MEASUREMENT OF FLOW RATE (FOR GASES) BY THERMAL METHOD USING DIODE AS A SENSOR

A THESIS
SUBMITTED TO THE
UNIVERSITY OF POONA
IN PARTIAL FULFILMENT
FOR THE DEGREE OF
MASTER OF SCIENCE
(IN CHEMISTRY)

BY

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PUNE – 411 008

SEPTEMBER 1986

CERTIFICATE

Certified that the work incorporated in the Thesis "Measurement of flow rate (for gases) by thermal method using diode as a sensor" by Shri P.D. Godbole, was carried out by the candidate under my supervision. Such material as that has been obtained from other sources have been duly acknowledged in the thesis.

(A.P.B. Sinha)
Research Guide

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CHAPTER I : SENSORS

INTRODUCTION TO SENSORS

Industrial revolution forced scientists to think of various sensors and materials, which can be used in industries. Demand for sensors is increasing every day. New materials and sensors are coming in the market every day. The simple example of it is the class of materials, which are developed for temperature measurement and sensing. Wide range of materials are developed for wide range of applications. Thermistors are developed with various compositions and materials to suit the requirements of industries. Thermistors are developed for protection of instruments and devices from over-heating. These are also developed for precise measurements and control of temperature which is essential for research and analytical instrumentation.

The important need in a chemical plant is the automatic control instruments. The main advantages of these instruments are that they are not subjected to distraction. They have a very great advantage over manual operation for the monotonous yet highly necessary job of monitoring the plant variables, such as temperature, pressure, flow rates of various gases and fluids, automatic control instruments offers many possibilities for improving plant and personnel safety. The main advantages are:

(i) Closer control for critical and dangerous processes

(ii) Removal of operating personnel from the vicinity of potentially dangerous operations

(iii) Better working conditions for personnel by eliminating the necessity for exposure to inclement and hazard environment.

Automatic control instruments needs Servo control operations and feed-back systems. These systems require sensors for their operation. Sensor gives a proportional signal for the parameter under consideration. This signal is electronically processed and is used for control and indication of the parameters under consideration. Simple example of such system is temperature control of the furnace. Sensor gives a signal proportional to the furnace temperature. It is compared with the reference signal which is generated electronically. If the sensor signal is higher than the reference signal, power to furnace will be cut off by control instrument. If it is lower than the reference signal, control instrument will put on the power to the furnace. Thus, it will maintain the temperature of the furnace at a pre-set temperature level.

Senor or a transducer is a device which converts the physical parameter to be measured into a corresponding mechanical or electrical equivalent quantity e.g. in case of calibrated U tube monometer, the level difference between the two arms, is proportional to the flow rate of the fluid. In a gas meter, the number of revolutions per second are proportional to the flow rate of the fluid. For measuring temperature with thermocouples or thermistors, emf at the open end or change in electrical resistance is proportional to the temperature.

Sensors are classified into three main classes, viz. Mechanical sensors, Electromechanical sensors and Electrical sensors. Electrical sensors are further classified into two groups. The first group is called as active sensors. In these type of sensors, electrical signal, proportional to the physical parameter, is generated by the sensor. It does not requires external power source for its operation.

Second group is called Passive transducers. In these types of sensors external power source is required for their operations. Thermocouples give emf with temperature and therefore it is an active sensor while thermistors require external power source for their operation when it is used as a temperature sensor and hence it is a passive sensor.

The transducer which converts the physical parameter into a corresponding measurable electrical quantity such as voltage or current analogous to the physical quantity is called as electrical sensor. The important parameters which determine the usefulness of an electrical sensor are as follows:

(1) Linearity - The relationship between a physical parameter and the resulting electrical signal has to be linear.

(2) Sensitivity - It is the electrical output per unit change in the physical parameter. High sensitivity is desirable for a sensor.

(3) Dynamic range - The operating range of the transducer has to be wide, which will permit its use under a wide range of measurement conditions.

(4) Repeatability - The input/output relationship for a transducer has to be predictable over a long period of time.

(5) Physical size - The transducer has to possess minimum weight and volume, so that its presence in the measurement system does not disturb the existing conditions.

(6) Response and hysterisis - Response of the sensor to variation in physical parameter should be fast and there should not be hysterisis.

Large number of sensors are available for measurement of various physical parameters such as, temperature, pressure, humidity, etc. In the present work we have restricted ourself to a particular class of sensors which can be used for flow rate sensing. Temperature sensors are used for flow rate measurement. Some electromechanical sensors are also used for flow rate sensing. There are some semiconducting materials which are used as a gas sensors. These materials can also be used for flow rate sensing. For temperature sensing, generally resistance thermometers, thermistors, thermocouples and PN junction diodes are used.

Temperature Sensors

Resistance Thermometers:

In resistance thermometer, change in resistance of the metal wire due to temperature change is used for temperature sensing. Most metals change resistivity with reference to temperature. It increases with temperature i.e. metals exhibit positive temperature coefficient (PTC). The change in resistivity with temperature is explained as follows: The increase in temperature of metal conductor leads to its atoms vibrating about their equilibrium position with larger and larger amplitude. At elevated temperature the atomic centres of a conductor are able to scatter electrons more efficiently thereby reducing their average velocity. This increases the resistivity of the conductor. Copper resistances are used for temperature range between $-140^{\circ}C$ to $+120^{\circ}C$. The temperature range that can be covered by nickel resistance is $-180^{\circ}C$ to $310^{\circ}C$. For high accuracy of measurements and reproducibility of results, platinum resistance is used. It gives the temperature range from $-180^{\circ}C$ to $+540^{\circ}C$. Resistance thermometer is a passive sensor.

Thermistors

Semiconductors possess finite energy gap between their valence and conduction bands. The number of electrons excited from the valence band to conduction band increases with the rise in temperature. This increases the number of electrons available for conduction thereby reducing the resistivity of the material. This is called as negative temperature coefficient (NTC). Resistances made out of these materials are called as thermistors. They are used as temperature sensors. The change in resistance with temperature is non-linear. However, these are rugged and possess high resistance values, which reduces the matching problems in electronic circuits. Thermistors are used for temperature range from $-60^{o}C$ to $+300^{o}C$. It is also a passive sensor.

Thermocouples

Thermocouple is an active temperature sensor. It generates emf with temperature. When two dissimilar metals are joined, junction is formed. If junction is heated, emf is developed at the free ends. The generated emf is proportional to temperature. This is attributed to two phenomena, namely, Peltier effect and Thomson effect. The former governs the emf resulting solely from the contact of the two metals, the latter is responsible for the emf produced by the temperature gradient. Factors that are considered in the choice of thermocouple for a particular application are:

(1) the maximum usable temperature of the thermocouple must be higher than the temperature being measured;

(2) the thermocouple must have a high temperature sensitivity over the temperature range of interest;

(3) the change in output emf for a given temperature should be as constant as possible;

(4) homogeneity and characteristic resistance of each material in the thermocouple should be considered to minimise the errors due to Thomsons' effect;

(5) the two metals forming the thermocuple have to be so chosen that they are unaffected by the environment in which the measurements are made.

PN Junction Diode

In semiconductor diode (PN junction) sensor, the forward voltage drop (Vf) and the reverse saturation current (Is) are temperature sensitive. Reverse saturation current (Is) has got non-linear relation with temperature. Forward voltage (Vf) changes linearly with temperature over a wide range, if forward current is kept constant and low, so as to avoid the self heating of the device. The relation Vf/t remains constant over a wide temperature range. The theoretical aspects regarding Vf/t relation are described in the introductory part of the experimental work.

Electromechanical Sensors

Variable inductance transducers: This is a simple electromechanical transducer. It can be used for flow rate sensing. It is called as linear variable differential transducer (LVDT). It consists of a primary winding and two secondary windings placed symmetrically on either side of it. An iron core moving axially inside the coil assembly couples the two secondary coils with the primary. The alternating voltage (AC) is applied to primary. Because of magnetic coupling voltages are induced in the two secondary coils. The induced voltage depends on the relative position of the iron core. When core is exactly at the centre, induced voltages are equal. If secondary coils are connected in series opposite type, then output voltage will be zero. Any change in core position will give voltage at the output. Its phase with reference to primary voltage will give the direction of the core movement. This sensor can be used for flow rate measurement of fluids with proper mechanical arrangement.

Gas Sensors

These sensors are called as conductivity type gas sensors. Conductivity of a semiconductor varies not only with temperature, light, mechanical tension, but it also varies with the chemical parameters. The most commonly used gas sensors are semiconducting metal oxides. These materials are semiconducting due to crystal defects, such as oxygen vacancies. Most of them are N-conducting. The mechanism behind their gas sensitivity is still not correctly known. But briefly one can say that when the oxygen in the air is chemisorbed on the metal oxide electrons become localised at the surface. This leads to a negative surface potential and charge carrier depletion in the surface region. Surface conductivity is therefore very low. In case of sintered materials where the resistivity is mainly determined by the contact resistance between the particles, a high resistivity is obtained. When the material is exposed to a gas which reacts with the chemisorbed oxygen, the resistivity decreases due to decreased amount of surface bond oxygen. Resistivity of the material depends on the concentration of oxygen. Therefore, change in resistivity can be used for measurement of oxygen flow rate.

Ceramic sensors are available for various gases. Highly selective gas sensor is obtained by adding a catalyst to ZnO oxide semiconductor.[1] Those types of catalyst containing a Pt compound are highly sensitive to hydrocarbon gases. Those that contain Pd compound are sensitive to carbon monoxide and hydrogen gas.

Tin oxide[2] can be used as a gas sensor. If a bead of tin oxide with a pair of contacts is heated in a clean air, oxygen is absorbed into surface layers until an equilibrium condition is achieved for the particular temperature involved. Conductance of the bead only depends on the concentration of the oxygen. This property is used to detect and control the oxygen gas itself. If a reducing gas is passed over the bead, then its conductance increases depending upon the amount of oxygen removed from the surface due to reduction.

Therefore same bead can be used for other reducing gases also.

All these gas-sensors cannot be used for measurement of flow rate of any gas because of their selective property i.e. change in conductivity is recorded in presence of a particular gas only. There are number of mechanical, electromechanical and thermic flow rate measuring techniques. In these types of instruments, sensing of flow rate is done by using displacement technique, dynamic, kinematic or thermic technique. All these techniques are discussed in the following chapter.

CHAPTER II : FLOW SENSORS AND FLOW METERS

INTRODUCTION TO FLOW SENSORS AND METERS

Automatic flow rate control of fluids is essential in order to maintain the uniform quality of the chemical products. Flow rate plays an important role in the chemical process. If the flow rate varies, other variables such as temperature, fluid levels and pressure get affected resulting into harmful defects in the final products.

Flow control is also essential for economising the cost of the final product. With the help of flow meters, it is possible to monitor the quantity of different ingredients consumed in a particular process. It provides good means for establishing accurate standard cost of the finished product. The flow meter helps to check the wastage of materials in the process. The flow sensors detect leaks in the system and gives warning about the abnormal conditions occurring in the process.

In order to understand how the flow rate is sensed and controlled, it is necessary to know the properties of the flowing fluid. Fluids in motion have different velocities at different points in the line perpendicular to the line of the flow. The particular distribution of the velocities depends on the geometry of the container, the physical property of the fluid and its mass flow rate. The flow is characterised as Laminar flow and turbulent flow. In laminar flow layers of fluid move relative to each other without any microscopic intermixing. In turbulent flow there is an irregular random movement of the fluid in the direction transverse to the main flow. This irregular fluctuating motion is regarded as superimposed on mean flow.

If flow is considered with reference to rectangular Cartesian coordinate system, x, y, z, then the point velocity at any instant in x-direction is given by

$$V_x = \bar{V}_x + \bar{V}'_x$$

where $\bar{V}_x$ is mean point velocity and is defined as

$$\bar{V}_x = \frac{1}{\Delta t} \int_0^{\Delta t} V_x . dt.$$

As irregular fluctuations are very rapid Δt should be very small. If mean velocity $\bar{V}_x$ is constant with time the flow in x-direction is said to be in steady state.

According to Newtons' law of viscosity, shear stress R is proportional to the velocity gradient in the fluid. The constant of proportionality is known as coefficient of dynamic viscosity (μ).

$$R = -\mu \frac{dV}{dZ}$$

The fluids which follow the above equation are called as Newtonian fluids. Those who do not follow the above equation are called as non-Newtonian fluids. The velocity gradient -dV/dZ is called as shear rate and is denoted as $\dot{r}$.

