DEVELOPMENT OF A THERMAL CONDUCTIVITY MEASURING APPARATUS FOR NON-METALLIC SOLIDS

BY

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A THESIS IN THE DEPARTMENT OF
MECHANICAL ENGINEERING

SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES
TOWARDS THE DEGREE OF M. ENG.
FEDERAL UNIVERSITY OF TECHNOLOGY AKURE

1996

ABSTRACT

A thermal conductivity measuring apparatus for non-metallic solids (poor conductors) based on modified Lee's disc method has been designed, constructed and tested.

Specimens of concrete, glass, portland cement, asbestosand corrugated cardboard were prepared in the form of discs each of diameter 50mm but of varying thicknesses.

The average thermal conductivity values obtained for these specimens over a heat source temperature range of 25°C - 60°C were found to be 1.285, 0.737, 0.327, 0.121 and 0.072 $Wm^{-1} K^{-1}$ respectively.

The values of thermal conductivity obtained for the various specimens were compared with those given in the literature for the purpose of determining the effectiveness of the apparatus. The differences in values ranged between 1.55 - 11.03 per cent thus giving credence to the effectiveness of the apparatus.

DEDICATION

This work is dedicated to my late Father, Pastor P.A. Anjorin and my Mother Mrs Abigail Anjorin.

CERTIFICATION

I certify that this work was carried out by Anjorin S. Ayodeji in the department of Mechanical Engineering, Federal University of Technology Akure and to the best of my knowledge has not been submitted elsewhere for the award of a degree.

Dr. C.O. Adegoke
Supervisor

ACKNOWLEDGMENTS

I acknowledge the supervision of the research work by Dr. C.O. Adegoke whose guidance and counsels have motivated me throughout the period of the research.

Acknowledgements will not be complete without thanking my Head of Department Dr. A.A. Aderoba for inspiring the spirit of brotherliness among the members of his department. It was this spirit in members that helped me during a trying period within which the research work was on.

NOMENCLATURE

A	Cross sectional area (m^2), Ammeter
C	Heat capacity (J/K)
D	Density (Kg/m^3)
E	Output voltage of a thermocouple (Volts)
I	Current (Amperes)
K	plug key, Kelvin
L	length of potentiometer wire (m)
M	Specimen
P	Power (watts)
Q	Heat flow rate (Watt)
R	Series resistance (Ω) Rheostat
S	Thermocouple sensitivity ($\mu V\ ^{\circ}C^{-1}$), source of power supply
T	Thermocouple
V	Voltage (Volts), voltmeter
X	Direction of heat flow
d	diameter of specimen (mm)
e	Thermally induced emf (mv)
h_o	Outside heat transfer coefficient W/m^2K
k	Thermal conductivity ($Wm^{-1}K^{-1}$
l	length of a balance point (Cm)
r	Resistance of potentiometer wire (Ω)
t	Temperature (°C, Kelvin)
x	Thickness (mm)
α	Thermal diffusivity ($m^2Kg^{-1}S^{-1}$)
ρ	Resistance per unit length (Ω/m)
τ	Time (seconds)

Ω	Ohms

Subscripts

1	Position of drilled hole in the first brass disc
2	Position of drilled hole in the second brass disc
3	Position of drilled hole in the third brass disc
4	Position of drilled hole in the fourth brass disc
a	Asbestos sheet
b	Brass
c	Concrete
cc	corrugated cardboard
g	glass
gw	glass wool
h	heat source
max	maximum
p	portland cement
pw	plywood

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CHAPTER ONE

1.0 INTRODUCTION

1.1 MEANING OF THERMAL CONDUCTIVITY

Heat conduction, as a mode of heat transfer, is the flow of thermal energy through a substance from a higher to a lower temperature region. It occurs by atomic or molecular interactions.

Steady state conduction is said to exist when the temperature at all locations in a substance is constant with time as in the case of heat flow through a uniform wall. Simple or complex combinations of transient and periodic heat conduction can also exist as in the case of pouring and curing of large concrete structures.

Consider a steady heat flow from a surface (fig 1.1) at temperature t_1 to a parallel surface at t_2. This heat flow is directly proportional to the difference between t_1 and t_2 $(t_1 - t_2)$, the area A normal to the direction of flow, and the time of flow τ and inversely proportional to the distance, l, between the two planes. These factors are modified by a co-efficient k accounting for the heat conducting nature of the particular distance between the two planes.

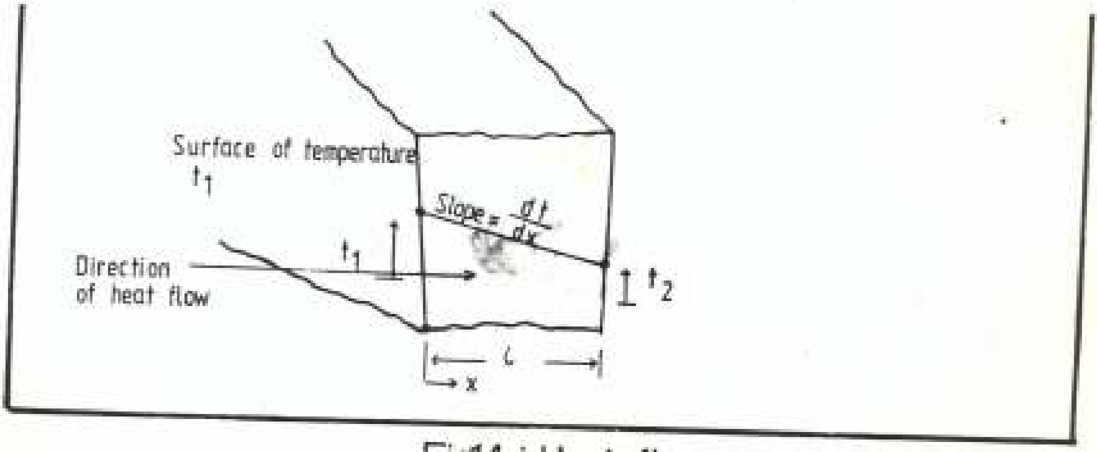


Fig1.1 : Heat flow by conduction

From Fig. 1.1 the heat flow rate $\dot{Q}$ (in Watts) across two surfaces at temperatures t_1 and t_2 separated by a distance l is given by

$$\frac{Q}{\tau} = \dot{Q} = kA\,\frac{(t_1 - t_2)}{l}\ldots\ldots\ldots\ldots\ldots\ldots(1.1)$$

Thus the heat flow rate Q through an infinitesimally thin layer dt is given by;

$$\dot{Q} = -kA\,\frac{dt}{dx}\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1.2)$$

This equation was first derived by J. Biot but it is often referred to as Fourier's equation in honour of J. Fouriers who did an excellent work in the field of heat conduction.

