coke or coal is scarce. Almost any fuel oil may be used, though care should be taken to avoid oils having 1 per cent. or more of volatile sulphur if a high-class lime is required. The proper burning of the oil requires some skill and the provision of suitable appliances, but when these are available oil burning is excellent in every respect. In countries where coal is plentiful it will usually be cheaper than oil, but there are many places where oil proves to be cheaper than coal and yields a superior lime.

The essential conditions for the satisfactory use of oil are :

(a) It must be broken up or "atomized" into extremely minute drops, each of which is suspended in a quantity of air sufficient to effect its complete combustion.

(b) The mixture of air and oil must be ignited in a chamber of such a size that combustion is almost or quite complete before the flames and hot gases come into contact with the lime and stone, as, otherwise, the flames will be chilled, smoke will be produced, there will be a serious waste of fuel, and some of the lime will be imperfectly burned.

(c) There must be sufficient air to prevent too hot a flame from coming into contact with the lime and causing local overburning.

The production of a suitable mixture of air and atomized oil is effected in a device known as an oil burner. It consists of a small orifice through which the oil flows (usually under a slight pressure), and then comes into contact with a blast of steam or air which breaks it up into extremely small drops, forming a sort of "mist." In some burners, the atomization is effected by steam and the atomized oil is then mixed with air in a mixing jet worked like an injector, whilst in others the atomization is effected by air alone. In the

"Rotax" burner the oil flows into a rapidly revolving cylinder which distributes it in the form of a very thin film on the walls of the cylinder, from which it then flows, and by the force of its propulsion is very effectively atomized. The chief advantage in this device is that it avoids the use of the very fine orifices needed in other types and, consequently, the risk of choking the burner with small particles of impurity in the oil is wholly avoided.

The flame from a good oil burner can be made of almost any desired length, but as a short flame is much too hot and would overburn the lime, a flame of 6-8 ft. in length is usually employed.

The burners are placed in combustion chambers built around the circumference of the kiln. These chambers are usually 3 ft. high, 2 ft. wide, and 3-4 ft. from back to front; they should be built of good firebricks surrounded by others of a cheaper quality, so as to produce walls at least 18 in. thick. If an insulating layer of kieselguhr or diatomite bricks is included it will be advantageous. The combustion chamber should be quite empty, except that a few firebricks may be piled up in front of the burner so as to baffle the flame and also to act as a catalyst and ensure good combustion. As the oil burns, the products pass out of the combustion chamber and into the kiln, entering the latter in a manner similar to the gas in a gas-fired kiln.

Some users of oil-fired kilns allow a considerable quantity of unburned atomized oil to enter the kiln direct, in the belief that such oil is burned to better advantage in contact with the lime than in the combustion chamber; this is a matter which depends on local conditions and particularly on the size of the spaces between the pieces of lime.

The general position and arrangement of the oil burners and the size, shape, and position of the combustion chambers should be similar to those of the gas ports, etc., in a gas-fired kiln. The other portions of oil-fired kilns so closely resemble those of gas-fired kilns that they need not be described separately.

Gas may be either (a) *natural gas* obtained from wells in the ground in some localities; (b) *Town's gas* supplied from the local gas works, which is usually far too costly for lime burning, or (c) *producer gas*.

Artificially made gas may be produced in retorts, as "Town's gas," or in producers, when it forms "producer gas" which is an excellent fuel for burning lime with the added advantage that it can often be obtained from comparatively low-grade coals sold at low prices, but not suitable for mixing directly with the limestone.

Producer gas is the only fuel which reproduces conditions approximating to those of wood. By suitable regulation of the primary and secondary air, a long and comparatively cool flame can be maintained with the elimination of all chance of contaminating the lime with ash. Furthermore, the control of temperature within narrow limits when using gas is perfectly simple, whereas with the other methods described it is almost impossible. For these reasons gas-fired kilns can produce a purer and better lime than any other type.

Producer gas is made by passing air, or a mixture of steam and air, through

a long column of coke or coal contained in a gas producer. The resultant gas is rich in carbon monoxide and also contains a smaller proportion of hydrogen. The gas should *not* be scrubbed or purified in any way, but should pass direct from the producer to the kiln, as any treatment which cools or purifies the gas only reduces its heating value. The only exception is when the gas is made from peat or lignite, as these fuels yield a gas so rich in steam that cooling is essential. The tar and other impurities which prevent crude gas from being used in gas engines are an actual advantage in a kiln because they help to produce a longer flame than is formed by a purer gas.

Although producer gas can be produced by merely blowing a suitable quantity of air through a deep bed of hot fuel, it is advantageous in several ways to admit a little steam along with the air. The chief of these advantages are :

- (i) Less clinker is formed on the grate of the producer.
- (ii) The steam is decomposed, forming hydrogen and carbon dioxide, the former giving an intensely hot flame when burned.
- (iii) The moist gas decomposes the limestone at a lower temperature than when a fan is used.
- (iv) The producer can be more easily controlled when the air is injected by means of steam than when a fan is used.
- (v) A steam injector serves the same purpose as a fan, is cheaper, and has less cost for repairs.

The dimensions of a gas producer for use with a lime kiln should be chosen with regard to the fuel and the amount of gas required per hour. The most essential feature is the depth of the bed of fuel, for if this is not sufficient it will be almost impossible to produce good gas in a regular manner. About 3 ft. is the minimum depth of fuel when a good coal is used, but 4–6 ft. is preferable with some coal and with some other fuel. A fuel bed 5 ft. deep is always preferable to one of lesser depth unless the fuel is very small, when a shallow bed is essential because of its compactness. Coke and lignite, being voluminous fuels, may, with advantage, have very deep beds.

The fresh fuel enters at the top of the producer and as it descends it is first dried by the hot gas rising through it. On descending still farther it attains a temperature at which it parts with its tar and the materials which form ordinary "town's gas." At a later stage, the fuel is decomposed, forming carbon monoxide gas principally, and in the lowest or burning zone of the producer the fuel burns in the ordinary manner, thereby providing the heat for the production of gas. The ashes may fall through the apertures in a grate or, if no grate is used, they may be drawn out at intervals with a rake.

The following figures show the composition of a good producer gas used for heating a lime kiln :

Useful gases.

Carbon monoxide	...	...	...	...	24 per cent. (by vol.).
Hydrogen	...	...	...	...	6 " "
Hydrocarbons	...	...	...	...	2 " "

Diluent gases.

Carbon dioxide	...	...	...	...	5 per cent.
Nitrogen	...	...	...	...	62½ „ „
Oxygen	...	...	...	...	½ „ „
					—
					100 „ „
					—

The calorific power of producer gas is about 180 B.T.H. per cubic foot as compared with 500 B.T.U. in ordinary "town's gas."

The rate at which the fuel can be gasified depends partly on the fuel and partly on the producer. An average of about 10 lb. of coal per square foot of grate area per hour is reasonable, but three times this rate can be secured under favourable conditions.

The use of a grate or of a plain bottom in a producer should depend on the fuel used. If a grate is employed it should be of ample size, so as to admit air as uniformly as possible. Air which is admitted irregularly produces poor gas. For burning lime, a producer with a grate is usually to be preferred, but so much depends on the fuel that no general rule can be stated.

Elaborate producers are not necessary for lime kilns and should generally be avoided. The producer most commonly used for lime kilns in England is known as the "Duff," with a "dog kennel grate," but other types of producer are used satisfactorily.

Producer gas is probably the best form of fuel which can be used in most localities where a pure lime is required, and it is particularly suitable in such countries as Great Britain, where coal is relatively cheap, whilst good coke and oil are relatively dear. The chief drawbacks to the use of producer gas in burning lime are two: (i) the plant required is expensive and requires skilled attention, so that it is not suitable for kilns of very small or very irregular output, though excellent for outputs of about 7,000 tons per annum; and (ii) a serious loss of heat is incurred in converting the coal into gas and delivering the gas to the kiln.

As the resulting gas can be burned under much better control, and far more regularly than if the same coal were burned in direct contact with the stone, advantages are gained in burning gas which are not readily secured in the direct combustion of coal, so that, on the whole, the use of producer gas is preferable to direct firing where a pure lime is required. Where a less pure lime—contaminated with ash from the fuel and with a variable proportion of unburned stone due to inevitable irregularities in burning—is regarded as satisfactory, coke or coal may be preferred to the use of gas as being somewhat cheaper.

Producer gas has a further important advantage over natural gas and coal inasmuch as it burns slowly and produces a comparatively low temperature, so that there is far less risk of overheating the lime than is the case with the

other fuels ; for the same reason, lime burned with the aid of producer gas is usually more uniformly burned.

TABLE XXXI—*Brief Comparison of Different Fuels*

Fuel.	Advantages.	Disadvantages.
Wood Coal (lump)	Long mild flames Low price, great heating power	Excessive cost. Liability to overburn lime ; volatile matter wasted.
Powdered Coal— Storage system	Low price of coal in most localities	Liability of explosion ; high first cost of installation ; contamination of product ; loss in calorific value in storage.
Powdered Coal— Unit system	Freedom from dust explosions ; low first cost of installation ; no drying necessary.	Contamination of product ; loss in calorific value in storage.
Coke	Low price ; great heating power	Short flame ; contamination of lime with sulphur and ashes.
Anthracite	Great and uniform heat	Cost ; short flame ; contamination with ashes.
Lignite	Mild heat	Low calorific power ; large ash-content.
Oil	Cleanliness ; ease of handling ; low first cost of installation ; no ash-handling ; no loss in calorific value in storage.	High prices in most localities.
Producer gas	More efficient utilization ; no smoke ; no contamination with ashes	Loss of part of energy in coal ; stand-by loss ; rather troublesome.

CHAPTER VIII

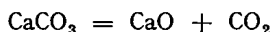
BURNING LIME

LIME is the most important product obtained by the decomposition of the various forms of calcium carbonate from which it is produced, and the art of burning lime is one of the earliest known to civilized-mankind. Curiously enough, many of the kilns used at the present time differ only slightly from the earliest lime kilns of which there are any records, such differences as do occur being chiefly due to the use of coal or coke instead of wood as fuel.

Before describing methods of producing lime, however, it is important to make clear the principles involved, and the various products which are formed.

If a pure calcium carbonate is heated to a temperature of about 800° C. in a sufficiently large vessel, the limestone will be decomposed into a white solid substance, *lime*, and a colourless odourless gas, *carbon dioxide*.

This decomposition may be represented by an equation such as



where CaCO_3 represents one molecule, or 100 parts by weight of calcium carbonate, CaO represents one molecule, or 56 parts by weight, of lime, and CO_2 represents one molecule, or 44 parts by weight, of carbon dioxide gas. In other words, the most carefully conducted experiments carried out on the purest materials under conditions which may be regarded as ideal, show that from each 100 lb. of perfectly pure limestone (calcium carbonate) the maximum amount of lime which can be produced is 56 lb., the maximum amount of carbon dioxide gas is 44 lb., and that there are no other products. Consequently, if the limestone is pure and the heating is conducted in such a manner that nothing can come in contact with the limestone except pure air, the resulting lime will be perfectly pure, and it will weight exactly 56 per cent. of the weight of the original stone.

The behaviour of calcium carbonate when heated depends on the pressure of the carbon dioxide present; if this is sufficiently great calcium carbonate can be melted at a temperature of 1062° C.¹ without any appreciable amount of lime being formed. At lower pressures, the amount of lime formed is proportional to the pressure of the carbon dioxide, but not to the total pressure. At the normal pressure of the atmosphere no lime is formed below a temperature of 898° C.; the corresponding temperature for magnesium carbonate is 402° C.² It is important to notice that it is only the pressure of the carbon dioxide which restricts the formation of lime, so that if a current of air is drawn or blown

¹ Smyth and Adams (*J. Amer. Chem. Soc.*, 45, 1167-1184, 1923) give the melting point as 1339° C. at 779,000 mm. of mercury or about 15,000 lb. per sq. in., which seems a fantastic figure.

² The figure 756° C. obtained by Mitchell and often quoted appears to be erroneous.

through the kiln to keep the pressure of carbon dioxide sufficiently low the pressure of the air is of minor importance.

Magnesian limestones behave peculiarly ; in some, the whole of the magnesium carbonate is first decomposed and the calcium carbonate later, but other magnesian limestones behave like a double carbonate and form lime and magnesia simultaneously ; the latter are the true dolomites. If lime is heated in contact with carbon dioxide gas at a greater pressure than corresponds to the temperature, calcium carbonate will be formed to an extent which depends on the temperature and pressure of the gas. In this way it is possible to recarbonate the lime in a kiln, but this seldom happens as the current of air passing through the kiln keeps the pressure of the gas below the critical amount.

The impurities present in limestone affect the temperature at which it can be burned satisfactorily. Overheating must be avoided as it forms lime which does not slake satisfactorily. Bleining and Emley have shown that the maximum permissible temperatures vary with the kind of lime and are approximately as follows :

High calcium lime, low in impurities	...	...	1300° C.
" " " high in impurities	...	...	1050-1150° C.
Magnesian lime, low in impurities	...	...	1000-1050° C.
" " high in impurities	...	...	900-1020° C.

These temperatures are much too high for many of these limes.

The amount of heat required to decompose calcium carbonate is 767¹ B.T.U. per lb., but for magnesium carbonate only 465 B.T.U. per lb. are required. These figures only apply to ideal conditions (see p. 390).

The rate at which limestone is converted into lime is roughly proportional to the temperature, the precise relation with pure calcium carbonate being—under laboratory conditions—

$$\log_{10}R = 0.003145t - 3.3085$$

where R is the linear rate of advance of calcination in the mass of limestone (cm.), and *t* is the temperature (°C.).

The curve representing the rate of conversion is almost identical with the one showing the ratio of gas pressure to temperature.

In the production of lime on a commercial scale there are many things which prevent the production of pure lime or so large a quantity of lime from a given weight of stone. The most important reasons for this are :

Impurities in the stone.—As only the calcium carbonate present in the stone can produce lime when heated, it follows that an impure limestone will not yield as much true lime as a pure stone. If the impurities remain solid when heated and then cooled, the weight of the burned product may be as great as, or even greater than that from a pure limestone, but the product will be a

¹ This figure, obtained by Backstrom (*J. Amer. Chem. Soc.*, 47, 2443, (1925)), appears to be the most accurate yet obtained though an older figure (776) is often used (see p. 390).

mixture and not pure lime. For example, if 100 lb. of limestone, showing the following results on analysis :

Calcium carbonate	87.5 per cent.
Magnesium carbonate	11.6 " "
Silica	0.7 " "
Iron oxide	0.2 " "
	<hr/>
	100.0 " "
	<hr/>

were to be "burned" under almost ideal conditions it would produce 55.42 lb. of material which might be regarded as *crude lime* and would actually consist of :

True lime (CaO)	49.00 lb.	88.42 per cent.
Magnesia (MgO)	5.52 lb.	9.96 " "
Silica	0.70 lb.	1.26 " "
Iron oxide	0.20 lb.	0.36 " "
	<hr/>	<hr/>
	55.42 lb.	100.00 " "
	<hr/>	<hr/>

Such a product will only contain 88.4 per cent. of true lime, together with 11.6 per cent. of impurities which may or may not be harmful, but are certainly not "lime." When it is important to supply a pure lime it is equally important to start with a pure stone, because the greater part of the impurities in the stone are concentrated in the burned product, so that, under ordinary circumstances, the impurities in 100 lb. of stone will be contained in about 56 lb. of lime. In other words, the percentage of impurities in the lime will be nearly double that in the stone !

Some impurities in limestone tend to cause *overheating* by lowering the temperature at which the lime is produced. Thus, some limestone and chalk containing only 8 per cent. of silica can be overburned at 1000° C. whereas purer limestones are not damaged by heating to 1500° C. When a siliceous material (such as greystone chalk) or a hydraulic limestone is being burned great care must be exercised to prevent overheating. Alumina is less deleterious than silica in this respect.

Impurities in the fuel.—If the fuel and stone are placed in alternate layers in the kiln so that both pass through it together, the final product or crude lime will contain all the incombustible matter or *ash* present in the fuel used. Consequently, if half a ton of coal is required to produce one ton of lime, practically the whole of the ash in the fuel will be present in the ton of lime. If the coal contains 10 per cent. of ash—which is by no means unusual—10 cwt. of coal would contain 112 lb. of ash and one ton of the crude lime would contain 112 lb. of coal-ash in addition to any other impurities it might have derived from the original stone. This proportion of ash is 5 per cent. of the lime so that the

crude lime would contain 5 per cent. of impurity even if a perfectly pure stone had been used. With a different coal the proportion of added impurity would differ according to the ash in the coal and the amount of coal employed. By using a type of kiln in which no fuel ash can become mixed with the lime it is possible to avoid this contamination so far as the non-volatile constituents of the fuel are concerned.

For many purposes the admixture of 5 per cent. of ash does not spoil the lime, but for other purposes it is objectionable.

Any sulphur present in the fuel in such a form that it can form sulphur dioxide gas when the fuel is burned will tend to produce calcium sulphate as a result of the combination of the sulphur dioxide, air, and lime. Calcium sulphate is an objectionable impurity in lime as it produces irregular hardening in mortar and also because it is useless for chemical purposes for which lime is used. Whenever possible, a fuel low in volatile sulphur should be used, but where this is impracticable the fuel should be gasified in a producer and the gas passed over lime, or a little lime mixed with the fuel in the producer so as to fix the sulphur dioxide and to prevent it entering the kiln (see p. 395).

Insufficient Heating.—If the limestone is in the form of a fine powder which is mixed with a large volume of intensely hot air, and is blown through a long chamber heated to the necessary temperature, its conversion from stone into lime is almost instantaneous; if, as is much more usual, the stone is in comparatively large pieces a much longer time, or, alternatively a much higher temperature, is required to effect the decomposition of the stone. For example, pieces of stone 4 in. in diameter usually require about 24 hours before they attain the necessary temperature at which decomposition can take place, and pieces 12 in. diameter may easily require to be heated for 88 hours or more before their central portion reaches the requisite temperature.

When the calcium carbonate is in a finely powdered state, it begins to decompose at 900°C. ,¹ but before a piece 4 in. in diameter has attained this temperature at its centre, the outside must usually be heated to 900°C. or even $1,200^{\circ}\text{C.}$, and the heating at this higher temperature must usually be prolonged for several hours. With still larger pieces a much longer time is needed. Unless this temperature is attained throughout each piece of stone, some of the material will pass through the kiln without being converted into lime and the crude lime discharged from the kiln will then consist of a mixture of "true lime" and of "unburned stone." Every lime burner is aware of this and the unburned stones are known by a variety of names, mostly of a purely local character. They are usually removed by hand picking—a process which is always uncertain in its results, but which is the best available. The proper procedure is to control the conditions of burning in such a manner that no unburned stone is allowed to pass through the kiln; this consists, briefly, in allowing the stone to remain in the kiln for so long a time that it becomes heated throughout to a temperature which is high enough to ensure its decomposition.

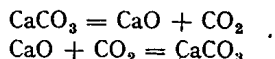
Although the minimum practicable temperature—when time is not

¹ See p. 404.

considered—is about 900° C. the temperature which is usually found to be the most convenient is between 1000° C, and 1200° C. An excessively high temperature must be avoided, or the impurities may combine with some of the lime, forming silicates, ferrates, etc., which not only convert some of the lime into useless compounds, but may cause technical difficulties, such as the “sticking” of the lime and stone in the kiln, which may necessitate much poking before any more lime can be obtained. Excessive heating is particularly to be avoided when hydraulic limes are being burned as it causes them to lose their useful properties. Even pure calcareous limes, when greatly overheated, are spoiled, as they become more dense and give much more trouble in slaking than when they have to be burned at a suitable temperature. As no limestone is perfectly pure, the best temperature at which to burn it can only be found by careful testing, for which purpose a properly equipped laboratory is required, as well as considerable experience in carrying out such tests. Irregular heating, wherein one portion of the contents of a kiln is overheated whilst another part is not heated sufficiently, may cause a double fault, namely, the passage through the kiln of unburned stone and the formation of partially fused lime compounds which are useless for the purposes for which lime is required. Hence, it is not only necessary to heat the stone sufficiently, but it must be heated as uniformly as possible.

Insufficient Duration of Heating will result in the formation of a mixture of lime and unburned stone, as just explained, and will have the same effect as if the interior of the kiln were at too low a temperature. The duration of heating usually depends on the length of the kiln, and is increased by using a taller or longer kiln. Many lime kilns are much too short, and, consequently, the crude lime produced by them contains an unnecessarily large proportion of unburned stone. Such kilns are also wasteful in fuel because much of the heat escapes without doing any useful work (see p. 384).

Insufficient Draught.—If a piece of limestone is heated in a closed vessel to a suitable temperature it will be decomposed to an extent which depends on the size of the vessel in relation to the amount of stone. As the stone decomposes and evolves carbon dioxide gas, the latter, being unable to escape, will gradually increase its pressure and when the pressure of the gas is equal to that of the atmosphere all decomposition will cease. If the pressure of the gas were to be increased still further, some of the lime would be re-carbonated, *i.e.* would be reconverted into calcium carbonate. This is sometimes represented by two equations :



each of these equations being reversible according to the conditions.

The fact that the decomposition of limestone can only occur when the pressure of the carbon dioxide gas is sufficiently low is of very great practical importance, and this is not always sufficiently realized. Complete and rapid decomposition will occur at a sufficiently high temperature if the gas is removed

as rapidly as it is formed so that its pressure never approaches that of the atmosphere. In burning lime on a commercial scale, this removal of the gas is most easily effected by drawing a current of air through the kiln. This air dilutes the gas and prevents its pressure from being excessive. The air may be drawn through the kiln by a natural draught, due to the shape of the kiln (which acts as a chimney) or to a chimney on top of the kiln, or by means of an artificial draught created by a pump, fan, or other exhausting device. The amount of air drawn through the kiln must be at least as much as the carbon dioxide produced, so that if a kiln produces one ton of lime per hour, corresponding to about 15,000 cubic feet of carbon dioxide per hour, the minimum volume of air which must be drawn through the kiln, over and above that required to burn the fuel, is 15,000 cu. ft. per hour. As the products of combustion of the fuel also tend to dilute the carbon dioxide and keep its pressure below the critical one there is seldom any need to measure the additional air passed through the kiln, and all that is usually required is to provide such a draught that there is no likelihood of the pressure of carbon dioxide being excessive. A draught corresponding to $\frac{1}{2}$ -in. of water is usually ample, but a greater draught is sometimes desirable for the proper combustion of the fuel and simultaneously serves to cool the hot lime. An excessive draught will usually do little or no harm if the kiln is sufficiently tall or long, as the heat contained in the excess of air will then be largely absorbed in preheating the freshly-admitted stone; in too short a kiln, on the contrary, an excessive draught will carry away a large amount of heat, and so will be wasteful in fuel. With some impure limestones it may cause the fuel to burn too brightly, and so may overheat the stone and cause it to "stick" or "hang" in the kiln.

An alternative method of preventing the pressure of the carbon dioxide gas from becoming excessive is to inject steam into the kiln, but under ordinary circumstances the use of air is much cheaper and more convenient. Steam may, however, be preferable when it is desired to collect the carbon dioxide for use and the passage of an excess of air through the kiln is, for that reason, to be avoided. Steam acts in precisely the same manner as air in diluting the carbon dioxide, so preventing its pressure from being excessive. It has the advantage over air in being easily separated, by cooling the gas after withdrawing it from the kiln. Some lime burners wet the stone before putting it into the kiln, so as to produce a sufficient volume of steam to dilute the gas to the required extent. The use of water in this manner, whilst often effective, is somewhat wasteful in fuel.

CONDITIONS ESSENTIAL TO GOOD BURNING

From the foregoing, it will be realized that in order to produce lime of first-class quality, it is necessary to use a suitable limestone, and to heat it by means of a suitable fuel to the requisite temperature—between 900° C. and 1200° C.—for such a length of time that every particle of stone is raised to that temperature and is maintained at it until decomposition is complete. At the

same time, the carbon dioxide gas produced must be removed as rapidly as it is formed, preferably by drawing a current of air or steam (or both) through the heated lime in the burning zone of the kiln.

The foregoing conditions are all quite independent of the quantity of fuel consumed, and as the latter is very important, it may be considered separately.

CONDITIONS ESSENTIAL TO FUEL ECONOMY

The heat from burning fuel may be transmitted to limestone in various ways, of which the most important are :

(1) By mixing the fuel and stone so that the former burns in close contact with the latter. If the conditions of combustion are perfect, this should be the most efficient form of applying the heat from solid fuel to the stone.

(2) By burning the solid or liquid fuel in a separate fireplace and allowing the hot products of combustion to come into contact with the stone. As some heat is necessarily lost in the fireplace, this is less efficient than the first method, but it has other advantages which sometimes compensate for the lack of efficiency.

(3) By using gas as a fuel, and burning this in direct contact with the stone. This is a highly efficient and satisfactory method when properly applied. In the conversion of solid fuel to gas, some heat is lost outside the kiln, and this reduces the efficiency to below that of the first method when all conditions are as nearly perfect as possible, but, under commercial conditions—where the combustion of solid fuel mixed with the stone is liable to be very irregular and is often incomplete—the use of solid fuel converted into gas may be fully as efficient as when the solid fuel is burned in contact with the stone.

Under the *best* conditions obtainable commercially, there is not a serious difference in cost between these methods of applying heat to the stone, and local conditions may make sometimes one and sometimes another method preferable. Thus, a poor fuel, rich in ash but very cheap, might be much more economical when burned in external fireplaces than if it were mixed with the stone. On the other hand, a fuel which is difficult to gasify, and not very suitable for burning in direct contact with the stone, may prove quite satisfactory when burned in outside fireplaces.

Hence, each case must be considered with due regard to the local conditions as well as with regard to general principles.

Under the best conditions, using a very pure calcareous limestone, and a first-class coal, with a calorific power of 14,000 B.T.U. per pound, the application of heat by burning the fuel in direct contact with the stone may be represented by the figure 10 ; the conversion of the fuel into gas, and burning the gas in direct contact with the stone may be represented by the figure 6, and the use of the fuel in external fireplaces by the figure 5, these figures being roughly the proportions of lime which will be produced by a given weight of fuel burned under the three conditions stated. In actual practice, where the conditions are less favourable, the corresponding figures would usually be 9, 6, and 4 respectively. In considering these figures, it must be remembered that they only

relate to the application of the heat to the stone, and do not apply to the *total* amount of fuel used in burning lime under these various conditions.

These figures show that, so far as applying heat to the stone is concerned, the most economical method is to burn the fuel in contact with the stone (provided the fuel is really suitable for that purpose), and that the use of external fires¹ is the least economical, unless the fuel is specially adapted to be burned in such fires, and not by the other methods. This is, however, only the first of several matters requiring consideration.

Assuming that the heat has been applied to the stone in a satisfactory manner, it is next important to know how to use it as fully as possible. It is imperative to pass a current of air or steam through the kiln in order to remove the carbon dioxide gas as it is produced, and this current, together with the products of combustion, will carry some of the heat from the fuel upwards if the kiln is vertical and horizontally if some other type of kiln is used. Consequently, there will be a considerable length of stone being heated at the same time, its temperature diminishing as the gases travel forward from the hottest part of the kiln to their exit. A little thought will show that if the length of the stone in contact with the hot gases were sufficiently great, the temperature of the gases would be so reduced that eventually they would have no further heating power and would be useless for that purpose. To take out all the available heat from the gases would require an inconveniently tall or long kiln, and the power required to draw the gases from the kiln would cost more than was really worth while. Consequently, it is cheaper to keep the height or length of the kiln within reasonable limits, even though this involves a small waste of heat from the fuel. In a horizontal kiln, it is found that 142 ft. is the greatest practicable distance in which the hot products of combustion can be kept in contact with the stone, and even this can only be secured when a fan or other mechanical draught producer is used. Where a chimney is employed as the source of draught, it is necessary to pass the gases through it at a temperature of not less than 250° C. (or 480° F.), or the chimney will not "draw" properly, as its draught-creating power depends on the difference in temperature between the external and inner atmospheres. Consequently, when a chimney is used the greatest length of stone which can usefully be brought into contact with the hot gases is about 90 ft. and, if the stone is very wet, only about 75 ft.

If a much shorter length of stone is brought into contact with the hot gases the latter will pass out of the kiln at an unnecessarily high temperature, and a corresponding amount of heat will be lost instead of being imparted to the stone. For instance, if a vertical kiln is so short that the temperature of the gases passing out of it is 750° C. (which is quite a common occurrence with badly-designed kilns), it will be found that about two-thirds of the available heat is wasted, and the fuel-consumption, instead of being (say) 5 cwt. per ton of pure lime produced, is 10 cwt., or even 12 cwt. Such a wastage of heat is very

¹ External fireplaces must not be confused with small gas producers, which resemble them in appearance, but work in quite a different manner.

serious, as it means that twice as much fuel is being burned as is really necessary.

The only means whereby such a wastage of heat can be prevented is by increasing the height of the kiln if it is a vertical one, or its length if it is a horizontal one. If the kiln is badly designed, such an increase in height or length may necessitate further alteration in order that an adequate draught may be produced, or in order that the stone may be conveniently and properly supplied to the kiln. Some kilns are so situated that the requisite increase in height or length would make the working of them very difficult ; in such a case the owner must decide whether it is better to waste fuel by using an uneconomical kiln, or to erect a new and efficient kiln on some other part of the site, where ease of working can be ensured.

Local conditions often seriously affect the relative dimensions of various parts of a kiln, but, under normal conditions, it is seldom necessary to have a kiln more than 50 ft. high above the hottest part ; what shorter height will suffice depends on the nature of the stone and the manner in which the heat is applied to it.

A third factor of importance in securing efficient use of fuel is the extent to which heat can be abstracted from the cooling lime and used to heat the stone. One ton of lime at the moment when its production from limestone has been completed contains as much available heat as that which would be produced by burning 60 lb. of good coal ; hot lime is inconvenient to handle, and is liable to burn trucks in which it may be placed, so it is very important to cool it properly. This cooling is most conveniently effected by drawing a current of cool air through the lime and then using the same air in the combustion of the fuel. In an upright or shaft kiln, no special device or appliance is needed for this purpose, all that is required being a sufficient space in the lower part of the kiln to enable the lime to be retained until it is sufficiently cool. The air rises from the cooled lime up into the kiln, and, mingling with the fuel or the gas to be burned, aids combustion, and makes use of its heat at the same time. In a horizontal kiln, the air passes horizontally instead of vertically, being drawn forward by the draught of the kiln ; in every other respect it behaves precisely the same as in an upright kiln.

The minimum length of the cooling zone cannot be measured accurately, as it depends on so many factors which cannot be adequately controlled. In most upright or shaft kilns a cooling zone of 6 ft. is ample, and 10 ft. is usually unnecessarily large, though not in the least harmful. In a horizontal kiln, 28 ft. is by no means unusual, and 72 ft. is used in some very large kilns ; these much greater lengths are largely due to the inefficiency of cooling in such kilns, and to the fact that the men have to enter them in order to remove the lime, so that a more thorough cooling is essential than in an upright kiln.

So far as the heat applied to the stone is concerned it will be seen that its efficient utilization depends on (1) the time the heating material (gases or solid fuel) is in contact with the stone ; (2) the extent to which the heat in the products of combustion is withdrawn from them and used to heat the stone ; (3) the extent to which the heat in the lime can be withdrawn and used ; and

(4) the proportion of heat lost by radiation through the walls of the kiln. Of these four factors the first and second can be raised to an optimum by using a kiln of sufficient height or length, the best results as regards the third will be obtained in kilns with a long cooling zone, and the fourth factor will be at a minimum if the walls of the kiln are thick, and especially if an insulating material, such as kieselguhr (preferably in the form of bricks), is used in their construction.

In short, an ideal lime kiln will be very long, and will have thick walls of great insulating power. Short kilns, with thin walls, will be extravagant in fuel because they fail to provide the four essential factors mentioned above.

The production of lime is an art which depends very largely on the skill of the lime burner, and most of the statements which imply that lime burning is simple and easy to control are misleading to those who have little or no knowledge of the subject. The main principles involved are simple and capable of accurate scientific explanation, but the limitations imposed by existing kilns are such that there is necessarily much more "art" than "science" employed in producing lime. This is easily realized when it is remembered that there is no means of determining the temperature in the interior of a lime kiln, *i.e.* "in the centre of the contents of the kiln." A pyrometer may be used to ascertain the temperature of the interior face of the kiln wall, or perhaps a little further in a Hoffman or rotary kiln, but it is impossible for it to record the temperature which it is really desired to know, namely, that of the lime in various stages of burning. A tunnel kiln offers some advantages in this respect, but they are very slight. In some industries, the man in charge of a furnace or kiln can see what is going on in its interior, but the lime burner is, to a large extent, denied even this advantage, for it is very seldom that he can see more than the exterior of the mass of lime. He has, therefore, to judge what is occurring in the kiln by a series of indirect observations, such as the distribution of the fuel and the composition and properties of the lime drawn from the kiln. An able man, after several years of experience, can produce excellent lime by the exercise of subconscious skill, yet that same man, if moved to another works where the stone is somewhat different though of the same general character, may require a year or more before he can produce equally good lime.

The fact is that a really good lime burner works far more by instinct than by conscious application of knowledge, and herein lies his success. If he were to think too much about his work, and especially if he were to "worry" about it unduly, his instincts would become subservient to his conscious thought and he would probably fail ignominiously. This is a psychological aspect of the subject to which very little attention has been paid hitherto, yet on the due recognition of it depends the success or failure of almost every lime kiln. A firm may take every precaution to provide the best and most suitable kind of kiln for their particular stone, the fuel may be skilfully bought and everything provided in the way of gauges and recorders, but if the burner's mind is not in a state in which he can do what is required instinctively the results will be

unsatisfactory. It is important to realize this at the outset, as, otherwise, much time may be lost in searching for the cause of trouble and the remedy in the kiln, stone, or fuel, when in reality they can be found only in the *personnel*.

What, then, can be done to produce the correct state of mind in the burner? In the first place, he must know his work, and to do this he must pay the fullest attention to his instructor; he must also observe all that he can, down to the minutest detail. He should think over what he is doing and learn the reasons for it and he should endeavour to connect cause and effect wherever he can do so. All this should be done in his "learning time," during which he should endeavour to form a habit of working so that he does the right thing unconsciously. Some idea of what is required can best be obtained by comparison with a man learning golf; at first he must pay detailed attention to every part of his stroke, but when once he has acquired the necessary movements and can make them in a proper manner, the less he thinks about them the better; if he begins to wonder what he had better do he will make a foolish mistake which he would never commit had he not stopped to think. This must not be understood to mean that no thought is required or that kiln burning is an automatic thing which can be done by a machine; on the contrary, the amount of thought and attention required in the learning are immense, so much so, in fact, that only a small proportion of those who attempt it ever become really skilled burners. The important fact to remember is that having once learned what to do, the burner should usually trust his instinct rather than his power of reasoning, for his instinct, when once trained, is sure and is unlikely to err, whereas his reasoning faculty, by working on insufficient data, may reach a very erroneous conclusion. It is the difference in ability to train this instinctive part of the mind which makes the difference between a good and a poor burner. It requires a long time, unremitting attention, and the absence of distractions; for this reason, a good burner is usually a man of somewhat narrow outlook and most men with many interests would not make good lime burners. Incidentally, a man with a good scientific training would probably not make a good practical burner, and although he would be able to point out what was wrong and the probable cause and remedy, he would probably not be able to carry out his own instructions! That is one result of knowledge retained in the conscious part of the mind as distinct from that in the subconscious part.

ADAPTATION TO TYPE OF KILN

Turning now to the more external part of the operation of burning a lime kiln, it is obvious that each type of kiln may require somewhat different treatment, although all will have certain requirements in common. In the first place, it is clearly necessary that the limestone should be heated to the temperature necessary to decompose it into lime and carbon dioxide; on a very small scale, this can be accomplished at about 900° C., but on a large scale a temperature of 950–1200° C. is needed to effect the decomposition at a profitable rate. An unnecessarily high temperature should be avoided, as "overburned" lime slakes so slowly as to be commercially useless. The best

temperatures for any given stone varies with the stone and the kiln, so that it can only be found by trial.

Heat alone is not sufficient, for if limestone is heated in a closed vessel it will decompose until the pressure of the liberated gas is equal to that of the atmosphere and no further heating will produce any further decomposition. Indeed, a reversal of the reaction may occur, and at a much higher temperature some of the lime may be re-carbonated ! Hence, in addition to heat, there must be sufficient ventilation or " draught " in the kiln to remove the gas as quickly as it is formed. The intensity of the draught required is quite small, especially at a bright red heat, but if rapid decomposition of the stone is desired there must be a definite draught through the kiln. The minimum ventilation is obtained when the gases passing out of the kiln contain 40 per cent. of carbon dioxide, but most lime kilns require so much more air than corresponds to this figure to be passed through them in order to cool the lime sufficiently that there is little risk of insufficient ventilation unless the supply of air is unduly choked.

That the supply of heat to the kiln should be as uniform as possible is clearly necessary ; it is secured by constant observation of the behaviour of the fires or producer as well as the kiln. Some amount of control may be effected by the designer of the kiln and by the manner of charging, but the main control of the fuel must necessarily be in the hands of the burner, except, possibly, in the case of a mixed-feed kiln.

BURNING A FLARE KILN

In a flare kiln, the stone is stacked over an open space in the bottom of the kiln in such a manner that the fuel is burned quite independently of the stone. Wood is the most suitable fuel for such a kiln, though coal is used where wood is scarce or costly. After the kiln has been filled with stone, a fire is lighted in the space or spaces beneath and the heat is gradually increased until the whole of the stone has been heated sufficiently to convert it into lime. A temperature of about 1000° C. is the highest which is generally reached and a somewhat lower maximum temperature is more usual. Comparatively little skill is needed in the actual firing and stoking, for so long as the heat increases steadily and the fuel is spread fairly uniformly over the hearth it will suffice. *The skill is needed in order to decide when to stop firing*, so as to avoid overheating the lime and yet to ensure that all the stone has been fully burned. In practice, the burner usually relies more on time than on any other criteria ; if the fire has burned clearly and brightly, with no set-backs due to disturbing winds, etc., he will cease firing at the end of four, five, or six days after a bright fire has been produced, according as his previous experience has shown to be necessary. He will make allowances for the stone being more than usually damp when placed in the kiln and for other variations from the normal conditions of firing ; these allowances will not be based on any definite data, but on the accumulated results of many years' experience which have been stored subconsciously in the burner's mind in such a form that he will do the correct thing without always realizing what he does or why he does it.

A flare kiln is of such a construction that it is almost impossible to control it accurately and, consequently, it is usually wasteful in fuel. The lime is usually of good quality, because the burner will prolong the heating to ensure that all the stone is burned, and by using wood, or a mixture of wood and coal, it is comparatively easy to avoid overheating, especially as the fuel is separate from the stone and the lime. A kiln of this type is an excellent example of the art of firing, and it cannot be converted into an "automatic" kiln without wholly destroying its nature. The output is small and the fuel consumption large, so that these kilns are now used only in places where a very small amount of lime is needed and where labour and wood are cheap; the quality of the lime produced is often superior to that produced in many more elaborate kilns.

BURNING A MIXED-FEED KILN

In a mixed-feed kiln, the stone and fuel are placed in alternate layers so that if these materials are in suitable proportions and the passage of the air through the kiln is skilfully controlled, the burning is almost automatic. This method of burning is not, however, so simple as it appears because the layers of material do not retain their original position, but become intermixed to some extent owing to the manner in which the lime is drawn out of the kiln. Unless the drawers are very careful, they will take more lime from the centre of the kiln than from the sides, and this will cause the mixture of stone and fuel to fall irregularly, and some of the stone to be incompletely converted into lime whilst other portions may be overheated. Hence, the skilled burner of a mixed-feed kiln pays very special attention to (a) the manner in which the stone and fuel are placed in the kiln; (b) the proportion of fuel to stone; (c) the draught; and (d) the manner in which the kiln is drawn.

When starting an empty mixed-feed kiln, the best method is to fill the kiln to a height of 10ft. with stone, using a bucket and rope to prevent the stone falling too far and damaging the kiln. On this bed of stone is placed a square wooden chimney. On the stone around this wooden chimney is built up a pile of shavings, small sticks and then larger pieces of wood, making a total thickness of about 40 in. A layer of coke, about 6 in. thick, is laid on the wood, then a layer of stone about 1 ft. 6 in. thick, and then alternate layers of coke and stone until the kiln is full. A burning roll of cotton soaked in paraffin is dropped down the chimney and lights the shavings. As the bed sinks, alternate layers of coke and stone are added in the proportion of about $2\frac{1}{2}$ cwt. of coke to each ton of stone. This corresponds to 5 in. of coke to each 12 in. thickness of stone. It is a mistake to add 15 in. of fuel to each yard of thickness of stone as the burning is then less uniform. The most suitable thickness of coke or coal required depends on the nature of the materials, and must be found by trial.

The kiln is drawn steadily, the unburned stone removed being returned to the top of the kiln (if practicable) until only lime is drawn. The kiln is then working normally.

When charging a mixed-feed kiln, it is unwise to stop with a layer of fuel on top as this will be distributed irregularly as the stone beneath it sinks.

Plenty of stone should be placed above as well as below the fuel so that the stone cannot get away from the fuel, or *vice versa*. Alternatively, it is well to have a series of four flat doors on top of the kiln and to put fuel and then stone on each of these in turn. On opening a door the fuel is driven forward by the stone and a fairly uniform distribution is secured.

It is a mistake to place the fuel uniformly over the whole area of the kiln because the stone does not travel uniformly downward through the kiln. In most cases, less fuel should be placed in the centre and more at some little distance from the sides (fig. 104), the precise arrangement depending on the size of the fuel, the nature of the stone, and the width of the kiln, so that it must be found by trial.

In all mixed-feed kilns the proportion of fuel to stone is important, because if this is wrong it is almost impossible to produce good lime. In a simple mixed-feed kiln, therefore, a definite attempt should be made to ascertain what is the best proportion of fuel. No general rule will suffice, because so much depends on the dimensions of the kiln and of the pieces of stone; each burner must find out for himself what suits the kilns under his charge. It frequently happens that each of the kilns in a battery requires a different proportion of fuel, because the conditions differ slightly in each; for instance, the end kilns are more exposed and, being cooler, will require rather more fuel than the others which are heated by their neighbours.

Guessing the weight of stone and fuel used is very common, but most unsatisfactory; crude attempts at measuring the stone in wagons or barrows is almost equally undesirable, and the only really satisfactory method is to weigh both stone and fuel.

Very frequent analyses of the kiln gases will show whether the correct fuel ratio is maintained, but the necessary apparatus is used in very few lime-works because it is fragile and few burners know how to use it. This is unfortunate, as there is no better means of controlling the working of a mixed-feed kiln than by studying the record of an automatic apparatus for analysing the gases from a lime kiln.

Some vertical lime kilns are not of the simple mixed-feed type, but have means for introducing some of the fuel into the hottest zone of the kiln, through feed holes or ducts provided for that purpose. This is a great advantage inasmuch as it permits the burner to add more fuel if he thinks it is required, whereas in the simple mixed-feed kiln no such addition is possible. The advantage gained has, however, its corresponding disadvantage, for it introduces an element of judgment into the burning of the lime which is absent from the simple mixed-feed kiln, and, consequently, the kilns with feed holes require more skill than those without them. In some works, the amount of fuel added

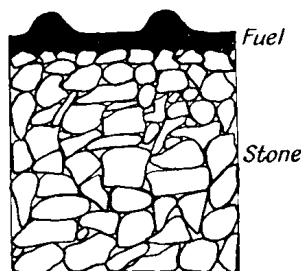


FIG. 104.
DISTRIBUTION OF FUEL IN
MIXED-FEED KILNS.

through the feed holes is made as constant as possible so as to ensure the regular action of the kiln ; when this is done, one of the chief reasons for using the feed holes is avoided, and equally good results could usually be obtained (if the kiln is tall enough) by putting all the fuel into the top of the kiln instead of some through the top and some through the feed holes. The feed holes have, in some kilns, a further advantage because they prevent the ashes from the fuel being mixed so completely with the lime as in a simple mixed-feed kiln ; this is sometimes a distinct gain, though the benefit which might be obtained from it is often lost through the carelessness of the men engaged in drawing the kiln.

The size of the pieces of stone in a mixed-feed kiln is important ; the large pieces will require longer to burn than the small ones so that the latter may be overburned or the former underburned, and as a mixture of pieces of different sizes will lie more compactly than when all the pieces are the same size the draught of the kiln will be reduced. It is usually wise to keep the pieces of stone not less than 4 in. diameter nor more than 6 in. diameter, and the more uniform they are in size the better will be the lime produced.

As the heating should be uniform, it is necessary that the air and gases rising upwards through the kiln should do so in a uniform manner, *i.e.* the draught should be the same in all parts of the kiln. This is not easy to secure as there is always a tendency to form channels in the stone up which an undue proportion of gases rise and so cause a sluggish draught in some other part of the kiln. Skilful charging, the use of pieces of stone of as nearly the same size as possible, and skilled drawing of the lime from the base of the kiln will reduce the irregularities in draught to a minimum, but they cannot be wholly avoided. If the kiln "sticks" or otherwise works in an irregular manner the draught will be correspondingly affected and the quality of the lime will deteriorate. A uniform draught also depends to some extent on the position and size of the chimney or of the duct through which the kiln gases are drawn away. A central, partly submerged chimney gives the most uniform draught as it is placed centrally and at such a depth that it can draw the gases from the sides of the kiln as well as from the centre. An outlet at one side of the kiln usually tends to produce more draught at one side than another, whilst if several outlets are placed on the periphery of the kiln and none in the centre they may tend to draw the gases up the sides of the kiln leaving the centre deficient in draught. This defect is not serious if the kiln is skilfully drawn, because the stone can be made to travel towards the sides and so enter the hot zone, or the sides of the kiln may be more closely packed than the centre so that the latter, being more porous, will allow the gases to rise more readily through it.

It is very difficult to measure the movement of the air or gases in the interior of a mixed-feed kiln, but in spite of this a continuous effort should be made to ensure that :

- (i) The pressure of the air entering the kiln is constant.
- (ii) The exit gases have a constant temperature. If it rises, the fire is rising too high in the kiln. The temperature must be measured close to the kiln.

(iii) The draught be constant, though it may vary greatly without affecting the lime.

(iv) Periodic gas analyses are made.

When once the correct proportion of fuel and stone have been found for a given mixed-feed kiln, the most important matter is the skilful drawing of the lime. Many attempts have been made to do this in a continuous and automatic manner and there is much to be said in favour of such a proposal. Unfortunately, variations in the rate at which the lime is produced and the irregular manner in which it descends through the kiln make continuous and automatic drawing far less satisfactory than when this work is done by skilled men. There are several reasons why the drawing of small amounts at very frequent intervals should be better than drawing large quantities at longer intervals, but, in practice, the "sticking" of the kiln sometimes compels the latter. The ideal method would be for the material to travel slowly down the kiln at a constant rate, but in most kilns the friction between the material and the sides of the kilns and between the different pieces of material is so great that the stone will only "fall" when it is unsupported from below; this necessitates drawing at longer intervals than is otherwise desirable. Whilst, therefore, no definite rule can be laid down as to the precise quantity to be drawn at a time or the amount to be removed at each drawing, it is sound practice to draw as often as the conditions will permit, a minimum quantity being drawn at each time. In a good mixed-feed kiln, the material should travel downward at the average rate of 6 in. per hour, so that a kiln 36 ft. high will require 72 hours for a piece of stone to pass through it and to be converted into lime. The rate of flow can be measured roughly by placing a marked firebrick in the top of the kiln and noting the time which elapses before it is drawn out with the lime. Some kilns are drawn so irregularly and so excessively that the output and the quality of the lime have been greatly improved by arranging for more frequent draws at regular intervals; in some cases, the increase in output has been no less than 25 per cent. and the resulting lime has contained less unburned stone.

Some burners have the idea that lime is only produced when the stone is stationary, and for this reason they let the kiln remain undisturbed as long as possible. For instance, the last draw will be about 4 p.m., after which there will be no further drawings until about 7 a.m. on the following day. If the conditions are extraordinarily good, this method gives lime of excellent quality, but with a great waste of fuel, for the hottest zone in the kiln rises during the night and the gases passing out of the kiln gradually increase in temperature because there is less depth of stone above to absorb the heat from them. In some localities, where the climatic conditions are unfavourable at night, it may be necessary to permit this waste of fuel to continue because it may be practically impossible for the men going on night duty to reach the works or their homes. In some parts of the lime burning districts of Derbyshire, for example, it would be extremely difficult to get men to work all night in the winter months in connection with a lime kiln. To overcome the disadvantage of the fire rising and so wasting fuel, one ingenious lime burner built his kilns to a height of

about 80 ft.; fortunately, the stone was a very hard one and the lime had a high crushing strength, so that this method served its intended purpose, though the cost of erecting such tall kilns at the present time would be almost prohibitive.

When burning chalk in a mixed-feed kiln, care must be taken that the latter is not too high or the chalk and resulting lime will be crushed to such an extent that there will not be sufficient space between the pieces and the draught will be impaired; by keeping the net height of the kiln below 30 ft. (and in a few cases much less) this trouble may be avoided, but the fuel consumption will not be as low as in a taller kiln burning a stronger stone; with care, the difference in fuel consumption need not be serious.

The principal defects which occur when burning lime in mixed-feed kilns are described on p. 429.

There are many variations of the simple mixed-feed kiln in use for burning lime; it is impossible to describe in detail the methods of controlling these, but if the general method and principles stated above are used the effect of the variations or additions to the structure of the kiln will readily be mastered. For example, the Cornet kiln is provided with a series of ports more than half-way up the kiln, in order that air which has been recuperatively heated may enter the kiln at about the level of the hottest zone; three rows of ports are generally supplied so as to allow for a considerable variation in the height of the hottest zone. By observing the appearance of the lime and stone through other openings in the side of the kiln, the effect of this supply of hot air can be ascertained—at least to a limited extent, for it is impossible to inspect the stone in the centre of the kiln. The purpose and use of the various dampers and “controls” with which other mixed-feed kilns are provided can soon be learned; some of them are useful and convenient because of some peculiarity in the stone or the fuel, but they do not seriously affect the general management of the kiln. Indeed, the author’s experience coincides very largely with that of an old and very experienced burner, namely, “the simpler the kiln and the fewer the ‘gadgets,’ the more easy is it to make it produce good lime.”

BURNING A KILN WITH EXTERNAL FIRES

To a large extent a kiln fitted with external grates or fireplaces is burned in the same manner as a mixed-feed kiln, but the fact that the fuel is kept separate from the stone necessitates the fires requiring almost constant attention, whereas this does not occur in a mixed-feed kiln. The kiln is charged and drawn in a similar manner to a mixed-feed kiln, but allowance must be made for the fact that the heat tends much more to rise up the sides of a kiln with external fires so that the lime must be drawn more from the sides than from the centre. Most kilns of this type have a central core of imperfectly fired material, and this is recognized by some kiln builders who erect a central core of masonry (fig. 105) in the kiln to avoid it.

In a kiln with external fires all the precautions needed in a mixed-feed

kiln should be taken (except that no fuel need be charged with the stone)¹ and, in addition, the burner must see that the fires are kept burning as steadily as possible so as to maintain a fairly constant temperature in the hottest zone in the kiln. By the very nature of the case, the temperature of the fires cannot be kept quite constant, for each time some more fuel is placed on them the temperature will be lowered and the admission of heat to the kiln will practically cease until the fuel last added is burning brightly. In other words, the temperature in each fireplace will rise and fall more or less regularly, periods of intense heating being followed by others in which scarcely any heating of the lime can occur. The drawing must, therefore, be regulated to "keep step" with these periods, or the lime will be irregularly burned. These periodical variations in

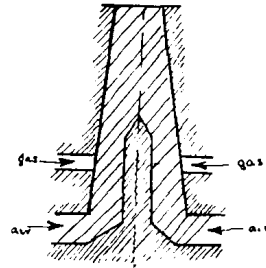


FIG. 105.
KILN WITH MASONRY CORE.

the heating are a very serious disadvantage and call for exceptional skill in the management of such kilns; they can be largely avoided by the use of semi-producers instead of fires, or by using fireplaces which are so wide that only one half of each is fired at a time, though the latter is very troublesome and not wholly satisfactory. Vertical kilns with external grates are extensively used in the United States, but they are not nearly so popular in the British Isles because of the large amount of skilled attention they require, most of which is due to the inefficiency of this method of heating.

BURNING A VERTICAL KILN WITH SEMI-PRODUCERS

When a vertical kiln is fitted with semi-producers instead of the fireplaces just described, it is possible to obtain an almost constant heat, because the production of gas can be made almost continuous and constant if the producers are well designed and suitable for their work. If the producers are too shallow they will be little better than external fires, but if of ample depth they will work in a satisfactory manner and produce gas in a regular stream of the required intensity, whereas fires have alternating periods, as described. These semi-producers should be managed in a manner similar to that of a larger producer described under "Gas-firing," but being smaller, they require more frequent attention and greater care. It may be noted in passing that these semi-producers do not save labour, but they avoid the serious loss of heat which occurs when the gas from a large producer is carried through a duct to various parts of the kiln. The other details of the burning are the same as for a gas-fired kiln.

BURNING A VERTICAL GAS-FIRED KILN

Many burners who are unfamiliar with gas-fired kilns regard them as being difficult to manage; they are certainly not as easy as mixed-feed kilns, but

¹ Some burners prefer to use only one-third to half of the fuel in the external fireplaces and charge the remainder with the stone.

they are much easier than a kiln with external fires or one with semi-producers. The general arrangement of charging and drawing are the same as in a mixed-kiln, and the same precautions should be taken. The main difference in feed management lies, of course, in the producer and in the delivery of the gas, or gas and air, to the kiln.

Assuming that the producer is working properly and producing a constant stream of gas of suitable quantity and quality, the control of the kiln is a comparatively simple matter if the kiln has been well designed. This, unfortunately, is not always the case, and many troubles have been experienced in trying to work gas-fired kilns which were deficient in some essential detail.

If the quantity of gas is constant and the supply of stone is regular, the dampers admitting the gas and air to the kiln can be kept open to a definite extent (which must be found by trial) and can so remain until the conditions in the producer or the kiln are changed, when the dampers must be altered accordingly. Inspection through the sight holes in the walls of the kiln will give a fair idea of the temperature at those parts. It is impossible to see into the centre of the kiln or to use any pyrometer to ascertain its temperature at any given moment. This is not as serious as might be supposed, because with a constant supply of gas the conditions of burning should remain constant, and an examination of the lime should give with sufficient accuracy, the requisite information as to the burning. If the supply of gas is irregular, it is almost hopeless to produce good lime until this irregularity is overcome.

The length of the flames in a gas-fired kiln depends partly on the quality of the gas and partly on the proportion of air mixed with the gas before it is ignited. By mixing the full quantity of air the flame will be very short, and by admitting no air until the gas has begun to burn and by allowing the two streams of gas and air to flow side by side and mix very slowly, a flame of maximum length will be produced. Between these two extremes the burner must regulate the gas and air according to the requirements of the lime produced and, to a lesser extent, by the proportion of fuel consumed. Some gas-fired kilns have no means of admitting air to the gas before the latter is burned; such kilns should produce a flame of great length, but of relatively low temperature, and, therefore, corresponding closely to the flames produced from burning wood. The temperature of such flames can be increased by mixing a little air with the gas before the latter begins to burn; this requires a burner of special construction.

From the foregoing, it will be seen that the control of a gas-fired kiln does not lie so much in the kiln itself as in the producer; if the latter is well managed, the control of the kiln is easy, but with a badly managed producer, or one which is in other ways defective, it is extremely difficult to produce well-burned lime.

The ideal conditions for the production of a good producer gas, rich in carbon monoxide, are:

(1) The surface of the fuel should be as large as possible; hence, coke is better than coal and pieces of moderate size are better than very small ones. Pieces 1-2 in. diameter are best; coke may be a little less.

(2) The time of contact between the fuel and the gas should be as long as possible. As the time factor at 1100°C . is about one second, unless the depth of fuel on the bed is sufficiently great little or no gas will be formed. If the bed is 4 ft. deep an increase in the temperature of the fuel will be more effective than an increase in the depth of the bed of fuel. The time of contact is also related to the rate of gasification, which should ordinarily be 18–24 lb. of fuel per sq. ft. per hour of producer area, but if the fuel is very rich in tar it may only be possible to gasify it satisfactorily at the slow rate of 8 lb. per sq. ft. per hour.

(3) The temperature in the hottest zone of the producer should be as high as possible, but it should not exceed 1100°C . ; the upper part of the producer should be black or faintly red. The bright red surface of fuel seen in some producers is a sign of bad management.

(4) As steam is the cheapest addition to carbon dioxide which will cause it to react endothermically with carbon, the use of steam in gas producers is desirable, as well as providing a convenient means of injecting air. The proportion of steam and air must be carefully regulated ; this is best done by having a simple steam injector, fitted with a thermometer to register the temperature of the air-steam mixture entering the producer. As the steam will heat the air to saturation or dew-point of the mixture, the temperature of the latter will show the amount of steam and (indirectly that of the air) admitted. In practice, the best way is to find what temperature of air-steam mixture gives the best gas and to regulate the steam valve to maintain this temperature.

(5) The temperature of the bed of fuel should be uniform all over its area at any given level. This must usually be secured by poking the fuel at suitable intervals, so as to break down any channels and fill any hollows in the bed. Gas producers tend to become hottest near the walls, as the resistance to the passage of the gas is less there than in the centre of the bed. This tendency should be minimized as much as possible by the manner in which the poking is effected, the centre being kept open and the circumference more compact.

(6) The supply of fuel to the producer should be as regular as possible, though there is no need to employ a producer with an automatic feed.

(7) The ashes should be removed at regular intervals, and if the producer has a grate it will require to be cleaned periodically ; this work should be done thoroughly and conscientiously or trouble will result.

(8) The gas must be delivered at a suitable pressure or there will be a cool column in the centre of the kiln (fig. 106). The effect of too little pressure is shown in fig. 107. In a well-managed gas-fired kiln, the gas will reach to the very centre of the kiln, as shown in fig. 108.

Although it may seem to be a crude device, a properly designed gas producer is an instrument of precision and should be treated accordingly ; the more

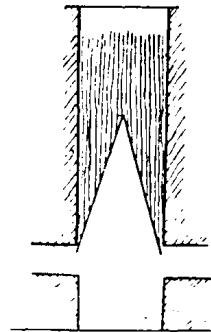


FIG. 106.—COLD CORE DUE TO INSUFFICIENT GAS PRESSURE.

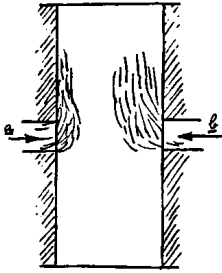


FIG. 107.—GAS-PRESSURE TOO LOW.

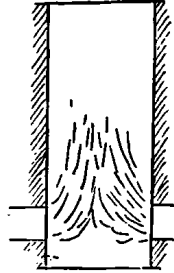


FIG. 108.—CORRECT GAS-PRESSURE.

regularly it works the better will be the gas produced and the easier will it be to produce good lime.

The principal *defects* occurring in burning lime are described on p. 429 ; some specially related to gas-fired kilns may more conveniently be noted here :

When the gas duct becomes choked with soot, the latter must be burned out by stopping the admission of gas and drawing or blowing air through the duct. This is a simple, but slow process, requiring the greater part of one day per week in some kilns, and is a great nuisance. It is due to the use of coal rich in tarry matters which are decomposed at the high temperature of the gas in the duct and form soot as one of the products of the decomposition. It may be prevented in one of the following ways, according to local conditions : (a) by using coal with less volatile matter, such as steam coal, anthracite, or even coke, or a mixture of coal and coke ; (b) by working with a deeper bed of fuel in the producer so that the tarry matters are decomposed in the producer instead of in the duct ; this is often difficult to manage, especially if a rich gas coal is used ; (c) by keeping the top of the bed of fuel cool so that the gas does not become hot enough to decompose the tarry matters in it until it has passed through the burners into the kiln ; this is liable to produce discoloured lime ; (d) by inserting a soot trap near the producer from which the soot can be collected instead of its being carried along the gas duct to where it is inaccessible.

When the gas is deficient in heating power, it is usually a sign that too much air is passing through the producer. The most satisfactory means of ascertaining this is to make an analysis of the producer gas, but few burners are able to do so. Alternatively, the fuel should be levelled and any hollows filled by poking, after which the admission of air should be reduced slightly and the effect noted. Too many inexperienced men endeavour to get more gas by working with too hot a producer, which has exactly the opposite of the effect desired. It is useful to have a slight hole through which the temperature of the hot zone can be observed, as this portion of the producer is often cooler than it should be whilst the top of the bed is too hot.

A low rate of gasification may be due to a badly-designed producer, unsuitable fuel, or bad management ; the last may include imperfect cleaning

of the grate, neglect to keep the bed solid and free from fissures, insufficient steam and air, or an excess of steam in proportion to air owing to bad adjustment of the injector. If the walls of the producer are in bad condition and leak badly, the gas may burn inside the producer and produce a low heating effect in the kiln.

Gas-fired kilns should be drawn at as frequent intervals as the local conditions permit. They do not work satisfactorily if no drawing occurs during the night, as the lime in the hot zone tends to be overheated. The ideal arrangement would be a constant removal of lime by mechanical means, but, owing to the friction of the stone in the kiln, this appears to be impracticable if lump lime is to be burned; it is more feasible with small pieces of hard stone provided they are sufficiently uniform in size to prevent "packing" and loss of draught.

BURNING LIME IN A HOFFMAN KILN

In a continuous kiln of the Hoffman or similar type the limestone is carefully stacked in a series of "chambers," arranged side by side in two parallel rows or in a circle or elongated ellipse so that the hot gases can travel into each "chamber" in succession. The packing of the stone requires both care and skill or the burning will be irregular. In packing the stone, small vertical hollow "pillars" are formed in which the fuel—small coal—is burned or, if preferred, larger coal can be burned on grates running from the front to the back of each "chamber."

Assuming that the kiln is in full running order (for the starting is best done by an "instructor burner" supplied by the kiln builder) the method of burning is somewhat as follows, details being varied according to local conditions:

In a kiln having 14 "chambers," one will be empty, one being filled, one being drawn, five being heated with hot gases, two being fired, and four cooling. The only damper which should be open will be the one in the coolest of the preheating chambers, so that the fire gases will travel forward through six or seven chambers and then out through this damper. If the kiln is of the "open" type, with no definite partitions between each chamber, a paper partition must be made and fastened in position as soon as a chamber is filled, to prevent the gases from going in any other direction than through the open damper. The lime is cooled and a supply of hot air for the fires is produced by drawing air through the cooling chambers and then into those being fired; this is done quite automatically and needs no attention.

When the stone in one of the firing chambers has all been converted into lime, the following changes must be made:

(a) The damper in an unheated chamber is opened and the one in the pre-heating chamber next to it is closed.

(b) The paper partition between these two chambers is cut or torn by means of a poker inserted for the purpose, or a partition-damper is drawn so

that the hot gases are able to enter the chamber in which the damper has just been opened.

(c) Fuel is fed in small quantities into the hottest of the preheating chambers, the amount used being steadily increased as the chamber gets hotter, care being taken to distribute the fuel in such a manner as to heat the stone uniformly. At the same time the next chamber (which is being fired) is heated in a similar manner, but more intensely. The heating of this second chamber is continued until it is judged that the whole of the stone has been converted into lime.

(d) The hot gases from the firing chambers pass quite automatically through the adjacent chambers, heating them gradually and without requiring any attention.

From the foregoing, it will be seen that if the stone is properly packed, the chief care of the burner must be to keep the fires in the two hottest chambers burning steadily and uniformly in the chambers so that the lime in them is evenly burned. The rest of the kiln proceeds automatically except when a chamber has finished firing, when the procedure described above is required; this is commonly known as "taking on a fresh chamber."

When a man is accustomed to the work and is reasonably skilled, the burning of a kiln of this type is a comparatively simple matter, but a novice often requires several years before he can manage a kiln satisfactorily, though men vary greatly in the time they need to learn how to manage such a kiln.

Among minor points which require attention are :

(1) The tendency of the stone to shrink during the heating so that the hot gases pass over the stone in adjacent chambers instead of through it. To prevent this, it is desirable to have drop arches in the kiln (unless there are definite chamber walls) so as to deflect the gases downwards.

(2) The chimney draught requires careful regulation; it must not be too sluggish or the gases will not travel fast enough to make the best use of the heat produced by the fuel. Too strong a draught is undesirable as it may cause overheating.

(3) When the coal is burned in hollow pillars formed among the pieces of stone, it tends to overburn the lime in its immediate neighbourhood; this is unavoidable as is also the spoiling of some of the lime by the ashes from the fuel. The use of grates for the fuel is better, but even with these overburning is still possible if a coal very rich in volatile matter is used.

(4) It is essential that the filling and drawing of the kiln should be quite regular, though it need not be done at night if the kiln has a sufficiently large number of chambers. The common mistake is to allow the fire to travel forward too rapidly in proportion to the filling and drawing, with the result that there are too few preheating chambers in use so that the fuel is wasted and some of the lime is underburned. It is not easy to adjust a kiln of this kind for Sundays and other holidays, but if sufficient chambers are provided so that the fire always travels forward at the same speed the conditions will be right for producing good lime.

BURNING LIME IN A TUNNEL KILN

So far, tunnel kilns, in which the lime is burned on cars which pass slowly through a long tunnel, have been used to so small an extent for lime that little information is available as to their management when burning lime. Such a kiln differs from a Hoffman kiln inasmuch as the lime moves in the former and the fire in the latter ; otherwise the general principles are the same. In some respects the tunnel kiln is the easier to manage, because it is worked like "clockwork," a constant temperature being maintained in the hot zone and the cars passed through the kiln at the rate of one car per hour or whatever speed may have been found suitable. In this respect, the tunnel kiln is the nearest approach to an automatic kiln for lime, but it is still in the early stages of its development.

The chief disadvantages of the tunnel kiln for burning lime are : (a) the cost of stacking the limestone on the cars is greater than that of charging any other form of continuous kiln, including the Hoffman kiln ; and (b) the shrinkage of the stone creates passages through which the hot gases and air pass more readily than through the stone or lime and thereby cause irregular heating and cooling. When the use of this type of kiln for lime has been more fully developed it is possible that both these difficulties will be overcome.

BURNING LIME IN A ROTARY KILN

The rotary kilns used for lime are of two kinds : those using powdered fuel or oil and those which are gas fired. In each case the supply of gas and air is regulated so as to maintain a constant temperature in the hot zone, and the speed at which the kiln is rotated is adjusted to ensure the stone remaining in the kiln a sufficiently long time for it to be thoroughly burned. It ought to be possible to keep the speed of the kiln constant, when once the best speed for a particular stone has been found, but, in practice, variations are needed from time to time. Similarly, if the supply of powdered fuel, oil, or gas is kept constant, the kiln should need no attention in this respect, but as a matter of fact no such kiln will run automatically. The variations and adjustments which must be made all depend so much on local conditions that it is useless to describe them in general terms ; each burner must find them out by trial. Apart from this, the more constant the conditions can be maintained in a kiln of this kind the better will be the quality of the lime produced.

In rotary kilns, the colour of the flame is a very useful guide. With the correct adjustment of gas, air, and steam, the flame "softens," *i.e.* it loses some of its brilliancy and becomes orange in colour.

The best results are obtained if the stone or other form of calcium carbonate is fairly uniform in size. Small particles tend to circulate in the centre of the kiln without being properly heated and thus produce a large proportion of core. Over-feeding the kiln with large pieces will also produce core.

BURNING SINTERED LIME

Dolomite and other Magnesian Limestones require special care in burning because the magnesium carbonate decomposes at a lower temperature than the calcium carbonate, and it is only too easy to produce an imperfectly burned product. For the manufacture of steel, *dead burned* dolomite and magnesia are much used; these require the highest attainable temperatures—at least 1600° C.—if the best quality of material is to be produced. To attain this temperature requires a blast of air and a kiln built on the same lines as a blast furnace, though gas-fired chamber kilns, with air heated in a special regenerator, are also used satisfactorily. The management of these kinds of kiln is by no means easy, but they do not differ in any essential principle from the kilns previously described; their chief distinction is that they are designed to heat the stone to a much higher temperature. Kilns for sintering or dead burning dolomite are worked in such a manner as to prevent the material “sticking” or “hanging,” but it is usually found that, after four or five weeks’ continuous working, the material cannot be loosened with either pokers or water; the kiln must then be allowed to cool and is afterwards emptied.

For fully sintered material the best procedure is to work in two stages: (i) ordinary calcination in a vertical shaft kiln, and (ii) sintering in an electric arc furnace. This is cheaper than using an electric furnace throughout and gives a better product than a blast furnace.

THE USE OF STEAM

As previously explained, the introduction of any gas which will dilute the carbon dioxide present in a kiln will facilitate the burning of the lime by reducing the partial pressure of the carbon dioxide. The composition of the diluent gas is quite unimportant, and, therefore, steam will do as well as air or any other gas. This is one reason why the injection of steam into a lime kiln facilitates the burning. Another reason is that if injected through the fuel, the steam is decomposed, forming carbon monoxide and hydrogen, both of which are valuable gaseous fuels. If the heat required for this decomposition of steam could be obtained free of cost its use would obviously be an important gain, but actually the amount of fuel used in decomposing the steam is at least as great and sometimes greater than the heat developed by the carbon monoxide and hydrogen produced. In that case, the only advantage is that derived from supplying the flames where they can do more good than if no steam is used and this advantage is so problematical that it is scarcely worth consideration.

If external fires or gas producers are used, the introduction of steam through the fuel may facilitate the combustion of the fuel and produce a series of flames more suitable for burning; it may then be a distinct advantage.

The direct dissociation of water by contact with hot lime alone is highly improbable as it requires a temperature of about 1760° C., which is much higher than that attained in any lime kiln. Hence, the value of steam injected

into or near the base of a lime kiln and out of direct contact with solid fuel is very doubtful, especially when the moisture derived from the fuel is taken into consideration. Steam should not be injected when the lime is to be used for chemical purposes for which the carbon dioxide gas is also required, because in the presence of steam any calcium sulphate will be reduced and sulphuretted hydrogen formed.

The use of superheated steam, instead of the products of combustion of fuel, for burning lime has been patented by Schaffer and Crow.¹ It has the advantage of avoiding overheating, but the "burning" is slow and the condensation of water on the freshly charged stone is very objectionable.

DEFECTS EXPERIENCED IN BURNING LIME

The production of good lime from so variable a material as are most natural stones, is a distinctly difficult piece of work and it is not surprising that many defects are experienced. To overcome these, many ingenious devices have been tried, of which the most important are the kilns in which attempts are made to reduce the operation of lime burning to as nearly an automatic procedure as possible. Much progress will have to be made before such a consummation is reached, though great improvements have been made in recent years in designing kilns for this purpose. Among the lesser devices for facilitating lime burning are (a) the addition of salts to the stone, and (b) the injection of steam into the kiln.

Only in exceptional circumstances can the addition of salts or other solid material to the stone serve the intended purpose so far as the lime is concerned, but there is a special case to be considered with respect to magnesia, as it is found that magnesite rich in iron oxide can be burned more effectively than a purer magnesite, and for most of the purposes for which dead burned magnesite is used the iron oxide does no harm. It has long been customary in some parts of Japan to add sea salt to limestone before burning it, rather less than one per cent. of salt being used. Elaborate tests have shown that the salt does not improve the burning or slaking, but it enables the lime to be ground more easily, so that it is more rapidly reduced to a fine state than when no salt is used. This is not a sufficient reason for adding salt under ordinary conditions, as the difficulty of burning is increased rather than diminished, because of the compounds formed between the salt and the walls of the kiln, which, being of an adhesive nature, increase "sticking" in the kiln.

Unburned limestone or "core" in the lime drawn from the kilns is usually the most serious result of defective burning, and one of the most difficult to prevent. Some kiln builders make remarkable claims as to the small proportions of core in the product of their kilns, but few of these are substantiated in everyday use, though many of them are justified when the kilns are managed by exceptionally clever burners; in other words, the skill of the burner is often quite as important as the device which is intended to make the burning easier

¹ U.S.A. Patents 1,291,425 (1919), 1,377,367 and 1,377,401 (1921).

In a vertical kiln, the formation of "core" depends partly on the manner in which the kiln is fed and drawn. In a mixed-feed kiln, for example, the proportion of core should not exceed five per cent. of the lime drawn, though with poor fuel and a kiln with a closed top it is difficult to produce less than ten per cent. of core, except by incurring a great waste of fuel. The only means of keeping the proportion of core at a minimum is to distribute the fuel in such a manner that every piece of limestone becomes sufficiently heated; this distribution depends on so many local conditions that it can only be found by trial. Merely to spread the requisite amount of fuel evenly over a layer of stone of convenient thickness in the kiln will not ensure a minimum of core, because the stone and fuel do not travel uniformly down the kiln. An experienced burner, with good powers of observation, will soon ascertain how both stone and fuel travel and will arrange to distribute the fuel accordingly, with the result that uniform heating will be secured and a minimum of core produced. The same is true of kilns in which some of the fuel is mixed with the stone whilst the remainder is added through separate openings, except that it is more difficult to distribute the latter so as to secure uniform heating without wasting fuel.

An indirect cause of "core" in vertical kilns is the lack of sufficient height in the kiln, with the result that the stone has not time to become thoroughly heated. Time is needed for the interior of a lump of stone to attain the same temperature as the exterior and this must be allowed for in arranging the rate at which the stone and lime will pass through the kiln. For pieces of stone 4-6 in. diameter about 70 hours is usually required, though much depends on the temperature and thickness of the hot zone and the temperature to which the lime can be heated without overburning.

Sometimes "core" is produced because the temperature of the kiln is too low, even in the hottest part. This is a serious trouble, and one which it is not easy to detect unless the burner is well accustomed to the type of kiln and to the stone. Inspection through holes in the sides of the kiln is useful, but it is impossible to see far into the kiln, though the skilful use of a poker will sometimes enable a horizontal channel to be made which will remain intact sufficiently long for the temperature to be observed with the eye or with a radiation pyrometer. Even then, as air is almost certain to enter through the sight-hole, the observed temperature will probably be a little lower than the actual one.

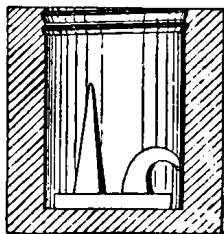


FIG. 109.—SEGER CONES.

A simple means of ascertaining the *maximum* temperature attained in a vertical lime kiln is to cement several Seger cones, each corresponding to a different temperature in a small fireclay box with a screw-cover of the same material (fig. 109). This box is dropped into the top of the kiln and gradually passes down and out with the lime. It can then be opened and the cones examined. The ones which show no signs of fusion obviously represent higher

temperatures than have been reached; those which are a shapeless mass indicate a lower temperature than that of the kiln. The cone representing the maximum temperature of the kiln will be the one which has begun to bend considerably, but not so much as to become shapeless. It may be well to start with three cones in each box and to use three boxes, namely:

TABLE XXXII.—*Use of Seger Cones*

Box 1 containing cones.	Box 2 containing cones.	Box 3 containing cones.
010a = 900° C. 08a = 940 06a = 980	04a = 1020° C. 02a = 1060 01a = 1080	1a = 1100° C. 3a = 1140 5a = 1180

This will cover the ordinary range of burning, though cones for higher and lower temperatures can be used if desired.

Supposing that all the cones in Box 1 are too low, all in Box 3 are unaltered, and in Box 2, cone 04a is so fused as to be shapeless, cone 02a has bent as shown in fig. 109, and cone 01a remains unaltered the temperature attained in the hottest part of the kiln would be about 1060° C. The results obtained by this test may be rather low because time is required for the heat to penetrate the fireclay boxes and affect the cones, but for practical purposes this "delay" is an advantage as the results are comparable to the temperature attained in the centre of a piece of stone the same size as the box; this is more important than the momentarily higher temperature obtained by a "spot" reading with a radiation pyrometer.

In a mixed-feed kiln, "core" is found when the lime is drawn irregularly, *i.e.* all from one side of the kiln or largely from one side, and then from another, instead of drawing it as uniformly as possible from the whole cross sectional area of the kiln.

A further cause of "core" is the charging of the kiln with pieces of stone which are too large, relative to the output and capacity of the kiln. For a given rate of downward travel of the stone and lime there is a maximum size of stone which can be completely burned, and it is useless to put larger pieces into the kiln and to expect them to be burned "right through." It is a wise precaution to fix a plain sloping grid, in such a position that all stone which enters the kiln must pass through it, oversize pieces being either rejected or broken smaller. It is equally wise to provide a second grid which will remove all the pieces of stone which are too small to be suitable for the kiln. Even when the use of these grids involves an extra handling of the stone it is still worth the additional cost, for the feeding and control of the kilns are greatly facilitated and the reduction in the proportion of core is usually considerable. For most mixed-feed kilns, the openings between the bars of the grids should be 6 in. and either 3 in.

or 4 in. respectively, but if there is a large accumulation of small stone and several kilns, it may be well to have a further set of grids so that one or more kilns can be supplied with stone in pieces not less than 2 in. or more than 3 in. in diameter. This kiln will require a more powerful draught, because the voids or interstices between the pieces will be individually smaller, though the total volume of air spaces will be the same in the two kilns; the additional draught is best secured by means of a fan or exhauster, which may be connected to the upper part of a "submerged chimney" if desired. In many cases, however, the chimney draught will be sufficient and no fan will then be needed.

Another cause of "core" is faulty selection of stone in the quarry, for some stones are fully burned at 900° C. whilst others require 1150° C., so that in a mixture of such stones some may be overburned whilst others form "core." When this is the case it is necessary to use several kilns and to supply each with a different kind of stone, or to set one stone aside until a sufficient quantity has accumulated to make a long "run" of it through the kilns; the latter is the better procedure for a small works. The difference is particularly noticeable in some magnesian limestones in which, if the stone is underburned, one of two things may happen: (a) the magnesium carbonate alone may be burned, leaving the calcium carbonate (which needs a higher temperature) as core or (b) the outer layers of the pieces of stone may be burned and the inner "core" may still be carbonate.

In *gas-fired kilns* and *kilns with external fires* the causes of "core" are largely the same, but some additional ones exist, because there is a greater opportunity for irregular heating in such kilns than mixed-feed kilns. For instance, one or more of the gas-burners or fires may be cooler than the others, so that that part of the kiln will be underburned, or there may be undetected fissures in the mass of stone up which the hot gases rise without being properly distributed through the kiln. With skilful management these defects may be avoided, but this requires more skill and attention than in a mixed-feed kiln.

Another cause of "core" in such kilns is the difficulty of getting the flames to the centre of the kiln, there being usually a central column of imperfectly burned stone, which seldom exists in a mixed-feed kiln. To keep this material for a sufficiently long time in the kiln needs great skill in the drawing, but as soon as the men have learned how to do this, they become accustomed to it, and it gives them no trouble. To men unaccustomed to gas or externally-fired kilns, it may, however, be a great source of trouble until they have learned what proportion of stone to draw from the sides and what from the middle. The arrangements shown in fig. 84-87 (p. 337) and fig. 105 (p. 421) are designed to minimise this defect.

The causes of "core" in other kilns do not differ substantially from those just described, and do not, therefore, need to be set out in greater detail.

It is sometimes a matter of some difficulty to ascertain which particular cause of "core" is operating in a given kiln, but a careful and systematic examination will usually enable the principal one to be found; this may require a considerable time, but it is surer than guessing.

Sticking is a term used to indicate a state of affairs which exists when the stone does not descend properly through the kiln. It may be due to a variety of causes, of which the most common are :

(a) Clay or other siliceous matter in the stone, which, during the burning, combines with some of the stone forming a fusible glass which, when slightly cooled, cements the pieces of stone together or to the sides of the kiln, and so prevents them from falling when some of the lime has been drawn. The best way to avoid this cause of sticking is to use only stone which is free from clay or other harmful material, but where this is not easy to separate it may involve washing the stone before use. Washing is costly, but it is usually cheaper than the trouble due to excessive sticking of the stone in the kiln. Where washing is impracticable, much of the sticking may sometimes be avoided by working the stone in shallow benches, so as to enable the thin strata of clay, etc., to be cleaned off and so separated from the stone. A common and wholly unnecessary cause of sticking is due to carelessness with respect to the removal of overburden ; this material consists largely of clay, and if it is not removed properly, it may be washed down by rain on to the stone in the lower parts of the quarry face, and become so intimately mixed with the stone sent to the kilns that it is impossible to remove it. The quarryman who takes a real interest in the kilns will see that the overburden is removed from the face to such an extent that this source of impurity cannot harm the stone. Mechanical methods of removing overburden often leave sufficient " dirt " behind them to injure a large quantity of stone ; this should be removed by hand in whatever way seems most suitable, or the stone immediately beneath the overburden should be used for some other purpose, and not sent to the kilns.

(b) The lining of the kiln may become excessively rough and worn, and offers so great a resistance to the downward passage of the stone that sufficient combination between the stone and the brickwork can occur to produce the molten glassy material just mentioned, and so cause sticking. The remedy, in this case, is to keep the interior of the kiln in good repair, and to use only bricks of suitable character, laid with the thinnest possible joints.

(c) Overheating of the lime in the kiln will often cause sticking, because some limestones are easily superfused at about 1150° C.—a temperature which is readily attained locally in some parts of a vertical kiln which is not under complete control. Sometimes the overheating and superficial fusion is due to impurities in the stone itself, and sometimes to the admixture of clay with the stone, as just described ; in either case the effect is the same, but a satisfactory remedy is often difficult to find, as the local overheating may be, in part, due to the faulty construction of the kiln as well as to lack of skill in management.

(d) The admission of stones of different fusibility will sometimes cause sticking, because some stones will be overburned whilst others are only partially decomposed. This is a special case of the overheating mentioned above. It can be prevented by admitting only one kind of stone to the kiln, though, in the case of some very irregular stones, it is impossible to effect a satisfactory separation. In that case it may be necessary to put up with the sticking as a

"necessary evil," or to use a different kind of kiln where the stone does not move, so that sticking is less important.

(e) The use of stones of too many different sizes is a further cause of sticking, because the small stones are more quickly burned, and are more easily overburned, with the results described above, and also because the diversity in the sizes of the stones causes them to pack more closely, so that a greater draught is necessary in the kiln, and if a fissure or channel forms in the mass the stone surrounding it may easily become overheated and sticky. Moreover, the irregular packing of the stone tends to an irregular distribution of heat in the kiln, and this may be a further cause of overheating of some of the material.

In general, it will be seen that the prevention of sticking lies in the use of clean stone, and in avoiding serious overheating of any of the material. The best means of securing these two desiderata must necessarily depend on local conditions, but a careful consideration of the information given above should lead to a prevention of the most serious part of this defect. It ought to be pointed out, however, that some tendency to stick is an advantage in the burning of stone in kilns which are not drawn during the night, for it enables a large quantity of lime to be drawn at once without much incompletely burned stone falling and being drawn with it. In this way sticking may not be so great a disadvantage as might otherwise be supposed, though an excess of it is liable to be serious.

When sticking occurs, it almost invariably causes other troubles, such as "core" and overheating, because sticking inevitably leads to irregular burning of the stone. As soon as possible after it occurs, the burner should make a serious effort to draw as much fully-burned lime as possible, and to separate the adherent pieces by means of a long poker inserted through holes in the side of the kiln; it is arduous and unpleasant work, but the longer the partially fused pieces adhere the worse will be the quality of the lime.

Sticking is naturally most serious in vertical kilns; it is of minor importance when the stone does not move appreciably during the burning, as in Hoffman kilns. In a rotary kiln the movement of the stone tends to break down any adherent pieces, though one of the disadvantages of the rotary kiln is its tendency to glaze the lime with a thin film of glassy matter which causes the slaking to be very slow. Some gas and externally-fired kilns tend to stick more than mixed-feed kilns, because in the former there is a natural tendency for the hot gases to creep up the walls of the kiln and so facilitate the combination of the lime with the material composing the brickwork. This can only be avoided by the most careful attention to the burning, and is one reason why gas-fired kilns need much more skilful attention than mixed-feed ones.

Overheating or overburning is chiefly due to unskilled management of the kiln, though it may be unavoidable in some badly-designed kilns. It is primarily caused by raising some of the stone or lime to too high a temperature, but this may be brought about in a variety of ways, such as (a) irregular heating

of the kiln—especially if gas fired or with external fireplaces ; (b) defective falling of the stone in a vertical kiln, so that some parts of the mass allow the gases to pass upward more readily than others ; (c) the use of mixed stone containing pieces which require to be heated to different temperatures, so that in order to burn some pieces the others are overburned. In all kinds of lime kilns there is always a risk of some of the material being overburned, but with care and skill this need not be serious ; with an unskilled burner, or one not accustomed to a particular kiln, the amount of overburning is likely to be seriously increased. The only way to keep it at a minimum is to employ a competent burner who is sufficiently interested in his work to look out for possibilities of irregular heating, and who will devote himself wholeheartedly to “ humouring ” the kilns under his charge. It is comparatively easy to say what is wrong when the lime is examined ; it is far more difficult to decide when overheating is occurring or is about to occur, and to stop or prevent it before it becomes serious. This ability to be constantly alert cannot be learned from books ; it is partly a natural gift, but it can be cultivated by will power and prolonged experience until it becomes “ a second nature.”

If the nature of the stone is such that there is a serious risk of overburning, this may be reduced by :

- (i) Re-introducing half the kiln gases into the kiln through the bed of fuel on the grates or in the producer (see Eldred process, later).
- (ii) Using a combination of forced and induced draught ; the forced draught permits of a better regulation of the fire and the induced draught prevents the products of combustion from descending into the cooling lime and recarbonating it.
- (iii) Injecting steam into the fuel so as to cool the flames and to produce hydrogen which will lengthen the flame. A quantity of steam greater than can be decomposed by the fuel is sometimes an advantage.

Overburning is usually caused by the use of too short and too hot a flame, and the three methods just described cool and lengthen the flame and so tend to avoid overburning.

Overburned lime is usually yellow or almost black, and can usually be distinguished at sight ; it also requires a very long time to slake. These properties are probably due to a chemical combination of lime with the silica, clay, or other silicates present in the stone ; the resulting silicates of lime fuse and the molten liquid forms a skin or film which protects much of the lime from the action of water and so delays the slaking indefinitely. It is almost impossible to overburn a perfectly pure lime, *i.e.* one which is free from silica.

If overburned lime is ground, the protecting action of the fused silicate formed by overburning is largely destroyed and the lime slakes more rapidly.

Underheating is usually due to insufficient fuel, but is sometimes the result of a bad distribution of the fuel. This is particularly the case in kilns with external fireplaces and in badly managed gas-fired kilns. In some of the latter, the underheating is due to the gas not being drawn inward by the natural

draught, but flowing outward when an opening is made in the wall of the kiln. This is due to :

(i) The hot air rising through the cooling lime creates a pressure which blows the gas outwards. The remedy is either to increase the pressure of the gas or to reduce the amount of air admitted.

(ii) There is too little space in the kiln to contain the gas. This is usually due to attempting to burn stone which is in too small pieces or insufficiently regular in size.

Underburned lime may usually be recognized by its "weight," but the only really satisfactory test is its effervescence when a few drops of dilute hydrochloric acid are allowed to fall on it. Underburned lime is really a mixture of lime and unaltered limestone. If it is worth the cost, it may be put back into the kiln and re-burned, when it will usually be converted completely into lime. More frequently it is sold at a low price for agricultural purposes.

Many curious terms are applied to lumps of underburned lime ; amongst the commoner ones are *core, yorricks, balls, dumps, skulls, nodules, noddles, weights, spoils, etc.*

Excessive fuel consumption is a defect, the importance of which is not so often recognized as it should be. This is partly due to lime manufacturers having become accustomed to certain types of lime kilns and accepting the fuel consumption as "inevitable" and to the fact that, prior to the Great War, too little attention was paid to avoiding the waste of fuel. Since 1915, the higher prices charged for fuel have necessitated great care in its utilization and the avoidance, as far as possible, of defective combustion, excess of air in contact with the fuel, high loss by radiation, and defective management of the kiln. Although seldom made in actual practice, it is highly desirable that someone in each lime works should make frequent analyses of the gases escaping from the kiln so as to enable a record to be kept showing the extent to which fuel is being wasted by improper combustion, which is the chief cause of an excessive consumption of fuel.

The chief causes of excessive fuel consumption are : (i) too much air coming into contact with the fuel and so causing more fuel to be burned than is really necessary ; (ii) too short a kiln, so that the hot gases escape at too high a temperature, whereas in a taller or longer kiln, much of the heat could be abstracted by bringing the hot gases into contact with more stone. In some cases, the use of stone in very small pieces may cause a waste of fuel because of the difficulty experienced in getting the heat properly distributed through the kiln.

Of these causes, the first is, in many respects, the most important. It can only be remedied by skilfully designing the kiln and by avoiding all opportunities for an excess of air to come into contact with the fuel.

Many erroneous figures have been published respecting the fuel consumption of various kinds of kilns ; those shown on p. 389 are fairly reliable. It is unusual to burn more than 6 tons of lime for each ton of fuel burned, and in most gas-fired kilns only 4 tons of lime are produced for each ton of fuel

burned. Some of the Continental kiln manufacturers claim to burn 10 tons of lime with 1 ton of fuel, but these figures are seldom substantiated when the amount of unburned lime is deducted.

An excessive consumption of fuel is often objectionable when the carbon dioxide as well as the lime is required for use. In such a case, the supply of air to the kiln should be very carefully regulated and the fuel applied in as skilful a manner as possible.

If the percentage of carbon dioxide desired in the gas is known, the quantity of fuel (coke) used for each ton of lime produced must be adjusted accordingly, as in the following table :

TABLE XXXIII

Cwt. of coke per ton of lime.	Percentage of carbon dioxide in kiln gases.
6.0	31
4.5	35
3.0	40

Only if the kiln is burned under the best conditions will the kiln gases contain as much as 40 per cent. of carbon dioxide. In most kilns, an average of only 25-30 per cent. of carbon dioxide is found.

The *hot zone rises too high* in some mixed-feed kilns and this causes a serious waste of fuel and involves a great risk of improperly burned lime. This rising of the hot zone is due to an insufficient quantity of lime being drawn out of the kiln. It chiefly occurs at night, especially in those kilns where there is no night drawing. The rising of the hot zone can only be prevented by drawing the lime at sufficiently frequent intervals. This defect cannot occur in gas-fired kilns and in those with external fireplaces. When once the hot zone has risen too high, the only remedy is to draw sufficient lime to bring the hot zone to a suitable position and then to maintain it there by drawing the lime at sufficiently long intervals.

When *kiln linings fail prematurely*, their failure constitutes a very serious defect. It may be due to the use of inferior firebricks or blocks, but the commonest cause is bad management of the kiln. Care should be taken to use suitable bricks or blocks of fine texture, with a dense skin on the exposed face. They should have been well burned and should be fairly smooth. Bricks with a coarse, open texture soon perish, because when the hot lime rubs against the surface of the firebricks, some mutual combination occurs and a glassy, fusible silicate is formed; the corrosion proceeds much more rapidly with a coarse than with a fine material.

The bricks or blocks should be regular in shape and size so as to produce a smooth wall, as free as possible from irregularity of surface. Hence, machine-made bricks are often more suitable than hand-made ones.

Wide joints are another cause of premature failure of lime kiln linings as they are much more readily attacked than the finer bricks.

The refractoriness required in a firebrick or block for lining lime kilns need not be very high (Seeger cone 30–31 is ample); the chief resistance the bricks are required to offer is to corrosion by the limestone in contact with them. Hence, a dense, hard brick of low refractoriness may be much more durable in a lime kiln than a softer brick of great refractoriness, for the latter will more easily part with some of the material to the limestone.

When working a lime kiln, care should be taken to avoid the intensely hot flames rising up the sides of the kiln instead of being distributed through the stone. Nor should a hot flame be allowed to play upon any part of the brickwork of a kiln or the lining will suffer.

Fireclay bricks are chiefly used for lime kilns and, if well selected, they are satisfactory. Silica bricks are being increasingly used for this purpose; they are more liable than fireclay bricks to spall or fuse if the kiln is badly managed, but with sufficient care and skill, they are as durable as fireclay bricks and in some cases are found to be even more durable.

Attempts have been made to use highly aluminous bricks for lining lime kilns, but without very great success, for lime forms a fusible compound with alumina almost as readily as it does with silica. A limestone lining would, chemically, be the most suitable, but it can seldom be used, as most limestones spall or crack when heated and cooled suddenly. At the present time, good firebricks are the best material for lining lime kilns. They vary greatly in durability, but if the bricks are well chosen and the kiln is skilfully handled, they will last for some years. Even good bricks will be spoiled in a few weeks in a badly managed kiln. If the lining of a gas-fired kiln lasts less than three years there is something wrong with it, or with the management of the kiln. The lining of a mixed-feed kiln should last 5–10 years (see also p. 290).

An excess of small lime is produced when the kiln is too tall or when a brittle stone is heated or cooled too rapidly. The remedy is obvious, but owing to the expense involved it may be a serious matter. If much small stone is to be burned, a rotary kiln is probably the most convenient.

Discoloration of the lime is usually due to clay having been admitted along with the stone, but it may also be due to imperfect combustion so that the lime is discoloured by soot. It may also be caused by reducing gases or by flames in contact with an impure limestone. Such discoloration is due to ashes from the fuel adhering to the lime so tenaciously that it cannot be removed. Some limes, when seriously overburned, change colour; in this case, the discoloration is an indication of overheating.

Dark coloured glass is sometimes formed by the combination of clay, sand, or other siliceous material in the stone with the lime. It is seldom serious, but can only be avoided by the use of a cleaner stone. Occasionally, it is formed by the action of the stone or lime on the lining of the kiln; it is then a sign that harder firebricks should be used.

Ash mixed with the lime is sometimes a cause of discoloration of lime,

though most of it may usually be removed with little trouble. Occasionally, such ash helps to form a dark coloured glass which adheres to the lime.

Where a very clean lime is required, fuel ash in it is, of course, objectionable, though usually to a far less extent than is generally realized. Under normal conditions, using a coal containing 10 per cent. of ash and 4 cwt. of coal per ton of lime, the ash added by the fuel in a mixed-feed kiln could not exceed 44.8 lb. per ton of lime, or 2 per cent. of the lime. As most of this ash would be in the form of powder, it would not be present in the lump lime, but even if it were all present, it would be insignificant in comparison with the impurities in the limestone and, therefore, in the lime. For instance, if a stone contained 97.0 per cent. of calcium carbonate and 3.0 per cent. of impurities, the resulting lime would contain almost exactly 5 per cent. of impurities or more than twice as much as the ash left by the fuel. Unless, therefore, a very dirty fuel is used, there is seldom any object in employing gas-fired kilns merely to avoid contamination with fuel ash, for the amount of ash introduced when mixed-feed kilns are employed is usually so small as to be negligible.

Some firms will not buy lime which is discoloured by red ash. This may usually be avoided by changing the fuel and using one which produces a white or pale grey ash, without going to the expense of using a gas-fired kiln.

For some purposes, however, where the purest possible lime is required, it is necessary to use gas-fired or externally-fired kilns in which the ash is kept quite separate from the lime. These purposes are much rarer than is commonly supposed.

The chief reason why ashes are regarded as so objectionable in lime is that with very impure coal, used in excessive quantities, the proportion of ash mixed with the lime may be serious. Thus, one well-known firm, with short mixed-feed kilns, burns 8 cwt. of slack coal per ton of lime, and this slack contains 15½ per cent. of ash. In this case, the lime would have 6¼ per cent. of ash added to it, and this would be more than sufficient to spoil it for some chemical purposes.

Low output is usually due to either too narrow or too short a kiln. In an ordinary mixed-feed kiln, the stone will usually require about 72 hours to convert it into lime and pass it through the kiln, so that the output under normal conditions can be calculated from this figure. Another figure which may be used is to reckon on an output of 19–25 lb. of lime per 24 hours for each cubic foot of space available in the kiln; this is a very low estimate for kilns of modern type, but it applies to many old-fashioned kilns.

KILN CONTROL

Lime burners are slowly realizing the importance of an accurate control of the kilns, this being aided by the use of instruments for recording temperature and draught. Such instruments do not, in themselves, control the kiln, but they greatly increase the ease with which the man in charge can effect the necessary changes in heating and draught in order that he may control the kiln or kilns effectively.

The chief requirements for adequate control are those for regulating the temperature in various parts of the kiln, and for withdrawing the kiln gases at such a rate that the partial pressure of the carbon dioxide gas is kept as low as possible consistent with fuel economy.

In practice, the firing of a lime kiln is controlled in four ways :

(a) By regulating the intensity of the draught by means of dampers which control the amount of air entering or the gases leaving the kiln.

(b) By varying the nature of the flame produced by the fuel, when externally-fired kilns, gas or oil-fired kilns are used. Thus, by using a deep firebox and injecting steam below the grate a kind of producer gas is formed, the flame from which is milder and much more under control than that from an ordinary fire.

(c) By regulating the amount of secondary air supplied to the products of combustion, *i.e.* by varying the amount of air which enters *above* the fuel or into the combustion chamber.

(d) By drawing gas rich in carbon dioxide from the top of a shaft kiln and passing it, along with fresh air, through the grates of the fireboxes or mixing it with the gaseous fuel in a gas-fired kiln (Eldred process). This spent gas dilutes the air and enables a long flame of low intensity to be produced and so tends to prevent overheating of the lime. Incidentally, a small proportion of the carbon dioxide in the spent gas is reduced to carbon monoxide and so can again be used as fuel, but the gain from this cause is scarcely appreciable.

To ensure the proper distribution of heat in the kiln, it is desirable to have the following information :

- (i) The temperature in the hottest part of the kiln.
- (ii) The temperature of each succeeding zone, *i.e.* in the preheating, burning, and cooling zones.
- (iii) The temperature of the producer gas when a gas-fired kiln is used.
- (iv) The temperature of the gases leaving the kiln.
- (v) The temperature of the mixture of steam and air entering the producer, when one is used.
- (vi) The draught or water gauge reading of the gases leaving the kiln.
- (vii) The pressure of the air entering the kiln.
- (viii) The percentage of carbon dioxide and of oxygen in the gases leaving the kiln.

The temperature of the interior of a shaft kiln can only be found by indirect means (p. 431) ; that of the gases leaving the kiln may be measured by a thermometer if it does not exceed 350° C., but for higher temperatures a pyrometer is needed. The temperature of the gases leaving the producer and of the steam and air entering it may be measured by a thermometer. Unfortunately, a pyrometer cannot be placed in the interior of a shaft-kiln as it would be broken by the descending stone. If, on the other hand, it is placed in the wall of the kiln, it will only register the temperature of the kiln wall and not of the interior. This gives a false idea of the temperature inside the kiln. The only means of ascertaining the temperature of the interior of the kiln is to bore a

hole in the mass of lime and to measure the temperature by means of a radiation pyrometer. As the stone falls, this "hole" will be destroyed so that no permanent record of the temperature can be made automatically. Consequently, it is almost impossible to determine the temperature inside the kiln with accuracy.