Therefore $R = \mu\dot{r}$

For Newtonian fluids plot of R and $\dot{r}$ is a straight line. Slope of the curve gives the coefficient of dynamic viscosity. In case of non-Newtonian fluids the relation between R and $\dot{r}$ is not linear. In such cases the coefficient of dynamic viscosity is called as apparent coefficient of dynamic viscosity and is written as μ_a.

There are three types of non-Newtonian fluids. The first type is called as 'PSEUDOPLASTIC' fluid. Here μ a decreases with increase in $\dot{r}$. The second type is called as 'DILATANT' fluid where μ a increases with increase in $\dot{r}$. The third type is known as 'BINGHAM' fluids. In this type of fluids the plot of R and $\dot{r}$ intercepts R axis at R_B called yield stress. R_B is the stress which must be exceeded before the flow starts. This is because the fluid at rest contains a three dimensional structure of sufficient rigidity to resist any stress less than the yield stress R_B.

ENERGY RELATIONS AND BERNOULLIS EQUATION

The total energy of the fluid consists of four components:

(i) Internal energy

(ii) Potential energy

(iii) Pressure energy

(iv) Kinetic energy

Internal energy of the fluid is associated with the physical state of the fluid i.e. energy of atoms and molecules resulting from their motion and configuration. It is a function of temperature. Internal energy is denoted by U per unit mass of the fluid.

The potential energy of the fluid is due to its position in the earth's field of gravity. If fluid is raised to certain height Z over an arbitrary chosen base level, then potential energy will be Zg per unit mass of fluid.

The pressure energy of the fluid is the energy that is required to introduce the fluid in the system. If P is the pressure, V the volume and m the mass of the fluid, then PV/m is the pressure energy per unit mass of the fluid. But since density is given by the relation $\rho = m/V$, the pressure energy can be written as p/ρ .

The kinetic energy is the energy of the fluid in motion. It is given by the relation $V^2/2$ for unit mass of the fluid where V is the linear velocity of the fluid.

The total energy E of the fluid is given by

Total energy = Internal energy + potential energy + pressure energy + kinetic energy

$$E = U + Zg + P/\rho + \frac{V^2}{2}$$

If we consider a system as shown in Fig. (1a) where fluid is flowing from point 1 to point 2, an Δq amount of heat is added to it. Let ΔW_1 be work done on the system, ΔW_2 be work done by the system on the surrounding, then

$$E_1 + \Delta q + \Delta W_1 = E_2 + \Delta W_2$$

$$E_2 - E_1 = \Delta q + \Delta W_1 - \Delta W_2$$

If $\Delta q = 0$, then

$$E_2 - E_1 = \Delta W_1 - \Delta W_2$$

As the same fluid flows from point 1 to 2, U is same at 1 and 2.

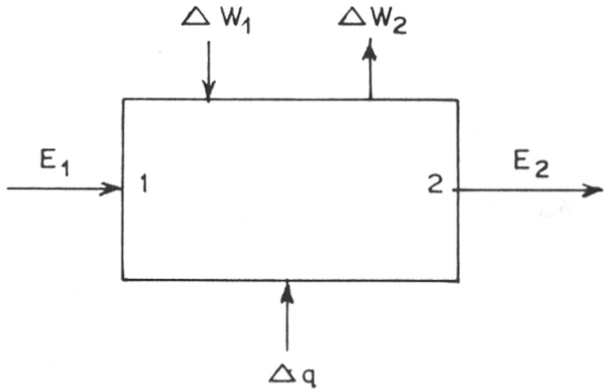


FIG. (1a) IDEAL SYSTEM

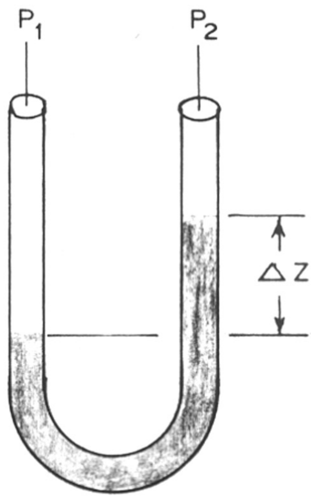


FIG. (1b). 'U' TUBE MANOMETER

$$U + Z_2 g + P_2 / \rho_2 + \frac{V_2^2}{2} - U + Z_1 g + P_1 / \rho_1 + \frac{V_1^2}{2}$$

$$= \Delta W_1 - \Delta W_2$$

or

$$(Z_2 - Z_1) + \frac{1}{g}\left(\frac{P_2}{\rho_2} - \frac{P_1}{\rho_1}\right) + \frac{1}{g}\left(\frac{V_2^2}{2} - \frac{V_1^2}{2}\right)$$

$$= \frac{\Delta W_1 - \Delta W_2}{g}$$

This equation is known as Bernoullis equation and is applicable to only for flow of fluids along a stream line or stream tube. For study flow in pipe equation is modified for velocity with a dimensionless correction factor which accounts for velocity distribution. The corrected form of Bernoullis equation is

$$Z_2 + \frac{P_2}{\rho_2 g} + \frac{V_2^2}{2\alpha_2 g} - Z_1 + \frac{P_1}{\rho_1 g} + \frac{V_1^2}{2g\alpha_1}$$

$$= \frac{\Delta W_1 - \Delta W_2}{g}$$

where α_1 and α_2 are correction factors. The terms $\frac{\Delta W_1}{g}$ and $\frac{\Delta W_2}{g}$ are denoted by Δh and Δf. Δh is the head imparted to the fluid and hf is the head loss due to friction. Also terms Z, $P/\rho g$, $V^2/2g$ are called as potential, pressure and velocity heads.

The flow meters are divided into two groups. The first group is displacement type. In this type the gas or the fluid whose flow rate is to be measured is divided into known unit volumes. The number of such unit volumes flown during a fixed time interval gives the flow rate.

In the second group the mean velocity of the fluid is determined by various methods namely, dynamic, kinematic, and thermic methods. In dynamic method, indication of the flow rate is based upon the flow laws e.g. construction in a pipe, orifice plate, venture tube. In kinematic method, velocity is measured by mechanical system e.g. rotameter, electromechanical systems, etc. In thermic method the sensor is heated and change in its electrical property because of flow gives the flow rate.

Type of Flow meters

Pressure difference devices: The most common flow meter is the pressure difference device, which is intrinsically a flow rate type of flow meter. The differential pressure caused by a change in the static pressure between the up stream and down stream side of the device is proportional to the square of the quantity flowing. The most frequently used type of pressure difference device is the orifice plate.

In these type of flow meters, the pressure difference is sensed by U tube manometer. Operation of these flow meter is based on the Bernoullis equation. A constriction in the flow path is used to increase the linear velocity of the fluid. This is accompanied by decrease in the pressure and it is measured by manometer.

U tube manometer is shown in Fig. (1b). One arm of it is connected to up-stream tap and the other to down-stream tap in the following fluid. The fluid in one arm is separated from fluid in the other arm by an immiscible liquid of high density. Generally mercury is used as a separating liquid. If ΔZ is height difference between the two arms and P_1 and P_2, the pressure at up-stream and down stream tap, then

$$P_1 + \rho \Delta Zg = P_2 + \rho_m . \Delta Zg$$

where ρ and ρ_m are densities of fluid and immiscible liquid.

Therefore, $P_2 - P_1 = (\rho_m - \rho) \Delta Zg$.

But according to Bernoullis equation

$$\frac{P_1}{\rho_1 g} - \frac{P_2}{\rho_2 g} = \Delta h$$

as fluid is same $\rho_1 = \rho_2 = \rho$

Therefore $$\frac{P_1 - P_2}{\rho g} = \Delta h$$

$$\frac{(\rho m - \rho).\Delta Z}{\rho} = \Delta h$$

This equation shown that pressure head loss is proportional to the height difference ΔZ and since pressure drop is proportional to square of flow rate, ΔZ can be calibrated in terms of flow rate.

An orifice meter consists of a flat plate with a hole at a centre placed in a pipe perpendicular to the direction of the flow, which provides contriction to flow path, leading to pressure drop. This pressure drop is measured by U tube arrangement. Orifice meters suffer from high frictional losses. The losses are reduced in the venturi tube by making outlet of the tube tapered keeping rest of the constriction the same as that of the orifice tube. A venturi tube is more suitable than orifice tube for metering liquids containing solids. One of the drawbacks of all pressure difference devices is that the flow rate range is restricted to about 5:1. The situation is improved[3] by introduction of a spring loaded differential pressure variable area orifice meter. In this design a centrally placed float moves against the action of a spring relative to fixed orifice. By a proper selection of the float and the spring the differential pressure can be made linear function of flow rate.

Rotameter: In rotameter the pressure drop is kept constant. The constriction area varies as the flow rate changes. A float is free to move up and down in a tapered tube. The float remains steady when the upwards force of the flowing fluid exactly balances the weight of the float in the fluid. The main disadvantage is that it is position sensitive and also it does not give electrical signal, by means of which one can control the flow rate in the chemical plant.

Mechanical and turbine type flow meter

In mechanical flow meter, mechanical counters are used. These counters are driven by flowing fluid. One can measure the flow rate by knowing the number of revolutions of counter in a known time. In turbine type flow meters, a free running rotor with small blades is placed in the fluid with a small blade tip clearance rotor rotates with an angular velocity proportional to the actuating velocity in the pipe. Hence, by accurate measurement of rotor speed the volume flow rate can be obtained. Turbine flow meter is viscosity sensitive i.e. calibration changes with the fluid. Basic theory of turbine flow meter is given.[4] The flow meter consists of three parts, the tangentially driven turbine, the high pressure enclosure and an opto electronic detection system for monitoring rotation speed without exerting an external load on the turbine.

The turbine rotor is driven by momentum transfer with a nozzle of dia d and volumetric flow rate Q of fluid with density ρ. The maximum available force from the stream is given by

$$F_{max} = \frac{4\rho Q^2}{\pi d^2}$$

The driving torque on the rotor of radius R is given by T_j.

$$T_j = K.\left(\frac{4\rho Q^2}{\pi d^2}\right)R$$

where K is coefficient of momentum coupling.

The rotor motion is opposed by friction at the bearings, the opposing torque is given by T_f.

$$T_f = \frac{\mu M g b}{2}$$

where M = mass of rotor

b = bearing diameter

μ = coefficient of friction

The starting minimum flow rate required to overcome the frictional torque is obtained by equating T_j and T_f.

$$Q_{stall} = \left(\frac{\mu M g b \pi d^2}{8 \rho K R} \right)^{1/2}$$

This expression gives the design requirements of the turbine flow meter. These are

(i) rotor mass should be kept small;

(ii) bearing diameter should be small;

(iii) coupling coefficient should be maximised by proper design of rotor and jet;

(iv) bearing friction should be small and

(v) rotor radius should be large.

Electromagnetic flow meters : Faraday's law suggests the possibility of inducing voltage in liquids moving through a magnetic field. Flow meter designed by using this fact is called electromagnetic flow meter. Fluid is magnetised by magnetic field and induced magnetic field in the fluid is detected which is proportional to the flow rate of the fluid. Size of the flow meter varies from few inches to few feet depending upon the application. This technique is used in the medical field for measurement of blood flow. In nuclear reactors it is employed for measurement of flow rates of molten metals. The main advantages of this type of flow meter is that it has no moving parts, it does not put restriction to flow path. But it can be used only for fluid which can be magnetised by field. Instead of d.c. magnetic field, pulsed electromagnetic flow meters are also developed.

Ultrasonic flow meters : When sound wave is transmitted against the direction of flow, it is slowed down, if it is transmitted in the direction of flow, it is speeded up. This is the basis of ultrasonic flow meter.

Resonator type flow meters: Recently resonator sensors are developed for flow rate measurement.[5]

These sensors are based upon the principle where the resonant frequency or the frequency distribution produced in a mechanical structure is measured and related to the flow rate. Such type of resonator sensors are developed by G.E.C. for measurement of liquid mass flow rate. In this type of device, a vibrating vane is introduced into a pipe containing the flowing fluid. The vane is of thin metal or ceramic mounted in a particular manner, so that middle section is free to vibrate at one of the flexural resonance frequency which is about one KHz. The vibrations are maintained by Piezo electric transducers bonded to the vane. As liquid flows, a phase difference is produced between the signals picked up by the transducers mounted at each end of the vane. The mass flow rate is computed from the measurement of this phase difference and resonant frequency of the vane. These sensor response is linear over a large flow range. These sensors are fabricated by using screen printing technique.