The minus sign is conveniently included to make $\dot{Q}$ positive when heat flows in the increasing direction of x since

$\frac{dt}{dx}$ is then negative

from equation (1.2)

$$k = \frac{-\dot{Q}/A}{dt/dx} = \frac{-\dot{Q}/A}{(t_2 - t_1)/l}\ldots\ldots\ldots\ldots(1.3)$$

The coefficient k is called thermal conductivity. It is an important property of matter and accounts for the heat conducting ability of a substance. It is defined as the rate of heat transfer through the material per unit area per unit temperature gradient across the faces of the material.

Thermal conductivity is a transport property since it is indicative of the energy transport in a fluid or solid. In gases and liquids the transport of energy takes place by molecular motion, while in solids transport of energy is mainly by free electrons and lattice vibration.

1.2 OBJECTIVE AND SCOPE OF THIS STUDY

Various thermal conductivity measuring devices for solids, liquids and gases have been developed in this century. Research efforts are geared toward determining thermal conductivities for materials whose thermal conductivities have not been previously determined with the ultimate goal of determining their suitability in the construction of thermal systems.

The fact that the design and construction of thermal conductivity measuring devices differ in design and construction for solids, liquids and gases makes it unjustifiable to generalise thermal conductivity measurements. Even the methods of determining thermal conductivities of non-metallic solids differ from the ones for metallic solids, Folayan and Marona (1988) reported that there are many methods that have been used to determine thermal conductivities of many materials depending on the state (solid, liquids, gas)

This project is aimed at designing, constructing and testing a thermal conductivity measuring apparatus for non-metallic solids. Results obtained from experiments will be compared with existing values of thermal conductivity in the literature to determine the reliability of the apparatus.

1.3 JUSTIFICATION FOR THE STUDY

The knowledge of thermal conductivity of building materials is required by the Building Services Engineer for the purpose of analysing heating and cooling loads in refrigerating and air conditioning plants. The Mechanical Engineer deals with problems of heat transfer in the field of internal combustion engines, steam generation and ventilation. In fact engineers in every field should be versed in the knowledge of heat transfer: Electrical Engineers apply their knowledge of heat transfer for the design of cooling systems for motors, generators and transformers; Chemical Engineers are concerned with the evaporation, condensation and cooling of fluids; the Civil Engineer employs the laws of heat flow in the construction of dams and structures.

The high cost of building materials presently being used calls for research into the properties of local materials which hitherto have not been utilized as building materials but which are cheap. A knowledge of their properties, of which thermal conductivity is one, will help to determine their suitability as building materials

CHAPTER TWO

2.0 LITERATURE SURVEY

Values of Thermal Conductivity for a variety of substances and materials are already available in tabular forms in various Thermodynamics textbooks: Subramayan and Kothandaraman (1992), Eckert (1972), Frank and Mark (1986), Isachenko and Osipova (1977)

Thermal conductivity measurements involve a determination of heat flow and temperature. In this chapter several types of temperature and thermal conductivity measuring devices are reviewed.

2.1 Review of Temperature Measuring Devices

Temperature can be defined in terms of observable characteristics of materials. Such characteristics include pressure, volume, electrical resistance, expansion co-efficient, etc.

According to Summer (1996) precision instruments for temperature measurements have been described in a National Engineering Laboratory publication by Hunter (1962). He reported that seger cones or pyramids consisting of various clay and salt mixtures have been used as temperature indicators. Each cone softens at a definite temperature, ranging from 500 to 2,000°C. When the particular temperature is reached the apex of the small cone or pyramid softens and bends over. These cones find application in the ceramics industry.

According to Summer (1966) there are a number of materials which produce a definite colour change at a specified temperature. Some of these materials revert to the original colour on cooling.

Heat sensitive paints or crayons usually consist of double iodides of mercury with other metals. The double iodide of copper and mercury is of a scarlet colour at room temperature but at 87°C it turns almost black. Cowling (1953) reported that the Silver - mercury indicator is prepared by shaking a solution of 11.25g of silver nitrate dissolved in 50 - 100 cm^3 water and pouring it into a solution of 15g mercury iodide and 11g potassium iodide dissolved in a small quantity of water and diluted to make $100cm^3$. A thick precipitate is formed. Water is added and decanted three times. The remaining water is then filtered off. The yellow precipitate is dried in air and mixed with a thin transparent lacquer to form a rather fluid paste.

Crayons and powders have also been used to indicate temperature. A mark is made with a crayon on the heated object at the point where the temperature is to be measured. If the colour change occurs within 1 - 2 seconds, the temperature range of the crayon indicates the temperature of the surface. Powders cover a similar range of temperatures as crayons when they are mixed with alcohol, and brushed or sprayed on the surface of the hot object they serve as means of indicating temperatures. A phosphorescent screen sensitive to infrared (heat) rays is excited by long wave (0.003 - 0.631μm) ultra-violet rays. Then the image of the hot surface is projected on to the screen, and the long after glow of the screen is extinguished in proportion to the incident heat radiation.

Summer (1966) further reported that a relationship between hardness and temperature has been discovered at the shell Thornton Research Centre. The hardness of certain martensitic structures changes reproducibly with temperature. The change is permanent. At a given temperature the magnitude of the change in hardness is proportional to the length of exposure and with the time known to the observer, the hardness and hence the temperature to which the test piece has been exposed can be found.

Low temperature measurements have been carried out using liquid thermometers, gas thermometers, carbon resistance thermometers and vapour pressure thermometers. Carbon resistors made excellent thermometers. The heat developed in the resistors must be less than 10^{-5}W to avoid errors of measurement. This blank carbon resistor usually cemented with some Araldite into a copper tube, Clement and Quinnel (1952) and Hoare (1955) submitted that carbon absorbs helium and this would alter the characteristics of the resistor if carbon should make contact with the liquid or gaseous helium.