In a horizontal kiln of the Hoffman, or similar type, the pyrometer may project through any part of the walls or roof, so that a more representative reading of the temperature may be obtained, though even with such a kiln it is almost impossible to ascertain the temperature of the interior of the mass of stone.

Notwithstanding these limitations, the use of a recording pyrometer is highly desirable, because it does enable the burner to maintain fairly constant conditions much more readily than when no pyrometer is used.

The most suitable type of pyrometer is a high resistance electrical pyrometer which should be of the recording pattern, the record being preferably

in the form of a long sheet. The thermocouple is placed in the wall of the kiln as shown in fig. 110. It must not be allowed to project into the interior of a shaft or rotary kiln, or it will be broken. This position of the thermocouple only indicates the temperature of the kiln wall, but this is

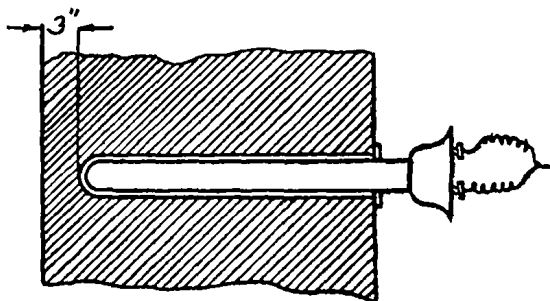


FIG. 110.—THERMO-COUPLE.

sufficient for most purposes, though it is far from ideal.

Several thermo-couples may be connected to one recorder, and each may operate the recorder in turn; any one of them may be connected to the recorder by moving a switch. This saves the cost of having several recorders, but involves greater care in reading the records.

The most convenient *draught gauge* is a plain glass tube bent like a letter U. A little water is placed in the bend, and one arm of the U is connected to a hole in the kiln wall. The draught of the kiln will cause the water in one part of the U tube to rise and in the other part to fall. The difference in height of the water in the two parts of the tube indicates the draught. A more sensitive gauge consists of an inclined tube—usually at an angle of 30 degrees—the lower end of which is bent vertically. The long, sloping arm has the effect of multiplying the scale of the instrument which, therefore, makes it easier to read accurately.

Much more elaborate instruments are often used, but they do not give much more accurate results. It is unusual to employ a recording draught gauge, but such an instrument may be used when required, and has the great

advantage of enabling variations in the draught to be studied more thoroughly than is otherwise possible. By this means, also, it is easier to maintain constant conditions in the kiln.

By attaching several draught gauges to different parts of the kiln, the variations in each can readily be observed and, when possible, corrected.

The pressure of air is usually measured by a gauge of the Bourdon type, such as is used for steam, but when the pressure is below 14 lb. per sq. in. a U-gauge containing mercury may be preferred.

There is ample scope for variety of choice in thermometers, pyrometers, and draught-gauges as many different patterns are made. If the purpose for which the instrument is required is stated, the makers will usually give sound advice as regards the selection of a suitable instrument, though they are liable to suggest unnecessarily elaborate ones.

Some kilns are supplied with a very elaborate array of pyrometers and draught-gauges; these are more impressive than actually needed. It is, however, better to have a few instruments which are well used than an over-elaborate set which are chiefly arranged for "show" purposes, and are of little practical value.

When rightly used, pyrometers and draught gauges are invaluable for aiding the control of the burning of lime, and it is unfortunate that their use is not more highly appreciated.

COOLING LIME

A few firms draw the lime from the kilns at a very high temperature, but there are many disadvantages and a considerable amount of danger in this, and, whenever possible, the lime should be reasonably cool when drawn.

Allowing a fuel : air ratio of 1 : 10 and a fuel : lime ratio of 1 : 5, the amount of air required by the fuel is twice the weight of the lime produced. As the specific heat of air and lime are almost identical, 1 lb. of air should, theoretically, cool 1 lb. of lime and the 2 lb. of air required by the fuel should be ample for cooling the lime produced, if the transfer of heat could be complete and instantaneous. In practice, far more than this quantity of air is required because the air travels through large interstices between the lumps of lime and does not remain sufficiently long in contact with them to cool the lime completely.

E. Chaudière has claimed that almost exactly ten tons of air are needed to cool one ton of lime rapidly, and in order that all this large excess of air need not be passed through the kiln, he has devised a cooling shaft passing vertically through the centre of the kiln to receive this air and convey it away from the kiln (p. 300).

In some kilns, very little air is drawn through the lime, but is admitted to the fires direct from the atmosphere. This is not desirable, because fuel is wasted in heating the air and heat in the lime is wasted.

The cooling is most conveniently effected (i) in the lower part of a shaft kiln; (ii) in the "cooling chambers" of a Hoffman continuous kiln; and

(iii) in a special rotating cooling cylinder connected to a rotary kiln. In intermittent kilns, the lime is cooled by the loss of heat by radiation when the firing has ceased.

In many works, the lime is drawn hot from the kiln and is allowed to cool on an open platform ; in this case, all heat is wasted, but its equivalent value is less than 3d. per ton of lime. A much more serious disadvantage is the re-carbonation of the lime which may occur.

In a shaft kiln, the cooling zone should usually be made of metal so as to allow of great loss of heat by radiation ; if it is built of brickwork it will be almost impossible to draw cool lime. A cooling zone 9 ft. deep is usually sufficient, but some kilns have a cooling zone 15 ft. deep, which is excessive, whilst others are only 4 ft. deep, which is not enough to produce cool lime. The cooling zone may be provided with ducts or with a double shell through which air is drawn, and then used to aid combustion or to dry stone. If all the available heat in the lime could be used it would be equivalent to about 35 lb. of good coal per ton of lime. As it is impossible to save all this heat it is seldom worth while incurring great expense in saving any of it. The amount of heat lost by radiation from a thin metal cooling zone may seem to be very serious, but the financial loss is far more apparent than real.

When the lime is in very small pieces or in powder, care must be taken to bring as little air as possible into contact with it. Otherwise, the air will partially re-carbonate the lime and so will spoil it. A recuperative device may be used, in which the air surrounds a battery of gilled tubes through which the lime passes. In this case the cooling air does not come into contact with the lime and so cannot harm it.

DRAWING LIME

The operation of removing the burned lime from a kiln is known as *drawing* ; in the shaft kilns it is effected by opening one or more doors or " shears " and allowing a suitable quantity of lime to fall out, its movement being aided, if necessary, by the use of pokers. In a Hoffman kiln the lime is usually removed with a large fork, the small pieces passing through the prongs of the fork and so being separated from the lump lime. A rotary kiln discharges the lime automatically.

If, when a limestone which does not readily " stick " is burned in a shaft kiln, a portion of lime is drawn from the bottom of the kiln, the remaining lime and stone will slide down the kiln and fill the space, but as the hot gases tend to rise up the sides of the kiln rather than the centre (fig. 111(a)) some underburned stone will travel more rapidly than the burned stone and the product drawn from the kiln will be a mixture of lime and " core." This may be avoided by leaving the fire doors open for 15-50 minutes before drawing. This admits an excess of air which chills the lining and solidifies any molten silicates, so that when lime is drawn, the remaining contents of the kiln do not slide down or " follow " properly, but remain in position (fig. 111 (b)). This " stuck " or " hanging " material is loosened from the sides by means of pokers, which are

applied in such a manner as to leave a vertical pillar in the centre of the kiln (fig. 111 (c)). Finally, this pillar (fig. 111 (d)), is knocked down by the poker (fig. 111 (e)) and the burning is continued. By drawing a kiln in this manner even heating can be assured, but much time is wasted in the drawing and the output is reduced because little or no burning can occur during the drawing.

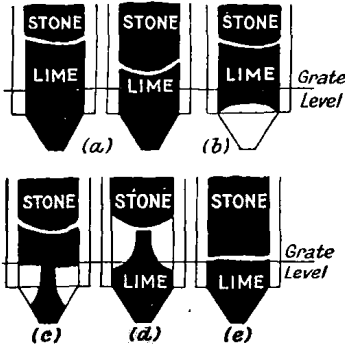


FIG. 111.—STICKING LIME.

On the whole, sticking should be avoided whenever possible, and the kiln should be so managed that when lime is drawn the remainder of the contents "follow" automatically.

Sometimes, part of the lime will stick, but will allow other material to flow past it, resulting in a mass of lime above unburned stone. This lime may exert a destructive effect on the lining of the kiln, partly by corrosion and partly by tearing away some of the lining when the lime does eventually fall.

Many attempts have been made to draw lime automatically from shaft kilns, but none are really satisfactory, so far as lump lime is concerned. Where small lime can be used the various devices for automatically drawing similar kilns containing Portland cement can be used. They are inapplicable to lump lime because they crush the lumps.

When the lime is drawn through an opening in the side of the kiln, there is always a risk of removing more lime from that side than from any other part. This is, to some extent, avoided by having four side-openings, but the best arrangement is a single opening in the centre of the kiln, towards which all the sides of the cooling zone slope.

The intervals at which a kiln should be drawn depend so largely on the nature of the limestone that no detailed statement can be of any general application. The extent of these variations may be shown by the following table, which indicates the intervals in 240 shaft lime kilns in the British Isles, France, and Germany inspected by the author :

8	are drawn at 1 hourly intervals.
4	" " " 2 " "
38	" " " 3 " "
65	" " " 4 " "
36	" " " 5 " "
32	" " " 6 " "
18	" " " 7 " "
9	" " " 8 " "
30	" not drawn at night.

Owing to the difference in behaviour of the various stones and of the same stone at different times it is essential that the head lime burner should have a fairly free hand in deciding the intervals at which the lime should be drawn and the amount to be removed from the kiln at each discharge.

Under normal conditions, a better quality of lime will be produced with frequent drawings than with those at longer intervals, but, as just stated, each kind of stone and each kiln must be considered separately.

When excessively hot lime is drawn it indicates (i) too short a cooling zone in the kiln (see Cooling) ; (ii) too much lime being drawn ; or (iii) defect in the draught whereby some heat is passing down the lime instead of up it.

The art of drawing a lime kiln requires much more skill than is often supposed and many defects attributable to carelessness in burning or to a badly designed kiln will be found, on further examination, to be principally due to the errors in drawing previously mentioned.

SORTING OR PICKING

When the lime has been drawn from the kiln it should be *sorted* or *picked* into four qualities : (i) " small lime " ; (ii) lump lime ; (iii) underburned lime or *core* ; and (iv) overburned lime.

The small lime may be separated in one of three ways :

(a) The lime, as it is drawn from the kiln, may be allowed to fall on a gently sloping grate, composed of bars $1\frac{1}{2}$ in. apart, so that the small pieces pass between the bars whilst the lumps remain thereon. This grate may serve as a picking table, the lumps being lifted one at a time and thrown on to the respective trucks according to their quality.

(b) The lumps may be picked up and sorted, whilst the small lime is left behind and can be shovelled up later.

(c) The mixed lime may be lifted by means of a large fork, with prongs $1\frac{1}{2}$ in. apart, so that the lumps are raised and can be thrown into a truck whilst the small lime falls between the prongs of the fork.

Careful and conscientious sorting is very important, and should never be omitted where lime of good quality is desired. It may appear to be expensive, yet, in most cases, the proportion of " good lump lime " is the simplest and most direct indication of the manner in which the kiln is working. Even if the whole of the lime is to be slaked or hydrated, the desirability of careful sorting is equally great, for the slaking of large quantities of " core " is a costly and unprofitable process. Almost the only industries which can use unsorted lime to advantage are the metal smelters and farmers. The former cannot be expected to pay for core at the same rate as lime, and the hard lumps of core which will not disintegrate are quite useless to farmers. Hence, even these two industries would be well advised to use picked lime.

Attempts have been made to effect the sorting mechanically, but so far without success. It may, however, be greatly facilitated by the use of travelling grates, conveyors, and other devices which carry the materials

slowly past the sorters who can then concentrate their attention on throwing out the useless material. In too many lime works the facilities for sorting are so poor and inadequate that efficient sorting is impossible.

TESTS AND REPORTS OF KILN PERFORMANCE

To ensure that a kiln is working under the best conditions it is necessary to make certain tests and reports at very frequent intervals, or even continuously. These have been neglected in the past—partly because their importance was not realized and partly because in a small works the cost is regarded as too great.

The tests and reports which should be made are :

(a) *Gas analyses* of (i) producer gas (if used) ; and (ii) the gases leaving the kiln. A recording CO₂-gauge for the latter is invaluable in controlling the burning.

(b) *Temperature measurements* of (i) the entering gas ; (ii) the interior of the kiln at various levels ; (iii) the exit gases ; (iv) the gases leaving any waste heat user, and (v) the lime leaving the kiln.

(c) *Draught measurements* in the producer and in various parts of the kiln, chimney, or exhaust flues.

(d) *Analyses* of the stone, lime, and waste-product (cores).

(e) *Times* of charging and discharging, and the quantity of material at each.

(f) *Excessive labour* due to “ sticking,” “ delays,” low output, excessive “ core,” and other causes.

It is obvious that the information provided by the foregoing will be of little practical value unless adequate use is made of them to improve the quality of the product, to increase the output, and to reduce the cost. It is in the use made of tests, rather than the tests themselves, that their great value lies.

CHAPTER IX

THE UTILIZATION OF WASTE PRODUCTS FROM LIME WORKS.

THE chief waste products obtained in the burning of lime are : (i) small pieces of limestone which are unavoidably produced in quarrying, but cannot be burned satisfactorily in ordinary lime kilns ; (ii) pieces of underburned lime or " core " ; (iii) pieces of overburned lime ; (iv) the gases escaping from the kiln, which are hot and rich in carbon dioxide ; (v) waste heat from various parts of the kiln, and (vi) small pieces of lime for which there is little or no profitable market. In any serious consideration of waste products it is necessary to take each of these in turn and to ascertain how and why they are caused and to what extent their production can be avoided. In localities where competition is serious, the utilization of waste products—which are more rationally termed *by-products*—may make all the difference between the success and failure of a works.

SMALL STONE

A common cause of serious waste is the fact that most of the lime kilns now in use will not work satisfactorily if supplied with a large proportion of small stone, *i.e.* stone in pieces less than about 3 in. diameter. This stone has to be quarried or is produced during quarrying, and if it cannot be sold profitably or converted into readily saleable lime it forms a serious part of the cost of manufacture. It may be sold for use as road stone or for various other purposes for which small pieces of limestone or powdered stone are employed, as already described, or if suitable kilns are employed it may be converted into lime.

The reason why a shaft or a Hoffman type of kiln will not burn stone containing many small pieces is that in a kiln filled with stones of various sizes there is a much smaller proportion of air space than in a similar kiln in which all the pieces of stone are approximately the same size. It can be proved mathematically that if all the pieces of stone were spheres and of the same size there will be a definite percentage of air space which depends on the relative positions of the pieces to each other, but is never less than 40 per cent. of the total capacity of the kiln. This figure is the same no matter what may be the sizes of the spheres, so long as all are the same size. That is to say, a kiln filled with balls 6 in. diameter will have precisely the same air space as an equally sized kiln filled with balls 12 in. diameter. If, however, the balls are of different sizes they will pack more closely together and the air space may be reduced to five per cent. Stones which are not truly spherical may pack either more closely or more openly, according to their shape, but the statement just made as to the air space applies generally, though less accurately, to all shapes.

This fact gives the clue to a means of burning small pieces of stone. They must be separated into their respective sizes and the pieces of each size must be burned separately from those of other sizes. Great exactitude is not necessary, but the following limits should not be exceeded :

TABLE XXXIV

Grade.	Maximum Diameter.	Minimum Diameter.	Mean Diameter.
A	8 in.	3½ in.	5½ in.
B	4 in.	2¾ in.	3½ in.
C	3 in.	1¾ in.	2½ in.
D	2 in.	1 in.	1½ in.
E	1 in.	½ in.	¾ in.

Pieces smaller than ½-in. diameter are difficult to burn in a shaft kiln.

To burn graded stone it is necessary to have a separate kiln for each grade though with an exceptional amount of care it is possible to use one kiln for several grades in succession. Small firms using only one or two kilns cannot make use of this means of burning small stone. By them, and in other instances where it is considered to be impracticable to separate the stone into the above mentioned grades, a rotary kiln may be employed as this is largely independent of the grading of the stone.

If the stone is graded, as suggested, it will be found that whilst the total air space in each of the sizes is the same, the size of each individual air space is much less with small stone than with larger pieces. It may, therefore, be necessary to use mechanical draught or air under pressure to ensure the proper combustion of the fuel and the uniform distribution of the heat through the kiln. Failure to realize this has been a cause of non-success in burning small lime.

See also the section on " Rotary Kilns " on p. 375 *et seq.*

UTILIZATION OF SMALL LIME

One of the chief problems of most lime burners is the disposal of the pieces of lime less than 2 in. diameter, *i.e.* the *small lime*, at a profit. It is not generally appreciated that the demand for lumps not only causes a great deal of trouble and loss to the lime burners, but also tends materially to keep up the cost of production. When lumps are required all the lime has to be *forked*, with the result that the residue is considerable and when there is practically no outlet for it, it is all waste and loss. The burners, naturally, have to cover expenses, and thus the loss on this waste has to be recouped out of the price charged for the lump lime which is sold. If the prejudice of builders and others could be overcome, and the lime sent out as it comes from the kilns, without the expense and loss of forking, the burners would be able to make an appreciable reduction in their prices, and the whole trade would benefit.

All that is really wanted is that customers should be enlightened as to the merits of the situation. Other things being equal, small lime is every bit as good as large stuff, and there is really nothing behind the demand for "big lumps." When small lime has to be sold separately, it may be supplied to farmers for agricultural purposes at a low price which is often below the cost of production—a very unsatisfactory procedure, especially . . . there is no demand by farmers for about six months in each year.

Some firms grind it to powder, but while this enables them to meet a certain demand, the amount of ground lime which can be sold is usually far less than the small lime produced so that this cannot be regarded as a satisfactory means of disposal.

A much better means of disposing of it is to slake it by hand or to hydrate it mechanically, by means to be described later. If this is done properly, the greater part of the unburned stone (core) and the coarser impurities can be removed and a hydrated lime of good commercial quality produced.

In the United States and on the Continent, the small stuff is hydrated and this is found to be more profitable than the sale of large lumps in the ordinary manner; few British lime burners have yet realized the possibilities of this part of their product.

UTILIZATION OF UNDERBURNED LIME (CORE)

The profitable use of the portions drawn from the lime kilns and thrown aside as "core" is a matter of great difficulty. This material includes undecomposed calcium carbonate as well as other minerals present in the original stone, such as iron ore, silica rock, pieces of burned clay, etc., which, by their nature, can never be converted into lime. Such other minerals must usually be discarded as waste which ought not to have entered the kiln; they must generally be sent to the spoil bank or tip and if their sale occurs it may be regarded as a piece of good fortune.

The calcium carbonate, or unburned stone, which usually comprises the greater part of the core could be converted into lime by putting it back into the kiln. This is seldom done because (i) it is usually more costly to put such core back into the kiln than it is to use new stone, and (ii) there is always a suspicion that a piece of stone which has come through the kiln imperfectly burned may do so again if replaced in the kiln. The first reason is more generally valid than the second, but the latter may apply if the stone is very impure and the impurities tend to segregate in the core.

The best method of treatment for the core depends on local conditions and on its nature. If it consists almost wholly of pure calcium carbonate it will almost certainly pay to replace it in the kiln, even when this means the erection of a hoist or lift to raise it to the level of the mouth of the kiln. If the core is very impure it will probably be well to pick out the pieces of relatively pure calcium carbonate and to re-burn these, but to throw the others away.

If the proportion of underburned lime or core exceeds 10 per cent., the conditions of the burning and general management of the kiln should be

investigated as a large proportion of core usually indicates that the kiln is not operating properly.

There is one part of the "core" which always seems to be worth using, namely, the lime on the exterior of lumps composed mainly of "core." Some of these lumps may contain an outer layer, an inch or more in thickness, composed of lime of excellent quality which is usually thrown away. To avoid this, the pieces of core may be passed into a hydrating plant (see later) and sold as hydrated lime. The stones left as a result of this treatment may, according to their nature, be returned or thrown away. The slaking or hydrating of "core" is a difficult process, but when once the men are used to it they do it very successfully and if it contains enough lime it should yield a good profit.

UTILIZATION OF OVERBURNED LIME

When a piece of limestone has been raised to a temperature much higher than that needed to convert it wholly into lime, it acquires properties different from ordinary lime and is said to be "overburned." The most noticeable difference is the fact that it slakes with extraordinary slowness and may even appear to be unaffected by water. There are two reasons for this unusual behaviour: (i) the lime may become converted into a denser and more resistant form, without altering its chemical composition (silica, alumina, and magnesia are known to do this), and (ii) the high temperature reached in the burning may cause any clay or free silica present to combine with the lime and form a fusible glass which spreads by capillary attraction through the mass of lime and, being impervious, protects the lime from the action of water.

Unless the overheating is very excessive, overburned lime may usually be slaked by grinding before adding water, though the process is costly and the slaking is very slow and requires much supervision. It is, however, almost the only means of dealing profitably with overburned lime.

UTILIZATION OF KILN GASES

The gases emitted by lime-kilns are hot and contain a large proportion of carbon dioxide, so that means should usually be found for making use of these two characteristics.

The most important uses of such gases are: (1) to heat a boiler which can provide steam for various purposes, particularly for use in gas producers when gas-fired kilns are employed, or to facilitate the burning of the fuel in coal-fired kilns. In some cases steam produced by the waste heat from lime may be used for driving a steam-engine; (2) to dry wet stone before it enters the kiln; (3) to modify the flames from the fuel used in the kilns and produce a milder burning; (4) as a source of carbon dioxide; and (5) as a source of fuel.

The use of the heat in the gases is comparatively simple, though it involves a considerable capital expenditure.

As the hot gases leave the kiln at about 1300° F. or 705° C., they can be passed into a "waste heat" boiler in which they can produce a supply of hot

water or, preferably, a supply of steam at a pressure not exceeding about 20 lb. per sq. in. This steam may be used in the producer if a gas-fired kiln is employed or it may be used for any convenient purpose. If it is desired to drive an engine, so as to produce power, the boiler and engine may have to be specially designed as it is somewhat difficult to obtain much engine power by this means, though it can be done satisfactorily with the aid of a turbine, when the conditions justify the requisite capital expenditure.

The amount of heat obtainable in this way is much too great to be wasted, as is so often the case, for the gas produced by a ton of lime will usually have the same heating power as 45 lb. of good coal, so that a kiln producing only 20 tons of lime a day will produce enough heat in its waste gases to be equivalent to 900 lb. or 0.4 tons of good coal each day.

The steam from a waste heat boiler may also be introduced into the gas producer, if one is used, so as to facilitate the gasification of the fuel. Only a low pressure of steam is required, and the amount produced is usually in excess of that required by the producer.

When a kiln is heated with external fires, these may sometimes be altered by conversion into small producers or semi-producers into which steam is injected so as to control the gasification of the fuel.

The use of steam in the producer has a further advantage inasmuch as it is largely dissociated into hydrogen and oxygen, the latter combining with the fuel to form carbon monoxide. These products burn in the kiln so that the introduction of steam tends to cool the fire and produce a longer flame—both desirable purposes when burning lime and enabling the output to be increased without much risk of overburning the lime.

Another important use of steam is to modify the burning of the lime, which is decomposed at a lower temperature when steam is present. Care must be taken not to admit enough steam to slake the lime, but any lesser amount is usually advantageous. The presence of so much steam in the products of its combustion is probably one reason why wood is such an excellent fuel for burning lime.

When passing steam into a mixed-feed lime kiln in order to reduce the temperature at which the stone is decomposed, the fact should not be forgotten that calcium sulphate is reduced to calcium sulphide which is converted by the steam into sulphuretted hydrogen, which is very objectionable if the carbon dioxide in the kiln gases is collected and liquefied. Hence, steam should not be used when the carbon dioxide is collected from the kilns and used for aerating beverages.

If a waste heat boiler is installed, it should be fitted with a "Dutch oven device" containing firebars, so that when re-starting the kiln the water in the boiler may be heated by coal until sufficient waste heat is available to render the use of coal unnecessary. Otherwise, it may be impossible to start the producer or kiln fire, because of the absence of steam.

When the hot gases from the kilns are used to dry the stone supplied to them, the latter is usually passed into a tall, vertical chamber fitted with sloping

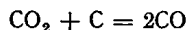
baffles, so that the stone does not pass vertically downward but flows from baffle to baffle whilst the hot gases rising through the chamber, are deflected from side to side by the baffles.

Various other shapes of dryer may be used, but the one just mentioned is usually one of the most economical and is easily repaired if damaged by the falling stones. Rotary dryers are equally satisfactory, but are much more costly.

Care should be taken to avoid condensation of moisture from the hot gases onto the stone, or the latter may contain more water when partially dry than when in its original state.

The use of the hot kiln-gases to modify the burning is commoner in America than in Europe. It is based on the fact that if a mixture of carbon dioxide and air is introduced to the fires instead of plain air, the combustion will be milder and conditions in the kiln will more closely resemble those which are observed when wood is used as the chief fuel. In the Eldred, Doherty, and other kilns, the kiln gases rich in carbon dioxide are forced to re-enter the kiln through the fires or producer. They cool the fire, prevent overheating of the lime, make use of the heat in the kiln gases, and create conditions which more closely resemble a wood fire than any other system in which coal is used. In the Doherty system, half the waste gases are returned to the gas producer, and some of the carbon dioxide present in that portion is reduced to carbon monoxide, which, when burned, has heating value. This is not, however, the usual purpose of returning the gases, which is to modify the manner in which the fuel is burned and prevent too hot a flame from being produced. It is necessary to restrict the amount of gases so returned, as an excess will extinguish the fire or make it so feeble as to be useless. It has been found that the maximum amount of the mixture of air and flue gases which can be used is that containing 6 per cent. of carbon dioxide, and this only when the waste gas has a temperature of 1000° C.; for cooler gases only a much smaller proportion of carbon dioxide is permissible, so that it is necessary to draw the gases from the kiln at a high temperature or little or no benefit would be obtained. The withdrawal of the gases at a high temperature results in a loss of heat which would otherwise be available for preheating the stone. Hence, the advantages of Doherty's method of reintroducing the gases are not as great as might appear to be the case if some of the other factors are neglected.

The idea of using the kiln gases as a source of fuel is based on the fact that if carbon dioxide is passed through brightly glowing coke a chemical reaction occurs and carbon monoxide is produced.



The carbon monoxide is a valuable gaseous fuel. A patent¹ has been granted for the use of two gas producers worked alternatively; one as a gas producer and the other for converting the carbon dioxide into the monoxide. Apart from any benefit to be derived from the peculiar nature of the gas formed, the

¹ Reid and others, Eng. Pat. 233,137 (1924).

process is not profitable, as it is more costly to decompose the carbon dioxide than to produce carbon monoxide direct from fuel.

MANUFACTURE OF CARBON DIOXIDE

The utilization of the kiln gases as a source of carbon dioxide is very important in some districts and in some industries where both lime and carbon dioxide are required. The present supplies of carbon dioxide are ample in many localities, but there are others where a plant for supplying compressed dioxide would be highly profitable.

Several methods of separating the carbon dioxide from the waste gases are available, but whichever is used it is essential that the kiln gases themselves should be as clean and concentrated as possible. For this reason, the gases from mixed-feed kilns are preferable to those from gas-fired kilns, and it is essential to use *coke* as fuel, as coal evolves a tar which it is extraordinarily difficult to separate from the gases, and is a constant source of trouble in other ways.

The proportion of the kilns is important when the carbon dioxide is to be collected, as, otherwise, the gases will be unnecessarily hot and troublesome to manage, or they will tend to include objectionable products of combustion. Convenient dimensions of mixed-feed kilns for this purpose are 33–40 ft. high and 7–10 ft. diameter; such a kiln will produce 15–18 tons of lime per day. F. Lunge has recommended shaft kilns 33 ft. high and 6 ft. internal diameter for burning lime and producing the carbon dioxide required by the ammonia-soda process for the production of caustic soda and sodium carbonate. In order to keep the kiln gases as concentrated as possible, such a kiln should only be expected to burn about 15 tons of stone, *i.e.* to produce only half this quantity of lime each day. The kiln may be of the simplest possible type, as additional "fittings" tend to introduce more air into the gases. It is desirable to have at least seven "spy-holes" at different parts of the kiln, in case of "sticking" or similar trouble. In addition to constant attention to the selection of stone of uniform physical and chemical properties, great care is given to securing a suitable ratio of fuel (*coke*) to stone, temperature, and draught, so as to produce a constant supply of gas containing 30 per cent. CO_2 by volume.

Coke is almost exclusively used to ensure the absence of odour and other impurities in the gas.

The following methods of obtaining carbon dioxide gas for general or specific purposes are in use:

(1) The gases are drawn from the kiln by means of a fan, and are then passed into one or more "scrubbers" filled with stone or coke through which flows a stream of water. To prevent undue waste of gas in solution, the water is recirculated through the scrubber. The scrubbed gas is sufficiently clean and cool to be used in the purification of sugar and for heavy chemicals, but the fuel used in the kiln must be *coke*, as coal produces a tar mist which is not removed from the gas by scrubbing.

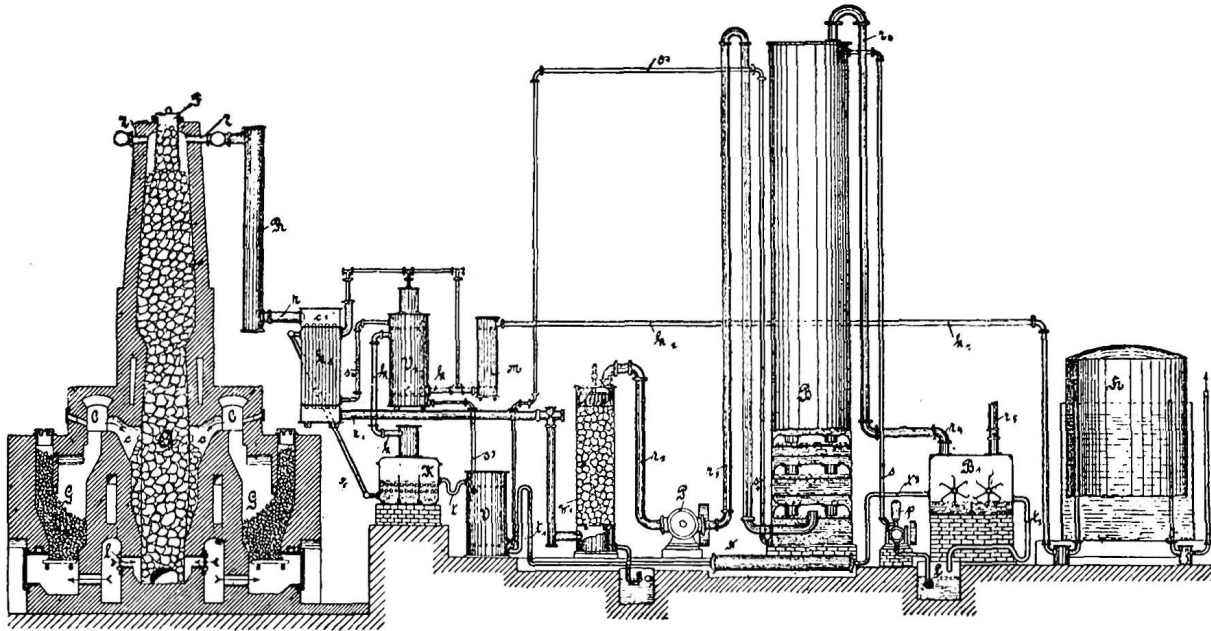
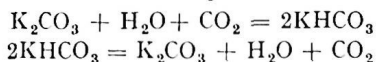


FIG. 112.—PLANT FOR MAKING CARBON DIOXIDE FROM LIME (*Schmatolla*).

(2) The gases are cooled by passing through a waste heat boiler, and are then passed into a solution of potassium carbonate (or bicarbonate). The liquid is then filtered, run into a closed boiler, and heated under pressure, when the bicarbonate is decomposed and carbon dioxide evolved. This is removed by a suction-pump, cooled, passed over calcium chloride to dry it, and is then compressed in iron cylinders until it liquefies, a pressure of about 1,036 lb. per sq. in. being required if the gas is at 31° C., but only 520 lb. per sq. in. if the gas is at 0° C.

The heated lye is cooled, and can be used over again, as the salt in it has been reconverted into normal potassium carbonate.



It is an advantage to "scrub" the gas with brine before passing it into the absorbers as this treatment enables the lye to be used longer than if the dirty gases were supplied to it. One form of plant used for this purpose is shown in fig. 112. In this, the gas from the lime kiln, *A*, is passed into a dust separator, *R*, and then into a cooler, *C*, which simultaneously warms the potash lye, and through the pipe *r* to the scrubber, *W*, the pump, *P*, to the absorber, *B*, where the carbon dioxide is absorbed in the second scrubber, *B*₁, and the gases, now freed from their most valuable constituent, pass into the atmosphere. Meanwhile, the potash lye, which should have a specific gravity of 1.125, is raised from the well, *e*, by the pump, *p*, to the top of the absorber *B*. The lye from this absorber then flows through the tube, *S*₁, to the boilers, *V*, *V*₁, *K*, in which it parts with the absorbed carbon dioxide, the latter being taken through the pipe, *K*, to the gas holder *H*.

The plant used for liquefying the carbon dioxide is shown in fig. 113, which represents the gas as being drawn from the gas holder, *M*, through two scrubbers, one of which contains calcium chloride and the other wood charcoal, by the compressor, *O*, which passes it into the cooler, *P*, into a second compressor *O*, which delivers it to the cylinders, *W*, in which it is liquefied.

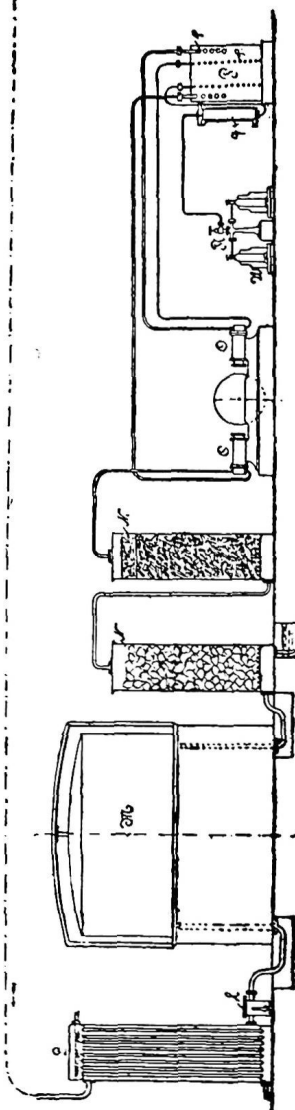


FIG. 113.—PLANT FOR LIQUEFYING CARBON DIOXIDE.

Various modifications of this type of plant are sometimes used, but the essential features are retained.

The recovery of carbon dioxide from lime kilns must, in some districts, compete with carbon dioxide made by passing a current of air through coke and, in others, by heating magnesite in retorts, though the latter process is seldom used notwithstanding its simplicity, owing to the ease with which the magnesite is decomposed into magnesia and carbon dioxide.

In the Gillette Research Corporation's method a pure carbon dioxide and a pure lime are prepared by the use of vertical continuous retorts made of silicon carbide (p. 308). This method is unprofitable for lime alone, but when the carbon dioxide can be utilised (*e.g.* for "dry ice," p. 459) it appears to be remunerative in some places.

Many other processes have been patented for the recovery of carbon dioxide from lime kilns, but most of them are of no practical interest, as the cost of the catalysts or other agents employed makes such processes unprofitable. Thus, the suggestion to supply oxygen instead of air to a lime kiln involves a wholly prohibitive cost with oxygen at its present price, but it might become commercially feasible, if the cost of oxygen were correspondingly reduced, as the much smaller volume of gas to be handled would effect a considerable saving. On the other hand, the oxygen would have to be diluted with kiln gases or the flames from the fuel would be far too hot; hence, the saving, even with very cheap oxygen, would probably be small.

Precautions.—In order to recover the carbon dioxide as economically as possible, various precautions must be taken, among which the following are important:

(i) The kiln gases used for the recovery of carbon dioxide must be sufficiently rich in that gas as to make the recovery profitable. The maximum proportion which can usually be present is 34 per cent., but if the cooled gases contain 30 per cent. or more of carbon dioxide, there is little cause for complaint. If a much smaller proportion of carbon dioxide is present, recovery will be costly and more difficult. It is almost impossible to maintain a constant proportion of carbon dioxide in the kiln gases and a variation of 24–34 per cent. can seldom be avoided. It is essential to keep the kiln, the flues, pipes, and exhauster as gas-tight as possible, or the percentage of carbon dioxide will fall rapidly.

(ii) The gases must be well scrubbed, or the impurities may cause trouble in the liquefying plant. The use of coke, instead of coal, in the lime kiln is highly advantageous in avoiding much costly scrubbing. Any water used in the scrubbers must be recirculated, as carbon dioxide is soluble in water. Sometimes, brine is used instead of water as the gas is less soluble in brine.

(iii) If the gas is to be used for aerated waters, or other purposes where a pyroligneous odour is objectionable, the cool, dry gas should be passed through a scrubber filled with wood charcoal just before it is liquefied.

(iv) Adequate regulation of the temperature and pressure in different parts of the plant is important as, if these are badly controlled, much carbon dioxide will be lost. The potash lye, for example, will not absorb its full

measure of gas unless it is sufficiently cool and the liquefaction of the gas may be dangerous unless a thoroughly dry gas is used. Liquefaction occurs most satisfactorily when there is a steady reduction in the volume of the gas at a constant pressure, 21.5° C. being a favourable temperature for liquefactions.

(v) The pressure required to liquefy the gas depends upon its temperature. At any temperature above 31.3° C. (the critical one) no pressure, however great, will effect liquefaction. At lower temperatures, pressure less than 929 lb. per sq. in. will be required, as shown in the following table :

TABLE XXXV.—*Temperature and Pressure at which Carbon Dioxide Liquefies.*

Temperature. ° C.	Pressure lb. per sq. in.
0	529.2
5	573.2
10	647.5
15	734.8
20	825.0
25	928.9
31.1	1072.1

(vi) The cylinders of liquefied gas must never be filled completely with the liquid at the maximum temperature to which they are likely to attain or they may burst.

So long as there is any vapour left, the pressure in the cylinder will be only that corresponding to the vapour pressure curve for that temperature, but immediately the cylinder becomes full of liquid the pressure rises enormously with further increases of temperature. If, however, a cylinder is charged at a density below the "critical density," or the density at the critical temperature (0.464), on raising the temperature of the cylinder above that at which it was charged, the reverse effect takes place, the liquid evaporating until, finally, there is nothing but vapour left. Cylinders intended for tropical countries, or conditions where a temperature of over 30° C. may be met with, should therefore be charged at a density not exceeding 0.46.

Properties.—The chief properties of commercially pure carbon dioxide are :

1 litre of pure dry carbon dioxide at 0° C., 760 mm. pressure, and at sea-level weighs 9.877 gram (Greenwood).

.1,000 cubic feet of pure dry carbon dioxide at 15° C., weigh 116.9 lb. (Greenwood).

Critical temperature—31.35° C. above which no amount of pressure will liquefy the gas.

The vapour pressure varies with the temperature as shown in Table XXXV.

The total heat of the gas between 0° C. and 1300° C. in Centigrade-pound units or Calories per kg. is shown in the following table :

TABLE XXXVI

Temperature	0°	100°	700°	1300° C.
Total Heat, Const. Pressure	0	20/82	170/9	247/2
Total Heat, Const. Volume	0	15/52	130/5	282/9

(Authorities : const. press., Holborn and Henning ; const. vol., Crofts).

The solubility in water at atmospheric pressure from 0° C. to 40° C. is shown in Table XXXVII (Greenwood) :

TABLE XXXVII

Temperature, ° C.	Solubility, vol. of gas (at N.T.P.) per vol. of water.
0	1.700
5	1.424
10	1.188
15	1.019
20	0.900
25	0.750
30	0.665
35	0.580
40	0.520

The solubility in water at 12.4° C. at pressures from 50–350 lb. per sq. in. (gauge) is as follows (Greenwood) :

TABLE XXXVIII

Pressure lb. per sq. in.	solubility vol. of gas (at N.T.P.) per vol. of water.
50	4.75
75	6.25
100	8.00
125	9.50
150	10.75
175	12.50
200	13.25
225	14.75
250	16.00
275	17.50
300	18.25
325	18.75
350	20.00

The Latent Heat of Vaporization in Centigrade-pound units per pound or Calories per kg. at three typical temperatures is as follows (Castell-Evans).

Temperature	...	7·25°	22°	30·6° C.
Latent Heat	...	50	31·8	7·26

The specific gravity of the liquid and that of the saturated vapour (water at 4° C. = 1·000) are as follows (R. T. Stewart) :

Temperature	...	5°	15°	25° C.
Sp. Gr. Liquid	...	·888	·814	·703
Sp. Gr. Vapour	...	·113	·158	·240

When the pressure on liquid carbon dioxide is released rapidly (as when a bottle is opened) the cooling effect due to the evaporation is so great that the gas solidifies and becomes "snow." This can readily be collected by placing a bag over the mouth of a cylinder, and opening the latter slightly; the bag is soon filled with the "snow" which can be compressed and retained for some time before it evaporates.

The advice is sometimes given not to attempt to compress hot or dry gas because of the difficulty of maintaining efficient lubrication. This advice is by no means sound, for water saturated with carbon dioxide has a highly corrosive action on iron and steel. There is no real objection to compressing dry carbon dioxide; on the contrary, this is the best state in which to compress it.

USES OF CARBON DIOXIDE

The principal uses of carbon dioxide recovered from kilns are: (i) for aerating water and other beverages; (ii) for raising beer; (iii) as a refrigerating agent, for which purpose it is superior to ammonia and sulphur dioxide; it may be circulated in a refrigerating machine or used as a "packing" in the form of "dry ice" or "snow";¹ (iv) for hardening steel; (v) in the manufacture of alkali by Solvay or ammonia-soda process and in the cryolite process; (vi) in the production of alumina, the gas being used to decompose sodium aluminate; (vii) for the recovery of sulphur from alkali waste in the Chance-Claus process; (viii) as a fire extinguisher, especially for inflammable liquids; (ix) in refining sugar by decomposing the calcium saccharate with precipitation of calcium carbonate; and (x) as a fertilizer, by growing plants in an atmosphere enriched with carbon dioxide (though this use is yet in its infancy).

For these purposes the carbon dioxide should be free from all odour or taste, free oxygen, nitrogen, carbon monoxide, sulphur dioxide, moisture, and dust. It must, therefore, be purified in the process of collecting and compressing and so cannot be used direct from the kiln.

¹ Solid carbon dioxide, sold under such names as "Dry ice" or "Cardice," "Drikold," etc., is one of the most convenient refrigerating agents yet discovered. It is made by cooling the gas until it liquefies and expanding the liquid in a chamber which forms part of a hydraulic press, whereby the rapid chilling due to evaporation forms carbon dioxide snow. The vapour produced is compressed and cooled so as to reliquefy it; the snow is compressed into blocks about 10 in. square and of variable length according to requirements. They usually weigh about 25 lb. each.

Carbon dioxide from lime kilns has usually to compete with that from other industries, such as brewing, magnesite, and natural supplies of the gas, so that the collection, purification, and sale must be conducted on sound commercial lines or they will be unprofitable. The chief demand for carbon dioxide is usually remote from lime works, and as the cost of carriage is heavy most lime works cannot profitably dispose of their carbon dioxide.

Solid carbon dioxide (see footnote on p. 459) is employed for refrigeration, oil-refining, testing building materials for resistance to frost, safeguarding wool, fur, and grain in storage, in chemical manufacture, and in laboratories. By far its most important use is as a refrigerant in the preservation of foodstuffs during transportation; for this purpose it has the advantage over ice in that, being dry, the foods can be packed in wood, cardboard, or even waxed paper.

In appearance solid carbon dioxide resembles a compact snow, with a waxy lustre. It is easily cut with a saw or knife and easily broken with a mallet. On exposure it becomes covered with a slight frost, due to moisture condensed from the surrounding air, and on evaporation it leaves no residue except this frost and sometimes a little lubricating oil which has escaped from the compressor.

Solid carbon dioxide does not absorb ink, chalk, dyes, etc., so that it cannot be marked except by impressing a branding iron on it. It does not absorb liquids, gases, or micro-organisms.

Its temperature is -79° C. and its density 1.45–1.56, but even with a density of 1.4 the blocks are liable to fly to pieces as a result of internal strains, due to the drop in temperature when evaporation occurs freely.

Its effective cooling power cannot be calculated from the fact that 1 lb. of solid carbon dioxide absorbs 273 B.T.U., as other factors to be taken into account are: (i) reduction of transport costs; (ii) absence of wet or saline solutions and their corrosive and other disadvantages, enabling cheaper packages to be used; and (iii) the thermal advantage over water ice rapidly increases with lower temperatures.

Whilst its use is increasing steadily, it is, at present, much too costly in comparison with water ice and until prices are approximately equal the sale of "dry ice" will be restricted.

For further details, see a paper by H. G. Littler and another by F. Heywood (*Chemistry and Industry*, 52, 533 (1933) and 53, 443 (1934)).

RECOVERY OF CARBOLIC ACID

There is in most lime kiln gases a small proportion of *phenol*, or carbolic acid, which can be recovered by washing the gases with a solution of caustic soda in which the phenol is soluble, but can be reprecipitated by the addition of an acid. The recovery involves the loss of a considerable amount of soda, which is neutralized by the carbon dioxide as well as by the phenol, so that the process is of doubtful value, though it is used to a limited extent in Germany.

RECOVERY OF WASTE HEAT FROM LIME KILNS

Much heat is wasted in burning lime and many attempts have been made to recover it. The most important of these include one or more of the following :

(i) The loss of heat by radiation through the walls of the kiln is normally about 10 per cent. of the total heating power of the fuel supplied in a mixed-feed kiln and about 13 per cent. in a gas-fired kiln. It may be reduced by building an insulating layer of kieselguhr bricks between the interior and exterior of the kiln and producer. These insulating bricks prevent the escape of a large amount of the heat which would, otherwise, be lost.

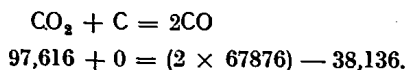
(ii) The heat carried away by the gases passing out of the kiln may be partially recovered by increasing the height or length of the kiln so as to preheat a larger quantity of stone. Further heat may sometimes be recovered by passing the gases through a gas-heated boiler which can then produce steam for gas producers or for any other convenient purpose.

(iii) The waste of heat which occurs in a gas producer can be lessened by attaching the producer direct to the kiln or by using several semi-producers instead of one large producer.

(iv) The loss of heat which occurs through cracks in the masonry is best prevented by using a steel or concrete casing, but much may be done by keeping the kiln in good repair.

(v) When carbon dioxide is required or can be used in the works, some of the heat in it may be recovered by cooling the gas in a recuperator. The amount so recovered is, however, very small in a well-managed kiln, and it is better to alter a badly-arranged kiln so as to avoid producing waste rather than to recover it when produced. Alternatively, the gases, or part of them, may be returned to the kiln so as to modify the burning, or to the gas producer, in which the carbon dioxide is reduced to the monoxide and so converted into fuel, the heat in the gas being simultaneously used in the kiln or producer.

Among many delusive ideas which have been tried for recovering heat from lime kilns is one which consists in passing the waste kiln gases through red hot coke and using the product to fire the kiln. Such a proposal ignores the fact that the amount of fuel used to convert the carbon dioxide in the kiln gases into the monoxide is greater than the heating value of the monoxide gas produced. The error underlying this proposed method of using the kiln gases is in the assumption that the equation,



includes all the carbon necessary for the reaction, whereas it need not necessarily do so. The figure 38,136 cal. indicates the amount of heat which must be supplied to the carbon dioxide and the carbon in order to form the reaction product, and if, as is usually the case, the heat is supplied by burning more carbon (in the form of coke) the cost of the large amount of fuel required for

this purpose is so great as to prevent this process of recovery from being profitable.

(vi) Many methods of recovering the heat in the hot lime drawn from lime kilns have been proposed, but none are profitable under normal conditions. When a vertical kiln is working properly the total amount of heat lost in the hot lime is much too small to be worth recovering.

RECOVERY OF DUST

In most lime works the recovery of dust is neglected, but in some Continental works it is collected by means of the Lodge-Cottrell electrical precipitation process or other forms of dust-extractor.

CHAPTER X

MANUFACTURE OF SPECIAL FORMS OF LIME

IN the strict chemical sense, the term lime refers only to calcium oxide, but commercial "lime" is seldom pure, and, for some purposes, the presence of other substances is of great importance.

Limes may be classified as :

(i) *Highly calcareous limes*, containing 90–99 per cent. of calcium oxide. This includes most of the "fat," quick, and caustic limes and some lean ones, but not hydraulic or dolomite limes. The highly calcareous limes are chiefly used for chemical purposes and where a relatively pure calcium oxide is required.

(ii) *Magnesian lime*, containing both calcium oxide and magnesium oxide. A magnesian lime is one containing a noteworthy proportion of magnesia. Strictly, a lime containing only 5 per cent. of magnesium oxide ought to be included, but most of the so-called magnesian limes contain at least 20 per cent. of magnesia.

When a magnesian lime contains 40 per cent. of magnesia and 56 per cent. of calcium oxide it is known as dolomitic lime, but this term is often used loosely (though incorrectly) for any "lime" made by burning magnesian limestone.

Magnesian limes are produced in the same manner as other limes, *i.e.* by burning a suitable limestone in a lime kiln ; for magnesian limes the stone must, of course, contain magnesium carbonate. When a dolomite or dolomitic limestone is used, a dolomitic lime is produced.

Magnesium carbonate is converted into the oxide at a much lower temperature than calcium carbonate, so that the magnesia in a magnesian lime is usually overburned ; this causes magnesian limes to slake more slowly than pure calcium limes—a serious disadvantage when making hydrated lime, or when magnesian lime is used for plaster or for lime-sand bricks. Magnesian limes expand rather less on slaking and shrink less on drying than calcium limes ; they also set more slowly. For many purposes, magnesian limes are equally as suitable as calcium limes ; it is only for those purposes where a retarded or incomplete hydration is serious or where the presence of magnesia is definitely objectionable (as in some branches of the chemical industry) that distinction need be made.

Dolomitic lime is made by burning dolomite—a double compound of magnesium and calcium carbonates. Its properties are those of a magnesian lime and the term "dolomite lime" is sometimes used for magnesian lime which is not made from a dolomite, but from a limestone containing less magnesia. It is suitable for the manufacture of mortar, and, for other purposes, where the presence of magnesia is not objectionable, but should not usually be employed for chemical, glass, leather, soap, water softening, and other purposes for which a purer calcium limestone is required, nor is it particularly suitable for

agricultural purposes, though some farmers do not seem to be aware of its objectionable influence on crops.

When burning dolomite and other magnesian limestones the magnesia tends to be overburned and then slakes very slowly. Dolomitic and other magnesian lime should, therefore, be left for at least three months after slaking before it is used for plaster work, but usually it need only be kept for three days after slaking if it is to be used for mortar.

(iii) *Siliceous limes*, containing silica in the free form as sand or in a combined form as calcium silicate (or a mixture of several calcium silicates) as well as free lime. The most important of the siliceous limes are the *grey* or *greystone limes* obtained by burning the greystone chalk which occurs between the chalk marl and the upper chalk in the southern and eastern counties and elsewhere. This lime contains a small percentage of silica which gives it feeble hydraulic powers. It slakes with much less vigour than lime made from the overlying white chalk. Grey lime is largely used by builders for mortar, partly because it is readily available in certain districts and partly on account of its producing a rather stronger mortar than a purer lime.

(iv) *Argillaceous limes*, containing clay or compounds formed by heating clay and lime. The most important are the *hydraulic limes*, particularly the Lias limes. The *hydraulic limes* are described on p. 472.

The term *Lias Lime* is applied to lime made by burning the argillaceous limestones which occur in the Lias formation of the Jurassic system, particularly in the Midlands and South Wales. The best lias limes are obtained from Aberthaw, Rugby, and Barrow-on-Soar; they are typical *eminently hydraulic limes*, but the poorer Liassic limes are only moderately hydraulic. Lias lime is used extensively for buildings and other structures which are exposed to water. For methods of manufacture and properties see under "Hydraulic Lime."

As the best lias limestone has a bluish colour when freshly broken, it is often described as *Blue Lias* and the lime made from it as *blue lias lime*.

Limes are also classified according to the treatment applied to them as *slaked lime*, *hydrated lime*, *ground lime*, *sintered lime*, etc.

(v) *Selenitic lime*, obtained by adding a suitable sulphate to an argillaceous or siliceous lime. Selenitic lime was originally made by calcining lumps of feebly hydraulic lime in a kiln with a perforated floor through which sulphur dioxide entered the kiln and formed calcium sulphide and calcium sulphate; such a product is known as *Scott's cement*, after its inventor. It was later, and is still, made by adding sulphuric acid to the water used in preparing the mortar, or by adding 5 per cent. of ground plaster of Paris to a feebly hydraulic lime and grinding the mixture. The precise form in which the sulphur is added is unimportant, so long as calcium sulphate is formed or is added to the lime. This addition greatly increases the strength of the lime, but does not make it equal to that of a first-class hydraulic lime. Selenitic lime is used only to a very small extent.

(vi) *Slaked lime* consists of lime which has been mixed with water, most of

which has entered into combination, forming calcium hydrate. In addition to this substance various others are formed when magnesian, siliceous, or argillaceous limes are slaked.

(vii) *Hydrated lime* is slaked lime in the form of a fine powder.

(viii) *Lime putty* is slaked lime containing so much water that it forms a paste.

(ix) *Milk of lime* is slaked lime suspended in water and forming a milk-like fluid.

(x) *Air slaked lime* is a mixture of calcium oxide (quicklime), calcium carbonate, and calcium hydroxide (slaked lime) which is formed when quicklime is exposed to the air.

(xi) *Ground lime* is made by grinding lime to powder.

(xii) *Lump lime* is that taken out of the kiln and freed from small pieces of lime.

(xiii) *Small lime* is that which is left when the lump lime has been removed.

(xiv) *Flour lime* is finely ground lime.

(xv) *Atomised lime* is a term applied to a finely-ground lime; it should not leave more than 10 per cent. of residue on a sieve with 180 holes per linear inch, but some samples which are sold as "atomized" are much coarser than this.

(xvi) *Coloured lime* is a mixture of lime and a pigment or dye. The Stettin Portland Cement Co., Stettin, Germany, have found that an extremely fine dust obtained in grinding hydraulic lime can be dyed effectively with various colours. The product is much more economical than the use of a coloured lime made by grinding a mineral pigment with the lime.

COMMERCIAL CLASSIFICATIONS

Commercially, limes are classified according to the treatment they receive at the works.

Unclassified or *Run-of-kiln lime* is that which is sold as it is drawn out of the kiln, no attempt being made to separate any impurities.

Selected lime is composed of lumps which have been separated—usually by lifting them with a fork having prongs $1\frac{1}{2}$ -in. apart.

Picked lime is composed of lumps each of which has been selected individually.

Screened lime consists of pieces larger than a prearranged size, the smaller pieces having been separated by means of a screen. In this country forks are generally used instead of screens.

Chalk lime is that which is obtained from *Chalk*.

Shell lime is that obtained from shells.

Free lime is calcium oxide or calcium hydroxide as distinct from calcium carbonate, calcium sulphate, or calcium silicate; the latter contain only *combined lime*.

Commercial limes are also classified in accordance with predominant properties as *quicklime*, *caustic lime*, *fat lime*, *lean lime*, *hydraulic lime*, etc., and

in accordance with their chief use, as *jewellers' lime*, *builders' lime*, etc., or their assumed place of origin as *Vienna lime*, *Lias lime*, *Greystone lime*, etc.

No single classification appears to be possible; the most convenient arrangement is to describe each of the principal kinds of lime in turn.

QUICKLIME AND CAUSTIC LIME

The term *quicklime* is applied to any lime which slakes rapidly with a considerable rise in temperature. It is independent of the composition of the lime, though most quicklimes contain 95 per cent. or more calcium oxide. A fat lime is usually a quicklime, though this is not always the case. When quicklime is exposed to moist air, or treated with water, it slakes, forming *calcium hydroxide*, *slaked lime*, or *hydrated lime*. If exposed to air it absorbs carbon dioxide and becomes *air slaked*. For use in plaster, mortar or in the chemical and some other industries, a quicklime of first-class quality should contain not less than 95 per cent. of lime plus magnesia and not more than 10 per cent. of carbon dioxide; a highly magnesian quicklime should also contain at least 20 per cent. of magnesia. A second-class quicklime may contain not less than 85 per cent. of lime plus magnesia. No good quicklime should leave more than 10 per cent. of residue when slaked and then washed through a 24-mesh sieve.

Caustic lime is a popular and ancient name for unslaked lime and it also indicates a fairly pure calcium oxide. Caustic lime is so called because it readily burns those who handle it carelessly, particularly if their hands are moist. It has a powerfully corrosive action which was, at one time, made use of in the practice of burying persons, executed for murder, in quicklime. Lime is used in the manufacture of caustic soda by treating a solution of sodium carbonate with lime; it was formerly thought that the caustic property of the lime was transferred to the soda, but it is now known that it is only a coincidence that lime and caustic soda have caustic properties. When caustic lime is treated with water, it slakes and forms *slaked lime* or *hydrated lime*. When exposed to air it forms *air-slaked lime*. It is made by burning a limestone containing at least 90 per cent. of calcium carbonate; poorer limestones produce a slow-slaking lime which is not usually regarded as caustic (see *Quicklime*).

Chalk lime is that made by burning chalk, that from the upper or white chalk being usually intended. It is a light, fat lime very suitable for softening water.

Shell lime is made by burning shells or a limestone which appears to be largely composed of shells. It was formerly supposed to be of unusual purity, but is inferior in this respect to lime made from marble.

Stone lime is a variety of lime made by burning the lower or grey chalk of the chalk formation. It usually contains 8-25 per cent. of silica, alumina, and iron oxide, and so is liable to be overburned. It slakes with only a moderate development of heat and a small increase in volume. *Dorking lime*, *Halling lime*, and *Medway grey stone lime* are varieties of chalk lime produced in the localities after which they are named.

Clunch lime is made by burning the chalk marl found in the lower part of the Chalk Formation ; it is impure, of uncertain quality, and liable to shrink in setting owing to the excess of clayey matter present.

FAT LIME

Fat lime or *Rich lime* is the term applied to a pure, calcareous lime (usually containing 95 per cent. or more of calcium oxide) which forms a plastic paste or putty when slaked with a suitable proportion of water. A lime of the same chemical composition which has been overheated during the process of burning. (*i.e. overburned lime*) and a lime containing 5–15 per cent. of silica (see "hydraulic lime") will not produce so plastic a paste, and are commonly designated *lean lime*.

As most fat limes slake readily with the development of much heat, whilst most lean limes slake more slowly, the terms fat and lean are sometimes used to signify quick and slow slaking, but this is undesirable. Fat limes usually contain at least 95 per cent. of lime plus magnesia, the proportion of magnesia seldom exceeding 20 per cent. (though some fat Italian limes contain 40 per cent. of magnesia). Lean limes usually contain 85–95 per cent. of lime plus magnesia, but the fatness and leanness do not appear to have any definite relationship to the composition of the lime. The precise cause of fatness is not known, but it appears to be due to the production of a small proportion of colloidal lime—a result of the action of water on the smallest particles of lime—which is only perceptible when a sufficient quantity of extremely minute (sub-microscopic) particles are present. The fact that the individual particles of pure calcium hydroxide are so much smaller than those of the complex silicates, which constitute Portland cement and hydraulic limes after they have been mixed with water, seems to confirm this view, as does the much greater swelling which occurs when a fat lime is slaked ; such a lime will increase to two or three times its original volume, whereas a lean lime will scarcely expand at all. If it is correct, fat limes should be distinguished from lean ones by the proportion of sub-microscopic particles formed when the lime is mixed with water.

Fat lime can only be produced from comparatively pure carbonates, such as white chalk, marble, some varieties of shells, and the purer mountain limestones, and these materials must be burned skilfully, so as to avoid overheating, which would reduce the porosity of the lime, and destroy its power of producing a plastic putty. The methods of burning are described in Chapter VIII.

A lime which is fat when properly burned may be made lean by overheating it in the kiln, the result of the overheating being to cause a slight superficial vitrification—a result of the combination of some of the lime with the impurities present in it or with material derived from the fuel or the lining of the kiln. It is customary to burn fat limes at as low a temperature as can conveniently be managed, because overheating reduces their fatness ; it is more profitable to pick out the pieces of underburned lime than to attempt to produce a first-class hydrate from overburned lime.

Fat lime is chiefly used for making mortar and plaster, and in the various chemical and other industries, where a pure calcium oxide is required. For many purposes, it is more convenient to purchase it in the form of *hydrated lime* (see later) than in the lump form. "Small lime," even when made from the same stone and burned in the same kiln, seldom produces as good a fat lime as the large pieces, because the ashes from the fuel, and the clay and other impurities in the stone tend to accumulate in the "small lime" and so alter its composition, making it resemble an irregular mixture of fat and hydraulic lime. If these impurities can be separated by skilful hydration, small lime will produce as plastic a putty as fat lump lime. For purposes when the chemical, rather than the physical, properties of the lime are important, either fat or lean limes may be used, but where the absorbent properties of the lime are of value (as in making bleaching powder or in purifying illuminating gas) a fat lime is preferable. In some chemical processes the nature of the precipitation is such that a fat lime is preferred to a lean one.

Although lump lime is described as "fat" its fatness or plasticity cannot be observed until it has been slaked with water and converted into a fat or plastic paste.

One measure of a fat lime will produce 2-3 measures of hydrated lime on slaking, whilst one measure of lean lime produces only about 1.3-1.7 measures of hydrated lime.

LEAN LIME

The term *poor lime* or *lean lime* is applied to any lime which slakes on the addition of a suitable proportion of water, but does not form a highly plastic putty. It is usually produced when a very dense limestone is burned and when any form of limestone containing more than about 5 per cent. of silica is overburned.

The lean, poor, or meagre limes include all limes which, when slaked, do not increase greatly in volume, but otherwise exhibit the same properties as the fat limes. The lean limes may be made of high calcium, dolomitic, or pure magnesian lime, because the terms "fat" and "lean" refer to the working properties and not to the chemical composition of a lime.

PROPERTIES OF HIGHLY CALCAREOUS LIMES

Limes containing 90 per cent. or more of calcium carbonate are used for a great variety of purposes and their properties are, consequently, of great importance. The principal properties are:

The **Chemical Properties** of a highly calcareous lime depend on the proportion of free lime present, but they may be modified by the other constituents. Thus, alumina, silica, and iron oxide, either in the free state or present as clay and other minerals, can combine with some of the lime and so reduce the value of the material.

The purest lime is usually prepared by heating Iceland spar or the whitest

and most translucent marble in a current of air. Unless the carbon dioxide is removed as rapidly as it is liberated the decomposition is not complete. Slightly less pure limes are obtained by heating the purest commercial limestones or white chalk.

The following analyses are typical :

A is a highly calcareous lime.

B is a siliceous lime.

C is a French hydraulic lime.

D is an English hydraulic lime from the Lias formation.

TABLE XXXIX.—*Typical analyses of highly calcareous limes*

	A Buxton Lime.	B Common Building Lime.	C Chaux de Teil.	D Blue Lias Lime.
Insoluble and combined silica	} 0.71	13.20	0.62	2.39
Alumina and Iron Oxide		10.34	22.10	14.17
Lime	0.11	1.64	1.82	9.13
Magnesia	98.72	51.10	66.72	63.43
Sulphur trioxide	0.46	1.04	1.17	1.54
Carbon dioxide	—	0.21	0.49	1.63
Water	—	8.00	0.64	3.64
Alkalis and loss	—	} 14.47	5.36	2.69
			1.08	1.38

The chief impurities in commercial lime are (a) sand, burned clay, and other matter insoluble in acid ; (b) calcium carbonate (unburned limestone) ; (c) magnesia and magnesium carbonate.

Most of these impurities merely lessen the amount of useful lime present, but for some other purposes they are harmful as they form coarse particles, some of which may act as stains. Magnesia, if present to the extent of about 20 per cent., renders lime useless for ordinary purposes as it slakes too slowly and imperfectly.

The leanness of some limes is undoubtedly due to the presence of silica and alumina, but the chief cause appears to be a physical one, dependent on the size of the particles and the porosity.

It is a mistake, when comparing chemical analyses of limes from different sources, to look only at the total calcium oxide present. Some of this is probably combined with silica, alumina, or carbon dioxide, and so is not available. For instance, a lime containing 86.8 per cent. of calcium oxide may consist of :

Quicklime (CaO) 70 per cent.
 Unburned stone (CaCO₃) 30 „ „

which is a lime of low quality, and anyone purchasing ten tons of it would be buying three tons of raw stone at the price of lime.

Where the free calcium oxide alone is required it is important to choose as pure a lime as possible, though commercially it is sometimes preferable to use a slightly less pure lime if it is much cheaper. If the price of the lime (per ton) is multiplied by the percentage of *free* lime, a figure is obtained which is very useful in comparing the commercial value of other limes. The hydration of lime is retarded by the presence of calcium sulphate or other alkali salt, also by several fusible aluminates and silicates which coat the surface of the lime and render it impervious to water. Magnesia has a similar retarding effect, but this may be minimized by using hot water or by adding 2 per cent. of calcium chloride to the water used for hydrating.

The *Chemical Reactivity* of a lime indicates the ease with which it combines with acids. Some limes, whilst apparently of high purity, react so slowly as to be inferior to others. The precise cause of this is not definitely known, though it appears to be related to the porosity, *i.e.* to the physical structure of the material. The smaller the alternate particles and the farther they are apart in a lump, the more active will be the lime. For the same reason, a dense lime with a small surface area is less active than a "lighter" lime with a large surface area.

The *Recarbonating Power* of a lime is important when the lime is used to absorb carbon dioxide or other gases and also when it has to travel long distances. Some limes absorb carbon dioxide four times as rapidly as others; this is a great advantage to chemical users, but is a disadvantage when the lime has to travel long distances or to be kept in stock for a long time. Some limes recarbonate much more rapidly at a bright red heat than when cold. Moist lime absorbs carbon dioxide readily at the ordinary temperature, but anhydrous lime only absorbs it when heated to 412° C.

The **Physical Properties** of highly calcareous limes include the following :

The *Solubility in Water* depends on the amount of free lime present. Further information will be found in the section on Lime Water.

The *Plasticity* of lime is a term which has led to much misunderstanding. Strictly, plasticity is the property possessed by a substance whereby it is enabled to change its shape readily under pressure and to retain the new shape without requiring any special support. Plastic substances usually consist of a solid and a fluid, and their physical properties are intermediate between these two states. Some people prefer the term *workability* to *plasticity* but this does not render the definition easier. If workability is measured in terms corresponding to the spreading power of a given weight of lime-putty, it includes only one form of change in shape, so that workability is not necessarily the same as plasticity.

At present, there is no satisfactory means of measuring plasticity as the term is used by practical men, who judge the plasticity by the "feel" of the paste when trowelling.

Limes containing more than 5 per cent. of magnesia are less plastic than

high calcium limes, work less smoothly, and are disliked by the workmen, who term them "weak," "lean," or "poor."

The *Porosity* of lime depends on the source of the stone, some limestones giving a dense lime whilst others, such as oolite and chalk, yield a light, porous lime. A highly porous lime will absorb 16 per cent. of its volume of paraffin or other inert liquid, but some dense stones will absorb less than 1 per cent.

The *Specific Gravity* of limes is closely related to their origin and structure, as well as to their porosity. Some oolitic limestones have a specific gravity of only 2.2-2.8, whereas some of the dense limes from the carboniferous limestones have a specific gravity of 3.3-3.6.

The specific gravity of lime tends to increase with the temperature at which it is burned. Thus, one sample gave the following figures :

Calcined at	Specific Gravity.
889° C.	3.10
1000° C.	3.13
1500° C.	3.30
2000° C. (electric arc)	3.40

Lime has been obtained by Brügelmann in minute cubic crystals with a specific gravity of 3.251 by heating the nitrate in a porcelain flask. Levallois and Meunier also found minute cubic crystals of pure lime, with a specific gravity of 3.32 in the lining of a continuous lime kiln which had been long in use. These figures indicate a high temperature of formation.

The *Specific Heat* is the relative amount of heat required to raise the temperature of 1 lb. of lime 1 deg. Fah., that required for water being regarded as unity. It varies with the origin of the lime and rises with an increase in temperature. A fair average figure is 0.20 at 212° F. to 0.23 at 1900° F., that of magnesia is 0.23 and 0.33 for the same temperatures.

The *Melting Point* of pure lime is 2540° C.

The *Thermal Conductivity* of lime varies from 10-18 B.T.U. per sq. ft. per hour per ° F.

The *Apparent Heat capacity* of limestone¹ includes both the sensible heat and the heat of dissociation ; it depends on the rate of calcination which diminishes as the amount of unchanged calcium carbonate becomes less. At first it may be 0.65 cal. per deg. C. per gram of CaO, but eventually it diminishes to 0.20 cal. per deg. C. per gram, the latter figure being the thermal-capacity of lime.

The *Electrical Conductivity* of lime is 1.62×10^{-7} mhos at 1100° C. and 9.33×10^{-7} mhos at 1235° C.

The *Hardness* of lime varies from 2-4 on Mohs' scale with 3 as an average figure.

The *Diffusivity* of lime is its power to break up into small particles and to distribute itself uniformly in a large volume of water. This property is very important in some of the chemical industries, particularly those in which milk-

¹ C. C. Furnas, *Ind. and Eng. Chem.*, 728 (1930).

of-lime is used. "Old Buxton Lime" is regarded as having an exceptionally high diffusivity.

The *Crushing Strength* of lime varies greatly and before erecting a tall vertical kiln, the strength of the lime should be determined. Limes of low crushing strength break down in the kiln and are very difficult to burn, as the crushed lime impedes the draught. In some respects resistance to angular shear is almost as important as direct resistance to vertical pressure.

The effects of *Overburning* lime on its properties are described on p. 435; the chief effect is to retard the slaking.

HYDRAULIC LIME

The term *hydraulic lime* is applied to any "lime" which possesses the property of "setting," or forming a hard, rock-like mass when mixed with a suitable proportion of water, and, at the same time, contains so much free lime that it will slake readily. Unlike the purer calcium limes (see FAT LIME), the hydraulic limes contain a considerable proportion of combined silica, and most of them also contain a notable proportion of combined alumina. In other words, hydraulic limes are obtained by burning impure limestones rich in free silica and clay. These natural mixtures, when burned, form a mixture of what may be regarded as cement and free lime. On adding a suitable quantity of water to such a "lime" the lime slakes, but the cement is unaffected and the mass falls to powder. On adding a further quantity of water the cement begins to set and harden like Portland and other calcareous cements and thus gives the material its hydraulic properties. The lime remains inert at first, but gradually hardens on exposure to air. Hence, a hydraulic lime behaves like a mixture of lime and cement. As the lime is only useful in causing the lumps to fall to powder when slaked, the proportion of free lime should only be just sufficient to serve this purpose; an excess of free lime reduces the quality of the material.

Hydraulic limes are arranged in three classes:

(i) *Feebly hydraulic limes*—those which only harden slightly when, in contact with water. They include those which become "set" or hard after immersion in water for 15–20 days and continue to harden for six months, after which the increase in hardening is very slow. The change in volume on slaking is very slight. Feebly hydraulic limes have a cementation index of 0.3–0.7 and a hydraulic index to 0.1–0.2.

(ii) *Moderately hydraulic limes*—those which set after 6–8 days and continue to harden fairly rapidly for a few days, and more slowly for another half year. At the end of this time the mass has the consistency of a soft building stone. The change in volume on slaking is small. *Moderately hydraulic limes* have a cementation index of 0.5–0.9. Most English hydraulic limes belong to the "moderately hydraulic" class and are weaker than the "emphatically hydraulic" limes of France and Germany. The strength of the English limes may be increased indefinitely by mixing them with a suitable proportion of clay before they are burned, though this would add greatly to the cost of production and

would make it approach that of Portland cement, to which hydraulic lime is inferior.

(iii) *Eminently hydraulic limes*—those which set within four days, are hard after a month, and at the end of six months can be worked like stone. The change in bulk on slaking is small. Eminently hydraulic limes have a cementation index of 0.7–1.1 and a hydraulic index of 0.2–0.4.

The most powerfully hydraulic limes contain approximately 65 per cent. of lime, 10–12 per cent. of alumina, and 23–25 per cent. of silica, which is the same composition as that of a typical Portland cement. The composition of hydraulic lime varies so greatly that no single set of figures can be regarded as typical; almost any natural mixture of limestone and clay may be used, so that such different limes as those from Merstham, Lyme Regis, and France (with the following compositions) are equally popular:

TABLE XL

	Merstham	Lyme Regis	France
Lime	50	72	66 per cent.
Silica	11	24	25 " "
Alumina	4	3	4 " "

The best hydraulic limes (known as *eminently* hydraulic limes) have a cementation index between 0.7 and 1.1, whilst the *feeble* hydraulic limes have a cementation index of 0.3–0.7.

The Cementation Index is found by multiplying the percentage of silica by 2.8, the percentage of alumina by 1.1, and the percentage of iron oxide by 0.7, adding these together, and dividing by the percentage of lime *plus* 1.4 times the percentage of magnesia. Thus a hydraulic lime which shows an analysis:

Silica	...	...	...	...	18.3 per cent.
Alumina	...	...	...	4.8	" "
Iron Oxide	...	...	...	3.5	" "
Lime	...	...	...	69.5	" "
Magnesia	...	...	...	3.0	" "

will have a cementation index of 0.80, which is calculated from:

$$\frac{(18.3 \times 2.8) + (4.8 \times 1.1) + (3.5 \times 0.7)}{69.5 + (3.0 \times 1.4)}$$

The cementation index is only a rough guide, for it is based on several assumptions which are not always tenable, but it is very useful in comparing different limes.

A simpler calculation shows the *hydraulic index*, which is found by adding the percentage of silica and alumina and dividing by the percentage of lime. Thus, the example just quoted has a hydraulic index of 0.32. The hydraulic index omits magnesia and is probably too crude to be of much value, though importance is attached to it by some chemists.

Some firms mix slaked lime and clay in suitable proportions to produce an artificial hydraulic lime or pozzuolanic cement ; others mix soft limestone or chalk with the clay, grind them together to form a paste, mould the mixture into rough bricks, and burn them. The proportions of clay and lime or limestone to be used, must depend on the composition of each, but the addition of one part of clay to four of rich lime is usual ; if an argillaceous limestone is enriched with a purer limestone or diluted with clay, the proportions of each must be adjusted so as to produce a lime having the properties desired. With care, a lime of any desired hydraulicity can be prepared.

It is possible to produce hydraulic limes of almost any composition by underburning a mixture of limestone and clay or shale, but such a lime may contain a large proportion of wholly inert material.

The mixture of limestone and clay—no matter whether natural or artificial—must not usually contain more than 80 per cent. of calcium carbonate, or the product will contain too much uncombined lime and silica.

Hydraulic lime is chiefly made from a natural mixture of limestone, sand, and clay, such as that constituting the greater part of the Lias Formation (whence the term *Lias lime*), but when an artificial mixture of limestone with clay, fine sand, or shale is used, the produce is known as a Portland cement.

In France, one of the best-known hydraulic limes is made from a siliceous limestone found at Ardèche, on the Rhône, and is known as *Theil lime*. It contains 65–75 per cent. of calcium oxide, 20 per cent. of silica, only 2 or 4 per cent. of alumina, and small proportions of other impurities. Another important French hydraulic lime is made at Flavigny and Menil, near Nancy. In the United States, hydraulic limes were, formerly, largely used, but they have been to a great extent replaced by Portland cement. The *Rosendale cement*, made of argillaceous magnesian limestone, and *Louisville cement*, which contains less magnesia, are, however, still used.

The best hydraulic limes are those made from a rock containing the ingredients in suitable proportions, for no mechanical method can produce so uniform a mixture as Nature.

Hydraulic limes are burned in the same types of kilns as quicklimes, but when the burned material is slaked at the works, it is possible and often advantageous to use an automatic discharging device, instead of drawing the kiln by hand, as shown in fig. 114, which is a section of a Thièl kiln in which the discharge is effected by a flat grate made in two parts which move to-and-fro and so heap up the pieces of lime. These then fall uniformly through the grate into the space below and are removed by a rotating valve. In the Steiger kiln, the grate (which is provided with vertical projections) revolves and so produces a constant discharge of lime. Hydraulic limes are less easy to burn than quick-

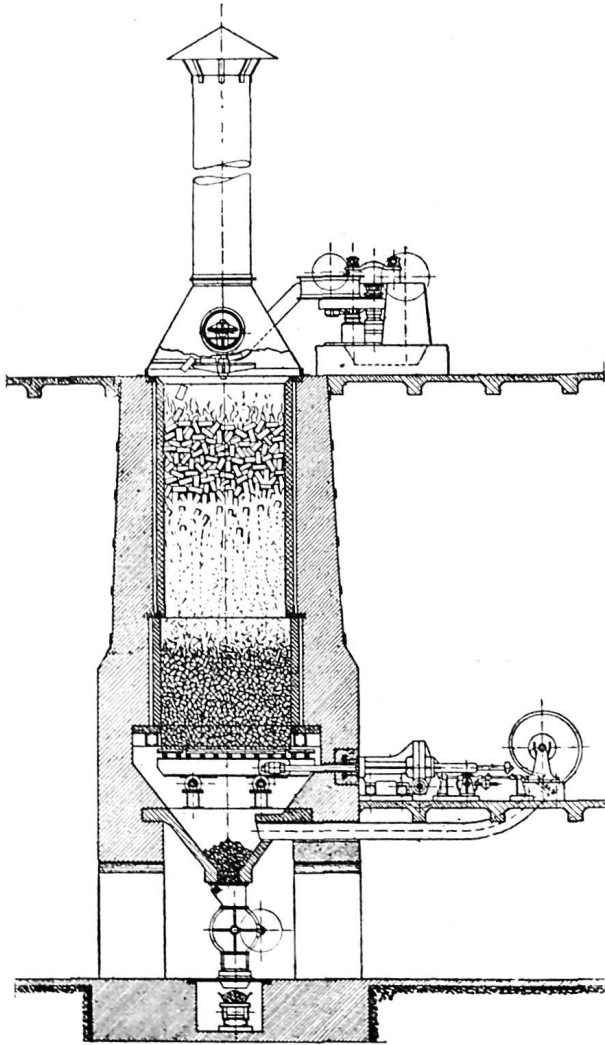


FIG. 114.—THIÈLE KILN with AUTOMATIC DISCHARGE.

lime, and the difficulties experienced in burning them are increased by the fact that they require a higher temperature than is needed for quicklime and because hydraulic limes are easily over-burned, owing to the readiness with which some of the material fuses ; in some works the sintered product (known as *clinker* or *grappiers*) is separated and used as cement.

When the materials for the hydraulic limes are burned, a complicated series of reactions occurs. The clay present is decomposed at 400–600° C. and

at a higher temperature (950–1400° C.) combines, in part, with some of the lime, forming complex silicates, aluminates, and alumino-silicates whose chemical constitution is very imperfectly understood, but among which tricalcium silicate and tricalcium aluminate appear to be the chief ingredients. A commercial hydraulic lime may, therefore, be regarded as composed of a mixture of (i) frelime or quicklime ; (ii) a cementitious material of complex nature ; and (iii) material which is more or less inert (such as silica or uncombined calcined clay) according to the conditions of manufacture and use.

Hydraulic lime is burned in the same manner as fat lime, but a somewhat higher temperature is usually required, and there is more risk of overburning. The higher the cementation index, the higher must be the temperature reached in the kiln, so as to ensure all the silica and alumina being combined with the lime. For this reason, a mixture with a cementation index of 0.7 is more difficult to burn than one with a cementation index of 0.85 ; with a still higher index it is difficult to have enough free lime in the product to enable it to slake properly.

Hydraulic limes were, at one time, supplied in the form of lumps, and their power of slaking was then important, as it saved the cost of grinding. At the present time, however, hydraulic limes are also sold in the form of a powder.

The best hydraulic limes will produce concrete almost as strong as that obtained when Portland cement is used, and at a much lower cost, but, unfortunately, the strength of hydraulic limes varies much more than that of Portland cement, so that the latter is often preferred in spite of its higher price.

The *properties of hydraulic limes* depend on their composition, the manner in which they have been burned and on whether they have been slaked prior to purchase.

If the lime is received in the form of lumps, it is almost certainly in an unslaked condition. Such a lime should fall to powder when slaked (see later), but the slaking proceeds very slowly and may require several days. Moderately hydraulic limes do not begin to slake in some cases for 10–15 minutes, after which they slake gradually with less activity than ordinary lime. The total time for slaking with moderately hydraulic limes is almost two days whilst more hydraulic limes may require as much as 7–14 days before the action is complete.

Some lias limes do not contain sufficient free lime to permit simple slaking. Hence it is always safer to use a lime which has been slaked at the works and is delivered in the form of powder.

In working up hydraulic limes with water it is necessary to mix them very thoroughly ; indeed, the better they are mixed, provided setting has not commenced, the harder will be the final product. No more should be mixed than can be used at once, as to work a hydraulic lime after it has begun to set is to court disaster.

The properties of *hydrated* hydraulic lime are the same as those of a mixture of Portland cement with a corresponding proportion of hydrated lime. The material is easy to use and flows freely under the trowel, but it sets and hardens much more slowly than Portland cement and does not attain so great a strength.

It is, however, quite suitable for structures where a quickly hardening mortar or plaster is not required and where very great strength is not necessary. Hence, hydraulic mortar is extensively used for buildings and other structures below ground-level or exposed to water.

The composition may vary within wide limits, but in no case should a hydraulic lime contain less than 60 per cent. of lime plus magnesia, nor more than 10 per cent. of carbon dioxide. A feebly hydraulic lime may contain only 15 per cent. of silica and alumina, a moderately hydraulic lime 15–25 per cent., and an eminently hydraulic lime at least 25 per cent. of silica and alumina.

The hydraulicity or time required for setting and hardening varies according as the lime is feebly, moderately, or eminently hydraulic. It is determined by mixing a convenient quantity of the material with sufficient water to form a soft paste, trowelling it well in order to mix it thoroughly, and then leaving it in a moist atmosphere; at suitable intervals the mass is tested with a wire, or preferably with a Vicat needle, to see whether the mass has become solid.

Its hardness is usually tested by making an 8-shaped briquette, storing it in water for various lengths of time, and then determining the tensile strength in the same manner as Portland cement.

The *tensile strength* of a hydraulic lime is usually determined by slaking it with water, leaving for 24 hours, mixing with three times its weight of standard sand and sufficient water to form a paste of good working consistency, forming an 8-shaped briquette, and storing this in moist air for 72 hours and then in water for as long as desired (usually 28 days after making). The tensile strength of such a briquette should not be less than 75 lb. per sq. in.; with some eminently hydraulic limes it is 300 lb. per sq. in. The form of the briquette moulds and the general conditions of the test are identical with those in the current British Standard Specification for Portland cement. To avoid variations in the consistency of the paste used for making the briquettes, it is convenient to specify that it must produce a 4-in. spread when tested in the consistency cone described in *Building Research Technical Paper No. 4* (H.M. Stationery Office).

The hydraulicity of a lime may be tested by kneading it with a little water—the amount of water needed varies between 30 and 50 per cent. of the weight of lime—so as to form a stiff paste, which, when made into a ball and thrown vigorously, does not crack nor spatter. This paste is then rammed in a small metal pan or mould, its surface is stricken off smooth and level by drawing a straight-edge over the top edges of the pan, and the latter is then immediately immersed in water; each day the test-piece is examined, to see if the lime resists a light pressure with the finger-nail. According to the degree of hydraulicity of the lime, the time of hardening will be one to three, or more, days, at an average temperature of 60° F. (or 15° C.).

If the sample is tested at a lower temperature, this must be taken into consideration in judging; thus, with an average temperature of 54° F. (or 12° C.), about one day more will be required. If the test pieces are exposed to

the air, they will, in each case, require a day less than when they are kept under water.

Uses.—Hydraulic lime is chiefly used in the building trades for making strong mortar, plaster, and concrete. It may be used in place of Portland cement for many purposes; it is not so strong as the latter, but has the advantage of setting more slowly and remaining plastic long enough to allow a slight settlement before becoming hard and strong. Mortars made of weak hydraulic lime require 7–21 days or more to harden in air before they can rightly be submerged in water, but those made of stronger hydraulic lime need less time for air-hardening.

WATER LIME

Water lime is another name for hydraulic lime, the term being used because such lime sets and hardens when immersed in water.

LUMP *v.* SMALL LIME

Many users of lime are under the impression that lime in large lumps is superior in quality to that in smaller pieces. Within very wide limits this is a mistake based on an old tradition and inapplicable to the lime produced by modern methods. In most cases a ton of small lime will produce equally good mortar and the same bulk as lump lime; the small lime is equally good for chemical and most industrial purposes, and it is only in those cases where the presence of ashes from the fuel is objectionable that the small lime (which contains the ashes) needs to be separated. In the United States *no* lump lime is sold.

The principal reason for preferring large lumps is that these show by their "lightness" whether they contain much unburned lime (core) or not, whereas small pieces cannot be so distinguished. With modern kilns the need for such a distinction is much less than formerly.

GROUND LIME

Instead of using lime in the form of lumps, it is more convenient for some purposes if it is ground to powder. Very fine grinding is seldom necessary, and if not more than 5 per cent. of residue is left when the ground lime is shaken on a sieve having 70 holes per linear inch it will be sufficiently fine for most purposes. Occasionally, a much finer powder, which will not leave more than 10 per cent. residue on a sieve with 180 holes per linear inch, is specified, but as it is very expensive, its use is limited.

The mills chiefly used for grinding lime are :

(a) Jaw-crushers, crushing rolls, and gyratory crushers for effecting a preliminary reduction to less than 1-in. diameter.

(b) Griffin mills and other pendulum mills, disintegrators, "lightning crushers," burr mills, ball mills, and tube mills for further reduction to any desired degree of fineness.

It is not economical to effect the preliminary crushing in a mill designed for grinding, nor to use a disintegrator where a fine flour is required. Hence, the selection of a crushing plant suitable for a given lime requires a knowledge of local conditions as well as of various kinds of lime and the merits of the various machines.

The methods used for grinding lime in many works are still very primitive and costly. Millstones and burr mills are still largely employed because they produce a fine product without great capital outlay, though the cost of dressing and driving the mills makes them expensive to use. Jaw crushers, disintegrators, crushing rolls, and ball mills are used as preliminary grinders, but the product from these is usually coarser than is required for ground lime, the best qualities of which do not yield more than 10 per cent. of residue on a 200-mesh sieve; where a lime yielding 10 per cent. of residue on a 100-mesh sieve can be used, a disintegrator may be employed and the product screened or sieved in a "dresser." Unfortunately, the tailings from the screen cannot be returned to the disintegrator as the latter is not a fine grinding machine.

Among the newer types of machines available for grinding lime, the most important are:

(i) *Griffin or pendulum mills*, in which a vertical rod with a massive grinding roll at its lower end is suspended from a suitable bearing. As this "pendulum" revolves, the roll swings outwards and presses with a centrifugal force of 6000 lb. against a hard grinding ring. Above the roll is a fan, and below it are scrapers or ploughs which stir up the material in the mill. The lower part of the mill is surrounded by a screen or sieve. When the mill is in use, the lime is stirred by the scrapers and brought between the roll and grinding ring, where it is reduced to powder and is afterwards drawn upward by a current of air created by the fan. The air passes out through the screen, carrying the smaller particles of lime with it, whilst the larger ones fall back into the mill and are re-ground. The fineness of the product can be varied by altering the screen, though the latter is always much coarser than the powder which passes through it. A Griffin mill will usually produce 2-3 tons of ground lime per hour, using 20-30 h.p.; the product should not leave a residue of more than 15 per cent. on a 200-mesh sieve. A finer powder can be produced at a lower output.

(ii) *A three-roll mill or Kent mill* consists of three rollers mounted on horizontal shafts within a vertical grinding ring against the inner circumference of which the rolls revolve. The lime passes between the rolls and the ring, and is kept in place by centrifugal force until sufficiently finely ground, when it escapes into the free space between the ring and the casing, and passes out of the mill in a constant stream. A Kent mill will grind 5-15 tons of lime per hour using 24 h.p., the product leaving only 10 per cent. of residue on a 200-mesh sieve.

(iii) *Ball mills* are of two types: (a) *Intermittent ball mills* consist of an iron or steel drum, mounted horizontally and rotated by a belt or gearing. A suitable quantity of lime and flint pebbles is placed in the drum through an opening, which is then closed and the drum rotated until all the lime is reduced

to a sufficiently fine powder. The drum is stopped, a grating fitted over the outlet, and the lime discharged whilst the balls are retained. Such a mill, 40-in. diameter and 40-in. long, holding 300 lb. of lime and 4 cwt. of flint pebbles, will, in 24 hours, grind the lime to leave only 10 per cent. of residue on a 200-mesh with an expenditure of about 3 h.p. A larger mill, 5 ft. diameter and 5 ft. long, holding 800 lb. of lime, will, in 24 hours, grind the lime to the same fineness as before, with an expenditure of 4–8 h.p. Where comparatively small quantities of very fine lime are required these mills are very useful; they are too costly for large outputs; (b) *Continuous ball mills* consist of (i) horizontal ball mills and (ii) vertical or centrifugal ball mills. The former consist of a cylinder or polygonal drum mounted horizontally on a shaft or trunnions and containing balls of steel or flint, which are lifted as the mill rotates and, falling on the material to be ground, reduce it to powder. Either at the end or on the circumference of the mill, there are perforations through which the ground material escapes. In the best type of ball mill, the perforations are so placed that they are not damaged by the falling balls and do not choke unless the mill is seriously over fed. A continuous ball mill, holding two tons of lime, will require about 40 h.p. to produce about 9 tons of ground lime per hour. Continuous ball mills are made by several firms and differ in details, but the general principle is the same in all. The product is not very fine, and will leave a residue of about 50 per cent. on a 100-mesh sieve. The output may be increased and a product of any degree of fineness obtained by connecting an air separator to the mill and returning the tailings from the mill to be re-ground. This arrangement is patented by Geb. Pfeiffer and others and extensively used.

In ball mills of the vertical or centrifugal type, only five to eight balls are used, and they rest on a rotating frame provided with divisions—one for each ball. When the mill is in use, the balls fly outward by centrifugal force and press against the inner circumference of a hard steel grinding ring. Material fed into the lower part of the mill is stirred by scrapers attached to the lower part of a rotating frame and thrown against the ring, where it is ground by the balls. The finely powdered material rises upwards in a current of air, produced by a fan mounted on the same shaft as the frame, and passes through a circumferential screen as in the pendulum mill (i), the coarse material falling back into the mill.

Ball mills of this type are excellent for outputs of about one ton per hour but the power required is large—sometimes 35–40 h.p. per ton—and wear and tear are considerable. The product may be of almost any required fineness, according to the mesh of the circumferential screen.

(iv) *Tube mills* are the best fine-grinding machines available, but are only suitable for large outputs and are expensive. They resemble a ball mill externally, but are much longer—being usually about 20–25 ft. long, and 4–5 ft. diameter—and have no peripheral perforations. The lime enters at one end of the mill and passes out at the other; the grinding is effected by steel balls or flint pebbles, as in a ball mill, but owing to the length of the tube mill a much finer product is obtained. The fineness of the product depends on the rate at

which the mill is fed and on the size of the pieces supplied. The output, when grinding lime to leave less than 10 per cent. of residue on a 200-mesh, is 2-5 tons per hour. Tube mills may be lined with steel or silex ; the latter is preferable where a very pure lime is to be ground, but for most purposes a steel lining is satisfactory. Similarly, whilst pebbles avoid the introduction of iron into the lime, steel balls are more durable and are usually cheaper, when the cost is estimated " per ton of ground lime."

(v) The *Hardinge Cylinder Mill* is a horizontal ball mill of double conical shape, owing to which it has a classifying effect on the material, the larger pieces remaining in the portion of the mill where the diameter is greatest and the smaller pieces travelling towards the apex of the longer cone. The Hardinge mill produces a material whose fineness is intermediate between a ball mill and a tube mill, and by combining it with an air separator (see ball mills) finely-ground lime can be readily and economically produced with a smaller expenditure of power than with an ordinary ball mill.

Quicklime or *Caustic lime*, when fairly pure, presents few difficulties in grinding if a closed system is used ; otherwise, the dust is very objectionable and may require to be removed by means of a fan and dust collector (see p. 172). Lime which has been overburned or underburned and that which contains much clinker or other hard impurities, is more difficult to grind, and the wear on the mills is much greater. A considerable saving may usually be effected with such limes, by reducing them to pieces not exceeding $\frac{1}{2}$ -in. diameter in a disintegrator, and screening the product. The harder material will tend to remain in larger pieces than the properly-burned lime, and may be separated by a screen with $\frac{1}{8}$ -in. apertures. The tailings should be carefully examined as they may contain too much good lime ; in that case, either the adjustment of the machine must be altered, or this method of separating the harder material must be abandoned.

Slaked lime or *hydrated lime* ought not to require grinding, but as it is frequently made from lime containing underburned or overburned pieces, some manufacturers grind it so as to dispose of the latter. This is not good practice, as it reduces the purity of the product (see *sack lime*). The better course is to separate the fine hydrated lime from the coarse particles and to treat the latter separately, selling them (after grinding) for agricultural and other purposes where a very impure hydrate will serve. The objection to this practice is that in some hydrated limes, the coarser particles of impurities cause much lime to adhere to them and the hydrate tends to segregate into large particles which are rejected by the separator. To avoid this, a disintegrator is frequently used between the hydrator or silo and the separator ; this enables a partial separation of the harder particles to be made automatically before they reach the separator.

When no separation of the impurities from the hydrated lime is desired, as in the production of *sack lime*, a ball mill is the most convenient grinding appliance ; if used alone, however, the large proportion of fine material present in the hydrate tends to overload the mill and reduce the output ; if a fine sieve

is used in connection with such a mill the gauze is quickly destroyed. These difficulties can best be avoided by passing the lime over a small grid to separate the coarse pieces which are taken direct to the mill; the rest of the material is then passed through an air separator fitted with a mechanical dispersing device; this removes the finest particles and returns the others to the mill. The product of the mill is returned to the separator and the finely-ground material separated. Such a separator is more efficient and more durable than a sieve, and by removing the fine material from the mill as soon as it is produced, the output of the mill is greatly increased. If desired, the product from the separator may be passed through two or more cyclone separators so as to divide it into grades of different fineness. The mechanical disperser consists of a horizontal fan below a revolving disc; the material falling on to the latter is dispersed by centrifugal force, the larger particles being carried to the periphery and back to the mill, whilst the smaller particles are carried in suspension by the air. The latter may be allowed to take a simple path, so that the particles settle rapidly, or it may be subdivided by a device such as Geb. Pfeiffer's "Selektor," whereby a much better grading is effected. As much hydrated lime consists of extremely small particles, a dust collector (see p. 172) must usually be provided to retain these particles of lime.

Hydraulic lime may be ground in any of the machines previously mentioned, but as it is usually advisable to divide it into several products the machines and separators or screens should be arranged accordingly. As explained in the section on hydraulic lime, this material consists essentially of a mixture of quicklime and cement in variable proportions. If it is slaked by hand, there is usually formed a quantity of lumps (grappiers) which slake extremely slowly and are objectionable in several ways. If, on the contrary, the hydraulic lime is supplied in the form of a powder, its use is greatly simplified.

No good purpose is served by merely grinding the whole of the hydraulic lime to powder, and as this process would be costly, it is never used. On the contrary, the lime is slaked with a limited quantity of water (see "Slakine Hydraulic Lime") and the coarse residue—known as "grappiers"—is alone ground to powder. Some of the ground grappiers may be sold as a substitute for Portland cement, but it is also customary to mix a little of it with the slaked lime to increase its hydraulicity.

As hydraulic lime slakes very slowly, it is troublesome to deal with; the water tends to be unevenly distributed and to produce a damp material which clogs the sieves and causes them to rust and wear away rapidly. To avoid this, the most convenient method is to combine the hydrating, grinding, and separation of the fine powder in one closed system, using air-separators instead of sieves.

A convenient arrangement of this kind for hydrating and grinding hydraulic lime, devised by Gebr. Pfeiffer, Kaiserlautern (fig. 115), consists of a hydrator, followed by an air separator (I) which separates the fine material and delivers the coarse material to the ball mill (II) and thence to an air-separator (III)

which separates the fine material, of greater density and hydraulicity, than that in the first separator. The tailings from this second separator are delivered to a series of screens (IV) which divide it into three grades: the finest and coarsest grades are returned to the mill (II), but the middle grade, consisting of particles 0.04–0.20-in. diameter, is separated and consists wholly of *grappiers*. These are taken to another ball mill (V), and then to an air separator (VI), whereby a very fine product is obtained. If required, additional plant may be installed to produce mixtures of light lime, heavy lime, and grappier cement in any desired proportions, but the one described is sufficient for most purposes and is almost automatic.

It has been definitely proved that the quality of hydraulic lime provided by an air separator is much better than that provided by a sieve or screen and the cost of its production is less than that of the screened product.

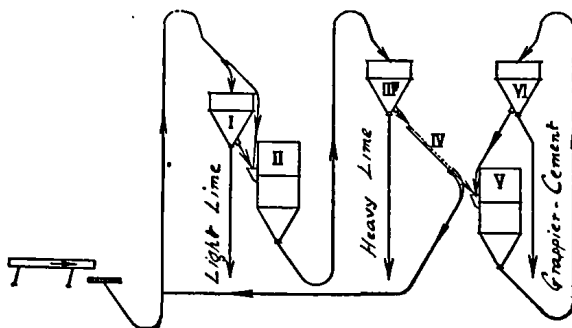


FIG. 115.—HYDRATING AND GRINDING PLANT FOR HYDRAULIC LIME.