Thermic type flow meters: A micro flow meter has been developed by R.F. Benseman[6]. In this flow meter, water is channeled through a rectangular tube and heated grid mounted at right angles to the direction of flow warms the water as it passes over it. The differential thermopiles mounted at up-stream and down-stream of the flow records the differential temperature. It has been found that the temperature difference registered by the thermopile at various flow rates of water is nearly proportional to the flow rate. Clayton et al.[7] fabricated an instrument for measurement of flow rate of slowly moving fluids. Flow rate was measured in terms of the change in the temperature of a heated copper body exposed to the fluid stream. The change in temperature is detected by a thermopile assembly whose output is recorded on spot galvanometer. The mass flow rate can be measured by measuring boundary layer temperature.[8] When fluid flows in a conduct, a thin film of fluid particles forms on the conducts inside the surface. This film is partly adhering to surface and partly in the laminar flow parallel to the surface. The amount of heat required to develop a known temperature difference across the boundary layer indicates the heat transfer rate and this rate through the boundary layer is a measure of the fluids mass flow rate.

Thermistors have found widespread application in instruments employed to measure the properties of the fluid[9] like flow rate measurements etc. When thermistor is heated to temperature T and then allowed to cool,the rate of cooling is proportional to the instantaneous temperature difference $T-T_x$. If T_x is temperature of the surrounding fluid and C is heat capacity of the thermistor, the heat transfer equation is

$$dT/dt = -K/C\,(T-T_x)$$

K depends upon thermodynamic properties of fluid and its speed relative to thermistor.

The sensitivities of a thermistor to change in fluid temperature and relative speed of fluid are of particular value. The sensitivities are defined as the fractional rate of change of thermistor voltage with reference to one variable and the other variable remaining constant. For small heating current, the sensitivity to temperature change is large. On the other hand, the sensitivity to speed variation increased with large heating currents i.e. as current tends to zero sensitivity to speed variation tend to zero. Therefore, greater sensitivities are obtained for fluid speed with large power dissipation in the thermistor.

A flow meter was developed by S.A. Veprek[10] where thermistor is supplied with constant voltage and was put in the bridge form. Output of the bridge was fed to indicator meter. When heating current was passed through the thermistor, it gets heated by joule heat to a temperature which is higher than that of flowing medium. Change in the velocity of the flowing medium produces a change of heat transfer from thermistor surface and consequently a change in its temperature and resistance. This change in resistance was measured and was related to flow rate since resistance change depends on the temperature and velocity of fluid. Fluid was first stabilised at constant temperature by allowing it to pass through long coil immersed into a constant temperature bath to eliminate the temperature effect.

Thick film resistors are also used as a flow sensor.[11] These are known as thermoconductometric flow sensors. When current flowing through the sensor is more than about 5 mA it brings about heating of the sensor and surrounding gas or liquid. At equilibrium, it gives some steady temperature and some resistance value of the sensor. When fluid flows, cooling of the sensor takes place which leads to change in resistance of the sensor which can be measured and calibrated in terms of flow rate. The resistance value is given by the equation

$$R_T = \frac{R_{273} . L \, (\lambda + A\sqrt{w})}{L \, (\lambda + A\sqrt{w}) - \alpha \, I^2 . R_{273}}$$

where L = length of thermistor

λ = thermal conductivity of medium

A = material and constrictional constant

w = velocity of the flowing fluid

α = T.C.R.

By using the above formula, instrument has been fabricated. Sensors are placed in a pipe with a heater between them. Sensors are wired in the bridge form with a centre zero meter indicating unbalanced emf. After the thermal equilibrium fluid is allowed to pass through the tube, meter indicates the unbalanced emf and direction of the meter indicates the direction of the flow through the pipe.

CHAPTER III : EXPERIMENTAL

EXPERIMENTAL

In conventional thermic flow meter, sensor is placed in the flow of fluid whose resistance changes with temperature. The sensor is fed with highly constant voltage. A current meter is placed in series with the sensor. The sensor is in the closed system, after sufficient time it attains a stable temperature. When the fluid is allowed to pass over it the sensor gets cooled and its resistance changes. But as the voltage is kept constant, the current changes. This current change is proportional to the flow rate. Thus, one can calibrate current change in terms of flow rate. In other type of thermic flow meters, thermocouples and heater are used to measure the flow rate. In some flow meters thermistors are used as a sensor. As mentioned earlier conducting pastes are also used as a flow rate sensing device. In our present work we have used semiconductor diode as a sensor. Three units were set up and measurements were carried out for flow rate measurement, response measurement, ambient temperature, variation compensation circuit performance checking and performance of diode as a sensor at various diode currents. Diode used was having No. 1N 914B.

Semiconductor Diode and its Properties

If the valence electrons in a crystal are tightly bound in the covalent bonds, there are no free charge carriers in the crystal and it acts as an insulator. On the other hand, if crystal structure is such that some of the valence electrons are not bound to any particular location in the crystal, then these electrons are free to move through the crystal. Such materials are called electrical conductors. Semiconductor have properties lying between the two extremes. At very low temperature there are no free charge carriers, at room temperature many free carriers are generated because of thermal agitation of the particles making up the material. There are two types of semiconductors. First one is P type material. In P type material, charge carriers are holes. When tri-valent impurity is added to pure silicon or germanium P-type material is formed. Second one is N type material. In these materials charge carriers are electrons. When pentavalent impurity is added to silicon or germanium N-type material is obtained. When P type and N type materials are in contact with electrical connections at P and N sides, PN junction is formed. An internal barrier is set up across the junction because of combination of holes and electrons. Internal field at this barrier is such that P type is negative with reference to N-type. Hence, for conduction, one has to apply external power so that it will overcome the internal barrier, i.e. P-type should be connected to positive terminal of power source and N type to negative terminal of the power source. This type of external supply arrangement is called as forward biasing. If the polarities are reversed it is called as reverse biasing. Complete V-I characteristic of a diode is shown in Fig. (2a) and forward and reverse biasing arrangement is shown in Figs. (2b) and (2c). Generally, series dropping resistance is provided to avoid the excessive current passing through the device. It is observed that when diode is in forward biased mode, voltage drop across it is about 0.1 to 0.5 volts. Also it is observed that it is a function of temperature. Change in forward voltage drop per degree change in temperature is about 2 mV. Fig. (3) shows the forward voltage against the temperature plot.

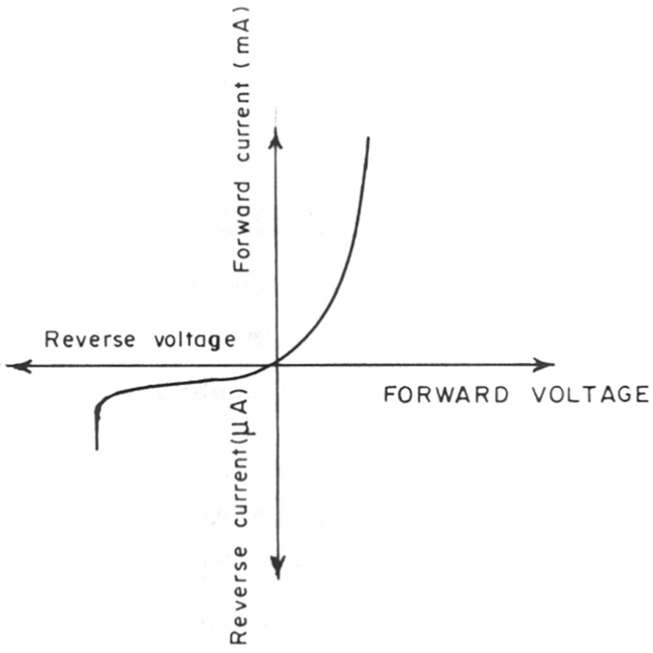


FIG. (2a). V.I. CHARACTERISTIC OF DIODE

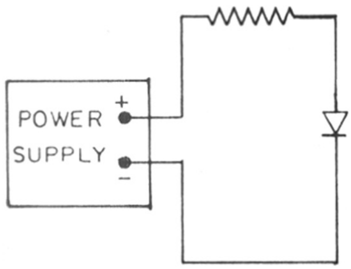


FIG. (2b)

FORWARD BIASED DIODE

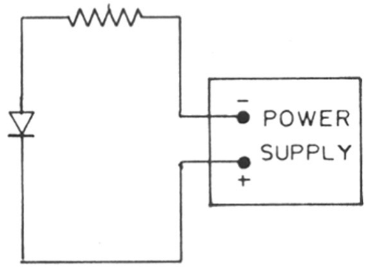


FIG. (2c)

REVERSED BIASED DIODE

Dependence of forward voltage drop on temperature

The forward voltage of the diode varies with temperature. The complete V-temperature characteristic over the temperature range from 4^{o} to 300^{o}K is shown in Fig. (3).[12]

Intrinsic characteristic is observed above 40^{o}K and below 40^{o}K. The forward voltage increases more rapidly with decreasin temperature.

Intrinsic range: The forward current through a P-N junction diode for voltage greater then a few KT/q can be represented by the equation

$$i = I_o A. \exp (qV/nKT)A \qquad (1)$$

where i is the current through the junction in ampheres

A is the effective cross sectional area of the junction in cm^2

V is the voltage across the junction

q is the electron charge = 1.6×10^{-19} Coulombs

K is the Boltzmann's constant = 1.38×10^{-23} J/°K,

T is the absolute temperature of the junction in °K

I_o is the reverse saturation current density in A/cm^2

and n is numerical factor.

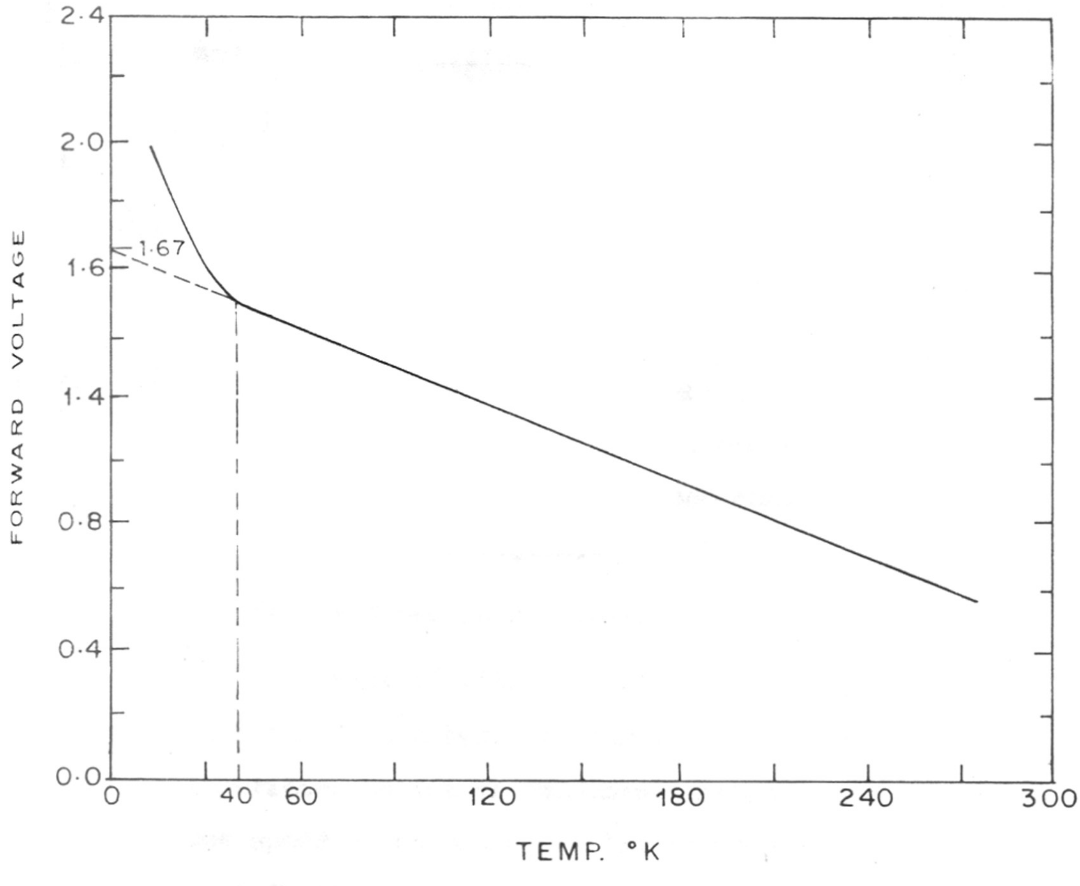


FIG. (3). PLOT OF FORWARD VOLTAGE VS TEMPERATURE

The parameters I_o and n depends on the location of the generation and recombination of the electrons and holes. Four different possibilities have been identified.