Vapour pressure thermometers enable very accurate readings to be taken. The thermometer vessel is connected to a mercury manometer the other limb of which may remain open to the atmosphere, or may be evacuated. A well constructed and maintained hollow key stopcock with obliques bore is used to avoid air leakage into the evacuated limb whose volume is quite small since air leakage into the limb would cause the temperature reading to be erroneous. Henning (1926) gave a list of suitable gases, which must be of the highest purity for use in vapour pressure thermometer.

According to Summer (1966) resistance thermometers for the range -182.970°C to +660.100°C have been developed in the National physical laboratory. Also thermometers for the range - 812.970°C to -253.000°C, have been developed. For coarse measurements nickel thermometers of various shapes can be constructed. The wire is usually wound on serrated mica discs.

Thermistors, owing to their resistance - temperature relationship, have been used for temperature measurements, in conjunction with a calibration chart. Thermistors are non linear temperature sensitive resistors, the resistance of which falls with increasing temperature. Resistors are of three groups;

i) Voltage dependent non linear resistors

ii) Light dependent non linear resistors.

iii) A negative temperature coefficient non linear resistors.

Summer (1966) reported that a calorimetric method for the measurement of very high temperatures has been developed at the Department of Aeronautical Engineering, Princeton University. Temperature up to 5,000°C have been measured. He also reported that R.M Baker, of the Westinghouse Defence Centre, has developed a calorimeter with a response time of about 0.1 milliseconds. The sensitive elements consist of a tangle mass of fine enamelled copper wire which is loosely packed into a small, internally silvered, glass or quartz beaker of about 50ml capacity. The reaction of the sensor is independent of the temperature distribution within the tangles of copper wire.

There are three types of radiation pyrometers for measuring very high temperatures: Total radiating pyrometer, disappearing filament type of optical pyrometer and polarizing type of optical pyrometer. The total reduction pyrometer can be used for the direct measurement of temperature up to 1400°C. The disappearing filament type optical pyrometers is an optical pyrometer in which the image of the distant source as a furnace is focused on to the filament of a glowing lamp by a telescopic objective lens. In the polarizing type of optical pyrometer mono-chromatic light from a hot source and that from a comparison lamp are polarized and their intensities are compared.

2.2 REVIEW OF TEMPERATURE MEASUREMENT USING THERMOCOUPLE

Thermocouples are employed in the measurement of absolute temperature, or of temperature differences. When two dissimilar metals are joined together (Fig 2.1) an electromotive force (emf) will exist between the two points a and b. This emf is primarily a function of the junction temperature. This phenomenon is called the seebeck effect. If the two materials are connected to an external circuit such that current is drawn, the emf may be altered slightly owing to a phenomenon called the peltier effect. There is also the Thompson effect which occurs as a result of a temperature gradient existing along either or both of the materials. This effect can simply be refereed to as additional alteration of the junction emf. Thus there are three emfs present in a thermoelectric circuit. The seebeck emf, the peltier emf and the Thompson emf.

The seebeck emf is of chief importance in the measurement of temperature since it is dependent on junction temperature. If the emf generated at the junction of two dissimilar metals is carefully measured as a function of temperature, then such a junction may be utilized for the measurement of temperature.

All thermocouple circuits must involve at least two junctions. If the temperatures of one junction is known, then the temperatures of the other junction may be easily calculated with the thermoelectric properties of the materials. The known temperature is called the reference temperature. Holman (1971) gave a common arrangement for establishing the reference temperature. The arrangement is the ice bath shown in Fig 2.2. An equilibrium mixture of ice and air-saturated distilled water at standard atmospheric pressure sets the reference junction temperature at 0°C. When the mixture is contained in a Dewar flask, the 0°C temperature can be maintained for extended period of time.

It is common to express the thermo electric emf in terms of the potential generated with a reference junction at 0°C. Standard thermocouple tables have been prepared on this basis, and a summary of the output characteristics of the most common thermocouple combinations is given by Summer (1966).

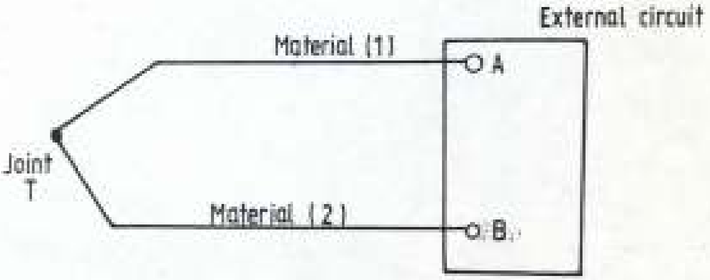


Fig 2·1: Junction of two dissimilar metals indicating thermo electric effect.

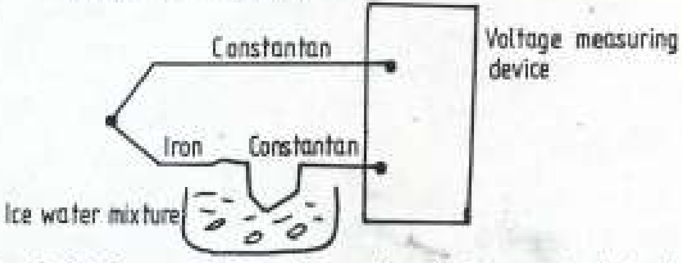


Fig 2·2: Conventional method for establishing reference temperature in iron constantan thermocouple circuit.

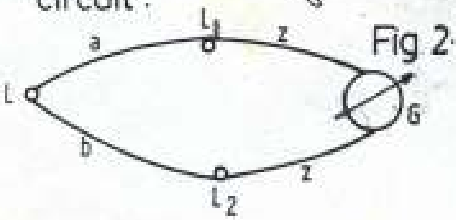
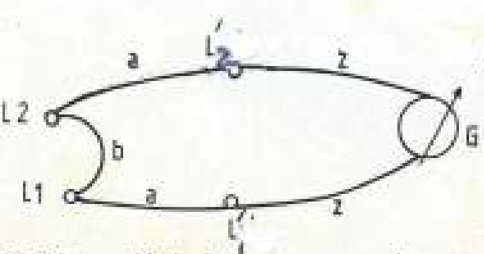


Fig 2·3: Thermocouple for temperature measurement.



LEGEND

G = Galvanometer

a,b = Thermoelectric wire

Z = copper wire

L_1', L_2' = Secondary cold junction.

L_1, L_2 = Hot junction.