A much cruder device for separating the fine particles of hydraulic lime from the grappiers is used in the Virieu hydraulic lime works on the Rhône. It consists of an inclined tube 5 ft. long and 22 in. wide, mounted on a shaft running through it, the upper end of the shaft being 12 in. higher than the lower one. Inside the tube is a series of elevators, made of short pieces of angle iron, which lift the material as the tube rotates. A current of air enters the lower end of the tube and is drawn through the tube in the contrary direction to that taken by the hydrated product. The air carries away the small particles and deposits them in an adjacent storage-chamber from which they are removed by a convenient means, whilst the grappiers are discharged from the lower end of the tube. This device avoids all the dust common to screens and saves the expense of the renewals. The power required to rotate the tube is no greater than that for a rotary screen. Such a tube may be used for materials which are not quite dry; it works automatically and eliminates in the simplest possible manner all the particles which will not pass through a 75-mesh.

SLAKED AND HYDRATED LIME

When a lump of lime falls to powder it is said to *slake* or to be slaked. This slaking may be effected by (a) the cautious addition of water to the lime, when

a large amount of heat is developed and a compound of lime and water—*calcium hydrate* or *hydrated lime*—is produced ; (b) the action of steam, which behaves like water, but enables a drier product to be obtained with less skill and is more rapid in its effects on some limes ; (c) exposing the lime to air, when the small proportion of moisture forms as much calcium hydrate as it can and the small proportion of carbon dioxide in the air combines with rather more than its own weight of lime to form calcium carbonate.

Most limes can be hydrated more rapidly if they are heated during the process of slaking, but, as the application of artificial heat is inconvenient, the heating is sometimes effected indirectly by the use of steam instead of water or by slaking the lime in a closed vessel in which the steam developed as a result of the chemical combination, being unable to escape, causes an increase in the temperature of the mass. For a similar reason, the vessel in which the slaking is effected is sometimes surrounded with a heat-insulating lagging, so as to retain as much heat in the slaking lime as possible and so hasten the slaking or hydration.

Even with cold water the combination occurs rapidly if the lime is pure and porous, but a dense or impure lime offers less surface to the action of the water, develops less heat, and slakes much more slowly ; for the same reason, if far too much water is used the slaking becomes so slow as to be commercially impracticable and the lime is described as “drowned” or “dead.” Overburned lime, on account of its density (and possibly because of the formation of a polymer of lime or a thin coating of fused silicate) also slakes very slowly.

The term *hydrated lime* is applied to the product formed when a pure, or almost pure, lime is mixed slowly with a suitable quantity of water to form an apparently dry powder. A chemical combination of the lime and water occurs, 56 parts of calcium oxide uniting with 18 parts of water to form 74 parts of *calcium hydroxide*. The combination occurs with so much evolution of heat that a larger proportion of water than that just mentioned is necessary, the surplus being driven off as steam, leaving a dry powder as the final product.

From the lime burner's point of view, the production of hydrated lime has the great advantage of converting “small lime,” which is not readily saleable, into a product which can be sold at the same profit as lump lime, because the hydrated material (when in the form of a fine, apparently dry, powder) is more convenient for plasterers and many other users than is the lump lime usually purchased. The reason is that, for most purposes, lime has either to be slaked before it can be used or it is slaked automatically during use, so that a suitable form of slaked lime is, for such purposes, equally as useful as lump lime and often has advantages to the user which lump lime does not possess.

When lime is slaked for the production of plaster, it may be made into a paste or *lime putty* and left as long as possible (seldom less than a month) before use. The resultant *putty* is a soft plastic material which is often more suitable for plastering than that prepared by mixing hydrated lime with water.

The terms *slaked lime* and *hydrated lime* both relate to the same material though the latter is usually restricted to limes which have been slaked in a

hydrator. The result of the action of water on lime is to cause the formation of a compound of the water and the lime ; if a pure calcium lime is used the resulting compound will be *calcium hydroxide*, but a magnesian lime will yield a mixture of calcium hydroxide and magnesium hydroxide in the same molecular proportions as the calcium oxide and magnesia in the lime.

Strictly, there is no distinction between the slaking and hydration of lime, but it is convenient to regard slaked lime as that containing more water than is essential for the conversion of the lime into a hydroxide. The term hydrated lime may then be restricted to the apparently dry powder. There are differences in the physical properties (particularly the plasticity or covering power) of lime paste made by slaking with sufficient water to form the paste and that produced by mixing a hydrated lime with water. For many purposes the difference is unimportant, but for high-grade plaster work the hand slaked lime is best.

Magnesian limes slake more slowly than high-calcium limes and often a large proportion of the magnesia will escape hydration altogether. They expand rather less on slaking and shrink less on drying than calcium limes ; they also set more slowly. Any impurities in the original lime will remain in the slaked or hydrated lime unless they are deliberately removed. As the calcium hydroxide produced is in the form of a very fine powder, the coarser impurities may be separated by screens or by air separators if the product is not too damp.

From a lime putty only the coarsest particles can be separated by screening, but finer ones can be separated from milk of lime, either by screening or by allowing them to settle.

Calcium hydrate or *calcium hydroxide* is the compound formed when a pure calcium lime is slaked under ideal conditions, 56 parts of lime (calcium oxide) combining with 18 parts of water to form 74 parts of the hydroxide. It is a fine white powder with alkaline properties, is slightly soluble in water, and is the essential constituent of *hydrated lime*. It is made by slaking the purest calcium lime under conditions approaching the ideal as nearly as possible.

When a pure quicklime is slaked the heat evolved is 15,200 calories per mole or 271 calories per gm.—an amount sufficiently large, with some limes, to raise the temperature of the product momentarily to 400° C., *i.e.* sufficiently high to ignite gunpowder !

Calcium hydroxide can exist in four forms : (a) a *colloidal sol* form in suspension in water, as in milk of lime ; (b) a mixture of *colloidal sol* and *colloidal gel* form as in lime putty ; (c) an indefinite amorphous form (sp. gr. 2.078) ; and (d) a crystalline form (sp. gr. 2.24). All these forms have the same chemical composition, but very different physical properties, so that for some industrial purposes one of the forms may be less suitable than the others. Thus, the colloidal gel form is essential for plasters and mortars, the crystalline form being useless. Fortunately, the ordinary methods of slaking tend to produce a useful form ; the crystals chiefly grow when a solution is very slowly evaporated. In some "poor" limes the crystals of calcium hydroxide are more prevalent than in fat limes.

The solubility of pure calcium hydroxide in water varies from 1.29 g. per litre at 15° C. to 1.00 g. per litre at 50° C., 0.67 at 80° C. and 0.3 in boiling water. Other figures have been published by various investigators.

Calcium hydroxide is decomposed on heating. At atmospheric pressure the minimum temperature required to drive off all the water is 547° C., but it can be dehydrated at any lower temperature above 300° C. if the pressure is reduced sufficiently.¹

The solution of calcium hydroxide is markedly alkaline.

Air slaked lime is that which has been exposed to the atmosphere, with the result that some of the lime has been converted into *slaked lime* by means of the moisture in the air, some has been *recarbonated*, *i.e.* reconverted into calcium carbonate by the action of the carbon dioxide in the air, and the remainder of the lime is unaffected. Air slaked lime is spoiled to an extent which depends on the amount of slaked lime and carbonate which it contains; for many purposes a slight air slaking is harmless, but where the caustic or basic property of the lime is important, air slaked lime may be objectionable. There is much unreasonable objection to air slaked lime by some users. A farmer may refuse to buy it, and yet when he buys fresh lime he merely lays it out on the ground where it becomes air slaked! Some builders object to lime which is slightly air slaked, yet raise no objection whatever to ground lime containing 20–30 per cent. of finely ground “core.”

Limes vary greatly in the extent to which they slake on exposure to air. In a high calcium lime the slaking can be fairly rapid, especially if the lime is stirred or moved frequently. Magnesian limes absorb moisture more slowly and carbon dioxide more rapidly than high calcium limes. Siliceous limes give variable results. The rate of absorption of moisture also depends on the physical structure of the lime, which is determined by that of the original limestone.

In ancient times, the value of old air slaked lime was highly appreciated on account of its mildness and freedom from causticity so that the surface could be painted without injuring the colours. For this reason, the finest lime was often stored in large vaults for eighty years or more, each generation contributing sufficiently to the store left by its grandparents—a process regarded as impracticable in this age of speed.

Aired lime is produced by burning lime at a temperature below that required to produce good “fat” or “white” lime so that a considerable proportion of unburned limestone or chalk is still present. It is also formed by exposing good lime to air; the lime absorbs carbon dioxide from the air and calcium carbonate is reformed.

The term “aired lime” is also applied to lime made from impure stone which has been heated almost to the sintering point. The term “air lime” is sometimes used (as a distinction from hydraulic lime) for lime which is not to be used under water.

¹ Johnston, *Z. phys. Chem.*, **62**, 336, (1908); *Dragert*, *Diss.*, Berlin, 1914. Some other authorities give 450° C. instead of 547° C.

As the proportion of slaking agents in air is very small, the proportion of combined lime in the product is very variable, and the properties of air slaked lime correspond to an irregular and variable mixture of quicklime, hydrated lime, and calcium carbonate; the last named being useless. Hence the value of lime is reduced by air slaking to an extent which is roughly proportional to the carbon dioxide which has been combined with the lime.

Most lumps of lime tend to air slake superficially on storage, but the film of slaked lime thus produced acts as a protecting agent by preventing the access of air to the interior of the material. Hence, a very long time is required before a lump of lime can be completely converted into calcium hydrate and calcium carbonate by the action of ordinary air. The air in some workshops, etc., is moister than that in others and is, therefore, more capable of causing extensive air slaking.

Perfectly dry carbon dioxide does not combine with dry lime except in the presence of moisture, so that as long as the lime is kept perfectly dry it will not air slake.

Dry slaked lime is lime which has been slaked with only sufficient water to form an apparently dry powder. It is the same as *hydrated lime*.

Sack lime is a term applied to hydrated lime supplied in sacks, though it is usually applied to an inferior quality made by grinding the crude hydrated product without separating any core or overburned material, the term "hydrated lime" being applied to that which has been separated from core and other impurities. The methods used for grinding sack lime are the same as those described under "Ground Lime."

According to Weimarn, Kohlschütten, Walther, and others, when lime is slaked part of it assumes a colloidal form, which is the cause of its plasticity and its shrinkage on drying. The shrinkage is lessened by adding sand (as in mortar) which prevents cracks. Hence, the hardening of mortar is due to the drying of the colloidal gel of lime and not solely to recarbonation as is often supposed.

WATER REQUIRED FOR SLAKING

The quantity of water required for slaking a given weight of lime varies with the nature of the lime and must be found by trial. Limes containing 95 per cent. or more of calcium oxide will usually require about 133 lb., or 13½ gallons of water for each 1 cwt. of lime for lime putty, but only about 50 lb., or 5 gallons, if a dry hydrate is to be made. Of these quantities, 35 lb. of the water may be expected to be combined with the lime, some of the remaining water will evaporate and the rest will be in the free state to make a putty of normal consistency.

Dolomitic and other magnesian limes require about 20 per cent. less water than pure calcium limes as most of the magnesia is not hydrated, but the proportion varies greatly with samples from different sources.

Hydraulic limes require sufficient water to slake the free lime present, but not to combine with the cementitious material.

The maximum amount of water which can combine with any lime is about one-third of the calcium oxide present, but more than this must be added to allow for that lost by evaporation and that required to produce a putty.

With all kinds of lime much depends on the nature of the material, and limes of very similar composition often differ greatly with respect to the amount of water needed.

The water used for slaking or hydrating lime should be fresh and, if possible, soft. Sea-water is objectionable as it tends to form scum if the lime is afterwards used in buildings.

The use of a suitable proportion of water is very important as the fineness, specific gravity, crystalline structure, and plasticity of the hydrated lime are all affected by the quantity of water used and the rate at which it is incorporated. The most plastic hydrate is produced in the presence of an ample proportion of water, under conditions where the hydration occurs rapidly.

RATES OF SLAKING

The rate of slaking depends largely on the compactness of the calcined material, the nature of the stone used, and the impurities present. Most limes which have been calcined at 900° C. are fairly porous and slake rapidly, but those calcined at a higher temperature may take 24–48 hours before becoming completely hydrated. The optimum rate of slaking may be ascertained by placing a weighed quantity of lime in water and determining the electrical conductivity of the liquid whilst it is constantly stirred. The time taken to reach the maximum conductivity is that needed for slaking. It depends largely on the source of the lime and the temperature at which it was burned.

The rate at which a lime slakes depends on :

- (i) Its porosity.
- (ii) The temperature of calcination, which should be below 1300° C.
- (iii) The presence of magnesia or other hydroxides, as these retard the slaking.
- (iv) According to Candlot, the presence of calcium chloride and salt accelerates slaking.
- (v) According to Rohland, small quantities of hydrochloric, nitric, and acetic acids accelerate hydration, but boric acid, hydroxides, sugar, and chromates retard it. In general, acids (except boric) accelerate and alkalis retard hydration.

The coarser and more compact the lime the slower will be the rate at which it slakes.

Hand Slaked Lime.—Until a few years ago, all slaked lime was prepared by hand. The essential feature of the slaking is the addition of water to the lime in such proportions and at such a rate as to produce either a dry powder or a plastic paste, according to what is required ; if a dry powder is desired the process is often known as *dry slaking*, but if a paste or putty is to be produced

the term *wet slaking* is used. If a large excess of water is added rapidly the slaking tends to be incomplete or so seriously retarded that the lime is said to be "drowned"; what really occurs is that the wet surface of the lime becomes impervious to water so that the latter does not reach the interior of the lumps. If "drowned lime" is used for plastering, the pieces of quicklime, which have been protected in the "slaking" and are, therefore, unaltered, gradually absorb moisture from the air, swell, and cause objectionable "blebs" or "blisters" on the surface of the plaster.

In slaking a fat lime by hand, the water should be sprinkled over the surface of the lime, the weight of water required being about half that of the lime, or about five gallons to each 1 cwt. of lime. If the lime were perfectly pure, the quantity of water which would combine with it would be exactly 32.1 per cent., but so much heat is generated during the slaking that a considerable quantity of water is driven off as steam, so that more than the theoretical quantity of water must be added.

When slaking a fat lime it is preferable to add the water slowly, but all at once, as when it is added in two or more successive portions, water is lost by evaporation and too little may remain in combination with the lime. The workman should place a convenient quantity (say 100 lb.) of lime on a concrete or stone surface and sprinkle water on it—preferably through the rose of a watering can—and then turn the material over repeatedly with a spade until the slaking is sufficiently advanced for it to be completed without further attention.

If insufficient water is used some parts of the lime will remain unslaked and this may cause serious trouble when the slaked lime is used. Incompletely slaked lime is said to be "burned." Precisely what causes "burning" during hydration is not known, but it appears to be due to the addition of too much water at first and too little at a later stage of the hydration, or to the use of too little water through the slaking. The excessive heat developed appears to cause the colloidal hydroxide to become hard and, therefore, non-plastic so that the "workability" of the lime under a trowel is diminished or even destroyed.

If too much water is used, however, the lime is said to be "drowned" and the resultant produced is a thin watery paste of little or no value.

When the slaking is properly conducted the product is either a light, dry and fine powder or a moderately soft paste according to whether hydrated lime or lime putty is required.

The men engaged in slaking lime by hand should have their mouths and noses carefully protected by means of respirators.

Unless the source of lime is changed too frequently, a man will usually be able to judge fairly accurately the amount of water required and the best rate at which to add it. Unless exceptional care is used, however, lime slaked by hand tends to be too moist and, therefore, "sticky," hence, the custom of making it into a putty or paste.

The slaked lime should be carefully examined and any unslakable materials such as unburned limestone, pebbles, or flints, removed. If, later, they are

mixed and ground with the slaked material they will detract from its quality.

For some purposes the slaked lime is passed through a sieve with 24 holes per running inch, and, occasionally, a much finer sieve is used. Hand slaked lime is, however, regarded as a crude product, and, consequently, few attempts are made to convert it into an attractive one. This is the more unfortunate as hydrated lime of first-class quality can be obtained by careful hand slaking followed by suitable screening or air separation.

Some men, when slaking lime by hand, add most of the required water to the lump lime and after a suitable time, place the product on a sieve with $\frac{1}{2}$ – $\frac{3}{4}$ in. holes; the finer material which falls through the sieve is used as slaked lime, whilst the coarser pieces are treated separately with more water to see whether they then fall to powder. This method separates the larger pieces of impurity and "core," but unless the fully slaked lime is passed through a fine sieve most of the other impurities will become mixed with the hydrated product.

If the process is carried out properly and suitable lime is used, the lumps will evolve much steam and will gradually fall to a moderately fine powder free from lumps. If an impure lime is used, or the process has been badly controlled, an unsatisfactory mixture of lumps and powder will be produced.

Notwithstanding the apparent crudity of the method of slaking by hand, some of the best commercial hydrated lime on the market is obtained by this method.

In *dry slaking* by hand the lime is spread on the ground in a layer, 4–6 in. thick, and is sprinkled with water by means of a rose on a watercan. It is mixed with the aid of a shovel, and is then heaped up and left to itself for a day, so that it may be fully slaked. It is advisable to cover the heap with sacks so as to retain the heat in it. It is also wise to watch the heap during the first few hours, as the temperature reached in slaking lime is often sufficient to set cloth or wood on fire.

In an alternative method, the lumps of lime, in a basket, are immersed in water for a short time and are then withdrawn and placed in heaps or silos to prevent the escape of water. The lime slakes and falls to powder but is very liable to contain some unslaked lime.

The dry, slaked lime is sifted, usually through sieves with 4–8 holes per running inch. Such coarse sieves are unsatisfactory, as they allow many particles which have not been sufficiently burned, and also small clots of paste to pass through them. It is much better to employ sieves with 36 or more meshes per linear inch, so that all coarse particles are separated and a really fine, soft powder is obtained. Indeed, the present tendency is to require all dry-slaked lime to leave less than 5 per cent. of residue on a 200-mesh sieve.

If the lime is properly slaked it will quickly fall to an apparently dry powder, but if a slight excess of water is added the product may be adhesive and plastic. Unless the excess of water added is large, the apparently pasty lime may evolve so much water that by the time it is cold it may be a dry powder.

During the slaking of lime a considerable amount of expansion takes place. One bushel of lump lime (made from stone) which contains little or no non-volatile impurities will produce 3-3½ bushels of dry powder. This is the case with the best limes made from blue or grey limestone. The colour of these stones before burning is due to combustible bituminous matter ; this burns away, leaving a pure white lime.

The amount of swelling depends partly on the purity and porosity of the lime and partly on the manner in which the water is added, the swelling being less if the water is added very slowly. This is particularly noticeable with magnesian limestone.

Dry slaking is *not* suitable for hydraulic limes.

In *wet slaking* by hand the lime is mixed with three or four times its weight of water (*i.e.* 33-45 gallons for each 1 cwt. of lime) in a shallow tub or trough, the mixture being well stirred with a wooden rake so as to produce a *milk* or *slurry* ; this is run off into another vessel or into a pit, as desired. This process ensures the complete hydration of the lime, which is uncertain with dry slaking, and produces a stronger mortar when such lime is mixed with sand or trass.

Care should be taken not to "drown" the lime in an excess of water, and it is desirable not to add too much water at a time. When the slaking is skilfully done the mixture remains at a boiling heat for some time.

Wet slaked lime should not be run through a grate or sieve, as this creates too great a temptation to use a large excess of water. Any pieces which cannot be slaked soon settle and remain behind when the slurry is run off. If a paste or putty is required it is sometimes better to dry slake the lime first and obtain a dry powder to which can afterwards be added the water necessary to produce a paste. If all the water needed is added at once, some parts of the lime may be "drowned."

The use of mechanically hydrated lime is increasing so rapidly that the production of hand slaked lime is quickly diminishing. This is unfortunate, because a skilled lime slaker can adjust the quantity of water added to suit each batch of lime, whereas a machine must be adjusted in order to produce slaked lime of "average" quality.

Hand slaking is very slow and, therefore, costly, but hand slaked lime is, for some special purposes, superior to mechanically slaked lime.

Greystone lime is slaked in a similar manner to fat lime, but a longer time is required, as the silica present is combined with some of the lime similarly to that in hydraulic limes.

Hydraulic lime is slaked in a different manner because such lime is really a mixture of two materials: (a) quicklime, and (b) a hydraulic cement. The slaking relates only to the first constituent, the resulting product being a powder containing unslakeable lumps (*grappiers*) which must be separated by screening unless the original lime has been ground to powder prior to slaking. Unless a hydraulic lime is to be used at once it is important not to add any more water than is needed to slake the quicklime present. Any excess of water will cause some of the "cement" to harden and will render it useless.

Unlike quicklime, hydraulic limes do not swell appreciably when slaking, and they develop far less heat. A hydraulic lime may, therefore, be mixed with a limited amount of water with little or no risk of spoiling it. According to Le Chatelier, the vapour tension of calcium hydrate, when cold, is practically nil, but that of calcium silicate is several millimetres of mercury. At 100° C. it is not more than 1 mm. for the first, but several centimetres for the second. Consequently, in a mixture of lime and silicate the lime will hydrate progressively without the silicate being hydrated and the silicate will, if necessary, part with its combined water until all the lime is fully hydrated. If only sufficient water is added to a lump of hydraulic lime, only the calcium oxide and magnesia will be hydrated, but the expansion due to this slaking should cause the whole lump to crumble to a fine powder, consisting essentially of calcium hydroxide, tricalcium silicate, tricalcium aluminate, and a complex mixture of more or less inert matter, the whole forming a cementitious material resembling a weak Portland cement.

About 10–15 per cent. of water is usually required for slaking a hydraulic lime, but the optimum proportion should always be found by trial as imperfectly slaked lime can cause serious trouble when in use. The water should be supplied in the form of a very fine spray so that no part of the lime receives an excessive quantity of water. If the water is added through coarse jets, part of the lime becomes too wet and then loses its cementitious properties unless it is used immediately.

The best qualities of hydraulic lime are not used for some time after being slaked, so as to ensure complete slaking.

A good hydraulic lime should fall to powder when immersed in water for 24 hours, or when sprinkled with a suitable quantity of water, and at the end of this time should not leave more than 5 per cent. of residue on a No. 24 sieve. A properly hydrated hydraulic lime will usually require only 7–8 per cent. of its weight of water, but 10–11 per cent. is usually added to allow for loss by evaporation.

A dry slaked hydraulic lime usually contains a considerable proportion of lumps (grappiers) of harder material; these should be removed by passing the product over a 50-mesh screen or sieve. As these grappiers can be ground and made into cement, it is an advantage if hydraulic cements are slaked by the manufacturer who can make use of the grappiers.

It may seem strange that hydraulic lime requires so long to slake completely because all movement ceases within 48 hours of adding the water and no vapour appears to be set free. The true test is that mortars made with hydraulic lime which has only been slaked for 48 hours, crack and show other signs of incomplete slaking, whilst mortar made of the same lime which has been slaked for a fortnight will be excellent. A hydraulic lime purchased in a ground state should pass completely through a 24-mesh sieve and not leave more than 10 per cent. of residue when washed through a 200-mesh.

Ample time must be allowed for slaking hydraulic cements, both when neat and when mixed with sand, but care must be taken to avoid re-working a

material which has been slaked with too much water and has begun to set. If the lime is slaked whilst warm, as it comes out of the kiln, or if *hot* water is used, the time of slaking may sometimes be reduced to three hours.

Hydraulic limes should always be sifted after slaking, in order to remove any imperfectly slaked lumps (*grappiers*) and it is preferable to grind the lime to powder before slaking so as to avoid inconvenience caused by the formation of these lumps.

When large quantities of hydraulic lime are to be slaked, as in France where the slaking is done at the limeworks, the lime is spread out in layers on large floors, sprinkled with just sufficient water to slake the free lime, and then shovelled into heaps or placed in bins where it is kept for about ten days, during which the slaking is completed. The product—which should chiefly consist of a fine powder—is then sieved or screened—usually through 50-mesh gauze—or passed through an air separator to remove the lumps (*grappiers*) and is then ready for sale or use. A portion of the *grappiers* is usually ground to powder and added to the sieved product so as to increase the hydraulicity of the latter. The process used is described under “Ground Lime.” In slaking prior to sale, an excess of water should be avoided, or some of the cementitious part of the lime will be spoiled.

It has been suggested that slaking hydraulic lime in layers contaminates it by the absorption of carbon dioxide from the atmosphere; such absorption does not affect the hardening properties of the lime, but only increases, very slightly, the proportion of inert matter present.

GRAPPIERS

The coarse material separated when hydraulic lime is slaked is known as *grappiers*. It is a highly cementitious and hydraulic material, though inferior to Portland cement. It is obtained as a by-product when hydraulic cement is hydrated at the works, as is usual on the Continent, and requires to be ground so as to leave not more than 10 per cent. residue on a 180-mesh sieve in order to be of the same fineness as Portland cement, for which it is used as a substitute. To be useful, the *grappiers* must be free from more than about 15 per cent. of unburned limestone and the more nearly their composition resembles that of Portland cement, the more valuable will be the *grappiers*.

Crude *grappiers* is an irregular mixture of white, grey, and black particles. It is first exposed to the air for a month or more, so as to hydrate the free lime completely. Sometimes steam is admitted to the aerating rooms in order to hasten the hydration. The product is screened and the fine “heavy lime” added to ordinary hydraulic lime. The residue is ground and forms the *white cement* largely used for mosaic work. The harder portions, which occur as tailings from the “white cement” screens, form a grey sand which, when finely ground, produces *grey grappier cement*.

Owing to the variability in composition and properties and the necessity of mixing various products to obtain others of uniform quality, the manufacture of *grappier cements* is extremely tedious, and partly for that reason, and partly

because Portland cement is so readily available, grappier cement is seldom made in this country.

In France, where the grappiers industry is more extensive, there is an increasing tendency to simplify the procedure by grinding the lumps of grappiers as finely as possible and adding them to the hydrated lime, thereby increasing the hydraulicity and cementing power of the latter. The method of grinding grappiers is described in the section on "Ground Lime."

Mechanical Slaking or Hydrating.—Instead of mixing the lime and water by hand, mechanical appliances may be used. These give use to two methods: (i) Batch hydrating, and (ii) Continuous hydrating.

Batch hydrating consists in mixing a known quantity of lime (which forms the *batch*) with a suitable amount of water. The term may be applied to hand slaking, but usually it refers to the use of a mechanical method in which a definite quantity of lime is hydrated at a time.

Continuous hydrating consists in the use of appliances whereby a continuous supply of hydrated lime is produced. It differs in this respect from the batch method, which is discontinuous.

For various reasons, much unnecessary mystery has been made of the production of hydrated lime. It is true that when working on a large scale, with lime which is not very suitable for the purpose, various difficulties are experienced and a crude product of small commercial value is obtained, but such results are wholly due to special circumstances. In itself, the hydration of suitable lime is exceedingly simple; it requires no machinery of any kind and is practically automatic; it is only when impure or overburned lime is used that difficulties are experienced and the use of various appliances becomes desirable.

The hydration consists, as already explained, in mixing the lime with a suitable quantity of water and keeping the lime at a suitable temperature for such a time as will ensure all the true lime (calcium oxide) being converted into the hydrate. To ensure a thorough mixing of the lime and water, some form of mixing machinery may be used; some kind of water measuring device may also be desirable in order that the water may be supplied at a suitable rate and so prevent "drowning" the lime, and, under some circumstances, it may be desirable to crush the lump lime into small pieces. The various appliances used for separating the coarse and fine materials in the hydrated produce have nothing to do with the hydration proper and are best considered separately so as to avoid confusion.

Hence, in selecting any plant or machinery for hydrating lime, the chief principles to be borne in mind are:

- (i) A suitable quantity of water must be added to the lime.
- (ii) The water must be added at a suitable rate and in a suitable manner.
- (iii) The water and lime must be suitably mixed.
- (iv) The water and lime must be maintained at a suitable temperature. The heat generated in the slaking must be removed as rapidly as possible in

order to keep the temperature sufficiently low to prevent "burning" the lime, but sufficient heat must be retained to enable the hydration to continue at a normal rate. The control of the temperature is generally effected by varying the stirring of the mixture; if the mixture is a paste, it will be too soft and wet, and the "hydrate" will be damp and difficult to sieve. The control of the water and the regulation of the conditions of slaking are most important and no effort should be spared in this part of the work if a high-class product is desired. The requisite control can only be maintained by repeated tests or "checks."

(v) The lime and water must remain in contact for a sufficiently long time to ensure complete hydration of all true lime present; in some cases, six days' storage is necessary, but with most fat limes storage for 24 hours is sufficient. Ample time is specially necessary with magnesian lime as the magnesia hydrates very slowly, and if slaking occurs after the lime is in use the resulting expansion may destroy the structure in which the lime is employed.

(vi) Some manufacturers consider that to hydrate lime effectively it should be ground to pass a 50-mesh screen, so as to eliminate variations due to pieces of lime of greatly different sizes. Whilst grinding is not essential it is usually advantageous when a mechanical hydrator is used. E. R. Sutcliffe recommends that when the ground lime is brought into contact with the water the mixture should be heated almost to boiling by injecting steam, whilst being thoroughly agitated.

When hydrating large quantities of lime which is irregular in composition (possibly through defective burning) it is sometimes desirable to crush the lime to pieces not more than 1 in. diameter and to keep them in a silo, so as to obtain an average of two or three days' burning and thereby eliminate some of the irregularity.

In the application of these principles various mechanical and other devices may be used, the choice of which should depend on the nature of the lime and on the quantity to be hydrated per day, week, or year.

A very common mistake in designing a plant for hydrating lime is to overlook the need for storage after mixing the lime and water, but before screening, air separating, or using the product. Some slow slaking limes require a considerable time before hydration is complete, and if this fact is overlooked it may be impossible to produce hydrated lime of good quality.

The use of a *suitable lime* is very important, because, as previously suggested, all limes are not equally suitable for slaking or hydration. The best are those composed almost wholly of calcium oxide; any other material ("impurity") present being of an inert nature and incapable of reaction with water. Limes which contain much silica or alumina have hydraulic properties and do not slake like pure calcareous limes, but gradually set or harden when in contact with water, like cements; such limes are unsuitable for making hydrated lime, though, if the proportion of hydraulic material is not large, the lime may be hydrated and the hydraulic portion separated. The yield of hydrated lime will be low but, in spite of this, in some localities it will be

worth while to hydrate the lime, especially if it is, otherwise, unsaleable except at a very low price.

When a perfectly pure calcareous lime is hydrated, 100 lb. of it will form 133 lb. of hydrate. If quicklime, consisting of a natural mixture of calcium oxide and inert material free from calcium, is hydrated, the product will consist of a mixture of calcium hydroxide and the inert material. The weight of calcium hydroxide will be equal to that of the free lime multiplied by 1.33 and the inert material will be unaltered. Thus, 101 lb. of "lime" consisting of 90 per cent. of free lime and 10 per cent. of inert material will, on hydration, yield 130 lb. of product consisting of 120 lb. of true hydrated lime and 10 lb. of inert material. If most of the inert material is of a coarse nature it may be separated by screening or other suitable treatment, so that the actual yield of "hydrate" might be 120 lb. as against 133 lb. for that from a pure lime.

It is, to some extent, possible to predict from a chemical analysis of a lime the amount of hydrate and lime which can be made from it. It is not, however, sufficient to multiply the calcium oxide shown in the analysis by 1.33 because some of it may be present in the form of calcium carbonate (unburned lime) or of various calcium silicates, aluminates, and aluminosilicates. Only the free or uncombined lime can be hydrated, and unless the analysis is in such a form as to show how much free lime is present or to enable it to be calculated, the amount of hydrated lime which can be produced can only be found by trial.

Trials on a small scale do not always show the amount of hydrated lime which will be produced on a large scale because the conditions are not precisely the same and the effect of "mass action" cannot always be allowed for in a test on a small scale. It is, therefore, desirable before erecting a hydrating plant to make a full-scale test of the lime if this can possibly be arranged. Failing this, a quantity of lime equal to a charge or batch for the plant should be slaked by hand and the time required for complete hydration should be noted.

The use of mechanical or other appliances may reduce the time needed, but too much reliance should not be placed on this until the machine under consideration has been used for that particular lime. Arguments of a general character are liable to be seriously erroneous when applied to the slaking or hydrating of a particular lime and great care is needed to avoid such mistakes. More than one manufacturer of hydrated lime has failed to allow for some particular property in the lime employed, and the result has usually been a serious loss.

In selecting a lime for making hydrate, or in considering which process to use for a particular lime, it is important to ascertain:

(a) What treatment of the lime is necessary (if any) in order to hydrate it uniformly (some limes require to be crushed or screened before hydration, if a large output is desired).

(b) The rate at which the water may best be added to the lime.

(c) The pressure (if any) which must be allowed to develop in the vessel in which the hydration takes place (usually termed the *hydrating chamber*).

(d) The amount of artificial heat (if any) which must be applied to the lime or water or both.

(e) The extent to which the lime and water must be mixed together.

(f) The time the hydrated lime must be stored prior to the (i) screening ; (ii) other treatment ; or (iii) use.

(g) What treatment (if any) is needed to separate any undesirable material from the hydrate.

(h) What weight of saleable hydrated lime is producible from 100 lb. of the quicklime it is proposed to use. The theoretical maximum is 133 lb. of dry hydrate.

Failure to ascertain one of these important factors may result in the production of hydrated lime of poor quality or in the creation of difficulties which make the hydration unprofitable.

The advantage of a continuous hydrating plant is that when supplied with lime of uniform quality the hydration occurs at a uniform rate and with a minimum amount of labour and attention so long as the plant is at work. If the lime were perfectly uniform, a continuous process would be almost ideal and highly efficient. Unfortunately, lime—even from one quarry—varies greatly both in composition and properties, and the chief purpose of a continuous plant is thereby frustrated. In a continuous hydrating plant it is difficult to watch the hydration and to regulate the amount of water added so as to adjust it to the variations in the lime. The lime must be assumed to be uniform, even when it is not so, and definite proportions of lime and water must be maintained. Some adjustment is possible, but by the time it has been made, a further variation in the lime may make it unsuitable and necessitate another adjustment. In a batch hydrating process each batch of lime is dealt with separately, and as the process can be watched it is fairly easy to see whether a batch is hydrating slowly or rapidly ; the supply of water and the duration of the mixing can then be adjusted accordingly, with much less risk of serious error than in a continuous machine.

Some limes do not slake properly unless immersed in water for some time ; for these most continuous hydrators are not suitable as they must inevitably supply the water or steam in a continuous small stream. Slow slaking limes are also difficult to hydrate in a continuous machine, because they require so much time that no machine would be long enough to complete the slaking. Attempts have been made to return the coarse "tailings" to the hydrator in the hope that they contain all the unslaked lime. This arrangement is not really satisfactory, for whilst it works well with some limes, it lacks the precision of control which is desirable.

Local conditions differ so greatly that no simple rule is applicable to all hydrating plants, but, briefly, a continuous plant should only be used where the lime is exceptionally uniform in quality, and a batch hydrator should be employed for limes of the more usual kinds, which require considerable variations in the water and in the time required for slaking them completely.

If the lime is in lumps it must first be sprinkled with sufficient water to

cause it to fall to powder, after which a suitable quantity of water to finish hydration is added and the mixing is completed by vigorous stirring, as when mixing water with Portland cement. Experience is needed to know how much water to add at each stage as "average" limes vary so greatly in the proportion of water required. It is better to use too little rather than too much water for the slaking if the product is required for chemical or agricultural purposes, but for sand-lime bricks and other products where any expansion of the lime is objectionable, complete hydration is essential.

TYPICAL HYDRATING PLANTS

A plant for producing hydrated lime in large quantities consists essentially of :

(a) A *crusher*, to reduce the lumps of lime to a convenient size ($\frac{1}{2}$ -in. and less) for uniform slaking. It is almost impossible to secure constantly satisfactory results if the hydrator is fed with large and small lumps simultaneously. Men may, of course, be employed to break down the lumps, but a pair of kibbler rolls or a jaw crusher is far more effective and, in all except small plants, will save one man's wages. The crusher may be used in combination with a grid and hopper so that all pieces of lime less than 2 in. diameter may be separated and only the larger ones passed through the crusher. The crusher and grid should deliver the lime on to an iron-sheeted platform, from which it can conveniently be raked into a wagon which serves as a measuring device and also for taking the lime to the hydrator. Automatic feeding of the crusher is best secured by means of a Ross chain (fig. 33) or equivalent device.

The omission of a crusher is a common cause of irregularities in hydrated lime, and especially of the occurrence of unslaked lime in the final product, yet few hydrating plants take this simple precaution for facilitating hydration.

Some firms wisely provide a second screen to separate all pieces of lime less than $\frac{1}{8}$ -in. diameter, and hydrate these apart from the other lime. A definite mixture of fine and coarse lime is used in some plants, the proportions being regulated to secure as constant a rate of hydration as possible; this could not be obtained with a variable mixture of large and small pieces.

Some manufacturers grind the lime to powder in a disintegrator or stone mill before slaking, but this is unnecessary unless a slow slaking lime is used. Even then it is better not to crush it to much less than $\frac{1}{2}$ -in. pieces and to store the slaked material, rather than to reduce the quicklime to powder before slaking and to omit the later storage; the latter practice tends to permit unslaked lime to pass into the final product where it may do harm, *e.g.* in the manufacture of lime-sand bricks, plaster, or paints.

(b) The necessary *storage bins* for the raw and crushed or ground lime and means for conveying it to the hydrators.

(c) A *hydrator*, in which the water and lime are mixed together and in which the greater part of the hydration takes place. If a quick slaking lime is used it may be completely hydrated before it leaves the hydrator. Various types of hydrator are described on pp. 505 *et seq.*

(d) A *Grid* or screen to separate any large pieces of core or slow slaking lime. This grid is not essential, but very convenient ; it also lessens the risk of damaging the conveyor used to take the lime from the hydrator to the silos. The residue on the grid may be treated separately or it may be returned to the crusher. The best mode of treatment will depend on its nature ; if it consists almost wholly of unburned stone or " core " it is useless to pass it through the hydrating plant and it should be thrown away. If, however, it consists chiefly of overburned lime or of pieces which are abnormally slow slaking it may be returned to the crusher and so passed (with fresh lime) into the hydrator. If the appearance and " weight " of the material does not enable its nature to be readily ascertained, a few drops of hydrochloric acid will rapidly do so ; under this treatment, " core " will effervesce violently, but overburned lime will not.

(e) A *Conveyor* to deliver the crude mixture of lime and water from the hydrator to the silo, or, in some cases, to the lime dresser or separator. Any convenient type of conveyor may be used, but, to prevent undue air slaking or re-carbonation of the lime, a closed conveyor is usually preferred. A closed trough, containing a rotating worm or screw, is generally used and is quite satisfactory if the lime is properly treated. Some limes tend to become " sticky " and are compressed so tightly in some parts of the conveyor that the blades of the screw break. This tendency to fracture is increased if the lime is slow slaking or contains much core, as a screw conveyor is not suitable for conveying stones, but only a relatively fine material. Some screw conveyors are far too long to be satisfactory and should be divided into lengths of not more than 12 ft. each ; they should be arranged one above another so that each discharges into a conveyor at a slightly lower level.

A plain rectangular trough, over which runs an endless chain provided with hanging scrapers, may be used satisfactorily where a screw conveyor is undesirable, but care should be taken to run it until it is empty each evening as lime left overnight in such a conveyor may be spoiled by recarbonation before the next morning. Such conveyors are less convenient than screw conveyors, as the returning portion of the chain is liable to be " in the way."

Belt conveyors may be used if made of suitable material, specially treated rubber or steel belts being the best.

A bucket conveyor or elevator is excellent for raising the material from the hydrator to the top of the silo when only one silo is used, but if several are employed, the bucket elevator may discharge the material into a hopper from whence it falls into a horizontal conveyor which delivers it to whichever bin is desired. In the latter, means should be provided for enabling any bin to be filled at will by simply moving a valve or other device. On a belt conveyor, a vertical piece of sheet steel mounted on a movable frame and fixed at an angle of 45 degrees to the direction in which the belt travels, will divert the material from the belt into the bin. Various devices for turning the belt sideways are also available.

For a screw conveyor, a series of openings in the bottom of the trough, each opening fitted with a simple slide, is usually the most convenient.

(f) Several *silos*, in which the crude mixture of lime and water is kept until the hydration is complete. If any particles of unslaked lime remain when the product is passed to the screen or separator they may pass through the latter, remain in the final product, and will cause it to expand when mixed with water. The result will be that damage may be done to the plaster, bricks, mortar, or other articles in which the hydrated lime is used.

Some makers of hydrating plants omit the silo, and unless the lime is very quick slaking, the results are disastrous. Even when a quick slaking lime is used, a silo is advantageous, as it enables the lime to cool, permits any surplus water present to be uniformly distributed, and greatly facilitates subsequent treatment. The size of the silo, or the total capacity of all the silos if more than one is used, should depend on the time required for completely slaking the lime. For a rapid slaking lime, a single silo, holding one day's output, should be ample, but a lime which requires four days to slake completely is best stored in six silos, each of which holds a full day's output. Freshly-mixed lime can then be supplied to one bin, whilst fully slaked lime is being drawn from another, the remaining four bins being used for intermediate storage. Hence, before the capacity of the silo or bins can be specified, the time required for slaking and the proposed daily output must be definitely known.

Although it may appear to be most natural to have the outlets at the bottom of the silos, it is found, in practice, to be more convenient if they are at the side, so that they discharge into a conveyor which is sufficiently away from the silo to allow of ready access in case of damage. When the conveyor is directly beneath the bottom of the silo, it is difficult to repair a broken blade. Moreover, by having the outlet at the side of the conveyor, it is much easier to insert a short poker, if for any reason the hydrated lime does not flow readily. The tops of the silos may conveniently be covered with loose boards, arranged in sections of such sizes as to be easily lifted off when required. A plank footway, giving access to the tops of the silos and the conveyor, is also an advantage which is often overlooked in planning the works.

The silos may be made of timber and lined with sheet iron, or of reinforced concrete. The latter material has the advantage of greater strength and resistance to fire, a matter of importance when hydrating limes which develop much heat on storing. It is unwise to use very large silos as, in them, the lime may become so dense and hard that they are difficult to empty. For this reason, bins more than 10 ft. deep are undesirable.

(g) A *conveyor* to take the material from each silo to the lime dresser or separator; a screw conveyor similar to the one described in (e) being usually the most suitable.

(h) A *disintegrator*¹ to free any pieces of core from adherent lime and to break down damp masses of the hydrated lime. Unless some device is used a large proportion of good hydrated lime will remain on the sieve or be discarded as useless and the loss of hydrate in the tailings may be serious.

¹ Sometimes the crude product is taken from the silos to an air-separator, the tailings being taken to a disintegrator, it being claimed that this is cheaper than passing all the material through the disintegrator.

These drawbacks can be avoided by using a suitable disintegrator, which will break down the segregated particles of hydrate and will "clean" the pieces of core by beating the greater part of the hydrate adhering to them. The well-known types of disintegrator consist of a series of hammers attached to a shafting rotating at 1,000 revolutions per minute in a closed casing, the crushed material passing through a stout grating which acts as an anvil. Various types of ball and pendulum mill may also be used. The disintegrator which is most extensively used for the purpose is the "Raymond" mill, which has the advantage of an adjustable outlet for the hard material, so that this may be discharged automatically instead of being ground to powder. This device saves power which would otherwise be wasted, and also separates the core and other undesirable materials at a point where they can do no harm.

As the object in using a disintegrator is to separate the small particles of hydrated lime from each other and from coarser impurities, the machine should be adjusted to secure this rather than efficient grinding. An examination of the contents of a disintegrator which has been running for several hours will show a much larger percentage of impurities than the material fed into the mill; this is due to the soft material passing out rapidly whilst the harder ones tend to accumulate, but by arranging for the removal of the latter, either periodically or continuously according to the design of the machine, the power used will be reduced to a minimum and a purer hydrate will be produced.

Whichever type of mill is used, it should be fully enclosed or the loss of the finest hydrate, in the form of dust, will be serious. This loss is avoided by connecting the outlet of the mill to the lime dresser by means of pipes, and, if necessary, enclosed elevators, or by using a cyclone and fan (fig. 116).

(i) A lime dresser to separate the coarse

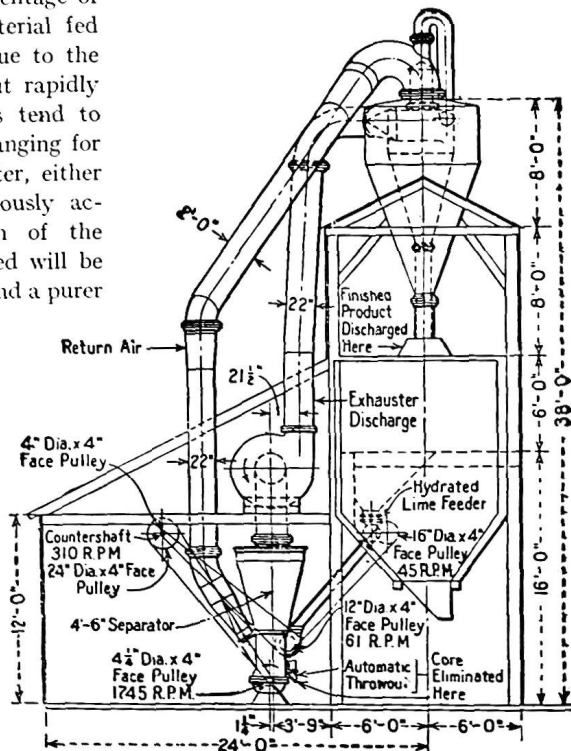


FIG. 116.—TYPICAL RAYMOND NO. 0 AUTOMATIC PULVERIZER INSTALLATION.
(By courtesy of Mining and Industrial Equipment, Ltd.)

particles (which usually contain most of the impurities). For this purpose, screens or air separators, or both, are employed.

The lime dresser may consist of a simple sieve or a more elaborate device comprising a disintegrator and air separator, according to the nature of the hydrate. Some hydrates are so soft and adhesive that it is difficult to separate them into their individual particles; to pass them over a screen or sieve would result in an unduly large proportion being rejected as "tailings," the particles of which, could they be separated, would readily pass through the sieve.

Where a hydrate is readily sub-divided and only a moderately fine product is required, a simple sieve or screen is quite satisfactory.

Horizontal or slightly inclined sieves, fitted with a rapper, or with a reciprocating or vibrating device, are usually satisfactory, or an inclined sheet of perforated steel may be used.

Revolving cylindrical screens may be used, but are very noisy and dusty as well as being costly to repair. Some firms prefer a hexagonal drum with a wire mesh mounted on the periphery, whilst others prefer plane sieves to which a reciprocating or vibratory motion is imparted so as to facilitate the passage of small particles and prevent clogging.

Various types of screens made for other purposes are available. The screening material should usually be of No. 24 or No. 36-mesh, as finer gauze will clog too readily.

As much dust is created by screening, the dresser should be completely enclosed in such a manner that the screen can readily be examined when required. A ventilating shaft, with suitable baffles, should be provided, as otherwise, it will be almost impossible to examine the screening without stopping it. Ready accessibility is very important, and seldom receives the attention it deserves. For the same reason, the screening material should, if possible, be mounted in frames, so that a section can be taken out and replaced in a few seconds; the customary method of bolting the gauze on to the fixed framework is clumsy and time-wasting, as it necessitates stopping the machine for half an hour or more each time a repair or replacement is necessary.

The screening or sieving device is usually mounted above a bin or silo, which should be large enough to hold two days' normal output. This will enable the hydrate to be packed or delivered to some other part of the plant, where it is used (as when making sand lime bricks, bleaching powder, patent plaster, paints, distemper, etc.) even when the sieve is under repair, or the hydrating plant has been stopped for some other reason. This silo should be provided with suitable outlets for packing or delivery, as the case may be. If the hydrate is to be bagged, several outlets from the silo should be used, each being of such a shape as to fit the mouths of the bags; if the material is to be delivered to a conveyor, a single opening, leading to the latter, is satisfactory. As previously explained in connection with the storage silo, the outlets should be so arranged that in case the hydrate does not flow freely, its movements can readily be assisted by a poker.

Instead of screens, the use of *cyclones* or *air separators* is increasing as they produce a finer quality of hydrate.

Where the finest grades of hydrated limes are required for use as a filler, etc., an air separator is essential, as it is impracticable to use very fine screens for hydrated lime.

An *air separator* consists of a cyclone fitted with a rapidly revolving horizontal plate on which the hydrated lime falls, but is quickly thrown off by centrifugal force. This device suspends the particles in the air, from which they afterwards settle by gravitation, the finer particles passing through one outlet and the coarser ones through another. An air separator largely does away with the need for a disintegrator, but it is less effective with highly cohesive hydrates. The fine product from an air separator of this type may, if desired, be passed into a cyclone.

A *cyclone* consists of an inverted hollow cone surmounted by a shallow cylinder. The powder-laden air enters near the top and travels spirally, its velocity and carrying power being reduced so that the particles gradually settle, the coarsest doing so more rapidly than the rest. It may be necessary to use several cyclones in succession if the whole of the powder is to be collected.

The fineness of the material collected in a cyclone depends on the speed at which the dust-laden air enters it, and the rapidity with which that speed is reduced before the air is discharged. A cyclone is not merely a settling tank; on the contrary, many of the particles fall out of suspension by contact with the sides of the cyclone. The action is partly sedimentary, partly centrifugal, and partly due to a baffling effect caused by the shape of the cyclone. The action is so complex that no satisfactory formulae have been devised to indicate the relation between the various dimensions of different cyclones and the sizes of particles separated. The best results can only be obtained by experience by trying cyclones of different dimensions, and by varying the speed of the air; fortunately, wide differences in the dimensions do not greatly affect the fineness of the product provided a sufficiently large cyclone is used, the small cyclones being ones which cause the most trouble.

As a cyclone separator has no moving parts, its use is very simple when the dimensions are suitable, and the ease with which particles of hydrated lime can be suspended in air makes the method of grading a very satisfactory one. From such a separator the hydrated lime can be discharged into bags or into a conveyor as may be desired. If the hydrating plant is worked continuously, but the product is only bagged during the day time, a further silo will be needed to store it, as the cyclones must not be allowed to retain much hydrate or their separating action will be diminished, or even destroyed. In other words, an almost empty cyclone is an efficient separator, but one which is nearly full of deposited material cannot function efficiently. When the finest and purest hydrated lime obtainable is desired, it is preferable to take the lime direct from the hydrator to an air separator, as by this means the most rapidly reacting hydrate is separated. The yield of this superfine product will be small, unless a very rapid slaking lime is used, but the quality of the product will be very

high ; it will tend to contain a little unslaked lime. The proportion of tailings may be inordinately large, and they may contain a large proportion of hydrate ; they may be passed through a disintegrator or other pulverizer and then into a separator or cyclone.

If the tailings contain any quicklime (which has not been hydrated) they should be wetted still further with an additional quantity of water and stored until hydration is complete, before being passed through a pulverizer and separator.

A very convenient arrangement is obtained by connecting the disintegrator (p. 500) to the air separator or cyclone and a fan, in such a manner that a current of air is drawn through the mill and carries off the fine particles, which are deposited in the separator ; the air is then returned to the mill, and by thus circulating it, the lime in suspension is eventually deposited. It is an advantage to use a second separator to receive a portion of the air discharged from the first cyclone, and so balance any leakage of air into the apparatus due to the suction of the rotating member of the mill not being fully balanced by that of the fan. Sometimes, a series of cyclones is employed, and a corresponding number of grades of hydrated lime produced.

With an output of 20–25 tons per hour it may be desirable to pass the hydrate through a 16-ft. separator, the tailings from this through a 12-ft separator, and the tailings from the latter to a pulverizer. Under good conditions, the first separator receives material showing 60–62 per cent. through 200-mesh, and yields a product testing 99·7 per cent. through 200-mesh. The second separator receives material averaging 20–25 per cent. through 200-mesh, and produces tailings leaving only a trace on a 200-mesh screen. The pulverizer produces a further quantity of hydrate, which may be passed into the second or a third separator.

The tailings from either a screen or separator should be carefully examined. They may contain sufficient hydrate to indicate a lack of adjustment in the screen or separator, that one or other of these appliances is unsuitable for the particular material it has to treat, or that the lime is so slow in slaking that additional bins are necessary. In a properly-designed plant the tailings should be free from hydrate, and should consist almost wholly of “core,” stone, fused clay, and other impurities present in the lime, such material is practically useless, and so valueless, but can sometimes be sold to farmers and builders at a low price, which is more profitable than sending it to a tip.

If the proportion of tailings is large, it indicates an error in the plant, or in the use of unsuitable lime ; the cause of such an error and the best means of avoiding it should then be investigated. The common practice of grinding the tailings and returning them to the separator or screen is unsatisfactory if a first-class hydrated lime is used ; a small proportion (say, less than 10 per cent.) of impurities introduced in the form of fine ground tailings is not objectionable.

The very smallest particles of hydrate form a white dust which is difficult to retain unless some form of dust collector (p. 519) is used.

(j) A small *Bin* to receive the hydrated lime and retain it until it has been placed in bags or delivered to trucks.

(k) A means for placing the hydrated lime in *bags*. It is not necessary to use automatic appliances for this purpose, but a weighing machine should be provided so that the same weight of lime is placed in each bag.

Avoiding Carbonation.—In grinding, hydrating, and screening or separating lime it is very important to avoid all unnecessary carbonation of the product. It is, therefore, necessary to restrict the amount of air brought into contact with the lime during these various processes. This can best be effected by working in a closed circuit and utilizing the same volume of air repeatedly. If an unlimited amount of air has access to the lime, the amount of carbonate formed may reach 8 per cent. of calcium carbonate—a serious matter for some users. For the same reason, the air used in the grinding and hydrating plant should be obtained from a source as remote as possible from chimneys, kilns, or other producers of carbon dioxide and other products of combustion.

HYDRATORS

The essential portion of the plant in which the greater part of the hydration is presumed to occur is known as a *hydrator*, and various types of such appliances are in use. In comparing them it is important to remember that the hydration of lime is wholly a chemical action, *i.e.* the combination of 100 parts of calcium oxide with 33 parts of water.

In other words, it is the water and not the machine which hydrates the lime; the hydrator is merely a convenient vessel or appliance for mixing the lime and water, and for retaining the mixture at a suitable temperature until either hydration is complete or until it is sufficiently far advanced for it to be completed by simple storage in a silo or bin.

Failure to recognize the purpose and limitations of a hydrator have led to many serious losses in hydrating lime and many hydrators have been bought under the mistaken idea that they can, in some mysterious way, do what is impossible by any other means; the use of the term "hydrator" instead of "slaker" has tended to increase the mystery of their use.

The conditions which must be observed if a good hydrate is to be produced are stated on p. 494.

These conditions differ in detail with limes from different sources, and even with lime from one source. An under-, or overburned lime will slake at a different rate and to a different extent from the same lime when properly burned, and as a plant, to be commercially successful, must be capable of dealing with a variable mixture of well-, under-, and over-burned lime, containing calcined clay, silica, and other impurities in variable proportions, it is necessary for it to be provided with various adjustments.

As stated on p. 494, hydrators are of two types—batch hydrators and continuous hydrators.

BATCH HYDRATORS

Batch hydrators are those into which a definite charge of lime and water is placed ; after a pre-arranged time, in which the hydration is supposed to be completed, the hydrator is emptied and is then ready to be recharged. Batch hydrators are of chief types :

(i) A plain floor or shallow tank in which the mixing of the lime and water is effected by hand.

(ii) *Closed drums* or cylinders with rotating paddles and corresponding to the pugmills used in the clayworking industries.

(iii) *Closed Rotating Drums*, with steel balls or pebbles, corresponding to the ball mills used in other industries.

(iv) *Closed Rotating Drums* with fixed baffles, rotating paddles, or independent mixing devices.

(v) *Open Rotating Drums* corresponding to some concrete mixers. These evolve too much dust and are seldom used.

(vi) *Circular pans* provided with a series of scrapers or ploughs on rotating arms, as in the *Clyde* hydrator (figs. 117 and 118). Rollers can also be used, but are not generally needed.

The simplest form of batch hydrator, though not usually known by that name, is a solid floor on which the lime is placed, water is added from a bucket or hose, but preferably from a watering can or spray, and the mixture is turned over with a spade until the water is absorbed. After a short time the lime will begin to steam and eventually, if sufficient water has been added, it will fall to a white powder, the volume of which is two or three times that of the original lime. If a quick slaking lime is used, a great evolution of steam will occur and the combination of lime and water will be complete in five or ten minutes

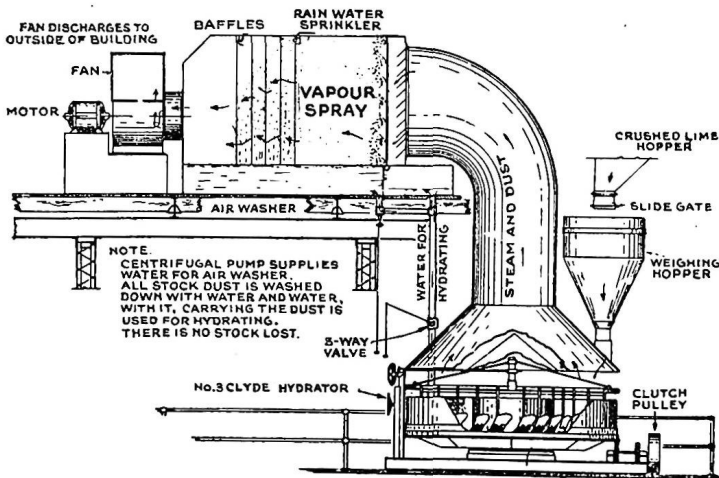


FIG. 117—SECTIONAL VIEW OF CLYDE HYDRATOR.

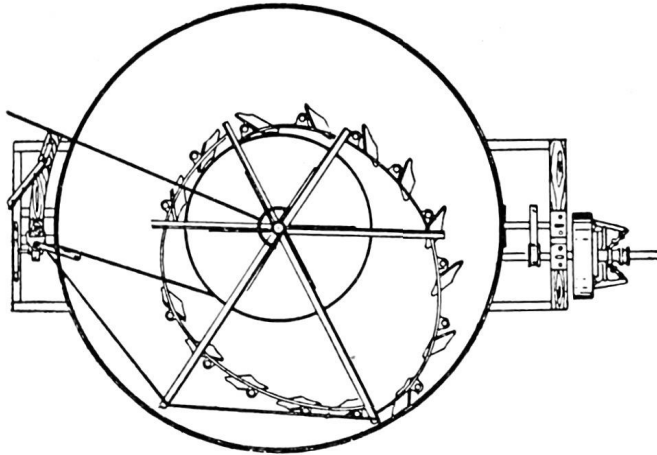


FIG. 118—PLAN OF CLYDE HYDRATOR.

according to the quantity of lime being treated and the nature of the lime. Some limes (especially those containing magnesia) will only slake very imperfectly by this method, except after prolonged contact with water, because the combination proceeds so slowly that sufficient heat is not developed to accelerate it.

Closed drums with rotating paddles are supplied by several firms but those used for hydrating lime should be capable of being readily opened for charging and should be fitted with a simple means for rapid discharge. A well-known machine of this type consists of a box, tank, or other container, fitted with paddles or their equivalent, in which the lime and water are placed and mixed by means of the rotating paddles. A hydrator of this kind, holding about 500 lb. of lime and the necessary quantity of water, is largely used for hydrating lime for the manufacture of lime-sand bricks. As made by Messrs. Herbert Alexander and Co. Ltd. (fig. 119), it consists of a rectangular trough with a

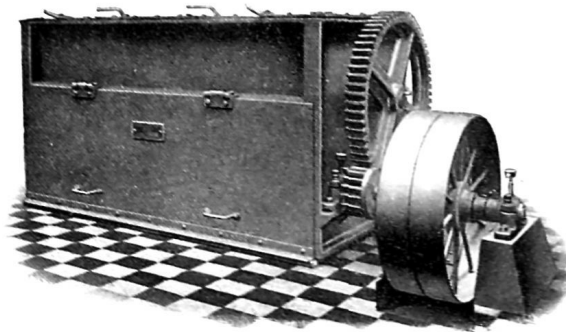


FIG. 119—LIME-HYDRATOR.
(By courtesy of Herbert Alexander and Co. Ltd.)

concave bottom and provided with a horizontal shaft bearing a number of arms or paddles of special shape which, when the shaft is rotated, will mix the lime and water very thoroughly. The trough is also provided with a stout lid or cover which can be fastened down so as to retain the steam produced by the slaking lime, and so conserve the heat to such an extent as to increase the rate of hydration. The lid does not fit so tightly that no steam escapes, but sufficiently to retain the steam under slight pressure. The shaft and blades are rotated mechanically as the work is too heavy to be done by hand. A slide at the bottom of the hydrator may be moved by means of the lever provided and the contents of the hydrator are then discharged.

In use, a suitable quantity of lime is placed in the hydrator and the water then added. After a short time steam is evolved, the lid is closed, and the shaft rotated from 10–15 minutes. The slide is then opened, and the contents discharged. The quantity of water can be varied as desired, and as the lid is not closed until vigorous steaming has commenced the man in charge has good control of the hydration. The time occupied in mixing the lime and water can be varied according to requirements, so that there is ample allowance for variations in the lime. Under ordinary conditions it is not profitable to mix the lime and water for more than 15 minutes, so that if the hydration is not complete in that time the mixture should be stored in a silo for as long as may be necessary. A very slow slaking lime may require to be made into a wet mixture, the excess of water being evaporated in the silo.

A similar hydrator with two shafts, each fitted with paddles and driven differentially (like trough mixers used in brickmaking), is largely used in the United States, under the name of Weber's hydrator. It is supplied by Arnold and Wiegel.

A *Rotating Drum with balls or pebbles* consists of a closed revolving cylinder into which a definite charge of lime is placed, and, after the drum has started revolving, the necessary amount of water or steam is introduced. The drum is rotated for 10–30 minutes (or longer if a very slow slaking lime is used), after which the drum is opened and its contents discharged. Such drums are dusty and somewhat troublesome to use; they are unnecessarily clumsy for quick slaking limes, but useful for very slow slaking ones, and though seldom employed for the production of hydrated lime for sale, they are used by firms who require this material for their own use, as in the manufacture of lime-sand bricks, bleaching powder, etc.

Concrete mixers of various kinds have also been used for hydrating lime. The open types are not very satisfactory because so much lime is lost in the form of dust, but by enclosing them this disadvantage is overcome. There is, in fact, great scope for more detailed investigation of the merits of some concrete mixers as hydrators, because the best ones are very efficient in mixing stones and water and ought to be equally so for mixing lime and water.

A *Circular pan* fitted with radial arms on a vertical shaft, each arm carrying one or more ploughs or scrapers, may be compared to an edge runner mill or mortar mill from which the runners have been removed. Either the pan or the

scrapers or both may revolve, the last named arrangement being used in the Miscampbell or Clyde hydrator (fig. 117 and 118), in which the scrapers or ploughs are placed spirally so that they sweep over every part of the pan in turn. This hydrator is provided with a large chimney stack up which the steam and dust are drawn by means of a fan, a washer being interposed to remove the dust. The water carrying this lime dust is used to slake the lime in the hydrator. In use, the pan is caused to revolve and a weighed charge of lime is introduced (the largest size will hold a ton). A measured quantity of water is then introduced through sprays and the mixing of the lime and water is continued for 10–30 minutes according to the nature of the lime. A door in the centre of the pan is then opened and the contents discharged through it by the action of the pan and ploughs. The operation can be watched continuously if desired, and the amount of water and the duration and intensity of the mixture can be varied to suit different limes.

CONTINUOUS HYDRATORS

Continuous hydrators are those which receive and deliver a continuous stream of material.

One of the earliest types of continuous hydrator consists of an almost horizontal cylindrical screen covered with gauze of No. 24- or 35-mesh and provided with sprays in its interior. The lime enters at the upper end of the screen and is slaked by the water with which it comes in contact. Some mixing is effected by the rotation of the screen, but it is not very thorough. The fine particles of hydrated lime and of unslaked lime pass through the screen and the large unslaked pieces pass out at the lower end as tailings. A considerable amount of water usually passes out with the lime and the product is scarcely saleable, but is useful for making bleaching powder and for some other purposes where only a crude hydrate is required.

A superior type of continuous hydrator consists of one or more almost horizontal cylinders provided with a longitudinal shaft fitted with paddles. As the shaft rotates, the paddles mix the lime and water and convey the mixture steadily through the hydrator and discharge it at the lower end. The cylinder may be heated with a steam jacket or by other means, and it, as well as the paddles, may be made to revolve. Several hydrators of this type have been patented; others are sold under fancy names as being far more novel than is actually the case.

When several cylinders are used in series, the lime passes through each in turn.

In the *Lauman Process* only a single cylinder with an external screw mixer is used. In other respects it is the same as one section of the Kritzer machine, but—unless of inordinate length—is not really so effective. It is, however, sufficient for limes which slake readily. If a Lauman machine were the same length as the total length of the various cylinders in the Kritzer machine, both would be equally effective as mixers, but so long a machine would be very cumbersome.

The *Schultess* hydrator (fig. 120) is of French origin, but is supplied in this country by Edgar Allen and Co. Ltd., Sheffield. It consists of a horizontal cylinder, (C), fitted with a shaft, bearing blades, which acts as a mixer and

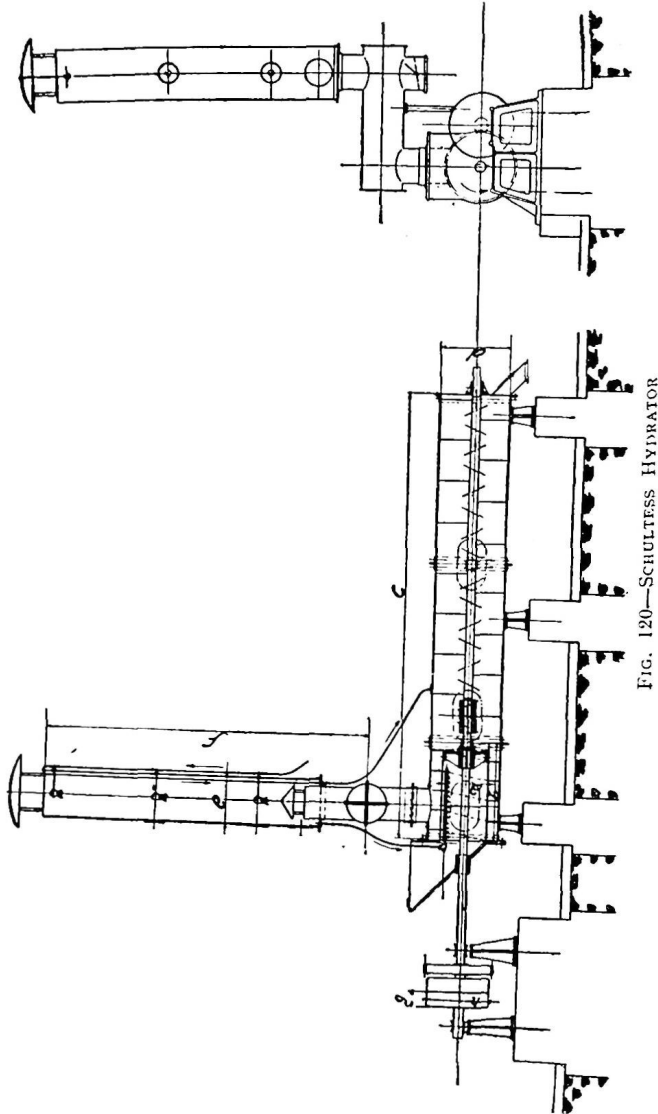


FIG. 120—SCHULTESS HYDRATOR

conveyor, and a steel stack, or condenser, (F), fitted with a water spray which collects the lime dust (which would, otherwise, escape into the atmosphere) and delivers it in the form of a slurry or "milk" to the hydrating cylinder.

The condensed steam heats the water in the condenser, so that it is delivered to the lime at a temperature of 195–205° C., and the slaking is facilitated accordingly. It is claimed that the mixing or pugging of the lime and water is unusually thorough, that the hydration is effected under exceptionally favourable conditions owing to the use of hot water, and that the product is unusually uniform.

The *Becker hydrator* (manufactured by Georg Becker and Co., Magdeburg-Sudenburg, 4, Germany) resembles the Schultess hydrator, but has five troughs (32 in. diameter) each fitted with paddles, through which the lime passes in succession and thence through a sifting drum.

The *Fusion Corporation, Ltd's* hydrator consists of a slowly rotating, almost horizontal, cylinder, about 3-ft. diameter and up to 30 ft. long, according to the time required for slaking the lime. The cylinder is provided with loose pieces of iron of X-shape which roll over the material as the cylinder rotates and ensure a very thorough mixing. The crushed lime is fed into the upper end of the cylinder by means of a jiggling conveyor and the water or steam through one or more pipes inside the cylinder and pierced with holes to form a spray. The mixture of lime and water is discharged from the lower end of the cylinder into the closed "boot" of a bucket elevator.

The *Anker* hydrator is similar, but has internal baffles or lifting plates instead of the loose members just described. In a newer form of the Anker hydrator, the cylinder is provided with a second, interior, perforated cylinder which extends about half the length of the outer one. By this means any dust and very small pieces of lime are separated in an unslaked state and travel along the outer cylinder. Meanwhile, the larger pieces are slaked with a small excess of water, and when they pass over the lower end of the inner cylinder into the outer one they become mixed with the small pieces of unslaked lime and slake the latter. This separation of small and large pieces of lime is advantageous, but its precise importance is unknown. It has a tendency to leave a little unslaked lime in the final product and this, for some purposes, is very objectionable.

Instead of the drum rotating it may be stationary, but provided with rotating blades or paddles as in the *Victory* hydrator, fig. 121, supplied by H. W. Portas,¹ which consists of an almost horizontal cylinder with an internal revolving shaft carrying a series of blades. A charge of lime and the requisite quantity of water enter the cylinder, and are mixed by the rotating blades for 10–30 min. The lower end of the cylinder is then opened, and the lime is discharged into a screw conveyor below. The steam and dust rise up a shaft connected to the upper end of the hydrator; the lime dust is retained in a dust collector.

The "*Kritzer*" hydrator, which is chiefly used in the United States (though one has been in regular use in this country since 1903), consists of four or more inclined cylinders, one above another, each being fitted with a screw-

¹ Also known as the Toepfer hydrator and supplied by W. T. Toepfer and Sons Co., Milwaukee, Wis., U.S.A.

conveyor instead of paddles. The lime is fed into the uppermost cylinder and steam and warm air rise up a steel chimney connected to the lime inlet. Water is admitted through sprays near the top of this chimney and passing downwards is heated by the steam and hot air; incidentally, this water removes most of the dust which it carries back into the hydrator. The mixture of lime and water passes down through each cylinder in turn and is eventually discharged at the bottom. Air entering through the lime outlet carries off the steam as it is

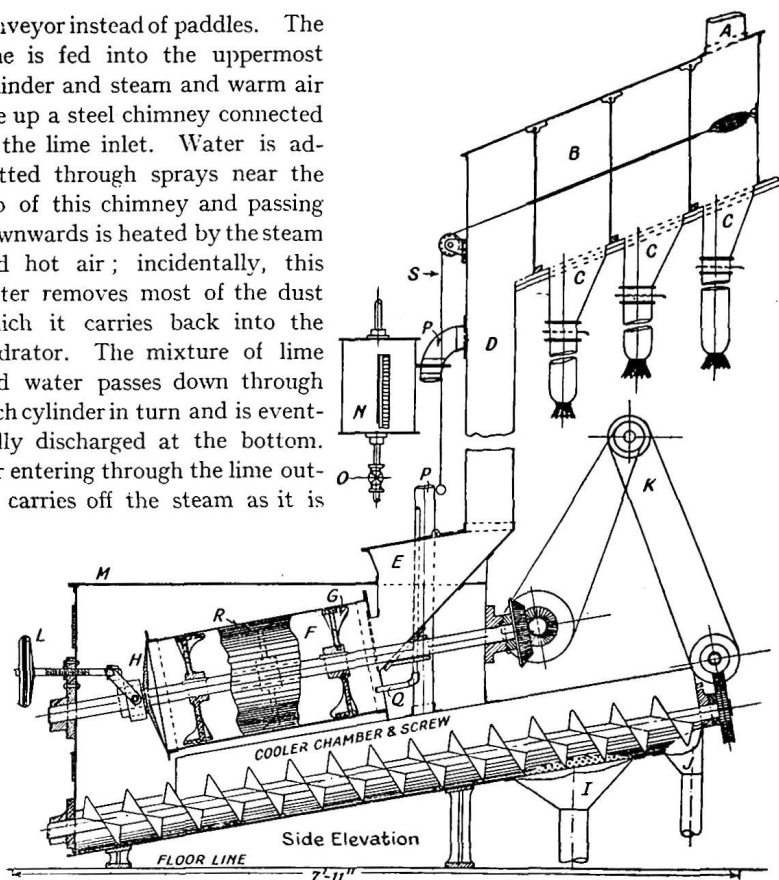


FIG. 121—"VICTORY" HYDRATOR.

generated and tends to cool the lime; this may be prevented by altering the form of lime outlet. The cylinders are not usually jacketed or heated, but could be if required. This hydrator is of such a length that a considerable time is required for the lime to pass through it; this, and the use of warm water, enables it to hydrate some comparatively slow slaking limes at a reasonable speed; others must be stored in order that hydration may be complete.

Another multiple-cylinder hydrator is that supplied by Sutcliffe, Speakman and Co. Ltd., Leigh, Lancs. It is fitted with a jacket through which steam can be passed, and the temperature of the hydrator is raised at the start and then lowered, or kept constant, as may be required. By this means, some limes, which would be imperfectly hydrated without being heated, can be slaked in 10-20 minutes. The same effect may be obtained, though to a lesser extent,

by lagging the outside of the hydrator instead of providing it with a steam-heated jacket.

The *Denchem* hydrator, patented by N. V. S. Knibbs and the Denny Chemical Engineering Co. Ltd., is of the continuous type and consists of two covered trough mixers, one above the other, each being provided with rotating blades which mix the lime and water and convey it first through one trough and then through the other. The lime is fed into the hydrator at a constant rate by means of a worm conveyor, and water enters the trough through two sprays, the first of which supplies rather less than is needed for completely hydrating the lime and the second supplies the remainder of the water. Steam is removed, and a current of air drawn through the hydrator by a chimney at the inlet end of the troughs.

The feature in which this hydrator differs from others is in the provision of a temperature-measuring device, consisting of two rods of different metals placed along the bottom of the upper mixer and extending across the short vertical pipe which connects the two mixers, so that it measures the temperature of the lime at that part of the hydrator and regulates the quantity of water supplied by the second spray, according to the temperature of the lime. This device is set so that the hydrated lime leaves the machine at a temperature of 80-100° C.

A vertical continuous hydrator, known as the *Schaffer*, is used in the United States. The lime and water fall on to a plate near the top of the hydrator, are "scrabbled" by a series of blades, dependent from a horizontal rotating arm, and eventually pass through an opening in the plate to a similar plate below. Four, six, or more of these plates, with scrapers, are placed one below the other in the hydrator, so that a thorough mixing of the lime and water occurs, and the material remains longer in this than in most hydrators. Steam and air pass upwards through the hydrator, which is about 24 ft. high, apart from the chimneys provided to carry off the steam. It resembles an ore-roasting furnace, and for some kinds of lime is very efficient, but costly. A Schaffer hydrator in Pennsylvania produces 18 tons of hydrated lime of first-class quality per hour. This is partly due to the design of the hydrator, but chiefly to the fact that the crushed lime is delivered to it in a steady stream from an automatic weighing belt, the addition of water being automatically regulated to correspond accurately with the weight of lime. By thus dealing with both water and lime in the form of a succession of innumerable small quantities, it is almost impossible to "drown" the lime by the addition of too much water, unless lime of very varying quality is supplied. The manner in which the lime and water are "scrabbled" by numerous rakes also facilitates the mixing without much risk of any lime coming into contact with too much water, as so often happens in other types of hydrator. A second water spray is provided where the lime must have the water added in two separate portions—one at the commencement of the slaking and the other later.

A further feature of importance in this hydrator is that the revolving plates are provided with rims which tend to retain the heavier, incompletely slaked

particles, whilst the lighter particles of hydrate pass over them readily. By this means the rapidly slaked material is quickly separated from that which requires a longer time and facilitates the further treatment of the latter. By means of a pressure- and temperature- regulating collar, the atmosphere in the upper part of the hydrator is saturated with steam and under slight pressure. The hydrated lime is cooled and any excess of moisture is removed by passing a current of air through the hydrator.

SEPARATING THE IMPURITIES

For many purposes it is very important that slaked or hydrated lime should be free from all unslaked particles of lime as well as from silica, burned clay, and other impurities. The most effective method of separation is by means of either a fine sieve having 25 or more holes per linear inch (p. 502) or a cyclone or air separator (p. 503). Several kinds of screens are available, but, as the operation is a dusty and unpleasant one, whichever kind is used should be totally enclosed.

In order to prevent undue loss of hydrate, the material should be passed through some form of disintegrator (p. 500) before passing to the screens or air separators.

The purification of the hydrated lime is only possible so far as the removal of coarse particles is concerned. This is sufficient for most purposes.

PRECAUTIONS WHEN USING HYDRATORS

Many lime hydrators have been regarded as unsatisfactory because the necessary precautions were not taken when purchasing or using them. As previously mentioned, a hydrator will not completely hydrate a slow slaking lime in the course of a few minutes; all that it can do is to commence the slaking under favourable conditions, and if the time required for complete hydration is longer than the material can be allowed to remain in the machine a bin or silo must be provided in which the lime can be stored until hydration is complete. Failure to observe this apparently elementary precaution is the chief cause of trouble in hydrating lime.

Almost equally important is the addition of the *water* to the lime in suitable quantity and in a beneficial manner. The water in a hydrator may be added all at once or in two or more separate portions. With some limes the former method is preferable, but other limes slake better if only sufficient water is added at first to enable a high temperature to be developed, the remaining water being then added at such a rate as to maintain a sufficiently high temperature throughout the slaking. Overheating of the lime should be avoided or slaking will be incomplete; similarly, the addition of too much water at once may prevent sufficient heat from being developed, and the result will be an imperfectly slaked lime. It is well known that if a lump of lime is given enough water to start the slaking, but not to complete it, the unslaked portion will "burn" and cannot be slaked later. Exactly what occurs to cause this "burning" is not well understood.

The total amount of water required necessarily varies with the nature of the lime and the amount of steam produced. It is always greater than that needed to combine with the lime, and, whilst no single figure can be reliable, it is well in designing a plant to provide 20 gallons of water for every 100 lb. of calcium oxide and 25 gallons for every 100 lb. of magnesium oxide in the charge, though all this may not be needed; indeed, a slow slaking lime may need only one quarter of these amounts.

When a hydrator has been in use for some time and has become warm, rather more water may be needed to slake further quantities of the lime than when the machine is cold. Hence, although an automatic device for supplying the water may seem convenient, in actual practice a skilled operator will vary the amount of water to suit the requirements of the lime and the varying conditions in the hydrator.

When a lime takes a long time before slaking starts, it is advantageous to use hot water or steam. In some hydrators, the water is heated by using it to scrub the dust-laden air and steam escaping from the hydrator, a double purpose being thereby served as the finest lime is recovered at the same time. The use of steam alone is unusual in the manufacture of hydrated lime on a large scale, but it is sometimes employed when a mixture of sand and lime is used in the manufacture of bricks, the water in the sand starting the hydration which is afterwards finished by injecting steam into the mixture. The use of steam alone tends to "turn" a pure lime, and very impure limes are not suitable for the production of a good hydrate. The use of steam under pressure to complete the hydration of a slow slaking lime to which water has previously been added is sometimes an advantage, as it reduces the time needed for storage and may enable the installation of additional silos to be avoided.

Even when water alone is used, the evolution of steam during the hydration of a quick slaking lime may create a pressure in a closed hydrator of 125–145 lb. per sq. in. This is objectionable, as the pressure ought never to exceed 110 lb. per sq. in., with such limes. A safety valve of ample size should, therefore, be provided to prevent an excessive pressure being developed. The design of some hydrators is such that no such pressure can be produced, and a safety valve is then unnecessary. A pressure gauge to indicate the pressure developed in a closed hydrator is also an advantage, and is convenient for enabling definite variations in the pressure to be produced.

Some limes develop heat so rapidly that means must be used to cool them—usually by the use of small hydrators made of steel or other material of high thermal conductivity. In at least one American works the hydrator is provided with a water jacket to avoid the overheating of the lime.

Other precautions have been mentioned on pp. 516–7.

Selecting a Hydrator.—From the foregoing pages, it will be clear that no hydrator is equally suitable for all limes, and that before one is purchased it is necessary to take certain precautions. Of these, the most important is to ascertain accurately the best conditions for hydrating the lime under consideration. This can only be found by trial on a moderately large scale; laboratory

tests will give useful information, but they should always be supplemented by the actual hydration of at least one ton of lime. Successful hydration often depends on the temperature attained by the mass of lime in the hydrator and on the time which the water takes to penetrate it completely, and these important conditions cannot be ascertained by working on a small scale. Hand slaking tests are useful, but not wholly reliable, as a lime which slakes easily on an open floor may be badly "burned" in a closed hydrator from which the steam cannot escape. Similarly, a lime which slakes very slowly by hand may do so rapidly in a suitable hydrator.

For these reasons it is desirable, wherever possible, to hydrate at least a ton of lime in a hydrator of the type it is proposed to purchase. To see a plant at work on another lime is of little use, for conditions vary so greatly that a machine which suits one firm may be useless to its neighbour or chief competitor!

If a lime varies greatly in character—and this is better ascertained by slaking twenty batches obtained on twenty different days, than by relying on the statement of the lime master or his foreman—a batch mixer will probably be the most satisfactory, but if the quality of the lime remains sufficiently constant, a continuous hydrator has several advantages. One of the most important of these is that the lime and water can be introduced in very small quantities, but in the correct proportions, whereas in a batch mixer there is always a tendency for too much water to come in contact with one part of the lime and the excess may not be uniformly distributed among the lime or hydrate as a whole; this leads to unslaked lime being included in the final product.

The value of any hydrating plant should be judged by:

(a) The quality of the product, especially as regards its fineness and freedom from unaltered lime.

(b) The cost of treatment, including a liberal allowance for depreciation of the plant.

(c) The amount of supervision necessary to obtain a high-grade product.

It is quite a mistake to suppose that any hydrating plant can work satisfactorily without some supervision, for the process is partly chemical as well as partly mechanical and, therefore, needs to be carefully controlled. If the lime is very constant in composition and the hydrating machine is a good one the amount of supervision required will be very small; with an irregular or variable lime or inefficient machinery, much supervision and testing of the product will be needed.

Some hydrators are sold with impossible claims; thus, no hydrator can completely hydrate a very slow slaking lime unless one or more silos are provided, yet it is by no means unusual to find plants in which this "impossibility" is being attempted. Again, it is almost impossible to determine the amount of free moisture in a sample of hydrated lime, yet a hydrator is sometimes sold with a guarantee that the product shall not contain more than 0.5 per cent. of free moisture!

There is a general impression that the hydration of lime is an extremely simple procedure, and a visit to a plant working under favourable conditions may confirm this ; actually, many months of careful observation and trial are sometimes needed before a satisfactory hydrate can be produced—not because of any inherent defect in the plant, but merely on account of the many factors which must be considered and the numerous adjustments to be made before the man in charge can work the plant properly. In principle, hydration is extremely simple—merely mixing lime and water—but to understand what are the best conditions for a particular lime and how to provide them is often a tedious matter.

Unless the foregoing precautions and those mentioned on p. 494 are taken, however, the satisfactory selection of a hydrator is almost impossible.

PROPERTIES OF HYDRATED LIME

Pure hydrated lime consists wholly of calcium hydroxide, a compound corresponding to the formula $\text{Ca}(\text{OH})_2$, but, commercially, the term is also applied to the product obtained from magnesian limes, so that some hydrated lime contains a considerable proportion of magnesia. When skilfully prepared, commercial hydrated lime is almost pure and should, after ignition at a red heat, yield not less than 95 per cent. of calcium oxide plus magnesian oxide and not more than 5 per cent. of carbon dioxide.

Crude hydrated lime is far from attractive and may contain large pieces of unburned stone, unslaked lime, calcined clay, coke, clinker from the fuel, a glassy slag, etc. In the commercial hydrate, these are largely absent, the separation being effected by screening or by means of an air separator. The separation is based on the assumption that the particles of hydrate are much smaller than those of the impurities, and, whilst this is broadly correct, a small proportion of the impurities in the form of particles as small as those of the hydrate may be present in it ; the proportion should be so small as to be negligible.

The *quality* of hydrated lime may be judged from the following :

(1) It should consist of a fine, white, apparently dry powder, capable, when mixed with water, of producing a smooth paste or cream.

(2) It should be quite free from caustic lime due to incomplete slaking ; otherwise, it may, later, burst the bags in which it is stored, or crack the plaster, bricks, etc., in which it is used. If caustic lime is present, the sample will expand and crack after it has been made into a paste with water and exposed to a steam-saturated atmosphere for twelve hours, whereas, in the absence of caustic lime, no cracking should occur.

(3) It should pass completely through a No. 20 standard sieve, leave not more than 5 per cent. residue on a No. 50 sieve, or more than 10 per cent. of residue on a No. 200 sieve. For some purposes, a coarser product, leaving 20

per cent. of residue on a No. 200 sieve, is not objectionable, but it is inferior to the finer hydrate.¹

(4) The sand-carrying capacity should be such that when mixed with at least four times its volume of sand and a suitable amount of water, a smooth-working plaster is produced. Poor or lean limes produce a rough mortar which spreads badly when so large a proportion of sand is used.

(5) The *fatness, plasticity, or workability* of hydrated lime cannot be rigorously tested, but a skilled plasterer can soon place a series of samples in order of merit. Mechanically hydrated lime, when mixed with water, seldom produces so plastic a putty as lump lime which has been made direct into putty. The paste or putty made with some hydrated lime does not spread so easily and it does not adhere so well to walls and ceilings as lime putty made in the old fashioned way. Several attempts have been made to explain the difference, and a statement that the product has been slightly overheated is sufficiently correct for many purposes. K. W. Ray and F. C. Mathers² have shown that the plasticity or workability of lime putty is due to the formation of colloidal lime and that the proportion of this substance is much larger in lime putty made direct from lump lime than in that made by using hydrated lime. This is fully in accordance with what would be anticipated from a knowledge of colloidal materials, for many colloidal gels are known which, if slightly overheated, cannot be made to recover their original state by any simple treatment, *i.e.* they are "irreversible gels."

This raises the whole question as to whether lime can be hydrated in such a manner so as to avoid "reversing" the gel, and, to ascertain this, more investigations will be required. Meanwhile, those engaged in the manufacture of hydrated lime should be increasingly watchful that the material does not become overheated in the process of hydration. It is far better to have a slight excess of water at first, which can be distributed uniformly through the hydrate by a few days' storage in a silo so that the final product appears to be quite dry, than it is to have a drier powder which, when wetted is devoid of plasticity.

Unfortunately, the purer the lime the more likely is it to be overheated during mechanical hydration and the less plastic will be the resulting putty unless the greatest care is taken. Limes which do not evolve much heat during slaking yield the best putty after previously being mechanically hydrated. Where a highly plastic lime putty is required, it is better to make it direct from carefully selected lump lime.

(6) Slaked lime may be raised to a temperature of 250–300° C. before it loses any water, but if heated to 530–540° C. the whole of the water is rapidly evolved and caustic lime is left. This is a good method of preparing caustic lime of very superior quality, where the cost is of minor importance.

¹ In the United States, a fineness of 99 per cent. through 300-mesh is frequently offered, but in Great Britain it is not usual to offer a finer product than one passing 95 per cent. through a 200-mesh.

² *Ind. Eng. Chem.*, 5, 475–7 (1928).

Owing to its purity and freedom from insoluble matter, hydrated lime is particularly suitable for use in many industries, and as its value is appreciated it will be used more and more in building, agriculture, and other industries where a crude and very impure lime is now often employed. The fact that hydrated lime can be mixed with water and used at once makes it invaluable to bricklayers and plasterers who must, otherwise, use a slaked lime of considerable age if "popping" and "cracking" are to be avoided.

Hydrated lime is the most convenient form in which to purchase lime which is afterwards to be mixed with water. It can be stored indefinitely in paper bags or sacks, so long as it is kept dry, it is convenient to handle, involves no trouble in use, and is in so many ways more convenient than lump lime that it should be preferred to the latter.

It should be pointed out that one reason why hydrated lime is not as extensively used in this country as it should be is that it is sold at too high a price. It ought not to be difficult to sell hydrated lime, profitably, at 10 per cent. above the price of lump lime, because, in hydrating, the weight of the pure lime is increased in the ratio of 56 : 74, *i.e.* by 33 per cent. If a firm cannot add 33 per cent. of water, separate out the coarse particles, and sell the fine product profitably for 10 per cent. more than the price per ton of lump lime, there is something wrong with the lime, the method of hydration, or the cost of the plant employed. So long as hydrated lime can only be bought at prices considerably above those asked for the lump lime from which it is prepared, it will not find such extensive use as its properties merit. In the United States, where hydrated lime is very extensively used, its price is almost identical with that of lump lime.

The properties of *hydraulic lime* are described on pp. 472-477 and p. 491.

DUST COLLECTION

An important feature of hydrating and lime grinding plants is the collection of the extremely fine dust which is produced. This is, in itself, a valuable material, but when it escapes into the atmosphere, it is an unmitigated nuisance. It is so extremely fine that its recovery is by no means easy, and its complete recovery in a dry and directly useful form is sometimes almost impossible. Ordinary cyclones are useless for the finest of this material, though they will retain about 95 per cent. of the material which is produced by hydrating lime; it is the remaining 5 per cent. which causes all the trouble.

The following are the means which have proved to be the most satisfactory, though none are free from disadvantages:

(i) A system of pipes or air ducts leading to a vertical stack with baffle plates will retain a considerable proportion of the dry dust, but may not meet the requirements of the Sanitary Authority of an Urban District or Town Council.

(ii) A system of pipes fitted with a fan which draws the air through them and delivers it into filters composed of flannel or other closely-woven material will retain practically all the dust, but the filters are troublesome and require frequent renewal. A useful form of filter, made by Musgrave and Co. Ltd.,

Belfast, consists of a light steel framework carrying a distributing bow, to the lower side of which is attached a suitable number of filter tubes. The dust laden air is blown into the distributing bow by a fan and passes down and out through the pores in the filters, the dust remaining behind and eventually falling into a receiving hopper from which it is removed periodically.

(iii) Electrical precipitation by the Lodge-Cottrell process is excellent but costly, and it is not suitable for the air discharged from hydrators, owing to the amount of steam present.

In the Austro Magnesite Co.'s plant at Radentheim, Carinthia, the Cottrell system is used to collect the fine dust. This increases the output from the kiln, but is costly, as a large motor is needed to create the draught.

(iv) Centrifugal separators are useful, but costly and do not retain all the finest particles.

(v) Scrubbers, *e.g.* a tower or shaft up which the dust-laden air is drawn whilst a series of sprays of water pass down the scrubber, will remove most of the dust if the sprays are rightly directed. Unfortunately, very fine lime dust is difficult to wet, and, consequently, a simple scrubber is not always effective. If steam is also present, as in the dust-laden air from a hydrator, the scrubber may also act as a condenser and the particles of dust then settle much more rapidly and completely. Hence, a comparatively simple set of sprays will suffice to remove the dust discharged from a hydrator, and the water, with the recovered lime, may be used for slaking more lime.

A cheap and wholly efficient collector to recover the hydrate which usually escapes as dust and deliver it in a dry state to a convenient container would be very useful, but, at present, no such device is obtainable. Hence, the dust must be recovered in a wet state, in which condition it is far less valuable.

MILK-OF-LIME

Milk-of-lime is a white milky liquid containing slaked lime in suspension and in solution. It is made by wet slaking a fat lime, as previously described, or, preferably, by mixing hydrated or dry slaked lime with a suitable proportion of water in a "blunger" or "mixer ark" provided with rotating paddles. The proportion of lime present varies from 5-50 per cent. For some purposes it is important that the whole of the lime should remain in suspension without settling; this requirement limits the proportion of lime which can be present and may affect the nature of the lime used. Thus, a chalk lime usually settles out of a "milk" much more slowly than lime made from marble. Some hydrated limes settle with extraordinary rapidity, notwithstanding the fineness of the particles.

When milk-of-lime is required, it is best to use lime which has previously been hydrated in one of the appliances just described, as such a product can be mixed with a definite quantity of water in a simple tank fitted with a mechanical

stirrer. When dry hydrated lime cannot be obtained, or when, for some other reason, it is desired to convert lump lime into milk-of-lime, a convenient device consists of a cylindrical tank fitted with a wire basket, to which is imparted an up and down movement. The requisite amount of lime is placed in the basket and the tank is filled with water. The basket is set in motion, and the lime, as it slakes, passes out into the water, only "core" and overburned lime eventually remaining in the basket.

Another method consists in slaking the lime by hand, placing it in a tank containing the requisite amount of water, and stirring it mechanically; the

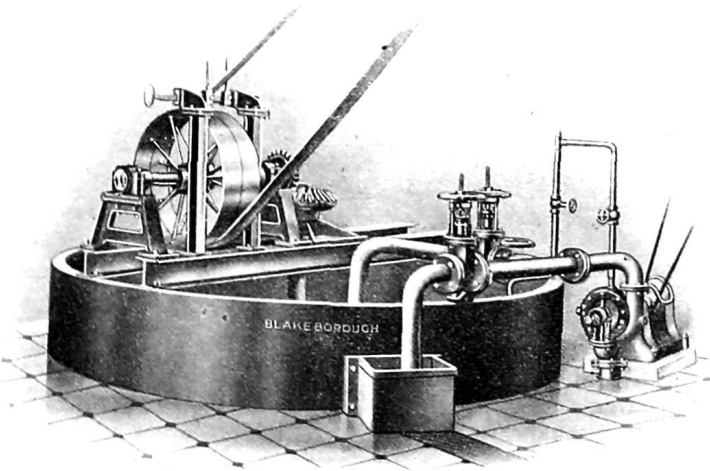


FIG. 122—LIME-MIXING MACHINE FOR MILK-OF-LIME.
(By courtesy of J. Blakeborough and Sons Ltd.)

objection to this method is the trouble involved in removing unslaked material from the tank.

A machine which is extensively used for preparing milk-of-lime for use in sewage and water softening plants is shown in fig. 122. It consists of a shallow tank, 6 ft. in diameter at the base and 3 ft. at the top, in which is a mechanically driven agitator. The lime enters the tank below water level (thus ensuring the absence of dust) and water is supplied from any convenient source, a pump being used when necessary. The milk-of-lime flows out at the same time as the water enters the mixer, about 400 gallons per hour being produced. The mixer and pump require about $2\frac{1}{2}$ h.p.

In a suitable blunger, 10 ft. diameter and 5 ft. deep, milk-of-lime may be supplied at the rate of 400 gallons per hour with a power expenditure of only 3 b.h.p. For some purposes it is essential that the temperature of the milk-of-lime should not exceed 90° F. when in use.

It is usually advantageous to place the lump lime in a perforated container or basket and to provide a conical base and valve or other means of removing the sludge which tends to accumulate when working on a large scale. The use of steam or hot water frequently increases the speed at which the lime is suspended in the water. The "milk" should be screened before use so that all particles larger than 0.01 in. (or, in some cases, 0.005 in.) diameter may be separated.

The quality of milk-of-lime depends upon (i) the proportion of calcium hydroxide in suspension and in solution; (ii) the size of the particles; and (iii) their activity.

The proportion of lime in suspension depends partly on the nature of the lime—a dense hard burned lime consisting of large particles settling out much more rapidly than a more flocculent material composed of smaller particles and made from a porous limestone and not overburned. It also depends on the purity of the lime and of the water used, the maximum amount of lime in suspension being obtained with a low hydroxyl-ion concentration. The presence of a small amount of sugar is supposed to increase the amount of lime in suspension and to delay the settling.

The manner in which the lime is slaked before being made into "milk" is also important. Thus, "milk" made from hand slaked lime settles more slowly than that made from hydrated lime. Lime slaked by means of adding an excess of water to a wet hydrate settles slowest of all. The presence of chemicals in the excess of water used in making a wet hydrate has little effect upon the settling. The presence of calcium chloride usually increases the rate of settling. If a suitable lime is used, a 10 per cent. suspension (1 lb. per gallon) is readily obtained and is very convenient in use. Much more concentrated suspensions—up to about 30 per cent.—can be employed, but are liable to be very irregular in composition. The amount of lime in suspension can be estimated from the specific gravity of the "milk"; a hydrometer is generally employed for this purpose in conjunction with the following Table. The instrument should be inserted gently and read rapidly or a low result may be obtained.

Milk-of-lime is used as a cheap alkali for neutralizing acids, causticizing soda solutions, depilating hides prior to tanning, etc., for the treatment of sewage, and as whitewash.

Tests should be made to ascertain what proportion of lime is most suitable for any particular purpose and an endeavour made to keep the proportion of lime present as close as possible to that desired.

Milk-of-Magnesia is similar to milk-of-lime and is made in a similar manner, using lightly calcined magnesia.

TABLE XLI.—*Amount of lime in Suspension*

Milk-of-lime.		Lime.
Degrees Twaddell.	Specific Gravity.	lb. per 100 gallons or grams per litre.
2	1.010	11.7
4	1.020	24.4
6	1.030	37.1
8	1.040	49.8
10	1.050	62.5
12	1.060	75.2
14	1.070	87.9
16	1.080	100.0
18	1.090	113
20	1.100	126
22	1.110	138
24	1.120	152
26	1.130	164
28	1.140	177
30	1.150	190
32	1.160	203
34	1.170	216
36	1.180	229
38	1.190	242
40	1.200	255
42	1.210	268
44	1.220	281
46	1.230	294
48	1.240	307
50	1.250	321

LIME WATER

Lime water is a saturated solution of calcium hydroxide in water. It is made by agitating slaked or hydrated lime with water and, after several hours standing, decanting off the clear solution or filtering it.¹ The cold saturated solution usually contains 1 lb. of calcium hydroxide in 70 gallons of water or 1 part in 790 parts of water. When heated, a portion of the calcium hydroxide is thrown out of solution as the solubility is less at high temperatures.

¹ In preparing lime water much more lime than will be dissolved should be used and the first solution should be rejected as it contains all the soluble salts present in the lime as impurities.

The solubility of lime in water depends on the source of the lime, so that different investigators have obtained widely divergent results. The greatest solubility (0.143 per cent.)¹ is obtained with hydrated lime which has been re-burned at a temperature only just high enough to secure complete removal of the combined water. The lowest solubility (0.074 per cent.)² is obtained with carefully-purified crystalline calcium hydroxide.

The following figures can only be regarded as approximate; they were obtained with hydrated lime made from a carefully burned, white chalk.