(1) Bulk generation-recombination outside the junction with a subsequent diffusion current to the junction.

(2) Bulk generation-recombination current in the transition region.

(3) Surface generation-recombination

(4) Surface channel current (generation and recombination in a surface channel next to the transition region).

The factor n has values ranging from 1 to 4.

In case of silicon diodes made by diffusion of boron into n type starting material with gold impurities to act as recombination centres to increase the speed of response, at low forward voltages, contributions from carrier recombination in the transition regions occurs (No.2), but at higher voltages around 0.5 V at room temperature the diffusion current (No. 1) becomes dominant. Above this voltage high level injection occurs and dependence of I_o is given by the equation

$$I_o = \frac{q.L\, n_i}{\tau} \text{ A/cm}^2 \quad n = 2 \qquad (2)$$

where L is the diffusion length of the carriers

τ is the life-time of the carriers

n_i is the carrier concentration in intrinsic silicon.

For silicon n_i is given by the equation

$$n_i = B.\ \exp.\ (-q\, V_G/2KT)\ \text{cm}^{-3} \qquad (3)$$

where $B = 3.87 \times 10^{16}\ T^{3/2}$

and $q\, V_G$ = energy gap of silicon at 0^oK.

Combining = Nos. (1), (2), (3)

$$V = V_G - (2.3)\ \frac{2KT}{q}\ [-\log i + \log \frac{q\,LBA}{\tau}]$$

For constant current of $i = 10^{-4}$ Amp.

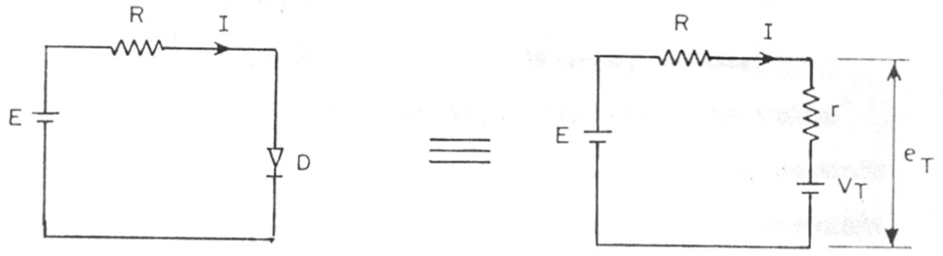
$$V = V_G - 1.59 \times 10^{-3}\ T\ [1 + \frac{1}{4} \log \frac{q\,LBA}{\tau}]$$

This expression shows linear dependence between V and T. Also it gives the band gap V_G when temperature is 0^oK.

Extrinsic region: Theoretical reason for more increase in the forward drop with decreasing temperature below $40^{\circ}K$ is conversion of PN junction into a PiN junction because of carrier freez-out.

Thus silicon junction diode above $40^{\circ}K$ gives linear forward voltage variation with temperature. Hence, it can be used as a temperature sensor.

The electrical equivalent circuit of the forward biased diode is as shown in Fig. below[13] for constant current of 1 mA V_T and r are 215 mV



and 54 ohms for germanium diode. For silicon V_T and r are 565 mV and 50 ohms.

For obtaining sensitivity of temperature indication to supply voltage differentiation gives

$$e_T = V_T + I.r.$$

$$= V_T + \frac{E}{r+R} r$$

Therefore, $$\frac{e_T}{E} = \frac{r}{r + R}$$

for R > > r

$$\frac{e_T}{E} = r/R$$

for typical values of r and R

$$\frac{e_T}{E} = \frac{50}{5000} = 10 \text{ mV/V}$$

Since 10 mV change corresponds to $5^{\circ}C$, when diode is used as a temperature sensor, supply voltage must be highly stable. The absolute value of the diode voltage at any given temperature depends on the diode type and supply voltage. For a constant supply voltage, it depends on the type of diode. The temperature forward drop for given type of diodes is identical for random statistical group. It is observed that in case of germanium diode mean slope is (1.83 ± 0.07) mV/$^{\circ}$C while in silicon it is (2.11 ± 0.06) mV/$^{\circ}$C.

It is also observed that in a batch of 30 diodes of silicon and germanium having same number and manufacturer 4 mV deviation is observed over the normal value of 618 mV in silicon diode and in case of germanium it was about 12 mV over the normal value.

Considering all these facts, silicon diode was used in our experiments. In the present work three systems were set up for studying the behaviour of diode as a flow rate sensor.

(i) Diode and a separate heater with very low diode current.

(ii) Diode as a sensor for measurement of heat transfer because of fluid flow with temperature control.

(iii) Heating the diode by the current passing through it and controlling the differential temperature with reference to ambient.

(i) Diode and separate heater with very low diode current

In this set up diode current was kept very low to avoid the self heating of the device. Construction of the sensor is as shown in Fig. (4). The heater was wound on a plastic bobbin. The diode was placed exactly at the centre of the heater. Heater resistance was about 20 ohms and it was supplied with 10 volts regulated D.C. power supply. Diode was biased in the forward mode with the same supply and 100 K ohms series resistance, so that current through the diode

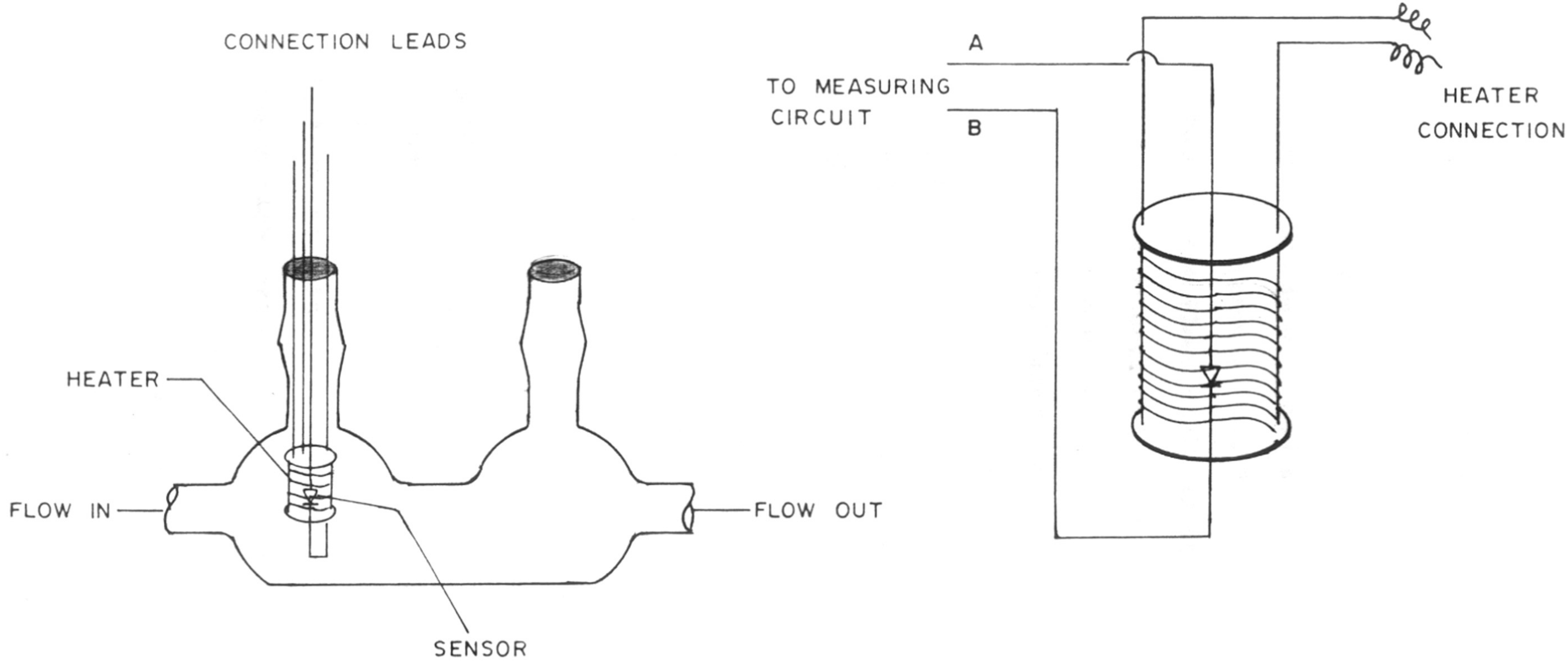


FIG. (4). GLASS APARATUS FOR HEATING DIODE WITHOUT TEMP. CONTROLLER is 100 μA leading to dissipation of 50 mW in the device which is very low as compared to 5 watts heater. Glass apparatus was fabricated to install the sensor in the flow, which is shown in Fig. (4). For measurement of changes in the forward voltage drop across the diode, because of flow, it is wired in the bridge form. Bridge circuit is shown in Fig. (5). 10 turn potentiometer is used for balancing the bridge. Since voltage drop across the diode is about 0.5 volts, drop across 10 turn potentiometer (5 K) must be about 1 volts so that variation of 100 mV per turn is obtained. Hence combination selected is 47 K and 5 K 10 turn potentiometer. Output of the bridge is given to Philips microvolt meter to indicate the unbalanced emf of the bridge.

For measurement of flow rate, a rotameter was used. As soon as power is given to the circuit, the heater heats the diode. After sufficient time thermal equilibrium is attained. Then with the help of 10 turn potentiometer, the bridge is balanced. The known flow rate fluid is allowed to pass over the sensor and unbalanced emf is recorded.

Oxygen was used as a fluid. A graph is plotted

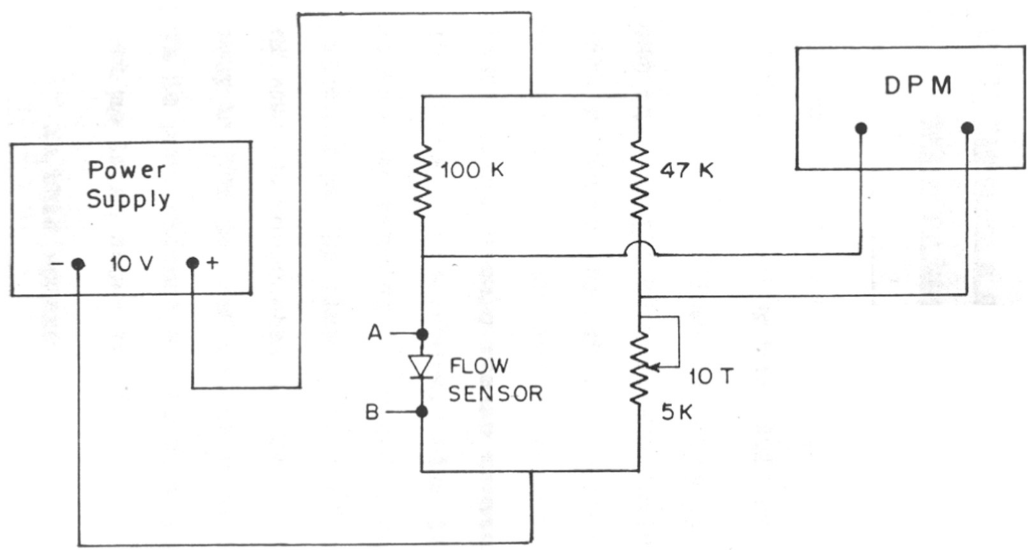


FIG. (5). MEASURING CIRCUIT

for flow rate against the emf, which is shown in Fig. (6) and table (1).

(ii) <u>Diode as a sensor for measurement of heat transfer because of fluid flow with temp.control</u>

In the second set up, attempt was made to measure the rise in temperature of the sensor because of heat transfer by the fluid at different flow rates.

It was decided to fabricate a circuit where one can control temperature inside the apparatus with reference to outside temperature or ambient temperature. The difference between these two temperatures should remain constant irrespective of the ambient temperature. Also it was decided that instead of heating the sensor, one can heat the incoming gas by fixed amount of heat irrespective of ambient temperature. The heat that is carried away by the gas can be detected by the sensor and it is proportional to the flow rate. The entire set up is as shown in Fig. (7).