Fig 2·4: Differential thermocouple

According to Holman (1971) the output voltage E of a simple thermocouple circuit is usually written in the form:

$$E = At + \frac{1}{2}Bt^2 + \frac{1}{3}Ct^3 \ \ldots\ldots\ldots\ldots \ (2.1)$$

and the sensitivity or thermoelectric power of a thermocouple is given by

$$S = \frac{dE}{dt} = A + Bt = Ct^2 \ \ldots\ldots\ldots\ldots \ (2.2)$$

where t is the temperature in °C and E based on a reference junction temperature 0°C. A B and C are constants dependent on the thermocouple material. Lion (1959) gave a table showing the approximate values of the sensitivity of various materials relative to platinum at 0°C.

Summer (1966) gave a similar equation to that of Holman (1971), for determining the thermal emf E_{th}

$$E_{th} = at + bt^2 \ \ldots\ldots\ldots \ (2.3)$$

where E_{th} is in millivolts, t = temperature of the hot junction in °C with the cold junction at 0°C, a, b constants. Values of a and b are given by Bensal (1962) as 36 ± 1 and 0.043 respectively for a Copper/Advance thermocouple (range 0°C to 100°C). Advance is a Cu - Ni alloy.

Summer (1966) discussed thermocouple for measuring temperatures: Two thermoelectric wires, a and b, are connected at one point L called the main junction (Fig 2.3). This junction is the temperature sensor. The free ends of the thermocouple wires are connected by copper wires z, z with a galvanometer G which is usually calibrated directly in temperature degrees. The secondary junction L_1' and L_2' are kept at identical temperatures usually 0°C to eliminate thermal currents in the wires z, z. The system behaved exactly as if L'_1 and L'_2 were joined directly together and formed a single secondary junction. A water-ice reference chamber was used to maintain the cold (reference) junction of the thermocouple at 0°C with considerable accuracy. The chamber consists of six tubes of stainless steel mounted with their ends in a large copper cylinder filled with water. Thermoelectric cooling keeps the chambers at 0°C so that ice begins to form at the walls. This causes an increase in volume which is taken up by some bellows. These operate a microswitch and cut off the current to the semiconductor once a preset temperature, i.e. a preset expansion of the bellows, is reached. The 0°C level is maintained within +0.01°C.

Differential Thermocouple, according to Summer (1966), are also available for measuring temperature differences (Fig 2.4). Two identical metal wires a, a are connected to another metal wire b so as to form two main junctions L_1 and L_2 which are exposed to temperatures t_1 and t_2 where $\Delta t = t_1 - t_2$ = temperature difference. As before L'_1 and L'_2 are the secondary junctions connected via copper wires z, z to the Galvanometer G. The temperatures of L_1 and L_2 are of no importance as long as they are identical.

Thermocouple junctions are formed by soldering or brazing the two thermoelectric wires together at one point. Kiernan (1955) discussed a special process for making junctions between thin wires, about 0.1 mm thick, to give a junction hardly any thicker than the wires. Silver solder is employed for fusing the wires at 620°C. The wires are cleaned with fine emery paper and held in two clamps so that about 5mm of wire projects from each clamp, with the projecting ends of the wires in contact. The projecting parts of the wires are wetted with an appropriate liquid flux and fine shavings of silver solder placed on a watch glass are also covered with flux. A small gas flame without compressed air is used. The jet of the burner is formed by a small glass tube with a capillary at one end. The gas is made to pass through glass wadding to filter off any impurities which might otherwise obstruct the capillary.

A drop of the flux containing the silver shavings is now put on the junction of the two wires, and the water in the flux begins to evaporate in the heat of the flame. Eventually, flux and solder start to flow. The whole process lasts only a few seconds, and during this time the flame is not allowed to touch the wires. When cold, the glassy bend of flux is shattered by a gentle blow with small harmer. The strength of the joint produced exceeds that of the metals used.

Thermocouple using constantan as one member for the couple have high sensitivity. Fig 2.5 shows a graph of thermoelectric power commonly used base-metal combinations against temperature.

Giauque and Buffington (1927) and Wiebe and Brevcort (1931) reported that for the measurement of low temperatures constantan/copper couples give an accuracy of ±0.05°C down to -258.00°C. Summer (1966) stated that for the measurement of the temperature of liquid hydrogen (-252.5°C) a silver/gold thermocouple is used. Liquid helium (-268.8°C) requires a 99 percent Au - 1 per cent Co against 99 percent Ag - 1 percent Au thermocouple. Pearson (1954) gave arrangements for measurements below 30°K.

The temperature of the secondary junction of a thermocouple is of considerable importance. Any temperature variations to which the secondary junction is exposed during normal operations, will cause erroneous readings. To prevent secondary thermoelectric currents which cause error the use of two compensating wires is accepted in practice, for example one of copper, the other of a copper - nickel alloy (1 - 5 per cent Ni). These wires are selected so that when at the same temperature as the secondary junction they will have the same electrothermal power as the limbs of thermocouple. The sum total of the emfs is therefore nil, and variations in ambient temperature no longer cause error.

While Summer (1966) stated that a Galvanometer calibrated directly in temperature degrees connected to the free ends of the thermocouple wires can measure temperature of a junction directly Holman (1971) said that for all precision measurement the output of a thermocouple is determined by a potentiometer circuit.

Thermocouple wires are prone to corrosion attacks because the different metals or alloys are in extremely close contact with one another. White (1933) discussed difficulties with contaminated thermocouple wires. It is generally desirable to operate a thermocouple in oxidizing conditions.

According to Austin (1911) and Cartwright (1931) there are special Thermocouple for measuring weak alternating current and radiation measurements.