TABLE XLII

Temperature ° C.	Gm. of calcium hydroxide per 100 c.c. of water or lb. of hydroxide per 10 gal. of water.
15	0.130
20	0.126
30	0.116
40	0.103
50	0.095
60	0.086
70	0.074
80	0.067
90	0.063
100	0.058

Many commercial limes yield lower results because of the higher temperatures at which the lime has been burned and because of the greater density of some limes.

The solubility is greatly reduced in the presence of other hydroxides, so that caustic soda precipitates calcium hydroxide.

Ammonium chloride increases the solubility of lime in water; thus, at 25° C. the solubility is raised from 0.150 gm. of calcium hydroxide per 100 c.c. to 0.442 gm. when 0.447 gm. of ammonium chloride is present. A double salt— $2\text{NH}_4\text{Cl}\cdot\text{Ca}(\text{OH})_2$ is understood to be formed. Calcium chloride also increases the solubility of lime if 10 per cent. or more calcium chloride is present.

Salts which are acidic in nature, greatly increase the solubility of the lime; in dilute solutions of these substances an increase of temperature causes a decrease in solubility, whilst at high concentrations of salt the solubility is increased by increasing the temperature.

¹ Lamy, *Ann. Chim. Phys.*, 14, 145 (1878).

² Johnson & Grove, *J. Amer. Chem. Soc.* 53, 3976 (1931).

Organic substances, such as glycerine and cane sugar, greatly increase the solubility, especially at high temperatures.

Acids which form soluble lime salts also increase the solubility, but decompose the calcium hydroxide and render it useless.

The *amount of lime* present in lime water or milk-of-lime can be determined by titration with decinormal hydrochloric acid using phenolphthalein as an indicator, or an electrometric method¹ may be used.

Uses.—Lime water is a well-known reagent for detecting the presence of carbon dioxide in gases, though a solution of barium hydrate is often preferred because it is more sensitive. Lime water is also used as a dilute alkali for neutralizing weakly acid solutions and for preventing milk and other food stuffs from turning sour. It is also used in medicine as an anti-acid.

SODA LIME

A mixture of ground lime and caustic soda forms a granular powder with a great power of absorbing moisture and carbon dioxide. It is used in chemical laboratories and in some works for removing moisture and carbon dioxide from air and other gases.

The most effective form of soda lime is a hard, highly porous granular material containing a large percentage of caustic soda. The granules may be of three distinct sizes :

- (i) *Large* (about $\frac{1}{4}$ -in. diameter or in lumps), for industrial use.
- (ii) *Medium* ($\frac{1}{8}$ -in.— $\frac{1}{4}$ -in. diameter), for laboratory work.
- (iii) *Fine* (powder), for special laboratory work.

A soft soda lime is objectionable as the granules soon fall to powder and clog the apparatus in which they are used.

An indicator, such as sodium manganate, is sometimes added ; this changes its colour as the carbon dioxide and water are absorbed and by this means shows when a renewal of the soda lime is desirable.

LIME PUTTY

Lime putty is a soft, plastic paste made by mixing a fat lime with about three times its weight of water (see *wet slaking*) and allowing the mixture to stand until it solidifies. Except for a slight superficial film of calcium carbonate, such a putty does not readily recarbonate and may be kept for many months in the open air.

Lime putty has the advantage (if not used too soon after it has been made) of being completely slaked, whereas a dry slaked lime which is merely mixed with water and if it is used at once may contain sufficient imperfectly slaked particles to spoil a plastered surface on which it is used.

If a knife blade or hoe is pushed into a mass of lime putty and the blade, when withdrawn, is dry and clean the lime is insufficiently slaked or is very impure. If small pieces adhere to the blade the tempering is not complete

¹ *Jour. Soc. Chem. Ind.*, p. 311 (1923).

and if the paste adheres strongly to the blade the lime is rich and properly slaked.

Ageing Lime Paste.—When lime is slaked by hand it is essential to allow it to remain for a sufficiently long time to ensure the slaking being complete ; otherwise, the unslaked portion of lime may cause blisters in mortar, plaster, or stucco work. This is the reason for allowing lime putty to remain for several weeks, or even months, before it is used.

The common practice of using lime within a few hours of soaking it by hand is responsible for much defective mortar and plaster as the lime is often imperfectly slaked and so causes cracks and blisters. This can only be remedied by allowing the paste to remain a sufficient time for it to age properly, or, by mechanical methods, ensuring the complete slaking of the lime. The latter produces "hydrated lime" which can be reduced to a paste when required and used immediately.

According to Kosmann¹ a good lime putty contains 64 per cent. of a gel (calcium tetrahydrate) and 36 per cent. of a sol containing 4.57 per cent. of lime, but the proportions must differ with limes of various origins.

100 lb. of lime should yield 3–5 cb. ft. of putty according to the nature of the lime.

Uses.—Lime-putty is chiefly used for plastering walls and ceilings.

PLASTER LIME

The term plaster lime is often applied to lime suitable for making plaster, *i.e.* a mixture of lime, sand, and water applied to walls and other surfaces.

CARBIDE LIME

Carbide lime is the residue left when calcium carbide has been wetted in order to produce acetylene gas. It is a crude calcium hydroxide, with an unpleasant odour, though the latter disappears in course of time. Where the odour is not objectionable, carbide lime can be used for many of the purposes for which ordinary slaked lime is employed. Carbide lime usually contains about 50 per cent. of free water ; this must be removed before the lime is sold. During the drying most of the odour escapes. Carbide lime should not be sent by rail, so that its use is generally confined to an area near the works where it is produced.

CEMENT LIME

Cement lime is another name for hydraulic lime (p. 472).

ELECTRICALLY FUSED LIME

Lime which has been fused in an electric furnace is less sensitive to sudden changes in temperature than ordinary lime. Blocks of it are sometimes used to form a basic lining in electric furnaces. It is much more resistant to water than ordinary lime, though it does eventually slake.

¹ *Verh. Ver. Beförd. Gewerbebeiss*, V, 61–65 (1920).

VIENNA LIME

A finely-ground, soft, slaked magnesian lime of Austrian origin, at one time largely used for polishing metals, was sold in this country as Vienna Lime. At the present time, a British material of similar composition is largely used. The most suitable stone is a fine-grained dolomite, containing 21 per cent. of magnesia and 30 per cent. of lime (CaO), which must not be overburned and is supplied in the caustic state in sealed containers. For some unknown reason, hydrated dolomitic lime from other districts is considered unsatisfactory by many polishers, but this may be due to prejudice. A high calcium lime is also regarded as an unsatisfactory substitute. The essential feature is a soft powder which is mildly abrasive, but free from sharp particles. Grit-free chalk or very finely ground pumice are sometimes sold as Vienna Lime and serve the same purpose.

JEWELLERS' AND PLATERS' BUFFING LIME

Buffing lime—sometimes known as *jewellers' lime* or *platers' lime*—is used for polishing metals. For some purposes, a moderately fine *hydrated lime* is quite satisfactory, but *Vienna lime* is preferred for copper, and nickel-plated and silver-plated articles. It is usually considered that a hydrated, high-calcium lime is unsuitable for the best work, as it is "too smeary," that a lime consisting of moderately hard abrasive particles is needed and that only certain dolomitic limes are of this nature. A careful comparison of suitable and unsuitable limes under the microscope, shows that the particles in the former have sharper outlines than those of the latter, and when a suitable material is moistened slightly with water and examined immediately, it is found to contain more definitely crystalline particles of very small size. It is uncertain whether these characteristics are essential to a good buffing lime. A buffing lime largely used in the electro-plating industry in Sheffield is a highly siliceous material and appears to owe its good polishing properties as much to the minute particles of quartz as to those of lime!

ARSENICAL LIME

Arsenical Lime or Arsenate of Lime is a white powder containing a variable proportion of arsenic, but not more than 0.75 per cent. of water-soluble arsenic pentoxide. It is best prepared by slaking 5 parts by weight of a high calcium lime, previously ground to pass an 80-mesh screen, with 6 parts by weight of arsenic acid containing 75 per cent. of arsenic pentoxide and having a specific gravity of about 1.88. This contains sufficient water to hydrate the lime and provides a readily saleable bulky product containing 42 per cent. of arsenic pentoxide. Dextrin is sometimes added to increase the adhesion and lime soap (calcium stearate) to render it less affected by water.

SUPPLIERS OF MACHINERY AND APPLIANCES

As it is impossible, in the space available, to illustrate or describe every machine or other article made by different firms, the following list is printed to

facilitate further enquiries. It is not complete, because some firms may have been unintentionally omitted, nor does it mention suppliers of articles which can readily be obtained with a minimum of enquiry. The list is also limited to appliances of which the author has had personal experience.

AIR-SEPARATORS (*see* p. 194)

BAGS (*see* p. 207)

BAGGING-MACHINES (*see* p. 197)

CENTRIFUGAL SEPARATORS

Broadbents Central Iron Works, Huddersfield.

Centrifugal Separators Ltd., 8 Iddesleigh House, Caxton Street, Westminster, London, S.W.1.

Hydraulic Separating & Grading Co. Ltd., 14, Queen Victoria Street, London, E.C.4.

CYCLONES (*see* p. 194)

CRUSHERS (*see* p. 200)

DISINTEGRATORS (*see* p. 202)

DRESSING MACHINES (*see* pp. 194, 203, 207, 210)

DRUMS AND CONTAINERS (*see* p. 202)

GRINDING MILLS (*see* p. 205)

HYDRATING PLANT

Alexander, Herbert, & Co. Ltd., Charnmouth Street, Leeds.

Allen, Edgar, & Co. Ltd., Sheffield, 9

Johnson, Wm., & Sons (Leeds) Ltd., Armley, Leeds.

Mining & Industrial Equipment Ltd., Aldwych House, Aldwych, London, W.C.2.

Sutcliffe, Speakman & Co. Ltd., Leigh, Lancs.

LIME HYDRATING PLANT (*see* HYDRATING PLANT)

LIME MIXING MACHINES

Blakeborough, J., & Sons, Ltd., Brighouse, Yorks.

Boulton, Wm., Ltd., Burslem, Stoke-on-Trent.

Edwards & Jones, Ltd., Longton, Stoke-on-Trent.

SACKS (*see* p. 207)

CHAPTER XI

STORING, PACKING, AND DESPATCHING LIME

LUMP *lime* cannot be stored for long as it readily air-slakes and eventually becomes useless.

Hydrated Lime and *Hydraulic Lime* may be stored in bags or bins for an indefinite length of time, so long as it is kept dry. Slaked or hydrated lime may also be kept in large heaps in a dry place, as the air slaking does not penetrate far into the mass, but it is better not to store it longer than necessary.

Lump Lime is usually despatched in open railway trucks which are covered with tarpaulin sheeting, but closed trucks, known as "box trucks," are sometimes used. For export, and when smaller quantities than a truck load are required, lump lime is despatched in barrels, iron or steel drums, and, occasionally, in sacks or bags made of jute.

The chief objection to sending lime in open trucks is the risk of it slaking on the journey—especially if there are delays in transit. If the sheeting is carelessly applied, becomes displaced on the journey, or is not waterproof, rain may gain access to the lime and slake it, with serious risk of burning the trucks as well as damaging the lime. Closed trucks are not always water tight and incur a similar risk.

- In Germany, special closed trucks, built wholly of iron and steel, are largely used.

When motor lorries can be used cheaply, they are preferable to railway trucks, as they avoid the risk of damage which occurs in journeys occupying a long time because of delays *en route*.

Ground lime and *hydrated lime* are usually packed in bags of jute, cotton, or paper, but, for export, steel-drums or wooden barrels are often used. For inland delivery, waterproof paper bags, made specially for the purpose, are excellent; for very long journeys, bags made of jute or cotton and lined with paper are stronger, though seldom required. The cotton or jute material used for sacks should be of a close texture, so as not to allow the contents to pass through the interstices. The paper used should be tough so as to withstand rough handling.

The best paper bags are made of several sheets of paper, the ends being reinforced. They may conveniently be fitted with a self-closing valve at one corner, but bags with one open end which is closed, after filling, with a wire tie, are also used.

If second hand sacks are used, they should be carefully cleaned and precautions should be taken to ensure that they have not been previously used for any material which might affect the lime or the purposes for which it is to be used. Paper bags, being non-returnable, are preferable to those of other materials.

Bags or sacks made of jute, hessian, or cotton, usually hold 100–112 lb. of lime. Paper bags are usually made to hold 56 lbs., but those holding 112 lb. are also used.

There should be a good sale of hydrated lime in paper bags, holding 10 lb. each, for amateur gardeners and household purposes, but this trade has not been developed.

PACKING MACHINES

Ground and hydrated lime can be packed into bags by means of automatic and semi-automatic machinery. With machines designed for bags with a self-closing valve, filling is rapid and there is no need to sew or tie the bags.

When plain bags are used, it is much cheaper to tie them with wire which is twisted by means of a simple tool, than to use string or similar materials which have to be tied by hand.

WEIGHT OR MEASURE ?

As a rule, merchants quote lime by the ton, but many of the yard men do not actually weigh the material—it is merely loaded up in bags filled to the top and charged out twenty sacks to the ton. If it is small stuff, and the sacks are well filled, the merchant is likely to cheat himself ; if, on the other hand, it is mostly in fair-sized pieces, with little slack, the customer does not get his proper weight. If builders weighed their lime every time on delivery, there would be many complaints on account of the great variation.

The only correct procedure is to weigh each sack to see that it contains exactly 1 cwt. ; the merchant then *knows* that he is not cheating himself, and also that he is neither cheating his customers nor taking an unfair advantage of other merchants. He also runs no risk on claims for short delivery or of upsetting customers.

SUPPLIERS OF MACHINERY AND APPLIANCES

BAGGING MACHINES (see p. 197)

SACKS (see p. 207)

CHAPTER XII
THE USES OF LIME

THE uses of lime are so multifarious that it is essential to subdivide them into various groups. Several classifications are possible, but, commercially, the most convenient are those in which (a) the kinds of lime are mentioned in one column and the corresponding uses in another, and (b) the uses of lime are arranged according to the industries in which they are employed.

TABLE XLIII.—*Uses of Lime : According to the Kind of Lime*

Kind.	Uses.
Agricultural lime	For agricultural and horticultural purposes (p. 534).
Air slaked lime	For agricultural purposes and for neutralizing acids when a small proportion of calcium carbonate is not objectionable.
Caustic lime	For almost all uses except agricultural, though a hydrated lime is often preferable.
Chalk lime (grey)	See <i>Greystone lime</i> .
„ „ (white)	For most purposes for which a fairly pure lime can be used. It is often more bulky than other kinds and is preferred for milk of lime, some chemical uses, and for building.
Chemical lime	For the manufacture of chemicals, and, generally, for purposes for which a relatively pure calcium oxide or calcium hydroxide is required.
Clot lime	The same purposes as <i>Lump lime</i> .
Cob lime	The same purposes as <i>Lump lime</i> .
Dolomitic lime	See <i>Magnesian lime</i> .
Fat lime	For most purposes, but especially where a smooth-working paste is required. Chiefly used in building and in preparing hydrated lime.
Greystone lime	Chiefly for building purposes. It has slight hydraulic properties.
Ground lime	Chiefly for agricultural purposes, but also for hydrated lime and in some chemical and allied industries.
Hydrated lime	For all purposes where the caustic or drying action of lime is not needed and where a hydraulic lime is not required. ¹
Hydraulic lime	Chiefly in the building and construction industries as hydraulic limes have cementitious properties.

¹ Some feebly hydraulic limes are sometimes sold as hydrated lime, but this is an unfortunate use of the term.

TABLE XLIII.—*Continued*

Kind.	Uses.
Lean lime	Chiefly for building and constructional purposes, but care must be taken to select suitable lime as some lean limes are unsatisfactory. A few lean limes make good hydrated lime and are useful in some industries where a cheap base is needed.
Lime putty	Chiefly for building purposes and especially for plaster work.
Lump lime	For almost all purposes, selection being based on the kind of lime required. For many purposes hydrated is preferable to lump lime (see <i>Selected lime</i>).
Magnesian lime	Chiefly for purposes where a pure calcium lime is not essential. For many purposes the magnesia does no harm, but is inert and useless. In some industries magnesia produces salts which are objectionable.
Meagre lime	See <i>Lean lime</i> .
Mild lime	See <i>Slaked lime</i> .
Plaster lime	For plaster work in buildings. It is usually a fat lime.
Poor lime	See <i>Lean lime</i> .
Pot lime	See <i>Run of Kiln lime</i> .
Quick lime	See <i>Caustic lime</i> .
Run of Kiln lime	For purposes for which a uniform powder is not required and for many of the purposes for which <i>Lump lime</i> can be used.
Screened lime and Selected lime	For all purposes for which <i>Lump lime</i> can be used. Selected lime is a lump lime of "selected" quality. Screened lime is obtained by separating the ash and small lime from <i>Lump lime</i> or <i>Run of Kiln lime</i> .
Shell lime	For building and constructional work and for a few special purposes for which it is (probably erroneously) regarded as superior to other lime.
Slaked lime	For most of the purposes for which <i>Hydrated lime</i> can be used.
Vienna lime	For polishing metals (see p. 533).

It is important to remember that for any given purposes lime of suitable quality should be selected, as one kind of lime is not equally suitable for all purposes and when several kinds appear to be suitable one possesses properties which make it more satisfactory than others. Thus, Vienna lime is made from magnesian limestone, but the lime from other magnesian limestones is not necessarily as suitable for polishing metals as is Vienna lime.

When selecting lime for any purpose its physical as well as its chemical properties must be considered. In many cases, the physical properties are much more important than the chemical ones.

In the following pages the uses of lime are grouped under the industries in which it is employed :

1. USE OF LIME IN THE ABRASIVE AND POLISHING INDUSTRIES

Polishes are of two kinds : those which rub away the surface of the material until a smooth and polished surface is obtained, and those which cover the material with a coating which is, in itself, smooth and reflective. The former kinds of polish are abrasives ; the latter are more in the nature of varnishes and lacquers, but differ from these in several marked respects.

Polishes may be required chiefly to restore a bright surface which has become dull on exposure, and, in the case of metals, has become covered with a film of oxide which makes it tarnished. The object of the polish is to remove this tarnish, whilst at the same time removing as little of the metal as possible. This may be effected by the process known as buffing, which consists in holding the article against a rapidly rotating disc of cloth charged with a mild abrasive, such as lime or chalk ; useful as is this method for the manufacturer, it would be too strong for the owners of the finished goods, and would wear away the surface too rapidly if frequently repeated. When polishing by hand, the abrasive is applied with a piece of flannel, and is rubbed by hand onto the object to be polished, the surface being afterwards finished with a washleather (chamois leather) or (in the " trade ") by rubbing with the fleshy part of the palm, this latter being superior to any other polishing medium for giving the final polish to metals.

When polishing brass, what is known as " Sheffield lime " is generally preferred ; the name is a misnomer, as Buxton lime is used. To apply the lime a buff of walrus leather with a smear of lard oil is usually employed. When the coarser markings are removed, the work is " glossed up " with perfectly dry lime on a calico mop or dolly. A thick paste of lime and water spread thinly over the metal and brushed off with a circular brush running at a high speed is recommended for chased or milled surfaces. The surface speeds should be modified with different qualities of metal under treatment.

For most polishing and abrasive purposes dry ground quicklime is used. Its composition is unimportant, but it must be free from sharp gritty particles which would produce scratches. The smaller the percentage of silica, alumina, and iron oxide, the less is the liability to cause scratches. Lime obtained from Carboniferous or Magnesian Limestone is usually preferred on account of the

hardness and density of the particles, but all limes from these sources are not suitable. A moderately lean lime is often preferred to a fat lime, but hydraulic limes are not satisfactory.

Whiting—calcium carbonate—is used far more extensively than lime for abrasive and polishing purposes, but as slaked lime is somewhat more active chemically and usually consists of smaller particles than whiting, it is preferred for removing tarnish and for fine polishing, especially by silversmiths.

Instead of ordinary lime, some polishers prefer to use *Vienna lime* (Chapter X) either alone, or mixed with crocus or rouge. Various patents have been granted for mixtures of lime and an adhesive, such as dextrin, glue, gelatin, gum or clay. Only about 5–10 per cent. of adhesive is used; an excess will prevent the lime from having a polishing effect.

Unless hydrated lime is employed—and this is not suitable for polishing some metals on account of the smallness of its particles—all lime used for polishing must be very carefully stored, as it is absolutely useless after it has been exposed to the air for some time, on account of the fact that it absorbs carbon dioxide and falls into an impalpable powder which has no polishing power. It is best bought in fairly large pieces which are preserved in airtight tins or jars fitted with suitable covers. When some lime is required, a lump is removed from the jar, powdered by means of a pestle and mortar, and passed through a sieve of the requisite fineness (see also *Jewellers' Lime* (Chapter X)).

2. USE OF LIME IN AGRICULTURE AND HORTICULTURE

The principal uses of lime in agriculture and horticulture are: (i) to neutralize any acidity in the soil; (ii) to sterilize the soil to the extent that objectionable bacteria, etc., in it are killed; (iii) to flocculate or precipitate colloidal matter and so increase the permeability of the soil; (iv) to separate the dense particles from each other and in this way increase the permeability of the soil; (v) to accelerate the decomposition of most organic manures and their conversion into plant food and to cause retention in the soil of some of the products which would, otherwise, escape; it also causes this decay to occur in a manner which is healthy to the plants, whereas in the absence of lime, injurious putrefactive decomposition occurs, with the formation of sulphides, acids, and other matters which are poisonous to vegetation; ammonium sulphate, in the absence of lime, may have a toxic action on plants. Blood, meat, fish, and similar fertilizers all tend to produce acidity and, therefore, require sufficient lime to neutralize this tendency. (vi) to displace ammonia, potash, and other substances from their insoluble compounds, and so render them available as plant foods; lime acts differently on soils of the same chemical composition but different colloidal state, as it tends to coagulate colloids into larger particles, but has no such action on coarser particles including the silt; (vii) to destroy by a chemical or other action those objectionable forms of life which are killed by "hot" lime; (viii) as a plant food, as lime is an indispensable constituent of many plants, especially meadow clover, peas, sainfoin, and other leguminous plants. It is also required in large quantities for sugar beet, turnips, swedes,

and barley, and in smaller quantities for rye, oats, tobacco, and potatoes. In the last named, the tubers are very low in lime, but the haulms are very rich in it. Lime does not, itself, contribute more than a minute proportion of the plant food; its function is to aid the decomposition of other materials and to convert them into plant foods. Hence, lime cannot form the sole fertilizer for an indefinite period; (ix) in a rich soil, it produces increased crops by helping the crops to use rapidly the store of plant food in the soil. Lime also ensures the best utilization of soluble acid manures, such as superphosphates, dissolved bones, and sulphate of ammonia, and it prevents any detrimental results from the acid nature of these manures. In the absence of lime in the soil, "soluble phosphate" combines with iron and alumina to form compounds which are not easily available and the advantage of the soluble phosphate is lost. The repeated addition of superphosphate or "dissolved bones" (containing water-soluble phosphate) without lime tends to increase soil acidity. The continuous use of sulphate of ammonia is an important factor in depleting the lime contents of soils. When this store is exhausted, the addition of lime alone is useless. Care should be taken, however, not to add lime at the same time as ammonium sulphate, manure, or superphosphate (see *Lime and Manure*, p. 559); (x) to act as a *fungicide* in the soil and thus prevent many plant diseases, such as "finger-and toe," "club root," "anbury," etc.; (xi) to destroy the toxic properties of some soils containing soluble iron and aluminium salts, rendering them insoluble; (xii) to improve the tilth by rendering heavy, cloddy soils more crumbly, friable, lighter, and much easier to work. Only quicklime and hydrated lime possess this power, the various forms of calcium carbonate being useless for this purpose.

The neutralization of acids in the soil is essential for the growth of most crops and is by far the most important reason for adding lime. Soils tend to increase in acidity unless lime is added, and when they become sour it is almost impossible to grow some crops satisfactorily on them (see *Effect on Plants*, p. 540). It is the neutralizing power which makes it so useful in the treatment of land which has become "sewage-sick," *i.e.* which has been treated with so much sewage-sludge that it has become sour. About 2 tons of lime per acre are required for this purpose. The amount of lime which must be added to destroy the acidity in a soil and to provide for any lime required by the crops is known as the *lime requirements* of that soil. It varies from season to season and should be tested periodically (p. 550).

According to Sir E. J. Russell, a clay containing sufficient calcium in combination and a suitable proportion of free lime or calcium carbonate is the most favourable of all soils for the growth of plants, and this fact gives calcium a unique position among chemical elements in determining soil fertility.

The sterilizing effect of lime on a soil consists chiefly of: (a) an initial reduction in the number of putrefactive bacteria, with a subsequent increase in numbers and activity; (b) the partial or complete inhibition of nitrifying organisms, thus retaining the ammonia in the soil; and (c) an inhibition of the large protozoa, including "soil-pests."

The precise effect of lime in precipitating or flocculating the colloidal matter in the soil is not fully understood. It appears to convert such matter into a form in which it can better be assimilated by the plants, and, in addition, it increases the permeability of the soil, permitting access of air and water—both of which are essential to plant-growth. In this way, the addition of lime to a soil increases the amount of soluble matter (in addition to the chemical action of the lime added). This increase in soluble matter is of great value to the plants in the soil, but may cause a serious impoverishment and loss of sulphur and nitrate if the soil is leached excessively, the soluble matter being removed before the plants can use it.

If lime is added to a very light soil, it may make it too stiff, but if the soil is heavy and clayey, the lime makes it more porous, allows it to drain better, and so makes it more fertile. Apart from the quantity required, ground limestone, chalk, and marl are equally efficient as lime, as this action is largely mechanical.

Lime is of value for treating wet heavy soils, such as the yellowish grey or blue clays of the Lias and other formations of the Midlands, the heavy soils of the Mountain Limestone districts, and the Till or glacial clays of the north. With these it appears to form a calcium humate, and at the same time makes the soil crumbly and more permeable. As distinct from a heavy soil, one which is well-granulated is looser, more open, and porous, and readily permits the penetration and wide distribution of roots. Equally important is the fact that the stem of the newly germinated seed may push its way through the surface with a minimum of resistance. Lime reduces baking and crusting, ensures a better stand of plants, and enables the soil to take up and retain a larger volume of water which is more uniformly distributed through the root zone and its subsequent deliverance to the plant is better regulated so that droughts are less felt by the crop on a well limed soil.

In very permeable or sandy soil, especially those deficient in lime, which holds the humus as a gel, the alumina, iron, and humus are apt to assume the sol form and to be washed by rain to a lower stratum where they gradually form an insoluble *hard pan* which, being impermeable, often leads to swampy conditions. This breaking up of a dense, impervious soil by the admixture of lime, is a further cause of introducing more air and water to the soil and, therefore, of increased fertility.

According to Hall, "the flocculating action is really not due to the lime itself, but to the soluble calcium bicarbonate which arises from the action of water and carbonic acid upon the calcium carbonate formed from the lime."

By sweetening the soil lime also provides a congenial environment for the soil bacteria to which the fertility of the soil is due as a result of their action in converting the various food elements present into such a form that the plants can take them up. In performing these functions, the bacteria throw out a minute amount of acid, and, unless steps are taken to neutralize this acidity, their surroundings are not healthy; the organisms languish, lose efficiency, and eventually die. Lime corrects this acidity and enables the

bacteria to carry on their beneficent work. The addition of small quantities of lime or calcium carbonate has little effect until the neutral point is reached ; after this, a further addition increases the bacterial content until an optimum point is reached, after which, further additions of lime may reduce the bacterial content.

Nitrifying organisms which convert albuminoid matter into nitrates in the soil can only act satisfactorily in the presence of a base, such as lime, otherwise, ammonium nitrate is the final product and this is soon washed away. The addition of lime or calcium carbonate to a soil does not necessarily increase the amount of nitrate present, and the addition of quicklime may reduce the amount of ammonia in the soil.

The use of lime to kill objectionable creatures is the least important and is seldom applicable in agriculture, because most of the lime is slaked before it comes into intimate contact with the soil. In gardening, on the contrary, small pieces of quicklime may be dug into the soil and slake after the next shower of rain ; the heat then produced tends to destroy slugs and other objectionable creatures, but unless great care is used, it may also destroy the plants and some of the organic plant food in the soil.

For neutralizing acidity in a soil, finely ground calcium carbonate is equally as effective as lime, except that twice as much of the carbonate is required. The reason lime is so largely used is that, prior to modern methods of grinding, the only means of producing a sufficiently fine powder was to burn the stone into lime and slake the latter, either with water or by exposure to air ; the resultant product is an extremely fine powder admirably suited for agricultural purposes. If ever it were possible to grind limestone or chalk to the same fineness as slaked lime and to deliver the ground stone to the site for half the price of lime, the ground stone would be cheaper and, in many respects, equally as effective as the lime. Which of the two should be used in any given instance depends almost wholly on the cost of the material delivered on the site. As twice as much stone is required, its price must obviously not exceed half that of the lime, and as the carriage on twice the amount of stone is often a serious matter, lime is often cheaper to use. In isolated districts where fuel is costly, and cheap power for grinding stone is available, it may be cheaper to use ground stone than lime ; in other localities, where fuel is not too costly, lime may be cheaper.

Quicklime or hydrated lime is preferable on heavy clay soils, but the carbonate (limestone or chalk) is safer on light land. An excess of caustic lime begins by causing a partial sterilization of the soil and a disturbance of the micro-flora, which results in a depression of the first crop, followed by a comparatively rapid decay of the plant reserves and increased yields later though accompanied by waste of these reserves. The action of calcium carbonate, even in large excess, does not cause either the preliminary depression or the too-rapid decay and waste of the organic matter in the soil.

The chief advantages of lime over ground limestone are : (a) only 56 lb. of lime are required for every 100 lb. of stone ; (b) the lime has a flocculating

effect on the colloids of the soil which is not possessed by the stone ; (c) lime is more effective in bringing about some chemical changes ; (d) when " quick " it tends to destroy some of the undesirable organic matter in the soil ; (e) lime more readily forms insoluble compounds with any soluble and toxic iron, manganese, and aluminium compounds in the soil and, by precipitating them, renders them harmless ; (f) lime or calcium carbonate, when present in great excess (as in some *marls*), may injure some crops, but this excess is never likely to be reached in soils which require the addition of lime or show a definite " lime requirement " when tested ; (g) the addition of lime or calcium carbonate may modify the physical properties of a clay soil and make it very friable. If much more than 5 per cent. is present, the soil becomes chalky. Assuming the added matter is ploughed in to a depth of only 3 inches, and is uniformly distributed, the addition of 5 per cent. would involve adding about 30 tons of lime or ground stone per acre—an amount which is never likely to be used.

The effect of lime on various soils differs with their nature. Clayey soils of all descriptions are improved by the addition of lime.¹ Stiff clay soils become porous and ameliorated by the use of lime. Heavy tillage clay land is benefited, both chemically and mechanically, by quicklime in a fresh state, but requires large quantities, and not occasional small dressings. Siliceous land, poor in organic matter, is greatly improved, acquiring a firmer texture, greater power of absorbing moisture, and less liability to drought, but, sometimes, in addition to lime, it needs clay and organic manure.

" Lime on land without manure,
Will keep both land and farmer poor."

All arable land not over rich in lime is greatly improved by liming, as are drained marsh-lands, deep peaty soils, and rich, dry, dense, mouldy loams.

Coarse grass land and pastures overrun with rushes, bents, and other innutritious vegetation, is greatly improved by lime, the benefit being greatly increased by ploughing. Many lands which have been regarded as merely wild sheep walks have been converted into good pastures by draining and liming. If a little lime is applied to coarse grass which cattle have refused, they will eat it close down.

Fine pasture lands to be continued in grass are greatly benefited by the carbonate, but lime, in the quick or caustic state, should be used very sparingly on them.

Lime is of minor value in soils of low plasticity, such as the milder loams, but in reclaiming moors and boggy lands it is invaluable on account of its action on the colloidal gels which give such soils their objectionable properties.

In heavy clays it neutralizes any acids present, reduces the plasticity, and makes the soil more porous, and, therefore, more fertile.

¹ In *tropical countries* the lime requirements of soils are often very different from those in the temperate zones, and soils, which in a temperate climate are deficient in lime, may require acidification in a hot, humid locality.

Many tropical soils contain alkali carbonates and so effervesce with acid. Yet they need the addition of " lime "—in the form of gypsum—followed by ample leaching with water to remove the alkali sulphates produced by the gypsum.

The farmers of some parts of Derbyshire found, many years ago, that by spreading lime on the moors the heath was replaced by good clover grass.

Lime is, therefore, spread :

1. On waste land, coarse pastures or degenerated meadows, to produce finer herbage or preparatory to ploughing.

2. On arable land which is ploughed immediately after a crop has been reaped in preparation for succeeding crops.

3. On arable land when the young crops are growing ; this is dangerous unless the lime has been fully hydrated.

4. On arable land which is ploughed at the conclusion of a bare fallow, as ancillary to the addition of newly added manure, and as a means of preparing the soil for the next crop.

5. On vegetable refuse and mixed so as to form a compost which, after several months, is applied to the land.

The addition of lime to a soil :

(i) Favours the growth of clover, vetch, alfalfa and other legumes, and most other crops.

(ii) Improves the feeding value of the land.

(iii) Increases the resistance of the crops to various plant diseases and represses some disease organisms.

(iv) Sweetens any decaying material, including manure.

(v) Increases the yield of crops and tends to earlier maturity.

It must not be forgotten that lime is only one of many plant foods, and that if any of the others are missing the crops will be poor. In such a case, the addition of lime without the missing substance will do no good. Failure to recognize the application of this obvious truth has often led to very seriously erroneous conclusions as to the effect of lime. Lime greatly accelerates the conversion of manure and other organic matter in the soil into plant food. Hence, it produces better crops and it is the crops and not the lime which exhausts the soil. The exhaustion may be immediately overcome by supplying to the soil the ingredients removed by the crops.

Hydrated lime combines promptly and completely with all forms of sourness in soils to which it is applied, rendering them immediately and thoroughly sweet, and whilst it prevents some noxious acids from acting injuriously, it brings others, such as nitric acid, into new combinations of greater value as plant food. Some substances cause sourness without being definitely acid ; thus, sulphate of iron, or green vitriol, frequently exists in soil and exercises an injurious effect on almost all vegetable matter ;¹ a dressing of lime (not carbonate) will at once render it harmless.

Apart from its caustic action in destroying certain soil pests and plant reserves—the total effect of which is very doubtful, because quicklime and hydrated lime are so quickly converted into carbonate in the soil—there is no

¹ Sulphate of iron is beneficial for some fine grasses as it hinders the growth of weeds. In such cases, the use of lime may be undesirable, though a limited amount of lime or of calcium carbonate in the soil appears to be essential, even for the finest grasses.

special chemical advantage to be gained from the use of lime. It is true that hydrated lime consists of much smaller particles, which is a great advantage, but about one-third more hydrated lime than ground quicklime is required. Twice as much chalk or limestone as lime is needed, but if the cost on the land is less than half that of lime, the chalk and limestone are cheaper. Hence, the choice as to the most suitable form of lime depends very largely on the cost of a ton of "effective lime" (calcium oxide) present in a form in which it is immediately available for use.

In short, calcium carbonate and lime sweeten sour soils and open up dense and heavy ones, so that the improvement effected is, with most soils, very marked. It does not appear to stimulate the oxidation of organic matter naturally present. Free lime cannot long exist in the soil; it is soon converted into calcium carbonate.

The effect of lime on plants varies with their nature. It is sometimes said that some plants love lime whilst others are harmed by it, but scarcely any plants can do wholly without lime, though some thrive best in a more alkaline soil, whilst others require it to be as nearly neutral as possible (see p. 539).

The grain from limed land is rounder and firmer, has a clearer or whiter colour, and gives less bran and more flour than that from land deficient in lime. A non-calcareous soil manured with hydrated lime is less exposed to danger from drought than a naturally calcareous soil manured with marl.

Cereals, legumes, and sugar beet require plenty of lime, but roots and potatoes¹ need less; the two latter must be grown in soil which is not sour, but it should not contain much free lime. Tobacco and cotton plants are liable to root rot when there is much lime in the soil, but some lime is essential. The maximum of lime seems to be reached with a pH of 5.5-6 and a pH of 5.0 is usually safer.

Lettuce, beet, barley, wheat, oats, grasses, rye, peaches, apples, plums, and cherries seldom grow to perfection without lime or limestone.

Rhubarb does better without lime; tomatoes require a very little and must not have too much. Cabbages, turnips, swedes, etc., are the first to suffer from shortage of lime, and show this by the development of "finger and toe," "club root," or galls.

Whenever a turnip crop is seen to be infected with "finger and toe" or similar diseases, the land should be well dressed with 3-4 tons per acre of lime immediately the crop has been removed and as long an interval as possible should be given before taking another cruciferous crop, substituting, for example, mangolds for turnips in the next rotation; every effort should be made to destroy cruciferous weeds, like charlock; turnip-fed dung should not be applied and another dressing of finely divided quicklime should be put on for the crop preceding the sowing of the new turnip crop.

¹ For potatoes the pH of the soil should not be higher than 5.3 nor lower than 4.8, *i.e.* the soil should not be strongly alkaline.

All useful grasses are much improved by lime and so are corn and most root crops, but it is injurious to flax and hemp plants.

Lime tends to destroy and to prevent the growth of many plants of low agricultural value, such as heath, moss, and many of the worthless grasses. Hence, lime may be used to prevent the growth of moss in low lying and badly-drained land, as a sour land is essential for the rapid growth of moss and if the land is rendered neutral by the use of lime, the moss is usually killed by the more abundant growth of grasses and other plants favouring a neutral soil.

All kinds of crops do not respond to treatment of the soil with lime. Most of those which do so give the best results when the lime or calcium carbonate added makes the soil exactly neutral, though few valuable crops are harmed by an excess of calcium carbonate; too much caustic or free lime may cause harm, inducing certain effects of partial sterilization and a too rapid exhaustion of the reserves in the soil to the detriment of succeeding crops; this action does not take place if the excess of lime is in the form of carbonate, *i.e.* if carbonate is used instead of caustic lime, or if the latter has been fully aerated before being worked into the soil.

A large excess of lime—which is only likely to occur in gardens and experimental plots and in some tropical soils (p. 538) can injure lupins, spinach, onions, vines, water melons, Norwegian spruce, evergreens, rhododendrons, azaleas, and most of the *Ericacae*.

Before deciding that lime is not required it is sometimes desirable to remember that the effect of lime on grass land is often more visible in the livestock than in the yield of grass or other plants. This beneficial effect is well known to graziers and others interested in feeding animals; it is attributed to the calcium content of the herbage and to the gradual incursion of clovers which enrich the grazing both in protein and in lime.

The quality of lime. Much of the lime sold to farmers and gardeners contains a far larger proportion of carbonate than they suppose, with the result that comparisons may be very misleading. Thus, any calculations on the relative values of lime and carbonate would be vitiated if an imperfectly-burned lime were assumed to be composed almost wholly of free calcium oxide.¹

In making comparisons between the action of lime and ground limestone or chalk, it is important to know, by analysis, precisely how much free lime is present in a material. Some farmers are accustomed to buying "lime" cheaply which contains a much smaller proportion of free lime than they realize, and they may be paying very dearly for the small amount of "effective lime" actually purchased. The best way is to calculate the true cost of the "effective lime" as described later.

For this reason, limes should be bought on the basis of guaranteed content of "effective lime," *i.e.* free calcium oxide or hydroxide. Calcium carbonate, hydrated lime, and quick or caustic lime are all "effective" for neutralizing

¹ The Fertilizer and Feeding Stuffs Act, 1926 (obtainable as a pamphlet, S. R. O. No. 658, 1932, from H.M. Stationery Office, Adastral House, Kingsway, London, W.C.2) requires that all lime (other than Waste Lime) sold for agricultural purposes shall have its content of free lime declared and that it shall conform to certain tests.

acids in the soils, but are required in very different quantities to neutralize the same amount of acid. Thus, 100 lb. of pure calcium carbonate (chalk or limestone), 74 lb. of hydrated lime, and 56 lb. of pure caustic lime all contain the same weight of "effective lime," viz. 56 lb. The "effective lime" in some commercial materials is much less than this.

Some lime burners regard magnesia as equal in value to lime, but, agriculturally, this is not the case.

Magnesian lime was, in the time of Sir Humphrey Davy and for many years later, thought to be injurious to the fertility of the soil. This opinion was largely due to some unfortunate trials near Doncaster, followed by some experiments by Sir Humphrey Davy, which showed that caustic magnesia alone is injurious to soils which are low in humus. By adding peat or other source of humus the adverse action of the magnesia is destroyed. It has since been found that magnesian lime is no worse than a mixture of pure lime with any diluent, such as silica, and that the only cases where a magnesian lime has not been satisfactory are those in which no account was taken of the proportion of lime present. The true value of magnesian lime is, in fact, that of the proportion of calcium oxide present; the magnesia is useless so far as fertilizing is concerned. Thus, 100 lb. of a magnesian lime composed of 57 per cent. of calcium oxide and 43 per cent. of magnesia is only equal to 57 lb. of a pure calcium lime. Hence, apart from its low proportion of "effective lime" and the necessity of applying it only to soils containing sufficient humus, dolomitic and other magnesian limes are satisfactory. It is also known that magnesium is a definite constituent of the chlorophyll molecule, serving as the means of linkage between its essential component organic groups. Because of this fact, magnesium starvation produces etiolated plants, which cannot function normally. Hence, some magnesium compounds appear to be essential in a soil.

Very heavy dressings of magnesian lime should not be used on arable land—for medium soils 2 tons, and for heavy soils 3 tons per acre should be regarded as maximum dressings. On sour matted grass land, magnesian lime gives good results, and heavier dressings than those recommended for arable land may be used.

The **forms of lime available** for agriculture and horticulture are :

(a) *Quicklime, Cob lime, or Lump lime*—usually bought in lumps. Many farmers and gardeners, however, buy "small" lime because it is cheaper, though usually much less pure.

Such lime must be spread out on the land to air slake and fall to powder before it can be worked into the soil. It is, therefore, difficult to distribute with sufficient uniformity and, for this reason, much of the lime is wasted. When pure, this form of lime contains 100 per cent. of "effective lime," but most commercial samples contain a much smaller proportion, and some "small lime" contains only 45 per cent. of "effective lime." Cob lime costs much less per ton than ground lime, but it is more costly to spread and is, therefore, no more economical than the ground product.

Good samples of burned lime should contain 90 per cent. and upwards of calcium oxide ; incompletely burned samples may be recognized if some of the larger lumps are broken, when a hard core of unburnt limestone will be noticeable. Such incompletely burned lumps do not fall to a fine powder when the lime is slaked.

Lump quicklime must be slaked before spreading on the soil ; in this process, there is a loss in strength due to imperfect action, so that most lump limes have an effective strength of 1600–1900 lb. per ton ; small lime may be as low as 1100 lb. per ton.

(b) *Caustic lime* is a term applied to free lime or hydrated lime in any form of commercial lime. The term is often applied to lump lime, ground lime, and other forms of quicklime. In the ground form, caustic lime—except when used in such a manner as to destroy manure or vegetation—is the most economical and the most powerful part of lime. It performs all the functions of the most finely ground chalk or limestone, but excels them in being more readily diffused through the soil on account of its greater fineness and solubility ; it is more readily absorbed by plants, only about half as much caustic lime as carbonate is needed, and it neutralizes weak acids and salts, which produce sourness far more readily than the carbonate. It is much easier and cheaper to distribute because of the smaller quantity required, and its action is much quicker, especially on inert organic matter.

A distinction should be made between quicklime (either lump or ground) and hydrated lime ; the former can have a destructive action on the plant reserves in the soil, but hydrated lime is harmless.

The widely held opinion that caustic lime destroys humus and other useful plant food in the soil has been disputed by several American soil chemists¹ on the ground that the heat developed is insufficient for such destruction. These chemists maintain that the idea of a chemically destructive effect of caustic lime on organic matter is due to a confusion with the natural decay of plant and animal material. The growth of many of these small plant forms is very much increased by the presence of a reasonable amount of dissolved lime in any form. As a result of that increased growth, decay proceeds more rapidly and more organic matter is destroyed. This process occurs when either carbonate of lime, such as limestone, or caustic lime is used ; it is more rapid with finely pulverized limestone than coarse material and the destruction of the organic matter is no reflection on any form of lime, but is rather a measure of its efficiency.

Lime which crumbles to powder by the mere action of the atmospheric gases is already a mixture of hydrate and carbonate, and all slaked or crumbled lime in the soil gradually loses its alkalinity and becomes converted into the neutral carbonate. Even caustic lime, therefore, in all the ordinary circumstances of its agricultural use, acts from the very first in some degree as a carbonate and comes to have the same action as finely-pulverized chalk or limestone. Only it is in a far finer state than that obtained by the ordinary

¹ *Bulletin 21*, State Department of Agriculture of Pennsylvania.

grinding of chalk or stone and can, therefore, be distributed much more effectively through the soil.

When pure, caustic lime contains 100 per cent. of "effective lime," whereas the purest hydrated lime contains only 75 per cent. of "effective lime." Most commercial samples contain a smaller proportion. Caustic lime will decompose dung and destroy its manurial value. Caustic lime applied to potatoes will corrode the sets and cause scabs; it scorches fine herbage and damages the roots of grasses.

The effectiveness of the caustic lime depends on the form in which it is used (see *Quicklime* and *Ground Lime*).

(c) *Ground Lime*.—The same as lump lime, but reduced to powder by grinding. As lump lime will fall to powder on exposure, it seems a waste of money to pay for grinding the lime artificially, unless it is required very quickly. Ground lime, when pure, contains 100 per cent. of "effective lime," but many commercial samples contain only 60–70 per cent. or 1350–1600 lb. per ton.

Unlike the lump form, ground quicklime need not be slaked preparatory to spreading on the land; hence, its strength is not diminished so seriously before use and no allowance need be made for loss of strength through air slaking. Physically, the ground material resembles coarse meal in appearance; particles of fresh granular quicklime are roughly the size of grains of rye. In the soil, these forms take on water and are thus converted into the slaked form, after which the lime constituents function the same as though applied as slaked lime. Ground lime is particularly easy to distribute, but it tends to have too caustic an action on the soil and to destroy some of the plant foods therein.

The advantages of ground lime are that it can be applied by a mechanical distributor—thus ensuring more even distribution—and that a smaller quantity suffices than when lump lime is slaked in the field. Even when ground lime is not very finely powdered, the coarse particles, on reaching the damp soil, slake into an impalpable powder if the material is good.

The most common impurities in ground quicklime are carbonate of lime and hydrate of lime (slaked lime). The presence of these is unavoidable if there is great delay between the time when the lime left the kiln and the time the purchaser receives it, and the absorption of water may, in addition to producing slaked lime, cause the bags to burst. The presence of much sand and clay is either the result of the use of limestone of low quality or of intentional adulteration; in either case it is to the prejudice of the buyer. Purchasers should submit samples more frequently to an analyst.

Ground lime is also inclined to inflame the eyes and the tender parts of the skin of the horses used to draw the distributor, unless the day be an exceptionally calm one.

Hydrated lime and pulverized carbonate share the virtue of being easily stored and handled, and of not being objectionable to distribute, but they do not possess the caustic action of ground lime.

Inferior samples of ground lime are not easy to detect. Their inferiority is due to the exposure of the freshly burned lime during grinding and the

inclusion of small lime, unburned stone and some of the cinders, etc., from the fuel used in burning. Some of these impurities are readily determined, but it is very difficult to distinguish between a good lime which has been spoiled by improper storage and an imperfectly burned sample.

Under the provisions of the Fertilizer and Feeding Stuffs Act, 1926, the percentage of calcium oxide (CaO) in quicklime (either lump or ground) must be declared on sale.

(d) "*Seconds*" or "*Small Lime*"—The small lime remaining after the selection of the best lump lime is often available for agricultural purposes at a cheap rate, and, provided it does not contain too high a proportion of cinders, etc., it is a very useful form of quicklime. It is sometimes supplied in a sufficiently fine state to allow of its being applied with a distributor, but it is more commonly applied direct from carts, harrowed in, and the land harrowed again repeatedly after the lime has begun to slake in the soil.

(e) *Hydrated Lime*.—A fine powder, excellent in every respect for agricultural and horticultural purposes and usually much purer than either lump or ground lime, though, owing to the combined water present, it cannot contain more than 75 per cent. of "effective lime." Its extreme fineness and low cost of production more than counterbalance its apparently low lime content, and render it, in practice, the most effective form of lime for agricultural and horticultural purposes. As all the lime is hydrated, it cannot damage the soil by overheating. It is quite as easy to distribute on the land as ground lime and does not so readily burst the bags in which it is transported. In short, it has all the advantages of ground lime except a high lime content, and none of its disadvantages, and, taking all factors into consideration, hydrated lime is the most satisfactory liming material for agriculture. On account of its comparatively high price, however, it is not regarded as an economical form of lime for ordinary agricultural purposes. Hydrated or slaked lime must now be sold with a statement of its content of calcium hydroxide, $\text{Ca}(\text{OH})_2$, and the equivalent in terms of calcium oxide (CaO).

(f) *Waste Lime or By-product Lime*.—This form is not easily obtained in this country and must not be used without special precautions. Typical examples of it are the "waste lime" from paper works, the "sludge" from alkali works, and "gas lime." Many forms of waste lime consist largely of calcium carbonate, so that the term "lime" is rather a misnomer. Waste lime often contains a small percentage of substances injurious to plants, and few waste limes contain more than 60 per cent. of "effective lime."

Carbide waste lime obtained as a by-product in the manufacture of acetylene gas from calcium carbide, is chiefly in the form of slaked lime containing 30–40 per cent. of water; when dried, it usually contains the equivalent of 60 per cent. or more of calcium oxide. This form of lime, however, must be used with caution; it frequently contains impurities likely to be poisonous to plant life.

So-called waste lime from soap works, paper works, bleach works, etc., is not strictly lime, but is composed chiefly of calcium carbonate in a very fine

state of division, together with small quantities of caustic lime, caustic soda, and carbonate of soda. In the fresh condition, this waste lime contains 30–40 per cent. of water and can frequently be obtained at a nominal price. It is difficult to handle or to transport by rail, but when spread on the land it dries out rapidly and falls to a fine powder. When dried, it may contain 60–90 per cent. of calcium carbonate. Generally speaking, $2\frac{1}{2}$ –3 tons of wet, or $1\frac{3}{4}$ –2 tons of dry waste lime would be equal to 1 ton of good burned lime. Dried carbonate of lime is now sold with a statement of its content of calcium carbonate (CaCO_3) and equivalent calcium oxide (CaO).

Lime Press Cake from Beet Sugar Factories usually contains about 50 per cent. of water and roughly the same amount of carbonate of lime, equivalent to about 20–30 per cent. of calcium oxide.

Burned Sewage may contain as much as 65 per cent. of carbonate of lime when dry; it is usually in a powdery form and has been used with good results in agriculture.

Waste Tannery Lime contains sulphides that are injurious to plants and should be exposed to the air for some months before coming into contact with a growing crop. The waste lime from some tanneries may also contain arsenic, and such lime should never be used on the land.

Most forms of waste lime possess one or more of the following disadvantages:

- (1) They may contain substances injurious to plants.
- (2) They are usually obtained in a wet and sticky condition, which makes even distribution on the land very difficult.
- (3) On account of the moisture and impurities they contain, they are not worth the cost of long distance transport and can only be used economically near the works that produce them.

(4) The various forms of by-product lime vary widely in composition and effective strengths. The majority contain 350–600 lb. of lime per ton of material, so that their price must be very low to compete with lime.

Before using waste lime that has not been previously tried the farmer should obtain advice as to its suitability.

(g) *Lime rich in Magnesia* is supposed to do harm on certain soils when heavy dressings (4 tons or more per acre) are applied to arable land, because of the great length of time during which the material remains caustic after its application to the soil. It is also supposed that an excess of magnesia, even when not in a caustic state, may reduce the fertility of soils (see p. 542).

(h) *Gas lime, i.e.* waste lime from gas works, is sometimes used by farmers on account of its cheapness. Its composition is very irregular; it consists chiefly of free lime, calcium carbonate, and various calcium sulphides, only the first two being useful for agricultural purposes.

Gas lime should never be applied to growing crops; it is best spread out on stubble, and ploughed in after a few weeks' exposure. This will effect the oxidation of the sulphides and will render them harmless.

(i) *Carbonate*.—Various forms of calcium carbonate (such as ground limestone, marl, chalk, various by-products, and materials sold under special names)

are often sold as "lime";¹ many of them are quite satisfactory, but twice as much is required as if true lime were used. Some of these products contain impurities which are injurious to crops (see also p. 545).

(j) *Basic Slag* is often regarded by farmers and gardeners as being rich in lime, but its "effective lime" content is very low, being seldom more than 5 per cent. and often very much less than this. Sometimes it does not exceed 2 per cent.

The chief constituent of value is the available phosphate, which seldom exceeds 20 per cent. and may be as low as 6 per cent. ! Almost the whole of the remaining constituents (about 75–80 per cent.) are inert and are only of value in mechanically separating the particles of soil from each other, sand or other cheap inert material of equal fineness being equally suitable for this purpose. Hence, the real value of basic slag is only that of the available phosphate plus that of the "effective lime" present. Whatever success can be obtained with basic slag can, almost invariably, be obtained much more cheaply with a mixture of superphosphate and ground lime, hydrated lime, or even ground limestone in the same proportions as these substances occur in basic slag (see p. 548).

(k) *Compost*.—A mixture of organic fertilizers with lime and burned clay or other materials, of which lime or calcium carbonate is by far the most important. Composts are, in effect, artificial soils; they are also used to conceal the defects of other soils. Lime composts are made of unslaked lime with vegetable matter, such as the scourings of ditches, sediments of pools, mud, refuse mould from garden edgings, decayed rubbish of weed heaps, and so on. A good proportion is two bushels of lime² per cb. yd. of refuse and an efficient dose is 50 cb. yd. of compost to the acre. A compost should not be used for ten days after it has been made, and, during this time, it should be dug into and turned over several times to prevent it from becoming overheated.

The value of a compost varies with its composition and, most of them are deficient in phosphates, potash, and nitrogen. They form a convenient means of using up waste matter rather than as a substitute for manure.

Some "fertilizers" are really composts.

(l) *Milk-of-Lime* is commonly regarded, as too expensive for field work, but is highly advantageous (see "Lime in the Garden" p. 564).

In whatever form it is used, lime is required solely as a base, so that compounds of calcium which will not neutralize dilute acids are useless in agriculture. It is also important to use the lime in a form suitable for simple and rapid distribution on the land and for this reason ground lime and hydrated lime are in every way preferable to lump or clot lime.

It is obviously useless to buy quicklime which has to be spread on the soil

¹ A momentary excitement was caused in 1932–3 by the advertising of a mixture of chalk with a very small proportion of wood ashes as *Super-lime*, but this is only one of several instances where the term "lime" has been wrongly applied to the carbonate.

² One bushel of ground lime weighs about 62 lb.

A chaldron of lime in small lumps weighs about a ton and measures 36 bushels.

A sack of lime nominally consists of 3 bushels and weighs about 186 lb.

to aerate and become mellow when for a less total expenditure hydrated lime can be obtained which is ready for immediate distribution.

The *ideal form* in which to supply the lime requirement of the soil is in two parts, *viz.* (a) as much chalk, limestone, or other form of calcium carbonate as will neutralize any acidity and supply the needed carbonate, and (b) just sufficient caustic or hydrated lime to effect any necessary sterilization and destruction of soil pests. The proportion of caustic lime in such a mixture will usually be very small; an excess of quicklime must be avoided, but hydrated lime is quite harmless. The quicklime destroys so much plant food as to require two years or more for the soil to recover its loss. In many localities the cost of hydrated lime, actually on the land, may be no more than that of the equivalent amount of carbonate (p. 542). In such a case, hydrated lime should be exclusively used.

The advantages of such a mixture as that of hydrated lime and finely-ground limestone or chalk do not appear to have received the attention they deserve. In such a mixture, the free lime exercises the limited chemical action required, whilst the chalk or ground limestone provides the diluting or opening agent which separates the clay particles from each other.

Basic slag has been largely used for this purpose. Its small proportion of free lime exercises a mild chemical action, as just described (though very feeble as the percentage is so small), whilst the ground slag acts as an opening agent. Basic slag is, however, far more expensive in relation to the amount required per acre of soil than the mixture just mentioned.

Not all "limes" are suitable for agricultural and horticultural purposes, and a distinction should be drawn between the white fat limes made from the White Chalk, the Mountain Limestone and other comparatively pure deposits of calcium carbonate, and the thin or lean Greystone and Lias Limes made from less pure and more argillaceous limestones. The fat limes are the purer, slake readily, and swell considerably in the act, forming afterwards a bulky white powder; the poor or thin limes slake with comparative difficulty and do not increase much in bulk. The latter partake of the nature of a cement, setting after admixture with water. Naturally, the fat limes are preferable from an agricultural point of view, both for their purity and the finer condition into which they fall, and should always be preferred by farmers and gardeners when fat and lean limes are equally available at equal or almost equal prices.

The **effectiveness** of the various forms of lime for agricultural and horticultural purposes depends on the percentage of "effective lime" present (p. 542), and on the fineness of the particles.

The *fineness* of the lime may be determined after slaking and mixing with about ten times the weight of water. Any residue left on a sieve with 100 holes per running inch should be regarded as useless by the farmer or gardener as it will not be available in the soil for ten years or more! The extreme fineness of hydrated lime makes it specially valuable for agricultural and horticultural purposes, and as it is usually purer than lump or ground lime owing to the underburned stone or core having been removed after hydration,

it is often profitable to use it even when its price is slightly higher than that of other lime.

Indications of the Need of Lime in soil are shown by the presence of the following plants: bracken, foxglove, gorse, ling, spurrey,¹ moss, sheep's sorrel, corn marigold (bozzel), potatoes with "scab," and turnips with "finger and toe" disease. A sparsity or absence of clover among grass, and the failure of a bean crop are also signs of insufficient lime in the soil.

In *Grassland*, the gradual accumulation of a "skin" or "mat" of undecayed vegetable matter on the surface is one of the most easily recognized and surest signs of want of lime. Such "mats" are usually accompanied by a poor "wiry" type of herbage consisting largely of bent grass, and containing sorrel-dock or sour dock (*Rumex acetosa*), sheep's sorrel (*Rumex acetosella*), heath bedstraw (*Galium saxatile*), tormentil (*Potentilla tormentilla*), and other moorland plants, such as bracken, ling, bilberry, etc. Deficiency in lime usually results in the absence of clover and sometimes in a total disappearance of the herbage in patches (particularly in smoky districts).

In *Arable land*, most cultivated crops—exceptions being oats, potatoes, and rye—are intolerant of sour soils. Clover, barley, turnips, and swedes are all unreliable on sour soils; they "go off" usually at a fairly early stage in their growth, almost invariably in patches, and are less capable of withstanding drought, insect attacks, and diseases, none of which can be so easily controlled as can soil sourness. A weak crop is always accompanied by an influx of weeds and the presence of spurrey (*Spergula arvensis*), sheep's sorrel (*Rumex acetosella*) or corn marigold (*Chrysanthemum segetum*) which are some of the best indications of want of lime.

Indication of the need of lime is the occurrence of "finger and toe" or "club root" in turnips, swedes, and other cruciferous crops.

A soil of excessive stickiness with a tendency to set hard, and difficulty to obtain a tilth is often an indication of the lack of that reserve of lime so necessary to heavy soils.

In *Ploughed-out Grassland*, a high proportion of the failures of arable crops, is attributable to want of lime. The presence of a considerable quantity of old undecayed turf after two or three years' cultivation is a good indication that the soil is sour; frequently, sheep's sorrel and spurrey become fairly common during the second or third year after breaking up the grass, and, on such soils, barley, turnips, swedes and wheat are so unreliable, unless lime is applied, that they often die away completely during the early stages of their growth.

Land of nice texture on which repeated failures of crops have been experienced should not be allowed to degenerate to a poor type of grassland before it has been definitely ascertained that the failures are not merely due to want of lime.

¹ Spurrey (*Spergula arvensis*) is known under a variety of local names, such as: Dother, perry, louse-grass, yarr, land-iron, beggar-weed, sand-weed, and toad-pike. It is an annual, and although the first essential step in its eradication is to apply lime in order still further to reduce its chances in competition with cultivated crops, the late sowing of spring crops on land infested with the weed should be avoided.

These readily observable indications give little idea of the amount of lime required, nor the form in which it can most advantageously be added; they should, therefore, be supplemented by various tests of the "lime requirement" of each soil under consideration.

The Lime Requirement of a soil is a term used to indicate how much lime should be added to produce the maximum fertility. This amount varies from time to time and must, therefore, be determined by tests or by actual trials following observations of the growth of such acid-sensitive crops as red clover or alfalfa.

Many attempts have been made to determine the amount of lime or calcium carbonate required to bring a sour or unsaturated soil into a fertile state, but no wholly satisfactory method has yet been devised owing to the "buffer actions" which occur. For reasons which need not be stated here, it is impossible to determine whether a soil is really acid or not by its reaction to litmus paper, because clay and finely divided silica in a soil can, under the prolonged action of water, develop an acidity to which litmus is insensitive though it can be revealed by other means. When, however, the filtered extract from a soil turns blue litmus red, the soil may be regarded as acid. Many soils which fail to give a definite acid indication are in need of lime.

Five general methods are in use in determining whether lime must be applied to secure a given reaction in an acid soil. These are:

1. Determination of the lime absorbing capacity of the soil to the point of alkalinity as shown by a suitable indicator (Veitch).
2. Determination of the concentration of the hydrogen ions (pH value) in the soil solution by colorimetric or electrometric means.
3. Measuring the amount of titratable acid which can be liberated by treating the soil with some soluble neutral salt, such as potassium nitrate or chloride (Hopkins), calcium acetate (Jones), or calcium carbonate (Tacke, Hutchinson and McLennan).
4. Measuring the amount of iron or aluminium which can be replaced in the soil by the use of some soluble salt, such as potassium thiocyanate (Comber, Emerson).
5. Indirect methods, such as Truog's.

The first method gives a point of equilibrium at which hydrolysis will yield a solution which is alkaline. Experimental study, unfortunately, has shown that the amount of lime water necessary to produce a change in the colour of the indicator varies considerably, depending upon the conditions as to evaporation and length of standing of evaporated soil and lime water residues, as well as upon the length of time involved after the treated soil, taken up in water, is allowed to stand in contact with the water before the supernatant liquid is tested. Furthermore, the method is tedious.

The second method permits of determining the acidity of the soil solution, but gives no indication of the capacity of the highly buffered soil to renew the hydrogen ions as they are removed from action by a neutralizing agent.

The upper limit of soil reaction lies at about pH 9; with a higher value, alkalis prove to be in excess and must be removed by treatment with gypsum, followed by thorough leaching with water.

The following plants prefer *slightly alkaline reaction*, i.e. pH rather greater than 7 : grain crops, oil seeds, hemp, jute, cotton, agaves, vines.

The following require a *neutral soil* : maize, millet, sugar beet, tubers and roots, tobacco, coconut palm, coffee, cocoa tree, fruit tree.

A *faintly acid reaction* (just below pH7) is favoured by oil palms and by tea ; these plants may require the addition of lime to the soil to neutralize an excess of acidity or of gypsum to remove alkalis.

The third method is fairly satisfactory from a laboratory point of view, but measures a factor which indicates the condition as to acidity of the soil rather than the solid factor itself, since, in reality, such a method is very largely a measure of the replacement of iron and aluminium in the soil.

The fourth method is the same in principle as the third except that only the iron (or the aluminium) is considered and the principle is colorimetric rather than volumetric.

Further details of these methods are given below :

1. *Veitch's method*, which consists in adding varying amounts of $\frac{N}{28}$ CaO solution and determining which just neutralizes the soil. To 10g. of air dry soil in a 250 c.c. Erlenmeyer flask are added 50 c.c. CO₂-free water and 2, 5, 10, 20 or 30 c.c. $\frac{N}{28}$ CaO solution respectively. The solution is dried down at once on a steam bath, and to the dry soil are added 100 c.c. CO₂-free water, the stopper inserted and the flask thoroughly shaken, and then placed in an inclined position overnight. 50 c.c. of the clear solution are drawn off, a few drops of phenolphthalein added, and the mixture is boiled until a colour develops. The smallest amount of lime water which gives the characteristic pink colour is taken as the amount of lime required.

The procedure, including time of drying, must be constant in all the tests. As 1 c.c. $\frac{N}{28}$ CaO equals 0.001 g. CaO, and 1 acre of air dry soil to a depth of 6 $\frac{3}{8}$ in. weighs 2,000,000 lb. or 907,184,800 g., so 1 c.c. $\frac{N}{28}$ CaO represents a lime requirement of 800 lb. of lime per acre, using 10g. of soil.

2. *Hopkin's method* (using potassium nitrate). To 100 g. of soil in a 500 c.c. flask, are added 250 c.c. $\frac{N}{1}$ KNO₃ and shaken constantly for 3 hours. The mixture is allowed to stand overnight, 125 c.c. drawn off, boiled for 10 min. to expel CO₂, and the liberated acid titrated with $\frac{N}{25}$ NaOH, using phenolphthalein as indicator. The treatment of the sample is repeated with more KNO₃ until no more acid is liberated, and the sum of all the titrations is found.

1 c.c. of $\frac{N}{25}$ NaOH = 0.00112 g. CaO
or 5 lb. of lime per acre 6 $\frac{3}{8}$ in. deep,
when using 100 g. of soil.

3. *Jones' method* is the same as Hopkins' method, but uses calcium acetate instead of potassium nitrate and so gives a slightly different result.

4. *Truog's method* assumes that soil acids liberate H_2S from zinc sulphide, and compares the discoloration of lead paper produced by a soil and various standard solutions.

A neutral suspension of 5 g. of zinc sulphate and 50 g. of calcium chloride in 250 c.c. of water is required.

10 g. of the air dry soil are placed in a 250 c.c. flask, and 5 c.c. of the solution and 100 c.c. of distilled water are added. The mixture is shaken thoroughly, brought slowly to the boil (in 4–5 min.), and boiled for 1 min. A strip of filter paper, moistened with a 10 per cent. solution of lead acetate, is then placed over the mouth of the flask and the boiling continued for 2 min. The colour produced is compared with a chart, or with a series of papers produced by soils containing a known amount of humic or other soil acid.

5. *Tacke's method* is slow, but avoids the objections to boiling. 20g. of air dry soil are placed in a 300 c.c. Kjeldahl flask, together with 2 g. or more of finely ground calcium carbonate and 100 c.c. of CO_2 -free water. The mixture is aerated slowly for 5 hours, shaken constantly, and the evolved CO_2 absorbed in 50 c.c. $\frac{N}{5}$ NaOH, diluted to 100 c.c. Later, the CO_2 absorbed is determined by titration.

The CO_2 liberated is equivalent to the acidity of the soil, and, therefore, to the lime requirement.

6. *Emerson's method* resembles Comber's method. It requires two solutions :

Solution 1.—Ether saturated with neutral ammonium molybdate.

Solution 2.—10 g. of potassium thiocyanate in 900 c.c. of acetone and 100 c.c. of ether (kept in a dark place).

A glass test tube is filled one-quarter full of soil, 10–20 drops of Solution 1 are added, the tube half-filled with Solution 2, corked, and shaken vigorously for 30 sec. On allowing to stand, the soil will settle in 45 sec. The red colour is compared with standards or with a chart. If the soil is dry, Solution 1 is not needed.

7. *Hutchinson and McLennan's method*¹—10 or 20 g. of the soil are placed in a 500–1000 c.c. bottle with 200–300 c.c. of a $\frac{N}{50}$ solution of calcium bicarbonate, and the air in the bottle is displaced by carbon dioxide. The bottle is shaken continuously for 3 hours, after which the liquid is filtered, and a portion equal to half the total liquid is titrated with $\frac{N}{10}$ acid, using methyl orange as indicator. The difference between the alkalinity of the final liquid and that of an equal amount of the original solution represents the weight of calcium carbonate absorbed by the soil, each 1 c.c. of $\frac{N}{10}$ acid being equal to 0.005 g. of calcium carbonate (1,000 lb. of calcium carbonate or 560 lb. of lime per acre of soil 6 $\frac{3}{4}$ -in. deep).

¹ *Jour. Agri. Sci.*, VII, 75–105 (1915).

All these methods only determine the amount of lime or calcium carbonate required to neutralize the actual acid in the soil. The addition of a further amount of lime to sterilize the soil is often necessary, but it is almost impossible to determine it by actual tests.

8. *Colorimetric method.*—The amount of lime needed to make the soil neutral to a sensitive indicator or to bring it to a certain hydrogen-ion concentration (pH value) is determined. British Drug Houses, Ltd., supply a "Soil Testing Outfit" for use with this method.

9. *Electrometric Methods.*—Much more elaborate appliances are required for determining the electrical conductivity and, from it, the hydrogen-ion concentration. A detailed description cannot be included here, for lack of space, but as electrometric results are usually reported in terms of Sorensen's unit or pH value, Table XLIV (due to Barnes) is useful :

TABLE XLIV— pH Value below which Growth of the Following Crops should not be attempted.

pH Value.	Crops.
6.5	{ Alfalfa Sweet Clover
6.0	{ Cabbage Cauliflower Lettuce Spinach Barley Sugar Beets
5.5	{ Red Clover Corn Wheat Cantaloups Timothy Canada field-peas Kentucky bluegrass
5.0	{ Oats Soy beans Cow peas Potatoes Tobacco Red top Canada bluegrass Alsike clover Mammoth clover
4.5	{ Strawberries Water Melons Buckwheat Rye

Spurway has suggested the following lime requirements for soils of various pH values:

TABLE XLV—*Lime requirements of Soils*

pH Range.	Tons of Limestone per Acre.	Tons of Lime per Acre.
Above 7.0	none	none
6.8-7.0	none	none
6.2-6.7	0-1.5	0-0.8
5.7-6.1	1.5-2	0.8-1.1
5.0-5.6	2-2.5	1.1-1.4
4.9 and below	2.5-3	1.4-1.7

It is usually better to have the soil tested by an analytical chemist than to attempt such tests in an amateurish manner as, in the latter case, they may be misleading.

As the different methods of testing are by no means perfect, agriculturists tend to neglect tests and to put as much lime on the soil as they feel they can afford. There is little or no harm in this because a slight excess of lime can seldom do harm and it is nearly always best to add it, especially as, in a clay soil, more lime may be needed than will suffice to neutralize the free acid present, in order to secure complete replacement of the sodium in the clay and to flocculate the colloidal clay.

Although an excess of highly caustic lime in a soil is a cause of *over liming* which, if followed by severe cropping, may exhaust the land very rapidly, this defect seldom arises and the risk is almost wholly avoided by using hydrated lime or a mixture of calcium carbonate with a small proportion of free lime as, suggested on p. 548. In most cases where overliming appears to have occurred the fault is not due to the lime, but to over cropping. The damage, where mild lime has been accused of exhausting the soil, will be found on further investigation to have been caused by the lack of organic manure (causing excessive cropping with no replacement of plant food) and not to the lime itself. Even the thinnest and poorest sandy soils, notwithstanding an excess of lime, will yield good crops if properly rotated and supplied with organic manure.

It is not generally realized that a soil may be calcareous (*e.g.* a highly chalky soil) and still need lime, because the chalk is unable to attack the colloidal organic matter and render the soil more fertile. Such a soil is greatly improved by the addition of hydrated lime; ground lime can be used, but it is liable to destroy much of the plant food present. As the fineness of the lime also affects the amount required, it will be found to be more profitable to buy hydrated or finely ground lime than lump, unless the lump lime is actually slaked and then sieved by the purchaser.

The effect of liming is not always to be seen in the first crop, but on soils deficient in lime it will increase the average crop production by 10 per cent. and on clay soils it will reduce the draught of implements by 10 per cent. to 20 per cent.

The Quantity of Lime to be added may be determined by tests, as suggested, but it is more usual to decide it empirically. The average "good" soil in Great Britain contains almost exactly 1 per cent. of lime whereas "poor" soils contain less than half this amount. Any soil can be made more fertile by adding sufficient lime to increase the lime-content to 1.0 per cent., but other substances, such as potash, ammonia, and phosphates, may also require to be added. As stated above, there is no necessary relation between the percentage of calcium in a soil and the amount of lime which should be added to increase its fertility.

When the need for lime is not great, the addition of 400 lb. of "effective lime" per acre should suffice for five years and, in well-cultivated gardens, small dressings of 10-20 cwt. of "effective lime" per acre are sufficient to maintain sweetness in an ordinary soil. Sour soils require much larger quantities, and in many localities where liming has long been neglected, 1-4 tons of lime will be required per acre as so much of the lime is not sufficiently well distributed to be fully used. On rough moorland, 2 tons per acre will usually be required for the first dressing. If the lime actually used contains less than 100 per cent. of "effective lime," a correspondingly larger quantity of it must be used so as to secure the addition of the equivalent amount of "effective lime." Thus, if a "small lime" or "waste lime" is used with an "effective lime" content of only 50 per cent., 2-4 tons of it may be required per acre.

As no less than 8 tons of pure lump lime is needed to add 1 per cent. of "effective lime" to a stratum of 6 inches athwart a single acre, or 24 tons to impart 2 per cent. of "effective lime" to a stratum of 9 inches extended over one acre, there is little likelihood of too much lime being added. On the other hand, to add too little may be scarcely worth while and it is, therefore, better to add at least sufficient lime to make the soil neutral. The determination of how much is required to ensure neutrality is a matter of testing (p. 550).

The Duration of the Lime, *i.e.* the length of time during which its effect on the soil continues, is as long as unused lime remains, but, in course of time, most of the lime is removed in solution or as part of the structure of the plants, so that fresh supplies are required from time to time. A period of twenty years appears to be the longest in which the beneficial effect of a single dressing with lime can be obtained, but five years is a much more usual limit, and full dressings every five years, or smaller and more frequent dressings are, therefore, desirable.

With a soil seriously deficient in lime, an adequate application results in a marked improvement over a long period, and, if followed by regular applications at suitable intervals, brings about a permanent improvement in the fertility of the soil. Light soils lose their lime and become sour more quickly than heavy soils; and, therefore, for the former, small dressings at frequent intervals are less wasteful than heavier dressings at less frequent intervals.

Under ordinary cultivation and provided the soil is reasonably healthy to start with, an application of 10 cwt. of quicklime or 1 ton of carbonate of lime per acre may be expected to last about one rotation (four or five years).

The great advantage of liming regularly is that the fertility of the soil is maintained without a check. A soil with a satisfactory supply of lime is much more reliable than a sour soil during a bad season, or during critical times in an average season.

If a soil is sour, a single application of lime in sufficient quantity to render it neutral will result in a marked improvement, and the amounts required in subsequent dressings will only be those needed to sterilize objectionable organisms, to replace lime lost by solution or removed in the crops, and that required to maintain neutrality. Subsequent dressings of 2 cwt. of "effective lime" per acre may be made each year, or 10 cwt. once every four or five years; these should be ample unless the loss of lime is unusually great or there is some abnormal cause of sourness.

Even under the best conditions, there is a constant loss of lime in the soil, because it is an essential plant food and so enters into the composition of all crops, and the removal of these, either directly or indirectly, through the agency of stock, leads to a depletion of the soil's reserves. This loss is, however, small in comparison with losses from other causes. Rain water and soil water are charged with carbonic acid gas which gradually converts the lime into carbonate, and this, in turn, into bicarbonate; the latter is soluble in water and so is gradually carried down below the soil and lost; as farmers say, "the lime sinks into the land." From this cause alone, the annual loss of lime may range from 3 to 5 cwt. of "effective lime" per acre.

Another cause of the loss of lime is the addition of fertilizers which form soluble compounds with it. Thus, when ammonium sulphate or potassium or sodium sulphate is added to a soil (in the form of a fertilizer) calcium sulphate is formed and is gradually washed away. Hence, the result of continued applications of sulphates in fertilizers is to deprive the soil of lime and this can only be avoided by continued applications of lime or finely ground calcium carbonate.

Hence, most soils need fresh treatment with lime every few years and some much more frequently.

For various reasons, much of the soil in the British Isles is, at present, very deficient in lime, and although warnings of the serious effect of neglecting to lime the land have been given by the Ministry of Agriculture, which has pointed out that most of the agricultural land throughout the country is in urgent need of lime to bring it up to its highest productive capacity, sufficient attention is still lacking. It is a fact that the soil has been so much neglected by British farmers during the past 50 years that much of the land is making very uneconomical use of the labour and manures put into it, and in various parts of the country there is evidence on almost every type of soil that a return to the practice of regular liming is essential if the fertility of the soil is to be maintained.

The Restorative Power of Lime is often hampered because of the absence of essential plant foods from a soil. Thus, a *worn out soil*, which has been depleted of its original fertility by constant cropping and will no longer produce crops at a profit without fertilization, may have become acid and will then require lime as the first step in its improvement. Lime alone, however, can *never* restore that soil to its original state of fertility. Usually, compounds of nitrogen and phosphorus, and sometimes potassium, must also be added—the nitrogen either through legumés or fertilizers and the phosphorus and potassium in the form of fertilizers. In this connection, lime is not considered to be a fertilizer in the same way as is rock phosphate, for example, but rather as a soil neutralizer. On the other hand, commercial fertilizers which contain no “effective lime” cannot be used to correct acidity.

Whatever is found to be lacking in a soil must be added to it if the best results are to be obtained, and it must be understood that lime alone is not a panacea for all soil ailments, as people are sometimes led to believe. For example, marsh soils are generally deficient in potash, and only a potassium fertilizer can supply this necessary element. Similarly, soils which show, by field and pot tests, a lack of phosphorus, should be treated with phosphorus fertilizers as well as with lime.

Many soils require the addition of nitrates or ammonium compounds; for information on these and other fertilizers, the reader should refer to books or journals on agriculture or to the Official Agricultural Advisors appointed by the Government.

The cost of liming when using different kinds of lime should always be determined, all the following items being taken into account :

- (i) The initial cost of the lime delivered at the station.
- (ii) Cost of cartage from station (or works) to the land.
- (iii) Cost of bags (if any).
- (iv) Cost of distribution on the land.

These costs must be calculated on the weight of “effective lime” as shown by analysis, and not on the total weight of material. This is done by multiplying the total cost by 100 and dividing by the percentage of “effective lime.”

Supposing two limes are available : A, costing 28s. per ton and containing 70 per cent. of “effective lime,” and B, costing 20s. per ton and containing only 55 per cent. of “effective lime,” and the cost of carriage and cartage onto the land is 16s. per ton, then Lime A will cost 44s. per ton of actual weight onto the land, but 62s. 10d. per ton of “effective lime,” and Lime B will cost 36s. per ton of actual weight onto the land, but 65s. 5½d. per ton of “effective lime.”

Hence, although the price of Lime B is 8s. less per ton than Lime A, the latter is actually the cheaper in use.

The Modes of Application of the lime depend on the form in which it

is used, on the nature of the soil, and on the extent to which the farmer or gardener is prepared to ensure a thorough mixing of lime and soil. A gardener can produce a much better mixture because he works on a much smaller scale, but a farmer must usually be content with a rough method, which is necessarily incomplete.

The method usually adopted by farmers consists in placing the lime in *heaps* at regular intervals on the land, allowing it to slake by exposure and then spreading it roughly on the ground with a shovel. It is afterwards worked into the soil by means of a plough or harrow, the latter being usually preferred as the plough tends to bury the lime too deeply. It is quite useless to plough in lumps of lime, as these remain for years in an undecomposed state in the soil.

The best means of securing the full value of the lime is to slake it by watering—by pouring water on the heaps about a week before the lime is to be spread about the land.

In this method, very large quantities of lime are applied at comparatively long intervals, *e.g.* 100–150 bushels per acre (2–4 tons) every eight or ten years, or an initial dressing of 100 bushels with a further dressing of 50 bushels per acre every third year. The reason for this interval lies in the fact that the best effects of lime are to be seen after a year or two when the lime has been converted into carbonate, which, being insoluble, is incorporated with the soil and passes into solution as bicarbonate very slowly. The objection to this method is that it is very crude, it involves a large amount of labour, the distribution is irregular and, consequently, imperfect—much of the lime being wasted—and unless the lime has been fully slaked before distribution, it may contain too much caustic lime, the immediate effect of which may be a diminution of the crop if the land is very rich or contains fresh dung, and there may also be some loss of ammonia by volatilization. This method only answers with “fat” limes which slake and fall readily to a dry powder; a better method is to lay the lime in heaps and cover them with soil so that the lime slakes gradually to a fine powder that can be spread before the plough.

It is not wise to spread quicklime over the land, as much of it, after slaking and becoming carbonated, remains in lumps which cannot be reduced to a powder.

The expense of liming in this fashion is considerable, and, as the action is not immediate, owing to the difficulty of getting the material mixed with the soil, it is desirable to replace it, if possible, by a better and cheaper process. This has been attained by the use of ground lime or hydrated lime distributed by a manure-barrow or by an artificial manure distributor.

Spreading from the wagon is preferred by some farmers. Any form of lime which is damp enough to prevent it from blowing away can be spread very well with a shovel directly from the wagon. A little skill in handling the shovel will enable the operator to spread it both quickly and evenly. Without any standard of measurement it is difficult, in spreading lime in this way, to determine just how thickly to spread it in order to apply the proper amount per acre. A square rod, which is an area of ground a little more than five paces

each way, is a good unit-measure for surface, and a shovelful¹ a good unit for the lime.

If, for example, the material is damp, ground limestone to be applied at the rate of two tons per acre, every square rod would receive 28 lb. which is equal to about two shovelfuls. It is very disagreeable and almost impossible to spread any dry, finely-divided lime satisfactorily from the wagons.

Fertilizer distributors and lime spreaders can only be used for powders, such as dry, air-slaked lime, kiln-dried marl, hydrated lime, ground lime, or dry pulverized limestone, which can be most satisfactorily applied by their use. Some lime spreaders, built on the plan of an ordinary grain seeder, are attached to the rear of the wagon, and the lime is shovelled into the hopper from the wagon box, as in the case of phosphate distributors. In some cases, an ordinary "seeder" has given very satisfactory results when the lime is free from coarse, hard lumps.

On a large farm, a lime spreader is a profitable investment or two or more farmers can easily co-operate in buying a machine.

Spreading lime by a manure spreader is also a satisfactory method of distribution. The spreader is set at its lower gear, a few inches of fine manure spread over the bottom of the box to hold the lime in, and the lime distributed evenly on top of this layer of manure. If two tons of lime are to be applied per acre, and the machine is set at four loads per acre, as on lowest gear, then each load must contain at least 1,000 lb. of lime.

Applying lime as a top dressing on young clover or alfalfa, growing on sandy soils, may prove very satisfactory if hydrated lime or finely-ground limestone is used, though better results may be obtained by liming the ploughed field before seeding. The openness of a sandy soil enables the fine lime particles to work their way down into the soil. Top dressings on heavy clay loam or silt loam do not, usually, give very satisfactory results, for these soils will not permit the easy entrance of the lime particles into the soil as in the case of sandy ones. Sometimes, however, after harvest or in the autumn, a farmer wishes to lime his spring's seeding of clover or alfalfa on a clay loam in order to increase the yield of hay the next year, if possible. In such a case, partially air-slaked or water-slaked lime, or preferably hydrated lime, applied early the next spring before the frost is over at the rate of 1-1½ tons per acre, may prove very beneficial. Unless hydrated lime is used, such an application should never be made after the young plants have started their new year's growth, because there may be sufficient caustic lime present to kill them. A sandy soil may be treated in the same way.

Liquid Manure from the farm-yard may be mixed with hydrated lime and used advantageously, especially with the *Brassicæ*, without any serious loss of nitrogen.

Milk-of-lime may be used with great success in gardens, but is difficult on

¹ A shovelful is presumed to hold 14 lb. of lime. The actual amount held by the particular size and pattern of shovel used should be ascertained and the amount to be added calculated accordingly.

the large scale of liming necessary in farming. In this method of distribution the lime is slaked, mixed with sufficient water to make a "milk" or "slurry," and this liquid is applied with a watering can or hose, or even with a water cart. Lime applied in this manner will do twice as much as lime applied in any other manner, as the distribution is so much more thorough, especially if several dressings are applied and the soil is turned over after each.

Lump and cob lime must usually be distributed by hand.

Ground lime, hydrated lime, and sifted slaked lime are preferably distributed by a mechanical spreader or distributor.

At one time heavy dressings of lime at long intervals were considered best, but carefully made tests have shown that lighter annual dressings are usually preferable (5-20 cwt. per acre being usually suitable).

Whatever method of surface distribution is used, it is of the greatest importance that the lime and soil should be thoroughly mixed in such a manner that the lime is distributed uniformly through the soil to a sufficient depth. On a small scale, the mixing may be done with a spade or hoe, but on the large scale a plough or harrow is used, the latter being preferable. Unless the land is rich in plant food and the lime very "quick" or caustic, it should be mixed as soon as possible after spreading, as carbon dioxide is quickly absorbed when free lime in any form is exposed to the air. Where its sterilizing or caustic action is important, the free lime should also be ploughed or dug in as rapidly as possible, or much of it will be useless for its intended purpose, and the much cheaper limestone or chalk would do equally well.

Many of the poor results obtained from liming are due entirely to careless distribution, or to imperfect distribution due to the wrong time of application (see p. 559).

In grass pasture, orchards, and fruit gardens, the lime (preferably hydrated) should be broadcast each year to the extent of about 8 cwt. per acre. For lawns, bowling greens, etc., 3 oz. of hydrated lime per sq. yd. of grass is usually a suitable quantity.¹ Fruit under glass may have several light applications of lime to the surface of the soil, the lime being washed in during the ordinary waterings. Vegetables are improved by a little hydrated lime between the rows when sowing or planting, and most flowers will grow better in well-limed soil.

Precautions.—When distributing lump lime, ground lime, or by-product lime on the land, care should be taken to avoid burning the hands; properly hydrated lime is free from danger in this respect. Most forms of lime should not be applied at the same time as, or shortly after, a nitrogenous manure, or a loss of nitrogen may result (see p. 562). Hydrated lime and the various forms of calcium carbonate may be used in this way, if desired.

Many forms of lime are unpleasant to use because of the dust produced. A respirator mask, or even a small, moist sponge worn under the nose will make the work less objectionable.

There is an almost unexplored market for hydrated lime packed in 10, 12, or 14 lb. paper bags for small lawns.

If, within a year or two after liming, coarse grass and weeds regain possession of the soil, it may be taken for granted that the lime has been ploughed too deep, that it has not been sufficiently mixed with the soil, or that an insufficient quantity has been used.

Time for Liming.—The best time for liming is usually the autumn or winter, as this allows the lime to slake thoroughly before it is ploughed into the soil. Spring liming is satisfactory if it is not deferred too long, and especially if hydrated lime is used. Carbonate of lime may be applied at any time without fear of checking the growth of grass, but as its distribution in the soil is effected only by gradual solution in rain and soil water, better results in the following season may be expected from an early than from a late application. Caustic lime should not be applied very soon after fresh manure, as it tends to cause loss of ammonia.

A heavy dressing of caustic lime or of imperfectly slaked lime is liable to check the growth of grass if application is made in the spring. In breaking up old grassland the lime should be applied after ploughing and thoroughly worked into the turned-up soil.

Both soil and lime should be in as dry a condition as possible and, therefore, either a dry time in autumn (for autumn-sown crops) or in spring (for spring-sown crops), when the lime can at once be harrowed in, should be chosen.

Quicklime or caustic lime should be applied to *meadow* or *pasture* during autumn or winter, as a heavy dressing is apt to check the growth of grass if applied in spring. The application should be made when the herbage is dry.

If the land is definitely sour, the first possible opportunity should be taken, whatever the next crop, but if the application is made merely to keep the land in condition, the best time is after the final ploughing, in the preparation for the root-crop.

When lime is applied to arable land it should be worked into the top 3–4 in. of the soil from 2–4 weeks before the crop is sown.

On arable land, lump lime or ground lime should be applied on the corn-stubble, so that it may be exposed for some time before being ploughed in at once. As a preventive of "finger and toe" it should be given to the crop preceding the roots, and not to the roots themselves. On soils deficient in lime, it should be applied to barley rather than to wheat, and to wheat rather than to oats. Lime should not be applied direct to growing potatoes, as it favours the growth of "scab."

The best time to apply it is immediately after the potatoes have been removed and not to apply more than is needed to satisfy the requirement of the crops in the one rotation.

When there is a danger of destruction of plant food, the lime should be exposed for sufficient time to ensure thorough slaking and carbonation, or hydrated lime or some form of carbonate (both of which have no destructive action) should be used. Many farmers make the mistake of ploughing the lime too deeply into the soil. In many instances, much better results would be obtained by harrowing without ploughing, especially when it is desired to

neutralize the effect of too much manure or to kill bent or couch grass. Light dressings of lime should not be ploughed in, as the lime is needed most near the surface. It is, therefore, best applied after ploughing.

The extent to which the lime can be uniformly mixed with or distributed through the soil depends, to some extent, on the time it is applied. An adequate distribution is not as easily attained if the material is applied to stubbles and then ploughed in as when the application is made after ploughing. For this reason the time, as well as the method of application, should be carefully chosen, so as to give the best results. It is necessary to lime afresh at intervals, depending on the nature of the soil and on what is grown in it. For most crops, a fresh liming once every four or five years is sufficient when once neutrality has been obtained, but in some localities the loss of lime is so rapid that more frequent liming is necessary.

In gardening or in the cultivation of special crops, and especially where light dressings are preferred, an annual application of lime may be essential, and in a few special cases, two or three light dressings each year are desirable.

LIME, MANURE, AND OTHER FERTILIZERS

It is not desirable to mix lump lime, "small lime," freshly slaked lime, ground lime, and some by-product lime with manure and with nitrogenous fertilizers because these forms of lime tend to react on the manure or other fertilizer, causing loss of ammonia. For this reason, lime should not be applied at the same time as dung, ammonium sulphate, or any nitrogenous manures, nor should it be added to superphosphates, as it converts the soluble phosphate into an insoluble and useless form.

Hydrated lime and all form of calcium carbonate which are free from "quick" lime may be mixed with or applied to manure and nitrogenous fertilizers without any risk of loss of nitrogen.

It is often useless to add fertilizers to a soil unless lime is also added, because many lime-free fertilizers tend to make the soil more acid. Many of the elements in fertilizers are not available as plant food unless there is lime present to set them free, and they cannot become free otherwise. Sulphate of ammonia is very destructive to lime in the soil, and, where frequently used, liming should on no account be neglected. The same is true where superphosphate is used. Nitrate of soda is also much more effective where lime is present in the soil. This applies both to out-door and to under-glass cultivation.

As an instance of the influence of lime application on the effect of manures may be mentioned a plot where a dressing of steamed bone flour and kainite produced 27 cwt. hay per acre on the unlimed area, whilst, on the limed portion, a similar dressing gave 40 cwt. per acre. Another plot which received 2 cwt. per acre each of steamed bone flour and superphosphate gave 28½ cwt. hay per acre as against 39 cwt. per acre from a similar dressing where lime was previously applied. All these plots were on soils deficient in lime and giving distinct reactions for sourness.

Many commercial fertilizers will not show their real value on acid soils. Some farmers have refused to buy the same fertilizers a second time because they failed to see a pronounced benefit ; the fault was not that of the fertilizers used, but the lack of lime.

Fertilizers containing Lime.—The number of fertilizers which can be mixed with lime and sold in the mixed state is very limited. Ammonium compounds and organic matters are all excluded, as the lime causes a loss of nitrogen. Superphosphate should not be kept mixed with lime as it "sets" and some of the phosphate is rendered insoluble. This statement does not apply to a mixture of superphosphate and limestone, because the reaction with this takes place much more slowly than with lime. Notwithstanding the objection to the use of lime in this manner, many patents have been granted for such mixtures!

Lime may be mixed satisfactorily with nitrate of soda, sulphate of potash or kainite, steamed bone flour or bone meal. Any one of these, mixed with ten times its weight of atomized lime or hydrated lime, will make an excellent fertilizer, each substance having a different use.

For swedes, turnips and mangels a suitable mixture consists of :

Bone flour	...	...	...	...	2 cwt.
Kainite	...	...	...	...	2 cwt.
Lime	...	...	...	...	1 cwt.

and used at the rate of 5 cwt. per acre.

For early potatoes, a suitable mixture consists of :

Nitrate of soda	...	...	...	...	1 cwt.
Bone flour	...	...	...	...	$\frac{1}{2}$ cwt.
Sulphate of potash	...	...	...	...	$\frac{1}{2}$ cwt.
Atomized lime	...	...	...	...	1 cwt.

and used at the rate of 3 cwt. per acre.

For main crop potatoes, the following may be used :

Nitrate of soda	...	...	...	...	2 cwt.
Bone flour	...	...	...	...	3 cwt.
Sulphate of potash	...	...	...	...	2 cwt.
Atomized lime	...	...	...	...	2 cwt.

and used at the rate of 9 cwt. per acre.

For Cereal crops no mixed fertilizer is of general application.

In each case, a much smaller proportion of bone flour, potash, etc., may be added to the lime, but the value of the mixture will be correspondingly reduced.

Some firms add a ridiculously small proportion of potash, etc., to the lime, but such mixtures (though profitable to sell) are not worth much more than plain lime to the purchaser.

LIME IN THE GARDEN

In gardening, lime is essential (i) as a plant food ; (ii) to liberate other plant foods ; (iii) for its mechanical effect on the soil ; (iv) to counteract sourness, and (v) to rid the soil of insects and other pests.

In these respects it serves the same purposes as in agriculture, but as gardening is on a much smaller scale than farming, lime can be used more effectively with the soil.

The precautions mentioned in the preceding pages apply equally to the use of lime in gardening. In addition, it should be remembered that many gardeners tend to add too much nitrogenous fertilizer and too little lime ; by this means they tend to make the soil acid and to charge it with material which the plants cannot use unless more lime is added. Thus, when garden-soil becomes very stiff, it usually lacks lime. Also, gardens which are manured readily yet show little or no improvement lack lime. Most gardens should be limed at least every five years, but it is still better, when once the initial sourness has been overcome, to apply a light dressing of 900 lb. of hydrated lime per acre (or 3 oz. per sq. yd.) each autumn so as to maintain the neutrality of the soil. This treatment is specially good for plum, peach, nectarine and apricot trees, as well as for most vegetables and flowers and for lawns.

It is surprising how many lawns are sour and would benefit greatly by the application of 3-4 oz. of slaked or hydrated lime per sq. yd. of lawn each autumn or early spring.

A saleable dressing for lawns consists of

Nitrate of Soda	...	...	...	...	10 lb.
Hydrated Lime	...	...	...	...	100 lb.

This should be applied at the rate of $\frac{1}{4}$ - $\frac{1}{2}$ lb. per sq. yd. of lawn.

Vegetables are improved by a dressing of hydrated lime at the time of sowing or planting. Harter has found that the application of $\frac{1}{2}$ ton of lime per acre doubled the output of cabbage, and still further increased the quantity of spinach. Potatoes are sensitive to an excess of lime and prefer a soil which is neutral or faintly acid, but this does not prevent them from being benefited by a light annual dressing of lime to keep the soil as nearly neutral as possible.

Plants grown in pots or tubs or under glass are greatly improved by occasional watering with milk-of-lime or more frequent applications of lime water.

Care should be taken to use only fully slaked lime (hydrated lime being the best and safest form) unless the caustic action is required, when a little ground lime may be used. For the quantities used in gardening, the troubles and uncertainties which accompany the use of lump lime and by-product lime more than counterbalance any saving and the use of hydrated lime is, therefore, always advisable.

TENNIS COURTS, GOLF AND BOWLING GREENS

These forms of "lawn" are greatly improved by an annual dressing of 8 cwt. of lime per acre, though some experiments at Arlington seem to suggest that in some localities undesirable forms of weed grow abundantly in the presence of lime.

LIME AND LIVESTOCK

It is not sufficiently recognized that lime is essential to the health of horses, cows, pigs, and other livestock. They may obtain some of the necessary supplies in the water or milk they drink, in the growing crops on which they feed, or in the additional feeding matter supplied to them, but, owing to the general insufficiency of lime in the soil, animals do not grow or "feed" properly on food grown on land deficient in lime.¹ It is, therefore, desirable to add a further supply of lime, because it builds bone, is an essential constituent of milk, and an important factor in resistance to diseases, such as tuberculosis and "foot-and-mouth." The susceptibility of cattle and sheep to disease may be reduced by providing lime salts, in the form of "licks," or by direct addition to the food, but it is much better to provide it in the form of food grown on well-limed land. If the livestock feed on such land, there is little need to use lime as a supplement to the food, but, in cases of doubt, small quantities of hydrated lime or finely ground carbonate may be used. Coarsely ground material is quite unsuitable as the gritty particles in it may do harm. The addition of hydrated lime or fine carbonate to the food is especially valuable in the case of pigs, though it is very beneficial for sheep and cattle.

According to Corne, growing *calves* should be supplied with 1½ oz. of "effective lime" per day; an average *cow* requires the same as a calf plus ¾ oz. for each gallon of milk produced. Keller and Henneberg have stated that a cow giving 3 gallons of milk daily requires ¼ lb. of lime (CaO) per day, and E. O. Fippin has shown that more than 100 lb. of lime is required per annum or nearly ½ lb. of lime per day is essential. In many "diets" for cattle the quantity of lime required has been overlooked or seriously under estimated. For *pigs*, ¾-oz. of "effective lime" per day, or 3 lb. of mixture of equal parts of hydrated lime and salt per month, is supplied to each pig, this amount being distributed regularly over the whole period. A *sow* with a litter of 10 pigs should be supplied with at least 2 oz. of "effective lime" per day to impart the necessary amount of lime to the milk.

Magnesian limestones and limes, and most by-product limes do not appear to be suitable for animals.

For obvious reasons, unslaked lime must not be fed to livestock, but the equivalent amount of hydrated lime is satisfactory.

It is better to apply lime and any other minerals to the soil, rather than to the animals' food, because application to the land costs less per head of stock, and it increases the quantity of pasture and the percentage of protein therein.

¹ Deficiency in lime is the chief cause of what is a paradox to many stockmen—a heavy crop of grass which looks well, but upon which beasts do not thrive.

Where the application of lime to the soil is regarded as an economic impossibility, calcium carbonate may be added to the food. It is important to realize that most of the great breeds of livestock have been developed in regions well supplied with lime and to secure good results in other districts lime, in some form, must be provided.

For *poultry*, the benefit derived from the use of hydrated lime is well-known; it may be dusted in the runs or added to the food; an oolitic limestone or "shell" stone is usually supplied, but it may, with advantage, be supplemented by a little hydrated lime in the mash.