In this apparatus, sensing diode used is 1N 914B type. The working of the temperature controller is as follows:

To control the differential temperature between inside the apparatus and ambient diodes are used as temperature sensors. It is shown in Fig. (8).

Table - 1

Flow rate in lit/min. and corresponding EMF in mV for system (1)

Flow rate in Lit/min.	Output EMF in mV
2	38
4	79
6	125
8	163
10	196
12	215
14	220

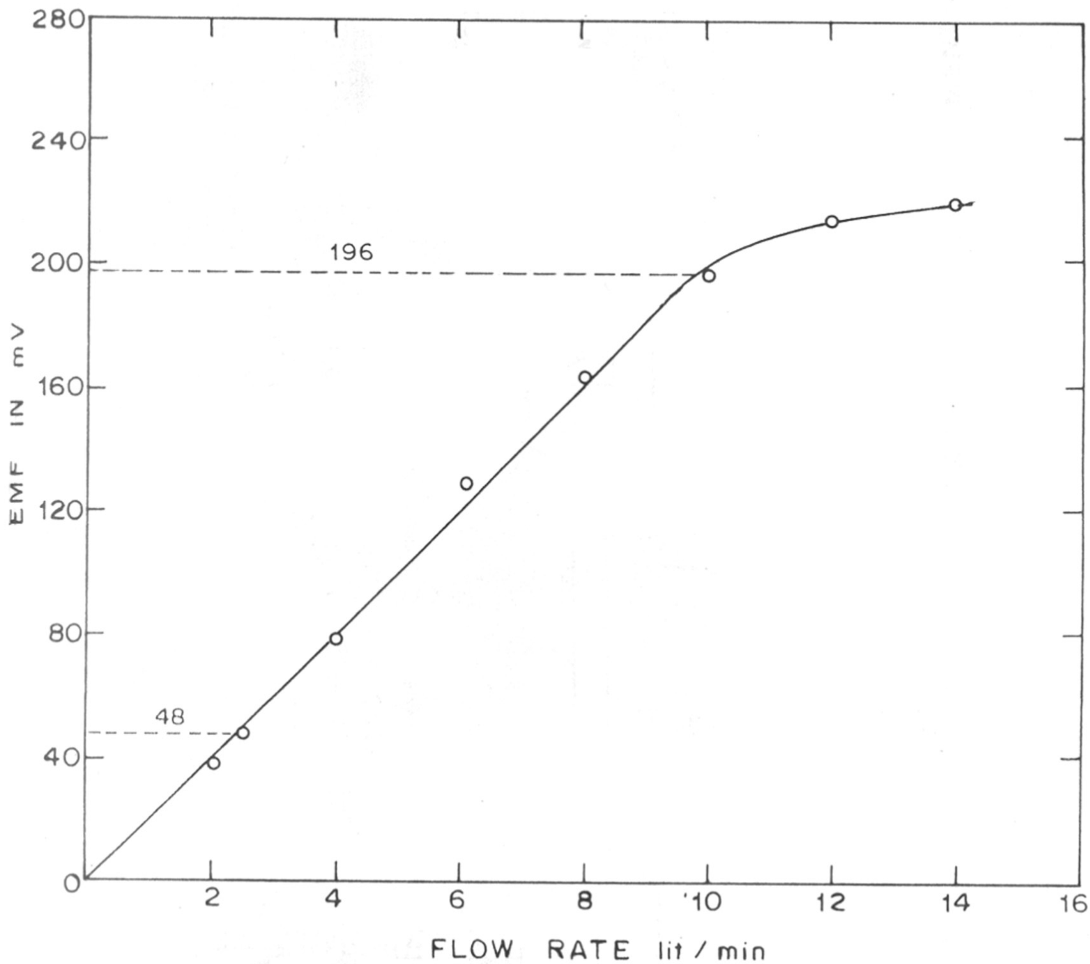


FIG. (6). PLOT OF FLOW-RATE VS OUT-PUT mV

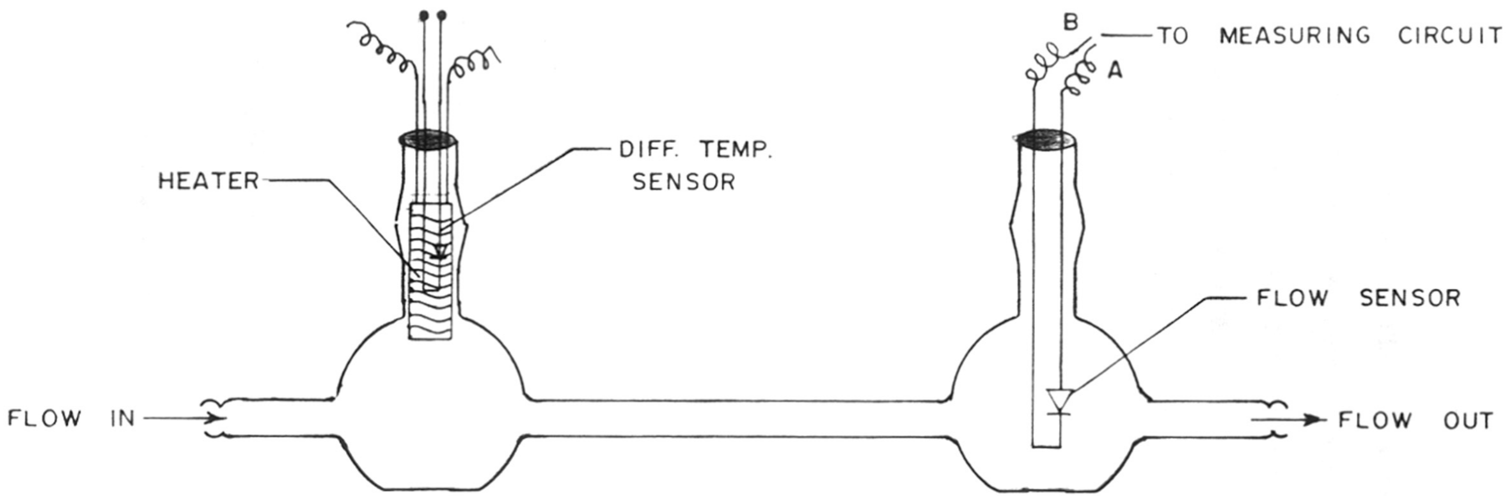
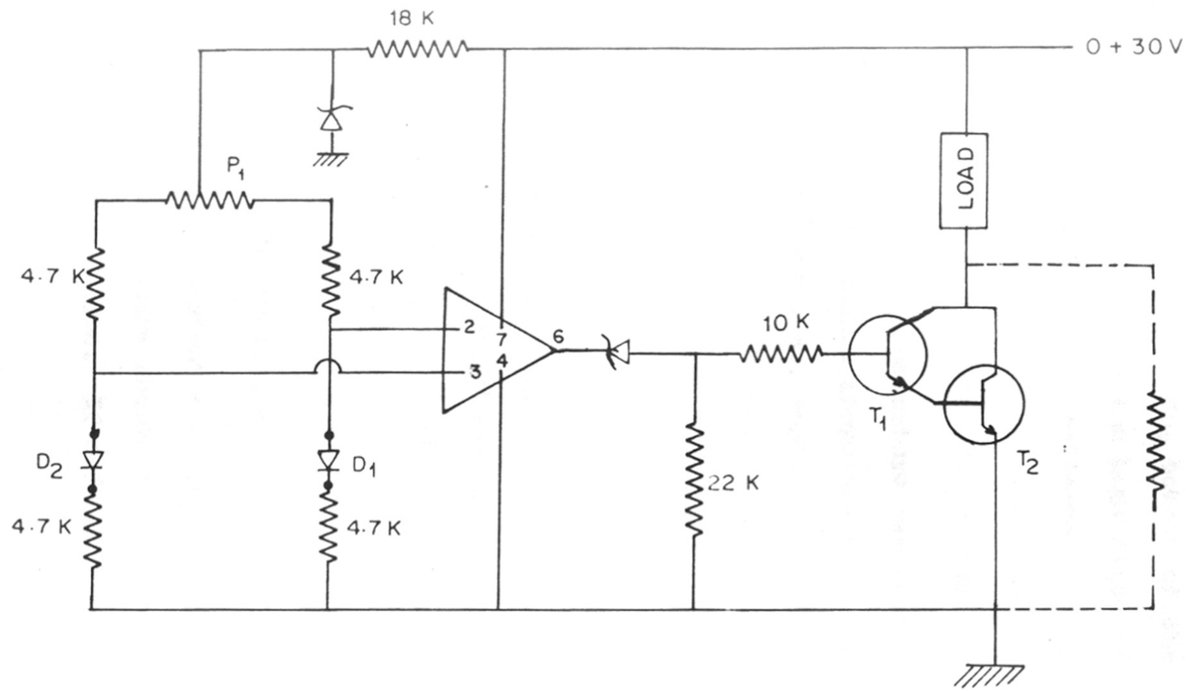


FIG. (7). GLASS APPRATUS FOR HEAT-TRANSFER MEASUREMENT

Referring to Fig. (8) two diodes marked ambient and inside are wired in the bridge form. The potentiometer P1 sets the differential emf of the bridge. The bridge output is given to the operational amplifier. The diode which is placed inside is connected to the non-inverting pin (3) of the operational amplifier. The diode which senses the ambient is connected to the inverting input pin (2) of the amplifier. The differential emf between pin (2) and pin (3) of the operational amplifier can be set with the help of potentiometer P1. As 100 mV charge in the forward drop corresponds to 50^{o}C, the differential emf between pin (2) and pin (3) is set to 100 mV, with pin (2) negative with respect to pin (3). As soon as supply is given to circuit, pin (2) becomes negative by 100 mV with reference to pin (3). Therefore, output of the operational amplifier goes high which drives two NPN transistors (SL 100 and 2N 3055) into conduction, As heater is connected in the collector circuit of the transistor it gets power. The temperature inside the apparatus starts rising up. Because of increase in temperature, forward drop of the diode inside the apparatus which is connected to pin (3) of the I.C. starts decreasing. As a result



D_1 – AMBIENT TEMP. SENSOR

D_2 – INSIDE TEMP. SENSOR

T_1 – SL100 TRANSISTOR

T_2 – 2N3055 TRANSISTOR

FIG. (8). CIRCUIT DIAGRAM OF DIFFERENTIAL TEMPERATURE CONTROLLER the differential emf between pin (2) and pin (3) of the IC also decreases. When the differential emf becomes zero, output of the IC goes to zero, which removes the base drive of the transistor. Therefore, the collector current of the transistor and the heater current becomes zero. The temperature inside the apparatus starts decreasing.

As temperature decreases, drop across the diode inside increases and when differential emf becomes 1 mV, again IC output goes high. This is because IC circuit is in open loop i.e. there is no feed-back. Therefore even for 1 mV, differential emf between pin (2) and pin (3), IC output goes high or zero depending upon the nature of the input emf. The current starts flowing through the heater till the differential emf becomes zero. This is the general operation of the controller for controlling the temperature.

Now ambient correction action of the circuit can be explained as follows:

Ambient correction means variation in ambient temperature should not change the differential temperature. If differential temperature is set to

$50^{\circ}C$ then for $27^{\circ}C$ ambient, inside temperature should be $27^{\circ} + 50^{\circ}$ or if ambient temperature is $20^{\circ}C$ then inside temperature should be $20^{\circ} + 50^{\circ}$. It means that if ambient increases then inside temperature should also increase by the same amount. If it decreases then inside temperature should decrease by the same amount.

The potential difference between pin (2) and pin (3) is set to 100 mV and for $1^{\circ}C$ change in temperature gives change of 2 mV in forward voltage drop of the diode, 100 mV corresponds to $50^{\circ}C$ differential. Once the differential is set and power is given to the circuit, inside temperature goes up till the differential emf between pin (2) and pin (3) becomes zero and temperature is maintained. If ambient increases by $2^{\circ}C$ then pin (2) becomes negative by 4 mV. Therefore, heater gets power. The temperature inside starts increasing as soon as diode inside senses 4 mV change, differential emf between pin (2) and pin (3) becomes zero. The power of the heater becomes zero because of circuit action i.e. $2^{\circ}C$ increases in ambient increases $2^{\circ}C$ inside the apparatus maintaining the differential temperature to $50^{\circ}C$. Now if ambient temperature decreases by

$2^{\circ}C$ then pin (2) of the IC becomes 4 mV positive than the pin (3). Hence, the heater current stops till inside temperature reduces by $2^{\circ}C$ to give 4 mV increase in the drop across the inside diode i.e. till the differential emf between pin (2) and pin (3) becomes zero.