2.3 REVIEW OF THERMAL CONDUCTIVITY MEASUREMENTS FOR SOLIDS

Among the earliest Scientists that devised an apparatus for the measurement of thermal conductivity is Searle who built an

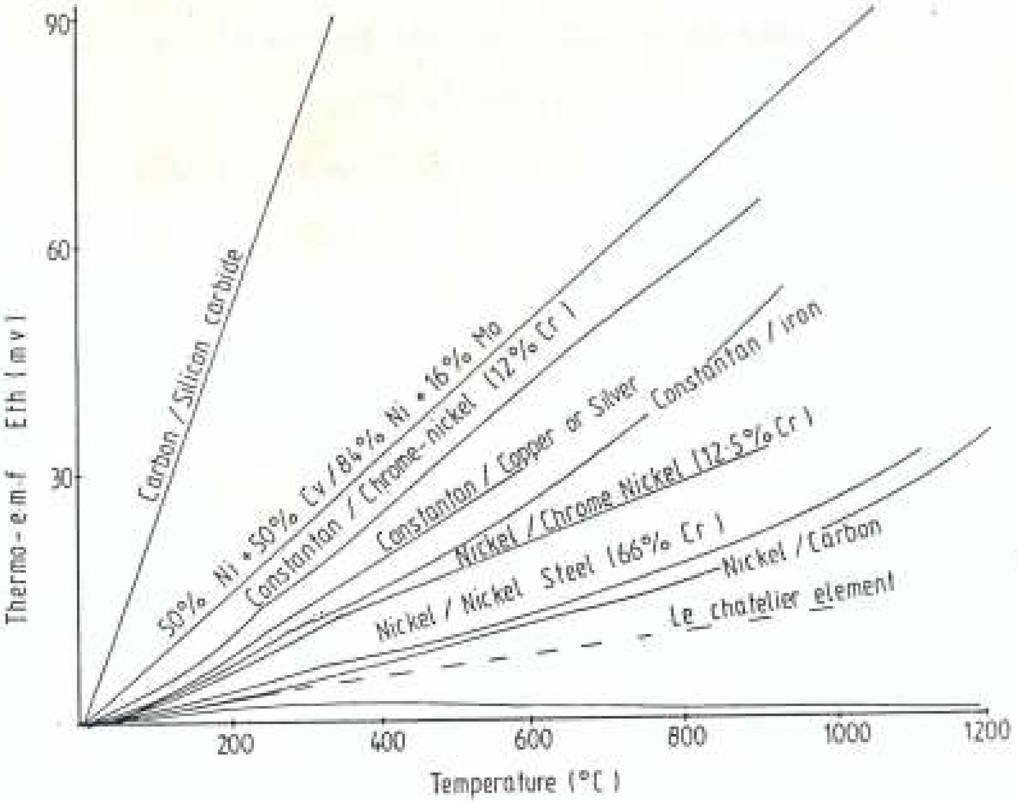
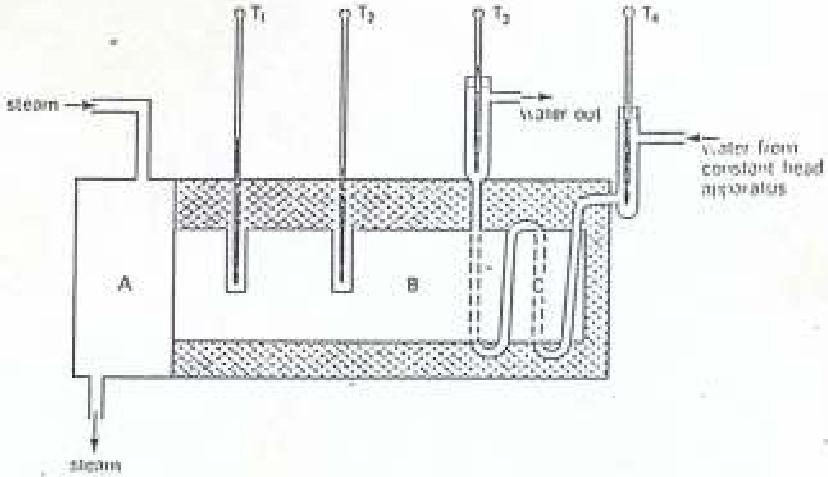


Fig2.5: Thermoelectric power of base-metal combinations [From summer (1966)]

apparatus to determine the thermal conductivity of metals. Tyler (1980) reported that the apparatus in its original form consists of a steam chest and an insulated cylindrical bar along which heat is conducted. Two thermometers were placed distance apart in different holes drilled on the bar. This was to enable the determination of the temperature along the bar. A metal spiral through which a steady flow of water is maintained by a constant head apparatus is wound round one end of the bar. Two other thermometers were used to measure the temperature of water entering and leaving this spiral. Searle's apparatus as described by Avery and Ingram (1976) is shown in Fig. 2.6.



LEGEND

A	Steam chest
B	Cylindrical bar
C	Metal spiral
T_1, T_2, T_3, T_4,	Thermometers

Fig. 2.6: Searl's Apparatus for determining Thermal Conductivity of a Metal

Avery and Ingram (1976) discussed an apparatus for the determination of the thermal conductivity of Rubber in the form of a tube. The apparatus consisted of about 0.8m of bunsen burner tubing; steam supply fitted with safety tube; calorimeter of large capacity, stirrer 200mm of glass rod; T-tube to take the rubber tubing; two spring clips; thermometer (0-50°C x 0.2); stop watch asbestos screen vernier microscope. In using this apparatus to determine the thermal conductivity of rubber the heat capacity of the calorimeter was found. The rubber tubing with a single coil in it was introduced into the calorimeter filled with water. The tubing was secured by tieing it to a glass rod which was supported vertically by means of a clamp and stand, one end of the tubing was connected over a sink to collect the water that condensed. Avery (1971) noted a source of error: condensation due to the fact that in the experiment steam is passed into a cold tube. This source of error they suggested, can be overcome by drilling a hole of the diameter of the rubber tubing in the bottom of the calorimeter, which is thereafter reserved for the experiment. Arrangement of the apparatus is to remain the same as before but a coil of rubber tubing led out of the calorimeter through a water tight joint is to be used.

They further suggested that steam be passed through the tube until it is issuing freely at the open end, which should be at least 30cm to one side of the calorimeter so that the emerging steam does not cause heating effects in the calorimeter or its content. Observation of the temperature rise of the water is to be made over a measured time interval.

An apparatus for the determination of the thermal conductivity of glass in the tube form was described by Tyler (1980). The apparatus consisted of a length of glass tubing about 50cm long and of 1cm internal diameter surrounded by a jacket through which steam is passed from a steam heater. A slow stream of cold water from a constant head device is passed along the tube which is tilted slightly to eliminate air pockets. Two glass pieces are attached at the ends of the tube to carry 1/10°C mercury in glass thermometers. A beaker to collect the outflow water, a stop clock and a travelling microscope were also provided. Having described an apparatus for the determination of the thermal conductivity of glass in form of a tube Tyler (1980) went ahead to state the procedure for the determination of the thermal conductivity of glass using the described apparatus.