Much has been written about the use of "lime" in poultry farming, but, in most cases, limestone and not lime is meant. Some poultry farmers find it advantageous to soak the grains of corn in lime water so as to ensure the birds absorbing lime, which is not always the case when only grit is available. Lime water is also used to preserve eggs. A mixture of 8 lb. of hydrated lime (or 5 lb. of quicklime) and 10 gallons of water should be made, and, after two days, the clean liquid should be poured off and used.

Lime wash should be freely used as a wash in cow houses, stables, hen huts and all farm-buildings. For the proportions of lime and water see p. 569.

For *Sheep dips* see p. 568.

LIME AS A FUNGICIDE AND INSECTICIDE

Lime is, in many cases, an effective *insecticide*. For efficiency in this direction, much depends on the fineness and purity of the lime and its correct hydration, for it is often quite possible to add too much or not enough water. Lime is well known for use against slugs, but it is not generally known that the slug has the power of exuding a slime which enables it to escape from the first powdering its body receives. A second application, however, within a short space of time, is beyond its powers and is generally destructive.

Lime is also extensively used for coating the trunks of fruit trees, and in the form of a lime sulphur wash which is applied as a spray to fruit and is used as a sheep dip.

These washes are specially used to protect trees and crops from the following diseases:

anthracnose	apple blotch	black rot
blight (early)	blight (late)	downy mildew
leaf spot	mosaic	scab
	stem rot	

Fungicides composed of lime and copper sulphate are sometimes termed *Bordeaux mixtures*. A typical one consists of:

Copper sulphate (blue vitriol)	...	...	...	...	8 lb.
Quicklime (or hydrated lime 11 lb.)	...	...	...	...	8 lb.
Water up to	...	...	...	...	100 gallons.

The lime prevents the copper salt from damaging the plants as well as causing it to adhere to them. Another *Bordeaux mixture* is made by mixing

4 lb. of quicklime with 25 gallons of water to form milk of lime, filtering off any coarse material, and pouring into the milky lime a liquid consisting of 4 lb. of copper sulphate previously dissolved in 25 gallons of water.

Woburn Bordeaux mixture is made in the same manner, but no excess of free lime is used.

Various other mixtures are made by altering the proportion of lime and copper. Quicklime, lump lime, and ground lime are all equally suitable (but *not* hydraulic lime) but have to be slaked before use. Hydrated lime can be mixed rapidly with the water and is less liable to cause accidents. Moreover, it is usually purer and, therefore, more valuable. Any unslaked material in the other forms of lime is not only useless, but, unless it is allowed for, the solution is too weak in lime.

As *Bordeaux mixtures* are usually applied by spraying they should be passed through a sieve having at least 50 holes per linear inch before use. If they can be passed through a much finer sieve they will be still more effective. For the same reason, hydrated lime is preferable to any other form.

The Specification issued by the Association of British Insecticide Manufacturers, with the approval of the Ministry of Agriculture (1934), requires the copper-content of the mixture to be stated and also that no water-soluble copper shall be present.

Popular *lime sulphur mixtures* used for the same purpose are made by boiling together for several hours :

				A	B	C
Lump or ground lime	...	...	...	5	10	16 lb.
Sulphur	...	...	...	10	20	32 lb.
Water	...	...	...	10	10	10 gal.

If hydrated lime is used instead of lump or ground lime, nearly half as much again is used, *i.e.* 14 lb. of hydrate instead of 10 lb. of lump or ground lime.

The mixture is then allowed to settle, and the clear liquid poured off and diluted with about ten times its volume of water so as to make 100 gallons of liquor.

Various other substances may be added if desired.

Some lime sulphur mixtures are made by placing the lime in a barrel with enough water to cover it, and as soon as it begins to slake the powdered sulphur is run in with constant stirring, more water being then added slowly to form a thin paste. The proportion of water added should be such as to produce a hot mixture which begins to cool appreciably after 15 min. ; if it remains hot too long, the proportion of objectionable polysulphides will be too large. The liquid is finally diluted with water to the desired strength.

These mixtures are amber coloured liquids, containing calcium polysulphides and some thiosulphate, with a specific gravity of about 1.3. They are largely used as cheap insecticides. To conform to the Specification issued by the Association of British Insecticide Manufacturers, with the approval of the Ministry of Agriculture (1934), lime-sulphur solutions should be clear and free from sludge, should have a sp. gr. of about 1.3 and should not contain less than 18.5 per cent. by weight of polysulphide of sulphur, equivalent to about

24 per cent. weight in volume, when determined by the prescribed method.

The lime used should be as free as possible from magnesia and "core" or unburned stone, as both these substances are useless. The fungicidal action is attributed to the slow oxidation of the sulphur deposited by the liquid onto the sprayed or dipped plants.

Lime Paraffin spray is used as an insecticide and especially to repel insects likely to lay their eggs on the trees. It may be made by mixing 50 lb. of lump or ground lime or 67 lb. of hydrated lime with 6-8 gallons of paraffin or crude mineral oil.

Dry sprays are being increasingly used. Two typical ones are :

		For apples.	For potatoes.
Anhydrous copper sulphate	... 10	10	15 lb.
Arsenate of lime (p. 527)	... 5	5	8 lb.
Hydrated lime	... 85	85	77 lb.

The lime prevents the arsenic compound from "burning" the plants and also enables the mixture to adhere better than when no lime is present.

Lime is also dusted over beans and peas in the proportion of 1 : 8 to repel bean weevils.

As the lime is required in the form of a powder, ground or hydrated lime is the best form to use. The hydrated lime is finer and is generally purer, but owing to the combined water in it a larger proportion may be required. This is not always the case, as some ground lime is so low in "effective lime" that it contains less of such lime than the hydrated lime.

For all fungicides only limes rich in calcium oxide should be used. The best and most convenient form is hydrated lime and one of the chief requirements is that it be free from grit, which would spoil the pumps used for applying the mixtures to the trees and crops.

SHEEP DIPS

The *sheep dips* containing lime are very variable in composition as shown by the following recipes :

TABLE XLVI—*Composition of Sheep dips*¹

Flowers of Sulphur lb.	Unslaked Lime lb.	Slaked or Hydrated Lime lb.	Water gals.
20	—	10	100
15	15	—	100
20	16	—	100
16	33	—	100
33	11	—	100
24	8	—	100

¹ Only one recipe with hydrated lime is shown, but it can replace the unslaked lime in the other recipes provided that one-third more is used, e.g. 20 lb. of hydrated lime instead of 15 lb. of unslaked lime.

It is dangerous to use more than 33 lb. of lime to 100 gallons of water, and 16 lb. is as much as should be used without expert advice.

These dips are usually made by slaking the lime in some of the water, sifting the sulphur into the paste, and stirring well. The mixture may then be diluted with the remaining water and boiled for 2-3 hours with constant stirring and replacement of any water lost by evaporation. The clear liquor which is run off after settling should be a dark brown colour ; it may be filtered if desired. The sediment should not be used in a sheep dip. Well-made lime sulphur dips are specially suitable as scab destroyers, but badly made dips are injurious to the sheep.

Arsenate of Lime (p. 527) is also used extensively as a sheep dip.

GENERAL DISINFECTANT AND PRESERVATIVE

Lime mixed with water to form *lime wash* is largely used as a general disinfectant in farms and gardens. It serves as a protective coating, lightens dark interiors, kills many insects and eggs which may be on the walls, ceilings, etc., and also acts as a mild germicide.

A suitable *lime wash* for general use consists of 10 lb. of pure lime or 14 lb. of hydrated lime and 2 gallons of water, but the proportions may be varied so as to produce a wash which "brushes on" easily. If about 1 lb. of casein (or 1 gallon of skimmed milk is used instead of one gallon of water) and $\frac{1}{2}$ lb. of sodium phosphate are added, a more durable wash will be produced. For interior work, a little size or powdered glue may be dissolved in water and added to the wash to make it adhere better.

For use as a disinfectant only limes rich in calcium oxide should be used as the germicidal effects of magnesia are doubtful.

Ground lime, air slaked lime, or hydrated lime is sometimes put into the ground around new fence posts to lessen the risk of decay.

The same material is used as an antiseptic and deodorizer in many parts of farms, and especially in poultry houses and runs.

For all these purposes, hydrated lime is preferable to any other form. If lump or ground lime is used it should first be slaked with just enough water to cause it to fall to powder, and it should then be passed through a sieve with 24 holes per running inch. Any residue should be re-slaked or examined ; it probably consists of useless "core" or unburned stone. The absence of such useless residue from hydrated lime is one of the chief reasons for its general superiority.

3. THE USE OF LIME IN BUILDING CONSTRUCTION

Lime has been used since prehistoric times as the chief constituent of *mortar*, *lime cement*, and *lime concrete*, in the production of *plaster*, *stucco*, and other facing materials in later times, and, still more recently, as a binding agent in the manufacture of *lime sand bricks* and to facilitate the placing of *concrete*. Other minor, yet important uses of lime in building construction are its employment as a *lime wash* or distemper, and as a constituent of some *paints*.

For most building purposes, a somewhat impure lime is often preferable, because the argillaceous material present, or the siliceous material introduced by burning the stone in contact with the fuel, produces feeble hydraulic properties which make a stronger joint or surfacing material.

A rough distinction exists in the building trade between "fat" or "rich," and "poor" or "lean" limes. The former slake rapidly with high rise in temperature; the latter slake slowly and without much rise in temperature. Fat limes set only by absorption of carbon dioxide, but lean limes are hydraulic and set like diluted cements.

LIME FOR USE IN MORTAR

Mortar is a mixture of sand and water with some binding material, such as lime or cement or both. A fibrous material, such as hair, is often added to increase the strength. In lime mortar the lime forms a colloidal gel with some of the water and this gel coats the sand grains. As the mortar dries, the colloidal gel dries and shrinks and so holds the particles together. A small proportion of crystalline calcium carbonate is also formed and the interlacing of the crystals increases the strength of the mass. The mixing of the various ingredients must be thorough; all fat lime mortars are improved by prolonged mixing, but in those containing hydraulic-lime cement the mixing must not be continued after the cementitious portion has begun to set. The mixing may be by hand or machinery; the use of the latter is generally known as *grinding*, but no actual grinding should occur with properly prepared materials. Mortar made with fat lime should not be used for 24 hours or more as storage greatly improves its workability.

For the production of ordinary mortar for general use by builders either a fat lime, a lean lime, or a hydraulic lime (Lias lime) may be used. Fat limes are preferred, but lean limes can be employed if they do not slake too slowly; they are regarded less favourably by some builders, because they have a much smaller sand carrying capacity, and the resulting mortar does not "work" very smoothly. Hydraulic limes are stronger in cementing power, and behave like a mixture of fat lime and Portland cement.

Magnesian limes are generally suitable for mortar and sometimes excel calcium limes in smoothness, working, sand carrying power, and resistance to weather. There is also evidence that magnesian limes give mortars that eventually give greater strength than those made of high calcium limes. They slake more slowly than calcium limes, and, unless care is taken, the mortar may prove to be unsound by a steam pat test. The slow slaking is often due to partial overburning of the lime.

Greystone limes are highly appreciated for the strength of the mortar which they produce as a result of being feebly hydraulic, though this reason is seldom realized. Ground greystone lime requires about one month after being mixed with water before it develops appreciable hydraulic strength. It loses this property if the lime is stored in the form of putty or if it is soaked and kept for a long time before use.

Mortar made with a *fat lime* or a *lean lime* with a low silica-content does not "set" in the same manner as hydraulic lime or concrete. Such lime merely dries, and by gradual absorption of carbon dioxide on its surface it becomes moderately hard externally, but the interior of the mass may remain soft for several hundred years. The purer the lime and sand used in the preparation of the mortar, the softer will be the mortar, no matter how long it has been in use. The carbon dioxide absorbed from the air combines with the lime at the surface of the joints, and, by closing the pores, prevents a further penetration, so that most joints in old masonry are only hard for a very short distance below the surface.

Hydraulic lime, on the contrary, undergoes a complex chemical change when in contact with water and "sets" to a hard mass. It does this equally well in air or under water, provided the mortar is supplied with sufficient water to ensure its adequate setting and subsequent hardening. If the supply of water is insufficient, the hardening will be incomplete.

Fat limes can be caused to harden like hydraulic lime and cement, by adding a suitable proportion of a material which will combine with the lime, forming a compound somewhat resembling those in hardened cement concrete. Such material is known as *pozzuolana*; the commonest variety is *trass*, which is extensively used on the Continent, but an equally good substitute is made by grinding underburned bricks or tiles to a fine powder, provided they are sufficiently rich in clay.

Pure limes to which no *pozzuolana* has been added should not be used for work in contact with water, but only for structures above ground level.

Lump limes for ordinary mortar may be composed chiefly of calcium oxide, or of a mixture of calcium oxide and magnesia, according to the nature of the stone from which the lime has been made.

High calcium limes are generally regarded as preferable, because they slake readily and completely in a short time whereas magnesian limes slake more slowly and uncertainly and may, therefore, cause trouble (see p. 485).

The precise composition of such limes is not of great importance provided the lime is properly burned. To guard against the inclusion of unburned stone or *core* and of overburned lime, it is desirable to specify that the sample shall not contain more than 10 per cent. of carbon dioxide and that when the sample is washed through a No. 20 sieve, it should not leave a residue of more than 5 per cent. (when dried).

Opinions differ greatly as regards composition, but for a high-class lime, the sum of the lime and magnesia present should not be less than 95 per cent. on the ignited sample, and a high-class magnesian lime should not contain less than 20 per cent. of magnesia.

For many structures, a lime containing only 85-90 per cent. of lime and magnesia is quite satisfactory.

In comparing two or more limes, it is important to compare the amount of sand which can be mixed with each lime without the mixture being too "lean" to "work" satisfactorily. Alternatively, the plasticity of the samples can be

determined before and after mixing with various proportions of sand.

In limes used for building construction, the physical characteristics, such as plasticity, time of set, colour, hardness, and strength, are of great importance, whereas chemical composition is immaterial except indirectly, inasmuch that limes made from limestone of different purity and composition usually have different physical characteristics. Thus, magnesian limes in general are more plastic than high calcium limes and are preferred for "finishing" purposes (but see p. 578).

The lime which can carry the largest quantity of sand should be the best for mortar. A useful indication of the quality of a lime is to measure its volume before and after slaking. All good limes will increase in volume, but a fat one should increase to three times its original size. Limes which produce less than twice their volume of slaked lime are described as *lean* or *poor*.

Before mixing it with sand or any other solid material, a quicklime should be slaked and made into *lime putty*; the hydrated lime merely requires to be mixed with water, and the hydraulic lime should be slaked by sprinkling it with water, avoiding an excess, and finally passing it through a No. 5 or finer sieve.

The chief disadvantages of lump lime for use in mortar are :

- (i) It requires slaking, which is troublesome and tedious.
- (ii) It frequently contains much *core* and useless material.
- (iii) The quality varies greatly and cannot easily be checked by the builder; consequently, the quality of the mortar also varies.
- (iv) It soon spoils if kept before being used.
- (v) It is inconvenient to keep on account of its caustic properties.

In short, it has all the disadvantages of a crude material. In the United States, it has been replaced almost completely by hydrated lime, which is free from all these objections.

In some localities, the quality of lime, as compared with that made fifty years ago, has deteriorated seriously. This is due to the skilled burners having left or died and other men with less care and skill having taken their places. To a smaller extent, the change is also due to the use of inferior coal, which does not burn the stone so effectively, and introduces a larger percentage of ash into the lime. It is, therefore, more than ever necessary that builders should ascertain the quality of the lime they are buying.

As lime in mortar fills the voids or interstices between the grains of sand, the dry mortar has only about three-quarters of the volumes of the sand and lime measured separately.

Hydrated lime serves precisely the same purposes in building as lump lime, but it does not require slaking (merely mixing with water) and it is free from several other disadvantages of lump lime. It does not "set" or "harden" like cement, but behaves in mortar like a skilfully slaked lime.

Hydrated lime may be a high calcium or a magnesian lime. In either case, the total lime and magnesia should not be less than 95 per cent. of the weight of the ignited sample in a high class hydrated lime, but may be 85-90 per cent.

in an "ordinary" hydrated lime. The carbon dioxide present should not exceed 5 per cent.

As a check on proper preparation, a hydrated lime should pass completely through a No. 20 sieve and the high-class hydrated lime should not leave more than 1 per cent. of residue on a No. 50 sieve or 10 per cent. on a No. 200 sieve. The "ordinary" hydrate may be rather coarser, but should not leave more than 15 per cent. of residue on a No. 200 sieve. Water should be used during the sifting.

Hydrated lime should not "blow" or "pimple" when mixed with sand and water and allowed to harden.

The advantages of hydrated lime in making mortar are :

- (i) It can be stored indefinitely and easily.
- (ii) It requires no slaking.
- (iii) It is more uniform in quality.
- (iv) It contains less "core" or useless material and so can be used without waste.

(v) It avoids the production of bad putty through carelessness or ignorance of the man in charge of the mortar.

(vi) It avoids the loss otherwise caused through having to make more putty than is needed to allow for useless material in the lime.

(vii) It is particularly easy to measure and use.

(viii) E. W. Lazell has shown that mortar made with hydrated lime is stronger than that made with hand slaked lime and used immediately. The reason is that mechanical slaking under proper control ensures complete hydration, whereas, with hand slaking, the paste must be left for some weeks before the hydration is complete. Moreover, in hydrated lime, the coarser, unaltered particles are separated, so that the risk of caustic lime in hydrated lime from a good firm is negligible. Much of the hydrated lime on the market is not as good as a hand slaked lime putty about a year old, because the plasticity of lime can only be developed in the presence of more water than is permissible in hydrated lime. For most building purposes, however, hydrated lime is as good as need be desired.

Various notes on hydrated lime and mortar are given in the section on "Hydrated Lime" (p. 517).

The *advantages* of fat lime—either lump or hydrated—are :

(i) It enables bricks to be laid more rapidly and more easily than when cement is used, as lime is more plastic than cement. A greater strength can be used by replacing some or all of the lime by Portland cement, but where such additional strength is wholly unnecessary there is no object in securing it, and lime mortar has ample strength for all ordinary buildings.

(ii) Fat lime produces the only mortar that can be prepared in large quantities in advance, *i.e.* that made from either quicklime or hydrated lime. All the lime mortar needed for a structure can be mixed before the walls are started. It may be stored, either in a stack or pit, until required, and, in fact, is actually better and more easily worked because of the ageing. This feature

of lime mortar affords a good chance for economy, as machine mixing is particularly suitable and satisfactory. As the mortar is required, it may be re-tempered to the desired consistency and used with full confidence.

(iii) Fat lime makes the most economical mortar. The cost of the materials is low, because of the high sand carrying capacity of the lime. The strength of the mortar is ample, thus permitting it to be used under practically all conditions. The natural plasticity of the lime decreases the cost of mixing the mortar, of spreading the mortar bed, and of placing the bricks. No mortar is wasted. If the mortar is mixed as needed, any left over at the end of a day, or not used, because of a sudden shut down on the job, can be stacked and used when work begins again. If cement mortar works short, the droppings are excessive, 10 per cent. being sometimes wasted. This is not the case with lime mortar, for the only droppings are due to trimming the joints, and these are negligible.

(iv) Fat lime mortar avoids delaying the bricklayers, who, when cement mortar is used, have to wait for mortar to be mixed. Lime mortar is always ready for use and so increases the efficiency of the entire force and makes maintenance of construction schedules easy.

Some builders add a small proportion (15 per cent.) of Portland cement to lime mortar in order that it may set quickly enough for the bricklayers to work rapidly, as in many modern steel skeleton structures with brickwork panels.

In order to secure the best results, the lime must be properly treated. The best method is to prepare a lime putty by slaking the lump lime or by mixing the hydrated lime with water (p. 525). The modern desire for speed makes most builders unable to keep the putty for a long time, and, consequently, the full plasticity of the lime is seldom developed in modern mortar. This is wasteful of lime as old lime putty will carry more sand than newly made putty.

Specification for lime for Mortar. A tentative specification for quicklime and hydrated lime for use in mortar has been prepared by the Building Research Station¹ which suggests:

Quicklime: Class A.—Not less than 95 per cent. of calcium oxide and magnesia in the ignited sample.

Class B.—Not less than 85 per cent. of calcium oxide and magnesia in the ignited sample.

In both classes: not more than 5 per cent. of residue when washed on a No. 20 sieve:

No fineness or soundness tests are imposed.

Hydrated Lime: Class A.—Not less than 95 per cent. of calcium oxide and magnesia in the ignited sample and not more than 0.5 per cent. of carbon dioxide. No residue to be left on a No. 20 sieve, not more than 1 per cent. on a No. 50 sieve, and not more than 10 per cent. on a No. 200 sieve.

Soundness: A pat, 4 in. diam. and $\frac{1}{4}$ in. thick, of the lime with five times

¹ Special Report No. 9, H.M. Stationery Office, 1s. 9d. net.

its weight of sand and enough water to make a paste, is allowed to set in air for 24 hours ; it is then covered with a thin coat of lime paste, allowed to set a further 24 hours and is then exposed to steam for five hours. It must not crack.

Class B.—Not less than 85 per cent. of calcium oxide and magnesia in the ignited sample, and not more than 5 per cent. of carbon dioxide. No residue on a No. 20 sieve and not more than 15 per cent. on a No. 200 sieve. No soundness test is imposed.

Hydraulic limes can be purchased in the lump or ground form, the latter being far more convenient. They are characterized by their power of setting and hardening in water and behave in many respects like a mixture of Portland cement and lime. They differ greatly in composition and properties, and are conveniently divided into three classes : (i) feebly hydraulic ; (ii) moderately hydraulic ; and (iii) eminently hydraulic.

Moderately hydraulic limes set in water in about 6 or 8 days and harden for a further period of several months. Eminently hydraulic limes may set in 3 or 4 days and become quite hard in one month.

The Government Building Research Department has suggested three specifications¹—one for each class. In each, the sum of the lime and magnesia (in the ignited sample) should not be less than 60 per cent. and the carbon dioxide should not exceed 10 per cent.

In the first class, there should not be more than 15 per cent. of silica and alumina, in the second class not less than 15 per cent. nor more than 25 per cent. of silica and alumina, and in the third class, not less than 25 per cent. nor more than 35 per cent. of silica and alumina.

No hydraulic lime should leave more than 5 per cent. of residue when washed on a No. 20 sieve, and the ground material should not leave a residue of more than 15 per cent. on a No. 200 sieve.

A further useful test is to make a small 8-shaped test piece of the lime after mixing it with water to form a paste, and storing it for 72 hours in moist air and 25 days in water. The tensile strength at the end of this period should not be less than 70 lb. per sq. in., and should preferably exceed 75 lb. per sq. in. No feebly hydraulic lime will pass this test.

Hydraulic limes are chiefly used where a mortar is required to have a greater strength than can be produced with a fat lime. At one time they were widely used, but since the use of Portland cement has become so popular the latter is usually preferred, as it is stronger and more regular in composition and properties.

Hydraulic limes are also used in foundations and in locations where the brickwork or masonry may be in occasional or constant contact with water.

When slaking hydraulic lime, the use of too much water must be avoided : too little will do no harm. It is usually better to buy the hydraulic lime ready slaked.

¹ *Ibid.*, p. 574.

LIMESTONE AND ITS PRODUCTS

LIME FOR WINTER MORTAR

When brick laying must be carried out in very cold weather, the most satisfactory mixture consists of one measure of Portland cement, two of fat lime, and nine of sand. This is much cheaper than a cement sand mortar, is less sensitive to frost, and is easier to work. Mortar must not be used during actual frost, and bricks laid just prior to a frost must be covered, or otherwise protected until the mortar has hardened.

LIME IN CEMENT MORTAR

The addition of a little lime putty or hydrated lime to cement mortar makes the latter spread more easily and work more smoothly. It also increases the adhesive properties of the mortar.

The lime putty, or a paste made by mixing hydrated lime with water, should be added to the dry mixture of cement and sand, any additional water required being then added and the whole mixed thoroughly.

The following proportions are suitable, but a larger proportion of lime should be avoided :

TABLE XLVII.—*Lime-cement Mortar*

Portland cement.	Sand.	Lime putty or paste.
1	5	$\frac{1}{2}$
1	6-7	1
1	8	$1\frac{1}{2}$
1	10	2

On work frequently exposed to water, the addition of lime is undesirable as it tends to be washed out and leaves a porous mortar.

The best lime is a fat, high calcium lime, such as is used for *fine stuff* in plastering. Hydrated lime is more convenient than lump lime.

LIME CEMENT

Lime cement is a term applied to lime when mixed with sand so as to form a mortar or plaster which is used as a cementing agent. Before the invention of Portland cement, lime was extensively used as a cement, and to-day when speed of hardening is not important, it is still useful for many purposes. Unfortunately, the tendency to require rapid hardening materials for all purposes, even under conditions where time is of minor importance, has led to an increasing failure to recognize the advantages of lime as a cement.

For this purpose, two kinds of lime are available : (a) a fat lime, and (b) a hydraulic lime.

The fat lime should be high in calcium oxide and very low in magnesia. In course of time, magnesian limes form products which are as hard and strong as those in which pure calcium oxide is used, but magnesian limes slake very slowly and somewhat uncertainly, so that they are generally less suitable than calcium limes.

The lime should contain at least 95 per cent. of lime and magnesia (on the ignited sample) and not more than 5 per cent. of carbon dioxide. It should, when slaked and washed through a sieve with water, pass completely through a No. 20 sieve and not leave more than 20 per cent. on a No. 100 sieve.

Hydrated lime, equal in quality to the lump lime just mentioned, may be used instead of lump lime and is usually more convenient as it does not require to be slaked.

Lime cement of the kind described is merely a good quality of lime, but lime cements composed of lime and casein or similar materials are quite different ; they are described later.

Lime cements composed solely of hydraulic limes resemble a mixture of fat lime and Portland cement, but are somewhat uncertain in their behaviour.

For structures requiring a material stronger than ordinary mortar, but not so strong as a cement sand mortar they are excellent and cheap.

LIME CONCRETE

Long before the invention of Portland cement, lime concrete was extensively used, especially in the East. The lime is mixed with twice its volume of coarse aggregate. If half the sand is replaced by trass, or, still better, by an artificial pozzuolana made by lightly calcining clay and grinding the mass to powder, a better concrete will be produced. The concrete is excellent in quality, but requires longer to harden sufficiently than do cement mortars.

The lime used should be a fat lime, such as is employed for mortar, but hydraulic lime is also used for the same purpose.

When rapid hardening is not essential, lime concrete will serve many purposes for which cement concrete is generally used, and will be much cheaper. It is not, however, suitable for reinforced concrete.

LIME IN PLASTER

Lime plaster consists of a mixture of slaked lime and sand (with or without hair) which is largely used for coating the walls, ceilings, or roofs of buildings.

A finer quality lime and sand is used for interior work, and hair is usually added to increase the tensile strength of the mixture ; other fibrous materials, including asbestos and wool waste, may be used for the same purpose. Instead of hair, other fibrous material may be used, but the fibres must be long and thin or the plaster will not adhere to them.

A coarser lime and sand—often with some gravel—is used for exterior work and, instead of hair, cow dung is sometimes added to make the mixture work

binding agent. It has a greater covering power than Portland cement. It is a mistake to use too little sand with the lime, as both "rough cast" and "stucco" should be as lean as possible.

The most suitable lime is a fat lime, such as that specified for interior plaster ("fine stuff") and, whilst an inferior lime may be used, it is not recommended.

The advantages of lime for exterior work are :

- (i) It is cheaper and "goes further" than Portland cement.
- (ii) It is equally durable.
- (iii) It has a greater sand carrying power.
- (iv) It is more plastic and so is easier to use.
- (v) The slow hardening enables the material to adjust itself to the background better than cement plaster can do.
- (vi) The waste is much less.

Fresco is made by mixing a fine, fat mortar with fine sand and water, applying over the ordinary "coarse stuff" on a wall, and painting on it with coloured distempers whilst the surface is still damp.

The quality of lime which should be used is the same as for the "fine stuff" in interior plaster.

Floor Plaster is now seldom made with lime, as a harder surface is obtained more rapidly when cement is used. When the wear is not likely to be severe, lime plaster makes an excellent floor; it is also useful as a base on which a thin coat of cement sand plaster can be laid.

The lime used for floor plaster should be the same as that used for *coarse stuff* in interior plaster, but, for the surface, the lime used for *fine stuff* is preferable.

Hydraulic lime is sometimes used for floor plaster and is satisfactory where wear is not excessive. It produces a slightly harder floor than fat lime, but not so hard as when Portland cement is used.

Precaution.—Lime to be used for plaster must be properly slaked or hydrated or the surface of the wall or ceiling will be spoiled by blisters, blow-holes, popping, or other disfigurements, due to the lime slaking after the plaster has been placed. Some hydrated lime has the same defect because it has not been properly slaked, either through too little water being added to combine with all the lime, or through too much water being added at once, so that the lime is "burned" and will not slake.

The workability of a dry hydrate is usually definitely lower than that of a putty, and, consequently, a different technique is required by the plasterer when using the hydrate. For the same reason, the sand carrying capacity of a dry hydrate is lower than that of a putty, and failures, which occur when a plasterer accustomed to the use of a putty is called upon to use a dry hydrate for the first time, are frequently attributable to the use of too much sand.

The workability of lime appears to be due to each particle being surrounded by a relatively thick film of water; the plasticity of clay is attributed to a similar cause.

Particles of slaked lime in a lime putty are chiefly 2–4 μ in diameter. Particles of hydrate are much larger, but only because the small particles are assembled in flocks instead of being separated.

The size of the particles (whether separated or in flocks) may have an important effect on the properties of the lime.

Blistering and similar defects are seldom serious with lime ground to pass through a No. 50 sieve prior to slaking or hydration. Little or no trouble will be experienced if a lime putty is made and kept for a month before use or if a reliable make of hydrated lime is used, unless the plaster is applied too quickly or carelessly, it is applied to insufficiently seasoned timber (which subsequently shrinks) or the plaster is disturbed before it has hardened properly.

The addition of a little (retarded) plaster of Paris to the plaster will often prevent defects because it expands slightly on setting and so neutralizes the shrinkage of the lime.

LIME PUTTY

Lime putty or *Plasterer's putty* is made by slaking a fat lime with as much water as will produce a soft plastic paste. All lump lime must be converted into this form before it can be used satisfactorily for plastering. The putty must be kept for at least a week and preferably for several months¹ before it is used, so as to ensure every particle of lime being fully slaked. Any unslaked pieces of lime will slake whilst the plaster is in place on walls or elsewhere, and will cause pimples, popping, or other unsightly defects. Lime putty does not spoil appreciably on storage.

Lime putty is made by placing the lime in a tub of water in which it is stirred and slaked. The slaked lime is then carefully sifted through a fine sieve (*e.g.* $\frac{1}{16}$ in. holes) into a wooden bin²; the residuum which does not pass is rejected for plasterer's work.

A considerable excess of water is added and the surplus is allowed to drain away from the bottom or through the sides of the vessel in which the putty is stored.

The finely sifted calcium hydrate with excess of water may be left with safety for a year or so to mellow, the water which rises to the top drains away through the joints of the wood-bin, or it evaporates, leaving the pure slaked lime putty as a creamy mass; only the thin outer crust exposed to the air will set. For the setting coat of plaster work, putty should not be used until it has mellowed for at least three months.

To obtain a fairly constant consistency, a specimen may be placed in an oiled galvanized iron tube, 2 in. internal diameter and 3 in. high, standing vertically on a glass plate, care being taken that the tube is filled completely

¹ The Romans required the lime putty to be kept for three years before it was used. The London County Council requires one month's storage!

² Concrete tanks appear to be unsuitable for preparing lime putty—probably because the surplus water does not drain away so readily as from a wooden tank. A concrete tank is quite satisfactory, however, if it is provided with a false bottom made of wooden planks and a drain through which the excess of water may flow.

and contains no air bubbles. The tube is then lifted vertically, and, after a convenient time, the height of the cylinder of putty is measured. It should preferably be $2\frac{1}{8}$ -in.¹

The volume of lime putty obtainable from a high calcium lime has been found² to be :

$$v = 100 \div nd$$

where v is the volume yield, n the percentage of quicklime (or, alternatively, the percentage of "ignited residue"), and d the density of the putty. Other useful formulae derived from this and from experimental values are :

$$v = \frac{1000 - 7n}{10n}$$

$$v = 0.7 \div (d - 1)$$

$$d = 100 \div (100 - 0.7n)$$

$$n = 100 (d - 1) \div 0.7d$$

These formulae show that the volume of lime putty is double that of the original lime when the putty has a density of 1.35 and contains 37 per cent. of its weight of quicklime.

The weight of lime putty produced from a given weight of quicklime (assuming it is pure and fully burned) is $0.7 \div (d - 1)$ where d is the density of the putty. Thus, 1 lb. of pure quicklime will produce, under ideal conditions, 2.7 lb. (0.032 cb. ft.) of lime putty with a density of 1.35 or 3.5 lb. (0.045 cb. ft.) of lime putty with a density of only 1.25.

Magnesian limes, which slake more slowly, should have the water added to them slowly at first, so as to cause a rise in temperature, and then more rapidly. Magnesian limes require much more stirring or "tempering" than pure calcium limes.

The long time required for ageing the best lime putty has caused hydrated lime to be used wherever possible, but even hydrated lime should be mixed with water to form a putty and kept for at least 24 hours before it is used.

Hydrated lime, whilst quite suitable for most purposes in building, does not form quite so plastic a paste as that produced by hand slaking and prolonged storage. Briscal and Mathers have found that very few dry hydrated limes yield a plastic mass when wetted. If a plastic putty is dried without dehydration and resoaked, the plasticity suffers.

Lime putty may be made from almost any kind of quicklime or hydrated lime, but *not* from liassic or hydraulic lime. Lime of poor quality is sometimes used for putty to be employed for coarse stuff, but it is wiser to use good lime for all purposes. When properly made, it should be a plastic paste, free from obvious non-plastic particles and uniform in texture. The finer the sieve used when preparing the putty, the smaller is the risk of unslaked material being present.

¹ Cowper and Williams, *Jour. Soc. Chem. Ind.*, 48, 278T (1929). More accurate methods are cited in this paper.

² *Ibid.*

Lime-putty has some curious properties. It will support a considerable weight and will not flow on the application of a pressure below the critical one, yet a portion of the same putty placed in a bucket and subjected to the jolting of a train will become fluid.

For further information on lime putty see p. 525.

LIME IN WALL COATINGS

Under the term *lime wash*, *whitewash*, *distemper*, *etc.*, is included a milky suspension of slaked quicklime or hydraulic lime or hydrated lime in water. No definite proportions of lime and water are used, the user judging by the appearance of the wash when applied to a surface. Equal weights of lime and water usually produce an excellent lime wash, but much depends on the nature of the lime.

The addition of 30 lb. of common salt or 10 lb. of dry calcium chloride to 100 lb. of the slaked lime or hydrated lime produces a superior lime wash. The addition of a little glue is also advantageous and prevents earlier work from being rubbed off. A mixture of 6 lb. of glue, 4 gallons of water, and a cream containing 100 lb. of slaked or hydrated lime is generally quite satisfactory. Instead of common salt, a mixture of 4 lb. of zinc sulphate and 2 lb. of common salt per bushel of lime is preferred by some architects.

The zinc sulphate combines with the lime, forming a substance similar to plaster of Paris and rendering the whitewash more durable.

Some users find that the addition of linseed oil or melted tallow lessens the tendency of the material to be "rubbed off," and one well-known builder uses milk instead of water for the same reason.

The National Lime Association (U.S.A.) recommends the following :

TABLE XLVIII.—*Lime-wash*

Exterior Work.		Interior Work.	
Hydrated Lime	50 lb.	Hydrated Lime	50 lb.
Common Salt	15 lb.	Water (containing 3 lb.	
Water	7½ gal.	of glue)	7 gal.

A more elaborate whitewash is made as follows :

Add enough water to 12 lb. of hydrated lime to make a thick cream. Dissolve 1 lb. of washing soda in 1 gallon of boiling water, and add this to the lime. Dissolve ¼ lb. of glue and 1 lb. rice flour in 3 quarts of water. Add this to the above mixture and apply. The above quantities will make enough whitewash to cover about 600 square feet.

Hydraulic lime must be carefully selected or the wall or other surface will not be sufficiently white. It will, however, be more durable than when quicklime or hydrated lime is used.

The mixture of lime and water (with or without other ingredients) should be made fairly thick, passed through a No. 50 or finer sieve, and then diluted with water as required. If the screening is omitted, the wash may not have a sufficiently smooth surface.

Whitewash is the cheapest of protective paints, but it requires frequent renewal. Its slight disinfectant power adds greatly to its value.

Coloured lime washes are made by adding suitable materials, such as Frankfort black, Paris black, lampblack, and carbon black used for greys and blacks; vermilion, Indian red, carmine, ochre, umber, sienna, Vandyke brown, ultramarine blue, and emerald green are the most popular colours. Whatever colour is used must not be affected by the lime.

LIME IN PAINTS

The *lime paints* are described on p. 639, so that it is merely necessary here to indicate their existence.

LIME IN CEMENTS

Lime is an important constituent of *Portland cement*, *Roman cement*, and similar materials, but as it is not used in the form of lime (but as stone), it is outside the scope of the present chapter.

Portland cement can be made slower setting and more plastic by the addition of a small proportion of hydrated lime. This is not usually done by the cement manufacturer, but by the concrete mixer (see "Use of Lime in Concrete").

Slag cement is made by grinding granulated slag to a fine powder and then adding a little lime or gypsum to retard the setting to a suitable extent.

Lime-glue cement.—Lime is occasionally mixed with *glue* to form a strong adhesive for wood and similar materials. One method of preparing such a mixture consists in mixing $\frac{1}{2}$ oz. of finely ground slaked or hydrated lime with 2 oz. of sugar and 6 fl. oz. of water, heating the mixture for several hours at 65° C., filtering and adding to the liquid one-fifth of its weight of glue. The product, which solidifies on cooling, is easily melted.

Lime-albumen cement is usually made by mixing finely-ground lime or hydrated lime with sufficient white of egg to produce a paste. It should be used at once. Other lime-albumen cements are known as casein-cements.

Casein-cements.—Lime is largely used in the manufacture of casein-cements, which are somewhat indefinite compounds of cheese and lime. For this purpose, the lime should contain at least 95 per cent. of free calcium oxide and it should, after slaking, be free from all gritty matter. To ensure this, the slaked lime must usually be sieved. Hydrated lime, if properly made, can be used without any preliminary treatment other than mixing with water. The most suitable form is *milk-of-lime*, which has been passed through a sieve with 80 holes per linear inch. It is important that the lime should be fully slaked before it is mixed with the casein, and, for this reason (unless hydrated lime is

used), the "milk" should be made some time before it is required, particularly if a slow slaking lime is used.

Casein-cement is largely used by joiners and other wood workers, as well as for a variety of minor purposes by plumbers and other workmen engaged in the building trades.

LIME FOR USE IN LIME-SAND BRICKS¹

Lime-sand bricks or *sand-lime bricks* (both terms are used indiscriminately) are made of sharp-grained quartzose sand to which is added about 6 per cent. of fat lime. It is essential that the lime should be completely slaked before the

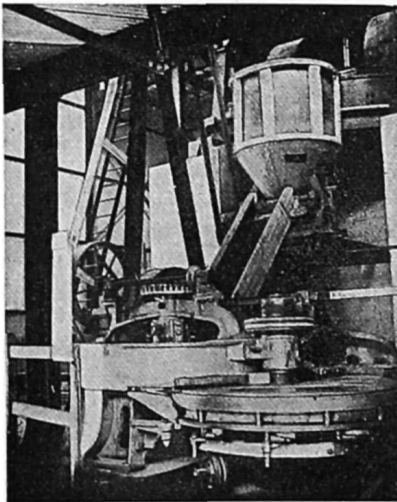


FIG. 123—LIME-SAND BRICK-PLANT.
(By courtesy of Herbert Alexander and Co. Ltd.)

mixture is made into bricks, and the various methods of manufacture differ chiefly in the means used to produce a homogeneous mixture of sand and lime and to slake the lime completely. So much difficulty has been experienced, and such serious loss has been suffered by firms who have not been able to secure both these essentials, that the manufacture of lime-sand bricks has undeservedly gained a bad reputation in some localities. Where an inefficient lime slaking plant has been installed, it is often cheapest to buy hydrated lime which immediately removes one great difficulty, though at a serious addition to the cost of manufacture, as good hydrated lime of local origin cannot always be obtained and the cost of carriage may be serious!

To ensure the complete slaking of the lime, if lump lime is used, a suitable slaking or hydrating appliance must be used. This need not be elaborate; it will suffice if it mixes the lime and water thoroughly during the requisite period and if, in the case of certain limes, it enables the mixing to be done in a closed vessel in which a small pressure may be developed. Limes differ greatly in the conditions they require for complete slaking, but the following facts should be noted:

(i) Unless the sand is very wet there is no need to slake the lime with a minimum of water, as is so often attempted.

(ii) If the sand is very wet, it is better to dry some of it by artificial heat, so as to enable an ample (or even excessive) amount of water to be used for the lime.

¹ A useful pamphlet on Sand-lime bricks was published by the Building Research Board (H.M. Stationery Office) in 1934.

The British Standard Specification for Sand-lime Bricks (No. 187) was published in 1934.

(iii) Few limes are *completely* slaked in the time usually allowed in a slaking machine or hydrator, and require 24 hours or more to complete the hydration. It is essential to ascertain what length of time is necessary and to allow additional time for safety ; failure to do this is one of the chief causes of loss in the manufacture of lime-sand bricks.

(iv) As wet lime is difficult to deal with mechanically and many sands are rather wetter than is desirable, it is good practice to mix the slaked lime with at least twice its volume of sand, and still better with a larger proportion, and to store the mixture as long as may be necessary to ensure the *complete* slaking of the lime. The cost of the additional mixer and of the six or more silos or bins in which to store the mixture, adds noticeably to the cost of the plant, but it is money well spent, and unwise saving in this respect has ruined several firms.

(v) It is not usually wise to attempt to slake the lime by means of wet sand, as the heat developed by the slaking is absorbed by the sand instead of by the lime, and the temperature attained is usually too low to ensure rapid slaking. Hence, it is better to mix the lime and water first, allow time for the greater part of the slaking to occur, and then to mix with sand and store the mixture.

(vi) Some limes are incompletely slaked by water alone, but readily in the presence of steam ; if no other lime is available, tests should be made to ascertain whether treatment with steam is necessary.

(vii) Overburned lime is usually extraordinarily slow in slaking. It is, to a large extent, removed by screening the freshly slaked lime, but sufficient may pass through the sieve to cause trouble if ample time is not allowed for storage.

(viii) Magnesian limes and dolomitic lime are unsuitable for use in the manufacture of lime-sand bricks, as they slake very slowly and irregularly, and produce bricks which are weak and liable to crack spontaneously. Magnesian limes may be used if fully hydrated (see p. 581).

For lime-sand bricks, a fat lime containing at least 90 per cent. of (total) calcium oxide and not more than 5 per cent. of magnesia or 5 per cent. of carbon dioxide, is the best. Limes containing silica, and some hydraulic limes, can be used if their true nature is properly understood and the necessary modifications in manufacture are made. The chief objection to siliceous and hydraulic limes is the difficulty experienced in slaking them under the ordinary conditions of brick manufacture, with the result that, unless special precautions are taken, the bricks expand and crack in the hardening chamber or shortly afterwards.

If hydrated lime is used it should be made from a fat lime of the nature just mentioned.

Lump lime usually contains a variable proportion of unburned "core," which is useless to the brick manufacturer. This core should be separated by screening the slaked lime or the mixture of sand and slaked lime. A sieve with 24 holes per linear inch is usually fine enough for the purpose. When purchasing lump lime for lime-sand bricks, it is well to specify that twenty minutes after slaking it must not leave more than 5 per cent. residue when

washed through a sieve with 20 holes per linear inch. Some brick manufacturers use inferior lime, but this is a mistake, as it results in a corresponding reduction in the strength and durability of the bricks. The effect is even more serious, for the use of a lime containing, say, only 80 per cent. of lime reduces the strength of the bricks to much less than 80 per cent. of that attained when a pure lime is used, even if more of the inferior lime is used. Sometimes, however, with a lime which is impure in certain respects, but which is used in a larger proportion than would otherwise be the case, bricks of ample strength may be obtained.

As steaming, the use of a larger proportion of material than the 6–8 per cent. of pure lime, and the impossibility of using wet sand all lead to additional costs when such unsatisfactory limes are used, it is better to avoid them. Fortunately, it is easy in this country to procure almost pure calcium lime at a reasonable price, and there is, therefore, little to be gained by using cheaper lime if the latter is very impure. In some other countries, the process of making the bricks may have to be modified to suit inferior limes.

The precise behaviour of any lime in a lime-sand brickworks cannot be completely predicted from a chemical analysis; it is necessary to know the physical properties of the lime, and particularly its behaviour when slaked. Imperfect slaking is shown if the "soundness" or "expansion" test applied to Portland cement¹ is used for a mixture of lime and a suitable sand.

The method recommended by the Building Research Station for testing the soundness of lime is as follows:²

Hydrated lime. 30 g. of the sample, 50 g. of fine silica sand passing a British Standard Sieve No. 150, and 120 g. of silica sand passing a British Standard Sieve No. 18 and retained on a Sieve No. 25, with 13 c.c. of water, is mixed and used to fill a Le Chatelier caliper, placed on a glass plate, care being taken to keep the jaws closed. The material is compacted by tamping level with the top of the mould and is covered with a second glass plate on which is placed a small weight. The distance between the points of the caliper is measured and the caliper is then placed in an autoclave and kept for at least 4 hours at 170° C. (or 115 lb. per sq. in. steam pressure). One hour should be allowed for the autoclave to attain this pressure, and one hour for blowing off steam and cooling, making six hours in all. The distance separating the points is again measured, the increase representing the expansion of the sample. It should not exceed 3 mm.

Quicklime. The lime is slaked by mixing 24 g., previously ground to pass a British Standard Sieve No. 25, with 52 g. of fine silica sand and 120 g. of silica sand (of the grades used for hydrated lime) and 12 cc. of water, transferring the whole to a tin or bottle, and kept for 16–20 hours at 15–25° C. Sufficient water is then added to bring the mixture to the consistency normally used for sand-lime bricks, *i.e.* such that the mix will just squeeze into a coherent mass

¹ British Standard Specification for Portland Cement, No. 12, 1931.

² *Journal Soc. Chem. Ind.*, 52, 446T (1933). As the test-pieces are made with far less pressure than the bricks, some limes which do not pass this test produce perfectly sound bricks.

between the fingers. From 2–10 c.c. additional water may be needed. The water is thoroughly mixed with the other materials, taking care not to use too much water, and the expansion of the mixture is tested in the same way as that of the hydrated lime mixture mentioned above. The expansion should not exceed 3 mm.

Dolomitic and other magnesian limes will not usually show so small an expansion, and, therefore, tend to produce unsound bricks.

Lime-sand bricks are excellent for building and general constructional purposes, being accurate in shape, clean in appearance, and of ample crushing strength. They have been used in enormous quantities in countries where clay is scarce or fuel is dear, but, in England, they are not so popular as red clay bricks, yet they cost almost as much to manufacture. There are, however, several successful lime-sand brickworks in various parts of the British Isles.

LIME FOR USE IN CLINKER AND SLAG BRICKS

Clinker bricks and *slag bricks* are made by the same process as lime-sand bricks (*supra*) modified to suit the properties of the clinker or slag. The same kind of lime should be used and the same precautions taken.

Both these kinds of bricks are principally made as a means of using a waste material. They are strong, accurate in shape, durable, and quite suitable for general purposes, though not as attractive in colour as bricks of red burning clay.

LIME IN FIREBRICKS

Bricks for use in furnaces and kilns may be made of fireclay or of silica rock of great purity. The latter is crushed to a coarse powder, mixed with 1–3 per cent. of lime, made into bricks, and burned at a temperature of 1400° C. or above.

The proportion of lime used is so small—averaging only $1\frac{1}{2}$ per cent.—that it is foolish to use any but the best lime. It should contain at least 95 per cent. of free lime, and, twenty minutes after being slaked, should not leave more than 5 per cent. of residue when washed on a sieve with 20 holes per linear inch. Hydrated lime of the same quality is equally satisfactory and saves the trouble spent in slaking. Lean lime is almost useless; the best lime for the purpose is one which, on slaking, produces a plastic putty.

Air slaked lime is not objectionable if due allowance is made for its composition and a correspondingly larger proportion is used.

The smaller the particles of lime, the more suitable are they for silica bricks, as their action is largely superficial and a given weight of lime in very small particles will cover a larger area of rock particles than an equal weight of coarse particles of lime.

It is a mistake to mix lump or ground quicklime with the crushed rock, as it is almost impossible to secure a uniform mixture of such lime with the silica.

The best procedure is to add the lime in the form of milk of lime which has previously been passed through a sieve having at least 20 holes per linear inch.

Dolomitic and magnesian limes do not appear to be as suitable as high calcium limes for making silica bricks, though the reason for this is not known.

Silica bricks are chiefly used in the arches of furnaces and under other conditions where a high temperature is attained. They are more sensitive to rapid changes in temperature than are other firebricks.

LIME IN POROUS BRICKS

Bricks of unusual porosity and very "light" in weight are made of crushed pumice or kieselguhr, mixed with 10 per cent. of hydraulic lime or Portland cement and sufficient water to form a paste. They are moulded by hand and allowed to dry and harden for several weeks, after which they are ready for use. Such bricks have a low crushing strength which is, however, ample for the purpose for which they are used, *viz.*, partition walls and, to a less extent, sound and heat insulators.

LIME IN ARTIFICIAL STONE

Artificial or Reconstructed stone is made of sand or crushed rock, suitably graded to contain the requisite proportions of grains of various sizes, and mixed with a binder or bond. Lime is very suitable for the purpose if the blocks are afterwards hardened in a chamber heated with steam under pressure, as in the manufacture of lime-sand bricks. This process produces a whiter and more pleasing product than that in which Portland cement is used as a binder, unless white Portland cement is used, and that is costly.

Ford's Silicate Stone is an artificial stone made by mixing 18 parts of fine sand with 1 part of chalk lime and ramming the mixture dry into a mould. A vacuum is formed in the mould, and the lime is slaked by admitting boiling water, after which steam, under a pressure of 120 lb. per sq. in., is applied to ensure complete slaking and form a lime silicate. The resulting stone is homogeneous, easy to work, and very durable.

The lime used for artificial stone should be of the same quality as that used for lime-sand bricks (p. 584) and about the same proportion (6 per cent.) should be used.

Artificial stone is chiefly used for lintels, window sills, steps, quoins, entablatures, and most purposes for which dressed stone is employed. The artificial product is cheaper, as it can be shaped by moulding instead of carving, and there need be no wastage due to unexpected flaws in the stone. Since 1918, the use of artificial or reconstructed stone has increased very rapidly. The quality of the product depends chiefly on a careful selection and grading of the stone, on the use of a suitable, plastic lime, and on its thorough distribution through the mass.

THE USE OF LIME IN CONCRETE

The addition of lime putty or of hydrated lime to cement mortar or to concrete increases the plasticity and smooth working; it also makes the concrete whiter and may, if the aggregate contains crushed bricks, trass, or other

pozzuolanic material, make the concrete waterproof. Numerous statements have been published to the effect that the addition of slaked or hydrated lime to a concrete mix will produce a watertight concrete. This is only true when the water is comparatively motionless. The lime is soluble in water and will, in time, be removed from the concrete, but, if the aggregate is well chosen, the proportions of cement, sand, aggregate, and lime, are suitable, and the mixing properly done, the addition of the lime may so increase the plasticity of the mixture that a concrete with very small pores is produced, which is, for a long time, more resistant to water than concrete to which no lime has been added. Unless these precautions are taken, the addition of lime will not, in itself, produce much improvement in the watertightness of the concrete, but it will make the concrete more easy to place and finish, and enables a smaller proportion of water to be used. In this way, its influence is indirectly beneficial.

Hydrated lime makes concrete more watertight for the following reasons : (i) it increases the workability of the mix ; (ii) it reduces honeycombing, stone pockets, etc., by causing the particles of aggregate to arrange themselves so as to produce maximum density ; (iii) it aids in filling the voids and thus prevents the passage of water through them ; (iv) it prevents unmixing or segregation which is specially liable to occur when much water has to be used to make the concrete workable ; and (v) it reduces the relative amount of water required to produce a concrete of workable consistency.

The increase in waterproofness only occurs when the concrete is intermittently in contact with water. If the concrete is kept continuously wet, the lime will be dissolved and so removed, and the concrete will then be porous. Hence, the addition of lime to concrete should not be made without due consideration of the conditions to which the concrete will be exposed, and, unless a concrete mix is difficult to work, it is usually better to avoid the addition of lime, and to vary the composition of the concrete. Where this is impracticable, the addition of hydrated lime is advantageous.

A large number of tests by Duff Abrams showed that the addition of lime slightly reduces the strength of concrete, but this is not serious if the proportions mentioned are not exceeded.

The richer the concrete, the less does the addition of lime increase its workability so that lime is chiefly used in lean concretes.

It is very important, according to D. Abrams, that the proportion of water used should not exceed that required to give the best results, and it is almost equally important that the concrete or mortar should be kept well wetted for about a week after it has been placed.

The lime should be fully slaked and in the form of a fine powder, free from all coarse material. Hydrated lime, if made from a sufficiently plastic lime, is wholly satisfactory, but properly prepared slaked lime, made into " milk of lime " and used instead of part of the water normally required, is equally satisfactory, though less convenient to most builders.

The proportion of lime to be added depends on the composition of the

concrete. An excess should be avoided, but the following figures represent normal practice :

TABLE XLIX.—*Lime-Concrete Mixtures*

Mixture			Pounds of hydrate per 100 lb. bag of cement.
Cement	Sand	Aggregate	
1	1½	3	8
1	2	4	10
1	2½	5	12
1	3	6	15

The hydrated lime is added to the batch as it goes into the mixer. Where large batches are the practice, sacks or half sacks are convenient units to use ; for small batches, pails or measuring boxes are preferable.

Hydrated lime weighs 40 lb. per cubic foot, and a 100 lb. paper bag contains 2.5 cubic feet. A measuring box, 12 ins. square, will hold approximately 3.33 lb. of hydrate for each inch in depth.

4. THE USE OF LIME IN ROAD AND PAVEMENT CONSTRUCTION

Lime is only used to a very small extent in road construction in the British Isles, where earth roads are unimportant, but in the United States, where they are larger and more extensive, the use of lime in them is well recognized.

For *Earth Roads*, any slaked lime of good quality made from a fat lime may be used, but the larger the proportion of free lime the better. Lime containing much lump material is objectionable because it does not mix readily with the earth, and is wasteful. A good hydrated lime is excellent in every respect.

An earth road must be in reasonably good condition before it can be surfaced, and the lime can be added with a minimum of extra work while the road is being made. In this way the cost of lime treatment is reduced to practically the cost of the lime alone. When treated with lime, the road will provide a suitable foundation for any further improvement that may be added at a later date.

When fine slaked lime or hydrated lime is mixed with the top layer of earth in the road, the soil loses its stickiness and does not cling to the wheels of vehicles. Because the wheels do not pick up the mud, the road remains smooth, and any excess of water drains off before it has a chance to soak in. At the same time, the lime serves to stabilize the soil, so that wheels do not sink in so much when the road is wet. Hence, the road remains smooth and firm and is free from ruts during weather which would make an untreated road almost impassable.

The method of treatment to be employed will vary somewhat with the earth, the moisture conditions, and the tools available. If the earth is a heavy

clay, the road should be dry when the work is started. It is best to plough the roadway to a depth of 6 in., breaking about 2 in. at a time to avoid turning out large clods, using a brush plough, rooter, or a scarifier. The loose soil is then broken up as finely as possible with a disc harrow before the lime is spread.

Sacks of lime are distributed along the road and so spaced as to give the proper amount of lime per square yard. The lime is spread in a uniform layer and thoroughly harrowed into the loose soil. If the treatment is more than 3 in. deep, it will be necessary to turn over the loose soil with a plough during the harrowing in order to mix the lime and earth thoroughly to the full depth of the treatment.

The amount of lime required depends upon the type of earth. For instance, a heavy clay may reach its greatest stability with an addition of 2.8 per cent. of lime, while a loamy clay may reach its maximum stability with 3.6 per cent. For a depth of 6 in., this is equivalent to 12.6 lb. and 16.2 lb. of lime per square yard, respectively. In estimating, the earth in place may be taken as weighing 100 lb. of dry material per cubic foot.

Tables L and LI published by the American National Lime Association are useful :

TABLE L.—Quantities of Lime for Roads

Depth of Treatment.	Pounds of Lime per Square Yard.			
	2.5 per cent.	3.0 per cent.	3.5 per cent.	4.0 per cent.
2 in.	3.75	4.50	5.25	6.00
3 in.	5.62	6.75	7.87	9.00
4 in.	7.50	9.00	10.50	12.00
5 in.	9.37	11.25	13.12	15.00
6 in.	11.25	13.50	15.75	18.00

TABLE LI.—Widths and Areas of Roads

Width of Road in feet.	Square Yards of Surface per Mile.
12	7,040
14	8,213
16	9,387
18	10,560
20	11,733
24	14,080
30	17,600

Experience has shown that less than 2.5 per cent. of lime is insufficient, while more than about 4 per cent. is generally unnecessary. With most of the troublesome clay soils, an addition of 3.5 per cent. will be most effective, while for silty soils 2.75 per cent. will produce the desired results. For a 6-inch treatment, this is equivalent to about 16 lb. of lime per square yard for clays, and 12.5 lb. per square yard for silt loams. There is no economy in treatments less than 3 in. in depth, and 6 in. has been found most satisfactory. Treatments of still greater depth are increasingly more effective, but require deep tillage machinery.

In addition to its use in improving earth roads, lime can be used to stabilize the soil on roads which are to receive a thin layer of gravel or other wearing surface. Regardless of the type of surface which is to be put on the road, it is necessary to have the sub-grade, or earth base, in such structural condition that the soil is stable. The stable sub-grade will prevent many cracks and waves in the wearing surface.

In many localities, the greatest expense in maintaining gravel roads comes through the sinking of the gravel into the plastic soil beneath and this loss requires the resurfacing of the road at frequent intervals. When the road is treated with lime, the structure of the soil is changed so as to increase its bearing power and keep it uniform under all weather conditions. The soil will then cease to work up through the gravel and change the surface back to an earth road as may be the case when lime is not used.

Farmers find lime treatment an ideal method for improving private lanes and for drying up barn lots and the earth floors in their stables. The lime corrects acidity, improves drainage, and makes a clean, firm, resilient floor, free from objectionable odours.

Treatment with lime is often of great value in landing places for aeroplanes and for football fields. The improved drainage of the soil and its greater water capacity tend to prevent the formation of a slippery surface. In addition to improving the stability of the soil and speeding up the drying out of the ground after a rain, the lime treatment also encourages the growth of thick, tough sod, an essential element in any good athletic field.

For *Concrete Roads*, the addition of lime makes the concrete more workable and more dense, as described in the section on "The Use of Lime in Concrete" (p. 588). The addition of a suitable proportion of lime also facilitates the uniform distribution of the water; it reduces and often completely prevents cracking and spalling, and reduces the amount of rolling needed to secure a compact road way.

In *Asphalt Pavements*, extensive tests in the United States have shown that hydrated lime is one of the best, if not the best, fine fillers. It is much finer than ground limestone, and has a stabilizing effect on the paving material as a whole which is not possessed by limestone, so that 13 per cent. by weight of hydrated lime is equivalent to about 20 per cent. of stone dust, and 8 per cent. of quicklime is equivalent to about 15 per cent. of stone dust. Lime is especially suitable as a filler when very fine sand is used.

5. USE OF LIME IN THE CHEMICAL INDUSTRIES

Lime is used extensively in the chemical industries for a great variety of purposes, as a (a) neutralizing agent ; (b) hydrolyzing agent ; (c) saponifying agent ; (d) causticizing agent ; (e) coagulant or precipitant ; (f) absorbent of gases and moisture ; (g) solvent ; (h) flux or slag forming agent, and for several other minor purposes.

The selection of lime for use in the chemical industries sometimes calls for great care. Insistence on an almost pure calcium oxide or hydroxide is not alone sufficient, as the physical properties of the lime often have important effects. For instance, when using limes of the same chemical composition, but derived from different sources, one lime will be preferable to another when making caustic soda because the resulting carbonate will settle rapidly instead of remaining in suspension. Another lime in the manufacture of bleaching powder will carry more chlorine, and another will bulk to produce a considerable variety of different volumes. Considering these few reasons as typical, it is easy to comprehend why users of lime in manufacturing processes are guided more largely by experience than by exact technical knowledge, and, as a result of this, some lime users are accustomed to a lime which really is not the proper and most economical product for their purpose.

The chemical industries use a far larger quantity of lime than is generally realized, several thousand tons per year being used for the manufacture of alkalis and ammonia alone. Owing to the troublesome nature of the sludge when impure or badly burned lime is used, hydrated lime is specially advantageous. Its form is peculiarly suitable for the chemical industries generally ; it is ready for use and is in every respect better than lump or ground lime.

In the *Neutralization of Acids*, lime has long been regarded as the cheapest and most convenient base, and is extensively used. The fact that most of its salts are insoluble is objectionable for some purposes, as they produce a sludge which is expensive to handle ; but it has compensations in other ways, by making the removal of the salts relatively easy. Sometimes the lime salts are decomposed at a later stage in the manufacture, and the lime so recovered may be used again ; but this is unusual.

Lime is used (i) for neutralizing arsenic acid in the manufacture of *insecticides* ; (ii) for concentrating *citric acid* in the manufacture of that substance from fruit juices ; (iii) for neutralizing *tar acids* in the manufacture of phenol (carbolic acid), cresylic acid, sulphonated naphthalene derivatives and ammonia, and in the manufacture of many *dyes* ; (iv) for concentrating *fatty acids* in the manufacture of soap.

For use as a neutralizing agent, the lime should be as free as possible from silica, alumina, and iron oxide. Magnesia is not usually objectionable, but is so in some instances, as when a pure calcium salt is required. A small proportion of unburned lime is not usually objectionable, but where the liquid is viscous the retention of bubbles of carbonic acid gas may cause frothing and prevent rapid settlement.

It is difficult to effect accurate neutralization when lump lime is used, but

this may be employed as a " preliminary " charge. Where the total amount of lime to be added at a time is not large, however, it is better to use ground lime or hydrated lime. Where very accurate neutralization is needed and an excess of lime must be avoided, it is preferable to add nearly sufficient lime at first, and to finish the neutralization by cautiously adding " milk of lime." When an excess of lime does no harm, lump lime, ground lime, or hydrated lime may be used.

In some chemical works a considerable saving in cost might be effected by the use of slaked or hydrated lime instead of lump or ground lime. Much lump lime is so irregular in composition that a large excess is added " for safety." This is not only wasteful in lime, but it often necessitates additional labour in cleaning out tanks, etc., and sometimes causes a serious waste of the manufactured product. To use ground lime is extravagant, as the cost of grinding lime is always greater than that of slaking it. Moreover, slaking has the advantage of enabling most of the impurities in the lime to be separated by screening or sifting, so that the user who buys lump lime and slakes or hydrates it has a rough idea of the quality of the lump lime supplied. It is much more difficult to judge this when ground lime is used.

Slaked or hydrated lime has a further advantage, inasmuch as it does not heat the solution to which it is added as does quicklime or ground lime and, consequently, there is less risk of the loss of valuable-material by volatilization. This does not matter in some cases, but in others it is important.

Except for the crudest works, lime of good quality should be used for neutralization, as this prevents many subsequent difficulties from occurring. Where a liquid is neutralized prior to its discharge into a river or sewer (so as to comply with Government regulations), a poorer quality of lime may suffice.

Hydrated lime contains about 25 per cent. of combined water, so that 74 lb. of hydrated lime are required to neutralize the same amount of acid as would neutralize only 56 lb. of quicklime. It thus appears to be wasteful to use hydrated lime, but the convenience of this material and the smaller proportion of impurities in it make its use profitable where accurate work is done. In a well-organized chemical works it would, probably, be cheaper to buy lump lime and hydrate it on the works, but as the plant required is somewhat costly, several works prefer to buy hydrated lime ready for use.

In the *Preparation of Organic Acids*, lime is used as a cheap base which combines with the acid and so enables it to be separated from the various impurities present in the crude acid. The lime salt is later decomposed by the addition of a mineral acid which liberates the organic acid in a relatively pure form.

Acetic acid obtained by distillation is usually in the form of a very dilute solution, but, by adding lime, calcium acetate is formed and the solution can be concentrated without appreciable loss of acid. The calcium acetate is, later, decomposed by sulphuric acid and the acetic acid obtained in a concentrated form.

In the preparation of *tartaric* and *citric acids*, the use of hydrated lime to precipitate the acid as a lime salt is preferable to lump lime and to chalk or whiting. If either of the latter is used alone, the amount required is difficult to gauge and an excess is wasteful in carbonate. Some carbonate should be used, however, for the reasons stated in Chapter IV.

Crude tartaric acid is sometimes purified by adding milk of lime which precipitates the tartarate and so permits it to be separated. This involves a larger volume of liquid, which has to be filtered, and always retains some tartarate in solution; if hydrated lime is used, this double loss is saved, though a little milk of lime is often useful for ensuring the final adjustment of the precipitation.

Oxalic acid is made by heating sawdust or other vegetable matter with caustic soda lye and eventually fusing the mixture at 240–250° C. The crude product is extracted with water and mixed with milk of lime or hydrated lime, which precipitates calcium oxalate; this is separated and decomposed by sulphuric acid, thus liberating the oxalic acid which is purified by crystallization. The lime used should be as pure as possible.

In the manufacture of *nitric acid*, a dilute acid is obtained which is difficult to concentrate direct, but by neutralizing with lime, then concentrating, and afterwards liberating the acid with sulphuric acid, a considerable saving is effected.

✓ In the manufacture of *hydrochloric acid*, the last traces of acid (which would be lost if water alone were employed to condense the gas) may be retained by milk of lime, which is poured over coke in wide mouthed vessels so that any traces of hydrochloric acid are converted into calcium chloride and may be recovered later.

As a *Base* in the manufacture of chemicals, lime is extensively used. It is the cheapest of bases and so is largely employed in the manufacture of chemicals, including the preparation of caustic soda, the liberation of ammonia from ammonium salts, and in the manufacture of bleaching powder, calcium carbide, and various chemicals. Where there is no objection to carbon dioxide being evolved, the use of chalk, whiting, or other form of calcium carbonate is cheaper than lime, though practically twice as much is required and various inconveniences may be created. Some of the lime compounds form the raw material for preparing other chemicals. For instance, lime can be used as a base to neutralize the various acids distilled from wood and so produce crude *calcium acetate* which is purified, if necessary, by recrystallization, and can then be used as a source of acetic acid, acetone, alizarin red, and various acetate mordants for "fixing" dyes.

Lime is also used as a base in the purification of tar oils and sugar juices, the manufacture of soap, and other chemical products.

Various sulphonated compounds, used as raw materials in the manufacture of dyes, etc., are best produced by the use of lime (p. 606). In ore-flotation, lime is sometimes used to impart a slightly alkaline reaction.

As an *Absorbent of gases*, lime is largely used: (i) in the manufacture of

bleaching powder, etc., (ii) to absorb objectionable gases and so separate them from the main product, as in the manufacture of coal gas; and (iii) to prevent objectionable gases from escaping into the atmosphere. For all these purposes a nearly pure calcium lime of great porosity is required. Hydrated lime is usually quite suitable, though ground quicklime is sometimes preferred where the gases are very moist and would reduce hydrated lime to a non-absorbing paste.

In *Hydrolysis*, lime is extensively used for causing the elements of water to combine with various compounds, as in the production of glue, the pre-vulcanization treatment of rubber, and the manufacture of various cellulose products. In such cases, lime softens the materials and makes them more reactive and, therefore, facilitates subsequent treatment.

As a *Drying* or *Dehydrating agent*, lime is cheap and efficient. It is chiefly employed as a preliminary dryer and may suffice, but for accurate work, a more powerful yet more expensive, drying agent may be used in a subsequent stage. The drying properties of lime are chiefly used in the manufacture of commercial alcohol, petroleum, acetone, and some greases.

For dehydrating alcohol, quicklime is mixed with the alcohol, a large excess of lime being used. The mixture is allowed to stand for some time and is then distilled, the alcohol passing off and being condensed. The distillation must not be carried too far, as the last portions of the distillate contain water.

Habermann has suggested that if the lime is contained in a gauze cylinder suspended in the vapour (instead of being loose in the still) less lime will be needed. In that case, the lime should be in pieces about $\frac{1}{2}$ -in. diameter.

Lime is used in the petroleum industry for the dehydration of petroleum and greases. It is also used as a dehydrating agent for sodium acetate in making *acetone*.

In *Saponification*, the lime is heated with fatty acids, fats, oils, greases, or various tar products, and forms *soaps* which can be separated from the associated liquor. *Glycerine* is often a by-product of the reaction. The term "saponification" is often applied in the chemical industry to a similar process in the production of organic compounds in which lime is also used.

As a *Causticising Agent*, lime is used in the manufacture of alkali hydroxides such as *caustic soda* and *caustic potash* from the corresponding sulphates, carbonates, or phosphates. In each case, the lime, being the more powerful base, decomposes the carbonate or other salt present, forming, *e.g.* calcium carbonate and a hydrate; the carbonate can be separated if necessary by filtration, and the hydrate recovered by evaporation.

As a *Coagulant*, lime is employed for clarifying various liquids, such as sugar and other plant juices, sewage, water, etc., to promote the separation of slimes containing useful metals, and so on.

The use of lime in the artificial ice industry also depends upon its coagulating power. Water suitable for artificial ice must be clarified and purified, and the most satisfactory process for this is the use of lime in combination with other reagents.

Lime also finds use as a flocculating agent in the rubber industry. The latex may be flocculated with lime and the clays used in making the compounding ingredients are also flocculated with lime to render them suitable as a filler for the rubber.

The use of lime in the sorghum industry also depends upon its coagulating capacity. The sorghum juice is clarified with lime in preparing it for the boiling operation.

The coagulating action of lime is also employed in the disposal of sewage, whereby the sewage is clarified by coagulating the colloidal matter with lime in combination with other chemical substances.

Similarly, water supplies may be deodorized and deferridized. Waste waters are also coagulated and disposed of with the use of lime.

The coagulating action of lime is one of its important properties and its uses by virtue of this property are numerous.

As a *Precipitant*, lime is used for forming insoluble compounds, which can then be separated by filtration and afterwards decomposed so as to enable the desired constituent to be recovered.

Lime is used in the soap industry as a precipitating agent for making lime soaps, which are used as lubricants and waterproofing material.

In the paint industry, lime is used for precipitating colloidal pigments, such as Satin White.

The sugar industry employs lime for precipitating carbonates, phosphates, and sulphites which function as absorption media for impurities in the juice. Cleaning mixtures are made by the precipitation of alumina compounds with lime.

Lime is used also as a precipitating agent for the rare earth oxides in the manufacture of cerium for the gas mantle industry.

As an *Absorbent*, lime readily absorbs most acid gases and some others, such as chlorine. This property makes it useful in the electrolytic alkali industry in which it is used to absorb and combine with chlorine in making bleaching powder, alkali hypochlorites and chlorates. It is the absorbing capacity of lime which makes it useful in the fixation of atmospheric nitrogen, where it is used to absorb nitrogen oxides in making nitric acid.

Lime also finds use in the paper industry. As a result of its capacity for absorbing gases, lime will absorb sulphur dioxide, forming bisulphides and sulphites, which are used for making paper pulp.

For the same reason, lime is used in purifying illuminating gas, in which process it absorbs sulphur dioxide, hydrogen sulphide, and hydrocyanic acid, rendering the gas non-corrosive to boilers and metal fixtures.

The absorption of carbon dioxide by lime is a process employed in the carbonation of sugar juices and in the manufacture of magnesia insulating material, and in the manufacture of phenol.

In the wood distillation industry, the absorption of acetic acid vapour by lime produces acetate of lime. Acetic acid may then be made from the acetate by distillation with sulphuric acid.

As a *Solvent*, lime is used in making casein glue and in the preliminary treatment of hides, prior to tanning.

As an *Oxidizing agent*, lime is used in the electro-thermic industry, where it oxidizes carbon, thereby reducing itself, forming calcium carbide. Similarly, lime has been used in the laboratory for making metallic calcium and magnesium. Of much more importance, however, is the manufacture of calcium silicide, whereby lime functions indirectly as an oxidizing agent.

As a *Reducing agent*, lime is used in the manufacture of calcium peroxide by reduction of hydrogen peroxide or other strong oxidizing agents. This is one of the newer uses of lime which may have important possibilities.

As a *Lubricant*, lime is used in the high temperature lubrication of dies in the drawing of steel-wire. Its fineness and refractoriness make it especially suitable for this purpose.

As a *Flux*, lime is used in blast furnaces, in the basic open hearth process for refining steel, and for the manufacture of glass, pottery, and porcelain in the ceramic industries. The electrothermic refining of steel, nickel, and copper involves the use of lime as a slag forming material. There is evidence that lime may function as a solute in fused melts whereby alkali earth metals can be produced by electrolysis. Limestone is used more extensively than lime in furnaces, but when the cost of carriage of the limestone and the space uselessly occupied by it in the furnaces are considered, it will often be found that lime is cheaper to use than stone, though the price per ton is greater.

As a *Catalyst*, lime facilitates various reactions and the production of useful chemicals, such as sodium peroxide and calcium cyanamide. Lime also assists in the vulcanization of rubber, and the hydrogenation of nitrogen in the Haber process of fixing atmospheric nitrogen. In the fusion of chromite with alkalis, lime functions as a catalyst in the preparation of alkali dichromates. The esterification of glycerine and the manufacture of chlorine in the Weldon chlorine process also involve the catalytic action of lime. The use of lime as a catalyst in the manufacture of organic compounds is also being extended. Some of the newer applications include the manufacture of acetone from acetic acid and the preparation of benzoic acid from benzyl chloride. One of the developments which seems to promise considerable tonnage is the process recently worked out for the manufacture of methyl or wood alcohol from methyl chloride by the use of granulated calcium hydroxide. Substitutes for platinum catalysts made from mixtures containing lime with other metallic oxides are finding satisfactory use in the oxidation of ammonia—a process which is extremely important in the development of nitrogen fixation process.

Lime as an *ionizing agent* finds application in the production of metals by the electrolysis of fused metals and in the clarification of sewage.

Ammonia can be recovered from its compounds or from solutions containing it by adding lime and distilling. The ammonia is thereby separated from all non-volatile substances. This use of lime is described more fully in the section on "Gas manufacture."

As a means of *Purification*, lime is largely used in the chemical industries.

It precipitates citric, tartaric, oleic, palmitic, and other acids as insoluble lime salts and so enables them to be separated from various impurities ; it can be used to purify Epsom salts, table salt, Glauber salts, borax, and ammonium sulphate.

In the soap industry, glycerine water is purified with the use of lime as a precipitating agent.

In the purification of illuminating gas, lime absorbs sulphur dioxide, hydrogen sulphide, and hydrogen cyanide.

Alkaloids, dye intermediates, and other organic compounds are purified with the use of lime.

In the metallurgical industry, lime is used as the purifying agent for ferro-chromium and as a decarbonating, dephosphorizing, and desilicizing agent.

In the petroleum industry, lime may be used for the desulphurizing of mineral oils. In the purification of palm oil, it is used as a deodorizing agent.

In the *Alkali Industry*, more lime is used than in any other. It is essential in the manufacture of *soda ash* and *caustic soda*, but the producers of these chemicals usually have their own lime kilns and only buy when—owing to some abnormality in the market—they can buy lime more cheaply than they can produce it.

In the manufacture of *soda ash* by the Leblanc process, lime is not used, but if the *salt cake* obtained as a by-product is to be employed in the manufacture of glass, it is usually purified and freed from iron compounds by dissolving it in water and making the solution alkaline with lime or lime water which precipitates the iron as ferric hydroxide. For this purpose, the lime should be as pure as possible, or the resulting salt cake will be of inferior quality. As the lime is to be added to a solution, it is preferable to use carefully slaked or hydrated lime.

In the Staveley process of alkali manufacture, salt cake (sodium sulphate) is mixed with calcium carbonate, the product being decomposed by carbon dioxide, which liberates carbonic acid and forms sodium carbonate. The calcium carbonate is prepared by mixing carbonic acid with milk-of-lime. For this purpose, the lime should be as pure as possible and either slaked and sieved at the works, or hydrated lime should be bought.

In the manufacture of soda ash by the Ammonia Soda Process, both lime and carbon dioxide are required, so that these substances are invariably produced at the chemical works, little or no lime being purchased. In this process, the lime is required to recover the ammonia from the waste liquor, so that pure lime is not essential, though very impure lime is wasteful and causes sludge troubles in the stills. It is advisable to slake the lime and screen it before use or to use hydrated lime ; this reduces sludge troubles and wastage of lime to a minimum and fully compensates for the apparent extra cost of the lime.

Caustic Soda is made by two processes, one electrolytic (in which lime is only used to purify the brine, as described under *Table Salt* on p. 600) and the other process in which lime is used as a chemical reagent. In the latter, soda

ash or other form of sodium carbonate is dissolved in water, and lime is then added so as to produce caustic soda, which remains in solution, and carbonate of lime, which is precipitated. The rate at which the latter settles depends on the lime used, and for that reason a practical trial with a new source of lime is necessary. Much stronger solutions of caustic soda are obtainable if only part of the lime is added and the precipitated carbonate is removed immediately; the remainder of the lime is then added and the causticization completed (see Courtauld's Pat. 182,661).

The lime used may be (i) milk-of-lime; (ii) quicklime, or (iii) hydrated lime. The first must be made from the second or third, the latter being preferable as it avoids the disposal of some sludge. The use of milk-of-lime is the more accurate, but requires the evaporation of more water in order to obtain the soda. The use of quicklime is wasteful and does not always causticize all the soda.

The lime used in the manufacture of caustic soda must be fairly pure, and should not contain any clayey matter or "core," as if either is present the caustic liquor is very difficult to clarify.

Magnesian limestone must not be used, but a very small proportion of magnesia is harmless.

The burned lime should contain as little calcium carbonate as possible as this is useless in the manufacture of caustic soda. For this reason, the quality of the lime is not determined by the total content of calcium oxide, but by the proportion of calcium oxide which is available in the process for which the lime is used. In the United States 85 is regarded as a fair standard for the percentage of available lime and 70 as that at which the value of the material is so low that it is not economical to use the lime for this purpose.

Equally as important as the absence of impurities is the use of a lime which produces a rapidly settling carbonate. This property can only be ascertained by actual use, but it is so important as to preclude the use of some limes of great purity.

Various methods are used for utilizing the lime sludge produced in the manufacture of caustic soda. It may be regarded as a crude calcium carbonate. It has been used to replace some of the limestone in the manufacture of black ash. It has also been burned in a rotary kiln and converted into quicklime and used for Portland cement or for preparing further quantities of caustic soda. The sludge may sometimes be used in glass works, though it is seldom pure enough for this purpose. Stürcke and Jobbins have treated the mud with carbonic acid and obtained a pure calcium carbonate suitable for use as whiting.

Table salt is obtained from crude brine, which is usually purified by adding milk-of-lime (preferably made from hydrated lime) in order to precipitate magnesia (as hydrate) and any bicarbonate present. Ammonium carbonate is then added to precipitate any calcium sulphate and chloride. The excess of ammonia is afterwards recovered from the liquor by adding milk of lime and distilling. The lime used must be as pure as possible and it is preferably used in the form of hydrate, though quicklime which has been carefully slaked and sifted at the chemical works is often used.

Soda lime is a mixture of lime and caustic soda which is used extensively as an absorbent of gases. It requires a very pure lime in a fine state of division, and though the sales are very small, the prices realized are high enough to ensure a fair profit. Superfine lime is not as satisfactory as that which is rather coarser. The lime should be slaked or hydrated before use. It is then moistened with a solution of caustic soda, and mixed mechanically in a closed vessel so as to avoid risk of absorbing carbon dioxide from the air. The mixing should be arranged so as to form granules, which are afterwards separated by sifting. The proportion of water present is important, as if the mixture is too wet the granules will have a low absorption. The granules are then dried under carefully controlled conditions. Sodium permanganate may be added as an oxidant and as an indicator. Well made soda lime will neither form a free liquid nor cake after prolonged exposure to moist air. To ensure this, it must not contain more than 20 per cent. of caustic soda.

The older method of making soda lime by stirring powdered lime into molten caustic soda is not suitable for modern requirements as the product has a low absorption.

Potash is made in the same manner as soda (the corresponding potassium compounds being employed), and lime is similarly used in its production. The properties which the lime should possess are the same as in the manufacture of soda. Potash is also prepared by heating a felspar or other potash-bearing product with lime and calcium chloride at 1100–1300° C.

The lime must be in an extremely finely divided state and a considerable excess of it must be used, or the yield of potash will be low. Limestone or chalk may be used instead of lime, but prolongs the heating process, as the carbonate must first be converted into lime.

In the United States, potash is obtained by heating greensand with lime both in a finely-divided state. As the materials must be mixed with water before being heated, the use of hydrated lime is advantageous.

Ammonium Salts are described in the section on Gas and Coke (p. 608).

Chlorine made by the Weldon process requires the addition of milk-of-lime to precipitate the manganese. The most suitable lime is a moderately pure high calcium lime, preferably hydrated, which does not contain more than 2 per cent. of carbon dioxide and not more than 2 per cent. of magnesia.

Bleaching Powder is a valuable agent in the textile industries, in which it is largely used as a convenient source of chlorine, though in recent years it has been partially replaced by the corresponding soda compounds. It is also used in sanitation as a disinfectant and, to a small extent, for various other purposes.

Bleaching powder is made by passing chlorine gas over dry hydrated lime in the form of a powder; the chlorine is absorbed and a fairly stable compound produced, consisting of a mixture of basic calcium hypochlorite, basic calcium chloride, and water.

A very pure fat lime is required, and it should be fully hydrated, as unslaked lime in the bleaching chambers must specially be avoided.

Fat limes absorb chlorine much more readily and in larger quantities than

leaner limes, and the bleaching powder prepared from fat limes may be preserved much more easily than that made from lean ones.

Lime which is to be used for the manufacture of bleaching powder must be burned very carefully and under no consideration must the ashes of the fuel used for calcining be allowed to mix with the burned product. Hence, gas-fired lime or that produced in externally-fired kilns is preferred.

The temperature at which the lime is burned is very important. The lime should be properly calcined, but it must not be over burned. The best finishing temperature and conditions of burning are those under which the lime produced contains less than 2 per cent. of carbonate and the slaking is complete in 20–30 minutes. Magnesia, if more than about 2 per cent. is present, is objectionable as it renders the powder hygroscopic and unstable.

There should be less than 0.5 per cent. of iron oxide as this substance tends to discolour the bleached products.

The particles of lime should be as fine as possible, and, for this reason, a well-made air-separated hydrate is preferable to a carelessly slaked material. The particles of lime can scarcely be too fine for this purpose. The lime, when ready to enter the chlorinating chambers, should not contain more than 4¹ per cent. of excess water, nor more than 2½ per cent. of carbon dioxide gas. About 2–4 per cent. of excess water is the best proportion, but the higher figure should not be exceeded, as whilst a damper lime facilitates the absorption of chlorine, it gives a much denser mass, with the result that a large proportion of the lime does not come into contact with the chlorine gas. Perfectly dry hydrated lime is useless as it does not absorb sufficient chlorine.

Any clay present is objectionable, as it impedes the settling of the powder when in use.

The best lime for this purpose is one which forms a large bulk of slaked lime (at least three times the volume of the original quicklime) of an open or porous texture into the interstices of which the chlorine can readily penetrate. Hence, the physical nature of the lime is almost as important as its chemical composition, and a dense slaked lime is almost useless. The misleading term "diffusivity" is sometimes used to indicate the ease with which lime will absorb chlorine gas, but it should be clearly understood that a high diffusivity is wholly due to the size and shape of the particles of slaked lime, as a result of which they form a porous mass. Any means—such as sifting the lime after slaking—which will separate the particles will increase their diffusivity, and, conversely, any means whereby the particles are compressed more closely together will reduce the diffusivity and render the lime less able to absorb the chlorine gas.

Under normal conditions, a dense limestone, such as marble, will yield a lime of low diffusivity, whilst a porous limestone, such as oolite or chalk, should yield a highly diffusive lime, but, for reasons which have not been fully ascertained, this is not always the case and the lime most generally

¹ Some manufacturers consider that 7 per cent. of moisture is the best proportion, whilst others prefer only 1 per cent.

favoured by bleaching powder manufacturers is made from a dense limestone.

The best bleaching powder prepared from French raw materials is rather more bulky than that made from English and Irish limestones, and is preferred by some paper makers, but most textile bleachers employ the English product.

No means, other than the test of actual use, has yet been devised for comparing the relative values of lime from different sources, as the power to absorb chlorine appears to be incapable of accurate determination on a small scale.

The lime should not be converted into bleaching powder immediately after slaking as it does not appear to be so readily converted as when it has been stored for a short time and has become quite cool. This cooling is a slow process, on account of the poor conductivity of the lime, so that some time is necessary before the lime is ready for use.

Slaked lime should not be left out in the sunshine immediately after slaking as this prevents its cooling down and delays the time when it may be chlorinated. As all the chlorine passed through the chambers is not absorbed by the lime, the gas may be re-circulated, but it is more usual to pass it through milk of lime so as to prevent its escape into the air.

It is seldom profitable for lime manufacturers to make bleaching powder, as the basis of the operation is not cheap lime, but cheap chlorine gas, and it is only where hydro-electric power or very cheap coal is available that chlorine can be made economically.

Bleach liquor or *hypochlorite of calcium solution* is sometimes used instead of bleaching powder; it is made by passing chlorine gas into a milk of lime containing 1-1½ lb. of slaked lime per gallon of water. It contains more active bleaching agent (calcium hypochlorite) per unit of lime than does bleaching powder, as the lime and chlorine unite more rapidly and completely when the lime is suspended in water than when it is in the form of powder. The chlorination proceeds most favourably at 30-40° C. Care must be taken to avoid supersaturation with chlorine, or some of the desired hypochlorite will be decomposed and useless compounds formed.

For making bleach liquor the lime should contain at least 95 per cent. of calcium oxide, less than 2 per cent. of alumina, less than 5 per cent. of magnesia, less than 0.2 per cent. of ferric oxide, and no appreciable amounts of sulphur, phosphorus, and titanium compounds.

Other liquid bleaches, consisting of solutions of various hypochlorites, are sometimes made from bleaching powder, but other methods, in which no lime is required, are now largely used.

Chlorates are made by passing chlorine into hot milk-of-lime, the resultant calcium hypochlorite being decomposed into a mixture of calcium chlorate and chloride. From this, potassium and sodium chlorate are prepared. The milk-of-lime should have a "strength" not above 16-17° Tw. (sp. gr. 1.12-1.14). Most chlorates and perchlorates are now made electrolytically, no lime being required. The lime should be as pure as possible and preferably hydrated, as this facilitates the production of the milk-of-lime.

Lime salts of commercial value are largely used. They are produced as a by-product under various neutralizing conditions. The most important substances are named below :

Calcium chloride is a by-product of several industries, but may be prepared separately by mixing lime with hydrochloric acid and evaporating to dryness.

Acetate of lime is made by absorbing the vapours of acetic acid, when distilled from wood, in milk-of-lime, the mixture being afterwards evaporated and the acetate recovered. It is desirable to use as pure and finely divided a lime as possible, as this reduces subsequent trouble in purification. Most hydrated lime is specially suitable, as, if well made, it is free from grit.

Calcium nitrate is made by absorbing in lime the oxides of nitrogen produced by various processes. For this purpose the lime should be hydrated, as this offers a larger surface per unit weight than ground lime, and the greater purity of the hydrate is a further advantage.

Calcium Carbide is made by heating a mixture of lime and coke in an electric furnace. It is possible to use limestone instead of lime, but the latter is more economical and produces carbide of superior quality. The lime should preferably have been obtained from white marble or mountain limestone; that from Oolitic limestone is usually unsatisfactory, the percentage of impurities being generally too high. Chalk lime, if of good quality, may be used for calcium carbide, but, as a rule, there is too much silica in this material. Lime from calcareous tufa and travertine are largely employed in Italy for the manufacture of calcium carbide, though some of these materials are unsuitable for use. They must, therefore, be carefully selected so as to obtain a suitable material. Whatever form of lime is employed, it should contain at least 97-98 per cent. of calcium oxide, as magnesia is useless.¹

The principal impurities to be avoided in lime used for making calcium carbide are magnesia, alumina, silica, iron oxide, sulphur, phosphorus, and alkalis.

Iron oxide is objectionable as it tends to form ferro-silicon.

Phosphorus is dangerous as when the carbide is wetted it tends to form phosphine gas, which is poisonous, and as it ignites spontaneously it may cause an explosion. Hence, the phosphorus content should not exceed 0.05 per cent., though in many cases it is higher. Where the coke used is likely to contain any appreciable amount of phosphorus, not more than 0.02 per cent. should be present in the lime.

The presence of silica and magnesia in carbide tends to cause too rapid an evolution of gas, so that a high temperature is produced which results in the formation of a brown dust, consisting principally of carbon, which clogs the gas producing apparatus in which the carbide is used, and this causes trouble. Silica should not occur to the extent of more than 2-3 per cent. and should preferably be less than 1-1.25 per cent. From a manufacturer's point of view, however, a small proportion of silica is an advantage, as it reduces the temperature at which the reaction takes place and facilitates the tapping of the furnace.

¹ Cf. Krieger, *Tonindustrie Zeitung*, 447 (1932).

Care must be taken in selecting the limestone, as magnesia stone usually has a very attractive appearance and may easily be mistaken for a calcareous limestone of good quality. Some carbide manufacturers stipulate that the lime used by them shall not contain more than 0.5 per cent. of magnesia, though carbide has been successfully made from materials containing as much as 1.45 per cent. of magnesia. Apart from its reducing the percentage of calcium carbide in the product magnesian limestone increases the cost of production and interferes with the tapping of the furnace.

The lime should not contain any appreciable amount of sulphur, though in most cases lime of good quality contains so little of this element that it may usually be neglected.

Aluminium compounds are less detrimental than magnesia in carbide though it is undesirable to have too much present as an impurity. It is supposed that aluminium compounds tend to form ammonia in the acetylene gas on account of the combination of some of the alumina with the coke to form an aluminium nitride which evolves ammonia in the presence of water.

Alkalis are objectionable—especially in the presence of silica—because they form readily fusible products which interfere with the action of the carbide when in use.

The physical nature of the lime used for the manufacture of carbide is also important. It should not be too dense or it will not permit the gases to escape.

Only fresh calcined lime should be used, as lime which has been kept for some time absorbs moisture and carbon dioxide from the atmosphere and so increases the cost of production of the carbide. Free unslaked lime in the finished carbide is objectionable as it causes a development of heat when the carbide is used and may create an explosion.

Attempts have been made to utilize the spent carbide, but none are completely successful (see Chapter IX).

Calcium cyanamide—an important fertilizer—is produced by the action of nitrogen on calcium carbide in the presence of calcium chloride or fluoride, the mixture being heated in an electric furnace. It has been found that carbide containing an excess of lime or a mixture of carbide and lime produces cyanamide much more readily and is free from the disadvantages accompanying the use of calcium salts.

When cyanamide is mixed with a small proportion of slaked or hydrated lime, to ensure alkalinity, and treated with superheated steam, ammonia is evolved. Hence, cyanamide is an important source of ammonia.

In the presence of water, cyanamide decomposes much more slowly and so is useful as a fertilizer, but must be used with discretion as it renders phosphates insoluble and useless.

The lime used for making cyanamide should be of the same quality as that used for calcium carbide.

Lime blue is a mixture of copper hydroxide and lime, prepared by adding lime to a solution of copper sulphate and filtering off the blue product. It is

now replaced by ultramarine which is often known by the same name. True lime blue is blackened by sulphuretted hydrogen, and so is not suitable for use in towns.

Milk-of-Lime, used extensively in the Chemical Industries, is described in Chapter X.

USE OF LIME IN THE MANUFACTURE OF DYES AND INTERMEDIATES

Most dyes may, rightly, be regarded as "chemicals" so that there is, in a sense, no need to separate the use of lime in the manufacture of dyes from that of other chemicals. It is, however, convenient to have a short, separate section, though the number of substances now made is so large that only a few typical examples can be mentioned.

In *sulphation processes*, the use of lime is confined to the neutralization of an excess of acid. It is particularly convenient as it forms an almost insoluble sulphate, and because, later, all excess of lime can be removed as an insoluble carbonate. Several kinds of sulphation processes are used in the production of many dyes and intermediates so that the total quantity of lime used for this purpose is large.

In *nitration processes*, lime is used to produce an alkaline solution, the preparation of H-acid (naphthylamine trisulphonic acid) being typical.

In the *hydrolysis of various chlorine derivations* lime is extensively used.

A *Brilliant Green*, similar in dyeing properties to Malachite Green, is made by heating benzoylchloride with lime and converting the resulting benzaldehyde into the bisulphide.

In the *conversion of anthracene* into alizarin, lime is used to remove chromic oxide from the mixture and so facilitate its recovery.

In the manufacture of *indigo* blue, lime is used to render the colour soluble and so enable it to be separated from various impurities. The colour is reprecipitated by blowing air through the solution.

Some *lakes* are fixed with hydrated or slaked lime.

Some *mineral colours*, such as *chrome yellow*, are also fixed by hydrated lime.

The use of lime in dye making is increasing as the variety of dyes increases, and especially now that sufficiently pure lime is available as hydrated lime.

In all the chemical industries in which lime is used, its value depends almost wholly on the percentage of free lime present. Lime in a state of combination may, like other impurities, be inert or actively objectionable, but in either case they involve unnecessary costs in moving them.

When quicklime is purchased and slaked at the chemical works, a product which varies from batch to batch is obtained, and unless special precautions are taken it will contain inert lumps, stone, cinders, unburned carbonate, and overburned oxide, in varying proportions, and, with these, its mechanical condition and chemical purity necessarily vary. The coarse impurities block the pipes and valves and cause other difficulties which are best avoided. Consequently, for most chemical purposes, the ideal lime is in the state of a fine powder of uniform composition and great purity. There is seldom occasion to

use quicklime in the chemical industries and, consequently, the form of lime which is most generally suitable is hydrated lime which has been screened or passed through an air-separator.

Selection of Lime for the Chemical Industries.—When lime is used as a chemical agent it is obvious that only the free calcium oxide or hydroxide is useful so that pure limes only should be used. The physical properties are, however, of almost equal importance in some branches of the chemical industry, because if the precipitate which is formed settles very slowly or is difficult to filter the lime will be unsatisfactory. This objection is well illustrated in the preparation of caustic soda liquor from recovered black ash. In this process the precipitate of calcium carbonate formed from Buxton lime flocculates and settles rapidly, but when Kent lime from the Chalk is used flocculation and sedimentation are very difficult operations. Extensive experiments with variations in the temperature of burning do not make any appreciable difference in the case of chalk lime, but a hard burned Buxton lime gives better flocculation than the same lime burned at a lower temperature. The importance of viscosity and the degree of agitation also become apparent in the preparation of calcium hydrochlorite solutions for bleaching.

6. USE OF LIME IN THE DISTILLING INDUSTRIES

Lime is largely used in several industries in which distillation is the predominant feature, especially in the distillation of wood, coal, shale, ammonia, alcohol, and some fine organic chemicals.

In the *distillation of wood*, lime is chiefly used in the production of methyl alcohol, acetone, calcium acetate, and acetic acid. The distillate consists of a watery liquid and tar. The former is separated, neutralized with lime, and distilled in an iron retort, methyl alcohol being collected in the receiver and brown acetate of lime left in the retort. Where the acetic acid is the chief product, it is obtained by distilling the watery distillate from the wood (pyro-ligneous acid) in a retort heated by coils containing superheated steam. The distillate may be neutralized with lime, concentrated, and the grey acetate mixed with sulphuric acid and redistilled.

Alternatively, the calcium acetate may be used in the preparation of acetone, which is obtained by heating it in the dry state in a retort and collecting the acetone and other volatile products after condensation.

Industrial alcohol (obtained by the fermentation of waste vegetable matter) is obtained in a purer state if the acids present are neutralized by the addition of lime prior to distillation.

Absolute alcohol is obtained by allowing rectified spirit to remain in contact with ground quicklime until the greater part of the water is absorbed, and then distilling off the alcohol.

In the manufacture of *Rum*, lime is used to correct any acidity in the juice or molasses from which rum is made by fermentation followed by distillation. Finely ground limestone, chalk, or whiting is equally effective, except that

100 parts of it are needed for every 56 parts of pure lime which would be used.

Crude Ether is purified by washing with milk-of-lime, drying over calcium chloride, and then re-distilling the ether.

In the *distillation of coal* for the production of coke and gas, lime is used for neutralizing various acids (see p. 609).

The treatment of the products of the *distillation of shale* is so similar to those from coal that no separate description is needed (see p. 609).

Ammonia and its compounds are usually obtained by distillation. The base which is generally used to liberate the ammonia is lime which is added, in excess, to the contents of the retort. As the residue left in the retort is usually thrown away, it is often supposed that crude lime is satisfactory, but careful records will show that a pure lime, and especially hydrated lime, is more economical, as its composition is more uniform and a smaller quantity suffices.

Among *fine chemicals* hydrocarbons are made from aromatic acids, pyridine and quinolic acid, and certain alkaloids from their salts by distillation with lime. Another typical example of the use of lime in the manufacture of some fine chemicals is *benzaldehyde (bitter almond oil)* which is made by mixing benzyldene dichloride with lime and distilling off the benzaldehyde. The residue in the retort contains calcium benzoate from which *benzoic acid* can be obtained.

In all these industries, calcium oxide or hydroxide is the chemical agent required so that a pure high calcium lime should be used. If the impurities do not exceed 5 per cent. they may usually be ignored. Hydrated lime is usually to be preferred on account of its convenient form and purity.

7. USES OF LIME IN COKE AND GAS MANUFACTURE

In the manufacture of coke and illuminating gas, various by-products are obtained which can be separated with the aid of lime. The *gas* is purified by passing over trays containing slaked or, preferably, hydrated lime which absorbs sulphur-compounds and carbon dioxide. In purifying the tar and other liquid by-products, the present tendency is to use caustic soda as a base instead of lime, because it forms soluble compounds, whereas most lime compounds are insoluble.