This shows that the difference of temperature between ambient and inside the apparatus is always $50^{\circ}C$. To confirm the working of the circuit, experiment was carried out in which after attaining the equilibrium, the differential temperature between inside and ambient was measured by using Cr-Al thermocouple in differential mode as shown in Fig. (9). The ambient sensing diode was heated upto $80^{\circ}C$ and differential emf was recorded. It was observed that differential emf of the thermocouple is same as it was at the equilibrium. Then ambient sensing diode was allowed to cool and differential emf of the thermocouples was recorded at various temperatures. The graph of differential emf against ambient temperature is plotted and shown in Fig. (10). The results are also given in table (2). It shows that differential temperature is always constant for any change in the ambient temperature.

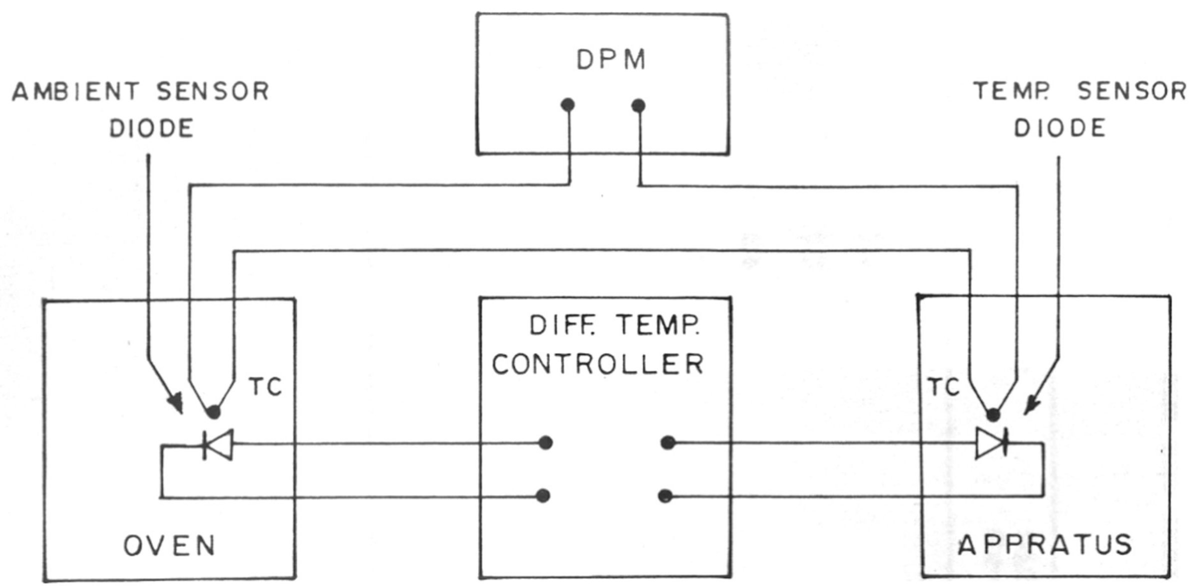


FIG. (9). EXPERIMENTAL SET-UP FOR CHECKING DIFFERENTIAL TEMPERATURE CONTROLLER

Table - 2

Temperature of ambient sensor and differential emf between ambient and inside the apparatus

Ambient Sensor Temperature	Differential EMF of Cr-Al Thermocouple
76	2.06
70	2.04
64	2.03
60	2.07
55	2.08
51	2.09
45	2.09
40	2.1

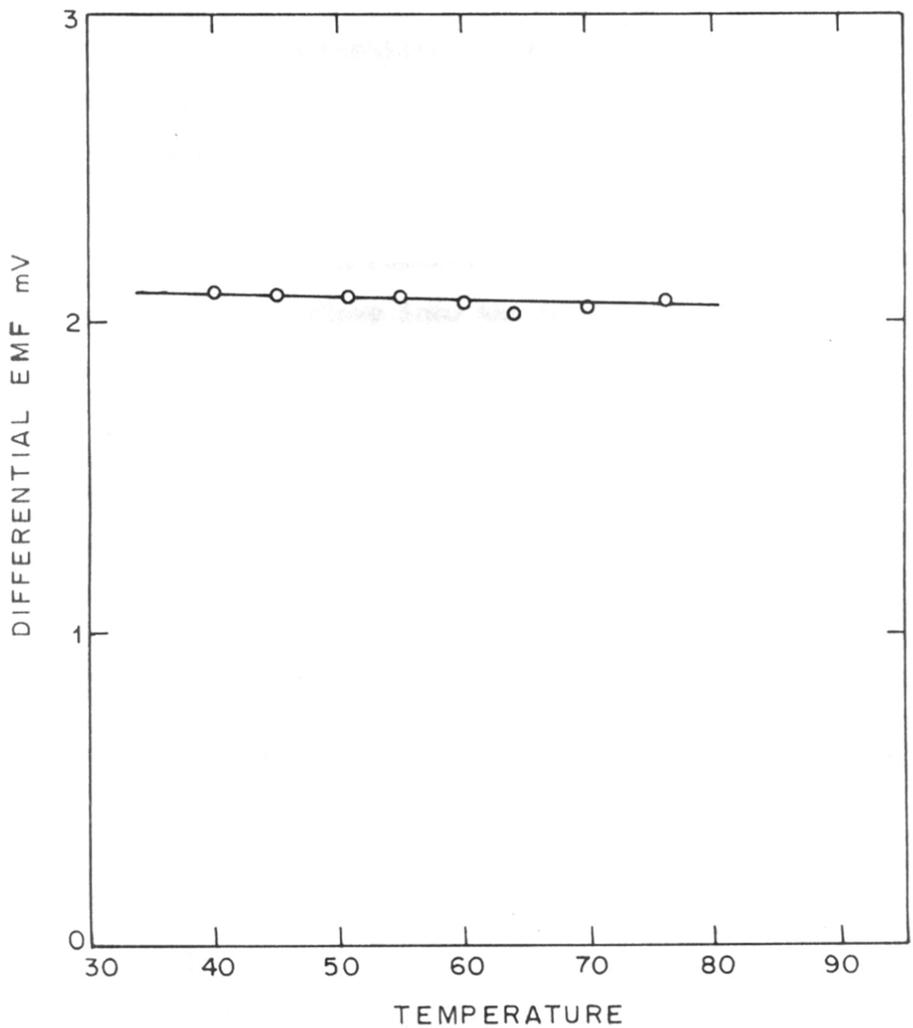


FIG. (10). PLOT OF AMBIENT TEMPERATURE DIFFERENTIAL EMF

It is observed that as heater is on/off type, it reflects on stability of temperature. To avoid the variation in temperature, an additional current path was provided for the heater. It is shown in Fig. (8) with dotted line. Because of this external current path when controller is in off state, a small current still flows into the heater preventing sudden decrease in temperature.

The entire apparatus is shown in Fig. (7). A 30 volts power supply was used. The heater resistance was 60 ohms. Bridge in the controller circuit was fed with 10 Voltzener stabilised power source. Flow sensing diode was kept away from the heater in a separate compartment. For measurement of emf change, due to flow, sensor is wired in the bridge form, the output of the bridge is given to D.P.M. for measurement of flow rate. Oxygen gas was used with known flow rate.and emf were recorded for different flow rates. The plot of emf against flow rates is shown in Fig. (11) and table (3).

(iii) <u>Heating the diode by the current passing through it and controlling the differential temperature w.r.t. ambient</u>.

Heating of the diode was achieved by passing current through it.

Table - 3

Flow rate in lit./min. and corresponding output EMF in mV for system (2)