Tyler (1980) and Avery and Ingram (1976) gave various descriptions of apparatus for measuring the thermal conductivity of solids which are non conductors based on Lee's disc method. Tyler described an apparatus in which steam was the source of heat. The specimen whose thermal conductivity is required is sandwiched between two copper discs. The whole arrangement was suspended by strings from a heavy stand. Avery discussed two different experiments based on Lees' disc method: the one involving the use of an electrical heating element as a source of heat the other involving steam, generated by a steam heater, as a source of heat. Avery's apparatus involving the use of electrical heating element consists of the specimen sandwiched between one metal disc and one of the discs aforementioned. In this method the rate of heat emission from the surfaces was taken into consideration in the course of calculating the thermal conductivity of the specimen.

The Lees's disc method is generally used to determine the thermal conductivity of poor conductors like rubber, glass, ebonite wood cork and other similar materials.

In the Lees' disc method, using steam as a source of heat, described by Avery and Ingram (1976) and Tyler (1980) there was no special provision for bringing the metal discs and the specimen into good contact; besides, there was no stand upon which the apparatus could be rested except that it is hung by means of three springs. A separate steam chamber was provided. Again, no enclosure and means of insulation were provided for the apparatus.

Folayan and Marona (1988) built an apparatus based on Fitch apparatus which they modified. In this apparatus water was heated by a thermostat heater in a vessel. Heat was passed through the vessel to an aluminum plug (the sink) via the specimen. A means for bringing the specimen, the heat source and the heat sink into good thermal contact was provided by an adjusting screw and a spring. An enclosure was provided for the apparatus and the insulation was of micro air. In the result obtained using modified Fitch apparatus Folayan and Marona (1988) observed that the value of thermal conductivity for Palm kernel and shell might have been over estimated by up to 4%, however they concluded that the experimental values for palm kernel and shell compares favourably with those obtained from literature. The thermal conductivity obtains by Folayan and Marona (1988) for the kernel and shell increase with temperature in linear fashion. They used the apparatus to obtain a value of 0.163 w/m°C for the thermal conductivity of asbestos at 65°C. The Nusselt spherical method, which is purely an electrical method was used by them for the determination of the thermal conductivity of fibre of varying density.

Experimental methods suitable for determination of the thermal conductivity of moisture free materials was reported by Folayan and Marona (1988). These methods include the calorimetric method by Dickson, the National Bureau of Standards cut bar method, Black and glaecer spherical apparatus, the guarded hot plate method and the heat meter method. According to Folayan, Jacobs spherical method has been used for measuring Thermal conductivity of fibres. Folayan and Marona's adapted apparatus based on Nusselts' spherical method reduces radial heat losses and the thermal conductivity values can be determined for various densities and temperature ranges. However, they found difficulty in filling the hollow sphere homogeneously and conjectured that the sagging or differential expansion between the sphere and material after it had been subjected to temperature change may lead to errors.

Kokos and Gschneidner (1989) used the flash diffusivity technique to determine the thermal conductivity of certain ternary rare earth sulphides. The thermal conductivities were calculated from the measured thermal diffusivity data, published heat capacity data and measured density data from x - ray diffraction patterns. Lattice and electric contribution together with grain sizes were found to affect thermal conductivity of each sample of the earth sulphide. They established the relationship

$$k = \alpha CD \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.4)$$

where K = thermal conductivity

α = thermal diffusivity

D = Density of the material

C = Heat capacity

Samples were found to show a slight increase in thermal conductivity with increasing temperature. Calculated values of thermal conductivity were compared with existing values in literature and the highest error associated with these comparisons was 10 per cent but in most cases it was less than 7 per cent.

Lambropoulas (1989) used a direct reading thermal comparator to measure the thermal conductivity of dielectric thin film coatings. Analytical heat flow model was applied. The thermal conductivity of most thin films was found to be several order of magnitude lower than that of the material in bulk form. The difference is attributed to structural disorder of materials deposited in thin film coatings. He said Decker reported the measurement of thermal conductivity for thin films of SiO_2 and Al_2O_3. Values were found to be one or two orders of magnitude lower than those for the corresponding bulk materials. The authors attributed this difference to the unique microstructure of dielectric thin films which along with defects and impurities would be expected to reduce the phonon mean free path, and thus the thermal conductivity.

The thermal comparator technique for measuring thermal conductivity of bulk solids has been extensively described by Powell (1957). Choy and Leung (1989) measured the thermal diffusivity α of three metallic glasses: $Fe_{80}B_{20}$, $Fe_{40}Ni_{40}P_{14}B_6$ and $Fe_{32}Ni_{36}Cr_{14}P_{12}B_6$ using Laser flash radiometry method.

The thermal conductivities have been calculated using the equation (2.4). With the use of this relationship both thermal conductivity and diffusivity were found to increase with increasing temperature over the entire temperature range of 160 to 500 K.

According to Holman (1971) van Dusen and Shelton used the method of connecting a metal rod of known thermal conductivity to a rod of another metal whose thermal conductivity is to be measured. A heat source and heat sink were connected to the ends of the composite rod, and the assembly is surrounded by insulating material to minimise heat loss to the surrounding and to ensure one dimensional heat flow through the rod. Thermocouples were embedded in both the metal rod of known thermal conductivity and the one whose thermal conductivity is to be measured. A measurement of the temperature gradient through the known material facilitated the determination of the heat flow. This heat flow was used to calculate the thermal conductivity of the unknown material. This method was used to determine thermal conductivity of metals up to 600°C.

David (1986) reported that values of thermal conductivity of Adobe (a building material) varied widely. The thermal conductivity of such solids is strongly related to density and modulated by the presence of moisture and both are related to the composition. He reported Rogers (1978 a) to have quoted a value of 0.996 W/m°C for Adobe with a density of 1442 kg/m^3 but made no mention of moisture content. He further reported Rogers (1978 b) to have shown data for the variation of the conductivity from about 0.4 W/m°C at 2% moisture content to about 1.5 W/m°C at about 11% moisture content.

David (1986) noticed an initial decrease and subsequent increase and decrease in conductivity of Adobe towards the end of his experiment and attributed this to changes in the internal moisture content of the Adobe.

CHAPTER THREE

3.0 DEVELOPMENT OF THE THERMAL CONDUCTIVITY MEASURING APPARATUS

3.1 THE APPARATUS

3.1.1 DESIGN SPECIFICATIONS

Dimensions of wooden cylindrical enclosure for brass discs - specimens assembly:

Outside diameter = 109 mm
Inside diameter = 89 mm
Height = 203 mm

3.1.2 INSULATION:

The insulation was 20mm thick. The insulating material was glasswool whose thermal conductivity from Subramayan (1992) is 0.037 W/mK. It is reasonable to assume effective insulation since the value of thermal conductivity is low.