Now that simple gas flames are no longer used as illuminants, it is more convenient to use iron oxide which absorbs sulphides much more readily than does lime and will purify six times as much gas as lime. Iron oxide does not remove carbon dioxide, but a small proportion of this is unimportant with non-luminous flames. Where exceptionally thorough purification is required both lime and iron oxide should be used; four sets of purifiers are employed as follows:

Set No.	Purifier.	Removes.
1	Lime	Carbon dioxide and some sulphur compounds.
2	Iron oxide.	Some compounds.
3	Lime	The bulk of the carbon disulphide.
4	Iron oxide	Last traces of sulphur compounds.

The addition of lime to the coal prior to distillation not only reduces the proportion of sulphur in the gas, but slightly increases the yield of ammonia. This use of lime is not satisfactory in coke ovens as it retains the sulphur in the coke and spoils the latter for metallurgical purposes.

Ammonia is separated by adding an excess of lime to the "ammoniacal liquor" and distilling, the ammonia being collected in a receiver or—more usually—absorbed in sulphuric acid. The lime is usually added in the form of milk-of-lime as this is the most convenient; the use of ground lime would be advantageous in several ways because it prevents the dilution of the liquor and makes use of the heat liberated by the slaking of the lime. It needs, however, a very pure lime or the residual sludge will be objectionable, and, so far, it has not been a practical success. As a lime paste cannot be pumped satisfactorily, a milk-of-lime of about 16 deg. Twaddell (sp. gr. 1.1) is the strongest that can be used. Continuous agitation of the lime in the mixer is essential. The milk of lime usually enters the still at 110° F.

The quantity required may be found from the equation :

$$V = 65F \div L$$

where V represents the volume of milk of lime in gallons, F the fixed ammonia in the gas liquor in oz., and L the strength of the lime in degrees Twaddell.

According to another formula, the amount of lime required to liberate the entire fixed ammonia and provide for a 20 per cent. excess, to allow for impurities in the lime and for a working excess in the distillation is 1040 lb. of lime for each ton of sulphate, but 1140 is often allowed.

An excess of lime is needed to ensure alkalinity, to combine with any carbon dioxide, and to ensure the removal of all the ammonia, but a large excess should be avoided. The lime should be added quickly to a batch of liquor rather than continuously in small doses as in the latter method there is insufficient at first and an excess later.

When milk-of-lime is used, cocks or valves should not be used on the pipe line, but each branch leading to a still should have a replaceable nozzle to regulate the amount admitted.

There is usually a serious waste of lime owing to the absence of sufficiently careful testing of the ammonia liquor and the use of lime of poor quality for preparing the milk. An undue excess of lime must, of necessity, adversely affect the production costs and lead to increased labour charges for the cleaning of stills and removal of sludge from spent liquor settling tanks. On the other hand, deficiency of lime is often the cause of very serious loss of ammonia.

Some wastage of lime may be prevented by removing the carbon dioxide from the ammoniacal liquor prior to adding the lime. This is best effected by distilling off the free ammonia first, then adding the lime and distilling off the ammonia liberated by it. If the liquor contains little or no free ammonia, the carbon dioxide may be removed by heating the liquor—preferably by waste heat—in a preheater. If the carbon dioxide is not removed, the calcium carbonate precipitated in the still may form a hard scale which is costly to remove.

The lime mixing chamber of the still must be provided with a drain cock of sufficient diameter to drain, between shifts, any lime sediments formed. A funnel-shaped bottom with a drain cock in the middle has been found to be the most suitable for keeping the lime chamber properly clean. To compensate for the lowering in temperature by the introduction of the milk-of-lime, a small steam pipe is brought into the lime mixing chamber immediately above the bottom, and the required amount of steam to supply the heat needed is allowed to enter. The steam pipe is arranged inside the lime chamber as a perforated coil to obtain sufficient agitation to prevent the lime from settling out. The end of the lime feed pipe is advantageously connected to the pipe through which the ammonia liquor enters the mixing chamber from the section above it; this prevents the dip pipe from getting obstructed, and at the same time ensures a thorough mixing of liquor and lime.

By using hydrated lime of good quality and constant composition, much of this wastage may be avoided. If quicklime is used, it should be carefully slaked, and the milk-of-lime made from it should be screened and its specific gravity determined before use. Lime which leaves a large residue on the sieves should not be used. Hydrated lime is usually preferable as it can be used at once and has no waste. The value of the lime for liberating ammonia depends wholly on the free lime present, so this should be tested frequently. Calcium carbonate is useless for liberating ammonia.

In some coke oven plants, the gases are passed directly into sulphuric acid and lime is not used.

The amount of ammonia can be increased by mixing about 2 per cent. of lime with the fuel¹ in a Mond producer. A much larger proportion of lime makes the ash too fusible and hinders the operation of the producer.

Ammoniacal Salts are largely used in the chemical industries, but chiefly in fertilizers and artificial manures. These salts are derived from a variety of sources, including coal (as just described), alkali liquor (see *soda*), waste animal products (bone, meat, blood, faeces, urine, etc.), vegetable matter (coal, peat), and other substances (soot, blast-furnace gases, etc.).

The crude salts—from whatever source—are separated and concentrated by adding lime and distilling, as described above, the ammonia being thereby liberated from its compounds in the form of ammonia gas which is collected in the condensers or in a solution of a suitable acid. The product is usually contaminated with volatile organic gases, but the salts can be purified by re-crystallization.

The lime used in the stills may be quicklime (which must be slaked before use), slaked lime, or hydrated lime, the latter being preferable on account of its more uniform composition and the fact that it can be added directly to the still without the risk which accompanies the use of quicklime. If hydrated lime is not available, it is better to convert quicklime into milk-of-lime, though some firms continue to add lump lime direct to the ammoniacal liquor—a proceeding which usually results in the loss of ammonia.

¹ Hollingshead and Chadwick, *Eng. Patent* 16,168 (1911).

The use of milk-of-lime has the advantage of adding the lime in suspension so that it is readily mixed with the ammoniacal liquor and can be run into the still in such a form that no loss of ammonia occurs. If a solid form of lime is used, it must be passed through a larger opening into the still and some ammonia is almost sure to escape.

The general procedure and precautions are the same as for ammonia from coal and coke manufacture. As in that case, a slight excess of lime must be present, but there is no need to waste lime by adding an unnecessarily large amount.

At the completion of the distillation it is always advisable to test the liquid in the still to see that it is sufficiently alkaline; otherwise, ammonia may be lost owing to an insufficient quantity of lime being added to the still.

The number of gallons of ammoniacal-liquor and the quantity of lime required for the manufacture of a ton of sulphate from liquor of varying, fixed, and total ammonia-content is found by a calculation based on the assumptions that :

$$\text{gal. per ton of sulphate} = \frac{26,700}{\text{total oz. strength}}$$

$$\text{lb. of lime per ton of sulphate} = \frac{1140 \times \text{fixed ammonia content}}{\text{total ammonia content}}$$

These formulae assume minimum plant losses and an excess of 20 per cent. of lime over the theoretical amount required. It is customary to allow this large excess of lime, but whether it is necessary is doubtful. A smaller excess would be probably satisfactory if the composition of the lime is uniform.

Ammonium sulphate is obtained by crystallization from the sulphuric acid solution in which the ammonia vapour is received.

Ammonium carbonate is usually made by heating a mixture of ammonium sulphate and chalk in a subliming chamber and collecting the sublimed product.

The lime in the sludge produced in ammonia stills can be recovered by first drying it and then reheating in a rotary lime kiln, but at the present price of lime the process is not economical.

The Quality of Lime required in the coke and gas industries is a fairly pure calcium lime, containing at least 95 per cent. of calcium oxide. Any calcium carbonate and silica present are useless.

The lime is usually bought in the form of lumps which are slaked in bulk as soon as possible after receipt, as lump lime rapidly deteriorates (owing to the formation of useless calcium carbonate). When storage is essential the lime should be kept in large heaps with a minimum of surface, or hydrated lime (which can be stored indefinitely) should be used.

In many gas works the slaked lime is used in an almost dry state, but this is not desirable as the absorbent power of dry lime is less than that of the moist material. Its most suitable consistency is that in which it aggregates readily and forms a pasty mass when strongly pressed. It usually attains a suitable

consistency if 13.5 gallons of water are added to each 1 cb. yd. (or about 11 cwt.) of quicklime.

About 6 cb. yd. of quicklime, when properly slaked, will usually purify about a million cb. ft. of gas, or 70 lb. of quicklime will suffice for the gas from a ton of coal.

Hydrogen may be obtained cheaply by passing carbon monoxide (water gas) and steam over hydrated lime at a dull red heat (500° C.). The action is exothermic and external heating may be discontinued when the reaction has been properly started. The presence of a little powdered iron (5 per cent.) is desirable as it acts as a catalyst.

The *spent lime* from gas works is chiefly used in agriculture as, when well exposed to the air before being dug or ploughed into the land, it loses its objectionable properties and forms a cheap source of lime. It is necessary to expose it sufficiently before use so as to oxidize the cyanogen compounds which would otherwise be poisonous to crops and other vegetables.

The *objectionable odour* of the spent lime from gas works and the impurities the lime has absorbed from the gas prevent it from being used in other industries.

Carbide lime is the residual obtained when acetylene is made from calcium carbide and water. It has an objectionable odour and is usually impure, but apart from this is suitable for the production of mortar and for agricultural purposes. Its composition is very variable, many samples containing less than one-third of their weight of lime.

8. USE OF LIME IN THE EXPLOSIVES AND ALLIED INDUSTRIES

In the manufacture of explosives, lime is used for three purposes: (i) as milk-of-lime to neutralize any acidity in the products and as a washing agent; (ii) to neutralize acid liquids before they are discharged into the drains; and (iii) to form salts which can be separated on account of their insolubility, or purified by crystallization. The formation of calcium picrate is an instance of the last named use. For the former, lime of good quality is desirable, as the impurities in poor lime increase the cost of treatment. For the second purpose, a lime of medium quality is satisfactory, though it should not contain more than about 5 per cent. of silica, or a large amount of inert residue will have to be handled.

Sometimes, hydrated lime is used as an anti-acid and is an absorbent or diluent of a powerful explosive, such as nitro-glycerine; for such purposes, it should be fine and quite free from grit.

Cartridges filled with quicklime are occasionally used where a very mild application of pressure is required. They are placed in the usual manner and sufficient water is then poured in to slake the lime, which swells and acts as a weak explosive. In winning Iceland Spar and Optical Fluorite, where it is important not to break large crystals, a hole is drilled a short distance away and

packed to a depth of 4 in. with tamped quicklime. A slender iron rod is then inserted and quicklime is packed around it to within 2 in. of the top by means of a curved tamping bar. The rod is then removed, and a cotton string saturated with water is dropped into the hole so that the end is suspended about $\frac{1}{2}$ -in. off the bottom. The opening of the hole is then sealed with clay or other similar material. The water dripping from the string causes expansion of the lime which bursts the rock with a minimum of damage to the spar.

9. USE OF LIME IN THE FOOD INDUSTRIES

The food industries in which lime is employed are those concerned with the manufacture and particularly the clarification of *sugar, glucose, lactose or milk sugar, dextrin, saccharin, starch, bread, malt, edible oats, fats, gelatin, and jellies.*

In *Sugar manufacture*, either ground quicklime, hydrated lime, or milk-of-lime is added to the crude sugar juice or syrup, in order to form a compound of lime and sugar, known as calcium sucrate, which is soluble in water. The mixture is well stirred and carbon dioxide gas is then pumped through the liquid so as to remove any excess of free lime which may be in solution and to carry down with the precipitated calcium carbonate and calcium salts of organic acids, the various proteins and pectines and the colouring substances. The juice is then filtered and, as the greater part of the colouring matter has been removed, the product is almost colourless. The treatment with lime is sometimes repeated two, or even three, times, and by this means a solution is obtained which, when bleached in a suitable manner, yields white sugar instead of the dark coloured and somewhat nauseous material obtained from the first juice when no lime is used. The residual liquid (molasses) is treated with finely-ground lime whereby tri-calcium saccharate is formed and is largely insoluble. This is separated and subsequently decomposed by carbon dioxide liberating the sugar. The precipitated carbonate is sold for use as a fertilizer.

Lime is the best defecating agent for sugar-cane juice because of its ability to neutralize the acids present, and to precipitate the phosphatic material and much of the organic non-sugars which hinder the crystallization of the sugar at a later stage in the manufacture.

An excess of lime must be avoided as this, at the high temperatures used, causes destruction of the reducing sugars and produces dark-coloured melas-sigenic substances which hinder crystallization.

Too little lime allows some free acid to remain in the juice, causing partial inversion of sucrose, and also fails to effect the precipitation of impurities, so that the final yield of sugar is reduced.

Many works use a wrong amount of lime. The point of maximum precipitation is one-third to two-thirds of the way between alkalinity to litmus paper and alkalinity to phenolphthalein. Its exact point can be determined by adding milk-of-lime (containing 1 g. of lime in 100 c.c. of water) in doses of 1 c.c. or less to 100 c.c. of the juice, boiling, filtering, and testing the filtrate with a further small quantity of the milk of lime.

In Cuba, about 2 c.c. of such milk-of-lime per 100 c.c. of juice will ensure neutrality to litmus and 4 c.c. to phenolphthalein. The point of complete precipitation is between 2 and 4 c.c.

When milk-of-lime is used in sugar manufacture it should have a specific gravity of 1.205 and contain about 25 per cent. of lime. Some manufacturers claim that the use of milk-of-lime involves less loss of sugar than any other form of lime, but this statement does not apply to hydrated lime. Other manufacturers claim that quicklime is more readily soluble in sugar solution than lime in the form of hydrate or milk.

A fat lime, with little or no magnesia, is preferred, as magnesium carbonate is soluble in sugar juice and causes trouble, later, by being deposited on the evaporator tubes. In the British West Indies, Natal, and South America large quantities of lime are used for sugar purification. In these countries it is usually purchased as *Bristol lime* (a term remaining from the days when it was shipped exclusively from Bristol), but most of the lime now used is from other localities. Any fat lime containing at least 98 per cent. of calcium oxide is suitable, provided it is not overburned and excessively slow in slaking.

Some sugar manufacturers prefer quicklime because the heat it generates on slaking tends to raise the temperature of the sugar juice. This is of much less importance than is generally supposed, and the risk of forming an insoluble sucrate by local overheating of the juice must not be overlooked.

When milk-of-lime is used, the lime should be one which remains in suspension a long time, but the precipitate of lime and juices should settle quickly. Manufacturers of beet-sugar usually burn the lime because they also need carbon dioxide, but as the latter can be recovered from fuel it is often economical to purchase about one-fifth of the lime required from outside. Manufacturers of cane sugar need no carbon dioxide and so usually buy all the lime required.

Molasses contain a large amount of sugar of such a nature that it cannot be obtained by direct crystallization. In what is known as the Elution process, the molasses is mixed with 25 per cent. of its weight of quicklime in an artificially cooled edge runner mill; the temperature of the mixture is then allowed to rise to 100° C. when the sugar and lime combine to form an insoluble saccharate ($3\text{CaO} \cdot \text{C}_{12}\text{H}_{22}\text{O}_{11} \cdot 3\text{H}_2\text{O}$) which sets to a hard porous mass. The saccharate is extracted with weak alcohol which removes the impurities, and the residual purified saccharate is then decomposed by carbon dioxide. Various modifications of this process are used, but in each of them lime is employed to form a tricalcium saccharate of low solubility in water.

Strontia is often used instead of lime; it is more costly, requires a higher burning temperature to convert its carbon into strontium oxide, and the latter has a greater effect on the kiln; these factors greatly reduce the gain due to the greater insolubility of strontium saccharate as compared with calcium saccharate.

The most suitable lime for the purpose is one containing at least 98 per cent. of calcium oxide. It must slake readily and completely. Hydrated lime may also be used and is more convenient than quicklime.

In *Glucose and Dextrin manufacture*, starch is boiled with dilute sulphuric acid and so converted into crude glucose. To the solution thus produced, hydrated lime or milk-of-lime is added in slight excess to precipitate the acid. The solution is then filtered and the sugar removed by evaporation. In some works, chalk is used to effect the greater part of the neutralization, and lime the remainder. This is supposed to be a cheaper method, but when the cost of dealing with the additional sludge and the loss due to frothing and uncertainties in the treatment are taken into account, it will usually be found that hydrated lime is more economical and much more satisfactory technically.

Lump lime, roughly slaked in water, is often employed, but hydrated lime is so much more satisfactory in every way that it should always be preferred.

Lactose or Milk sugar is obtained from milk by first removing the butter fat with a cream separator, then warming the milk to 75–80° C. and adding about 10 per cent. of milk-of-lime which precipitates the casein and any remaining fat. The product is filtered and the solution treated with carbon dioxide which decomposes the calcium lactosate, the lactose being afterwards recovered by crystallization.

In *Saccharin manufacture*, hydrated lime is used to facilitate the concentration of the crude saccharin.

In *Starch manufacture*, the spent pulp from the separation of starch is mixed with milk-of-lime prior to dressing it in order to coagulate the fibres and prevent them from escaping and to neutralize any acid present which would facilitate a harmful fermentation. So long as the "milk" is made from lime of reasonably good quality, the purity is not very important. Only calcium lime should be used, as magnesia is less satisfactory. Hydrated lime is much more convenient and is better in every way than lump lime.

In *Bread manufacture*, the use of a little lime-water in place of some of the plain water ordinarily used produces loaves which are more spongy, pleasant to the taste, and free from all taint of sourness. Lime-water is also used in bread-making to prevent "excessive diastasis during primary fermentation." It has the advantage over alum that it does not retard the fermentation of the yeast. It also increases the water retaining power of the flour, and enables a given weight of flour to produce a greater volume of bread. A very fine lime must be used; 2 oz. of quicklime may be added to 11 gal. of water and the whole stirred up, or an excess of lime may be added, stirred, and allowed to settle, the clear liquid being decanted or siphoned off. Hydrated lime is preferable to quicklime as it is finer and usually purer, and is more readily dissolved. The quantity of lime-water required varies with the flour and must be found by trial.

In *Malting*, lime may be used to improve the germinating power of grain-seeds by steeping them in saturated lime water for 24–48 hours. Quicklime is used as an antiseptic for the bins used for storing corn and barley. The kilns used in the malting industry are frequently lime washed inside. Lime wash is also applied to the iron tanks and cisterns used in the malting industry in order to preserve the water contained in them from putrefaction.

Edible oils and fats are freed from acids and "rancidity" by washing with lime water, the materials being warmed and well-churned so as to ensure thorough admixture. Sometimes milk-of-lime is used instead of lime water as it can neutralize much more acid. The lime most conveniently used for this purpose is hydrated lime, made from lime containing not less than 98 per cent. of calcium oxide nor more than 0.3 per cent. of iron oxide.

Gelatin and Jellies are clarified by means of lime, as described on p. 622.

Eggs may be preserved in lime water, but water glass is usually easier to use and is more certain. The chief recommendation of lime water is its cheapness, but this only applies when used on a very large scale and under skilled supervision.

For destroying food of a dangerous character, such as diseased meat, quicklime is sometimes used, the food being laid in a pit or trench, dug in the ground, on a bed of quicklime and covered with quicklime as well as mixed with it.

Lime as a food. The addition of lime in various forms to food for cattle, horses, etc., is well known, and the beneficial results obtained from it are very striking. Only to a negligible extent is lime similarly used in human food, and its value for this purpose to human beings is worth very careful study.

Lime is not only a constituent of the harder portions of the human body, but it is present in solution in the contents of most cells and in cellular tissues, particularly in the muscles and heart, the white corpuscles in the blood, and the grey matter of the brain. An ample supply of lime in the food is, therefore, essential to health.

Lime water given to infants greatly increases the strength of their bones and teeth, especially in districts where the water is soft, and it has also proved highly beneficial in cases of tuberculosis and diabetes and after an accident in which one or more bones have been broken. The fear that it may cause ossification or sclerosis of the blood vessels appears to be unfounded.

For food purposes, only hydrated lime or lime water can be used if lime is to be employed, but for many purposes, some form of calcium carbonate can be substituted. It must be free from grit, and should be made from lime containing not less than 98 per cent. of calcium oxide.

For information on the use of lime in treating effluents, see p. 653.

10. USE OF LIME IN FUEL

In the preparation of some oils for use as liquid fuel, thorough agitation with hydrated lime or with ground quicklime at 80° C. is important, as it increases the stability of the oil and removes acid compounds which would corrode the burners. Instead of lime, the stabilization is sometimes effected by the means of soaps made of lime and resin acids.

Lime is sometimes mixed with the resin or other binder used in the production of *briquettes* made of anthracite or other carbonaceous powders. It enables a smaller proportion of binder to be used, but the resulting increase in the ash left when the fuel is burned is sometimes regarded as objectionable.

In gas works, lime was, at one time, extensively used to absorb sulphides and other impurities. It has, however, ceased to be used for this purpose since the sulphur clause of the Gas Referees was rescinded in the Gas Regulations. Iron oxide is now used almost exclusively for this purpose. Lime is still used for the recovery of ammonia from gas liquor.

11. THE USE OF LIME IN FURNACE CONSTRUCTION AND FOR REFRACTORY MATERIALS

The chief uses of lime in the construction of furnaces are (i) as a constituent of the cement or mortar in which the bricks are laid, and (ii) in the manufacture of some of the refractory bricks and blocks of which such furnaces are built.

Lime, alone, is one of the most highly refractory substances known, but it combines so readily with silica at a high temperature that it is of little direct use in furnace construction, and it slakes so readily on exposure that blocks of it can only be used for building small experimental furnaces.

Cements and mortars containing much lime can only be used where the temperature is comparatively low, as lime is a powerful flux, and when combined with sand or other form of silica it melts rapidly when heated to a high temperature. For furnace linings, the only "mortar" which can be used satisfactorily is fireclay, or a mixture of fireclay, grog, and just sufficient Portland cement or water glass to ensure rapid hardening without making the mixture too fusible.

Silica bricks are largely used in the construction of various kinds of furnaces, gas retorts, coke ovens, etc., and are a well-known refractory material. Such bricks are made of crushed quartzite or other form of nearly pure silica, the particles of which are united by about 2 per cent. of their weight of lime, which is usually added in the form of milk-of-lime.

Some manufacturers of silica bricks do not pay sufficient attention to the quality of the lime used and so impair that of the resulting bricks. As only the smallest particles of pure, free lime (calcium oxide) are of use in the manufacture of silica bricks, any unburned lime or other impurities are not merely useless, but may be definitely harmful. For this reason, the lime used should contain not less than 96 per cent. of calcium oxide and it should not be overburned. Either quicklime or hydrated lime may be used, but if the former is employed it should be carefully slaked and passed through a 60-mesh or finer screen before being used. The residue on such a screen may be regarded as waste and its amount is a useful indication of the quality of the lime. The chief advantage of hydrated lime is that it is ready for use.

When lime from several sources is available, that which produces the most plastic mass when mixed with the silica, in the ordinary process of silica brick manufacture, should be selected, provided it is sufficiently pure.

The fluxing power of lime is so great that the proportion of it used in silica bricks is necessarily kept as low as possible, and for this reason it is unwise to use an impure lime.

12. THE USE OF LIME IN GLASS MAKING

Lime is an important raw material for glass making. Ordinary lime soda glass contains from 10–15 per cent. of lime. Both burned lime and raw limestone are used for making glass. There is some difference of opinion among glass makers as to the advantages of two forms, and some works use one form and some the other.

In the manufacture of glass it is customary to use a finely-ground limestone of great purity, but where it is specially necessary to avoid the formation of bubbles (which are evolved when the glass mixture is heated and the limestone converted into lime) it is advisable to use quicklime. For bottles, pressed and blown wares, and some special varieties of optical glass, hydrated lime is preferable to quicklime as it is more constant in composition, can be obtained free from unburned lime, and is converted into quicklime at a temperature far below that at which any fusion of the glass can occur. In other words, hydrated lime provides with great certainty a purer lime than is usually obtained with quicklime. Its great cost is a disadvantage. It has the further advantage of allowing the glass mixture to be melted more rapidly and with less fuel than limestone.

Quicklime is usually inferior to hydrated lime because the particles are larger, the quicklime is more irregular in composition, and its behaviour correspondingly uncertain. In addition, quicklime suffers from the serious disadvantage that it alters in composition upon storage. Its composition has to be controlled by analysis, or the composition of the batch will alter to the detriment of the resulting glass, and "stony" glass may be obtained owing to the alteration in composition of the lime used in mixing. If the lime has been stored it will be partly slaked and partly converted into carbonate. If this fact is overlooked, the actual amount of calcium oxide going into the glass will be lowered, causing the percentage of silica to increase, with the result that, on working the glass, "blobs" of silica, either singly or in strings, will appear in the finished ware. The addition of alkali to the batch only increases the trouble, possibly because the "metal" becomes less viscous and allows the devitrification to proceed more easily. The correct remedy is the addition of more lime to the batch.

A further disadvantage of lime is the unpleasantness of handling it when mixing. Its fineness causes it to be blown about, particularly where the mixing is "open," and it causes considerable irritation to the mixers. Unless precautions are taken, the fine dust settles upon other materials and mixed batches, causing contamination, and the batch from which the fine dust emanates is deficient in some of its lime.

Slaked lime suffers from the disadvantage of altering the composition on storage, absorbing carbon dioxide and passing into carbonate. It also tends to clog together in lumps to the detriment of good batch mixing.

The lime used in glass manufacture should contain at least 95 per cent. of calcium oxide (or an equivalent amount of calcium hydroxide). The percentage

of silica should be below 1 per cent., and for white glass the percentage of iron oxide should not exceed 0.10 per cent. ; for green glasses, a higher percentage of iron oxide is permissible.

Many glass manufacturers do not care to use dolomitic lime, but for many glasses it is excellent. Contrary to general belief, the presence of magnesia in glass is in many respects advantageous. When introduced in small amounts in place of an equal weight of lime, it does not interfere with the melting properties of the glass to any marked extent, its effect being, if anything, beneficial. It endows glass with extra toughness and strength, and this fact is of especial importance in the manufacture of bottles which have to hold gassy liquids in which pressure is set up. The presence of magnesia also appears to promote annealing at a lower temperature and tends to prevent devitrification when the glass is molten. Unfortunately, dolomitic lime is never as pure as the best calcium limestones, having a higher iron content. This property debars it to a large extent from use for colourless glass, except in small quantities.

The fineness of the lime or limestone is important, as large grains are slow in melting and may remain as "stones" or "seeds" in the glass. The whole of the lime should pass through a 12-mesh sieve, and at least 90 per cent. of it through a 20-mesh sieve. Many manufacturers require a much finer material.

The United States Bureau of Standards (*Circular 118, 1921*) issued a Specification which divides lime and hydrated lime into three classes, depending on the kind of glass for which they are suitable, and requires :

(i) That the non-volatile constituents shall not exceed the maximum or fall below the minimum in Table LII.

TABLE LII.—*Composition of the Non-volatile Portion of Quicklime or Hydrated Lime*

	Class 1.		Class 2.		Class 3.	
	Max.	Min.	Max.	Min.	Max.	Min.
CaO + MgO .	—	96	—	91	—	83
Fe ₂ O ₃	0.2	—	0.4	—	0.8	—
Sulphur dioxide and phosphoric pentoxide	3.0	—	3.0	—	3.0	—
Silica	4.0	—	9.0	—	17.0	—
Alumina	3.0	—	5.0	—	5.0	—

The sum of the calcium and magnesium oxide is specified in the above Table. In order to prevent undue variation in the relative proportions of these two ingredients the percentage of calcium oxide shall be established by contract, and shall not vary more than 2 per cent. either way from the contract figure.

An approximate figure for the content of alumina should also be included in the contract. This figure must come within the limits set in the above Table, and it is specified that the amount of alumina in the material delivered shall not vary more than 1 per cent. either way from the contract figure.

(ii) *Composition.* Quicklime shall not contain more than 3 per cent. CO_2 as shipped. Hydrated lime shall not contain more than 5 per cent. CO_2 as shipped, and shall contain sufficient water to meet the chemical requirements of the calcium oxide.

(iii) *Fineness.* Unless otherwise specified, limestone, quicklime, and hydrated lime shall be crushed so that all will pass a sieve with an opening of 1.19 m.m. and a wire diameter of 0.54 m.m., with a permissible tolerance of 2 per cent. in the opening and 10 per cent. in the wire diameter.

Limes from different sources "melt" at different rates in the manufacture of glass, so that care must be exercised if the source of lime is changed. The difference is due to the physical properties of the minerals (marble, calcspar, limestone, chalk, etc.) from which the lime is made.

Five special impurities are mentioned in the above specification as likely to occur from time to time in lime. In the case of at least two of them, *viz.*, silica and alumina, they are themselves glass making materials and, therefore, not necessarily harmful; and provided the sulphuric and phosphoric anhydrides are also small in amount they likewise present no difficulty to the glass maker.

Whilst, therefore, silica and alumina, in particular, may in some specimens be present to a considerable amount, the importance to the glass maker is perhaps as much one of price of the material as of any serious consequence to the melting of the glass. Lime is, as a general rule, dearer than glass making sand; hence, if it contains several per cent. of silica, the purchaser is not acquiring value for money. On the other hand, if only silica and alumina, and perhaps even a small amount of sulphuric and phosphoric anhydrides, are present, it may be cheaper for the manufacturer to purchase a less pure material in preference to a lime which is practically pure. If he has the requisite knowledge or employs a chemist, any slight change in the batch necessary because of the lime or limestone containing silica or alumina can be adjusted. It is to the advance of technical knowledge that the manufacturer must look in order to safeguard both his glass and his economic interests.

The iron oxide presents a different problem, as if the manufacturer desires to produce a colourless glass this oxide must be kept at a minimum. If the maximum permissible amount of iron oxide in the glass is known, the amount contributed by the sand, soda, and salt cake can be calculated, and, from this, the maximum amount permissible in the lime can be found. This is much better than insisting on an amount less than a maximum shown in a general specification, and will often allow a lime or limestone to be used satisfactorily which would otherwise be excluded.

For pale green glass, the use of lime with 0.6 per cent. of iron oxide is feasible so long as the total iron oxide in the glass is not excessive.

For dark green glasses, the proportion of iron oxide is unimportant ; in many cases, the larger it is the better will be the colour.

Another *minor use* for hydrated lime is to mix it with the plaster of Paris used for bedding plate glass on the polishing table.

13. THE USE OF LIME IN GLUE, SIZE, AND GELATIN MANUFACTURE

Glue, gelatin, and size are different forms of the same material which is obtained by boiling animal flesh, skin, or bones. To make clear the function of lime in the glue and gelatin industry, it is necessary to point out briefly the several steps in glue and gelatin manufacture. Several types of raw stock are used, which include hide pieces and trimmings from the tanner or the packer ; fleshings, which consist of the under layer of the hides and are made up of loosely packed fibres of skin substance, fat cells, and thin muscles attached to the skin ; sinews or tendons and connective tissues ; ossein, which is the organic portion of bones left behind when the mineral matter is dissolved out with acids, and bones. All of these, with the exception of untreated bones, are conveniently grouped together as " hide stock." Since bones receive a different lime treatment, they may be omitted from this discussion. The washed and shredded " hide stock " is allowed to stand in vats with milk of lime for about two weeks.¹ The stock is forked out and fresh milk of lime is added. After two or three such treatments the stock will have attained a plump, uniformly swollen condition and it is then removed and washed, first with water and subsequently with a dilute acid solution to neutralize the excess of lime. The stock is placed in a large open tank with water and steam admitted until the mixture has attained a temperature of 80° C. or higher. This operation, known as the boiling process, extracts the gelatin. The liquor is run off after a few hours, and the boiling repeated a number of times with fresh lots of water. The liquors may then be filtered or clarified, and, being too thin to gel well, are concentrated *in vacuo* and allowed to form a jelly, after which they are dried and ground as desired.

The lime is used to increase the volume of the stock greatly and to loosen the hair. It also effects important chemical changes. If raw hide were heated with water, solution would be effected very slowly, unless a temperature above 100° C. (under pressure) were used. Gelatin, the constituent of glue which gives it the power to form a jelly and upon which adhesiveness seems to depend, is a heat-sensitive substance, and, when exposed to high temperatures, rapidly undergoes a decomposition, breaking up into constituents which have very little or no value as jelly producers or adhesives. As a result of the lime treatment, however, the hide pieces are enabled to pass into solution by only a moderate heat treatment with water, and the valuable properties of the gelatin are preserved.

¹ By using rotating drums throughout instead of stationary vats, and carefully adjusting the pH-value of the liquors, the time can be greatly reduced.

All the water should be softened with lime and soda before use.

The precise action of the lime in bringing about this result is not yet clear, but it seems that the lime solution induces a loosening and separation of the fibres in the hide, and the distension produced by it offers a greater surface to exposure and, consequently, permits a greater rapidity of solution.

This plumping action appears to be due to a particular concentration of hydroxyl ions or alkali, and the alkalinity of a saturated solution of lime is very close to that at which maximum swelling occurs. Clear lime water very rapidly becomes less alkaline, and is soon almost neutral, but by using milk-of-lime this difficulty is overcome, as the "milk" is merely a saturated solution plus an excess of the undissolved lime. As rapidly as the hydroxyl ions are removed by the hide, just so rapidly will the undissolved lime pass into solution. By this means the alkalinity of the mixture is automatically held constant. This property of a nearly foolproof and automatically controlled alkalinity makes lime better than most other reagents for this service.

Besides collagen, which is converted into gelatin by heating in water, glue stock contains several other proteins that have no value whatsoever in glue. If these substances were allowed to be cooked with the stock, the product would be weakened, and would also give a turbid, muddy, or opaque glue. These proteins, especially albumen and mucin, are soluble in alkaline solutions, and so are dissolved out of the stock by the lime, which is particularly suitable for the purpose, as solutions of stronger alkalinity would dissolve increasing amounts of the collagen, and solutions of weaker alkalinity would not be effective. Some of the fat of the stock is also acted upon by the lime, forming insoluble lime soaps that should be removed in the washing process if a clear product is desired.

The greater part of the fat is liberated in the "boiling" process, and can be removed by skimming, but some is converted into insoluble lime soaps, and can be recovered by washing and subsequent treatment.

In the manufacture of glue and gelatin from bones, the latter are crushed and then degreased in a closed steel tank with a volatile solvent (benzine or carbon tetrachloride), which is afterwards distilled off from the greases and recovered. The bones are then leached in dilute (about 8 per cent.) hydrochloric acid, whereby the mineral constituents are dissolved, leaving a soft, cartilaginous substance (collagen), which preserves the original shape of the fragment of bone.

The solution contains acid phosphate of lime, which is afterwards precipitated by the careful addition of milk-of-lime in very slight excess. The "precipitated bone phosphate" is largely used in the manufacture of "bone china," and the "acid phosphate" is used in baking powders. In order to avoid an excess of lime, which would reproduce tricalcium phosphate, a filtered sample of the liquor is, from time to time, tested with a solution of ammonium molybdate, which will give a yellow precipitate if any phosphoric salt remains in solution, and the addition of lime stopped as soon as the failure of the ammonium phosphomolybdate precipitate to form indicates that no more phosphoric acid or acid phosphate is in solution. If an excess of lime be

accidentally added, the error can be retrieved by the addition of a suitable quantity of the acid liquor. The precipitate is pumped or forced by compressed air into a filter press and washed free from soluble salts.

The soft collagen is washed free from acid (using lime water to neutralize if necessary), and made directly into glue, but some of it usually is dried at a low temperature, yielding commercial ossein.

A product of better quality than usual is obtained by adding the calculated quantity of milk-of-lime, stirring thoroughly for several minutes and then allowing the precipitate to settle. The liquor is then run into another neutralizing vat and the neutralization completed therein. The two precipitates may either be mixed or kept separate. The first will be mainly the acid phosphate. The second precipitate will be richer in tricalcic phosphate.

The milk-of-lime should have a specific gravity of 1.116, and should be made by adding the calculated quantities of slaked or hydrated lime and water to a mixing vat, or by slaking quicklime in water, adding a little more water, passing the liquid through a sieve with at least 60 holes per linear inch, and then diluting with water, if necessary, until the desired specific gravity is obtained. It is desirable to use a duplicate plant comprising two neutralizing vats and two lime vats, one of each pair being employed in preparing the milk-of-lime and the acid liquor.

Fresh bone is sometimes boiled without a preliminary washing, but if washed and degreased (by the so-called benzine process) it yields a much clearer glue. Bones may be made into glue by the "sulphurous acid process" patented by Grillo and Schroeder, according to which bones are disintegrated by moist sulphurous acid gas or liquid sulphur dioxide. Bones thus treated readily dissolve in hot water; any acidity is neutralized with milk-of-lime, and the resulting "mud," after the calcium sulphite is oxidized by exposure to the air or by oxidizing agents, forms a valuable fertilizer.

Prepared horn pith is an ossein stock made from the interior supporting bony core of horns. As it is the only part of the osseous structure that does not come in contact with flesh, horn pith yields a singularly pure and high-class gelatin, and its porous structure renders its treatment and subsequent extraction easy.

Fish stock, i.e. the heads, bones, and skins of fish similarly treated yield liquid glues. The swim bladders of certain species of fish constitute what is known as *isinglass*.

The later stages in the manufacture of glue and gelatin do not use lime to any appreciable extent, and so need not be described.

Selection of Lime.—Only a high calcium lime containing at least 95 per cent. of calcium oxide is suitable for use in the manufacture of glue and gelatin, for it has been found that dolomitic limes which contain large amounts of magnesia are decidedly inferior to the high calcium limes. For some reason that is not entirely clear, the magnesia tends to offset the normal swelling induced by the lime. The iron oxide content of the lime should be low, as otherwise the colour imparted by it to the finished glue or gelatin may be objectionable, and bleaching may then be necessary.

In practice it is usually most satisfactory to procure a high grade quicklime and slake it at the works just prior to use, or to use hydrated lime. The fineness and freedom from impurities of hydrated lime, and the ease with which it can be used, more than offset its greater cost, and give it special advantages in the manufacture of glue, size and gelatin. When slaked and suspended in water the lime should settle very slowly; otherwise, it will appear to have too low a solubility.

14. THE USE OF LIME IN LEATHER MANUFACTURE

In the manufacture of leather, lime is employed for softening the raw hides and causing them to swell (thus giving them greater bulk and opening the pores ready for the tanning agent), and also to loosen the hairs, which are afterwards removed by a blunt knife in the currying process.

In the production of *sole* and *belting leather*, fresh limes are usually employed, the amount of lime used on the weight of the hide being from 10–25 per cent. This liming is usually done in a series of pits, the hides being transferred forward each day from the *tail* pit toward the *head* pit. The time usually taken for this class of leather is 5–6 days.

The use of a series of pits is important, as a fresh lime liquor which contains no dissolved hide substance will dissolve much more of this material from the hides than an old lime liquor. In such a system the lime is added to the head liquor according to the judgment of the tanner. The excess from the head pit overflows to the next in series, and so on to the tail pit, where the excess still remaining again overflows and goes to waste. Liming handled in this manner ensures uniform treatment of the stock and obviates any danger from so-called "putrid limes."

For *harness*, *strap* and *bag* leather, a certain amount of flexibility in the finished product is desired. This is largely dependent upon the lime treatment, and is secured by subjecting the hides to a somewhat longer immersion in the limes (8–10 days).

In the production of *glazed kid* from goat skins, the nature of the pelt makes it necessary to subject the skins to a fairly long lime treatment (12–15 days).

Glove leather must be very elastic. This property is obtained by the use of "old limes," which destroy a certain amount of the hide substance, causing a very open and flaccid condition of the pelt. The time of liming for this kind of stock is usually 15–20 days. In the production of a certain class of glove leather known as "Mocha" and "Caster," an exceptionally long liming is given, usually extending over a period of 40–60 days. During this long treatment, the hair is not only removed, but the grain of the leather is loosened and is subsequently removed on a beam by means of a blunt knife or stick, a process known as "frizing." This process is also used in the production of *buckskin* leather.

In the production of *calf skin* and *side* leather for shoe uppers, the leather must have a fairly tight grain, to produce which a mixture of lime with sodium

sulphide is used, about 1 lb. of sodium sulphide being used for every 5 lbs. of lime.

Some tanners, using lump lime, mix the sulphide with the lime at the time of slaking, whereas others dissolve the sodium sulphide separately and add it to the lime pit. In the case of hydrated lime, the sulphide may be dissolved in the water used for mixing with the lime, or it may be dissolved separately and added to the lime.

Sodium sulphide has the property of dissolving fine hairs, and, if used in strong solution, will also dissolve the mature hairs. Used, however, in the amount mentioned, it simply aids the lime in producing a rapid depilation and ensures the complete removal of the fine hairs. By using lime and sulphide, the time of depilation can be materially reduced, and it is not uncommon to find tanners who are depilating stock for this grade of leather in three days.

When sodium sulphide is added to milk-of-lime, sodium hydroxide is produced. This acts as a strong plumping agent, while the calcium sulphhydrate formed has a solvent action upon the fine hair.

In the removal of wool from pelts, or the treatment of skins where the hair is of considerable value, a mixture of lime and sodium sulphide in the form of a paste is employed. This mixture is usually made by dissolving sodium sulphide in sufficient quantity of water to produce a solution with a specific gravity of 1.286, and to this solution is added enough hydrated lime or lump lime to make a fairly thick paste. A sulphide mixture of this character, when painted on the flesh side of the skins, acts very rapidly loosening the hairs within a few hours. The usual procedure, however, is to paint the flesh side of the skins and place them in piles, flesh to flesh, the hair being pulled on the following day. The skins that have been pulled in this manner are then usually given a straight lime treatment to prepare them better for the subsequent tanning processes.

In the liming of goat and kid skins for both shoe and glove leather, where a long lime process is desired, but where the depleting action is to be reduced to a minimum, the tanner often mixes his lime with a small quantity of arsenic sulphide, which has the advantage over sodium sulphide that no caustic soda is produced, and, consequently, where excessive plumping is not desired, arsenic can be used with good results.

In the manufacture of patent leather, acids are used which are sometimes neutralized by subsequent treatment with milk-of-lime.

The lime is dissolved in water, and as the solution acts better when slightly warm, it was formerly the custom to add quicklime. The objection to this, unless very great care is used, is the risk of burning the hides by the caustic action of the lime, and in many modern tanneries slaked or hydrated lime is used, the temperature of the liquor being raised by means of steam. This procedure enables a much more accurate control to be effected, and avoids the objectionable accumulation of "sludge," which is almost unavoidable when lump lime is placed directly into the pits.

Another objection to common quicklime is that it rapidly absorbs moisture

from the air, producing what is known as "air-slaked lime," so that it is necessary to keep it in fairly tight barrels. Even with this precaution however, the lime is apt to absorb moisture, with the result that damaged and broken barrels of lime exposed to the action of the weather in freight yards and other places become wet from rain storms, etc., and burst, the action being so violent that fires occasionally result. Hydrated lime is free from these disadvantages, and may be kept indefinitely without deterioration, and, when required for use, may be simply mixed with water and added to the pits.

The absence of "dirt," stones, and the need for slaking, together with its fineness of texture, freedom from impurities, and ease of use make hydrated lime by far the most suitable form of lime for use in leather manufacture, though many English tanners regard it (erroneously) as too costly.

When lump lime is to be used, great care should be exercised to see that all of the lumps are disintegrated, as the presence of even small pieces of unslaked lime will cause damage to the leather by getting into the folds of the skin and generating heat. In the absence of a good hydrating plant, the best method of slaking lime in a tannery is to place the lumps in an open box and to pour over the mass small quantities of water. Heat is at once generated, and as the produce becomes swollen and dry, more water is added and the pasty material worked over with a hoe until a creamy product free from lumps is the result. When properly slaked, such a paste may be kept almost indefinitely without danger of deterioration, and may be used in making up the limes to the required strength.

On account of its limited solubility, lime is probably the safest material to use for depilation, for any excess remains inactive and is only dissolved as fast as taken up by the hide. The solubility of lime is 1.3 parts per 1,000 parts of water, or, roughly, 100 gallons of water will dissolve $1\frac{1}{4}$ lb. of lime. In making up a lime liquor, no matter how much is placed in the pit, only the above quantity will be active. As a matter of fact, however, there is always present more than $1\frac{1}{4}$ lb. of lime for each 100 gallons, because the hide is constantly absorbing the lime and there must be a sufficient quantity present to keep the liquid saturated. In practice, many tanners use far too much lime, which is a waste of money; 10 lb. of lime for each 100 gal. of liquor is more than sufficient to furnish all the calcium hydroxide required; any amount over this is unnecessary, and is usually wasteful.

The lime used in leather manufacture should contain at least 95 per cent. of free calcium oxide, or an equivalent amount of calcium hydroxide. Dolomitic lime should not be used, as magnesia produces a harshness in the leather and is useless as a depilatory.¹ The percentage of iron oxide present should not exceed 0.15, or it may cause stains in the leather. It is important that when slaked and suspended in water the lime should settle very slowly otherwise much of its value may be lost.

The addition of a small proportion of caustic soda to the lime is desirable when hard, dry skins have to be treated.

¹ Except in the liming of Morocco leather for which a lime rich in magnesia is usually preferred.

The hides should be "drawn" (lifted from the pit) at least once daily and the pit well stirred to distribute the undissolved lime through the liquor before the hides are again immersed.

Liming is one of the most important operations in the making of leather, as upon the way in which it is carried out depend very largely both the quality and the weight of the leather produced.

Tannery Lime-Residues.—About two tons of slaked lime contaminated with dirt, soluble nitrogen compounds, sulphur compounds, hair, and grease are obtained in the de-hairing of 1,000 hides. No cheap method is at present available for the treatment of this waste. Residues are not easily disposed of for agricultural purposes, as the price obtained, after drying, is not competitive with that of fresh unslaked lime. Moreover, such residues contain little free lime and are of negligible value for agriculture.

Tannery Effluents.—For the use of lime in treating tannery effluents see p. 655.

15. THE USE OF LIME IN MEDICINE AND PHARMACY

The medical uses of lime include the manufacture of *lime syrup*, which is used as an acid corrector and bone builder, *calcium tannate*, which is used as a cure for dysentery, and *calcium sulphonate*, which is used against night sweats. There is considerable evidence that *lime dust*¹ is effective in the treatment of tuberculosis. Professor Coutière has reported to the French Academy of Medicine that 40 per cent. of the tuberculosis cases in which lime treatment has been tried have resulted in complete cures. The chemical, bacteriological, and radiological results are all said to be equally striking in this method of combating this dread disease. While the experience of quarrymen tends to scepticism as to many cures being effected from inhaling limestone dust, it is generally believed that lime can stop the spread of the disease by surrounding the diseased section with a calcareous coating. Other producers assert that many of their employees have come to their plants suffering from tuberculosis troubles, and in a short time recovered their health and strength and remained on their jobs for years afterwards. Still others say that the men who work in lime plants are unusually healthy and noticeably free from disease.

General medical experience seems to show that soluble calcium salts are more effective than hydrated lime (quicklime cannot be used as it is corrosive) and of these calcium chloride is the most extensively used in Germany, though it has a very unpleasant taste which is only partially disguised by the addition of saccharin in the proportion of 3 parts per thousand of calcium chloride solution. Mineral oils are purified with lime in making *salves*.

Lime in the form of *lime-water* is used :

- (i) In the treatment of sour stomachs and skin diseases.
- (ii) To counteract acidity in foods, especially milk, making finer curd which is easily digested.

¹ The quantity of quicklime inhaled must be very small on account of its highly destructive action on the tissues. Air slaked or hydrated lime is much less risky.

(iii) To allay vomiting.

(iv) As an astringent in diarrhoea ; usually lime-water is too weak for this purpose, but chalk mixture is useful.

(v) As an anti-acid and for a soothing action on the bowels, though chalk mixture is preferable as it is stronger.

(vi) When mixed with an equal quantity of linseed oil lime-water forms *carron oil*—a useful application for burns and scalds, though now largely replaced by picric acid solution. *Linimentum Calcis* is a similar mixture of lime-water and olive oil.

(vii) For preparing *Argenti Oxidum*, *Linimentum Calcis*, *Lotio Hydrargyri Flava*, and *Lotio Hydrargyri Nigra*.

Lime-water for medicinal purposes is made, according to the British Pharmacopoeia, by shaking washed slaked lime with 100 times its weight of distilled water and siphoning off the clear liquid. It is to be kept in green glass bottles.

Lime-syrup (Liquor Calcis Saccharae) is made by shaking slaked lime with twice its weight of sugar and twenty times its weight of water and siphoning off the clear liquid.

Calcis Hydras is the pharmaceutical name for slaked lime made from a calcium lime "yielding only the slightest reactions characteristic of iron, carbonates, chlorides, sulphates, or silica," but may apparently contain magnesia and alumina. It must not contain more than 20 parts of lead or 5 parts of arsenic per million.

Slaked lime mixed with caustic potash forms *Vienna paste* which is used to destroy warts and other small growths.

Calcium chloride (not to be confused with bleaching powder) is unpleasant in taste, but does not waste gastric juice in the same manner as calcium carbonate. A mixture of 30 per cent. of table salt and 70 per cent. of calcium chloride is better than the calcium chloride alone as the latter sometimes causes a rash which the table salt prevents. It is convenient to make a solution containing 166 g. of (pure) calcium chloride and 100 g. of table salt in one litre. This can be made from the syrupy chloride formed as a by-product in the manufacture of soda by the Solvay process, the proportion of salt (also present in the syrup) being adjusted when required. One dessertspoonful of the solution is the normal dose for an adult ; it must be diluted with about a gill of water to which can be added a teaspoonful of sugar or a little saccharin.

Calcium phosphate is insoluble and, therefore, of little or no medicinal value.

Calcium lactate is equally as suitable as calcium chloride and has a less objectionable taste, but is more expensive.

The medicinal value of *lime in food* has been explained earlier (p. 613).

Lime is sometimes used in the preparation of various hypophosphites and other salts, though these are generally prepared by indirect means.

It need hardly be stated that for medicinal purposes, a pure lime should be used, and as it cannot be used in the unslaked state, a carefully prepared

hydrated lime is usually the best and most convenient form in which to use it. Grit is objectionable, but is not excluded by the official tests ! It is seldom found in good hydrated lime.

16. THE USE OF LIME IN METALLURGY

Lime is used in large quantities in the metallurgical industries for several purposes, particularly as a flux in the open-hearth (Siemens-Martin) process of steel making, in blast furnaces for smelting iron ore, and in the refining of zinc, silver, copper, nickel, tin, and other metals. For many of these purposes, limestone is used more extensively than lime, but smelters are realizing that the much smaller space occupied by lime (especially in shaft furnaces) enables a larger output to be obtained, as well as effecting a saving on the carriage of the lime to the works. The saving effected in fuel by the lime being ready for use whilst limestone has first to be converted into lime is too small to be considered in most furnaces.

LIME FOR BLAST FURNACES

Most iron ores contain silica and alumina, as impurities, and the addition of a basic flux, such as lime or limestone is necessary to form a slag which will "liquefy" these impurities and enable them to be run out of the furnace. Lime alone is infusible, but when it combines with the silica and alumina of the ore and the ash of the coke it forms a liquid slag which floats on the molten metal. Thus, molten iron, freed in large measure from these impurities, is tapped off through a lower spout whilst the slag is drawn off separately and taken to the slag heap.

Another purpose of the flux is to remove the sulphur from the charge, for this element is a serious impurity in iron and steel. Normally, the slag removes about 85 per cent. of the sulphur entering the furnace. Lime is regarded as a better desulphurizing agent than magnesia. Lime has a greater affinity for silica than it has for sulphur, hence it forms calcium silicates until the silica is exhausted, after which it reacts with the sulphur to form calcium sulphide. It is important, therefore, to have present an excess of lime above that required to combine with the silica. For the most effective reaction, a high temperature should be maintained, for at high temperatures the slag will more completely desulphurize iron than at low temperatures. This is due to increased rates of interchange between the slag and metal at the higher temperature, and to the fact that a more basic slag is formed. Sulphur and other impurities are best removed where the slag has a high fluidity.

As the impurities in lime and limestone are usually the same as those in the ore, for the removal of which the flux is added, *viz* : silica and alumina, the impurities in the lime and limestone are doubly detrimental ; in the first place their presence reduces the percentage of lime and magnesia in the flux, and in the second place they require a certain share of the lime and magnesia to flux them off, as the flux must neutralize its own impurities as well as those of the ore.

The presence of impurities in the lime has other disadvantages. They require additional coke above that required for fluxing the silica and alumina in the ore.

A third source of loss, due to impurities in a lime or stone, is a reduced furnace output. Furnace output for a given ore is, in general, inversely proportional to coke consumption per unit of slag, and as the extra slag requires extra coke, furnace production is reduced. For this reason, lime is preferable to stone.

Other impurities in the lime or stone are sulphur and phosphorus. Usually they are present in amounts so small as to be negligible. A sulphur content of less than 0.2 per cent. does no harm, and it is unusual to find more than this amount in commercial lime. Phosphorus is usually deleterious only where the flux is used in the manufacture of Bessemer iron. Where so used, the phosphorus content should be as low as possible, and should not exceed 0.02 per cent. For other grades of iron, the phosphorus content in the lime may reach 0.1 per cent. without harmful results, but a content as high as this is exceedingly rare.

The effect of magnesia in lime used for fluxing is not clearly known. Some men are opposed to it, whilst others use magnesia stone successfully. Dolomite is widely used as a blast furnace flux. As a rule, high calcium fluxes are preferred if they are readily obtainable, but the difference in action between the high calcium and the dolomitic fluxes is so small that usually the choice is governed by other factors, such as cost or percentage of impurities.

The cost of lime delivered at the furnace has a very direct bearing on the quality used, because an inferior lime or stone may be used if the price is low enough. The question of quality is so intimately related to cost that the problem of purity of blast furnace flux is complex. The impurities fall into two classes: some, such as sulphur and phosphorus, are detrimental to the quality of the iron produced; hence, the use of lime or stone containing excessive quantities of these impurities could not be justified no matter how low the price. The other more common and abundant impurities are silica and alumina, and they are not detrimental to the iron, their chief disadvantages, as pointed out previously, being the requirements of additional lime and coke to convert them into slag. Hence, when a relatively pure lime or stone and an impure lime or stone are both available and the impurities are of the silica-alumina type, which have no detrimental effects on the iron, if the price (delivered) of the impure material is low enough to overcome the disadvantages, then it may be used in preference to the pure material.

The quality of the ore also influences the degree of impurity permissible in the flux. Thus, it would not be wise to use a flux high in silica with a high-silica ore.

It is evident that no definite rules can be laid down regarding the purity of a lime or stone that may be used for flux. One that might be condemned in one locality might be quite acceptable in another where the conditions are different. The direct bearing of cost on use indicates how important it is to

be able to calculate even approximately the relationship between the percentage of impurities and price. Usually, the use of an impure lime or stone can be justified only where it has the advantage of close proximity to the furnace, thus eliminating the usually heavy item of transportation expense.

Lime for fluxing is used in a great variety of sizes. At some furnaces the run-of-kiln is used directly without screening. Usually, the fines below $\frac{1}{2}$ -in. are taken out, partly because they tend to retard the draught, and partly because they usually contain more impurity than the lump lime, as sand and clay segregate in the fines. A common range in size is $4\frac{1}{2}$ in.— $\frac{1}{2}$ -in., though larger sizes are often used. Smelting companies who operate their own fluxing quarries may use lime or stone as small as $\frac{3}{4}$ -in. mixed in with the larger sizes, but where purchases are made from independent producers it is unlikely that sizes smaller than 2 in. would be acceptable. Thus, 2-4 in. lime might be used in blast furnaces in limited quantities, though a large amount of the small-sized lime would be undesirable when not mixed with the larger sizes. Several blast furnace troubles have been attributed in some instances to irregularities in size of the lime or limestone used, and uniform sizing generally improves the working of the furnace.

Either a high calcium lime or dolomitic lime may be used for this purpose, though the latter tends to produce a more viscous slag, from which the molten metal does not separate readily (but see p. 630).

The lime used in blast furnaces is in the form of quicklime, either "lump," "small," or a mixture of both being used. It is seldom that sufficient care is taken to ensure that only well burned lime is used, yet when this is not the case much of the desired advantage is lost.

The chief benefit resulting from the use of quicklime instead of stone is in the saving in carriage—56 tons of lime serving the same purpose as 100 tons of stone. If, however, the "lime" contains 25 per cent. of unburned stone, 63 tons would have to be used, and carriage on a useless weight of 7 tons would have to be paid.

Lime is also used in the separation of ores by flotation.

LIME AND FLOTATION

In the preliminary separation of copper and other ores from the useless material (gangue) by flotation lime is extensively used to soften the water and to neutralize any acidity in the crushed and ground rock and to facilitate the formation of froth. It is usually necessary to have both mineral and water as neutral as possible, especially when oleic acid or soap is used as a frothing agent.

Dry ground lime should not be fed into the circuit, as this gives very irregular results. Milk-of-lime, on the contrary, is wholly satisfactory if the proportion of lime present is kept constant and does not exceed 10 per cent. of the weight of the milk.

The amount of milk-of-lime to be added varies with the ore. A lime containing at least 90 per cent. and preferably 96 per cent. of calcium oxide or

the corresponding hydrated lime should be used. If quicklime is employed it should be slaked mechanically and then converted into milk of lime of uniform concentration. In some mines the lump lime is slaked and ground simultaneously in a Hardinge or other ball mill in the expectation that this will yield a milk-of-lime of constant quality.

Hydrated lime is purer and so introduces less useless material into the circuit; it is easier to use, produces a more uniform-milk, and simplifies the flotation process. Its chief disadvantage is that carriage or freightage has to be paid on the combined water present.

Dolomitic and other magnesian lime should not be used in flotation.

The lime used should be one which settles slowly out of suspension in water.

The lime may be added at various stages in the flotation process, but it is generally best to introduce it as early as possible to the crushed material. In some instances it is desirable to soften the water, independently of the lime used to neutralize or precipitate soluble salts in the mineral.

LIME FOR OPEN HEARTH FURNACES

The open hearth process of making steel consists in melting pig iron and steel, or iron scrap, and "boiling" the mixture (generally with the addition of some very pure lump iron ore) until the carbon is reduced to the desired amount. A flux is added to the charge in the furnace mainly for the removal of phosphorus. For a phosphorus content in pig iron not exceeding 0.25 per cent., additions of 6-12 per cent. of limestone, or half this amount of lime, are considered good practice. When a pig iron with a higher phosphorus content is used, as much as 17 per cent. of limestone may be charged. The phosphorus is oxidized to phosphoric acid, which unites with the lime to form calcium phosphate.

The ability of a slag to take up phosphorus depends both on basicity and fluidity. Fluorspar sometimes is added to increase the fluidity without decreasing the basicity of the slag. It is possible, however, to have the slag too fluid, for it then attacks the furnace lining. The more basic the slag, the higher its melting point, and the higher its temperature, the more lime it can absorb. An excessively high temperature is also destructive to a furnace lining, as it may approach the softening point of the refractory material.

Either lime or limestone may be used. When the flux is added in the form of stone the evolution of carbon dioxide makes the bath "boil," ensuring a lively "stirring." Extra heat is required for calcination, but evidently no more additional heat is needed than would be required for precalcination. Hence, the saving due to lime is that due wholly to the lesser charge for carriage.

A lime with a maximum silica content of 2 per cent., and an alumina content not exceeding 1.5 per cent. is usually specified.

As the chief purpose of the flux in a basic open hearth furnace is to remove

the phosphorus; and as magnesia has a lower affinity than calcium oxide for this element, dolomitic or magnesian limestones are undesirable. The maximum permissible proportion of magnesia is usually fixed at 5 per cent. in a stone, or 10 per cent. in a lime.

The size of lime or stone to be used in open hearth steel furnaces depends, to some extent, on the rate of solution of the flux in the slag. Both lime and stone from different sources vary greatly in the rate at which they dissolve in the furnace charge, and yet no definite data have ever been assembled on the rate of solubility of various limes and stones in the open hearth furnace. The furnaceman must, therefore, rely on experience.

In the basic process of steel manufacture, sintered dolomite and magnesite are used in the construction of the furnace linings.

The chief advantage of lime in open hearth furnaces is the lower cost of carriage (as explained in connection with blast furnaces). The lime must be fresh, as it slakes and carbonates on exposure, and this necessitates a larger quantity being used. Some steel makers believe that limestone is superior to lime, as the former may be more free from sulphur, the *bête noir* of the manufacturer, and usually forms a cleaner and more vitrified slag.

LIME FOR MELTING IRON

In foundries, various kinds of iron are melted together to produce "cast-iron," the furnaces used being a kind of blast furnace, known as a "cupola." To remove "dirt" and various impurities in the iron, a flux must be used, and either limestone or lime is employed for this purpose.

Lime is superior to limestone as it reacts more quickly, occupies less space in the furnace, requires no heat for conversion from the carbonate, and ensures a larger output of metal.

The quality of lime used should be the same as that for blast furnace work.

LIME IN PUDDLING IRON

Lime may be used as a substitute for ferrous oxide in the puddling furnace so as to remove more readily, and with the formation of a small quantity of slag, any siliceous matter or phosphorus which may be present. To be suitable for this purpose, the lime should be in the state of a fine powder, and should be slaked before use. Hydrated lime is excellent and highly convenient.

LIME IN WIRE DRAWING

Finely ground quicklime is used as a lubricant in dies employed for drawing fine steel wire, and in some works the rods or wire are dipped repeatedly in milk of lime which adheres to the metal and lubricates the die as the wire is drawn.

To be suitable for this purpose, two characteristics are essential—the lime must be *pure* and *soft*. Foreign matter scratches the wire, causing weakness and imperfections. A coarse lime cannot properly lubricate the die and so results in a very poor quality of wire.

LIME IN LEAD SMELTING

Lime is used for three distinct purposes in the production of lead from its ores :

(i) In roasting lead ores in a reverberatory furnace, slaked lime is added to the charge in order to prevent the ore from melting, and to produce a more spongy mass. In this way, it facilitates the removal of the lead without disturbing the other materials present.

In the absence of lime, the ore may melt and the required reactions do not take place as conveniently. The lime also assists chemically in liberating the lead and silver from the ore.

(ii) Lime is used as a flux in smelting roasted lead ores in a special form of blast furnace. It is not essential, but when it is used the resulting dross slag contains a very much smaller proportion of lead than is, otherwise, the case, and a cleaner and more readily flowing slag is produced. For this purpose, lime is preferable to limestone, as it allows more space in the furnace, and allows the latter to work more rapidly and to give a larger output.

The lime should be freshly burned and in lumps 3-6 in. diameter. It must not be in a partially slaked state due to exposure or difficulties will occur in working the furnace, and there may be much difficulty in obtaining a good draught of air through the shaft.

Some furnace men consider that lime should not be used as a flux in the presence of zinc ores as it volatilizes the latter and causes it to incrust the furnace walls.

(iii) The flue dust from lead blast furnaces is mixed with 8-10 per cent. of slaked lime and made into bricks which are hardened by drying and then added to the other raw materials in the furnace. By this means a considerable amount of lead is recovered. In some localities, the gases from the lead roasting furnaces are passed up a scrubbing tower down which flows a stream of lime water or of milk of lime. This absorbs the sulphurous gases and makes the gases passing out of the chimney unobjectionable.

In the re-smelting of crude lead or base bullion, lime is sometimes used in order to aid the separation of the desirable metals (silver and lead) and to effect a better separation of the slag.

LIME IN MERCURY RECOVERY

Lime is sometimes used in the recovery of mercury from cinnabar. It is mixed with the ore and the mixture is heated in small retorts, the mercury being volatilized and condensed in a separate receiver, leaving calcium sulphide in the retort.

LIME IN GOLD RECOVERY

In the recovery of gold from quartz by the cyaniding process, the finely-crushed ore is treated with a slightly alkaline solution of potassium cyanide which dissolves out the gold. The solution is made alkaline by lime, but great

care is needed in controlling it or all the gold will not be dissolved. The lime also causes the precipitation of undesirable substances, and flocculation and settling of ore slime.

Where the cyanide solution is used repeatedly for extracting fresh batches of ore, the magnesium oxide present in the lime cannot be used advantageously to neutralize acidity, so dolomitic lime should not be used or magnesium salts will accumulate and eventually form a saturated solution in which the cyanide loss would be high, unless an unusual amount of "bleeder" solution is run to waste.

In ores which are not acid, the lime being merely used as a precipitating agent, dolomitic lime may be substituted for pure calcium lime, as it is then as effective as lime in preventing cyanide loss. It nearly parallels lime in its precipitating and settling effect and causes no difficulty in filtration of the solution or in the precipitation of silver and zinc and equals calcareous lime in the quantity of precious metals recovered. In treating other ores by the cyanide process, the recovery of silver with the use of calcined dolomite as an alkaline agent is not equal to that obtained with the use of lime. The use of calcined dolomite should, therefore, be confined to neutralizing acidity and aiding settlement where the ore is crushed in water for amalgamation prior to cyanide treatment, and in cyanide practice where the solution could be discarded or "bled" sufficiently to keep down the excess of magnesium salts. Calcined dolomite should not be purchased as a substitute for lime in the cyanide process without a thorough investigation as to its action on the ore to be treated and of its effect on all operations connected with plant practice.

Whichever form of lime is used should be fresh, as old lime loses much of its activity. Hydrated lime is free from this defect, is usually purer than lump lime, and is much more convenient in use.

When the amalgamation process is used prior to treating the ore with cyanide, it is advantageous to add ground lime to the oil as it increases the amount of gold recovered by coagulating the slime and any grease present and tending to keep the plates clean.

LIME IN COPPER SMELTING AND REFINING

The lime used for copper smelting and refining is employed for the same purpose as in the manufacture of iron and steel. A material of similar properties should, therefore, be used. Lime is also used in the preliminary separation of copper and other ores from gangue (see "Flotation," p. 631.)

LIME AND ZINC SMELTING

Lime is seldom used in the direct smelting of zinc, as the latter is a volatile metal which is separated by distillation and not by fusion.

In Silesia, however, the acid vapours from zinc roasting furnaces are neutralized and made harmless by passing them through a tower packed with limestone blocks through which a stream of milk of lime flows.

LIME IN SMELTING TIN ORE

Lime, tin ore, and charcoal are mixed together and heated in a reverberatory furnace. The charcoal reduces the ore to metal and the lime, acting as a flux, forms a slag. Limestone may be used instead of lime, but occupies much more space in the furnace, so that, where lime can be obtained at a suitable price, it is more economical to use it.

LIME IN MOULDING ALUMINIUM WARE

The use of lime is extending for the washing or dusting of moulds in which various metal parts are to be formed. This use is receiving particular attention in the aluminium industry, and some manufacturers of aluminium ware whitewash all their iron moulds for casting this metal, so obtaining a smoother casting, and find that its strength is considerably increased. A coat of lime not only prevents fusion of the aluminium to the mould, but also, in the case of one particular alloy at least, actually increases the calcium content of the alloy. This might be a fertile field for the extension of the use of lime, *i.e.* to whitewash or dust all iron moulds.

LIME IN PICKLING LIQUORS

Refuse liquors containing iron in solution (*e.g.* the pickling liquor from tin plate works, etc.) are mixed with an excess of lime which precipitates crude ferric oxide; this is filtered off, roasted, and used as a red pigment. The shade produced depends on the temperature attained during the roasting and not on the lime, though a large excess of lime should be avoided as it is apt to produce white spots in the pigment.

For this reason, the greater part of the acid may be neutralized by limestone or chalk, the precipitation being then effected by slaked lime followed by milk of lime.

Even when no recovery of the iron oxide is desired, local authorities usually insist that all pickling liquors shall be neutralized before being discharged into a stream or sewer. Lime is more expensive than limestone for this purpose if only the cost of the material is considered, but the greater convenience attending its use, the absence of bubbling and frothing, and the fact that only half as much lime as stone is required often result in the use of lime being advantageous and sometimes cheaper than that of stone.

LIME AS A POLISHING AGENT

Lime in a powdered form has long been used as a polishing agent. Hydrated lime is the most convenient form in which to use it. It is generally used alone, but other abrasives, such as emery flour, tripoli, pumice, silica, and rouge, are sometimes used with it. The lime used must be fine and free from grit or it will scratch the goods instead of polishing them (see p. 533).

LIME FOR FURNACE LININGS

Dead burned dolomite and other magnesian limestone is used for making bricks for lining furnaces. It is an irregular mixture of lime and magnesia.

17. THE USE OF LIME IN REFINING NON-EDIBLE OILS AND LUBRICANTS

Lime is an important material in the oil refining and lubricant industries, and is used for several purposes. It is employed as a refining agent to neutralize any rancidity or other acid in the oil.

By suitable treatment the oil may be decomposed and a lime soap formed; this may be used as a stiffener for oils and greases, or it may be filtered off and decomposed, the fatty acids being obtained in this manner in a fairly pure state.

It is used for solidifying oils and in the manufacture of *grease*; for both these purposes lime acts as a hardening or stiffening agent and raises the melting point of the grease or "solidified oil."

The process consists in mixing the correct proportions of lime and tallow or other fat, boiling with an excess of water until a complete reaction has taken place, forming calcium soap, and introducing mineral oil with constant stirring until a grease of the proper consistency is obtained on cooling. The consistency, otherwise called "body" or "density," is governed by the amount of oil absorbed by the soap jelly, the temperature conditions, the proportion of moisture, and, to a certain extent, by the nature of the fat. A wide range of fatty materials may be used; each different fat requires somewhat different treatment in the boiling, and the resulting greases differ slightly in melting point, tendency to separate, and amount of soap required to make a given consistency. The fats commonly used are inedible packers' tallow, horse fat, white grease (inedible lard), soya bean oil, and the fatty acids of these and other oils and fats after the glycerine has been separated.

Typical greases of this kind are composed of the ingredients shown in Table LIII.

TABLE LIII.—*Typical Greases*

Mineral oil	100	100	100	100
Linseed or rape oil	30	30	25	30
Mineral wax	20	20	25	30
Lime	9	—	10	15
Dolomite	—	9	—	—

For *Belgian wagon lubricant*, 100 parts of slaked lime, 12 parts of caustic soda, and 300 parts of rosin oil are mixed until white, heated gently, 300 parts

of tar-oil added with constant stirring, and 800 parts of paraffin and 800 parts of fine ground talc added.

Lime is also an essential constituent of another, though distinctly lower quality, lubricating grease, known as "rosin grease" or "cold set grease." When ordinary hard gum rosin is heated in a still, decomposition takes place, and the distillate, known as "rosin oil," has the power of reacting with lime at ordinary temperatures. Such greases are made by mixing dry slaked or hydrated lime with a mineral oil, and stirring in 10-15 per cent. of rosin oil. The mixture starts to stiffen immediately and sets, to form a smooth grease in a very short time. Rosin grease made from paraffin oil forms the common "light axle" grease. When summer black oil is used, a dark sticky grease, much used for lubricating rough gears, wire ropes, rail curves, and similar rough work, is obtained.

These greases lose body quite easily when worked, and contain an excess of free lime and sometimes free rosin oil, both of which lower the lubricating value. They are distinctly cheaper, however, than greases made from animal and vegetable fats, and are used extensively, generally with satisfaction.

As grease has several advantages over oil, being much more dependable, lasts longer with each application, does not squeeze out, is cleaner and more economical, its use is increasing steadily, and, with it, the profitable outlet for high grade lime of considerable importance because they afford improved lubrication for machinery of many kinds and greatly aid in the conservation of oil. Such soap greases withstand pressure and heat much better than oil lubricants, waxes, and petrolatum; compared with soda soap greases (sponge greases) they form a smoother, more continuous film of lubricant in a bearing, so giving better lubrication within the range of work for which they are suitable. Lime soap greases are preferable for the majority of grease applications, including all cups on ordinary machinery, shafting, and motor-car chassis.

The value of the lime in a grease lies in the softness and plasticity of the particles of lime soap when saturated with oil.

The lime is used in the form of milk-of-lime, though some text books describe the use of lime water—probably in error, as lime water contains too small a proportion of lime for this purpose.

The lime used in refining oils and in making grease must consist of the smallest possible particles, be quite free from grit, and should also be free from more than 3 per cent. of matter insoluble in hydrochloric acid. Limes consisting of coarse particles—even when very pure—are inferior in quality so far as the manufacture of greases is concerned. Impurities are not only useless, but they usually tend to introduce grit. The most suitable form is hydrated lime containing 90-98 per cent. of calcium oxide, but lump lime which has been carefully slaked and then passed through an 80 mesh sieve will usually give satisfactory results.

Dolomitic or highly magnesian lime is generally of little value, as a calcium soap and not a magnesian one is usually required.

At one time, lime was extensively used in the manufacture of candles, which

consist of wax or fatty acids surrounding a wick of cotton thread. The fatty acids are made from oil which is decomposed by means of lime in a manner similar to that used for making soap. The resulting lime soap, which is insoluble, is filtered off, and is then treated with some acid (usually hydrochloric acid) so as to form the fatty acid and a lime salt; the fatty acid being largely insoluble is filtered off; when cold, it solidifies, and can be made into candles.

The reason that lime is used instead of soda in making the soap is that a lime soap which has subsequently to be decomposed is as good as a soda soap and is cheaper to produce, because lime is cheaper than soda.

The use of Twitchell's method of obtaining fatty acids direct from oils and fats has largely done away with the use of lime in the manufacture of candles, but prior to Twitchell's discovery, lime was very important.

18. THE USE OF LIME IN THE PAINT, DISTEMPER, AND ALLIED INDUSTRIES

In the paint, distemper, and allied industries, the chief materials in which lime (as distinct from whiting) is used are pigments and extenders for oil paints, distempers, whitewash, cold-water paints, including casein paints, varnishes, and enamels.

PIGMENTS AND EXTENDERS

In ordinary *oil paints*, the lime is chiefly used as a base with which to combine various other substances, in the formation of various pigments, and also as an "extender" or "filler."

The following colours are fast to lime and are, therefore, suitable: Earth colours (*e.g.* Vandyke brown, red oxide, yellow ochres, siennas, umbers, Venetian red, Indian red, light red), lithophone, zinc-white, whiting, cadmium yellow, ultramarine, cobalt blue, chrome green, emerald green, lamp black and nearly all black pigments.

Lime greens were formerly made by adding slaked lime to various solutions of chromium salts, the resulting precipitate being the chief constituent of the pigment, but nowadays green ultramarine is commonly sold as "lime green."

Lime blues are prepared by precipitating a solution of copper sulphate by the addition of lime in the presence of ammonium chloride, the resulting mixture of copper hydroxide and calcium sulphate forming the blue pigment. It is, unfortunately, discoloured by sulphur compounds so that most modern "lime blues" are really ultramarine.

Venetian red is sometimes made by heating ferrous sulphate with lime, thereby forming calcium sulphate and ferric oxide. The mixture may also be ground in the wet state and a red colour produced, but that is less stable than the precipitated oxide.

Chrome yellow and orange are made by digesting neutral lead chromate with milk-of-lime. This base displaces part of the lead oxide and forms calcium chromate and a red basic lead chromate, which is the source of the orange tint.

The resulting colour depends on the proportion of base used and the conditions of digestion.

Other yellow and brown colours are made by adding milk-of-lime to a crude solution of green vitriol or *vice versa* ; the larger the proportion of sulphate, the darker will be the colour. The precipitate is collected and exposed in thin layers on boards so as to oxidize it, thus producing the required colour. As soon as it reaches the desired shade it is dried and ground, but for some shades the product is calcined before grinding.

Lime arsenic paints are used in the leather industries for swelling the raw hides and loosening the hair and are regarded as superior to simple sulphide paints.

Grey acetate of lime is not a paint, but a "dryer" used extensively in painting. It is prepared by neutralizing the crude acetic acid obtained from the distillation of wood with either lime or some form of calcium carbonate. Slaked or hydrated lime has the great advantage of causing no effervescence and so making the neutralizing much easier and the product is cleaner.

As an *extender* or *filler* lime is used to a less extent than whitening, but when the pigments are unaffected by it, hydrated lime is preferable as the particles are much smaller and the slight plasticity of the lime when mixed with oil increases the covering power of the paint in which it is used.

Crimsons and greens are most likely to be affected by lime and should not, usually, be employed in its presence.

It should be remembered that in the use of lime as an extender it is not merely a diluent ; it serves a useful purpose, in correcting the volume weight of the paint, making it lighter or heavier as may be desired, increasing the durability, and lessening the cost.

The lime used in the production of pigments should be composed of the smallest possible particles and should be free from grit. It should usually contain at least 95 per cent. of free calcium oxide. Either freshly slaked or hydrated lime should be used ; the former should be passed through a sieve of at least 80-mesh and should be fresh. Hydrated lime of good quality will keep indefinitely if properly stored.

When lime is used as an extender or filler, its chemical composition is of minor importance, but its physical nature, especially its fineness and whiteness, determines its value.

LIME STAIN

The surface of wood may be darkened by painting it with a mixture of slaked lime and water, allowing this to dry slowly, and afterwards brushing it off. Repeated applications darken the colour and tend to make it redder. The surface may afterwards be washed and then varnished.

LIME WASH

Lime wash is a simple mixture of slaked or hydrated lime and water which is applied with a brush or a spraying device to walls of cellars, cattle sheds, etc.

A fat lime is generally used, but as it is liable to "rub off" or "flake" it is preferable to mix it with a binding agent or siccative, thereby producing a distemper or water paint, or to use a hydraulic lime. Common salt (in the proportion of about half the weight of lime) or calcium chloride (about one-seventh of the weight of lime) is sometimes added under the impression that it produces a harder surface. A variable proportion of alum is sometimes added for the same reason.

The proportions of lime and water are not important. About 5 lb. of lime to one gallon of water is satisfactory, but less is often used.

Lime wash of good quality may be made by either of the following methods:

(a) Soak 10 lb. of casein in 4 gallons of hot water for two hours or more. Dissolve 6 lb. of trisodium phosphate in two (separate) gallons of water and add to the casein. Prepare a thick cream by mixing 25 lb. of whiting and 50 lb. of hydrated lime (or the putty made from 38 lb. of quicklime) with 7 gallons of water and when this mixture is cool, add the previous (cool) solution to it, stirring thoroughly. Finally, add slowly a solution containing 5 pints of formaldehyde in 3 gallons of water, stirring constantly.

A cheaper mixture can be made by using less of the formaldehyde or by omitting it.

(b) Dissolve 3 lb. of glue in 2 gallons of water after soaking all night. Make a thick cream of 50 lb. of hydrated lime (or the putty from 38 lb. of quicklime) and 7 gallons of water. Add the glue solution to the lime cream, stirring constantly. If necessary, thin to the desired consistency. This mixture is not quite so good as (a), but is much cheaper.

It is commonly supposed that the caustic power of quicklime is retained in lime wash, but this is a mistake so far as well slaked lime is concerned.

The disinfectant power of lime wash is often overrated; its chief value lies in covering the "dirt."

DISTEMPER

"Distemper" is the name given to whiting (or sometimes to lime) which has been mixed with size or casein and water and coloured by the addition of earthy pigments, such as ochre, umber, Indian-red, ultramarine, or lamp black.

Distempers are intermediate between whitewash and paint, being more lasting than the former, but less so than the latter. Many materials now sold as distempers are *water paints* (see p. 642).

The following mixtures are suitable for the *exteriors* of buildings:

(a) 15 lb. of common salt is dissolved in 8 gallons of water, 50 lb. of hydrated lime (or the putty made by carefully slaking 38 lb. of fresh quicklime) added, and mixed thoroughly until a thick paste is formed. This paste is then diluted with water to make it of the desired consistency. If desired, 5 lb. of dry calcium chloride may be substituted for the salt.

(b) The following distemper has a yellow tinge at first which disappears within a few days and a very white and durable coating results:

12 lb. of salt and 6 oz. of powdered alum are dissolved in about 4 gallons of hot water, and 1 quart of molasses added. In a separate vessel, 50 lb. of hydrated lime is mixed with about 7 gallons of hot water, and the clear solution is added to the lime water and stirred vigorously. The desired consistency is obtained by adding water. If preferred, 38 lb. of fresh quicklime may be substituted for the hydrated lime. The quicklime must be carefully slaked and screened before use.

If the coating is not required to be non-rubbing, the salt or calcium chloride may be omitted, and a simple mixture of lime and water used.

All these mixtures should be allowed to rest for 48 hours before being used.

For *interior* work, a water paint or casein lime paint is usually preferred, but mixture (a) or (b) (p. 641) is satisfactory.

Any desired colour or shade may be secured by adding any of the pigments named on p. 639, which are not affected by lime. These may be purchased as dry powders and added in any desired proportions. The amount of pigment necessary will depend upon the shade of colour desired. It is always advisable to prepare a small sample and allow it to dry before mixing a large quantity, so as to be sure that the desired shade will be secured.

Dry Distempers are sold which can be stored in handy containers until needed. All that is then necessary is to add sufficient cold water to bring the mixture to the desired consistency for use. They are made by mixing hydrated lime with 1 per cent. of its weight of zinc sulphate, or a casein paint may be used.

Before applying a distemper, all the old material should be removed from the surface, which should then be washed and allowed to dry. Any holes or cracks should be filled with a paste made of plaster of Paris and water.

FRESCO

Fresco (more correctly *al fresco*) is not a paint, but a mode of working in which the artist uses a "fresh"¹ and still damp wall surface, made of sand and lime, as the background on which to apply his water colours. The pigments must be resistant to lime or they will be destroyed. The most popular pigments are cadmium yellow, ochre, red iron oxide, ultramarine (blue), various chromium compounds (green), and lamp black.

In order to obtain the best results, the slaked lime must be properly mellowed. The old Italian artists used to keep it moist for many years before use, but modern workers are seldom able to use lime putty more than two years old.

WATER PAINTS AND CASEIN PAINTS

Water paints are a form of distemper in which the lime or equivalent material is held to the wall surface by an adhesive, such as casein. When a water paint is made by mixing a solution of casein or glue with lime, all the

¹ Ital. : *al fresco*—in a fresh state.

materials must be cold, or a lumpy paste will be produced. If the mixture becomes hot, or a hot ingredient is used, a smooth working paint cannot be obtained. Casein paints are stable and cheap, and are, therefore, used extensively for both exterior and interior work. In casein paints, lime renders the casein soluble and eventually causes the product to "set," forming a strong, irreversible gel. The proportion of lime to casein must be carefully adjusted, as too little will produce a paint lacking in adhesion whilst an excess of lime will precipitate the casein and the paint will work badly. Usually 119-parts of calcium hydroxide are needed for 100 parts of casein, but these figures are only a rough guide.

Many distempers and water paints contain both lime and calcium carbonate; the lime is used as a chemical agent to combine with and dissolve the casein present, whilst the chalk is used as a white pigment or filler.

A typical mixture in which both are used consists of: Casein 10, Lime 12, Chalk 60, China Clay 10, and colour (if any) 8 per cent.

There are many mixtures suitable for use as water paints, but the following is one of the best of the "home made" ones:

5 lb. of casein is soaked in 2 gallons of hot water until quite soft. To this is added a solution of 3 lb. of trisodium phosphate¹ in 1 gallon of water and well stirred. The mixture is allowed to cool, and is then added slowly to a cold paste, made by adding 50 lb. of hydrated lime (or the product obtained by slaking 38 lb. of quicklime) to 7 gallons of water. Just before use, a solution of 3 pints of formaldehyde in 3 gallons of water may be added slowly; this improves the hardness of the paint when dry.

Another good water paint is made by soaking 10 lb. of casein in about 4 gallons of hot water until thoroughly softened (about 2 hours), dissolving 6 lb. of trisodium phosphate¹ in about 2 gallons of water, and adding this solution to the casein. The solution is allowed to cool and is then added slowly to a cold mixture of 25 lb. of whiting and 50 lb. of hydrated lime, with about 7 gallons of water. To this mixture, just before use, 5 pints of formaldehyde, dissolved in about 3 gallons of cold water, are slowly added, stirring constantly. The cold lime paste resulting from the careful slaking and screening of 38 lb. of quicklime may be used instead of hydrated lime. A slightly cheaper paint can be made by substituting the 25 lb. of whiting mentioned above by 50 lb. of hydrated lime, *i.e.* by using 100 lb. of hydrated lime instead of that and whiting.

The following mixtures have been recommended by A. S. Jennings:

A. (1) Slake 6 lb. of quicklime in 1½ gal. of hot water, or mix 8 lb. of commercial hydrated lime to a cream-like consistency with water.

(2) Dissolve 4 oz. of white resin in 12 fluid oz. of boiled linseed oil.

(3) Beat 6 lb. of whiting in 1 gal. of skimmed milk.

Mix (2) with (1) while hot, then add (3).

¹ Borax, ammonia, soda-ash, caustic soda, or sodium silicate may be substituted for the phosphate if desired, but are less satisfactory. These substances are added to prevent the flocculation which may occur with lime alone. The mixture must not be too alkaline; a pH value of 8.0 is the best for the final product.

B. Mix 10 lb. hydrated lime, 1 lb. casein, $1\frac{1}{2}$ oz. soda ash.

C. Mix 10 lb. hydrated lime, 1 lb. casein, 1 oz. powdered soap, 2 oz. pulverized borax, 3 oz. dry carbonate of soda.

D. (1) Soak $\frac{1}{2}$ lb. of white glue at least four hours in 1 pint of water, and then fully dissolve in 1 quart more water in a double boiler.

(2) Mix 16 lb. of hydrated lime thoroughly in 1 gal. of hot water.

Pour (1) into (2) and mix well.

E. (1) Mix 12 lb. of quicklime slaked in 3 gal. of hot water, or 16 lb. of commercial hydrated lime, to a cream-like consistency.

(2) Thin 3 lb. of silicate of soda (water glass) with 1 gallon of hot water, then stir in $1\frac{1}{2}$ lb. of casein, and continue to stir until all is dissolved.

(3) Soak 2 lb. of strong white glue at least eight hours in $\frac{1}{2}$ gal. of cold water; then dissolve in $\frac{1}{2}$ gal. of more water in a double boiler.

(4) Dissolve 2 lb. pulverized alum in $\frac{1}{2}$ gal. of hot water to which is added 24 lb. of whiting.

Mix (1) and (2) well, then stir in (3), add (4), and again stir well.

The following is recommended by W. G. Scott as being waterproof:

Beat up 1 lb. of casein with 1 pint of cold water; dilute with $\frac{3}{4}$ gal. of cold water and add 8 fluid oz. of ammonia. Stir this until a smooth jelly is formed and then add $\frac{1}{4}$ fluid oz. of formaldehyde as a preservative. Stir in hydrated lime until a moderately thick paste is formed and then dilute with water, alcohol, turpentine, or linseed oil as may be desired, until proper brush consistency is obtained.

A *Washable Cold Water Paint* may be made, according to A. S. Jennings, as follows:

(1) Soak $\frac{1}{2}$ lb. of white glue at least four hours in $\frac{1}{2}$ gal. of cold water, then completely dissolve by boiling in a double boiler.

(2) Dissolve $\frac{1}{4}$ lb. of phosphate of soda in $\frac{1}{8}$ gal. of hot water.

(3) Mix 16 lb. of hydrated lime thoroughly in 1 gal. of hot water.

Pour (1) into (3), stir well, then add (2), and stir again.

The following is the formula used by the United States Lighthouse Board:

Make a thin paste of 50 lb. of hydrated lime in boiling water (or slake $\frac{1}{2}$ bushel of quicklime in about $7\frac{1}{2}$ gal. of water, keeping the vessel well covered and stirring occasionally), add 1 peck of common salt dissolved in hot water, 3 lb. of rice flour boiled to a thin paste and stirred in while hot, $\frac{1}{2}$ lb. of Spanish whiting, and 1 lb. of clear glue thoroughly dissolved in boiling water. Mix well in the order given, and let the mixture stand for several days before using. Apply as hot as possible with a brush or spray.

Instead of casein, powdered glue is sometimes used, the proportions being 3 lb. of glue in 2 gal. of water, added to 50 lb. of hydrated lime (or the equivalent amount of slaked lime) in 7 gal. of water.

Casein is superior to glue as a siccative or binder, and of various salts available for accelerating the solution of the casein, trisodium phosphate is the best, though borax is also satisfactory.

Sodium silicate has no beneficial effect when mixed with the paint, but if a solution of sodium silicate is applied to a surface coated with casein paint, the silicate forms a valuable protective coating.

Soap and *flour* are of little value, and *alum* is inferior to *salt* in simple distempers, but salt must not be used with casein.

In glue paints, the addition of ammonia or phosphate is advantageous. The best proportions are about 3 parts each of glue and trisodium phosphate or ammonia to 50 lb. of hydrated lime or its equivalent ; if formaldehyde is also added, the amount should equal that of the glue used.

When manufacturing water paints on a large scale, it is desirable to grind them finely in a colour mill before use. Many of the proprietary water paints are prepared by grinding the various ingredients in the dry state ; such paints then merely require the addition of water to make them ready for use. When casein paints are made in this manner, the casein should contain sufficient soda to render it easily soluble in water ; the use of trisodium phosphate or borax is then unnecessary.

Colours.—Cold water paints may be tinted by the use of any of the pigments mentioned on p. 639.

Covering power.—One gallon of a good distemper or cold water paint, diluted with water to the consistency most suitable for use, weighs, on an average, about 12 lb. and has (approximately) the following covering capacity :

On wood, about 225 sq. ft. (10 ft. by 22½ ft.).

On brick, about 180 sq. ft. (10 ft. by 18 ft.).

On plaster, about 270 sq. ft. (about 8 ft. by 33 ft.).

According to A. S. Jennings, a man with a four-inch brush should cover the following surfaces per hour :

On rough walls, 22 sq. yards.

On smooth walls, 38 sq. yards.

On flat surfaces, 40 sq. yards.

On ceilings, using a step ladder, 25 sq. yards.

The lime used for water paints must be fully slaked (*i.e.* wholly free from particles of quicklime), entirely free from grit, uniformly fine, and of a pure white colour. Hydrated lime containing 95 per cent. or more of calcium hydroxide combines these qualities with the ready property of forming a homogeneous cream, which, owing to the lightness of the individual particles, does not settle out during use. The property of giving a hard flat coat that neither flakes nor dusts off is dependent upon the physical properties of the slaked or hydrated lime and requires a fat lime with high plasticity or covering power, *i.e.* a lime which consists of very minute particles each capable of absorbing water readily and retaining a film of water around itself.

If quicklime is used, it should be of very fine texture, quite white, and free from grit and black spots or streaks of colour ; it should contain at least 95 per cent. of free calcium oxide as magnesia is objectionable.

Freshly slaked lime is often considered to be better than old hydrate.

The method of slaking the lime used in casein paints is regarded as of

importance. A method found to be satisfactory by several manufacturers consists in covering lumps of lime with water and allowing to stand. In 5-10 min. the mass will begin to "boil" and swell. More water should then be added to keep the mass covered. It must not be stirred or it will "curdle." After about 20 min. the mixture is passed through a fine sieve and is ready for use.

VARNISHES AND ENAMELS

Some varnishes and enamels may be defined as solutions of a resin in a drying oil (such as tung-oil or linseed-oil) or in some other solvent, such as alcohol or acetone. In the best varnishes, lime is not used, but in the manufacture of some of the cheaper varnishes and enamels, lime is added to combine with resinic acids (resin oil) to form soaps, thereby clarifying and hardening the varnish and increasing its workability and durability. Treatment with lime lessens the tendency of a varnish to become sticky in warm weather and to become dull on exposure.

The resin or resin oil is melted and heated to about 350° F., sufficient hydrated lime being then added to reduce the acidity from about 160 to 65, but not to neutralize it completely. After stirring and heating for a short while the treatment with lime is completed.

The general practice is to buy ground quicklime and slake it, but hydrated lime is being increasingly used for the best varnishes of this type.

If the lime is slaked at the varnish works it must form a dry powder as the addition of a wet product will spoil the varnish.

Lime of an unusually high quality is required. It is important for it to be very fine and of a very high lime content. The magnesia content must be low in order to avoid viscosity and low fusibility in the varnish. The lime, when slaked or hydrated, should be free from colour, so that no pronounced darkening of the varnish will result, should enter into reactions with the resin with rapidity, and should, therefore, be of such a texture and degree of fineness that all portions of it will rapidly come into intimate contact with the resins.

The following specifications have received the approval of authorities in the varnish industry, have been adopted by the American Society for Testing Materials as tentative standards, and are recommended as a basis for contracts.

1. *Fineness.* Not more than 10 per cent. to be retained on a 250-mesh sieve.

2. *Composition of the non-volatile portion :*

	Per Cent.
(a) Minimum Calcium Oxide (CaO)	94.0
(b) Maximum Magnesium Oxide (MgO)	3.0
(c) Maximum Iron Oxide, Aluminium Oxide, and Insoluble Matter	3.0
(d) Maximum Iron Oxide (Fe ₂ O ₃)	0.4

(e) Maximum Carbon Dioxide (CO ₂) :	
(1) If the sample of lime is taken at the place of manufacture	5.0
(2) If the sample of lime is taken at other than the place of manufacture 	7.0

An additional requirement is that the lime must give satisfactory results in the tung-oil heat test when made as follows :

In a 100 c.c. beaker place 50 grams of raw tung oil. Stir in 1 gram of the sample of slaked or hydrated lime. A cloudy mass will result. Apply heat. High quality hydrated lime will usually start to react at about 80° C., small bubbles rising to the surface. As heating is continued, large flakes of lime tungate will form, and rise to the surface to form a thick white scum. The oil below will gradually become fairly clear. These changes will usually be completed by the time the temperature reaches 120° C. The heating should be continued until the mass reaches 140° C. Allow to cool. Note the formation of a thick scum on the surface which will, when freed of air, gradually fall to the bottom of the beaker. Tung oil lime soap is quite insoluble in the oil, but the addition of rosin will readily effect its solution.

Lime of poor quality will fail to react, the absence of the bubbles or flakes of lime tungate being noticeable. The oil will remain quiescent and cloudy, only a small amount of soaps forming on the surface.

Formerly, it was thought that a purer raw material than ordinary limestone was required for the manufacture of varnish maker's lime, but it has now been found that many limes made from limestone and carefully hydrated, are satisfactory for varnish manufacture.

The use of commercial hydrated lime of first class quality is recommended because :

1. It is much easier to use and the final cost is less than that of any other material.
2. Its production by special manufacturers ensures prompt delivery of a material of constant quality.
3. The quality of the varnish made with it is entirely satisfactory.

Lime is used in the scrubbing operation involved in the recovery of fumes from the varnish kettles, in making linseed oil substitutes, and in removing free fatty acids from the oils. Shellac is bleached with lime and chlorine. Rosin is hardened with lime and, in the distillation of rosin oil, lime is used to produce more satisfactory and uniform distillates. There are other direct or indirect uses, such as the catalysis of the esterification of rosin with glycerine and the precipitation of such driers as manganese oxide, the clarification of linseed oil, and the hardening of soap lacquers.

19. THE USE OF LIME IN THE PAPER AND CELLULOSE INDUSTRIES

Lime is used in the manufacture of paper and cellulose for a variety of purposes, the most important of which are :

1. In the manufacture of cellulose from wood pulp, the wood is boiled under pressure with water containing calcium sulphite and sulphurous acid. The lime serves a double purpose as it dissolves the lignin so liberating the cellulose, and it combines with any free sulphuric acid which, at the high temperature attained, would discolour the cellulose and, therefore, the paper. The lime should have been slaked or hydrated prior to use and it should be free from grit and other insoluble matter which would be entangled with the paper fibres and cause damage later. Hydrated lime is the most convenient, but slaked lime which has been passed through a fine sieve is also satisfactory. It is usually added in the form of milk-of-lime with a specific gravity of about 1.0075.

Some paper manufacturers prefer a magnesian or dolomitic lime, as magnesium sulphite is more stable and produces a more general liberation of sulphur dioxide in the cooling processes. This results in a much more uniform pulp which is considerably easier to bleach and is softer, whiter, and more pliable than that resulting from pure calcium bisulphite. In a recent investigation it was found that a number of mills using calcium lime were making as much as 8 per cent. of screenings, as compared with 2-3 per cent. of screenings where high magnesian lime was used. To be satisfactory to the paper manufacturer lime should be free from iron and other metallic impurities, and be well burnt. Air slaked lime should not be used, as the moisture is likely to vary, and a uniform proportion of base to acid is difficult to maintain. The lime should not be overburned.

2. Lime is also used in boiling the rags used for better qualities of paper in order to clean them and also to destroy any wool accidentally present. In England, 54-100 lb. of lime are normally used for 1,000 lb. of rags. In Continental practice, 9-14 per cent. of lime, and in American practice, 5-18 per cent. of lime is used. The usual boiling is for 12 hours at 30 lb. steam pressure.

As lime is only soluble to the extent of 1 part in 1,500 of boiling water, the solution is very dilute. Caustic soda can be used in stronger solutions, but is more costly, and rags boiled with lime are usually brighter and of cleaner appearance than those boiled with soda ash or caustic soda.

An objection to lime is that it forms insoluble soaps which are difficult to separate; on the other hand, it does not destroy the fibres so readily as caustic soda, and so is generally safer to use.

The lime used should be one which slakes rapidly, and should be as free as possible from iron compounds and grit. If slaked at the paper works, the lime should be made into a "milk" by vigorous stirring with water and should be passed through a fine wire gauze screen before use. Hydrated lime is more free from grit and is easier to use.

After boiling, and before washing, the rags should be kept for some hours to soften them. Some paper makers insist that the washing should be done in cold water as lime is more soluble in it than in hot water.

The quantities of lime used for different materials are shown in Table LIV.

TABLE LIV.—*Lime Required for Boiling Rags*

Quality of Rags.	Lime lb.	Hours.	Steam-Gauge Pressure in lb. per sq. in.	Temperature °C.	Loss in Weight per cent.
Coarse dirty grey linen ...	12	5	45	144	17
Strong grey and new fine linen	16	6	60	153	19
Strong, medium linen ...	18	7	60	153	15
Fine and coarse linen sacks	20	7	60	153	15
Grey old linen sacks ...	15	8	72	158	18
Coarse worn linen ...	15 ¹	8	72	158	21
Jute	25	10	45	144	21
Thread, string, and cordage	15 ¹	8	72	158	18
Tarred thread and common string	20 ¹	10	72	158	23
Coloured fine linen ...	18	10	60	153	10
Coloured strong linen ...	20 ¹	10	60	153	16
Light cotton	10	5	45	144	6
Dark cotton	18	5	45	144	10
Half wool and linen ...	22	6	60	153	30
Waste wool and cotton ...	22	6	60	153	30
Oil rags	15 ¹	5	45	144	35

¹ It is desirable to add 2 or 3 lb. of caustic soda as well as the lime.

3. In an alternative method, the wood pulp is boiled with a caustic liquor made by dissolving soda ash in water, and to this solution adding about 55–60 per cent. of slaked (made from pure quicklime), or hydrated lime, bringing the mass to a boil, mixing it thoroughly by stirring, then allowing the calcium carbonate produced to settle to the bottom. The clear caustic liquor is siphoned off, and the lime sludge washed two or three times with water to remove as much of the caustic soda as possible. It is useless to attempt to produce a stronger solution than 6 per cent. of caustic soda with a sp.gr. of 1.08 at 15° C.