Flow Rate Lit/min.	EMF mV
1.5	8.7
2.0	14.9
2.5	18.2
3.0	22.2

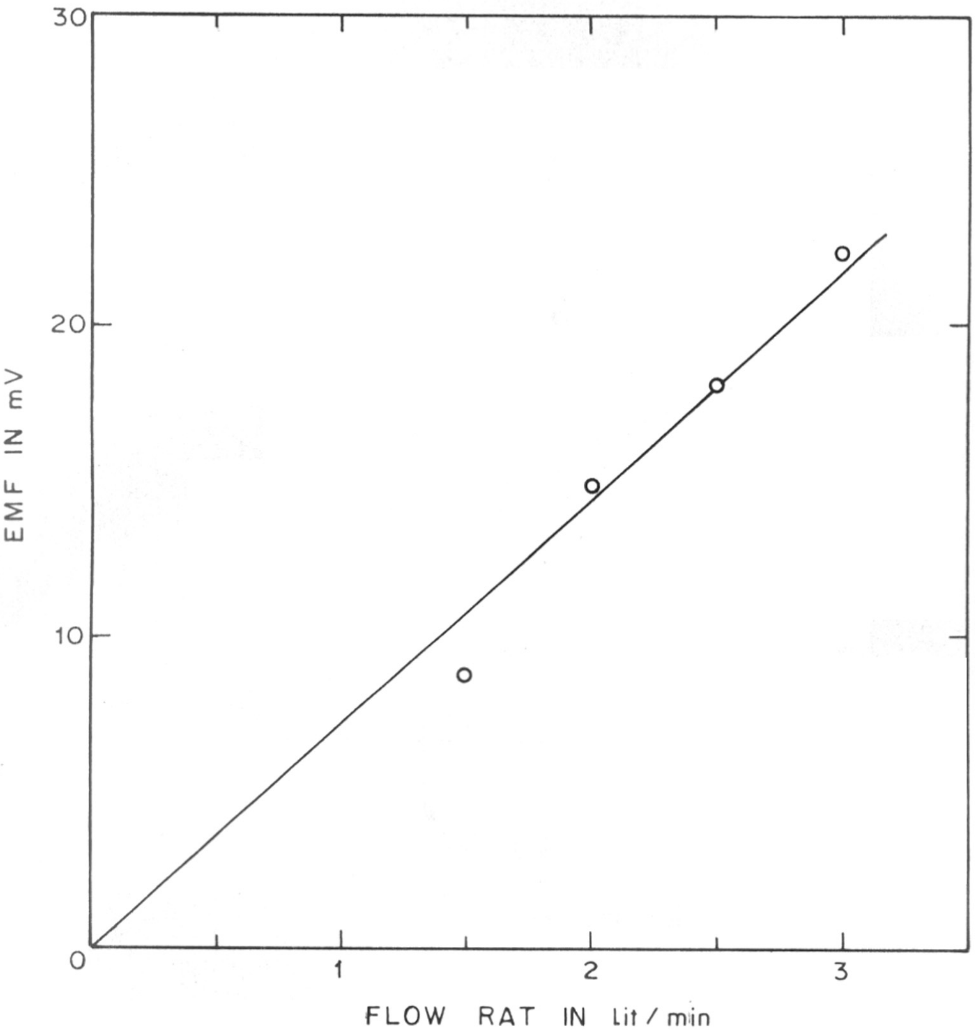


FIG. (11). PLOT OF FLOWRATE AND OUT-PUT EMF IN mV

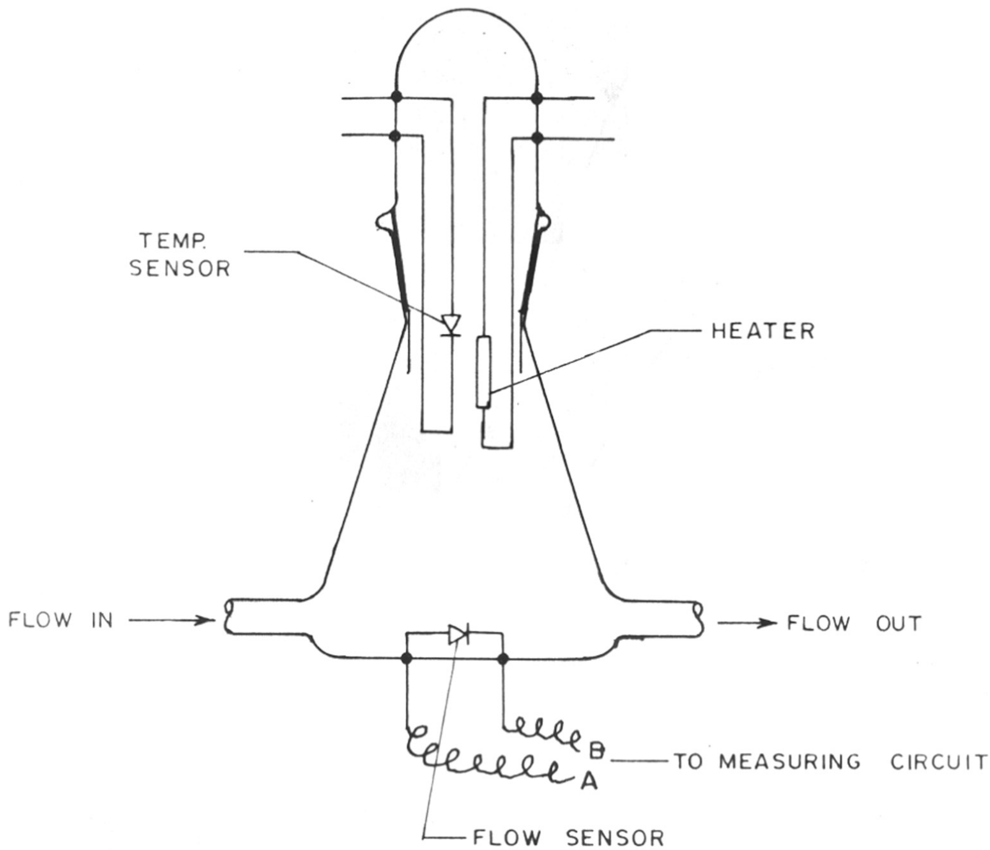


FIG. (12). GLASS APPARATUS FOR MEASURMENT OF FLOW RATE AT DIFFERENT DEVICE CURRENT

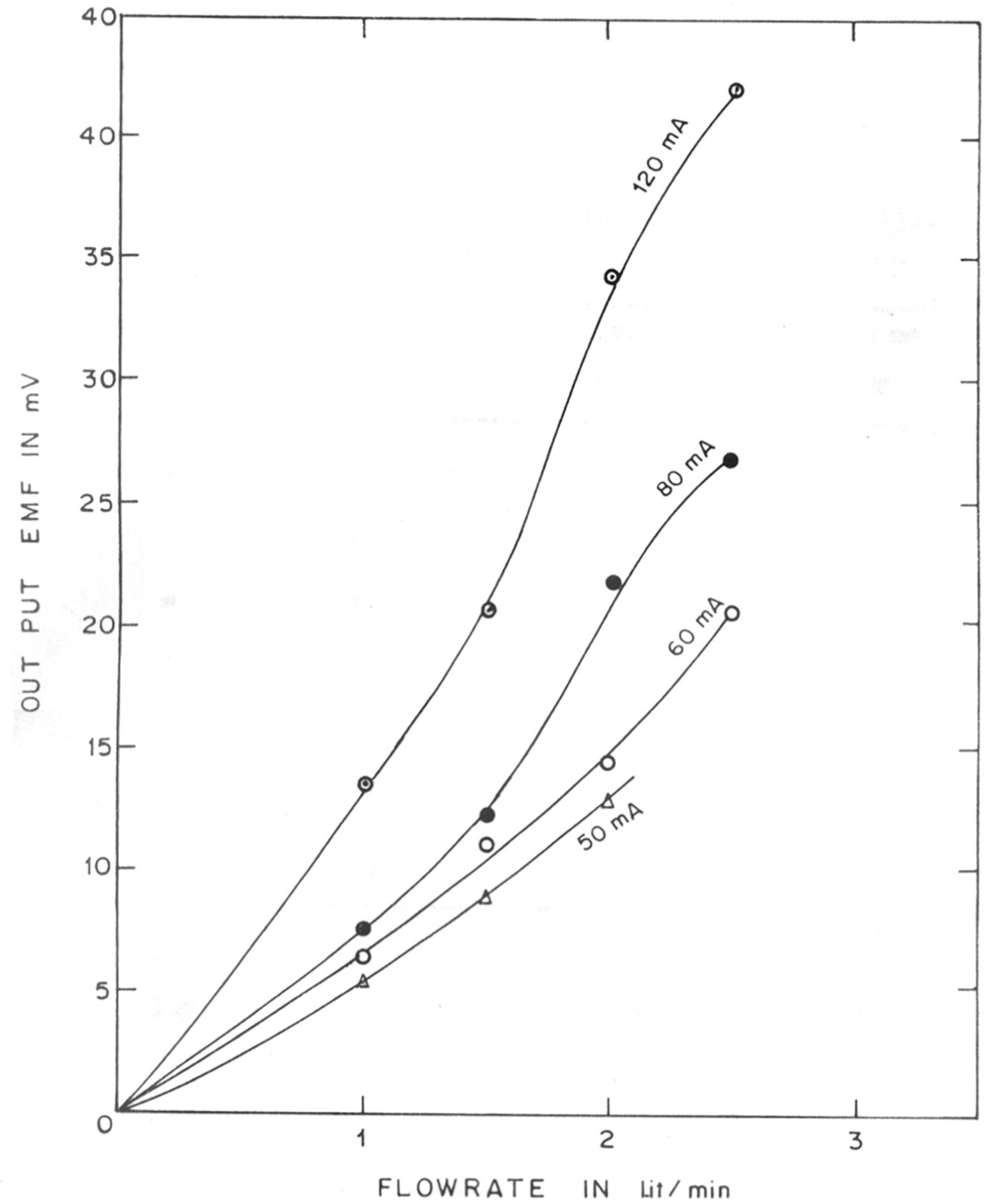


FIG. (13). OUT PUT EMF FOR DIFFERENT FLOW RATE

<u>Table - 4</u>

Flow rate in Lit/min. and corresponding output EMF in mV with different device current system (3).

Device current = 120 mA		Device current = 80 mA	
Flow rate	EMF	Flow rate	EMF
1	13.5	1	7.3
1.5	20.6	1.3	12.1
2	34.3	2	22.1
2.5	42	2.5	26.9

Device Current = 60 mA		Device Current = 50 mA	
Flow rate	EMF	Flow rate	EMF
1	6.3	1	5.6
1.5	9.6	1.5	9.3
2	14.9	2	13
2.5	20.4		

In this set-up the diode is heated by the current that is passing through it. Glass apparatus is as shown in Fig. (12). In this set-up, inside temperature is controlled with reference to ambient temperature by employing the same circuit as described in the earlier set-up. 150 ohm resistance is used as a heater. Its position with reference to sensor is adjusted in such a way that its on/off will not affect the temperature of the sensor.

Measurements were carried out for flow rate and emf for four different device current. These are shown in Fig. (13) and table (4).

CHAPTER IV : RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

Experimental results show that when diode is heated separately high output emf is obtained for a particular flow rate as compared to the other two systems. For 2.5 litre/min. flow rate, it gives 48 mV while in other two cases it is 18.2 mV and 42 mV respectively. This is because the temperature inside the system was not controlled. The inside temperature depends solely on the heater resistance and current. As cooling effect is measured with reference to flow rate of the fluid which is at the ambient temperature. The sensor can cool upto the fluid temperature or ambient temperature. The relation between flow rate and emf therefore becomes non-linear after a certain flow rate. The range over which output emf varies linearly with flow rate is from 0 to 10 litre/min. The emf corresponding to 10 litre/min. is 196 mV indicating that the fluid has cooled the sensor by about 96°C. Hence when flow rate is brought to 0 from 10 litre/min. sensor temperature should rise again to 96°C, so as to indicate the zero emf. Since heater power is not controlled, it will take a longer time to attain the thermal equilirbium. In short, the response of the sensor solely depends on the heater efficiency. In our first experiment it was very poor.

One of the important aspects in flow rate measurement with thermic method is the effect of ambient temperature variation on the flow rate measurement. For example, in the first experimental set-up heater power is fixed so that the system will attain thermal equilibrium at fixed temperature. Now if ambient temperature decreases cooling effect with fluid flow will be more. On the other hand, for the same flow rate if ambient temperature increases the cooling effect will be less. Hence for the same flow rate output emf will change with ambient temperature. Therefore, one must think of ambient variation correction.

One way to come out of this problem is to stabilize the incoming fluid at a constant temperature and then allow it to flow into measuring system. The same technique was employed in experiments that are carried out by S. A. Veprek[10] in their set-up. Fluid was allowed to pass in a long tube which is immersed into a thermostat to acquire a constant temperature. Then it is allowed to pass into measuring system. However, this way of ambient correction is possible in research laboratories. In industries this type of arrangement is not possible every time.

The other solution to the problem is to control the inside temperature with reference to ambient temperature or in other words maintain the difference between inside temperature and outside temperature at a constant level. In the case of diode as a sensor, the temperature against forward voltage drop characteristics is linear over a wide range of temperature as shown in Fig.(3). The emf change from 20°C to 70°C is therefore the same when the temperature variation is between 30°C to 80°C. Thus, if the temperature difference between ambient and inside the system is maintained constant, one can overcome the ambient variation difficulty. This is achieved in our second and third experimental set-ups.

In the second set-up, the differential temperature is set to 50°C. Measurements were carried out for the increase in fluid temperature when it passes over the heat source. As the flow sensor was kept away from the source, for any change in flow rate response to indicate change in emf depends on how fast sensor acquires the fluid temperature. Therefore, response observed was better than earlier system. Measurements were carried out for response where flow rate is raised from certain level to another level i.e. from 1.5 lit./min. to 2 lit/min. and time was recorded till it attain the stable emf which was measured in initial experiments. Also the time was recorded in a reverse cycle. The trend shows exponential increase or decrease in emf with time as shown in Figs. (14) and (15) and table 5.

In our first experimental set-up, current was kept very low of the order of 100 μA to avoid the self heating, so that it will not contribute to rise in temperature of the system, or in short system temperature is solely governed by the heater. In third system, cooling effect was observed but instead of continuous heater, the temperature controller was used. Working of the controller was same as that of controller in second system. But device current was kept high of the order of 50 mA to 120 mA. It is observed that as the device current increases, the sensitivity to flow increases i.e. for the same flow rate and same differential temperature, emfs obtained