3.1.3 ELECTRICAL ANALOGUE

Heat flow within the apparatus in the radial direction:

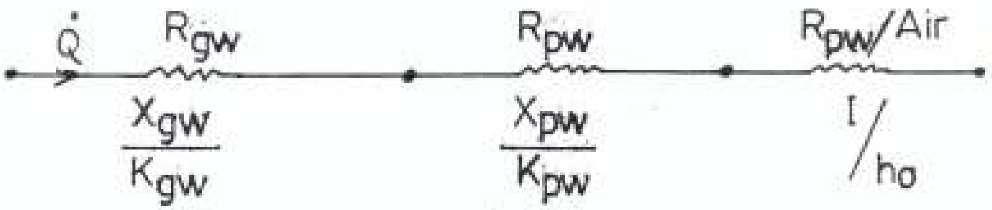


Fig. 3.1: Electrical Analogue for heat flow within the appatatus in the radial direction.

$$\text{Conductance per Unit area} = \frac{1}{\frac{1}{h_o} + \frac{X_{gw}}{k_{gw}} + \frac{X_{pw}}{k_{pw}}} \qquad \ldots\ldots (3.1)$$

where $k_{gw} = 0.037 w/mK$

$x_{pw} = x_{gw} = 0.02m$

$k_{pw} = 0.166\ w/mK$

$h_o = 10\ w/m^2K$

Substituting these values into (3.1) gives:

Conductance per Unit area of 1.314 w/m^2K in the radial direction.

Heat flow within the apparatus in the axial direction is as shown in Fig. 3.2.

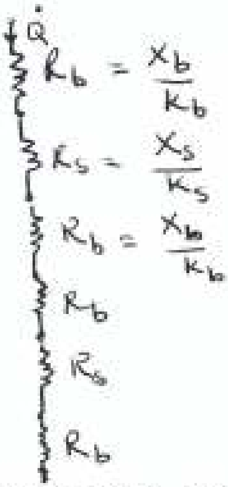


Fig. 3.2: Electrical Analogue for heat flow within the apparatus in the Axial direction

$$\text{Conductance per Unit area} = \frac{1}{2\left(\frac{2x_b}{k_b} + \frac{x_s}{k_s}\right)} \quad \ldots\ldots (3.2)$$

with $x_b = 0.013m$
$x_b = 111\ w/mK$
$x_s = 0.002m$
$k_s = 1.279 w/mK$

(here the subscript s refers to the specimen which has the greatest value of k which is concrete),

the Conductance per unit area in the axial direction is 293 w/m^2K.

293 $w/m^2K \gg 1.314\ w/m^2K$, therefore a unidirectional heat flow in the axial direction is assumed.

3.1.4 HEATING ELEMENT

The heating element chosen is constantan having a resistance of 1.4Ω. It was wound round a Mica sheet. Mica is heat resistant being able to withstand temperature up to 450°C. Since temperatures far below 450°C are being handled Mica is a suitable material on which the heating element can be wound.

Constantan has a maximum operating temperature of about 460°C (Fig 3.3). This is suitable for the present design since a temperature range very much below 460°C is being handled.

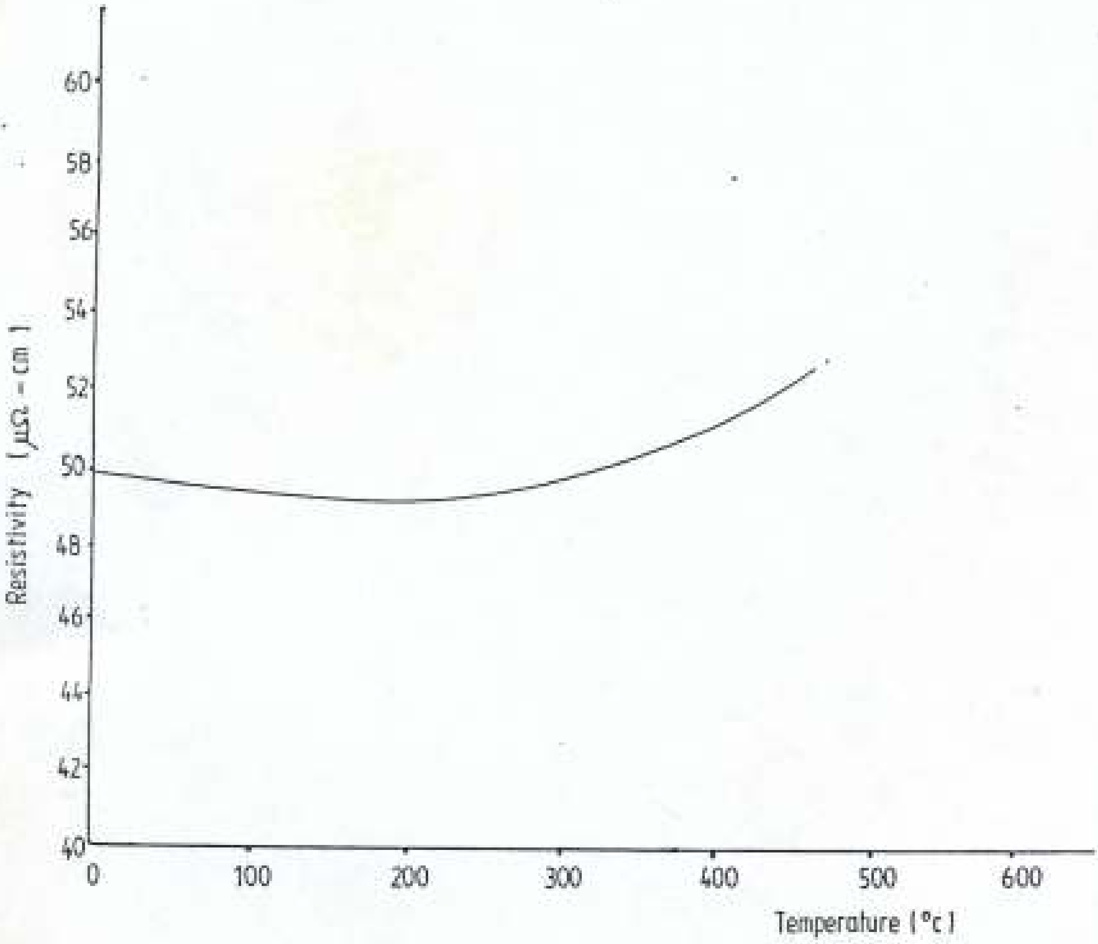


Fig 3.3: Variation of Resistivity with temperature for Constantan.
[ADAPTED FROM SUMMER (1966)]