The low solubility of the lime in water is not so serious an objection as might be supposed, because as soon as the lime in solution combines with grease, etc., to form a soap more lime enters into solution and this continues so long as any free lime is present. As only a small proportion of lime is present in solution at once there is less chance of excessive chemical action in the rags than when caustic soda is used.

For use in causticising liquors, a dense well-burned lime which forms a dense quick settling sludge is preferable to one which forms a more voluminous precipitate. The lime should contain at least 90 per cent. of free lime and not

more than 2 per cent. of matter insoluble in hydrochloric acid. The sludge (consisting mainly of calcium carbonate) is of no great value, but may be converted into lime by calcining in a rotary kiln, 100 ft. by 6 ft., which will deal with 20-30 tons per day, using 675 lb. of coal per ton of lime burned.

Lime is also used in recovering caustic soda from the waste liquors from the boiling cylinders. These liquors are treated with 60-70 parts of quicklime to every 106 parts of sodium carbonate present, the mixture being heated by steam pipes until the reaction is complete. The clear liquor is used for boiling more rags or pulp.

4. Lime is used in bleaching the rags or pulp, because if bleaching powder alone is used, the loss of chlorine is excessive, but by adding 3 parts of freshly burned quicklime to 7 parts of bleaching powder, the loss is reduced to a negligible proportion. Many paper mills have now abandoned the use of bleaching powder and make all the bleach liquor from lime and chlorine. The lime used should be a high-grade quicklime which slakes easily and leaves little residue, or an equally high grade hydrated lime. For information about the lime used for making bleaching powder see p. 601.

5. Hydrated lime is used to absorb the excess of chlorine evolved in the bleaching engine and to produce more bleaching powder.

6. Lime, made into a milk and mixed with a solution of alum, is often used as a loading agent or *filler* for paper. Calcium sulphate is precipitated and remains in the pores of the paper; a similar substance, produced when alum and slaked lime are ground together with water to form a paste which should not react alkaline, is known commercially as *satimite* or *satim white*, but is preferably prepared by the paper manufacturer instead of being bought ready made. For this purpose, a white, lightly burned lime of high purity, fine texture, and free from grit or dark spots, is required. Hydrated lime is excellent, but carefully slaked lime can be used if all the grit and core have been removed by screening.

7. In the manufacture of *artificial parchment*, lime water is used to neutralize any excess of acid left after treatment with nitric acid. As only the lime in solution is effective, a pure calcium lime is required; the lime water should be filtered before use so as to separate any insoluble matter.

8. In the *straw paper industry*, an alkali is used to harden the stock by dissolving out the non-cellulose constituents. Prior to 1927, lime was used exclusively for this purpose, but since then soda ash has also been used together with the lime. Lime is much cheaper than other alkalis, but the mixture requires a longer period of cooking. On the other hand, it destroys less cellulose and so is safer. The proportion of lime or alkali used can be reduced if the stock is "aged" after cooking (see p. 648).

9. Lime is sometimes used for removing the soluble organic matter from the waste liquors derived from boiling esparto, leaving a filtrate containing only caustic soda which may be recovered by evaporation. The difficulties of this process are so great, however, that the recovery of the soda is seldom attempted.

10. Lime is also used in reclaiming paper stock (old newspapers, etc.) so that it may be used again. The treatment is similar to that of cleaning old rags, and a similar quality of lime is required. For the use of lime in treating paper trade effluents see the section on "The Use of Lime in Sanitation" (p. 655).

A relatively new use for the calcium carbonate obtained as a by-product in paper manufacture is to work it into the stock as a substitute for china clay. It is not so good as the clay, but may replace half or even a larger proportion of the latter for several classes of paper.

20. USE OF LIME IN REFINING PETROLEUM

In the refining of petroleum, lime is used to neutralize any organic acids present and to prevent them from passing over when the petroleum is distilled. Quicklime has the advantage of simultaneously retaining any water present in the petroleum, but hydrated lime is easier to handle and is frequently used.

Krupowjess has found that lime removes from crude petroleum a yellow naphthene oil which burns well in lamps, but is not separated when caustic soda is used instead of lime. As this oil is a useful constituent, its removal by lime causes a loss without offering any commensurate advantage over caustic soda.

21. USE OF LIME IN THE POTTERY, GLAZE, AND ENAMEL INDUSTRIES

Lime is used only to a very small extent in the pottery and enamelling industries, though the carbonate (in the form of whiting) is extensively employed and marble is used to a smaller extent. As all forms of calcium carbonate are converted into lime on heating to about 900° C., the actual active agent in pottery, enamels, and glazes is quicklime, but it is preferably supplied in the form of whiting or marble. The addition of lime, like that of other substances soluble in water, to a glaze is undesirable, but by using an insoluble form, such as whiting, this objection is overcome. The chief objection to the use of either quicklime or hydrated lime is that they absorb moisture and carbon dioxide from the air, and, consequently, do not remain constant in composition. Lime is also very dusty and unpleasant to use. The carbon dioxide evolved when whiting is used stirs up the melt and helps to ensure a homogeneous product.

22. USES OF LIME IN THE RUBBER AND RESIN INDUSTRIES

In the vulcanization of rubber, lime is used as an accelerator; litharge, magnesia, and various nitrogenous bases are used for the same purpose. One advantage of a mineral accelerator over an organic one (apart altogether from the question of catalytic effects) is the value of the mineral as a filler or extender.

Lime appears to be most advantageous in those mixtures in which only a limited proportion of sulphur can be used.

The most suitable form is hydrated lime, as this consists of minute particles, free from coarse, inert impurities, and is of very uniform composition. Apparently, a dolomitic or magnesian lime is equally as good as a pure calcium lime.

Excessive striving after purity has led to unnecessarily severe specifications which serve no useful purpose, and a hydrated lime containing 95 per cent. of calcium hydroxide is sufficiently pure for all purposes in connection with the manufacture and curing of rubber.

Several curious errors have been made by analysts who are insufficiently acquainted with the rubber industry. For instance, cases have been known where an analyst has rejected goods for containing 2 or 3 per cent. of sulphate of lime when none was present. The error arose from taking the calcium sulphate in the ash of the rubber as having been introduced as such, instead of recognizing that it was produced from the lime and free sulphur during the incineration of the rubber. In the absence of evidence to the contrary, it may be assumed that the lime exists as hydrate in the vulcanized goods, so the lime found by analysis should be calculated as hydrate and not oxide. An error, though only a small one, may arise here because the lime product is usually hydrated to the extent of 22-25 per cent. of water, while the theoretical amount of water taken up by pure lime is 32.1 per cent., which is the figure used in calculating to calcium hydrate.

Unprepared lime, which to the buyer in the cheapest market has its attractions, is objectionable, as it requires skill and special plant to hydrate it properly. Lack of uniformity in hydration and the presence of gritty particles are drawbacks which it is good policy to avoid, by paying a somewhat higher price to the manufacturer of hydrated lime, who understands the requirements of the rubber trade, and is able to supply a suitable product.

Many articles are now made of plastic materials known as "solidified resins." They differ greatly in composition, but are mainly condensation products of the action of formaldehyde on phenol. Hydrated lime is extensively used in such materials as a filler. Thus, according to English Patent 128,477 (Scott), 5-10 per cent. of rubber dissolved in naphtha is added to an alcoholic solution of a synthetic resin and then, after stirring, 5-20 per cent. of the powdered calcium oxide, any other fillers, if used, being afterwards stirred in gradually. The mixture is moulded, dried at about 75-80° F., and heated to 350-400° F.

23. THE USE OF LIME IN SANITATION

The use of lime in sanitation may be grouped under seven main headings: (1) the purification of water; (2) the treatment of sewage; (3) treatment of trade refuse and effluents; (4) the disposal or deodorization of garbage; (5) as a disinfectant or absorbent of disinfectant; (6) as a fungicide and insecticide; and (7) various minor uses.

The use of lime in the purification of water is described in the section on "Water Purification and Softening" (p. 664).

In the *treatment of sewage*, lime may be used directly as a chemical coagulant or precipitant, and, indirectly, in the electrolytic treatment.

In the chemical treatment of sewage, the lime neutralizes any acid present and precipitates any substances with which the lime can form insoluble compounds. As the precipitate forms and settles it entangles small particles of suspended matter and enables these to be separated by sedimentation or filtration. In this way, the addition of lime enables a large amount of material to be used which is not affected chemically by the lime, but is removed mechanically. When the addition of lime alone does not produce a sufficient amount of precipitate to effect the desired enmeshing of the suspended organic matter, some substance, such as alum or aluminoferric sulphate, is added prior to the lime. The alum or other salt forms an insoluble compound with the lime and produces a bulky precipitate which, in settling, carries down most of the suspended matter, and produces, after sedimentation or filtration, a (sufficiently) clear effluent.

For some sewages, finely-divided plastic clay is used instead of a sulphate. The mixture of lime and clay with water forms a flocculent precipitate of great absorbency which rapidly decolorizes the sewage and produces a sludge which settles and filters readily.

Lime is of special value in treating sewage containing salts of iron and mineral acids (as those at Birmingham, Sheffield, Wolverhampton, etc.), as it combines with iron salts and forms a precipitate which, in settling, acts as a good coagulant.

In ordinary sewage, the addition of lime acts as a neutralizing agent, a bactericide, and a catalytic agent for the oxidization of some organic matter. No other substance obtainable at a similar cost is so useful as lime.

The quantity of lime required varies with the nature and concentration of the sewage. A common proportion is 15–20 grains of lime per gallon, but sewage containing trade wastes may require much more lime.

Experience has shown that the best results are obtained by adding just enough lime to decompose the carbonates present and to neutralize the sewage. If too great a quantity is added, soluble organic salts are formed, and produce a putrescible and obnoxious effluent. If too small a quantity is added, sedimentation takes place at a very slow rate,¹ but the best results are obtained with lime or a combination of lime and iron salts. This combination is found to remove most of the soluble organic matter as well as suspended solids, since a flocculent precipitate of iron hydroxide is formed which is very efficient in carrying down suspended matter and colouring materials.

Full scale tests for the amount of lime required to produce certain results, have been found to be the best way to determine the optimum properties of lime or other chemicals to add to a given waste effluent.

In the proper proportions and with suitable treatment, the addition of lime

¹ If the pH value of the sewage is maintained above 7.0 (*i.e.* if the sewage is faintly alkaline) its digestion in the sewage tanks will proceed normally, without odours and without foaming. The rate of precipitation is increased by the use of more lime to produce a pH of about 9.0 especially if iron salts are present.

enables between 80 and 90 per cent. of the suspended solids to be removed in a retention period of 6-8 hours.

The lime used should be almost pure calcium oxide, as all other constituents are useless and add greatly to the cost of treatment.

Its origin is not important, but lime made from the Upper Chalk and the crystalline limestones of Derbyshire are usually preferred.

Chloride of lime (bleaching powder) is occasionally used in addition to quicklime, as it has a powerful disinfectant action. It is too costly for general use, and the admission into rivers of sewage containing free chlorine is objectionable. Hence, the use of bleaching powder is restricted to a few special instances where the chlorine is thought to be needed.

It is not economical to add the lime direct to the sewage; it should first be made into milk-of-lime and a suitable proportion of the latter added to the sewage. When added in this way there is much less waste of lime than when quicklime is added direct to the sewage (see fig. 122, p. 521).

There is no great advantage in purchasing hydrated lime if the lime works are near to the sewage works, but where the latter are small and the distance great, hydrated lime is preferable, as it can be stored indefinitely with little risk of loss, whereas quicklime readily becomes carbonated (air slaked) on storage.

As the chief purpose in adding lime to a normal sewage is to provide a precipitate which will entangle the suspended matter and so facilitate clarification, any other physical or mechanical method which will ensure coagulation will serve the same purpose. At present, the use of rotary blades which beat air into the sewage and effect both oxidation and coagulation is very popular and has the advantage of not adding any solid material to the suspended matter. As such methods and bacterial processes are improved, the use of lime tends to diminish, except for special sewages which are of an acid nature, to which lime must be added for the purpose of neutralization.

The use of lime in association with some bacterial processes is increasing; it is added to produce that hydrogen-ion concentration (pH) which ensures the optimum growth of the purifying bacteria or the maximum electrolytic action, or to improve the physical condition of the sludge and thus make it easier to filter, as well as to increase its value as a fertilizer. Some sludges which nitrify extremely slowly are greatly improved if a suitable proportion of lime is present, but it must be added (as milk-of-lime) to the sewage and not to the sludge.

The *trade effluents* are waste liquids produced in various industries and usually discharged into streams or other water courses. Some trade effluents are quite harmless, but others contain mineral acids, dyes, wool washings, tannery waste, brewery waste, and various other substances which would kill the fish in any stream to which they are admitted, or would render almost impossible of clarification any sewage with which they are mixed. Most local authorities, therefore, insist that objectionable trade effluents shall be treated in some prescribed manner before they leave the works. The chief treatments

of such trade effluents are, (1) neutralization of any acid present ; (2) removal of any readily precipitable matter, and (3) removal of any matter in suspension (clarification).

For each of these purposes, the addition of lime in sufficient quantity to make the effluent faintly alkaline is the most satisfactory. It is the cheapest neutralizing agent known, it precipitates soap and many other substances which would, otherwise, be objectionable, and it is a valuable coagulant and clarifying agent. For the last-mentioned purpose it may be used in conjunction with alum or alumino-ferric sulphate.

The following notes very briefly indicate the use of lime in certain typical trade effluents :

Tannery waste.—The various liquors from the tanning processes are precipitated with lime in a settling basin and are then run into aerobic filters. These waste liquors are made up of wash water from the preliminary washing process, lime dehairing waters, tanning pit liquors containing tannic and other acids, as well as pieces of skin and other putrescible matter, and are very obnoxious. The lime treatment assists in the deposition of the sludge and produces alkalinity conducive to the desired putrefaction on a sand filter. About 60–70 per cent. of the organic matter is removed by this treatment and the effluent is in a satisfactory condition to turn directly into the streams.

The waste liquor from *woollen mills* contains fat soaps, saponifiable matter, free alcohols, and waste scouring agents, and is high in suspended solids and mineral matter, as well as in grease and fats. When lime and iron sulphate are added, the fats and soaps are precipitated and, after filtration, they can be recovered.

Acid suds effluents resulting from grease recovery by the use of sulphuric acid are also successfully treated with lime. Indeed, lime is almost the sole precipitating agent for this type of trade waste.

Dye wastes are very difficult to treat. They are usually high in suspended matter and contain dyes, acids, and other obnoxious material. Some dye wastes contain starch, soap, gums, dyes, and acids. When treated with lime and alumino-ferric sulphate, the effluent is in an entirely satisfactory condition to discharge, but when ferrous salts or alumina alone are used, imperfect results are obtained unless lime is also added. The most effective agent for dye liquors of all colours is a mixture of lime and ferric chloride. This gives excellent coagulation and removes most of the colouring matter. Other precipitants may also be used in combination with lime.

Paper mill waste liquors from the alkali process are very polluting, even after the soda has been removed. The wash liquors and other wastes are first strained to remove fibres of pulp. They then contain clay, soaps, soda, and colouring matter which are removed by adding lime and ferric chloride.

The waste liquors from the sulphite process of paper manufacture are usually high in organic matter and sulphur dioxide. The treatment consists generally in adding milk-of-lime and settling.

Waste from *card and strawboard works* which are high in organic, colloidal,

and suspended matter, are treated by adding lime, running the liquor through a settling basin, and finally through screened cinder filters. These are particularly difficult wastes to treat since they contain much putrescible matter.

Creamery and dairy wastes are of three types: (a) fresh milk wastes; (b) butter milk wastes; (c) whey. In large creameries, they are first treated with lime and then given a biological treatment. Lime and ferric chloride have been found to be the best removers of the odour of milk wastes, which in the main are due to the decomposition of nitrogen compounds and to rancid fats. Most of the organic nitrogen can be removed by adding an excess of lime over that required to neutralize acidity and then passing the effluent over septic beds. The activated sludge process alone has not proved satisfactory, in general, for this type of waste, except after treatment with lime.

Lime is almost exclusively the precipitating agent, and, according to Guth, "lime is the proper precipitant for all creamery waste products."

For *Canning wastes*, many kinds of treatment have been tried, but no method has proved entirely satisfactory, though lime and ferrous sulphate appear to be the best.

Starch products wastes are particularly heavy in total solids and are high in phosphates. The fact that the liquor is acid and contains nitrogenous matter, proteins, and carbohydrates leads to rapid fermentation and makes the liquors difficult to treat. As the liquors contain phosphates, when lime is added it forms a flocculent precipitate of calcium phosphate so that it is unnecessary to add iron salts or alum in order to get flocculation and a clear non-offensive effluent. In one works it has been found that 12 lb. of lime are required per 1,000 gallons of water.

In *brewery wastes*, as at Burton-on-Trent, the added lime combines with the carbon dioxide gas which occurs in large proportions in the water and precipitates it as carbonate of lime. It also combines with any sulphuretted hydrogen and acid present and renders them innocuous. The precipitated carbonate, in settling, carries down with it any fine, suspended organic matter and so effects clarification.

Acid wastes from metal pickling are effectively treated by adding lime until the liquid is faintly alkaline. The iron salts present combine with the lime and produce a precipitate which settles rapidly and is easy to deal with. Acid wastes from other industries are equally well treated with lime, but if much fine suspended matter or colour is present, an iron salt should also be added.

Acid mine waters are a source of pollution to many streams and are particularly detrimental to soil. They are best treated with lime, but there is need of accurate information on how to carry out the treatment effectively, as the flow and acidity of the water vary so greatly that it is difficult to add the correct proportion of lime at all times.

The most suitable form of lime for use in purifying trade wastes is either (i) quicklime, which must be slaked in a systematic manner at the works where the waste is produced and added in the form of milk-of-lime, or (ii) hydrated lime, which requires no slaking.

It is necessary to have some means of chemical control so as to avoid adding either too little or too much lime ; the former will cause trouble with the local authorities, and the latter will not only waste lime, but may bring about a partial re-solution of precipitated matter.

In treating trade effluents, the lime acts chiefly as a neutralizing agent, a precipitant, and a coagulant, and by producing a precipitate of a flocculent nature it also acts as a clarifying agent.

The problems of sludge handling and sludge dewatering are in most cases bound up with hydrogen ion concentrations, and the use of lime in this connection needs to be studied.

In the *disposal of garbage*, lime is used : (i) to cover the material and render it innocuous ; (ii) to combat flies and destroy germs ; (iii) to neutralize any acidity and prevent nitrogenous putrefaction ; (iv) to increase the fertilizing value of the mixture ; and (v) to enable ammonia to be recovered by destructive distillation. Corpses and carcases of animals buried in quicklime are rapidly disintegrated. This was, at one time, supposed to be a good means of disposing of the bodies of victims of plague and cholera, but it has been proved that any disease germs present may not be destroyed, so that this treatment is useless for infected bodies.

When garbage is to be mixed with or covered with lime, it is sometimes advantageous to use a mixture of hydrated lime and bleaching powder, as the chlorine in the latter has a strong disinfectant action. Bleaching powder should not be used, however, if the garbage is to be employed as a fertilizer.

Quicklime or ground lime is often used in connection with garbage disposal, but the loss of ammonia involved (as a result of the evolution of heat) is so serious that if the mixture is to be used as a fertilizer, only slaked or hydrated lime should be employed.

As a *disinfectant*, lime is used (i) in the form of *lime wash*—a form of *white wash*—which is merely a milk-of-lime, and (ii) as an absorbent for tar oils, phenols, and other liquid-disinfectants which it is desired to use in the form of a powder. Sometimes a little bleaching powder is mixed with the hydrated or ground lime used for these purposes.

The disinfecting power of lime is not nearly so great as was formerly supposed, and other disinfectants are now preferred in most cases.

The use of lime as a *fungicide and insecticide* has been described in the section on " Use of Lime in Agriculture and Horticulture " (p. 566).

Among the *minor uses* of lime in hygiene and sanitation may be mentioned the employment of a clear solution for the determination of the carbon dioxide in rooms which are suspected of poor ventilation. For this purpose, baryta has several advantages though it is more expensive.

24. USE OF LIME IN THE SOAP AND ALLIED INDUSTRIES

In the soap and allied industries, lime is used : (a) as a saponifying agent in the production of (i) soap ; (ii) fatty acids and similar products ; (iii) glycerin ; (b) as a precipitating agent in the purification of soap ; (c) as a

neutralizing agent, especially in Twitchell's process (steaming with sulphobenzene stearic acid as catalyst) where the lime is used to neutralize any sulphuric acid in the soap, and (d) for causticizing solutions of sodium or potassium carbonate in order to produce caustic alkali.

Soap. . In the ordinary way, soap is made by boiling oil or fat with caustic soda, which decomposes the oil into fatty acid and glycerin. Sufficient soda is used to combine with the fatty acid, forming the soap, common salt being then added to make the soap insoluble, so that it can be filtered off, leaving the water with glycerin in solution as a by-product.

As soda is expensive, many attempts have been made to replace it by lime. In that case, the first process is to form a lime soap which, being insoluble, can easily be separated, purified (when very cheap oils are used), and then converted into a soda soap by means of sodium carbonate. Under such conditions, the lime is merely employed to produce a soap of no commercial use, but convenient chemically as a cheap means of obtaining a substance which can be purified and after all the impurities have been removed, converted into ordinary soap.

In the autoclave method of making soap, the previously purified fat or oil is mixed with lime and water, and is heated in an autoclave for several hours. This causes a splitting up of the fat into a lime soap and glycerin. The lime required is, theoretically, 8.7 per cent. of the weight of the fat, but, in practice, 2-4 per cent. is sufficient. The lime soap is filtered off and mixed with sulphuric acid, which converts it into calcium sulphate (gypsum) and a free fatty acid. The latter can then be separated and afterwards mixed with a solution of sodium carbonate or caustic soda and converted into a soda soap.

The gypsum produced by the sulphuric acid is insoluble in water and tends to block pipes, etc., so that magnesia or zinc oxide—which form a soluble sulphate—are sometimes preferred to lime.

In the Krebitz method of soap manufacture, the oil or fat is heated with 12-14 per cent. of slaked lime and 3-5 per cent. of water. The resulting lime soap is washed and then treated with sodium carbonate to produce soda soap, the lime being separated as a sludge of impure calcium carbonate containing about 10 per cent. of soap which cannot be washed out. The disadvantages of this process are the large proportion of lime required owing to not working under pressure, and the difficulty in recovering all the soap from the sludge. As regards the latter, it is better to decompose the lime soap with acid and then neutralize the fatty acids with soda.

The most suitable form of lime for the soap industry is hydrated lime, but milk of lime, if carefully screened so as to remove all coarse particles, is satisfactory. There should be less than 2 per cent. of magnesia present, as magnesium compounds do not settle readily and are difficult to filter.

As impurities are useless and may cause undue wear of valves, etc., the lime should contain less than 1 per cent. of matter insoluble in dilute hydrochloric acid and the free lime, as calcium hydroxide, should not be less than 90 per cent.

Fatty acids are now chiefly made by the Twitchell process, in which the oil

is heated with a catalytic acid. The lime is then used merely to neutralize the excess of acid at the end of the reaction. Sometimes, however, fatty acids are made by first producing the lime soap, as described, and then decomposing it with sulphuric acid. For this purpose, the lime should be of the same nature as for the manufacture of soap.

Candles. Milk of lime is used in the preparation of candles, about 12–15 per cent. of the lime being added to saponify the fatty acids, as many modern candles are not made of fat, but of fatty acids. The lime is used in the same manner as described under "Soap." In some modern methods, the fatty acids are produced without making a soap and very little lime is then required except, occasionally, sufficient lime to neutralize the excess of sulphuric acid present.

Glycerin. The liquid left on saponifying a fat or oil and removing the soap, contains the glycerin produced by the reaction. This solution or "first lye" is neutralized with lime until it shows pink with phenolphthalein, about 0.25 per cent. of lime being usually required. The liquid is run off, the deposited lime salt (which contains a considerable amount of glycerin) filtered, and the glycerin liquor squeezed out. Usually the filter cake is of little or no value. The clear solution is made slightly acid with sulphuric acid and evaporated to a low bulk. The residue, which contains glycerin and water, is diluted to 20 Bé (sp. gr. 1.16) and boiled for some time with milk of lime or with hydrated lime, separated from any precipitated matter, neutralized with sulphuric acid, filtered, and distilled in the presence of steam. Most of the glycerin is distilled over and collected, but some remains in the concentrated liquor and is purified by filtration and distillation. The distilled product is usually re-distilled in order to concentrate it to a syrup.

The lime being used solely as a neutralizing agent, its quality is not of great importance, though it is usually cheapest, eventually, to use hydrated lime, as it avoids dealing with large quantities of impurities, which, if gritty, cause undue wear of the pumps and fittings.

If quicklime is used, it is advisable to use only lime which contains less than 2 per cent. of magnesia and less than 1 per cent. of matter insoluble in dilute hydrochloric acid, and the available lime, as calcium hydroxide, should not be less than 90 per cent.

25. USES OF LIME IN THE TEXTILE INDUSTRIES

In the early days of the textile industries lime was the chief agent employed for cleaning the cloth and for removing various pectin-like bodies. The introduction of caustic soda was thought to be advantageous because of its more powerful action and the greater ease with which it could be used when compared with quicklime. The losses which accompany the use of strong alkalis, and the fact that hydrated lime is just as easy to use as soda, have led to a revival in the use of lime which has more than justified the enterprise of those who have tried it under suitable conditions. The idea that the iron compounds in lime

stained the textiles has been shown to be quite erroneous, and it is a fact that lime does not adversely affect the cloth in any way.

At present, the use of lime is largely confined to vegetable fibres such as linen, cotton, and jute, and in treating artificial silk; its use in the woollen industries is still largely in an experimental stage.

The principal uses of lime in textile works are in the processes of cleansing and dyeing the goods. Four distinct purposes are served: (1) boiling, bucking or scouring; (2) bleaching; (3) kier liming; and (4) dyeing. Lime is also used for water softening, for making mercerizing caustics, and for recovering waste lyes, but these uses are not special to the textile industries and will be omitted from further consideration in this section.

In the *boiling, bucking, or scouring process*, lime functions as a saponifying, hydrolyzing, neutralizing, and emulsifying agent, whereby the goods can be cleansed of the waxy coating, the starch, the tannins, the pectin bodies, the motes, and, possibly, some of the oily and resinous impurities. Such cleaning is necessary in order to make effective the processes of bleaching and dyeing that follow. It may be applied either to the fibre, the yarn, or the cloth, but, except in the manufacture of special products, such as absorbent cotton, it is the general practice to apply it to the goods.

Lime used in the kier boil for the clearing of cotton cloth and to remove the fats, waxes, and pectin bodies works very satisfactorily. It fulfils this purpose with less drastic action on the cloth than when the stronger alkalis are used, acts upon the pectin bodies in the cloth, and removes them more efficiently.

In carrying out the lime boil, unless hydrated lime is used, the lime is first slaked and then made into a milk of lime of such strength that after the goods have been passed through it and squeezed, they will contain between 1.5 per cent. and 2 per cent. of calcium oxide. The limed goods are then run into a kier or tank and boiled for 12 hours, washed, and then continued in process. This is what is known as a "half bleach boil," and is satisfactory when the goods are to be dyed with dark shades. For a "full bleach," the goods, after washing, are treated with dilute hydrochloric acid and then replaced in the kier and boiled for 8 hours with a solution of soda ash containing 1.5 per cent. of the chemical. The object of this is to remove the lime soaps.

Soda has the advantage of producing soluble soaps which are readily removed by washing, whereas the lime soaps require treatment with acid and then with soda. Lime is so much cheaper that it is usually preferred for the preliminary saponification. Lime has the further advantage of being only slightly soluble in water, so that too strong a solution cannot be obtained. As some of the lime in solution is used, its place is taken by lime formerly in suspension so that the strength of the solution is kept constant. If, on the contrary, soda is used, the whole of it is present in solution. At the beginning of the digestion it will be present in maximum concentration and there is danger of the formation of cellulose hydrate, especially where the cotton saturated with alkali lies in contact with a highly heated surface. If, in the effort to avoid destructive and mercerizing effects, the quantity of caustic soda is

reduced, there may be insufficient present to react completely with the impurities, with the result that the goods will not be properly cleaned and unable to withstand steaming and storing.

By the use of lime, the dilemma encountered with the use of caustic soda is avoided.

Owing to the tendency of oxy-cellulose to form in the presence of air and alkali, the prompt removal of all surplus alkali is required as soon as the cotton is withdrawn from the kier. Sometimes, through the use of improperly-slaked lime or cores, particles of sensible size remain entangled in the goods even after the hydrochloric acid treatment and rinsing. These particles, in conjunction with the air, cause the formation of oxy-cellulose and, eventually, of holes in the fabric.

Where an absolute white is required, a treatment with some oxidizing agent is necessary, followed by washing, scouring, and again washing. This operation is independent of the preliminary treatment, and so does not enter into the question of the relative merits of lime and soda in cotton cleaning.

Years ago, complaints frequently arose that the use of lime made the textile tender, and no wholly satisfactory explanation has been found. The defect is worse when lime is used with alkaline carbonates, for it converts the latter into caustic alkalis which greatly reduce the strength of textiles wetted with them and then exposed to the air. With greater care and skill and the avoidance of too high a temperature, the risk of "tendering" is now much less than formerly.

Either quicklime or hydrated lime may be used for making the milk-of-lime. It is very important, however, that lime of suitable properties be selected. If quicklime is used, it must be properly slaked and purified and all lumps must be removed.

In the *bleaching* or "*chemicking*" process, the lime functions as a base and carrier of chlorine under conditions which make possible the control of the special oxidation process required by the textile fibres. The oxidizing action must be very mild, such as is obtainable with hypochlorite of lime solution, in order to avoid oxidation or hydrolysis of the cellulose. The object of the bleaching operation is to remove the organic colouring matter, which is done by oxidizing it to colourless soluble compounds.

Bleaching or "chemicking" consists of steeping the goods in a clear bath of hypochlorite of lime of 1-2° Tw. strength at a temperature of about 80° F. It is customary to use wooden or concrete vats. The amount of hypochlorite solution is dependent upon the goods and the impurities in them. The time of steeping is dependent upon such factors as the strength of the bath and nature of the goods. After steeping the goods in the hypochlorite bath, they pass through a series of washings and acid treatments which vary with the use intended for the goods.

Contrary to what is stated in some text books, the goods are not dipped first in bleaching powder solution and then in acid, but are left in the bleach liquor until the colour is practically destroyed, are then washed, dipped in acid.

and again washed. The use of acid is merely to remove basic calcium compounds from the cloth.

The hypochloride bleaching bath or "chemic" solution may be made by passing chlorine gas into milk-of-lime, or preferably by adding bleaching powder to water and beating the mixture in a small tank into a paste, passing it through a sieve, and agitating with water at 75–85° F. in a larger tank. About 100 gal. of water are used for each 100 lb. of bleaching powder. After the sludge has settled, the clear supernatant solution is drawn off ready for use.

If lime and chlorine are used, the first operation is the preparation of the milk-of-lime. Either quicklime or hydrated lime may be used, but the former must be carefully selected. For every 250 gal. of water there should be used 110 lb. of hydrated lime or 80 lb. of quicklime, the latter being carefully slaked and then passed through a 50-mesh sieve before use. The chlorine may be introduced through a lead pipe reaching to the bottom of the vat. The chlorine should pass in slowly with the temperature at 68° F. 100 lb. of chlorine are required to bring the mixture to the desired state. After the sludge has settled, the clear supernatant liquor is drawn off ready for use. An alternative method for the absorption of the chlorine is with absorption towers, such as are used in the paper industry.

The lime must be in excess or the bleaching will be irregular. Bleaching powder rots wool and silk, though, under suitable conditions, it may be used for imparting lustre to wool. Wool may be cleaned by soaking it for 48 hours in milk-of-lime in the cold and without an excess of air. This treatment is said to cause the wool to absorb dyes more readily. About 1 lb. of slaked or hydrated lime and 400 gal. of water are used for 200 lb. of wool.

Kier liming is a term used when lime is applied so to form a protective coating on the inside of the iron-kier, to prevent staining of the goods by contact with the iron walls.

Either quicklime or hydrated lime may be used, but quicklime is preferred. 5 lb. of quicklime is made into a milk-of-lime with 50 lb. of water. Skimmed milk or casein is sometimes added to ensure better adhesion. The kier should be warm when the lime is applied with a broad brush, and the entire inner surface of the kier is coated. Steam is then turned on for 20 mins., after which the kier is allowed to cool. It is next given a second coat and the steaming repeated, when the kier is ready for use. The liming should be repeated every six months, care being taken to scrape off all the loose lime before applying the new coat.

In *dyeing*, lime is used for several purposes, the most important being in connection with mordanting, in which lime functions as an alkali and precipitating agent whereby the metallic salt is fixed upon the fibre. The deposition of the metallic salt is necessary to enable the fibre to hold the dye.

In the "new Turkey red" process, the goods, after bleaching, are treated with a solution of an aluminium salt and then washed in a bath of milk-of-lime. This operation fixes the alumina in a basic condition suitable for receiving the dye. Lime can also be used in the actual dyeing operation; the bath should

contain 2 per cent. of hydrated lime to ensure the proper depth of shade.

In dyeing *wool*, the colours are sometimes fixed by converting them into insoluble *lakes* by adding lime to the solution. Lime is also used in dyeing wool with indigo in the presence of zinc dust, to combine with the zinc and liberate hydrogen. In dyeing wool with chrome yellow, milk-of-lime is used after the material has passed through the chromate bath.

In the use of alizarine in the dyeing of cotton mordanted with chromium, lime is preferable to chalk for rendering the chromium acetate basic and for fixing the chromium compounds, as in the cases of the aluminium compounds. The amount required is 2 per cent. of hydrated lime by volume.

In vat dyeing in general, lime can be used for keeping the bath alkaline.

Lime is also used to soften the water used in dye works, and in the manufacture of some dyes, such as (i) *malachite green*, which is made by heating oil of bitter almonds with benzaldehyde and milk-of-lime and is then converted into the disulphite; (ii) in the production of alizarine from anthracene, lime is used in the recovery of the bichromate as an oxidant; (iii) in the manufacture of *indigo blue*, the commercial indigo is digested with a hydrosulphite solution and milk-of-lime.

Either quicklime or hydrated lime may be used in the dyeing operations. The remarks mentioned above regarding selection, slaking, and sieving the quicklime, or using hydrated lime, apply equally to that used for dyeing.

Apart from the kier liming, for which almost any kind of high grade lime is satisfactory, the lime used in the textile industries should contain, on non-volatile basis, less than 2 per cent. of iron and alumina, less than 3 per cent. of magnesia, less than 2.5 per cent. of silica, and a calcium oxide content of more than 94 per cent. It is desirable also that the slaked lime be fine, free from lumps, and very reactive chemically. It must be practically free from iron compounds.

The lime should be a fat one and, when slaked or hydrated, should form a soft, fine, and pulverulent powder which, when stirred with a little water, should yield a smooth, fat slippery paste.

In all branches of the textile industries, hydrated lime is preferable to quicklime, as it is free from "core," does not require to be slaked, but can be mixed with water and used immediately, and is much easier and more convenient to use than any other form. It is expensive in first cost, but when the cost of slaking, screening, etc., in the textile works is considered, it will usually be found that quicklime proves, in the end, to be dearer than hydrated lime.

For *bleaching* textile materials lime is combined with chlorine in the form of bleaching powder (p. 601).

The *advantages* of lime in the textile industries are:

1. A simplification and improvement in the scouring process, especially by the use of a dilute soda ash boil after the lime boil.
2. Safeguards against unwanted mercerization, such as occurs with the use of soda.
3. Better "bottoming" for the bleaching process.

4. The mild reaction of lime and chloride of lime tends to prevent hydration and oxidation of the cellulose.
5. The protection against excess caustic action, due to the limited solubility of lime.
6. The constant concentration of the alkali maintained throughout the boil.
7. The prevention of excessive action on the cellulose—due to the precipitation of insoluble calcium carbonate on it.
8. The smaller loss in weight, length, and strength of the fibre when bleaching with chloride of lime.
9. The cheapness of lime and its use.
10. The relative ease and safety of handling.
11. The permanence of bleaching by hypochlorite of lime.
12. The adaptability of the lime boil to the requirements of special finishes, such as a firm, silky finish.
13. Its superiority as a saponifying agent in high pressure kiers.
14. Simplification of the kier boiling, which results from there being less attention required to the flow of the liquid through the kier.
15. The greater uniformity of scouring in all parts of the kier.
16. The solution of the proteid matters without an undue attack on the fibres.

26. USE OF LIME IN THE SOFTENING AND PURIFICATION OF WATER

Lime is used in the general purification of water, and also for that particular form of purification which is known as *softening*.

Public water supplies are not usually softened (though many advantages would be gained by such treatment), but they are purified to such an extent as will render them harmless for drinking and culinary purposes. Such purification consists essentially in (i) removing coarse particles by sedimentation or filtration; (ii) precipitating any objectionable matter which is in solution; (iii) neutralizing any acidity; (iv) decolorization or bleaching of peaty water; and (v) sterilization or destruction of disease germs present in the water.

Special water supplies may need a mode of treatment which removes impurities which are objectionable when the water is used for a particular purpose, e.g. the removal of iron (deferritization) which would stain some textile materials, and the removal of acidity from mine waters, or of oil from recovered water, condensed steam, etc. (see *Deferritization, Treating Acid Waters, and Removal of Oil*).

Water for industrial purposes need not usually be purified in the same manner as a public supply, but it should usually be softened so as to prevent the occurrence of minor reactions of a troublesome nature. This is particularly the case with water which has to be heated in boilers or other appliances, or which is to be employed for dyeing, laundry work, or other purposes where a soft water is required (see *Hard and Soft Waters, Water Softening, et seq.*).

For *precipitating* impurities inimical to a drinking water, it is usually best to add milk-of-lime, though it is not necessary to add sufficient to soften the water completely. Sometimes alum is added, in addition to the lime, to produce a precipitate which settles rapidly and entangles the smaller particles in suspension, thereby removing them more easily. Quicklime is generally used for making the milk-of-lime, but the process is greatly simplified and is capable of much better control if hydrated lime is used.

River water in time of flood is liable to contain an excess of fine suspended matter which does not settle readily. Its settlement is greatly facilitated by the addition of milk-of-lime which coagulates the particles and causes them to sink rapidly.

For the prevention of *corrosion* and *plumbism*, the addition of milk-of-lime is excellent (see *Treating Acid Waters*). Acid waters must not be used in a boiler on account of corrosion.

For the *decolorization* of water, the addition of milk-of-lime, followed by filtration, is usually the best method. An automatic device for delivering a definite quantity of milk-of-lime to the water is useful, but it should be checked several times a day so as to avoid adding an excess of lime.

For the removal of *Iron compounds* see *Deferritization*.

The *Sterilization* of water is readily effected by adding milk-of-lime in slight excess. Houston has shown that *B. coli* is killed in 5–24 hours in the presence of only a faint excess of lime (the total amount of lime required by Thames water being only 1 lb. per 500 gal.).

According to Scott and McClure,¹ the sterilization appears to be largely due to the low hydrogen-ion concentration of lime-treated water, since bacteria of the colon typhoid group are destroyed in media of low hydrogen-ion concentration, the limiting value being in the neighbourhood of pH 9.5, though a pH of 10.0–10.3 is suggested. This pH is ordinarily attained by the addition of lime to the extent of a caustic alkalinity of 10–20 parts per million.

The lime used for sterilizing water should be a fat lime which has been carefully slaked or hydrated. It should be made into milk-of-lime, and if slaked lime is used the "milk" should be passed through a 60-mesh sieve. The "strength" of the "milk" should be carefully tested and adjusted so that the amount of lime needed can be accurately added. Hydrated lime has the advantage of not requiring so much adjustment, as it is more regular in composition than lump lime. For this reason, lump lime should not be added direct to the bulk of the water.

The results of tests by Hoover and Scott indicate that the lime has a selective action. Intestinal bacteria are destroyed, but the reduction of the total number of bacteria is not high.

Many other laboratory experiments have been made which lead to the following conclusion :

1. When enough lime is added to water to absorb the free and half bound carbonic acid and to precipitate the magnesium, the bacteria of the colon and

¹ *J. Amer. Water Works Ass.*, **11**, 598-604 (1924).

typhoid group are killed in 48 hours after being so treated, provided the water does not contain large quantities of organic matter.

2. The germicidal action is effective in from 5-24 hours, when an excess of $\frac{1}{2}$ -1 grain per gal. is added beyond that needed to reduce the temporary hardness to the lowest possible figure.

3. Intestinal organisms will not live in water containing no free and half bound carbonic acid.

4. Twenty-four hours contact is not sufficient to ensure complete destruction of intestinal bacteria unless the water is slightly overtreated with lime.

5. Turbid waters can be successfully disinfected by softening with lime, and then allowing the turbidity to settle out along with the precipitated carbonates. Turbid water has never been successfully disinfected with hypochlorite or chlorine, because the bacteria embedded in the suspended matters are not destroyed.

6. The sterilizing action persists indefinitely. In a paper on water disinfection by chemical methods, Rideal states the advantages of using chemicals that persist in their disinfecting action as follows :

"It is at the same time a disadvantage if a disinfectant, however powerful in its first onset, is very evanescent, as many disease germs are strongly resistant, and we know that the time factor is of extreme importance in sterilization."

The lime used for sterilizing should contain at least 90 per cent. of free calcium oxide, or the equivalent amount of calcium hydroxide, and less than 1.5 per cent. of magnesia and 2.0 per cent. of matter insoluble in dilute hydrochloric acid. The purer the lime, the less will be the cost of dealing with the "core" and other impurities present, which form a useless residue in the milk of lime.

The risk of lime being deposited in the pipes, pumps, etc., must not be overlooked, though at Canterbury (which has used the process since 1860) and Southampton (which has used it since 1888) the deposition of lime has not proved serious.

For *increasing the rate of filtration* of water, lime and alumino-ferric may sometimes be used (see *Removal of Oil*).

Hard and Soft Waters.—The popular method of describing waters as "hard and "soft" is based on their behaviour towards soap. Those waters which readily give a lather are described as "soft," while those which do not are described as "hard." In washing processes in laundries, the use of hard water results in wastage of soap, because an amount of soap equivalent to the hardness of the water is destroyed before any detergent action takes place.

The hardness of most waters is due chiefly to calcium bicarbonate, magnesium sulphate, and common salt (sodium chloride), though in some cases other salts are the cause of this property.

Natural waters also contain silica (SiO_2), but as the solubility of this compound is only 0.28 grains per gal. it does not occur in solution to any great extent.

Iron is sometimes present in the form of ferrous bicarbonate, but, on exposure to air, this compound absorbs oxygen with deposition of ferric oxide, which is only slightly soluble in water. In surface waters, therefore, iron is rarely present in any quantity. For certain industrial purposes, the presence of even minute quantities of iron in water is objectionable, and its elimination before the water is used is, therefore, desirable.

Some natural waters are strongly alkaline on account of the presence in solution of sodium bicarbonate. For reasons which will be made clear later, waters of this type usually contain only small quantities of calcium compounds. In some districts, waters of an entirely different type, which are acid in reaction, may occur. In moorland districts, for instance, the water is often almost free from calcium and magnesium compounds, and is distinctly acid by reason of the presence of organic acids derived from decaying vegetable matter. Such waters are corrosive and require treatment for the neutralization of acidity before they can be used with satisfactory results for industrial purposes.

Some waters, particularly river and canal waters in manufacturing districts, contain impurities derived from industrial effluents. Such waters may be strongly acid or alkaline, and they may contain large quantities of objectionable organic or inorganic compounds. The use of such waters for industrial purposes should be avoided as far as possible, but in cases where no alternative supply is available, the water should undergo suitable treatment based on a careful analysis of a representative sample. It is obvious that no definite rule can be laid down for the treatment of such waters. Each case must be considered on its own merits, and an investigation of the chemical composition of the water is essential.

For most purposes it is sufficient to regard the hardness of water as due to (a) calcium bicarbonate and magnesium bicarbonate—known as *temporary* hardness—and (b) calcium sulphate and magnesium sulphate—known as *permanent* hardness. Sea water owes much of its hardness to the common salt present, but is so rarely used industrially that its treatment need not be considered here.

The bicarbonates are decomposed on boiling the water, the corresponding carbonates being formed, which are insoluble in water. Hence, the bicarbonates can be rendered insoluble by simply boiling the water. The other compounds are not affected by boiling.

It is usual, therefore, to distinguish between two kinds of hardness in water :

- (i) Hardness which is destroyed by boiling, called *Temporary Hardness*.
- (ii) Hardness which is not destroyed by boiling, called *Permanent Hardness*.

Both kinds of hardness result in wastage of soap, and are, therefore equally important from the soap users' standpoint.

When the water is used for certain purposes; however, especially for the

feeding of boilers, the salts causing permanent hardness often have more serious effects than the carbonates which cause temporary hardness.

It is well known that the impurities in water which give rise to hardness are important, not only because they result in wastage of soap in the soap-consuming industries, but also because they have harmful effects in a large number of other ways.

Lime not only removes the temporary hardness from the water in swimming pools, but also sterilizes it, thus rendering it satisfactory and safe for bathing purposes.

The advantages of a lime-treated water over water sterilized with hypochlorite or chlorine is that the disinfecting action of the lime persists, because the lime removes all carbon dioxide from solution and thus deprives any pathogenic germs of their chief source of life. A water sterilized by hypochlorite or chlorine is only satisfactory so long as some is present; when this has been dissipated the water offers no resistance to the development of disease-producing organisms introduced into the water by the bathers.

Where a softened water is used for a public supply, most of the matter precipitated during the softening should be separated by repose. The water should then be run off and carbonated by passing carbon dioxide gas through it before it is filtered.

The filtration of lime-softened, but uncarbonated, water through sand filters has a bad effect on them, because the normal carbonates in saturated solution crystallize on the surface of the sand grains, cover them with an adherent coating, causing them to grow in size, and finally to lose their effectiveness as a filter medium. The sand grains not only grow in size, but they cement themselves together, forming hard lumps in the filters, and the water to be filtered will not pass through them. Once or twice a year, sand filters used for softened water must be spaded up, and all hard lumps broken up. The filter must be rebuilt after seven or eight years service.

The hardness of natural water has been shown to be principally due to the presence in solution of calcium and magnesium compounds which react with ordinary soaps, forming insoluble lime and magnesia soaps which have no detergent action. It is only when the lime and magnesia compounds have been precipitated from solution that the soap becomes effective as a washing agent.

Taking 1,000 gal. of water as the unit, every degree of hardness will destroy 9,400 grains or 1.35 lb. of soap, and 1,000 gal. of water of 22 degrees of hardness will destroy 29.7 lb. of commercial soap before any soap becomes available for washing purposes. If the soap costs 2d. per pound, *five shillings-worth* of soap will be required for softening 1,000 gal. of such water, *i.e.* rendering it fit to dissolve soap, or, in other words, to wash clothes, while at the same time it leaves floating about in the water 30 lb. of a sticky, greasy curd (stearate of lime and magnesia) which attaches itself to the fabrics to be washed, and, as it cannot be removed by rinsing even in softened soapy water, it will dry with the clothes and render them sticky and patchy, and will communicate to them the

objectionable smell of the oils used in the manufacture of the original soaps.

The life of the cloth is thus shortened, stains often occur, and the appearance of the washed goods is unsatisfactory. In the cleaning and scouring processes of the textile industries, the use of hard water results in loss of soap, as in the case of the laundry industry. In the cleaning of wool, there is a marked tendency for insoluble soaps to become fixed in the fibres, and to cause uneven dyeing. The use of hard water in degreasing wool causes deterioration in the quality of the fibre, and interferes with the uniform fixation of mordants and dyes.

It is, therefore, abundantly clear that the use of soap as a material for softening water is both costly and objectionable. As the water must be softened before the soap can perform its own special duty, it is only reasonable to suppose that any process which will remove the hardness without introducing any other objectionable materials, and at a nominal cost as compared to soap, would be a great advantage to laundries. Soft water is an essential in every laundry and in every works where soap is used.

Apart from its use for the laundry, soft water is a requisite for toilet purposes. Soaps which are used for washing the skin are generally superfatted in order that they should not cause irritation or a feeling of harshness, and when a soap thus prepared is acted upon by a hard water, not only is a sticky insoluble lime soap formed, as described, but the free fat is also precipitated as a sticky mass, together with the lime soap, on that part of the skin to which it is applied.

Under these circumstances, it is quite clear that effective washing is rendered impossible, as the skin is coated with a film of greasy insoluble matter which prevents the penetration of that part of the soap which has dissolved.

Meats and vegetables cooked in softened water are more nutritious than when cooked in hard water. Coffee and tea are better made from softened water, and less coffee and tea are wasted.

In dye works, print works, and bleach works it is now realized that the use of clean, soft water is desirable, in order that satisfactory results may be obtained.

In the leather and tanning industries, hard water has been shown to cause formation of insoluble tanning compounds which give rise to serious waste of tanning and cause an uneven shade in the final product.

In the chemical industries, it is known that the use of hard water causes the formation of precipitates, which lower the quality and purity of the manufactured products.

In many other industries, *e.g.* in paper mills, distilleries, etc., the importance of avoiding the use of hard water in order to improve the quality of the work is now realized.

Ice should only be made of soft water, because the minerals present in hard water have the effects shown in Table LV (due to Behrmann and De Celle). The result of treating hard water with hydrated lime in an efficient water softening plant is also shown :

TABLE LV.—*Effect in Ice of Minerals in Hard water*

Minerals in Water.	Effect in Ice.	Result of Treatment with Hydrated Lime.
Calcium Carbonate	Forms gritty, dirty, discoloured deposit, usually in lower part and centre of the ice. Causes shattering of ice at low freezing temperatures.	Practically eliminated.
Magnesium carbonate	Forms gritty, dirty, discoloured deposit, milky patches and bubbles, and also causes shattering of ice at low freezing temperatures.	Practically eliminated
Iron Oxide	Causes bad discoloration, yellow or brown deposits, and also stains the calcium and magnesium deposits.	Eliminated
Aluminium Oxide and Silica	Cause dirty deposit and sediment	Practically eliminated
Suspended Matter	Causes dirty deposits and sediment	Eliminated.
Calcium Sulphate Calcium Chloride	Act like sodium sulphate and sodium chloride. Do not form deposit.	No change
Magnesium Sulphate	Causes greenish or greyish cast, concentrate in core water, retards freezing, and causes heavy cores. Often shows up as white spots and dirty coloured streaks.	Changes to Calcium Sulphate
Magnesium Chloride	Acts like sodium sulphate and sodium chloride. Does not form deposit.	Changes to Calcium Chloride
Sodium Sulphate Sodium Chloride	Cause white butts, concentrate in core, make heavy core, and retard freezing, but do not form deposit.	No Change
Sodium Carbonate (Actually present as Sodium Bicarbonate)	Even in small quantities often causes shattering of ice at temperatures below 16°. Also causes white butts, concentrates in core, retards freezing and makes heavy cores. Does not form deposit.	Treatment changes sodium bicarbonate to sodium carbonate, and improves ice very little.

As previously explained, the salts forming permanent hardness can be removed by adding soda ash as well as lime, though this further purification is seldom needed for ice.

It was formerly supposed that the use of lime caused discolouration of the ice, but it has been found that *red ice* is due to rusty iron pipes or to splashes of brine entering the ice tank.

The cracking and shattering of the ice has also been attributed to the use of lime, but this has been shown to be erroneous. These defects have nothing to do with the water or the manner in which it has been treated.

When water is used for steam raising its hardness is a factor of the greatest importance. Most of the difficulties experienced in the working of boilers are due to the hardness of the feed water, which give rise to the formation of *scale*. This results in decreased efficiency, increased fuel costs, and straining of the plates, and necessitates frequent cleaning. Under the high pressure and temperature conditions which obtain in boilers, many hard waters, especially those containing magnesium chloride and nitrate, liberate acids which set up serious corrosion of the fittings and plates.

The very great waste of fuel in scale encrusted boilers, feed water heaters, and auxiliaries is universally recognized. In boilers, the presence of scale increases the consumption of fuel from 10–30 per cent. above normal.

The attendant corrosion, pitting, foaming, overheating, leaks, waste of time, labour, and money in repairs, replacements, shortened life of boilers, cleaning, idle equipment, interrupted service, and reduced production—all emphasize the importance of maintaining a supply of soft water for boilers.

Too little of the re-agents fails to carry out the softening to completion, while too much tends to harden the water again. The re-agents, therefore, should be chosen for purity and uniformity rather than price, and should be added in carefully regulated quantities.

The hardness of a water is often expressed in terms of “degrees of hardness,” one degree being the hardness imparted to water by the presence of one grain of calcium carbonate (CaCO_3) per gallon.

In recent years an attempt has been made to establish in this country the statement of hardness in terms of “parts CaCO_3 per 100,000.” There is much to be said in favour of this system, but the old method of expression in terms of “grains CaCO_3 per gallon” is still widely used, especially by engineers.

The *whole* of the hardness of the water, whether due to calcium or magnesium compounds, is expressed as the equivalent of calcium carbonate. The temporary hardness may be distinguished from the total hardness by determining the hardness both before and after prolonged boiling of the water.

It is much better, however, to determine by chemical analysis the proportion of calcium carbonate and magnesium carbonate separable by prolonged boiling, the proportion of calcium and of magnesium present as permanent hardness, and to calculate from these figures the quantities of lime or caustic soda and of soda ash which are required to soften the water.

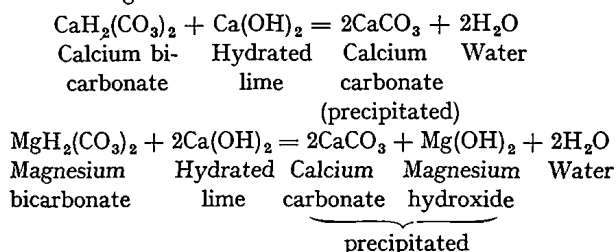
Water softening is a term applied to any process which removes from water those substances which make it *hard*.

As explained before, it is usually sufficient to regard water softening as a means for removing (a) calcium bicarbonate and magnesium bicarbonate, and

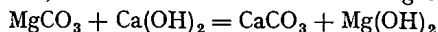
(b) calcium sulphate and magnesium sulphate. The removal of an excess of sodium bicarbonate, acidity, or "special" impurities requires exceptional treatment, but waters containing these substances are unusual.

The *temporary hardness*, due to calcium and magnesium bicarbonates, can be removed by boiling the water, but such treatment is costly; and does not remove the precipitated carbonates which may, later, form a hard and troublesome scale.

It is, therefore, preferable to use some other method of removing the temporary hardness, *viz.*, by adding caustic alkali. Either caustic soda or lime will serve equally well, but lime is very much cheaper and so is generally used. The lime or soda combines with half the carbon dioxide present, thereby liberating the calcium and magnesium carbonates in an insoluble form. The following reactions occur :

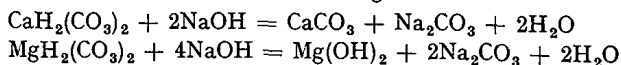


In the latter case, one half of the added lime serves to combine with the carbonic acid, and thus liberates the magnesium carbonate from combination, while the other half of the lime reacts with the magnesium carbonate to form magnesium hydroxide, in accordance with the following equation :



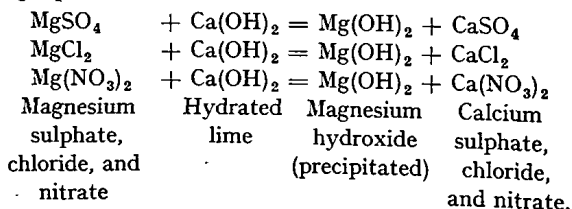
This reaction should be carefully noted, because it indicates that temporary hardness due to magnesium bicarbonate requires twice as much lime for its removal as is required when the hardness is due to calcium bicarbonate.

When caustic soda is used, the following reactions occur :

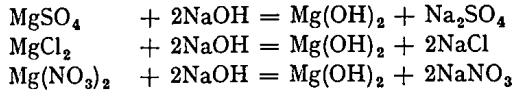


These reactions are very similar to those which take place when lime is used, but it should be noted that the caustic soda is converted into sodium carbonate, which remains in solution and may be useful later.

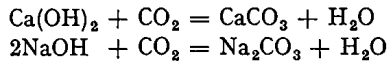
The lime reacts with any magnesium salts forming part of the permanent hardness, with the formation of magnesium hydroxide in accordance with the following equations :



Caustic soda also destroys any permanent hardness due to magnesium salts, as shown by the following reaction :



In addition to the quantities of re-agents required for the treatment of water by lime or caustic soda, allowance should be made for the free carbonic acid present in the water, because although it does not make the water hard it uses up some of the re-agent by converting an equivalent part of the added lime or caustic soda into calcium or sodium carbonate, in accordance with the following equations :

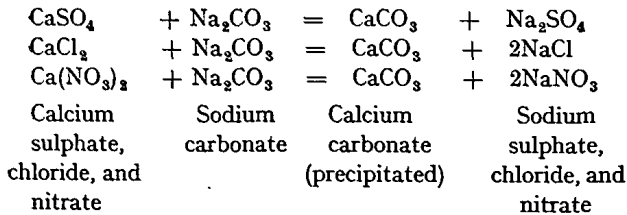


If a water contains only temporary hardness, it can be completely softened by adding the correct amount of lime or caustic soda. When lime is used, it should be added in the form of milk-of-lime, the amount required being ascertained from a chemical analysis of the water, as 56 lb. of lime are required for each 144 lb. of calcium bicarbonate, for each 128 lb. of magnesium bicarbonate, or for each 44 lb. of carbon dioxide in solution in the water.

It is desirable to add a very small excess of lime, so as to ensure complete precipitation. Consequently, a water softened by lime usually has a slight residual hardness of one or two parts per million.

The treated water may be allowed to settle or it may be passed through a filter. If sufficient time is allowed for the reaction, the clear water is free from any serious quantity of material causing temporary hardness.

The permanent hardness, due to calcium and magnesium sulphates, etc., is not affected by boiling the water, but it may be removed by adding a suitable quantity of soda ash as shown in the following equations :



The magnesium salts behave similarly to the calcium ones. If no lime or caustic soda is added, the soda ash will be the sole re-agent and will completely soften a water which has only permanent hardness. In most cases, however, the reactions are complicated by the following :

(i) Part of the lime or caustic soda added to remove the temporary hardness will react with the magnesium sulphate, etc., precipitating magnesia and leaving calcium sulphate, chloride, and nitrate in solution. These soluble calcium salts then react with the soda ash as shown above.

For the removal of permanent hardness due to magnesium salts, therefore both lime (or caustic soda) and soda ash are required, while for the removal of permanent hardness, due to calcium salts, soda ash only is required.

(ii) If caustic soda is used instead of lime for removing temporary hardness it will form soda ash (sodium carbonate) and so will reduce the amount of soda ash which need be added. In some waters, the amount of sodium carbonate is considerably greater than the quantity required for the destruction of the permanent hardness due to calcium salts, and the softened water after treatment may contain free sodium carbonate in solution. The presence of an excess of sodium carbonate in the treated water is objectionable, especially when the water is to be used for boiler feed purposes, and caustic soda should, therefore, not be used in the case of waters in which the sodium carbonate which would be formed in the destruction of the temporary hardness is greater than the equivalent of the permanent hardness due to calcium salts. Such waters should always be treated by lime and soda ash.

If the untreated water contains sodium bicarbonate in solution, as may be recognized by the hardness being wholly temporary and the boiled water being alkaline, this impurity may be removed by the addition of a suitable quantity of milk of lime. This will remove all temporary hardness, as previously explained, and will also convert the objectionable bicarbonate into the (for most purposes) harmless sodium carbonate. If too much lime is added, the sodium carbonate will be converted into caustic soda, which is objectionable as it attacks the brass fittings of boilers. In the rare cases where sodium carbonate is objectionable, it can be removed by the addition of calcium chloride.

Sea water cannot be completely softened by any process other than distillation, because there is no chemical means of rendering the common salt in it insoluble. The best that can be done is to use a suitable mixture of caustic soda (or lime) and soda ash to precipitate all the lime and magnesia salts, leaving the common salt still in solution.

The use, first of lime and then of soda ash, to soften a hard water, is commonly known as the *lime-soda-ash process* and it is applicable to all ordinary waters. The proportions of lime and soda ash required should be ascertained from a chemical analysis of the water, and care should be taken to add only the smallest possible excess of each re-agent.

The *advantages of the lime-soda-ash process* are :

(i) It is a scientific process based on definite and well-known chemical reactions, and the quantities of re-agents are varied according to the composition of the water.

(ii) When a suitable modern plant is used, very little attention is required, and the hardness of the water can be reduced to 3 degrees.

(iii) The actual cost of the treatment depends upon the relative proportions of temporary and permanent hardness, because the former can be destroyed at less cost than the latter. The re-agents required can be obtained at a comparatively low price, and in the case of waters of medium hardness the total cost

of the treatment is not greater than 2d. per 1,000 gallons and is often as low as 1d. per 1,000 gallons.

(iv) With normal water there is no objectionable sodium bicarbonate left in the softened water as is the case when a zeolite is used.

(v) The slight hardness (usually about 3 degrees) left in the softened water is generally an advantage, as it prevents corrosion of the boiler. In most cases, there is no real advantage to be gained by reducing the hardness to zero.

(vi) The precipitated calcium carbonate can be recovered and converted into lime, part of which can be used in the plant and the remainder sold to farmers. The recovery is effected at the Chelmer and Blackwater branches of the Southend Waterworks Co. by filtering the precipitate and burning it in an oil-fired rotary kiln.

The *Quality of the lime* used for softening water is important. Any magnesia present is useless, and it and all other impurities are undesirable because they increase the amount of sludge produced and so add to the cost of softening the water.

As only true lime, calcium oxide (CaO), has any softening effect, it is clear that the larger the proportion of true lime present, the more effective will be the lime. The lime used should, therefore, contain at least 90 per cent. of free lime, or the equivalent amount of calcium hydroxide.

To be effective, the lime should slake readily and form a large volume of light powder (hydrate) which readily spreads through the water. A dense lime, composed of small hard particles, which does not slake readily and which does not swell sufficiently on slaking, is not so satisfactory as one which is more porous and diffusive.

As the lime is most advantageously added in the form of milk-of-lime, either lump lime may be purchased and slaked, or hydrated lime may be used.

When ordinary lime is used for water softening, one half is often wasted. Not only is this a source of expense, but the excess means: (1) clogging of the valves; (2) stoppage of the machine; (3) extra power for agitation; (4) extra work for the filters; and (5) more sludge to be removed.

As some commercial limes only contain 40 per cent. of real lime, nearly 3 lb. of lime may have to be put into the machine to get 1 lb. of real lime into action. This not only increases the amount of sludge to be dealt with, but also increases the cost very materially. Hence, when the cost of slaking, etc., is taken into account, it will usually be found that hydrated lime is no more expensive and much more convenient. If lump lime is used, it should not be stored as received, but should be slaked and made into a putty, which can be stored indefinitely, whereas lump lime is quickly spoiled by air slaking.

Precautions.—Much of the trouble experienced in some water softening plants and attributed to the lime is due to other causes, the chief of which are:

(a) A badly-designed softening plant, the chief defects of which are a mixing device which does not mix with sufficient thoroughness, and a device which "sticks" or otherwise ceases to operate, because it is clogged with calcium carbonate or because the mechanism has been strained.

- (b) A softening plant which is too small.
- (c) Insufficient mixing of the water and milk of lime.
- (d) Variations in the hardness of the water.

(e) In many water softening plants, a mixture of lime and soda ash is added to water. This is a messy material which is liable to clog the " dosing " device and put it out of order. Unless the mixture is used in a device which it cannot " foul," it is better to use caustic soda instead of lime, or to have two tanks and to add the milk of lime from one, and the solution of soda ash from the other.

(f) Variations in the composition of the lime will produce poor results ; it is, therefore, desirable to test each lot of milk or to use hydrated lime of constant composition.

(g) Unless the plant includes an efficient settling device and filter, some of the precipitate will enter the supply pipes, boilers, etc., and eventually cause objectionable clogging. When the precipitate is so fine that it passes through an ordinary filter, the addition of sodium aluminate or phosphate is useful in forming a more flocculent precipitate consisting of larger particles.

(h) If sufficient time is not allowed for the re-agents to soften the water, scale and sludge may be formed in the boiler.

The advantages of using soft water are so great that hard water should be softened whenever possible.

The *Decolorization* of water is best effected, whenever practicable, by the addition of milk-of-lime and of alum. These react and form a flocculent precipitate which absorbs the colour and so removes it from the water. The use of lime as well as alum is advantageous as it partly softens the water, and it also effects a much better decolorization than the alum alone.

The *Deferritization or Removal of Iron* from water is best effected by adding a slight excess of lime. This precipitates the greater part of the iron, and the precipitate formed by the simultaneous softening of the water facilitates the settlement of the iron compound and its subsequent removal by filtration. The effect of the lime is to precipitate the iron compounds as hydroxide. Complete removal of the iron from water is not always practicable, but lime will leave so little iron in solution that it can do no harm.

Treating acid waters to render them harmless is best effected by the cautious addition of milk-of-lime, which is the most satisfactory neutralizing agent. In peaty districts, the addition of lime is desirable, because the water collected from peat is usually slightly acid and so corrodes iron and other pipes through which it is conveyed. The addition of sufficient lime to make the water neutral or very faintly alkaline avoids this trouble and makes the water harmless at a very small cost.

The corrosion of boilers by water containing acids or salts which yield an acid when heated (such as magnesium chloride, ferrous sulphate, etc.) can be stopped by adding lime, with or without soda ash, enough being added to leave a little free caustic lime in the water.

Many mine waters are acid and cause serious corrosion of pumps, pipes,

etc. It is quite easy to avoid this by adding a slight excess of milk of lime and to filter the water before it enters the pumps. Care should be taken to add only just the amount of lime necessary to neutralize the free acid and to precipitate the ferric sulphate, as an excess of lime increases the bulk of the matter to be settled, which is an objectionable feature owing to the lack of settling space underground. Only such a volume of water as is necessary for surface services should be treated.

Acid waters are liable to corrode lead pipes, producing *plumbism* or *lead poisoning*; this corrosion is completely avoided by adding a slight excess of lime to the water, as suggested above. Unless the water is hard, the addition of 2 grains of lime per gallon will usually stop all solution of lead and render the water suitable for drinking purposes.

The *removal of oil* from water obtained by condensing steam or from other sources is essential if the water is to be used in a boiler, as, otherwise, there is a serious risk of explosion. The particles of oil are too small to be removed by simple filtration and must be entangled in a flocculent precipitate. This is best effected by adding alum or "alumino-ferric" to the water, stirring, adding milk-of-lime, and again stirring.

Sometimes, iron sulphate is used instead of alum. The voluminous precipitate produced contains all the oil and can be removed by filtration.

It is necessary that a slight excess of lime should be present, as, otherwise, some alum or "alumino-ferric" will remain in solution and may corrode the boiler.

27. MISCELLANEOUS USES OF LIME

The miscellaneous uses of lime include the manufacture of a large number of products, some of the more important of which are phenolic aldehyde, photo-sensitizers, calcimine, crucibles, 85 per cent. magnesia, chloropicrin, basic alkaline earth compounds, alkaline earth oxychloride, gas mantles, hydraulic cement, artificial stone, fibrous composition, camphor, cocoa, pharmaceutical preparations, calcium light pencils, phosphorescent mixtures, tungsten and molybdenum compounds, buffing and polishing compounds, oxidized turpentine, trichlorethylene, magnesium flash-light powder, soda lime, calcium and magnesium salts, antiseptics, quickly drying varnishes, and carbonizers for metals.

Lime acts as a *scouring agent* in several industries, including the scouring of rags in the paper industry, the scouring of textiles in the dyeing industry, and of metals in electro-plating processes.

Lime is used in the *cooking* of certain materials, such as animal matter in the manufacture of glue, and vegetable matter in the manufacture of paper and dyes.

The *briquetting* of iron ore in the smelting industry involves the use of lime, as does also the briquetting of such vegetable matter as lignite in making fuel.

Lime is also used as a *cleansing agent* for wooden containers, such as cider and oil barrels. Metals of various kinds are cleaned with lime as a preliminary to the polishing process, and it serves as a cleanser for insanitary containers, such as garbage cans.

In electric welding, lime serves as a *weld regulator* and coating for the electrodes.

In *illumination*, lime is used directly in the limelight and as a gas purifying material.

The *limelight* consists of the use of a small cylinder of moderately hard quicklime in the production of a brilliant incandescent light, and was first introduced by Thomas Drummond in 1825 in connection with heliostat signalling. Since that time its chief use has been in "magic lanterns," in which a small, pointed flame, produced by an oxy-hydrogen or oxy-coal gas blowpipe, impinges on the front of a small vertical cylinder of lime. As the lime volatilizes a small depression is formed; by rotating the lime cylinder occasionally a new surface is presented as required.

For successful use as a lime light, the lime cylinders must consist of fine particles forming a compact mass of uniform structure which will not flake, spall, or "fly," when in use.

The cylinders are best made by turning a lump of lime to the required shape on a lathe.

Lime serves to retard the *rusting of metals*, such as iron, under certain conditions. In *ore flotation*, pine oil may be rectified with lime.

The *milling industry* makes use of lime to remove smut spores, and thereby improve the grade of the grain.

In the *lumber industry*, by-product sawdust is saccharified with acids in making cattle food, and lime is used in the neutralization of the excess of acid.

In the *mining industry*, waste ore liquors may be treated with lime for the recovery of hydrogen cyanide.

In the *coal mining industry*, colliery waste is admixed with lime and made into coal briquettes.

In the *chemical laboratory*, lime is used :

(i) As a gas absorbent, a mixture of caustic soda and hydrated lime, known as *soda lime*—preferably with a very small proportion of potassium manganate—being extensively used in organic combustions for removing moisture and carbon dioxide from the air before it is passed through the apparatus. The soda lime is preferably in granular form, of a fineness and porosity selected to suit the size of the tubes in which it is used. The advantage of the manganate is that by changing from green manganate to red permanganate under the action of CO_2 , it gives visual indication of the degree of saturation of the granules. Soda lime has proved equally suitable for gravimetric work.

(ii) As a dehydrating agent, as it absorbs moisture readily from all liquids with which lime does not react appreciably. Thus, 90 per cent. alcohol, after standing for some time over ground quicklime, will yield absolute alcohol on

distillation. Similarly, articles of bright, polished steel retain their polish if packed in ground quicklime, which prevents moisture from reaching them.

(iii) As a chemical re-agent, lime is used as an alkali or base in producing numerous chemicals.

(iv) In chemical analysis, lime is added to substances containing ammonium compounds in order to liberate the ammonia, which is then distilled off and determined in the distillate. Lime is sometimes used in Lewis Smith's method of determining potash and soda in various minerals.

Hydrated lime is used as a *filler* in several industries, including various *composition floorings, linoleums, asphalt pavings*, etc. It is so fine that 10 per cent. of hydrated lime will confer as much stability on an asphalt paving mixture as will 20 per cent. of limestone dust, and the lime will fill the voids more completely.

For *dietetic* purposes, hydrated lime appears to be of value, but there is some uncertainty as to its precise effect. According to Otto Carque :

"Lime, to be of any benefit to the system, must be supplied in the organic form, such as is found in fruits and vegetables. The common practice of giving lime water to babies cannot be justified in the light of modern physiological chemistry. In fact, very hard water often causes dyspepsia and constipation, which are relieved by the use of soft or distilled water."

Yeast for dietetic and medicinal use is prepared by growing yeast on molasses to which a little ammonium sulphate and phosphate of lime have been added. When fully developed, the yeast is suspended in water and precipitated by the addition of milk-of-lime. The product contains 12 per cent. of ash, but is a valuable food and medicine.

As a *thawing agent*, lime is sometimes used in the following manner to draw frost from frozen ground in order to get at a pipe beneath :

At the spot where it has been determined to dig, decide the size of trench desired, and pick out the frozen surface to a depth of 8-10 in. Place enough unslaked lime in the hole to form a good thick bed. If possible, do all this in the evening, and, on leaving, throw such a carefully judged quantity of water over the lime as will keep it "working" for the longest period during the night. A quantity of straw and a canvas covering should be placed over the whole, weighting it down at the edges to keep the heat in, and then left until the next morning. Upon returning it will be found that the heat generated by the working of the lime overnight has drawn the frost out of the earth in and around the hole to a depth of from 2-4 ft., and that digging to the pipe is thus rendered comparatively easy. This device is not a speedy one, but is safe, cheap, and convenient. When it is decided to dig at a certain point the following day, it can be planned and started the night before, and no time is lost ; nor are the services of a watchman required. As no fire is used, the plan has the merit, moreover, of avoiding the danger of igniting any possible escaping gas from a broken main beneath ; and it is cleaner than where steam is passed through a hose into a drill hole for the purpose of thawing.

Foot warmers are sometimes charged with ground quicklime to which a

measured quantity of water is added. Such a mixture is hotter and retains its heat longer than boiling water, and there is no risk of damage by spilling.

The word "lime" has many curious uses, some of which are misleading ; to mention only one :

Bird lime is not related in any way to ordinary lime, but is a wax-like oil obtained in the form of an extremely sticky and tenacious paste by macerating the inner bark of the holly with boiling water.

Novel uses for lime are constantly being discovered, both by users and manufacturers, and better means of utilizing lime in existing processes are being frequently found.

The closest possible co-operation between chemists, manufacturers and users of lime is essential if new and better uses of lime are to continue to be found, as the time when these can be found accidentally has now passed.

A greater technical knowledge of the customer's requirements is of great importance to the lime manufacturer ; it oftens enables him to give better service, to gain a new friend and to assist in securing for lime the recognition it deserves.

CONCLUSION

Some of the multifarious uses of lime as brought out in this chapter have not been generally known because this subject has not been studied by either technologists or laymen to the same extent as many other less widely used and potentially less useful materials. As a result, the general impression prevails that lime is merely a cheap building material that may be used in a few technical processes. It would lead to important economic improvements if the scientific, industrial, and business world realized that of all the nation's raw materials and manufactured products, few are more richly endowed than lime with intrinsic merits and capacities for broad application to industrial life.

Lime is distinguished not only by the number of purposes for which it can be used, but also by the diverse nature of those purposes. This diversity makes it adaptable to manufacturing processes of the most varied nature. It is not, therefore, to be wondered at that the technical uses of lime have developed to such an extent that most of the lime now produced goes into the chemical industries.

No less important, however, as a distinguishing feature of lime, is the fact that of all our raw materials or manufactured products, lime is one of the cheapest and the most generally available.

In the past, the use of lime has been hampered by three adverse properties : (a) its variable composition ; (b) the difficulty experienced in storing it without waste ; and (c) the danger incurred in mishandling it. These properties only occur in quicklime and, for most purposes for which lime is used, quicklime is neither convenient nor necessary. By substituting carefully prepared *hydrated*

lime, all the foregoing objections cease to apply, and instead of an unpleasant risk and uncertain material, hydrated lime is easy to store and handle, is as regular in composition as most commercial chemicals, and is perfectly easy and safe to use. By employing hydrated lime, most of the difficulties otherwise experienced with lime cease to appear, and the great value of lime for innumerable purposes is readily realized.

APPENDIX

MEASURES FOR LUMP AND HYDRATED LIME

THE following figures do not apply to all limes, but are cited as average figures which may be used as a *rough* guide in calculations :

- 1 bushel of *lias* lime weighs about 75 lb.
- 3 bushels of *lias* lime equal 1 bag or sack.
- 30 bushels of *lias* lime equal 1 ton.
- 1 *chaldron* of lime equals 36 bushels.
- 1 bushel of *stone* lime weighs about 70 lb.
- 2 bushels of *stone* lime equal 1 sack.
- 16 bushels of *stone* lime equal 1 cu. yd.
- 8 sacks of *stone* lime equal 1 cu. yd.
- 1 bushel of *hydrated* lime weighs about 52 lb.
- 2 cu. yd. of *stone* lime equal 1 ton.
- 1 *hundred* of lime equals 100 pecks, or 25 bushels.
- A *single load* equals a hundred of lime, or 1 cu. yd. heaped up.
- A cubic yard equals 21 struck bushels, or 17 heaped bushels.
- A *struck bushel* equals 1.284 cu. ft. or 0.0475 cu. yd.
- 10 bags of *lias* lime equal 1 ton.
- 1 barrel of lime (300 lb.) equals $7\frac{1}{2}$ cu. ft.
- 1 paper bag of lime weighs about 50 lb.
- 1 paper bag contains about 1.25 cu. ft.
- 1 sack weighs about 100 lb.
- 1 sack contains about 2.5 cu. ft.
- 1 cubic foot of lime weighs about 40 lb.
- One cubic foot of *lime putty* weighs 80–110 lb.
- One cubic foot of putty requires about 27 lb. of lump lime.
- One cubic foot of putty requires about 44 lb. of hydrated lime.
- One bushel of lump lime yields 3 cu. ft. of putty.
- One 50 lb. bag (paper) of hydrated lime yields 1.14 cu. ft. of putty (average).
- One 100 lb. sack of hydrated lime yields 2.28 cu. ft. of putty.

INDEX

- Aalborg kiln, 285, 286, 295, 296
 A.B.C. Construction Co., 194
 Aberdare, 19
 Aberthaw limestone, 19, 464
 Abrams, D., 589
 Abrasion, 35, 351, 366
 Abrasive wheels, 122
 Abrasives, 178, 182
 suppliers of, 193
 Absorbent of gases, lime for, 595, 597
 Accelerator, lime as, 651
 Accurate Recording Instrument Co. Ltd., 210
 Acetate, calcium, 594, 595, 597, 604, 607, 640
 lime for, 594
 of lime—*see* Calcium acetate
 Acetic acid, 594, 597, 607
 Acetone, 596, 607
 Acid compounds in limestone, 38
 wastes, treatment, 656
 waters, treatment, 656, 676
 Acids—*see* under their respective names
 in soil, neutralization of, 535 *et seq.*
 manufacture of, 248
 neutralizing, 248
 Adits, 39, 40
 Aerated waters, gas for, 456
 Aerial ropeways—*see* Ropeways
 Aeroplane landing-places, lime for, 592
 Ageing lime-putty, 526
 Aggregate for concrete, 191, 231–4
 Agriculture, use of lime in, 531, 534–69
 limestone in, 191, 215–25
 Ainley's, George E., Sons, 207
 Air admitted improperly, 348, 349, 363
 at too low a temperature, 349
 badly distributed, 349
 compressed, 54, 55
 -compressors, 54, 55
 suppliers of, 100,
 excess of, 362
 -filter, 519, 520
 -flues, 298
 for cooling, 299, 359
 kilns, 299, 359, 362, 363
 -heaters, suppliers of, 194
 -holes, 294
 -hose, suppliers of, 100
 hot, 363
 injecting, 423–5
 in kilns, 275, 276, 363
 -inlets, 299, 311–14
 -lime, 486
 mixing with gas, 348
 pressure of, 442
 Pumps, Ltd., 100
 -separation, essentials for, 171
 -separators, 143, 169–73, 503, 504
 suppliers of, 194
 -slaked lime, 465, 466, 486, 487, 531
 Air slaking, 341
 supply to kiln, 296–300, 348, 349, 363,
 386, 387
 Aired lime, 486
 Alabaster, 6, 211
 Alcohol, 596, 598, 607
 Alexander, Herbert, and Co. Ltd., 101, 102,
 110, 200–2, 204, 205, 207, 507, 528, 534
 Alizarin, 606, 663
 Alkali industry, lime in, 250, 599
 -waste, 211, 250, 267
 Alkaline earth oxychloride, 677
 Alkalis in limestone, 38
 Alkaloids, lime for, 599, 608
 Allen, A., and Son, Ltd., 110
 Edgar, and Co. Ltd., 102, 121, 131, 143,
 169, 194, 200, 202, 205, 207, 209, 210,
 394, 510, 528
 John, and Sons (Oxford), Ltd., 101, 104,
 202
 W. G., and Sons (Tipton), Ltd., 110
 Alley and McLellan, Ltd., 100
 Allis-Chalmers Co., 131
 A.L.M. Engineering Co. Ltd., 203
 Alpha Cement, Ltd., 199
 Alport, 5
 Alston, 17
 Alumina, 28
 production of, 459
 Aluminium ware, use of lime in, 636
 Aluminous bricks, 292
 Alundum, 121
 Amberley Heath, 21
 American Society for Testing Materials, 646
 Ammonia, 598, 608
 production, lime in, 598
 oxidation of, 598
 recovery, lime for, 599, 609
 -soda process, 250, 599
 Ammoniacal liquor, 609
 salts, lime used for, 610
 Ammonium carbonate, lime for, 611
 chloride increases the solubility of lime,
 524
 sulphate, lime for, 611
 Analyses of limes, 469
 Analysis, 27
 Ancaster freestone, 20, 30, 39, 226
 Anderson-Grice Co. Ltd., 102, 104, 120–3,
 125, 199, 201, 207, 210
 Anglesey, 14, 17
 Anglo-American Asphalte Co. Ltd., 194, 196
 Rope and Oakum Co. Ltd., 107
 -Cuban Asphalt and Bitumen, Ltd., 194
 -Scottish Chemical Co. Ltd., 196
 Angus, G., and Co. Ltd., 198
 Animals, lime for, 565, 566
 Anker hydrator, 511
 kiln, 326, 336, 337
 kiln-discharging device, 337, 338

- Annular kilns, 274
 Anthracene, conversion of, 606
 Anthracite, 398
 Antiseptic, lime as, 569
 Antrim, 25
 Apparent density, 33
 Appin, 14
 Apuan Alps, 7
 Arable land improved by liming, 538
 Aragonite, 2, 211
 Arborescent marble, 230
 Archaean beds, 15
 Archless kilns, 372, 373
 Ardèche-on-Rhone, 5
 Arenaceous limestone, 4
 Argenti Oxidum, 628
 Argillaceous lime, 464
 limestone, 4, 5, 8, 23, 36, 211
 Armagh red marble, 17
 Armstrong Whitworth, Sir W. G., and Co. (Engineers), Ltd., 100
 Arnold and Wiegel, 508
 kilm, 304, 305, 333
 Aromatic acid, 608
 Arsenate of lime, 527
 Arsenical lime, 527
 Artificial asphalt, 244
 chalk, 188
 silk, treating, 660
 stone, 230, 231, 588
 Artists' white, 257
 Ash from fuel, 358, 370-3, 386, 406, 407, 438, 439
 removal, 333
 Ashmore, Benson, Pease and Co. Ltd., 318
 Ashton and Holmes, Ltd., 196
 Asphalt, 178, 182, 192, 193
 artificial, 244
 filler for, 247
 -macadam, 192, 193
 paths, limestone for, 246
 pavements and roads, 244, 245, 592, 679
 suppliers of, 194
 Asphaltic limestone, 244
 Associated Asphalt Co. Ltd., 194
 Atkinson Walker Wagons, Ltd., 110
 Atlas Diesel Co. Ltd., 100, 104
 Atmosphere, effect on limestone, 228
 Atomized lime, 188, 211, 465
 Attwater and Sons, 198
 Auger drill, 59, 60
 Auvergne (France), 5
 Aveling and Barford and Perkins (Sales), Ltd., 209
 and Porter, Ltd. 110, 209
 Avening, 20
 Avery, W. and T., Ltd., 111
 Axe for stone, 119
 Axminster, 24
 Aylesbury, 23
 Aymestry limestone, 15, 225
- Babcock and Wilcox, Ltd., 102, 104
 Babies and lime-water, 679
 Back-firing in kilns, 311
 Backstrom, 405
 Bacteria, effect of lime, 536, 537, 654
 Bagging, automatic, 530
 machines, suppliers of, 197
 Bag-leather, lime for, 624
 of lime, 682
 Bags for lime, 505, 529
 Bagshaw and Co. Ltd., 102
 Bailey, Sir W. H., and Co. Ltd., 107, 210
 Baker-Perkins, Ltd., 201, 204, 207
 Bala limestone, 15
 Baldry, Yerburch- and Hutchinson (Roads), Ltd., 194
 Ballachulish, 14
 Ballast, 248, 262
 Ball-mills, 143-7, 179, 180, 479-81
 Balls, 436
 Ball's Green stone, 20, 226
 Band-saws, 122
 Bannister, Ed., and Co. Ltd., 194
 Barber and Coleman, Ltd., 106
 Barnack stone, 226
 Barnstone Cement Co. Ltd., 199
 Barrel kilns, 284
 Barrels, cleaning with lime, 678
 Bar-riddles, 153, 154
 Barrington Park, 22
 Barrow, Hepburn and Gale, Ltd., 198
 -on-Soar, 464
 W. S., and Son, Ltd., 202
 Barrows, 78, 79
 suppliers of, 101
 Bars in kiln, 335, 336
 Barton, 225
 Base, 248
 bed, 23
 lime as, 595
 of kiln, 288
 Basic calcium carbonate, 2
 hearth process, 18
 linings, 365
 slag, 222, 547, 548
 Basicules, 331
 Batch-hydrating, 494, 506-9
 Bath, 19, 21, 22, 40, 226
 stone, 18, 21, 22, 30, 40, 115, 226
 Bathampton Down, 22, 226
 Bathgate, A., and Sons, Ltd., 194
 Batter of kiln-walls, 286
 Baxter, W. H., Ltd., 200, 202, 207, 209
 Baynton stone, 22, 226
 Bearings in cars, 87
 Becker hydrator, 511
 Beer, 227
 stone, 24
 Behrmann and De Celle, 669
 Belgian kiln, 371
 Bellis and Morcom, Ltd., 100, 104
 Belt-conveyor, feeding onto, 159
 Belting leather, lime for, 624
 Belts, suppliers of, 198
 Bembridge limestone, 25
 Benches in quarries, proportions of, 42
 Benjamin Electric, Ltd., 106
 Bennett and Sayer, Ltd., 102, 103, 105, 201, 204, 205, 207
 Bennis, Edward, and Co. Ltd., 102
 Benzaldehyde, 608
 Benzoic acid, 598, 608
 Bergamo, 7

- Bertham Fell, 229
 Berthier, 255
 Berwyn, 6
 Berry, 119
 and Son, 204
 Wiggins and Co. Ltd., 194
 Bethersden marble, 7, 230
 Beynon, T., and Co. Ltd., 199
 Bichromates, 251
 Bimoid, Ltd., 194, 197
 Binders for roads, 242
 Bins, 126, 176, 332, 341, 342, 367, 498, 500
 502, 505, 514
 Bird-lime, 680
 Bisulphite of lime, 259
 Bitter almond oil, 608
 Bitterspar, 2
 Bituloid Marketing Co., 197
 Bitumen and Asphalt Co. Ltd., 194
 Bituminous concrete, 243
 limestone, 4
 materials, suppliers of, 194
 matter in limestone, 38
 Road Products, 194
 Black ash, recovery, 607
 chalk, 11, 188
 limestone, 8
 marble, 8, 17
 Blackboard chalk, 11, 264
 Blackmore, H. G., 106
 Blacknell, H. and H., 101
 Blackstone and Co. Ltd., 104, 106, 107
 Blakeborough, J., and Sons, Ltd., 521, 528
 Blanc de Bougival, 258
 Meudon, 258
 Orleans, 258
 Troyes, 258
 Fixe, 179, 260
 minérale, 257
 Blast-furnaces, 191, 254, 255, 598, 629-31
 Blasting, 56-70
 Bleach-liquor, 603
 Bleaching powder, 249, 468, 601-3, 654, 661,
 662
 process, lime in, 650, 661, 662
 Bleiminger and Emley, 405
 Blisters, 578-80
 Blisworth, 226
 Bloch, B., 334
 Blockley stone, 226
 Blocks, artificial, 231
 for lining kilns, 292, 293, 437, 438
 of stone, raising, 56, 78
 Blondin conveyor, 89, 90
 suppliers, of 101
 Blue, indigo, 663
 has lime, 464
 lime-, 605, 606
 Blyde, A., and Co., 109
 Board, John, and Co. Ltd., 199
 Boby, Robert, Ltd., 102
 Bock, O., 372
 Bohle Engineering Co., 170
 Boiler, corrosion of, 676, 677
 for kiln, 330
 waste-heat, 317, 330, 450, 451
 -scale, prevention of, 671
 Boilers, suppliers of, 199
 Bologna chalk, 258
 Bolsover limestone, 17, 225
 Bon-Accord Pneumatic Tool Co., 100
 Bone phosphate, 622, 623
 Bones, treatment with lime, 189, 622, 623
 Booth, J., and Son, Ltd., 202, 204, 205
 Bordeaux mixtures, 566, 567
 Bore-holes, 57, 58, 66
 Boring, 26, 56-8, 66
 -Machines (*see* Air-compressors)
 Bothenhampton, 230
 Bottom bed, 23
 Boulton, W., Ltd., 205, 528
 Bourton-on-the-Hill, 20
 Bourton stone, 226
 Bowden marble, 230
 Bowl Classifier, 180
 Bowling greens, lime for, 565
 Box Ground stone, 22, 30, 226
 Norman E., 196
 Boynton, 227
 Brachernagh, 13
 Bradford, 22
 Winsley Ground, 226
 Bradley and Craven, Ltd., 102, 103, 105,
 201, 204, 205
 Pulverizer Co., 147, 148, 200, 205
 Bradshaw & Co. (Asphaltes) Ltd., 194
 Braham, Patterson & Benham, Ltd., 199, 202,
 209
 Bramley Engineering Co. Ltd., 100, 102, 193,
 199-201, 207, 210
 Brass casting, 182
 polishing, 533
 Brassington, 10
 Bratton, 230
 Bread manufacture, 615
 Breakers, suppliers of (*see* Crushers)
 Brealey, W., and Co. Ltd., 200, 202, 205,
 207
 Brescia, 7
 Brewery waste, lime for, 654, 656
 Brewing, uses of calcium carbonate in, 263
 Briancon chalk, 258
 Bricks, aluminous, 292
 durability in kiln, 293
 for lining kilns, 293, 437-8
 insulating, 290
 'light,' lime in, 588
 magnesia, 292
 porous, lime in, 588
 refractory, 291-3, 437, 438
 Bridgend, 19, 226
 Bridlington, 227
 Briggs, Wm., and Sons, Ltd., 194, 196
 Brights Asphalt Contractors, Ltd., 194
 Brightside Foundry and Engineering Co.
 Ltd., 105, 201, 204, 205, 207
 Brill, 23
 Brilliant green, 606
 Brindley, F. J., and Sons, 109, 110
 Briquettes, lime in, 616
 Briquetting, 677
 Briscal and Mathers, 581
 Bristol, 7, 20
 lime, 614

- Bristowes Machinery, Ltd., 101, 102, 109,
 199, 200, 202, 207
 Tarvia, Ltd., 196
 British Air Conditioners, Ltd., 202
 and Foreign Machinery Co. Ltd., 200, 207
 Calol Asphalt, Ltd., 194
 Drug Houses, Ltd., 553
 Flottman Drill Co. Ltd., 100
 gum, 249
 Jeffrey Diamond, Ltd., 102, 104, 200, 202
 Rema Manufacturing Co. Ltd., 194
 Road Tar Association, 196
 Ropeway Engineering Co. Ltd., 108
 Ropeways, Ltd., 102
 Standard Cement Co. Ltd., 199
 Specification, 152, 154, 177, 231, 234,
 574, 575, 584
 Steel Piling Co. Ltd., 101, 209
 Taroleum Co. Ltd., 197
 Tarspraying, Ltd., 196
 Timber and Wood Paving Co. Ltd., 101
 Wedge Wire Co. Ltd., 206, 207
 Broad and Co. Ltd., 199
 Broadbent, R., and Son, Ltd., 200, 207
 Broadbents Central Iron Works, 528
 Brockham kiln, 286
 Brockley Down stone, 19
 Brodsworth, 17, 18
 limestone, 225
 Broken stone, 177-9
 Brookes Chemicals, Ltd., 195-7
 Ltd., 196
 Tool Manufacturing Co. Ltd., 107
 Broom and Wade, Ltd., 100
 Broomell kiln, 303
 Brotherton and Co. Ltd., 196
 Brown acetate of lime, 607
 chalk, 11
 coal, 398
 spar, 10
 Brügelmann, 471
 Brushing chalk, 174
 Bryozoa, 2
 limestones, 13
 Buchanan, J. B., and Son (Liverpool), Ltd.,
 201, 204, 205
 Bucket elevator, 50, 331
 loaders, 77, 78
 for ropeways, 93, 94
 Bucking process, lime in, 660
 Buffing lime, 527, 533
 Bühler kiln, 371
 Builders' lime, 466, 572
 Building stone, 225-31
 uses of limestone, etc., in, 225-37
 Bulmer, G. A., and Co., 202
 Bumping of rolls, 135
 Burford, 226
 Burning dolomite, 464
 flare kiln, 415, 416
 gas-fired kiln, 421-5
 Hoffman kiln, 370-3, 425, 426
 irregular, 408
 kiln with external fires, 420, 421
 lime, art of, 404, 407-9, 413, 414, 429, 452
 when hydrating, 518
 slaking, 489
 Burning mixed-feed kiln, 416-20
 rate of, 367
 rotary kiln, 427
 sintered lime, 428
 small stone, 329, 448
 time required for, 368
 tunnel kiln, 427
 use of steam in, 428, 429
 vertical kiln, 421
 zone, temperature of, 279
 Burns, lime as remedy for, 628
 Burrell, Charles, and Sons, Ltd., 110
 Burt, Boulton and Haywood, Ltd., 196
 Bushel of lime, 547, 682
 Buxton lime, 472, 607
 By-product lime, 545
 Byrd, A. A., and Co., 209

 Cables for Ropeways, 76, 91, 92
 Cadeby, 18
 Calcareous lime, 463
 ooze, 12
 Calcimine, 677
 Calcination, rate of, 367
 Calcis Hydras, 628
 Calcite, 2, 211
 Calcium acetate, 594, 595, 597, 604, 607, 640
 bicarbonate, 3, 6
 carbide, 251, 604
 carbonate, basic, 2
 behaviour when heated, 404
 forms of, 1, 2
 in agriculture, 215-25
 paper trade, 651
 recovery, 675
 solubility of, 6, 28
 uses of, 211-66
 v. Basic slag, 222
 chloride, 604, 627, 628
 effect on solubility of lime, 523, 524
 cyanamide, 251, 598, 605
 hydrate—see Calcium hydroxide and
 Hydrated lime
 hydroxide, 466, 484, 485
 hypochlorite, 603
 lactate, 628
 metallic, 598
 nitrate, 604
 oxide, free, 470
 phosphate, 38, 253, 628
 peroxide, 598
 silicide, 598
 sucrate, 613
 sulphate, 267
 tannate, 627
 Calcsinter, 2
 Calc-spars, 8
 Calf skin, lime for, 624
 Calico, dressing for, 178
 Calkstone, 25
 Calne stone, 21, 226
 Calves, lime for, 565
 Cambrian beds, 15
 marble, 230
 Wagon Co. Ltd., 110
 Cambridge Instrument Co. Ltd., 210, 304
 marls, 234

- Campbell kiln, 297, 336
 Tile Co. Ltd., 202
 Camphor, 677
 Camphorated chalk, 253
 Candles, lime for, 638, 639
 Candlot discharging device, 338
 kiln, 297, 330, 344, 359
 Canning wastes, treatment, 650
 Capstans, 97
 Carbic, Ltd., 106
 Carbide lime, 526, 545, 612
 Carbofrax, 121
 Carbolic acid, 460, 593
 Carbonaceous matter, 38
 Carbonating lime in kiln, 298
 Carbonation of lime, 443, 505
 Carbon dioxide, compressing, 459
 corrosion by, 459
 kilns for, 453
 limestone for, 250
 liquefying, 455-9
 manufacture of, 453, 454
 properties of, 457
 snow, 459
 solid, 459, 460
 solubility of, 458
 uses of, 459, 460
 monoxide in gases, 366, 452
 Carboniferous beds, 15
 limestone, 16, 211, 225
 Carborundum, 121
 saws, 121, 122
 Cardboard-works waste, treating, 655, 656
 "Cardice," 459
 Carlingford (Ireland), 7
 Carron oil, 628
 Carque, Otto, 679
 Carrara marble, 7, 15, 30
 Carr disintegrator, 137
 Carrier Engineering Co. Ltd., 202
 Carter, J. Harrison, Ltd., 202
 Cartridges filled with quicklime, 612, 613
 Carved work, stone for, 229
 Carving machines, 124, 199
 Case, H., and Son, 101, 102
 Casebourne and Co. (1926), Ltd., 199
 Casein cements, 583
 paints, 642
 Casings round kiln, 280, 289
 Casterton stone, 20, 226
 Catalyst, lime as, 598
 Cattle, lime for, 565
 Caustic lime, 465, 466, 481, 517, 518, 531,
 543, 554
 effect on soil, 554
 uses of, 531
 potash, lime for, 596
 soda, 466, 596, 599, 650
 Causticising agent, lime as, 596
 liquors, lime for, 649
 Cawood, G. R., and Co. Ltd., 199
 Caxton Wood Turnery Co., 109
 Cement, 234, 236, 569, 677
 lime-, 526, 576
 lime in, 583, 584
 Marketing Co. Ltd., 199
 -mortar, 576
 Cement, natural, 235
 rock, 235
 Scott's, 464
 suppliers of, 199
 Cementation index, 473
 Centrifugal mills, 147
 separators, 176, 520
 Ltd., 528
 suppliers of, 528
 Cellulose, manufacture of, 647, 648
 products, lime for, 596
 Chadderton Conveyor Co. Ltd., 102
 Chains, suppliers of, 101
 Chaldron of lime, 547, 682
 Chalk, 2, 11, 23
 artificial, 188
 as base, 595
 building stone, 115, 227
 beds, 14
 black, 188
 brushing, 174
 burning, 420
 dressing, 115
 drying, 118
 for lime-burning, 24
 freestones, 229
 impurities in, 37
 kiln for, 384
 -lime, 465, 466, 531
 levigated, 183
 -marl, 24
 powdered, uses of, 178
 precipitated, 183
 prepared, 183
 purifying, 190
 quarrying, 43
 Spanish, 188
 strength of, 30
 uses of, 24, 211
 in agriculture, 219, 220
 paints, 257
 washing, 190
 Chalking soil, 220
 Chalmers Edina Co., 107
 Champagne chalk, 258
 Channelling machines, 53
 Channels, specification for, 231, 234
 Charging appliances, 345, 361
 bore-hole, 66
 central, 343
 kilns, 341-6, 366, 370
 peripheral, 343
 platform, 127
 Charlbury stone, 20, 226
 Chaser mills, 139
 Chaseside Engineering Co., 101, 104, 109
 Chaudière kiln, 300, 301, 359, 442
 Chaux de Theil, 5
 Cheltenham, 20, 226
 Chemical agent, lime as, 679
 limestone as, 250
 analysis, lime in, 679
 industries, lime in, 593-607
 limestone in, 248-51
 laboratory, lime in, 678, 679
 lime, uses of, 531
 properties of calcium carbonate, 27, 28