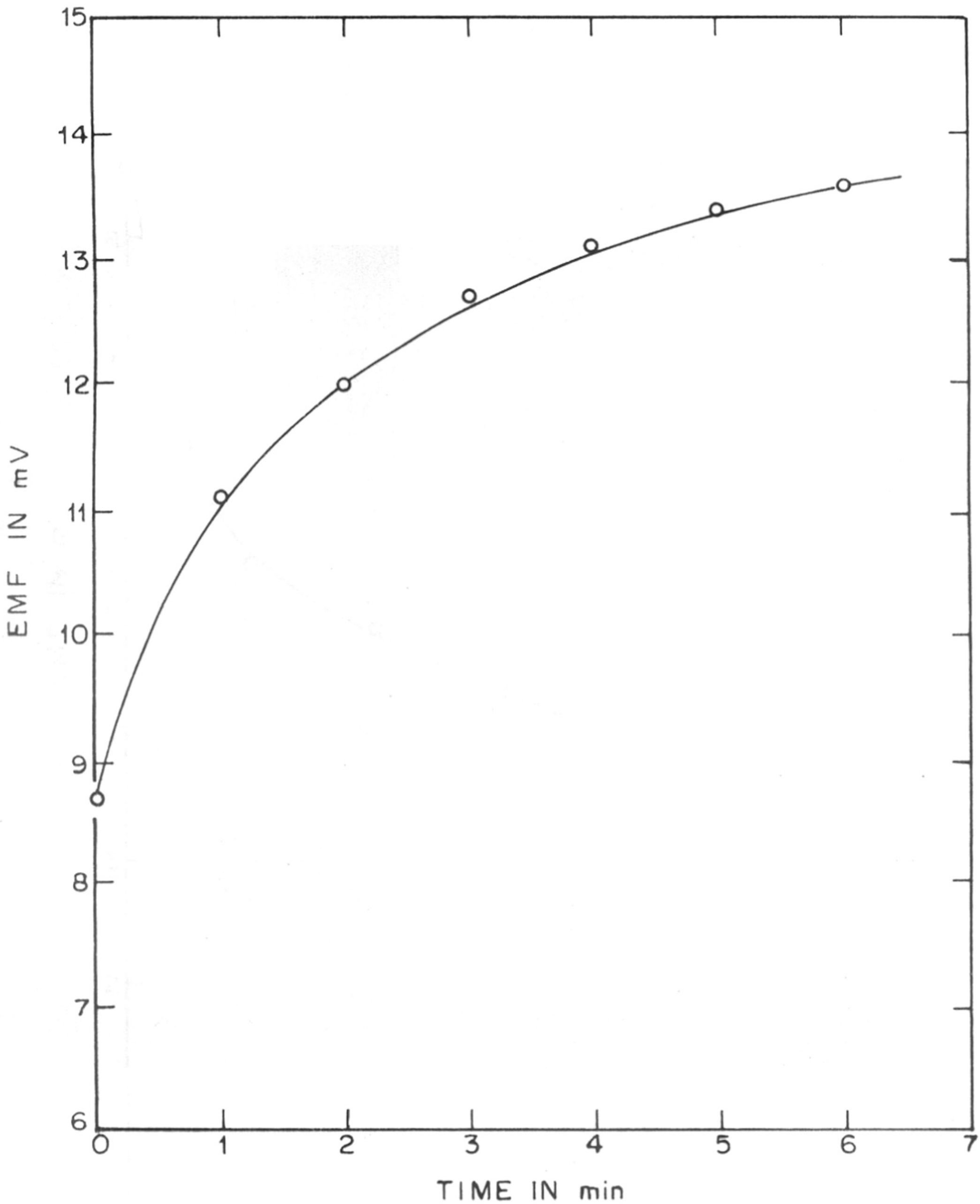


FIG. (14). RESPONCE TIME FOR VARIATION OF FLOW FROM 1·5 lit / min TO 2 lit / min

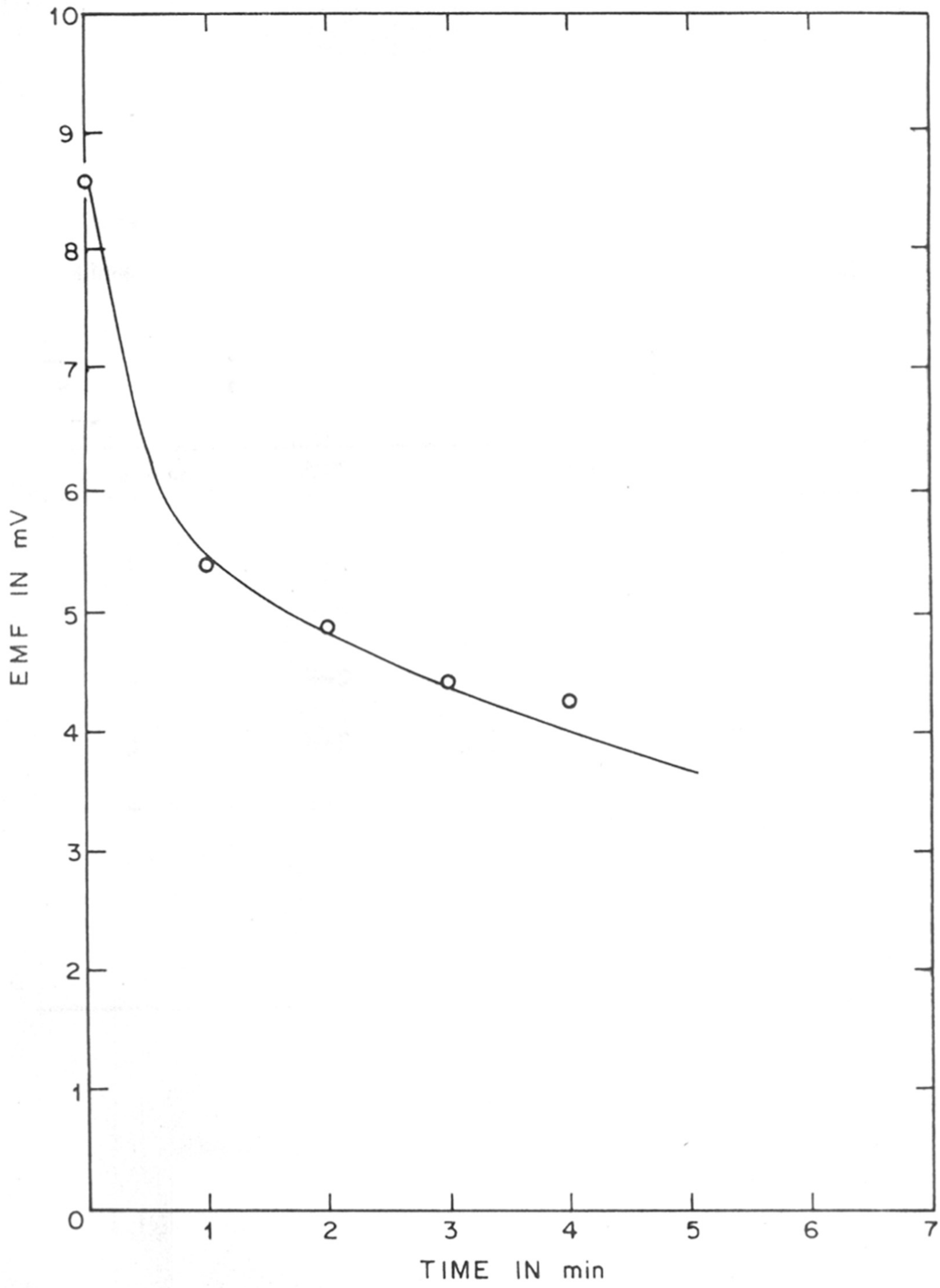


FIG. (15). RESPONSE TIME FOR VARIATION OF FLOW FROM 1·5 lit / min TO 0

Table - 5

Response time for increasing and decreasing flow rate from a pre-set flow rate.

Response time from 1.5 lit. to 2 cm.		Response time from 1.5 lit. to 2 lit/min.	
Time min.	EMF	Time min.	EMF
0	8.6	0	8.7
1	5.4	1	11.1
2	4.9	2	12.0
3	4.7	3	12.7
4	4.4	4	13.1
5	4.3	5	13.4
		6	13.6

are of higher value for increased device current and it is shown in Fig. (16). For 2 litre/min. with 120 mA device current emf is of the order of 34.3 mV. When current is 80 mA, it is 22.1 mV while it becomes 14.9 mV and 13 mV when current is 60 mA and 50 mA showing that sensitivity increases as the device current increases. This is given in Table 6 for 2 litre/min. flow rate. The same behaviour was observed in case of thermistor. In this, it is observed that when thermistor current is very low, it is more sensitive for temperature rather than for flow rate, but as temperature is raised it becomes more sensitive to flow rate change.

The response of the system was improved remarkably when device current was high. Response for variation from certain flow rate to another flow rate was in few seconds and response from certain flow rate to zero was about 30 seconds which is very good as compared to earlier system.

One of the essential requirements of flow sensor is that it should not put restriction to flow. The orifice plate or electromechanical flow sensors restrict the flow. But when thermic method is used diode can be pladed in such a way that it will not

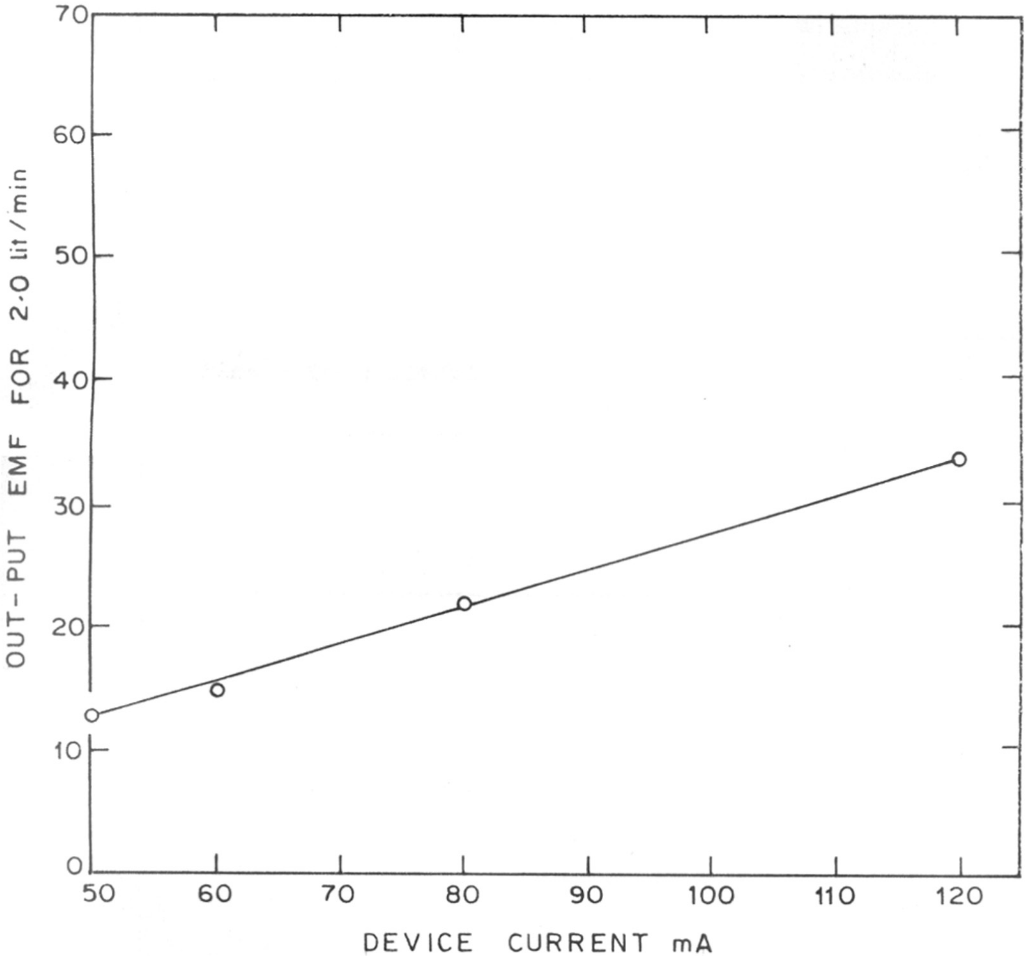


FIG. (16). OUT PUT EMF FOR THE SAME FLOWRATE OF 2·0 lit / min AT DIFFERENT DEVICE CURRENT

Table - 6

Output EMF in mV for the same flow rate of 2 lit/min. for different device current

Flow rate 2 lit/min.	2	2	2	2
Device current in mA	50	60	80	120
Output EMF	13	14.9	22.1	34.3

resist the flow. Secondly, in both pressure type devices and mechanical devices, electrical signal is not obtained which plays an important role in control and automation of chemical plant. In case of mechanical systems, wear and tear problems are serious. These problems can also be reduced by the thermic system.

Considering all these facts, diode with high current through it and suitable temperature controller can be used as a flow rate sensing device when it is cooled by the incoming fluid whose flow rate is to be measured.

REFERENCES

1. Noboru Ichinose, J.E.E. Oct. 1982, 81.

2. J. Watson, Electronic Engineering, May 1985

3. Paul Harrison, Chemical Engineering, Jan. 14, 1980, 77.

4. R.E. Whelan, J. Physics E. Scientific Instruments, Vol. 12, 1979, 553-556.

5. G.R. Jordan, Scientific Instruments, Vol. 18, Sept. 1985, 729.

6. R, F. Bensman, Journal of Scientific Instruments, Vol. 41, 1964, 100-1.

7. B.R. Clayton, Journal of Scientific Instruments, Vol. 40, 1963, 579-82.

8. J.H. Laub, Control Engineering, March 1957, 112.

9. R.A. Rasmussen, The Review of Scientific Instruments, Vol. 33, Jan. 1962, 38.

10. J.A. Vepřek, Journal of Scientific Instruments, Vol. 40, 1962, 66-68.

11. J. Janusz, Third European Hybrid Microelectronic Conference, Avignon, 1981.
    Microelectronics, Thermoconductive Flow-rate Sensors made on Thick-film Technology

12. N. Scalr and D.B. Pollock, Solid State Electronics, Vol. 15, 1972, 473-480.

13. A.G. McNamara, The Review of Scientific Instruments, Vol. 33, No.3, 1962, 330-333.

ACKNOWLEDGEMENTS

It gives me pleasure to record my deep sense of gratitude to Dr. A.P.B. Sinha, F.N.A., Scientist, National Chemical Laboratory, Pune - 411008, for suggesting me the research problem and for his inspiring guidance throughout its progress.

I owe a profound sense of gratitude to Dr. S.D. Sathye and Mr. M.V. Kuber for their invaluable suggestions and continuous help during the course of the work.

I am thankful to all members from S.I.L., colleagues and friends for their whole-hearted cooperation.

Finally, I am grateful to the Director, National Chemical Laboratory, Pune 411 008, for allowing me to submit this work in the form of a Thesis.

Date: August 1986 [P.D. Godbole]