- Chemical properties of lime, 468-70
 reagent, lime as, 679
 Chemicals, use of limestone in manufacture of, 251
 Chemicking process, lime in, 661, 662
 Chenard-Walcker Tractors, 110
 Chilmark stone, 23
 Chimney, dipping, 278, 326, 344
 supplementary, 329
 temperature in, 411
 Chinnor Cement and Lime Co., 199
 Chipping Campden stone, 226
 Chippings, 177, 246
 Chisels, pneumatic, 124
 Chittenden and Simmons, Ltd., 195
 Chlorates, lime for, 603
 Chloride of lime—*see* Bleaching powder.
 Chlorine, 249
 absorbing, 601, 650
 in limestone, 38
 lime for, 601
 Chloropicrin, 677
 Christy and Norris, Ltd., 200, 202, 205
 Chromates, 251
 Chrome orange, 639
 yellow, 606, 639
 Churn-drill, 63
 Chutes, 56, 83, 339-41
 Circular saws, 120, 121
 Citric acid, 249, 593, 595
 Clare, R. S., and Co. Ltd., 196, 197
 Clarification of water, 665
 Clarmac Engineering Co. Ltd., 199, 209
 Classifications of limes, 463
 limestones, 465
 Clay, 4, 36
 as binder, 242
 effect of, 433, 475
 in bleaching powder, 602
 separation of, 190
 Clayey limestones, 4, 37, 211
 Clayton, Goodfellow and Co. Ltd., 204, 205, 207
 Cleaning mixtures, 597
 Cleanliness factor, 247
 Cleansing agent, lime as, 678
 Cleator, 229
 Cleeve Hill, 20
 Clermont (Normandy), 5
 Cleveland Slag Roads, Ltd., 195
 Climax Rock Drill and Engineering Works, Ltd., 100
 Clinker, 475
 -bricks, 587
 Clipsham stone, 20, 226
 Clot lime, uses of, 531
 Club root, 549—*see* plant-diseases
 Clunch lime, 24
 stone, 24
 Clydach, 17
 Clyde hydrator, 506, 509
 Coach-maker's putty, 266
 Coagulant, lime as, 596, 597
 Coal, 295, 395-8
 addition of lime to, 609
 disadvantage of, 358
 measures, 15
 Coal mining industry, 678
 Products and Derivatives, Ltd., 196
 Coarse stuff, 578
 Coated limestone, 191, 192
 Cob lime, 531, 542
 Cocoa, 677
 Coke, 295, 397, 608
 Colas Products, Ltd., 195
 Colbit Road Spray, Ltd., 195
 Coleman, Thomas, and Sons, 199, 209
 Colliery waste, 678
 Colloidal lime, 467, 485, 487, 518
 matter, effect of lime, 534, 536, 656
 Cologne chalk, 258
 Colour washes, 583
 Coloured lime, 465
 Colours, 182
 fast to lime, 639
 manufacture of, 248
 of limestone, 4, 30
 Combe Down limestone, 22, 30, 226
 Comber, 550
 Combined lime, 465
 Combustion, 276, 277, 313, 362
 Composition floorings, 679
 Compost, 547
 Compressed air, 54
 Compressing carbon dioxide, 459
 Concentric screens, 162, 166, 167
 Concrete, 232, 233, 569, 588, 589
 aggregate, 231-4
 blocks, facing, 234
 kerbs, specification for, 231
 lime, 577
 roads, 246
 Cone in kiln, 335
 Cones, Seger, 430
 Conical screens, 157, 161, 162
 Connemara marble, 8, 14
 Consolidated Pneumatic Tool Co. Ltd., 100
 Constable, Hart and Co. Ltd., 195
 Constaninesco, G., 55
 Constantine (Africa), 5
 Containers, suppliers of, 202
 Continuous kiln, 273-5, 368
 Contract and Works Supply Co., 199
 Conveying overburden, stone and fuel, 52, 78, 330
 Conveyor-belts, 52, 56, 102, 159
 screens, 167, 168
 Conveyors, 52, 56, 102, 159, 167, 332, 499, 500
 suppliers of, 101-3
 Cooch and Sons, 207
 Cooke's Explosive Factory, 105
 Cooking, lime in, 677
 Cooling, air required for, 299, 300
 bins, 332
 cone, 324
 lime, 324, 331, 332, 362, 377, 412, 442, 443
 zone, 279, 331, 334, 349, 366, 412, 443
 Copper smelting and refining, lime in, 256, 598, 635
 Coral, 2, 12, 211
 rag, 18
 reefs, 12
 rock, 13
 Corallian limestones, 21, 226

- Core, central, in kiln, 300, 335, 420, 449
 -drills, 62
 in lime, 340, 367, 407, 427, 429-32, 434, 436, 445, 449, 450, 486, 499, 504, 505, 571, 572, 585
 Cork red marble, 17
 Cornbrash, 18, 21
 Cornet kiln, 297, 298, 335, 344, 359, 420
 Corn grit, 226
 Cornstone, 5,
 Corrosion of boilers, 676
 kiln lining, 351, 366, 665, 671
 Corry, James P., and Co. Ltd., 199
 Corsham Down stone, 22, 226
 Cort, Robert, and Son, Ltd., 207
 Cosmetics, 187, 204
 Cotham, 230
 Cotswolds, 19
 Cotton plants, effect of lime on, 540
 treating, 660
 Coutière, 627
 Coventry Chain Co. Ltd., 105
 Cowan, Hulbert, Ltd., 101, 102
 Cowper and Williams, 581
 Cows, lime for, 565
 Crab, 78
 Cracking, 519
 Craggs, 13
 Cranes in quarrying, 70-74, 331
 suppliers of, 104
 use of, 70-4
 Creamery wastes, treatment, 656
 Cresylic acid, 593
 Creta praecipitata, 253
 preparata, 183, 253
 Cretaceous rocks, 14, 23
 Crimson affected by lime, 640
 Crinoidal limestone, 2, 12, 211
 Croggon and Co. Ltd., 101, 109, 199
 Crone and Taylor, Ltd., 101, 202
 Crops, effect of lime on, 535-41
 need of lime, 549-55, 563
 Crosland's, F., kiln, 318
 Crosscut saws, 122, 123
 Crossley Bros. Ltd., 104
 Engineering Co., 144
 Crowbars, 394
 Crow, Catchpole and Co. Ltd., 196
 Crucibles, 677
 Crushed stone, drying, 117, 118
 specifications for, 177, 178
 uses of, 211
 Crushers, 126-38, 498
 suppliers of, 200, 201
 Crushing—see Crushers
 rolls—see Crushers
 strength of lime, 472
 stones, 31, 227
 Crust on stone, 114, 115
 Crystals of lime, 471
 Cubical pieces, producing, 135
 Cubic foot of lime, 682
 Curf, 22
 Cutting tools for quarrying, 52
 Cyanamide, 598, 605
 Cyclone separator, 503
 Cylindrical screens, 158
 Darglish, R., and Co. Ltd., 205
 Dairy wastes, treatment, 656
 Dallow, Lambert and Co. Ltd., 203
 Dammann Asphalte Co. (Great Britain), Ltd., 195
 Dargue Acetylene Gas Co. Ltd., 106
 Darlington, 17, 225
 Davidson and Co. Ltd., 204
 Davies Bros. (Asphalters), Ltd., 195
 R. S., and Co. Ltd., 100
 Dawson, James, and Son, Ltd., 198
 Dead-burned dolomite, 252, 381-3, 388, 428, 637
 magnesia, 428
 space in kiln, 337
 Deal, 23
 Dean, Hetherington and Co., 394
 Decay of stone, 228
 Decolorization of water, 665, 676
 Decomposition of limestone, 404, 408
 Decorative building stones, 229
 Defacating agent, lime as, 613
 Deferridizing by lime, 597, 676
 Deficiency of lime, 549
 Deflocculating agents, 174
 Deganwy, 225
 Dehydrating agent, lime as, 596, 678
 Denbigh, 17
 Denchem hydrator, 513
 Denholm Contractors Machinery Co. Ltd., 104
 Denison, Samuel, and Son, Ltd., 111
 Dennis, W. F., and Co., 108
 Denny Chemical Engineering Co. Ltd., 513
 Density, 33
 of precipitated chalk, 183, 186
 Dent, 229
 Dentifrices, 182, 187, 254, 264
 Denton Blue stone, 226
 Deodorizer, lime as, 569, 597
 Depilation by lime, 626
 Dermatine Company Ltd., 198
 Derrick cranes, 71
 Descamps, Georges, 104, 106, 109, 204
 Despatching lime, 529
 Desulphurizing, lime for, 599, 629
 Detergents, 126
 Detonator, 68
 Devonian limestone, 15, 16, 211, 225, 230
 Devonshire marble, 13
 De-watering—see "drying" and "filter-presses,"
 Dexine, Ltd., 198
 Dextrin, 249, 615
 Diamond-saws, 121
 Diamonds, suppliers of, 193, 201
 Dichstadt, 261
 Dietetic purposes, lime for, 679
 Dietzsch kiln, 284, 285, 296, 360
 Diffusivity of lime, 471, 602
 Dip, following, 43, 44
 Discharge of kilns, 333-41, 354, 359, 366, 367, 387, 443, 444
 Discoloration of lime, 438
 Discoloured stone, 113
 Disinfectant, lime as, 569, 657, 666
 Disintegrators, 135-7, 500
 suppliers of, 202

- Dispersing agents, 174
 Dispersion of particles in water, 173
 Disposal of waste, 99
 Distemper, 258, 582, 639, 641, 642, 645
 Distilling industries, lime in, 263, 607, 608
 Dog tooth spar, 8
 Doherty-Eldred kiln, 304, 305, 452
 Dolls, 182
 Dolomite, 2, 3, 9, 182, 211, 252, 381-3, 388,
 390, 404, 405, 428, 463, 464, 527, 637
 as whitening substitute, 182
 dead-burned, 252, 381-3, 388, 428, 637
 dissociation, 390
 uses of, 211, 252
 Dolomitic lime, 463, 531, 585, 587, 588, 619,
 632, 635, 638, 648, 652
 limestone, 4, 17, 633
 marl, 9
 Doncaster limestone, 17, 225
 Dorking lime, 24, 466
 Dorman, Long and Co. Ltd., 108, 196, 197
 W. H., and Co. Ltd., 55
 Dorr-Oliver Co. Ltd., 175, 180, 181, 205, 210
 Doulling stone, 20, 226
 Dover, 23
 Dowdeswell stone, 226
 Dowdings, Ltd., 207
 Dowlais, 7
 Dowson and Mason kiln, 317, 318, 330
 Drag for dressing stone, 119
 Drag-line scoops and excavators, 48, 77
 suppliers of—*see* Excavators
 Drainage of quarries, 44
 Draught, 306, 317, 322, 324-30, 358, 359,
 364, 408, 411, 415, 435
 gauges, 359, 394, 441
 measurement, 446
 Draw kiln, 273
 Drawing kilns, 425, 426, 443-5
 Dredges, suppliers of—*see* Excavators
 Dresser, lime-, 502
 Dressing and Screening Co. Ltd., 207
 for calico, 178
 white shoes, 182
 lime as, 559
 limestone, 119
 Machines, suppliers of, 202
 rolls, 134
 stone, artificial, 588
 Drewry Car Co. Ltd., 106
 "Drikold," 459
 Drilling, 56, 58-63
 Drills, 53, 58-63
 power-, 60, 61
 suppliers of—*see* Air-compressors
 Drives, limestone for, 246
 Drowning lime, 489, 491, 494
 Drum Engineering Co. Ltd., 107
 Drummond, Thomas, 678
 Drums, Ltd., 202
 suppliers of, 202
 "Dry ice," 459
 Dryers, 116-19, 202, 452
 Dry-ground material, 179
 Drying, 115-9, 175, 181, 184, 243 (*see also*
 Dryers)
 agent, lime as, 596
 Drying, substitute for, 119
 time-factor in, 116
 Duchez kiln, 297, 298, 322, 327, 328
 Dudley limestone, 16, 40
 Duke and Ockenden, Ltd., 62
 Duke's Red limestone, 17
 Dumont flues, 327
 Dumps, 436
 selecting, 51
 Dundry stone, 20, 226
 Dunstable, 24
 Durability of brick lining, 293
 testing, 35
 Duration of lime in soil, 555, 556
 Durness limestones, 15
 Dursley, 227
 Dust-collection, 172, 173, 186, 203, 462, 519,
 520
 electrical precipitation of, 520
 -proof casings, 172
 Dusting agent, whitening as a, 264
 Dwight-Lloyd sintering machine, 382
 Dyckerhof, 390
 Dye-intermediates, lime for, 599
 -wastes, treating, 655
 Dyeing, lime in, 662, 663
 Dyes, 182, 593, 606
 Dynamite, 251
 Earle, G. and T., Ltd., 199, 207
 East Anglican Cement Co. Ltd., 199
 Eastwoods, Ltd., 199
 Easyloader, Ltd., 110
 Ebano Oil Co. Ltd., 195
 Edge Hill, 19
 Edible oils, lime for, 616
 Edmunds, H. M., 124
 Edwards and Jones, Ltd., 528
 Effluents, industrial, 667
 Eggs preserved in lime, 616
 Egremont, 229
 Elasticity of limestone, 31
 Eldred kiln, 304, 440, 452
 Electric kiln, 381
 Electrical conductivity of lime, 471
 Electrolytes, use of, 174
 Elevators, 331, 332, 341 (*see also* Conveyors)
 suppliers of, 102
 Elliott Bros., Ltd., 210
 Elliptical kiln, 360
 Elutriation, 173, 174
 Embankments, 191
 Emerson, 550, 552
 Emso Engineering Co. Ltd., 106
 Emulsions, suppliers of, 197
 Enamels, 646, 651
 Endless haulage, 81, 82, 86, 87
 Endothermal reaction, 390
 End Runner Mills Co. Ltd., 200, 205
 Engines, suppliers of, 104
 English Tools, Ltd., 109
 Engraving, 182
 Eocene beds, 14
 Epure, 244
 Erith's Engineering Co. Ltd., 107
 Estuarine mud, 5

- "Etageofen," 285
 Ether purified by lime, 608
 European Amiesite, Ltd., 195
 Ewart Chain Belt Co., 102, 105
 Excavators, 48-52
 suppliers of, 104
 Exhauster, use of, 279
 Expansion of lime, 498
 Exploders, electrical, 68, 69
 Explosions in kilns, 311
 Explosives, 51, 57, 63-9, 182
 industries, lime in, 612, 613
 limestone in, 251
 suppliers of, 105
 Extenders, 257, 639, 640, 651
 Extracting stone, 39, 52
- Facing-moulds, 182
 Fahnehjelm kiln, 315
 Fans, 279, 327-30
 suppliers of, 204
 Farleigh Down, 226
 Farmer Bros., 204
 Farmers, lime and limestone for, 215, 449
 (*see also* Agriculture)
 Fat limes, 27, 37, 463, 465, 467, 468, 531, 570, 571, 573, 578
 Fatness of hydrated lime, 518
 Fats, lime for, 616
 Fatty acids, 658
 Fawcett, J. Dawson, (Darlington), Ltd., 102, 103, 105, 117, 118, 200-2, 204, 205, 208-10
 Thos. C., Ltd., 102, 103, 105, 201, 204, 205, 208
 Feeble lime, 37
 Feeder-screens, 159
 Feeders for crushers, etc., 137, 138, 142
 suppliers of, 204
 Fellner and Ziegler kiln, 379
 Felspar in limestone, 37
 Ferruginous limestone, 4
 Fertilizer and Feeding Stuffs Act, 219, 541, 545
 distributors, 559
 Fertilizers, 223, 224, 459, 535, 541, 545, 547, 557, 563
 Fielding and Platt, Ltd., 104, 107
 Field kiln, 272
 Filey, 23
 Fillers, 178, 182, 191, 244, 245, 247, 260, 592, 640, 650-2, 679
 for asphalt, 244, 245, 247
 pavements, 592
 paper, 260, 650
 synthetic resin, 652
 lime as, 640
 Filling or loading stone, 70, 191
 Filter-cloths, suppliers of, 205
 for dusty air, 519
 -presses, 175, 184
 suppliers of, 205
 Filters, 171, 172, 175, 184
 suppliers of, 205
 Filtration, 175
 of water, 668
- Fine chemicals, 608
 stuff (plaster), 576, 578
 Fineness of lime, determining, 548
 particles, 29
 Finger-and-toe disease, 540—*see also* plant diseases
 Firebricks, lime in, 587
 Fireclay bricks, 291
 Fire-extinguisher, 459
 -irons, 394
 -places for kilns, 301, 411, 420
 Fireworks, 182
 Firmin and Co. Ltd., 207
 Firth of Clyde, 13, 17
 Forth, 13, 17
 W., and Co., 108, 110
 Fish stock, 623
 Flags, specifications for, 231, 234
 Flag-stones, 228, 231, 234
 Flare kiln, 271, 385, 415, 416
 lime, 24
 Flash-light powder, 677
 Fleming and Co., 100
 Birkby and Goodal, Ltd., 198
 Fletcher, George, and Co. Ltd., 137, 148, 164, 200, 208
 Fletcher's Malleable Foundry, Ltd., 102
 Flint, 17
 -mill, 179
 Flocculating agent, lime as, 597
 Floor-plaster, 579
 Floors, earth, lime for, 592
 Florence, 7
 Flotation, lime in, 631, 632
 Flour-lime, 465
 Flour, limestone-, 188
 Flue-dust, recovery, 634
 Flues, 294, 298, 352
 Flux, lime as, 178, 254, 598, 629
 Fluxes in limestone, 37
 Fluxing stone, 24, 191
 Fodens, Ltd., 110, 209
 Food, destroying, 616
 industries, lime in, 613-6
 "Foot-and-mouth" disease and lime, 565
 Foot cube of lime, 682
 -warmers, 679
 Football fields, lime for, 592
 Foraminiferal limestone, 2, 12, 212
 Forced draught, 306, 322, 325, 327-9, 359
 Ford's silicate stone, 588
 Forest marble, 18, 21, 23, 230
 of Dean, 17
 Forks, 394
 Fossiliferous limestones, 30, 38
 Foster Instrument Co. Ltd., 210, 394
 Wm., and Co. Ltd., 110
 Foundation for kiln, 356, 357
 Foundries, lime in, 633
 Fowler, John, and Co. (Leeds), Ltd., 102, 106, 110, 209
 Fox, C. J., and Sons, Ltd., 203
 Stockell and Co., 195, 197
 Foyne, 13
 Frame-saws, 119, 120
 Francis, F., and Sons, Ltd., 202

- Fraser and Chalmers Engineering Works, 102, 200, 205, 208
 Fraser, Ltd., 102
 Free lime, 465, 470
 Freestones, 19
 French chalk, 11
 Fresco, 579, 642
 Frizing, lime for, 624
 Frome, 230
 Frost, Albert, and Co. Ltd., 207
 effect of, 34, 35
 Frosterley limestone, 13, 17, 229
 Fruit juices, treatment of, 248, 593-7, 613
 trees, lime for, 566-8
 Fuel-ash, effect of, on lime, 406
 -consumption, 296, 352-4, 367, 372, 379, 382-5, 391
 conveying to kiln, 330
 distribution of in mixed feed kilns, 417
 economy, essentials to, 410
 for kilns, 295, 359, 395-403
 from kiln-gases, 452
 impurities, effect of, on lime, 406
 incompletely burned, 362
 lime in, 616
 powdered, 308, 396, 427
 storage, 342
 sulphur in, 395
 Fuller and Thompson, 233
 Engineering Co., 205
 Lehigh Co., 146
 Pulverizer mill, 146
 Fuller's earth limestone, 21
 Fungicides, 535, 566
 Furnace construction, lime and limestone in, 252, 617
 linings, 617, 637
 Furnaces, lime for, 632
 Furnas, C. C., 471
 Furness, 16
 Fused lime, 381, 526
 Fuses for explosives, 67
 Fusion Corporation, Ltd., 185, 511
 F. W. D. Lorry Co. Ltd., 199
- Gandy Belt Manufacturing Co. Ltd., 198
 Garbage, treatment, 657
 Gardening, lime in, 537, 564
 Garden paths, limestone for, 224, 225, 246
 Gardner and Sons, Ltd., 204, 208
 Garner-Denver Co. Ltd., 100
 Motors, Ltd., 111
 Garratt, R., and Sons, Ltd., 110
 Gas-absorbent, limestone as, 265
 analysis, 394, 446
 compressing, 459
 -fired kilns, 274-8, 308-24, 346-53, 359, 362, 363, 366, 371, 385, 386, 400, 401, 421-5, 432
 drawing, 425
 -firing, advantages of, 278
 Light, and Coke Co. Ltd., 196, 375
 -lime, 545, 546
 liquefying, 455-7
 mantles industry, lime in, 597, 677
 manufacture, 401, 453, 597, 608-12
 -producers, 347, 402, 422
- Gases, objectionable, lime for, 596
 uses of, 450-2
 Gates gyratory crusher, 131
 Gatty Saunt and Co., 195
 Gault clay, 5, 14
 Gelatin manufacture, lime in, 621-4
 General Electric Co. Ltd., 106
 Genoa, 7
 Geographical distribution of limestones, 13
 Geological distribution of limestones, 13
 Germicidal action, 666
 Getting stone, 52
 Gilbert and Whittaker kiln, 321
 Gilder's chalk and whiting, 182, 258
 Gilkes (Gilbert) and Co. Ltd., 107
 Gillette kiln, 307, 381
 Research Corporation, 456
 Gillogue, 13
 Glamorgan, 18
 Glasgow Engineers, Ltd., 102
 Glass in lime, 433, 438, 450
 manufacture, uses of lime in, 600, 618-21
 limestone in, 252, 252^o
 Glazes, lime in, 651
 whiting for, 260
 Globe Pneumatic Engineering Co. Ltd., 100
 Glossing discs, 125
 Gloucester, 18, 19
 Glove-leather, lime for, 624
 Glucose, 249, 615
 Glue manufacture, lime in, 621-4
 Glycerine manufacture, lime in, 599, 659
 Goatskins, liming, 625
 Gold, recovery of, 634
 Goodacre, Wm., and Sons, Ltd., 104
 Goodwin, Arnold, Ltd., 100, 107
 Barsby and Co. Ltd., 102, 166, 199-202, 204, 208-10
 Grab-excavators, 50
 suppliers of, 105
 Grading, 148, 213, 214, 245
 Granite beds, 15
 Grantham, 20, 21, 226
 Granulators, 130
 suppliers of, 200, 205
 Grappiers cement, 475, 483, 491, 493, 494
 Grass for burning lime, 399
 Grassland and lime, 538, 541, 549
 Grates as screens, 56, 159
 in kilns, 335
 Gravity-haulage, 82, 83
 saw, 122
 Grease and lime, 638
 manufacture of, 637
 Greases, drying, 596
 Great Oolite, 21, 226
 Weldon, 20
 Green, brilliant, lime for, 606
 colour, affected by lime, 640
 E., and Son, Ltd., 194
 malachite, 606, 663
 marble, 8
 Greening, N., and Sons, Ltd., 102, 198, 206, 208
 Greensand beds, 14
 Greenwood and Batley, Ltd., 106, 111

- Grey acetate of lime, 607, 640
 chalk, 24
 lime, 464
 powder, 253
 Greystone chalk, 11, 24, 406
 lime, 24, 464, 466, 490, 491, 531, 548, 570, 578
 Grids, 153, 154, 286, 297, 499
 Griffin and Tatlock, Ltd., 210
 mill, 147, 148, 479
 Grills and Schroeder, 623
 Grimwood and De Geus, Ltd., 195
 Grinding, 138, 139, 478, 479, 570
 mills, suppliers of, 205
 Grindstones, 148
 Grit, suppliers of, 193
 Grizzlies, 159
 Ground lime, 449, 464, 465, 478, 479, 529, 531, 544
 limestone, 179, 221
 Grueber discharging device, 338
 Guiting stone, 22
 Gun cotton, 251
 Gunther and Sons, 107
 Gus pendulum mill, 148
 Gwynne's Pumps, Ltd., 107
 Gyrotory crushers, 130, 131
- Habermann, 596
 H-acid, lime in, 606
 Hadfields, Ltd., 102, 128, 129, 131-3, 200, 205, 208
 Hainault, 7
 Halkyn, 17
 Hall, 536
 Hallen, A. G. A., and Co., 206
 Halling lime, 24, 466
 Ham Hill, 226
 Hammer-drills, 60
 mills, 135, 206
 Hammers, suppliers of, 109
 Hampton stone, 226
 Hancock, C. C., and Co., 197
 Hand-slaked lime, 488
 Hanging—*see* sticking
 Hanley, A., 108
 Harboro Rocks, 10
 Hardinge Mill, 145, 481
 for slaking lime, 632
 Hardman and Houlden, Ltd., 196
 Hardness, 26, 35, 471, 671-6
 of water, 666-76
 Hardy, T., 204
 Hardy and Padmore, Ltd., 208
 Harness leather, lime for, 624
 Hardypick, Ltd., 100, 102, 106-9, 136, 201, 202, 207
 Harrington cableway, 52
 Harris, Francis, and Co. Ltd., 198
 Harrison Bros., Ltd., 100, 193, 207, 210
 Hartam Park, 226
 Hartington Quarries, Ltd., 196
 Hartlepool, 17
 Harvey, G. A., and Co. (London), Ltd., 205, 206, 208
 Harwich, 25
- Hassock stone, 25
 Hauenschild kiln, 296, 326, 328, 338
 Haulage, 78-94
 suppliers of, 105
 Haverford West, 15
 Haydor stone, 20, 21, 226
 Hayward-Tyler and Co. Ltd., 107
 Head, Wrightson and Co. Ltd., 102, 117, 200, 202, 208, 210
 Headington stone, 21, 226-
 Heat balance of Hoffman kiln, 373
 capacity of lime, 471
 distribution of, 277, 313, 391, 440
 loss of, 279, 280, 351, 387, 388, 391, 413, 461
 from lime-kilns, 279
 utilization of, 279, 461, 462
 waste of, 279, 412, 461
 Heaters for dryers, suppliers of, 194, 206
 tar, suppliers of, 199, 206
 Heath and Co., 101, 111, 208
 Heating agent, lime as, 679
 lime—*see* Burning
 Hebblewarte Bros. Ltd., 198
 Heckel Co. Ltd., 108
 Heenan and Froude, Ltd., 102, 194
 Helmedon, 20
 Henderson, John M., and Co. Ltd., 70, 88, 89, 101, 102, 104, 108, 200
 Hendry, James, Ltd., 198
 Henley's, W. T., Telegraph Works Co. Ltd., 198
 Hepburn Conveyor Co., 101, 102
 Herman's kiln, 398
 Herrmann, R., Ltd., 204
 Hexagonal screens, 160
 Hexham, 225
 Heywood, F., 460
 Hibberd, F. C., and Co. Ltd., 106, 111
 Hides, liming, 621, 622, 624-7
 Hierapolis (Asia Minor), 5
 Highways, Colloidal, Ltd., 197
 Construction Ltd., 195
 Hildenley stone, 226
 Hiscox, W., Ltd., 102, 208
 Hockley, J. T., 197
 Hodkin and Turner, 252
 Hoffman kiln, 330-2, 353, 354, 356, 357, 359, 368-74, 396, 425, 426, 442, 443, 447
 Hoists, suppliers of, 106
 Holden and Brooke, Ltd., 107
 Hole, E., and Son, 204
 Holland, Bernard, and Co. Ltd., 106
 Hollingshead and Chadwick, 610
 Holman Bros. Ltd., 61, 100, 106, 107, 109, 208
 Holy Isle, 14
 Honig and Mock, Ltd., 107
 Hoover and Scott, 665
 Hopkin's method, 550, 551
 Hopton Wood stone, 17, 30, 229
 Horizontal kilns, 273, 301, 368-74
 Horn pith, 623
 Hornton stone, 19
 Horses, lime for, 565
 Horsham Engineering Works, 204
 Horsmann, W. E., Sons and Co., 208

- Horstmann Gear Co. Ltd., 106
 Horticulture, uses of lime in, 534-69
 limestone in, 215-25
 Hot zone too high, 437
 Houston, 665
 Howard, J. and F., 111
 Howden, James, and Co. Ltd., 194
 Howden-Ljungström Preheaters, Ltd., 194
 Huddleston stone, 18
 Hudson, Clarke and Co., 106
 Robert, Ltd., 106, 108, 110, 111
 " Hummer " screen, 163
 Humus, effect of lime on, 543
 Hundred of lime, 682
 Huntington, Heberlein and Co. Ltd., 157,
 168, 203, 208, 382
 Hustleton, 20
 Hutchin's dryer, 185
 Hutchinson and McLennan, 550-2
 Hydrated hydraulic lime, 476
 lime, 464-6, 476, 481-5, 494-7, 514-9,
 529-31, 545, 572-4, 619, 620, 647, 648,
 682
 for building, 572-82
 mortar, advantages of, 573
 varnish, 647
 measures for, 682
 packing, 529
 production of, 494-8
 properties of, 517-9
 separating impurities, 514
 specification for mortar, 574
 (U.S.A.) for, 619
 storing, 529
 uses of, 531
 Hydrating lime, 484-501, 514-7
 Hydrators, 497, 498, 505-17
 Hydraulic index, 474
 lime, 28, 236, 386, 408, 464, 465, 472-8,
 482, 483, 491-3, 529, 531, 571, 575-9,
 581-3, 585
 limestone, 5, 406
 removal of overburden, 46
 Separating and Grading Co. Ltd., 528;
 Hydraulicity, 477
 Hydrocarbons, 608
 Hydrochloric acid, 595
 Hydrogen-ion, concentration of, 550
 manufacture of, 612
 Hydrolysis, 596, 606
 Hydro-separator, 180
 Hypochlorite of calcium, 603
 Hypophosphites, 628
 Hythe beds, 24
- Ice, manufacture of, 596, 669-71
 red, 671
 Iceland spar, 8
 Igneous beds, 15
 Illumination, lime in, 678
 Impact drills, 60, 61
 machines, 134
 Imperial Chemical Industries, Ltd., 105
 Improved Road Construction, Ltd., 195
 Impurities in stone, lime and fuel, 28, 36-8,
 290, 358, 405-7, 469, 514
- Incandescent Heat Co. Ltd., 194
 Inclined kilns, 273
 screens, 155
 Index, cementation, 473
 hydraulic, 474
 India Rubber, Gutta Percha, and Telegraph
 Works Co. Ltd., 198
 Indigo blue, 606, 663
 Induced draught, 306, 322, 325-8, 359
 Ingersoll-Rand Co. Ltd., 100, 106, 107
 Ink, 182, 262
 -test for permeability, 35
 Innes, Sons, and King, Ltd., 102
 Insecticides, 566-8, 593
 Insulating bricks, 290, 360, 387
 kiln, 290, 293, 360, 387, 461
 Intermittent kilns, 271-3
 International Clay Machinery Co., 204
 Combustion, Ltd., 208
 Crushing and Grinding Equipment, Ltd.,
 197
 Harvester Co. of Great Britain, Ltd., 111
 Iona marbles, 7, 10, 14
 Ionizing agent, lime as, 598
 Ippepen, 230
 Irish dove marble, 17
 Iron compounds in limestone, 37
 removal by lime, 597, 599, 676
 melting, lime for, 633
 oxide, 4, 28
 Isinglass, 623
 Islay, 14
 Isle of Wight, 25
 Isserlis kiln, 322, 323
- Jard, 261
 Jaspers, 7
 Jaw-crushers, 127-30
 suppliers of, 200, 201, 206
 Jennings, A. S., 643-5
 " Jenny Lind " polishing machine, 125
 Jewellers' buffing, lime, 466, 527
 Jigger-conveyor, 167, 168
 Jigging screen, 168
 Johnson and Grove, 524
 C. H., and Sons, Ltd., 102, 208
 S. H., and Co. Ltd., 204, 205
 Wm., and Sons (Leeds) Ltd., 103, 200, 201,
 203-5, 208, 209, 528
 Johnston, 486
 Bros., 101, 199, 209
 Jones, 550, 552
 John, and Sons, Ltd., 204
 Wm., Ltd., 100, 104-6, 109-11
 Juices, treatment of, 248, 593-7, 613
 Jumper, 59
 Jurassic beds, 14
 Jute, treating, 660
- Karlsbad (Bohemia), 5
 Kay, J. C., and Co. Ltd., 106
 Kaye and Co. Ltd., 199
 Keinton, 40
 Keith and Blackman, J., Co. Ltd., 203, 204
 Keller (*see* Steenbrugge), 203

- Kendal, 229
 Kennedy-Van-Saun Manufacturing and Engineering Corporation, 103, 200, 208
 Kent lime, 607
 mill, 470
 Kentish Rag, 24, 25, 227
 Kenyon, Alexander, and Co. Ltd., 101, 109
 Kerbs, Standard specification for, 234
 Kerr, Stuart, and Co. Ltd., 106, 111
 Kestner Evaporator and Engineering Co. Ltd., 205
 Ketton limestone, 20, 30, 39, 226
 Keys, W. H., Ltd., 195
 Keystone Driller Co., 105, 107
 kiln, 303
 Kid skins, liming, 624, 625
 Kier-boil, lime in, 660-2
 -liming, 660-2
 Kieselguhr bricks, 588
 Kilkenny, 8, 17
 Kilmarnock Engineering Co. Ltd., 199, 203
 Kiln, Aalborg, 285, 286, 295, 296
 air-supply, 362, 363, 386, 387
 Anker, 326, 336, 337
 archless, 372, 373
 Arnold, 304, 305, 333
 base of, 288
 Belgian, 371
 Brockham, 286
 Broomell, 303
 Buhner, 371
 Campbell, 297, 336
 Candlot, 297, 336, 344, 359
 -casings, 289
 chalk, 384
 Chaudière, 300, 301, 359, 442
 continuous, 273-5, 368
 control of, 439-42
 Cornet, 297, 298, 335, 344, 359, 420
 Crosland, 318
 Dietzsch, 284, 285, 296, 360
 Doherty, 452
 Doherty-Eldred, 304, 305, 452
 Dowson and Mason, 317, 318, 330
 -draught—*see* Draught
 Duchez, 297, 298, 322, 327, 328
 Eldred, 304, 440, 452
 electric, 381
 elliptical, 360
 externally-fired, 275, 277, 301, 359, 411, 420, 421, 432
 Fahnehjelm, 315
 Fellner and Ziegler, 379
 flare, 271, 385, 415, 416
 furnace-fired, 301-6
 -gases, utilization of, 450-9
 gas-fired, 274-8, 308-24, 346-53, 359, 362, 363, 366, 371, 385, 386, 400, 401, 421-5, 432
 Gilbert and Whittaker, 321
 Gillette, 307, 381
 -grates, 335
 -grids, 286, 297
 Hauenschild, 296, 326, 328, 338
 Herman's, 398
 Hoffman, 330-2, 353, 354, 356, 357, 359, 368-74, 396, 425, 426, 442, 443, 447
 Kiln, horizontal, 273, 301, 368-74
 Isserlis, 322, 323
 Keystone, 303
 Lengersdorff, 322
 -linings, 290-3, 324, 350, 351, 365, 437, 438
 location of, 387
 Mannstaedt, 326, 328, 329, 338, 339
 Meiser, 322, 323
 Mendheim, 322
 mixed-feed, 274, 277, 280-9, 353, 358, 384, 391, 416-20
 Mount, 318, 320
 O'Connell, 306
 oil-fired, 277, 278, 306-8, 376, 399
 Otto, 308, 396
 oval, 282, 284, 309, 321, 322, 360
 Peretti and Funck, 321
 -performance, tests of, 446
 Pfeiffer, 379
 Polysius, 298, 379
 Priest, 306, 315-7, 330
 "R," 285, 296
 rectangular, 282
 returning gases to, 452
 Ring, 368
 rotary, 273, 301, 332, 353, 354, 357, 368, 375-81, 383, 385, 396, 427, 443
 Ryan, 296
 Schmatolla, 309, 313-5
 Schneider, 326
 selecting, 383
 separate feed, 280, 302
 shaft, supporting, 288
 shape unsuitable, 360
 short, 408-13
 Smidth, 285, 286, 296, 321
 Spencer, 285, 296
 spiral shaft in, 286
 square, 282
 steam-injection into, 306, 333, 378, 409, 428, 435
 Steiger, 298, 328, 474
 Stein, 293, 326
 -temperature, determining, 413
 Thièle, 474, 475
 tunnel, 368, 374, 375, 427
 vertical, 273, 274, 283, 284, 353-5, 385, 421
 -walls, 286, 289
 Wiegand, 333
 with two shafts, 285
 wood-fired, 302
 works irregularly, 351
 Kilns, adaptation of, 324
 bands around, 294
 bricks for, 293, 437, 438
 chief features of, 389, 393
 connected, 384
 constriction, in, 284, 288
 core in, 300, 335, 420, 449
 cross-section of, 282, 283
 diameter, 287, 360
 discharging, 333-41, 354, 359, 366, 367, 387, 443, 444
 fuel-consumption, 296, 352-4, 367, 370, 382-5, 391
 for, 295, 359, 395-403

- Kilns, height of, 287, 355, 356, 411
 improvement in, 392
 inspection holes in, 294
 insulation of, 290, 293, 360, 387, 461
 length of, 411
 masonry, 286
 openings in, 334
 output too low, 364
 oxygen used in, 312
 patent, 301
 pressure of, on foundation, 356
 recovery of waste heat from, 461
 sizes of, 388
 stone for, 357, 418.
 short, 346
 suppliers of, 394
 temperatures attained in, 291
 thermal efficiency of, 355, 389-92
 width of, 287
 Kinds of lime, 464, 465
 King, John, and Co. Ltd., 103
 T. A., and Co., 193
 Kirkham, J. and W., Ltd., 107
 Knappers, suppliers of, 206 (*see also*
 Crushers)
 Knaresborough, 17
 Knibbs, N. V. S., 513
 Knight, J., and Hale, Ltd., 107
 Korting and Mathieson Electrical, Ltd., 106
 Kraft Sacks, Ltd., 207
 Krieger, 604
 Kritzer hydrator, 509, 511
 Krupowjess, 651
 Krupp, Fried, 200

 Labour charges, 353
 Lactic acid, 248
 Lactose manufacture, 615
 Lacustrine limestone, 12
 Lacy-Hulbert and Co. Ltd., 100, 107
 Ladder-excavators, 50, 76
 Lafarge Aluminous Cement Co. Ltd., 199
 Lakes fixed with lime, 606
 Lamy, 524
 Landscape marble, 230
 Lanes, lime for, 590
 Latex, flocculating, 597
 Lathes, 123
 Latil Industrial Vehicles, 111
 Lauman hydrator, 509
 Laundry industry, 669
 Lawns (sieves), 149
 Lawns, lime for, 564, 565
 Lay-out of quarry, 41
 Lead smelting, lime in, 634
 Wool Co. Ltd., 100
 Leakage of heat, 352
 in kilns, 279
 Lean lime, 37, 463, 465, 467-9, 532, 570-2
 Leather manufacture, lime used in, 624-7
 Leblanc process, 250
 Le Chatelier, 492
 Leckhampton, 20, 226, 229
 Ledham and Heaton, Ltd., 109
 Lengersdorff kiln, 322
 Levigated chalk, 175, 183
 Levigation, 173
 Lewis and Taylor, Ltd., 198
 Lexlip, 13
 Leyland and Birmingham Rubber Co. Ltd.,
 198
 Lias lime, 386, 464, 466, 474, 548, 581
 rocks, 14, 18, 212, 226
 Lifts, 95-7, 106, 331
 Lifting-jacks, 78
 stone, 78
 Lighting, suppliers of, 106
 Lignin dissolved by lime, 648
 Lignite, 398
 Lime, absorbent properties of, 468
 advantages in agriculture, 537
 air-slaked, 341, 486
 -albumen cement, 583
 analyses of, 469
 and fertilizers, 562, 563
 livestock, 565, 566
 zinc smelting, 634, 635
 application of, 557-62
 argillaceous, 464
 arsenate of, 527
 -arsenic paints, 640
 arsenical, 527
 as accelerator, 651
 as flux, 629
 food, 616
 fungicide, 535, 566-8
 insecticide, 566-8
 polishing agent, 636
 refractory substance, 617
 saponifying agent, 657
 atomized, 188, 465
 bisulphite, 259
 -blisters, 578, 579
 -blue, 605, 639
 -boil, 660
 Bristol, 614
 buffing, 527
 builders', 466
 burned (in slaking or hydrating), 489, 514,
 518
 burning, 390, 404-46
 by-product, in agriculture, 545
 calcareous, 463, 468
 carbonation of, 298, 443, 470
 caustic, 465, 466, 481, 517, 518, 543, 554
 -cement, 576
 chalk, 465, 466
 coloured, 465
 combined, 465
 -concrete, 577
 conductivity of, 471
 cooling, 331, 412, 442
 crushed in kiln, 356
 -crystals, 471
 deficiency in, 549
 despatching, 529, 530
 diffusivity of, 471
 discoloration of, 438
 disinfecting power of, 657
 dolomitic, 463
 drawing, 443-5
 -dresser, 501, 502
 drowning, 489, 491, 494

- Lime, duration of, in soil, 555, 556
 -dust, 627
 dyed, 465
 effect in agriculture, 538-48, 562
 "effective," 542
 expansion of, 498
 fat, 463, 465, 467, 570
 advantages of in mortar, 573
 fineness of, determining, 548
 -flour, 465
 fluxing power of, 617
 for agriculture, 534-60
 blast furnaces, 629-31
 bleaching powder, 601-3
 buffing, 533
 carbide, 526
 causticising, 640
 clinker bricks, 587
 concrete, 232, 588-90
 dyes and intermediates, 606
 effluents, 652
 enamels, 646, 647
 explosives, 612, 613
 exterior work, advantages of, 570
 furnace-linings, 637
 interior plaster, 578
 melting iron, 633
 mineral acids, 595
 mortar, 570-6
 open-hearth furnaces, 632, 633
 organic acids, 594
 plaster, 526
 slag bricks, 587
 smelting, 629
 softening and purification of water,
 664-77
 trade-wastes, 654-7
 varnishes, 646, 647
 water-paints, 645
 free, 465
 from waste products, 379
 fused, 381, 526
 -glue cement, 583
 -green, 639
 grey, 464
 greystone, 24, 464, 466, 490, 491, 531, 548,
 570, 578
 grinding, 478, 479
 ground, 449, 464, 465, 478, 479, 529, 531,
 544
 hand-slaked, 488
 hardness of, 471
 heat-capacity of, 471
 hot, 350, 366, 412
 hydrated, 464-6, 476, 481-5, 494-7, 514-9,
 529-31, 545, 572-4, 619, 620, 647, 648,
 682
 hydrating, 484-501, 514-7
 hydrators, 497, 498, 505-17
 hydraulic, 28, 236, 386, 408, 464, 465,
 472-3, 482, 483, 491-3, 529, 531, 571,
 575-9, 581-3, 585
 impure, burning, 290
 impurities in, 37, 469
 in artificial stone, 588
 bacterial process, 654
 boiling rags, 648, 649
- Lime in cement, 583, 584
 -mortar, 570
 chemical industries, 593-607
 coke manufacture, 608-12
 copper smelting and refining, 635
 distillation, 607, 608
 enamels, 646, 651
 firebricks, 587
 flotation, 631, 632
 food, 613-6, 628
 fungicides, 652
 furnace-construction, 617
 garbage-treatment, 652, 657
 gardens, 537, 564
 gas-manufacture, 608-12
 gelatin manufacture, 621-4
 glass-making, 618-21
 glazes, 651
 glue-manufacture, 621-4
 gold-recovery, 634
 hygiene, 657
 lead-smelting, 634
 leather-manufacture, 624-7
 medicine, 627-9
 mercury-recovery, 634
 metallurgy, 629-37
 moulding aluminium ware, 636
 paint industries, 639-47
 paper and cellulose industries, 647-51
 paving materials, 590-2
 pharmacy, 627-9
 pickling liquors, 636
 plaster, 577-80
 porous bricks, 588
 pottery manufacture, 651
 puddling iron, 633
 refining lubricants, 637-9
 oils, 637-9
 petroleum, 651
 resin industries, 651, 652
 roads, 590-2
 rubber industries, 651-2
 sanitation, 652-7
 sewage-treatment, 652-7
 size-manufacture, 621-4
 smelting tin ore, 636
 soap and allied industries, 657-9
 textile industries, 659-64
 wall-coatings, 582, 583
 wire-drawing, 633
 inferior, 113
 jeweller's, 466, 527
 -kilns, 268, 270-403, 408-52, 474, 475
 suppliers of, 394
 temperature in, 291
 lean, 37, 463, 465, 467-9, 532, 570-2
 lias, 386, 464, 466, 474, 548, 581
 loading, 341
 loss of, in soil, 556
 lump, 445, 465, 478, 529, 542, 572
 magnesia in, 469, 470
 magnesian, 290, 463, 466, 485, 532, 542,
 570, 572, 578, 581, 585, 587, 588, 619,
 632, 638, 648, 652
 materials used for, 267-9
 meagre, 468
 measures for, 682

- Lime, melting point of, 471
 milk of, 465, 520-3, 547, 559
 -mixing machines, 528
 modes of application, 557-60
 moist, 470
 -mud, 184, 249, 267
 need of, in soil, 217, 549-55
 overburned, 387, 408, 414, 433-5, 450, 463, 467, 472, 505, 515
 packing, 529, 530
 -paraffin spray, 568
 -paste, ageing, 526
 phosphorus in, 630
 picking, 38, 340, 407, 445, 465
 -plaster, 577
 plasticity of, 470
 poor, 468, 485, 532, 572
 porosity of, 471
 -precipitates, settlement of, 607
 -press cake, 546
 properties of, 468-72, 541
 pure, 406
 -putty, 465, 484, 485, 489, 518, 525, 526, 532, 574, 576, 580, 682
 quantity to be added to soil, 555
 reaction with magnesium salts, 672
 reactivity of, 470
 recarbonation of, 298, 443, 470
 -requirement of soils, 549-56
 restorative power of, 557
 rich, 467
 in magnesia, 546
 sack-, 481, 487
 -salts, 604
 -sand bricks, 231, 463, 498, 502, 584-7
 sand-carrying capacity of, 518
 screened, 465
 "seconds," 545
 selecting, 465, 496, 533
 selenitic, 464
 shell-, 465, 466
 sifting, 490
 siliceous, 464
 sintered, 464
 slaked, 464-6, 481-94, 532, 628
 slaking, 463, 481-97, 515, 525
 slow slaking, 497, 515
 -sludge, 212, 250, 545, 593, 600, 611, 625, 650
 -slurry, 491
 small, 438, 445, 448, 465, 478, 484, 542, 545
 smeary, 527
 -soaps, insoluble, 648
 -soda-ash process, 674
 solubility of, 470, 486, 523, 524
 solution of, 523
 sorting, 445
 soundness, testing, 586
 -spars, 2, 8, 212
 special forms of, 463
 specification for, 574, 619
 specific gravity of, 471
 heat of, 471
 spreading, 558, 559
 -stain, 640
 sterilising power, 535
 storing, 341, 529
- Lime, strength of, 472
 sulphur in, 630
 mixtures, 566, 567
 -syrup, 627, 628
 Theil, 474
 unburned stone in—see "core"
 unclassified, 465
 underburned, 340, 367, 407, 427, 429-32, 434, 436, 445, 449, 450, 486, 499, 504, 571, 572, 585
 uses of, 448-50, 531-680
 varieties of, 37, 527
 Vienna, 257, 269, 466, 527, 532, 534
 -washes, 566, 569, 582, 583, 640, 657
 waste, 545, 546
 -water, 478, 523-5, 627
- Limelight, 678
 Limerick, 13
 Limes, classification of, 463
 Limestone, 267
 as base, 248
 flux, 16, 254
 chippings, 246
 decomposition of, 404, 408
 defined, 1
 dressing, 119
 -flour, 188
 for agriculture, 191, 215-25
 asphalt roads, 244-6
 bitulithic pavements, 245
 cement, 234
 lime-burning, 16, 267-9
 paving, 228
 roofing, 228
 Telford roads, 237
 mines, 39
 mixtures, 189
 origin of, 12
 powdered, uses of, 178
 purifying, 190
 rocks, 3
 sand, 234
 screening, 247
 uses of, 211-66
 Liming land, effect and modes of, 555-61
 Limmer and Trinidad Lake Asphalt Co. Ltd., 195, 203
 Limonite, 37
 Lincolnshire limestone, 18, 20
 Linen, treating, 660
 Liner Concrete Machinery Co. 208, 209
 Linnimentum Calcis, 628
 Lining, excessive abrasion of, 366
 corrosion of, 366
 of kilns, 290-3, 324, 350, 351, 365, 437, 438
 Linoleum, 178, 182, 679
 Linseed oil, clarification by lime, 647
 Lintels, 588
 Liquid Oxygen Explosives, Ltd., 63, 105
 Liquids, compressed, 55
 Lismore, 14
 Lister, R. A., and Co. Ltd., 101, 104, 111
 Lithographic stones, 261
 Littler, H. G., 460
 Livestock, lime for, 565, 566
 Llangollen, 5, 6, 227
 Llyn Peninsula, 14

- Lloyd, J. D., and Sons, 193
 Llysfaen, 225
 Load of lime, 682
 Loaders, mechanical, 77, 101
 Loading Appliances, suppliers of—*see* Scoops
 and Conveyors
 lime, 341
 stone, 70, 71
 Loam as binder, 242
 Locan and Rawlinson, Ltd., 195
 Location of kilns, 387
 Locker, Thos., and Co. Ltd., 103, 206, 208
 Locomotives, suppliers of, 106
 Lodge-Cottrell, Ltd., 203
 process, 462, 520
 Löhnerts discharging device, 339
 Long Burton, 230
 Loosening blocks of stone, 52, 56
 Loss of lime in soil, 556
 Lotis Hydrargyri Flava, 628
 Nigra, 628
 Louisville cement, 474
 Lowthian Bell, 255
 Lubricant industries, lime in, 637-39
 lime as, 598
 Lucas, E. and W., Ltd., 109
 Lumber industry, lime in, 678
 Lump lime, 445, 465, 478, 529, 542, 572
 v. small lime, 478
 Lutes, 236
 Luxton, A. M., and Co. Ltd., 197
 Lyme Regis lime, 18, 28
- Macadam, 193
 roads, 238-42
 Macdonald, John, and Co. (Pneumatic
 Tools), Ltd., 100, 109
 Machinery-bearings, use of limestone in, 265
 position of in quarries, 45
 suppliers of, 99, 193, 527, 530
 Magnesia, 463, 677
 Alba, uses of, 212
 bricks, 292
 effect of, in fluxing, 630
 in agriculture, 542
 lime, 469, 470
 milk of, 522
 Magnesian lime, 290, 463, 466, 485, 532, 542,
 570, 572, 578, 581, 585, 587, 588, 619,
 632, 638, 648, 652
 for building, 572
 glass making, 619
 lime-sand bricks, 585, 587
 lubricants, 638
 silica bricks, 588
 in agriculture, 542
 paper manufacture, 648
 plaster, 578
 rubber industries, 652
 slaking, 463, 485, 581
 tempering, 581
 uses of, 532
 limestone, 9, 10, 17, 212, 221, 225, 226,
 228, 236, 250, 252, 253, 256, 260, 404,
 405, 432, 600, 633
 as flux, 256
- Magnesium Lime, behaviour when heated,
 404, 405, 428
 in agriculture, 221
 furnace construction, 252
 glass manufacture, 253
 metallurgy, 255, 633
 pottery manufacture, 260
 putty, 236
 soda manufacture, 600
 underburned, 432
 uses of, 212
 quicklime—*see* magnesian lime
 stone, 383
 Magnesium compounds in limestone, 37
 metallic, 598
 salts reaction to lime, 672
 Maidstone, 24
 Makin, W., and Sons, 100, 109, 207
 Malachite green, 663
 Malting, 615
 Malton, 226
 Manlove, Alliot and Co. Ltd., 175, 205
 Mannstaedt kiln, 326, 328, 329, 338, 339
 Mann Steam and Motor Wagon Co. Ltd., 111
 Mansfield, Frank, and Co., 200, 202
 limestone, 10, 17, 225
 Manure, effect of lime on, 539, 544, 559, 562
 Marble, 2, 6, 17, 178, 212, 229
 powdered, uses of, 178
 uses of, 212
 Marley Hill Chemical Co. Ltd., 196
 Marls, 2, 8, 36, 212, 220, 538
 Marlstone, 18, 19
 Marnhull stone, 21, 226
 Marple and Gillott, Ltd., 111
 Marsden, H. R., Ltd., 103, 199, 200, 204, 206,
 208, 209
 Marshall, Sons, and Co. Ltd., 103, 111, 199,
 201, 203, 208, 209
 Mason Bros., 103, 200, 202, 209
 Masonry kilns, 286
 Mastic asphalt, 193
 flooring, 246
 Mather and Platt, Ltd., 107
 Mathers, F. C., 518
 Matlock, 5, 6, 227
 Matthews and Yates, Ltd., 203, 204
 Ernest, and Co., 195
 Mayhew, Ramsay and Co. Ltd., 200, 202
 McCreath, Taylor and Co. Ltd., 197
 McDonald, David, and Son, Ltd., 101
 McEwan, Denby and Hart-Briggs, Ltd., 193,
 207
 James, and Co. Ltd., 197
 McLaren, J. and H., Ltd., 111
 Meade, R. R., 391
 Meadow lime, 9
 Meagre lime, 468, 532
 Measures for lime, 682
 Measuring appliances, automatic, 345
 Mechanical draught, 327, 357
 strength, 31
 Tar Spraying and Grouting Co. Ltd., 196
 Medicinal preparation, uses of lime in, 627
 limestone in, 253
 Medway, 24
 lime, 466

- Midway Paper-Sacks, Ltd., 207
 Meiser kiln, 322, 323
 Melting point of calcium carbonate, 36
 lime, 471
 Mendheim kiln, 322
 Mendip marbles, 16, 229
 Mercury, recovery of, 634
 lime in, 634
 Metal bands round lime-kilns, 294
 Containers, Ltd., 202
 linings, 293
 pickling wastes, treatment, 656
 Union, Ltd., 100
 Metallurgy, uses of lime in, 254, 255, 599,
 629-37
 limestone in, 254-6
 Metamorphic beds, 15
 Methyl alcohol, 607
 Meunier, 471
 Mica in limestone, 37
 Midland Tar Distillers, Ltd., 196, 197
 Mild lime, uses of, 532
 Milk-of-lime, 465, 520-3, 547, 559
 magnesia, 522
 sugar, manufacture, 615
 wastes, treatment, 656
 Millars Machinery Co. Ltd., 101, 103, 107,
 200, 203, 208, 209
 Milling industry, lime in, 678
 Mills, 139-48, 479-81
 feeders for, 142
 Millstone Grit, 15
 Milton, 226
 Minchinhampton, 21, 22, 266
 Mine waters, treatment, 656, 676
 Mineral colours, 606
 Minerals in limestone, 2
 Mining and Industrial Equipment, Ltd., 145,
 194, 200, 205, 208, 501, 528
 Engineering Co. Ltd., 103
 industry, lime in, 678
 limestone in, 256
 limestone, 39-99
 machinery, suppliers of, 107
 Miscampbell hydrator, 509
 Mitchell, 404
 Conveyor and Transporter Co. Ltd., 103
 Mixed-feed kilns, 274, 277, 280-9, 353, 358,
 384, 391, 416-20
 v. gas-fired kilns, 353
 Mixers, suppliers of, 206 (*see also* Stone-
 coating plant)
 Modulus of rupture, 31
 Molasses and lime, 607, 613, 614
 Monarch Co., 204
 Monks Park, 226
 Mono-rails, 95
 Monsal Dale, 5
 Montdardier stone, 262
 Monumental stones, 230
 Moor lime, 9
 Moorlands Engineering Co. Ltd., 107
 Moors, reclaiming, use of lime in, 538, 539
 Morecambe, 16
 Morocco leather, lime for, 626
 Morris, Herbert, Ltd., 103
 R., Ltd., 111
 Mortar, 569-76
 Moss, destruction by lime, 541
 Mossay and Co. Ltd., 107
 Motor-lorries, 97
 Motor, Rail and Tram-car Co. Ltd., 106
 Moulding machines, 124, 206
 Moulds, dusting with lime, 636
 Mountford, P., and Co. Ltd., 109
 Mount kiln, 318, 320
 Moyes, Wm., and Sons, 109
 Mud-capping, 67
 Muir Hill (Engineers), Ltd., 105
 Multiple screens, 165-7
 Mumford and Moodie, 169
 Municipal Appliances Co., 199, 203, 209
 Musgrave and Co. Ltd., 194, 203, 204, 519

 Nailsworth, 20, 226
 Namur, 7
 National Gas Engine Co. Ltd., 104, 107
 Natural draught—*see* Draught
 gas, 400
 Navvies, mechanical, 48-50, 74-6
 Naxos, 7
 Neal, R. H., and Co. Ltd., 101-5
 Need of lime, indications of, 549
 Neuchatel Asphalte Co. Ltd., 195
 Neutralization of acids, lime for, 248, 534-8,
 593, 594, 658
 Newell, Ernest, and Co. Ltd., 103, 200, 201,
 208-10
 New Kent Brush Co., 109
 Northern Quarries, Ltd., 196
 Newsome, Arthur, Ltd., 197
 Newton Abbot, 225, 230
 Bean and Mitchell, 107
 Chambers and Co. Ltd., 196
 Nickel refining, lime in, 598
 Nitrate of lime, 604
 Nitration processes, lime in, 539, 606
 Nitric acid, lime for, 595
 Nitrifying organisms, effect of lime, 537
 Nitrogen, hydrogenation of, 598
 loss of, by lime, 563
 Nitro-glycerine, lime with, 612
 Nodules, 436
 Nordberg Manufacturing Co., 200
 North Anston limestone, 18, 225
 Cherton, 230
 Northern Sabulite Explosives Co. Ltd., 105
 Nortons (Tividale), Ltd., 103, 208
 Norwich Sack and Bag Co., 207
 "Notanos" dryer, 117
 Nottingham, 17

 O'Connell kiln, 306
 Oil-burner, 399
 fired kilns, 277, 278, 306-8, 376, 399
 for power, 55
 from water, removal of, 677
 paints, 639
 refining, 460, 637
 Oils, edible, lime for, 616
 Old Red sandstone, 15, 16
 Oligocene beds, 14

- Oliver, J. C., and Co., 106, 108, 110, 111
 Ontario, 15
 Oolite limestones, 4, 14, 18, 19, 23, 212, 226
 Open hearth process, lime in, 598
 Optical instruments, use of calcite crystals
 in, 265
 Ord and Maddison, Ltd., 161, 162
 Ordovician limestones, 15, 212
 Ore-flotation, lime for, 595, 631, 678
 Organic acids, preparation of, lime for, 594
 compounds, 598, 599
 limestones, 11
 matter, removal by lime, 650
 Origin of limestone, 12
 Ornamental work, plaster for, 229
 Osbournby, 227
 Osmington stone, 21, 226
 Oswestry, 17
 Otto kiln, 308, 396
 Oundle, 226
 Output of kiln, 353, 364, 376, 393, 439
 Oval kilns, 282, 284, 309, 321, 322, 360
 Overburden, 41, 43, 46, 51, 52
 Overburned lime, 387, 408, 414, 433-5 450,
 463, 467, 472, 505, 515
 Overhead ropeways, 88-94
 suppliers of—*see* Ropeways
 Overheating lime, 387, 406, 434
 Overliming soil, 554
 Oxalic acid, lime for, 595
 Oxidizing agent, lime as, 598
 Oxygen, liquid, as explosives, 64
 use of in kilns, 312
- Packing lime, 529, 530
 material, lime as, 679
 Padley and Venables, Ltd., 100, 110
 Painswick stone, 20, 226
 Paint industry, lime in, 597, 639-47
 limestone in, 257-9
 Palm oil, lime for, 599
 Paludina marble, 7, 12, 230
 shells, 23
 Pan-mills, 139-43
 Fantin, W., and Co., 102
 Paper bags, 528, 529
 industry, lime in, 597, 647-51, 655
 limestone in, 182, 259, 260
 Sacks, Ltd., 197, 207
 Paraffin spray, 568
 Parallel wire screens, 153
 Parchment, artificial, lime for, 650
 Parian marble, 10
 Paris chalk, 257
 white, 179, 182, 212, 261
 Park, Wm., and Co., 109
 Parker, Frederick, Ltd., 101-3, 200, 202, 203,
 208-10
 Winder and Achurch, Ltd., 160, 208
 Parkinson, W., and Co., 106
 Paros, 7
 Pastures improved by lime, 538
 Patent kilns, 301
 Lightning Crusher Co. Ltd., 201, 202
 Pavements, lime for, 590-2
 limestone for, 245
- Paving stones, 228
 Peace, Samuel, and Sons, Ltd., 111
 Pea-grit, 19
 Peak, John, and Co. Ltd., 196, 197
 Pearl spar, 10
 Pearson, R. H., Ltd., 108
 Peat, 398
 Pebble dash, 229
 Peckett and Sons, Ltd., 106
 Pegson, Ltd., 101-3, 201, 203, 208-10
 Pendulum mills, 147, 148, 479
 Pennine Range, 16
 Percussion power-drills, 60
 Peretti and Funck kiln, 321
 Perfect Concrete Mixer Co., 209
 Perforated Metal, suppliers of, 206
 steel plates, 154
 Permanent hardness, 667, 673
 Permeability, 34
 Permian beds, 15
 dolomite, 10
 limestone, 10, 15, 17, 212, 225
 Perpignani-Candlot kiln, 297
 Petrified objects, 6
 Petroleum industry, lime in, 596, 599, 651
 Petrol Loco Hirers, 106
 Petters, Ltd., 104
 Petworth marble, 23
 Pfeiffer, Gebr., 482
 recuperator kiln, 379
 pH values, 540, 550, 553, 554
 Pharmaceutical preparations, uses of lime in,
 627
 limestone in, 253
 Phenol, recovery of, 460
 Phenolic aldehyde, 677
 Phillips, Charles D., Ltd., 108
 J. Sadler, and Co. Ltd., 196, 197
 Phoenix Engineering Co. Ltd., 101, 107, 110,
 199, 203, 209
 Phosphates in soil, effect of lime on, 535
 Phosphorescent mixtures, 677
 Phosphorous pentoxide in limestone, 38
 Phosphorus in lime, 604, 630
 limestone, 255
 Photography, use of calcium carbonate in,
 265
 Photo-sensitizers, 677
 Physical properties of lime, 470-2
 limestone, 29-36
 Pickaxes, suppliers of—*see* Shovels
 Picking lime, 38, 340, 407, 445, 465
 Pickling liquors, lime in, 249, 636
 Picks, suppliers of, 109
 Picture-frame mouldings, 182
 Pigments, use of lime in, 639, 640
 limestone, in, 257, 258
 Pigs, lime for, 565
 limestone for, 224
 Pike, George, 110
 Pimples, 580
 Pinder, E. W., 210
 Pipes, corrosion of, preventing, 677
 Pisolite limestones, 4
 Planing machines, 123, 124, 206
 Plant diseases, 216, 535, 540
 food, lime as, 534, 535, 539

- Plants and soil-reaction, 551
 effect of lime on, 216, 534-7, 540, 541, 549, 551
 showing need of lime, 549
 Plascom (1909), Ltd., 196
 Plaster, lime for, 526, 532, 569, 577-80
 Plasterer's putty, 580
 Plastering, 228, 576
 Plastic compositions, 265
 Plasticity of lime, 470, 518
 Platers' buffing lime, 527
 Platforms, inadequate, 368
 Pleistocene beds, 14
 Pliocene beds, 14
 Plough and scraper for overburden, 48
 Plugs-and-feathers in quarrying, 53
 Plumbism, prevention of, 665, 677
 Pumping skins with lime, 622
 Plums in concrete, 232
 Plymouth, 225
 Pneulec, Ltd., 103
 Pneumatic appliances, suppliers of—*see* Air-compressors
 Scale Corporation, 197
 Poke-holes, 294, 299, 352
 Pokers, 394
 Polishing agents, 126, 178, 182, 187, 260, 527, 533, 636
 machines, suppliers of, 206
 stone, 125
 Pollard, Ravenscroft and Co. Ltd., 195
 Polygonal sieves, 160
 Polysius kiln, 298, 379
 Ponton, 226
 Pool, J. and F., Ltd., 161, 208
 Poolwash, 17
 Poor lime, 468, 485, 532, 572
 Popping, 519, 579, 580
 Porosity, 32, 33, 471
 Portable track, suppliers of—*see* Rails
 Portas, H. W., 511
 Porthywaen, 17
 Portland cement, 583
 Cement Selling and Distributing Co. Ltd., 200
 limestone, 22, 30
 stone, 18, 22, 226, 227
 Post-Tertiary beds, 14
 Potash, manufacture of, 251, 601
 Potassium compounds in limestone, 38
 Pot kiln, 271
 lime, uses of, 532
 Potter, F. W., and Soar, Ltd., 194, 206, 208
 Pottery manufacture, use of lime in, 651
 limestone in, 261
 whiting in, 260
 Poultry-farming, limestone in, 224, 566
 Powdered coal, 395
 stone, drying, 118
 Powell Duffryn Steam Coal Co. Ltd., 196
 Power for ball mills, 144
 crushers, 130
 Gas Corporation, 203
 in quarries, 66
 sources of, 45, 54
 Pozzuolana, 571, 577
 Pozzuolanic cement, 474
 Pragos Engineering Co. Ltd., 103, 104, 201, 204, 208
 Pre-Cambrian limestone, 14, 15, 212
 Precipitant, lime as, 597
 Precipitated chalk, 183, 186
 Preheated air, advantage of, 299
 Preheating zone in kiln, 278, 347, 361, 362
 Premier Bitumen and Asphalte Co. Ltd., 195
 Filter-press Co. Ltd., 205
 Preparation of calcium carbonate, 179, 221
 chalk, 179, 183, 221, 250, 258
 stone, 112, 246
 Prepared chalk, 183
 Preservative, lime as, 569
 Pressure, effect of, on burning, 408, 409
 Prestwich, Wm., and Sons, Ltd., 196
 Previte (Trinidad Bitumen), Ltd., 195
 Price's Patent Candle Co. Ltd., 195
 Priestman Brs. Ltd., 50, 104, 105
 Priest's kiln, 306, 315-7, 330
 Furnaces, Ltd., 384, 394
 Primary air, 275, 312
 Primers, use of limestone, etc., in, 257
 Priming, 258
 Printing, use of limestone, etc., in, 182, 261, 262
 Proctor and Schwartz, 203
 Bros. (Wireworks), Ltd., 206, 208
 Producer gas, production of, 309, 310, 400, 401, 422
 Properties of lime from rotary kiln, 380
 limestone, 27-36
 required in various industries, 211-66, 448-50, 531-680
 Prospecting for limestones, 25
 Provident Steel and Tool Co. Ltd., 207
 Prudham, 225
 Psychology of burning, 413
 Puddling furnaces, lime in, 633
 Pullen, F. A., and Co., 100, 107
 Pulley-blocks, 78
 Pulp, bleaching, lime for, 650
 Pulsometer Engineering Co. Ltd., 107
 "Pulver-blender," 157, 170
 Pulverized coal, 396, 397
 Pulverizers, suppliers of, 206—*see also* Disintegrators
 Pumice bricks, 588
 Pumping, 43, 44
 Pumps, suppliers of, 107
 Purbeck limestone and marble, 14, 18, 23, 40, 226, 227, 230
 Pure lime, gas-fired, 358
 Purification, lime used in, 598, 599
 of water, 664-77
 Purifying limestone and chalk, 190, 191
 Pusher-scoops, 77
 Putty, 236, 266, 465, 484, 485, 489, 518, 525, 526, 532, 574, 576, 580, 682
 coach-maker's, 266
 lime-, 465, 484, 485, 489, 518, 525, 526, 532, 574, 576, 580, 682
 plasterer's, 580
 Pyridine, 608
 Pyrites in limestone, 37
 Pyrometers, 294, 394, 413, 440, 441

- Quadrants, specifications for, 231
 Quality, kilns for, 393
 Quarries, machinery in, 45
 Quarry-face, height of, 43
 floor, 43
 planning, 42-4
 sap, 114
 waste, 112, 191
 Quarrying, 39-99
 Quarternary beds, 14
 Quebec, 15
 Quicklime, 465, 466, 481, 532, 542, 618, 625
 Quilliam, Ltd., 207
 Quinolic acid, 608
 Quoins, 588
- " R " kiln, 285, 296
 Radiation losses, 279, 280, 351, 387, 388, 391,
 413, 461
 Rags, boiling with lime, 648, 649
 Ragstones, 19
 Rails, 84, 108
 Railway, 99
 and General Engineering Co. Ltd., 108
 engineering, uses of limestone, etc., in, 262
 Rammed linings, 292
 Rancidity and lime, 637
 Ransomes and Rapier, Ltd., 101, 103-6, 109,
 209
 Machinery Co. Ltd., 106
 Rapid Packer, The, Co. Ltd., 198
 Rattler test, 35
 Rawdon Foundry, Ltd., 204, 206
 Ray, K. W., 518
 Raymond Bros. Impact-Pulverizer Co., 118,
 148
 mill, 118, 119, 501
 Reactivity of lime, 470
 Reavell and Co. Ltd., 100
 Recarbonation of lime, 443, 470
 Recent limestones, 25
 Reciprocating screens, 158, 159
 Reclaiming paper stock, lime for, 651
 Reconstructed stone, lime in, 588
 Rectangular kilns, 282
 Red chalk, 11
 marble, 7
 Redcar, 18
 Reddaway, F., and Co. Ltd., 103, 198
 Redler Patents, 103
 Reducing agent, lime as, 598
 Reef limestone, 10
 Refractoriness of limestone, 36
 required in kiln-lining, 438
 Refractory materials, lime in, 617
 Refrigerant, 460
 Refrigerating machines, 459
 Refuse liquors, 249, 636
 Registered names, 189
 Reid, 452
 " Rejects," 114
 Renton, Holdsworth and Co. Ltd. 198
 Repairs, excessive, 352, 361
 Residues from tanneries, 627
 Resin-fillers, 652
 industries, lime in, 651, 652
- Resistance furnaces, 381
 Restorative power of lime, 557
 Retorts for lime, 381
 Revolving v. Vibrating screens, 162
 Rexman Mill Co. Ltd., 201, 206
 Rice dolomite, 3
 Richards, A. H., 195
 Richardson and Co., 194
 Rich lime, 37, 467
 Richter and Pickis, 103, 201
 Manufacturing Co., 197
 Ridding, 46
 Riddles, 149, 153, 207
 Ring kilns, 368
 Roach, 22
 Road construction, lime for, 590-2
 limestone for, 191, 192, 237-48
 Plant Construction Co. Ltd., 209
 scrapings, use of, 220
 Roadstone—see Road construction
 Roadways Equipment, Ltd., 110, 203, 209
 Roberts, Thomas, and Co., 195
 Robey and Co. Ltd., 100, 111, 201, 208
 Robinson, T., and Sons, Ltd., 194
 Robson, G., and Co., 103, 109
 Roche Abbey limestone, 18, 225
 Rock bed, 19
 gardens, limestone for, 224, 227
 Rocmac, Ltd., 195
 Roestone, 4
 Roll mills, 147, 479
 Rolls, crushing, 132-5
 dressing, 134
 " Roiling " screen, 163
 Roman cement, 583
 Rome (Italy), 5
 Roofing stones, 228
 Roofs over kilns, 294
 Roots, effect of lime on, 540
 Ropes for haulage, 83, 92-4
 ropeways, 91-4
 lubrication of, 76
 suppliers of—see Haulage
 Ropeways, 88-94, 108, 331
 Ltd., 103, 105, 108
 Rosendale cement, 474
 Rosin grease and lime, 638
 hardened with lime, 647
 " Ross " chain feeder, 138
 Ross Patents, Ltd., 127, 138, 204, 208
 Rotary Air Compressor Co. Ltd., 100
 dryer, 117
 kiln, 273, 301, 332, 353, 354, 357, 368,
 375-81, 383, 385, 396, 427, 443
 multiple screens, 166
 power-drills, 60
 screens, 159-62, 247
 Rough-cast, 229, 578
 walling, 228
 Rowland Bros., 101, 110, 111
 Royce, Ltd., 103
 Royles, Ltd., 194
 Royle, Sir S. W., and Co. Ltd., 196
 Rubber industry, lime in, 596-8, 651, 652
 limestone in, 182, 262, 263
 Rubbish, removal of, 70
 separation of, 56

- Rubbish, tipping, 112, 113
 Rubble, uses of, 212
 Rugby, 19, 464
 Rum, lime for, 607
 Running kilns, 273
 Run-of-kiln lime, 465, 532
 Rushton Tractor Co. Ltd., 104, 111
 Russell, Sir E. J., 535
 Rusting of metals, retarding, 678
 Ruston and Hornsby, Ltd., 108
 -Bucyrus, Ltd., 49, 104-6, 108
 Ryan kiln, 296
- Saccharin manufacture, 615
 Sack-Filling and Sewing Machine Syndicate, Ltd., 198
 Sacking, automatic, 530
 Sack lime, 481, 487
 of lime, 547, 682
 Sacks, 207, 529
 Sadler and Co. Ltd., 196
 Safety belts, suppliers of, 108
 Salt-cake, purified by lime, 599
 Salts, 114, 115, 429, 524
 addition of to stone, 429
 increase solubility of lime, 524
 in stone, 114
 Sampling, 26
 Sampson, H., and Sons, Ltd., 204, 206, 210
 Sand, 4
 -absorbing power, 571, 572
 in limestone, 37
 -lime bricks, 231, 463, 498, 502, 584-7
 separation of, 190
 Sandstones for lining kilns, 291
 Sandycroft, Ltd., 106, 201, 208
 "Sangwin" dryer, 117, 118
 Sanitation, lime in, 652-7
 Sankey, J. H., and Sons, Ltd., 200
 Sap in stone, 32, 114
 Saponification, lime for, 596
 Sargeant, E. F., 109
 Satinite, 650
 Satin-spar, 8
 white, 597, 650
 Sawing in quarrying, 53, 119-23, 193, 207
 Sawyer-Massey, Ltd., 201
 Saxon Iron and Steel Works, 206
 Scale in boilers, 671
 Scammell Lorries, Ltd., 111
 Scarborough, 227
 Scar limestone, 17
 Schaffer and Crow's kiln, 301, 378, 429
 hydrator, 513
 Schists for lining kilns, 291
 Schmatolla kiln, 309, 313-5
 Schneider kiln, 326
 Scholefield, R., 201, 204, 208
 Schultess hydrator, 510
 Scoops, 76, 77, 109
 Scott, 101, 110, 644, 652
 and McClure, 665
 Scott's cement, 464
 Scottish Tar Distillers, Ltd., 196, 197
 Scouring agent, lime as, 660, 677
 process, lime in, 660
- Scrapers for overburden, 48, 109
 Screen-conveyors, 167, 168
 Screened lime, 465, 532
 Screening, 148-68
 lime, effect of, 38
 Screenings, use of, 242
 Screens, 149-68, 339, 501
 concentric, 162, 166, 167
 conical, 157, 161, 162
 cylindrical, 158
 distribution of material on, 157
 efficiency of, 155, 156
 feeder-, 159
 for discharging kiln, 339, 340
 lime, 340
 hexagonal, 160
 moving, 158
 multiple, 165, 167
 polygonal, 160
 ratio of apertures to product, 164
 reciprocating, 158, 159
 revolving, 159, 162
 slope of, 156
 speed of rotation, 165
 suppliers of, 207
 supports for, 156
 vibrating, 157, 162, 163
 Screw-jacks, 78
 Scrubbers as dust-collectors, 520
 for gases, 453
 Seacombe stone, 23
 Seasoning, 114
 Sea-water, treatment of, 674
 Secondary air, 275, 312
 Seconds lime, 545
 Sedimentation, 174
 Seger cones, 430
 Selected lime, 465, 532
 Selecting a hydrator, 515
 kiln, 383
 Selenitic lime, 464
 Sellars Cement, Ltd., 200
 Semi-producers, 421
 "Sentinel" Wagon Works, Ltd., 111
 Separate-feed kilns, 280, 302
 Separating fine particles of lime, 483
 small and large stones, 56
 useful stone and rubbish, 56
 Separators, centrifugal, 176
 Septaria, 5, 25
 Settlement of sludge, 607
 Sewage, burned, 546
 clarification of, 597
 -sick land, curing, 535
 treatment of, 596, 653-7
 Sexton & R. E. Holding, 206
 Shaft kilns, 273, 353-5
 Shafts, supporting, 288
 unbalanced, for screens, 163
 Shalebrook limestone, 15
 Shale, distillation of, 608
 Shalstone, 226
 Sharpeners for drills, suppliers of—see Air-compressors
 Shaw, John, Ltd., 105
 Sheepbridge, Coal and Iron Co. Ltd., 201
 Sheep-dips, 568

- Sheffield lime, 533
 limestone, 225
 Wire Rope Co. Ltd., 105
 Shell lime, 465, 466, 532
 limestone, 2, 12, 212
 marl, 9, 12
 -Mex, Ltd., 195
 sand, 12
 Shellac bleached with lime, 647
 Shells, 11, 12, 212, 267
 Shelly oolite, 4
 Shenton, J. W., 204
 Shepherd, William, and Sons, Ltd., 195, 196
 Sheppey, 25
 Shepton Mallet, 19, 20, 226
 Shields and Whittaker, Ltd., 199, 203
 Shoes, manufacture of, 182
 Shoots—*see* chutes
 Shotover Hill, 21, 23, 226
 Shovel, weight moved by, 46
 Shovelful, 559
 Shovelling earth, 47
 Shovels, 49, 109, 393
 Side leather, lime for, 624
 Siemens Bros. and Co. Ltd., 394
 Sieves, 149-68, 207
 meshes of, 151
 Sifting lime, 490
 Sihi Self-Priming Pump Co., 108
 Silica bricks, 291, 617
 in limestone, 5, 28, 36, 37, 433
 Siliceous limes, 464
 limestone, 5
 matter, effect of, 433
 Silician marble, 15
 Silk, treating, 660
 Silos, 126, 176, 332, 341, 342, 367, 498, 500,
 502, 505, 514
 Silundum, 121
 Silurian limestones, 15, 212
 Sinter, 6
 Sintered lime, 382, 428, 464
 Sintering machine, 382
 Site, selection of, 40
 Size, effect of, on burning lime, 277
 manufacture, lime in, 621-4
 of apertures, accuracy of, 214
 kiln, 388
 stone, effect of, on burning, 357, 377,
 407, 418
 Sizing, 148
 Skelland, W., 110
 Skelton, C. T., and Co. Ltd., 109
 Skerries, 13
 Skins, plumping with lime, 622-4
 Skipton, 17
 Skulls, 436
 Slag bricks, 587
 cement, 583
 Slaked lime, 464-6, 481-94, 532, 628
 Slaking lime, 463, 481-97, 515, 525
 magnesian lime, 463, 485
 rate of, 488
 water required for, 487, 492
 Slate-spar, 8
 Sleaford, 20, 226
 Sleepers, 85
 Slime-fungus, 216
 Slimes, treatment of, 596
 Slingsby, H. C., 101
 Slots in screens, 154
 Sludge, lime-, 212, 250, 545, 593, 600, 611,
 625, 650
 recovery of lime, 607, 611, 675
 washing, 649
 Slugs, effect of lime on, 566
 Slurry, drying, 185
 Small lime, 438, 445, 448, 465, 478, 484, 542,
 545
 stone, 212, 447
 Smedley Bros., 206
 Smelting, lime for, 629-36
 limestone for, 256
 Smidth, F. L., and Co. Ltd., 198, 201, 210
 kiln, 285, 286, 296, 321
 Smith, H. V., and Co. Ltd., 196
 Thomas, and Sons (Rodley), Ltd., 103-5
 Wm., and Sons, 101, 199
 Smithie, W. C., and Co., 196
 Smith's Executors, Richard, Ltd., 195, 197
 Smoothing stone, 125
 Smyth and Adams, 390, 404
 Soap industry, lime in, 593, 597, 657-9
 limestone in, 263
 wastage by hard water, 668
 Sobek discharging device, 338
 Société des Ateliers de Bondy, 204
 Soda ash, 599
 caustic, 599
 lime, 525, 601, 678
 recovery of, 650
 Sodium acetate, dehydrating, 596
 compounds in limestone, 38
 peroxide, 598
 Softening water, 664-77
 Soft water, 666
 Soil, calcium carbonate v. lime, 218
 effect of lime on, 534-40, 554
 limestone on, 215-23
 lime-requirement of, 219, 549-56
 pests, 535-9
 Sokolov, V., 312
 Sole-leather, lime for, 624
 Solenhofen, 261
 Solidified oil, manufacture of, 637
 Solo kiln, 379
 Solubility of calcium carbonate, 6, 28
 lime in water, 470, 486, 523-6
 Solvay process, 250
 Solvent, lime as, 598
 Soot, 424
 Sorensen's unit, 553
 Sorghum industry, lime in, 597
 Sorting lime, 340, 445
 limestone, 112
 Soundness of lime, testing, 574, 586
 Sourness in soils, effect of lime on, 535, 539
 Southend Waterworks Co., 675
 South Metropolitan Gas Co., 196
 Shields, 17
 Western Tar Distilleries, 196
 Spades, 100, 109, 394
 Spalling, 36, 291
 Spanish chalk, 188

- Spanish white, 179, 212, 268
 Sparksford, 19
 Specific gravity of lime, 471
 limestone, 33
 heat, 471
 Specification for broken stone, 177
 channels, 231, 234
 flags, 231, 234
 hydraulic lime, 575
 kerbs, 231, 234
 lime for mortar, 574
 varnish, 646
 sand-lime bricks, 231, 584
 issued by Association of British Insecticide
 Manufacturers, 567
 standard, 152, 154, 177, 231, 234, 574, 575,
 584
 (U.S.A.) for lime, 619
 Spencer & Halstead, Ltd., 172, 203, 205
 kiln, 285, 296
 (Melksham), Ltd., 102-4
 Spent lime, 612
 Spiral shaft, 286
 Spiros, 100
 Spoil bank, 45, 51
 Spoils, 436
 Spreading lime, 558, 559
 Spurway, 554
 Spy holes, 352
 Square kilns, 282
 Stage kilns, 285
 Stairways, inadequate, 368
 Stalactites, 6
 Stalagmites, 6
 Stamford marble, 20, 226, 230
 Stamp-mills, 127
 Standard and Pochin Bros. Ltd., 194, 203
 specification, 152, 154, 177, 231, 234, 574,
 575, 584
 Starch manufacture, 615, 656
 sugar, 249
 Steam, 54
 - injecting, 306, 333, 378, 409, 428, 435
 navvies, 49, 50
 use of, in hydrating, 515
 kilns, 332, 333, 347, 423, 428, 429, 450,
 451
 Steel Band Conveyor and Engineering Co.
 Ltd., 103
 manufacture, lime and limestone in, 598,
 632, 633
 Steenbrugge, M., and Co., 105, 203, 204
 Steetly limestone, 17, 89, 225
 Steger discharging device, 338
 Steiger kiln, 298, 328, 474
 Stein kiln, 293, 326
 Stephens-Adamson Manufacturing Co., 159
 Sterilizing effect of lime, 535, 665, 666
 Steves' Emulsions, Ltd., 195
 "Sticking" in kiln, 37, 283, 284, 294, 334,
 338, 350, 352, 360, 364, 365, 408, 409,
 418, 419, 428, 429, 433, 434, 443, 444
 Stockton Heath Forge, 109, 110
 Stoke Ground, 22, 226
 Stone, 677
 artificial, 230, 231, 588
 -breakers, 130, 209
 Stone-breakers, suppliers of, 209
 broken 177-9
 -coating plant, suppliers of, 209
 conveying to kiln, 330
 crushed—*see* crushed stone
 crushing, 126-48
 discoloured, 113
 dressed, artificial, 588
 drying, 115-8, 451
 dust for roads, 247
 dusting in collieries, 178, 256
 lime, 466, 682
 loose, loading, 73
 monumental, 230
 preparation of, 112
 rejected, 113, 114
 sawing, 120
 size of, for kiln, 277, 393, 418, 447
 small, 212, 447
 burning, 277, 388, 447, 448
 small-sized, kiln for, 393
 storage for kiln, 342
 unburned, in lime, 367, 407
 unsound portions in, 115
 useless, disposal of, 99
 wet, 411
 -working machinery, suppliers of, 210
 -yard, position of, 45
 Stonehouse, M. J., Ltd., 195, 197
 Stonesfield slate, 22, 228
 Stoppings for polished stones, 126
 Storage of fuel, 342
 lime, 341, 529
 stone, 176, 342, 351
 Stothert and Pitt, Ltd., 101-5, 108, 203, 208,
 209
 Stott, S. S., and Co., 103
 Stourbridge Gas Construction and Engineers,
 Ltd., 394
 Strata, selection of, 41
 Strawboard works waste, treating, 655
 Straw paper industry, 650
 Strength of lime, 472
 limestone, 30, 227
 ropes, 83
 Strike, 43
 Stringer and Son, Ltd., 101, 103
 Stripping, 46
 Stroud, 20
 Stubbs, W. B., and Son, 101
 Stuc, 228, 230
 Stucco, 229, 569, 578
 Stürcke and Jobbins, 600
 Sturtevant Engineering Co. Ltd., 130, 136,
 147, 194, 201-4, 206
 Submerged chimney—*see* Dipping chimney
 Suction draught—*see* Draught
 Suds treated with lime, 655
 Sugar industry, lime in, 456, 595-7, 613-5
 Sullivan Machinery Co., 100
 Sulphonated compounds, lime for, 593-5, 606
 Sulphur dioxide, absorbing, 597
 effect of, on lime, 407
 in fuel, 395, 396, 407
 lime, 38, 407, 630
 limestone, 38, 255
 mixtures, 567

- Sulphur, recovery of, 459
 washes, 566
 Sulphurous gases, effect on limestone—*see*
 Sulphur
 Sulzer Bros., 108
 Summerston, Thomas, and Sons, Ltd., 108
 Sunderland, 17
 Engineering Co. Ltd., 208
 Super-lime, 547
 Suspension of particles in water, 173
 Sussex marble, 7, 18, 23, 230
 Sutcliffe, E. R., 495
 Speakman and Co. Ltd., 134, 146, 194, 201,
 512, 528
 Ventilating and Drying Co. Ltd., 194, 203
 Sutton stone, 19, 226
 Swanage stone, 23, 227
 Sweetening soil, lime for, 536
 Swift, Samuel, 100, 110, 111
 Swindon, 23
 Swinney Bros. Ltd., 101, 204, 206
 Sykes, Henry, Ltd., 108, 201
- Table salt, 600
 Tabular hills, 227
 Tacke, 560, 552
 Tadmerton, 226
 Tailings, hydrating, 497, 500, 504
 testing, 156
 Tailors' chalk, 264
 Tamped linings, 292
 Tamping explosives, 66
 Tangyes, Ltd., 104, 108
 Tanning, use of lime in, 546, 624-7, 655
 Tar acids, 693
 and tar compounds, suppliers of, 196
 Distilleries, Ltd., 195, 197
 in gas, 401
 purifying, 608
 Tarfroid, Ltd., 195, 197
 Tarmac, 192
 Ltd., 197
 Tarmacadam, 192, 243
 Tarphalte, Ltd., 197
 Tarred roads, 242-4
 Tarslag (1923), Ltd., 197
 Tartaric acid, use of lime in, 248, 595
 Taskers of Andover, Ltd., 111
 Taylor and Hubbard, Ltd., 105, 209
 J. Darnley, and Co. Ltd., 208
 Taynton, 22
 Technical carbonate, 10, 189, 212
 Telford roads, 237
 Telfer lines, 95
 temperature difficult to regulate, 361
 for burning lime, 279, 291, 390
 irregular, 361
 measurement, 413, 431, 440, 441, 446
 Tempering during slaking, 581
 Temple Guiting, 22
 Temporary hardness, 667, 672, 673
 Tenedos, 7
 Tennis courts, lime for, 565
 Tensile strength, 31, 477
 Terrazo flooring, 230
 Terre blanche, 258
- Tertiary limestone, 14, 25
 Testing lime for use in varnish, 647
 -requirement, 550-3
 limestones, 27
 precipitated chalk, 187
 soundness of lime, 586
 Texas Oil Co. Ltd., 195
 Textile industries, lime in, 659-64
 limestone in, 263
 Texture, 4, 26, 29
 Thame, 23
 Thawing agent, lime as, 679
 Theakston, Francis, Ltd., 110, 111
 Theedam, E. C., Ltd., 101, 108, 110, 199, 203
 Theil lime, 5, 474
 Thermal conductivity of lime, 471
 efficiency of lime kilns, 355, 389-92
 Thermo-couple, 441
 Thermometers (for Dryers), suppliers of, 210
 Thiële kiln, 474, 475
 Thomas, W. K., and Co., 207
 Thom's patent, 231
 Thorp and Son, Ltd., 111
 Tilghmann's Air Compressor Co., 100
 Tilley Lamp Co., 106
 Tilsbury stone, 23
 Tilth, improving by lime, 535
 Time required for burning, 368
 Tin ore, smelting, 636
 Tip, selecting, 45, 51
 Tipping-wagon, 86
 Tیره marble, 230
 Tivoli (Italy), 5
 Tobacco, effect of lime on, 540
 Todbere stone, 21
 Toepfer hydrator, 511
 Toilet-powders, 264
 Tokscliff, 8
 Tomatoes, effect of lime on, 540
 Tools, suppliers of, 109
 Tooth-pastes and -powders, 182, 187, 254,
 264
 Topeka mixture, 245
 Torquay, 225, 230
 Totnes, 225
 Totternhoe stone, 24, 227
 Townsend, A. P., 101
 Town's gas, 400
 Tracks in quarries, 44, 45
 Traction, 97
 -engines, 97
 Tractor Traders, Ltd., 106, 109
 Tractors, suppliers of, 79, 110
 Trade effluents, lime for, 654-7
 Tramways in quarries, 44, 79
 Transport, 78
 Transverse strength, 31
 Trass, 577
 Travertine, 2, 5, 212, 227
 Traylor Engineering Co., 157, 165
 Triassic beds, 15, 18
 Trichlorethylene, 677
 Tripod-drills, 60-3
 Tropical soils, 538
 Trucks for moving blocks, 86
 Truesdell, A. E., 393
 Truog, 550, 552

- Tube mills, 145, 146, 480
 suppliers of, 210
 Tubes, 85
 Tufa, 2, 5, 212
 Tuff, 2
 Tuke and Bell, Ltd., 108
 Tullamore, 13
 Tullis, John, and Son, Ltd., 103, 198
 Tung-oil heat test, 647
 Tunnel kilns, 368, 374, 375, 427
 burning, 427
 disadvantages, 427
 Tunstalls Seyssel and Limmer Rock Asphalte Co. Ltd., 195
 Turin, 7
 Turkey red process, 662
 Turn-tables, 84, 110
 Turpentine, 677
 Tuscany (Italy), 5
 Tyler, F. G., and Son, 137
- Unaphalte (Roads), Ltd., 195
 Unburned limestone—*see* "Core"
 Underburned lime—*see* "Core"
 uses of, 449
 Underburning, 407, 435
 United Coke and Chemical Co. Ltd., 197
 States Lighthouse Board, 644
 Uses of calcium carbonate, 211-66
 carbon dioxide, 459, 460
 chalk, 24, 211
 "core," 449
 hydraulic lime, 478, 677
 kiln-gases, 450-9
 lime, 448-450, 531-680
 lime-putty, 526
 limestone, 211-66
 lime-water, 525
 milk-of-lime, 522
 overburned lime, 450
 small stone, 448, 449
 steam, 451
 underburned lime, 449
 waste products, 447-62
 Utilization of heat, 279
- Val De Travers Asphalte Paving Co. Ltd., 195
 Varnishes, 646, 647
 Vat dyeing, 663
 Vegetable matter for burning lime, 399
 Vehicles, suppliers of—*see* Locomotives and Wagons
 Veitch's method, 550, 551
 Venetian red, 639
 Vents in stone, 115
 Verona, 7
 Vertical kilns, 273, 274, 283, 284, 353-5, 385, 421
 Vibrating screens, 157, 162, 163
 Vicenza, 7
 Vickers, Thomas, Ltd., 203
 Vicona separator, 164
 Victory hydrator, 511
 Vienna lime, 257, 260, 466, 527, 532, 534
 Vienna paste, 628
 white, 257
 Vigau stone, 261, 262
 Visco Engineering Co. Ltd., 194, 203, 205
 Voids in lime kilns, 277
 stone, 233
 Volume, increase in, on slaking, 572
 -weight, 32, 33
 of stones, 32, 33-
- Wagon lubricant, 637
 Wagons, 85-8, 110
 Wainwright, J., and Co. Ltd., 197
 Wake, John F., 203, 210
 Wakeley, 20
 Waldon stone, 226
 Walker, James, and Co. Ltd., 198
 Wm., and Sons, Ltd., 198
 Wall-coatings, lime for, 582, 583
 Walling, 228
 Wallis and Stevens, Ltd., 111
 Wallpaper, use of limestone, etc. in, 257
 Walsall, 40
 Waltham, 20
 Wanstrow, 230
 Ward, T. W., Ltd., 108, 201
 Warden, F. H., Ltd., 109, 111
 Wardle Engineering Co. Ltd., 106
 Wardour stone, 23
 Warner, Robert, (Pumps), Ltd., 108
 Washable paint, 644
 Washers (for stones), suppliers of, 210
 Washing chalk, 190
 limestone, effect of, 232
 Wash-mill 179, 190
 Waste, 112, 191
 gases, 333, 350, 450-9
 heat, 279, 412, 461
 boiler 317, 330, 450, 451
 in handling, 42
 land, use of lime on, 539
 lime, 545, 546
 liquors, recovery, 650, 678
 products from lime-works, utilization of, 447-62
 tipping, 112
 Wastes, various, treatment of, 655-7.
 Water absorption, 34
 acid, treating, 676
 at the quarry-face, 44
 carriage, 99
 clarification of, 665
 decolorization of, 665, 676
 deferritization of, 676
 disinfection of, 666
 filtration of, 668
 -floated whitening, 179
 for steam raising, 671
 lime-treated, advantages of, 668
 minerals in, 670
 paints, 642-6
 purification of, 664-77
 required for slaking lime, 487, 492
 separation by 173, 174
 softening, 521, 664-77,
 product from, 184

- Water, sterilization of, 665
 -works carbonate, 184
 sludge, recovery, 675
- Watkinson, F., Ltd., 198
- Wave-transmission, 55
- Wealden beds, 14
- Weathering, 114, 228
 tests, 35
- Weber's hydrator, 508
- Wedges in quarrying, 52
- Weeds and lime, 549
- Weeks, W., and Son, Ltd., 199
- Weighing machines, 111, 505
 suppliers of, 111
- Weight or measure, 530
- Weights, 436
- Weir, G. and J., Ltd., 108
- Welding, lime in, 678
- Weldon marble, 20, 226, 230
 process, 249
- Weld regulator, 678
- Well-drill, 61, 62
- Wellman Smith Owen Engineering Corporation, Ltd., 105, 108
- Wells, A. C., and Co. Ltd., 110
- Welsh Navigation Steam Coal Co. Ltd., 197
- Wenlock limestone, 16, 40, 225
- Westinghouse Morse Chain Co. Ltd., 105
- Westwood Ground stone, 22, 226
 J., and Co. Ltd., 105
- Wet-process of lime-burning, 378
 -slaked lime, 491
- Wheatley stone, 21, 226
- Wheel-barrows, 78, 101
 suppliers of, 101
- Whey, treatment, 656
- Whitby and Chandler, Ltd., 100, 103, 111
- White chalk, 11
 lias, 19
 R., and Sons, Ltd., 101, 108, 110
- Whitehead, John, and Co. Ltd., 111, 201, 204,
 206, 209
- Whitening—*see* Whiting
- Whitewash, 258, 259, 582, 583, 640
- Whiting, 24, 149, 179-83, 212, 258-64, 534,
 600
 and Turner, 390
 substitute, 182
- Whittaker, C., and Co. Ltd., 86, 101, 111,
 201, 204, 206, 209
- Width of kiln, 287
- Wiegall kiln, 333
- Wiggins, 119
- Wald, George, 106, 110
 James and F. C., 110
 M. B., and Co. Ltd., 109
- Willcocks and Son, 206, 207, 210
 W. H., and Co. Ltd., 108, 198
- Willett, Harold, Ltd., 107
- Wills, W. and F., Ltd., 205
- Wilson, Alexander, (Aberdeen), Ltd., 100,
 103, 207, 210
 A. P., 187
 John H., and Co. (1929), Ltd., 105
- Wimpey, George, and Co. Ltd., 195
- Wincanton, 230
- Winch, 78
- Wind pressure, 357
- Window sills, 588
- Windrush stone, 22, 226
- Wines, improving, 263
- Winget, Ltd., 101, 108, 111, 135, 201, 209,
 210
- Wingrove and Rodgers, Ltd., 107
- Winning stone, 52
- Winsley ground, 22
- Winteringham, 19
- Winter mortar, lime for, 576
- Wire drawing, lime in, 633
 gauze, suppliers of, 206
 ropes, suppliers of—*see* Haulage
 saws for stone, 53, 122
- Wirksworth, 225
- Woburn Bordeaux mixture, 567
- Wolff, 203 (*see* Bulmer)
- Wollastonite marble, 7
- Wood as fuel, 302, 392, 399
 distillation industry, lime in, 597
 fired kilns, 302
 Hugh, and Co. Ltd., 103, 201, 202, 209
 lime as stainer of, 640
 -pulp and lime, 648
- Woodite Company, Ltd., 198
- Wool, treatment of, 625, 663
- Woolhope limestone, 16, 225
- Woollen mills effluents, lime for, 655
- Wootton Bros. Ltd., 205
- Workability of lime, 470, 489, 518, 579
- Worksop, 17, 89
 limestone, 225
- Worthington-Simpson, Ltd., 100, 108
- Wrexham, 5, 227
- Wright and Co. Ltd., 210
- Wright's Ropes, Ltd., 105
- Writing chalk, 11, 264
- Yeast, 679
- Yellowstone Park (America), 5
- Yoredale beds, 15
- York, 10
- Yorkshire Patent Steam Wagon Co., 111
 Road Tar Binders, Ltd., 197
 Tar Distilleries, Ltd., 197
 wolds, 23
- Yorricks—*see* "Core"
- Zinc ores and lime, 634, 635