3.1.5 RESISTANCE PLACED IN SERIES WITH THE BATTERY DRIVING THE POTENTIOMETER.

The series resistance, R was computed using the formula

$$\frac{V_{max}}{r} = \frac{E}{R + r} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

for the present design:

$E = 1.5V$

$r = 2.5 - 3.0\Omega$

$V_{max} = 4\ mV$

Hence using equation (3.3) $R = 937.5 - 1125\Omega$

A value of $R = 1100\Omega$ was chosen to ensure that balance points were spread well along the wire.

3.1.6 SOURCE OF POWER

A 12V battery (d.c) was employed as a source of power to supply current to the heating element. A rheostat was connected and used to vary the current and hence the voltage.

3.1.7 TEMPERATURE MEASUREMENT

Theremocouple arrangements were used for temperature measurement. The thermocouple wires are copper and constantan of 0.3mm diameter.

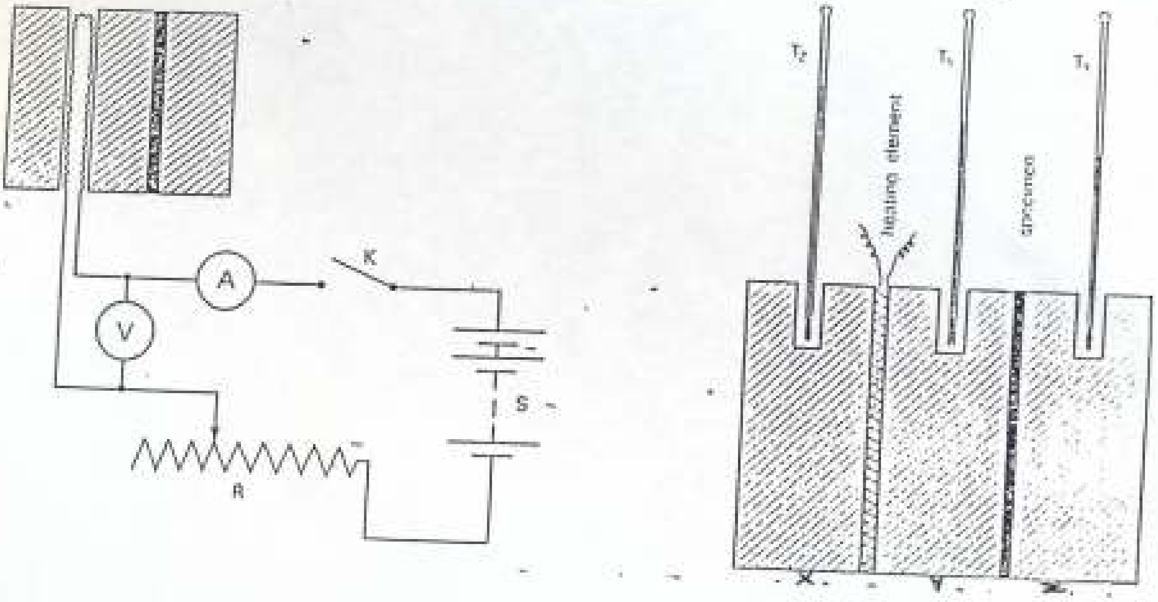
3.1.8 LEADS FOR CIRCUIT CONNECTION

The leads are copper of diameter 0.5mm.

3.2 THE THERMAL CONDUCTIVITY MEASURING APPARATUS: A MODIFICATION OF LEES' DISC METHOD

The thermal conductivity measuring apparatus is a modification of the Lees' disc method described by Avery (1976).

Avery described a Lees' disc apparatus (Fig. 3.4a and 3.4b) which uses an electrical heating element. This consists of three brass discs about 50mm in diameter and 13mm thick drilled with 6mm diameter holes to take three mercury in glass thermometers, the heater consists of 0.32m of 28swg nichrome wire wound on a mica sheet which is about 40mm in diameter and having a mica sheet about 50mm diameter on either side of it. The apparatus is supported by a cradle and placed in a box. Voltmeter (0 - 12volts) ammeter (0 - 3 amperes), Rheostat (0 - 12Ω to carry 3 amperes). Plug key and a 12V battery were instruments supplied along with the apparatus.



A - ammeter
V - voltmeter
K - plug key
R - rheostat
S - supply of current

X,Y,Z - Brass discs
T_x,T_y,T_z - mercury in glass thermometer

Fig. 3.4(a) and 3.4(b): Lee's Disc electrical method for determining thermal conductivity of a solid poor conductor as described by Avery.

The present apparatus consists of three units;

i) The brass discs, the heater element and the two samples of the specimen whose thermal conductivity is required. These are enclosed in an insulated box and brought into good thermal contact by a clamping device.

ii) The potentiometer circuit for measuring the thermal electromotive force registered by the thermocouples inserted in the holes drilled in the brass discs.

iii) An ammeter (0 - 5 amperes), a voltmeter (0-5 volts), a rheostat (0 - 17Ω to carry 3.3 amperes), plug key and 12 volt battery. The battery is to supply the current to the heater element while the ammeter and voltmeter measures the current and voltage respectively. The rheostat is used to adjust the value of the current.

The developed apparatus is a modification of the Lees's disc apparatus earlier described. The major modifications are:

i) Four brass discs were used in the present apparatus whilst three were used in the one described by Avery.

ii) Two samples each of the specimen whose thermal conductivity is required were used in the present apparatus whilst only one sample of specimen was used in the apparatus described by Avery

iii) The box in the present apparatus in which the brass discs and the samples of the specimen whose thermal conductivity is required were enclosed in a box insulated within by glass wool whilst the brass discs and specimen were enclosed in an uninsulated box in the apparatus described by Avery.

iv) Temperature measurements in the present apparatus were carried out using copper-constantan thermocouples whilst in the apparatus described by Avery, mercury-in-glass thermometers were used.

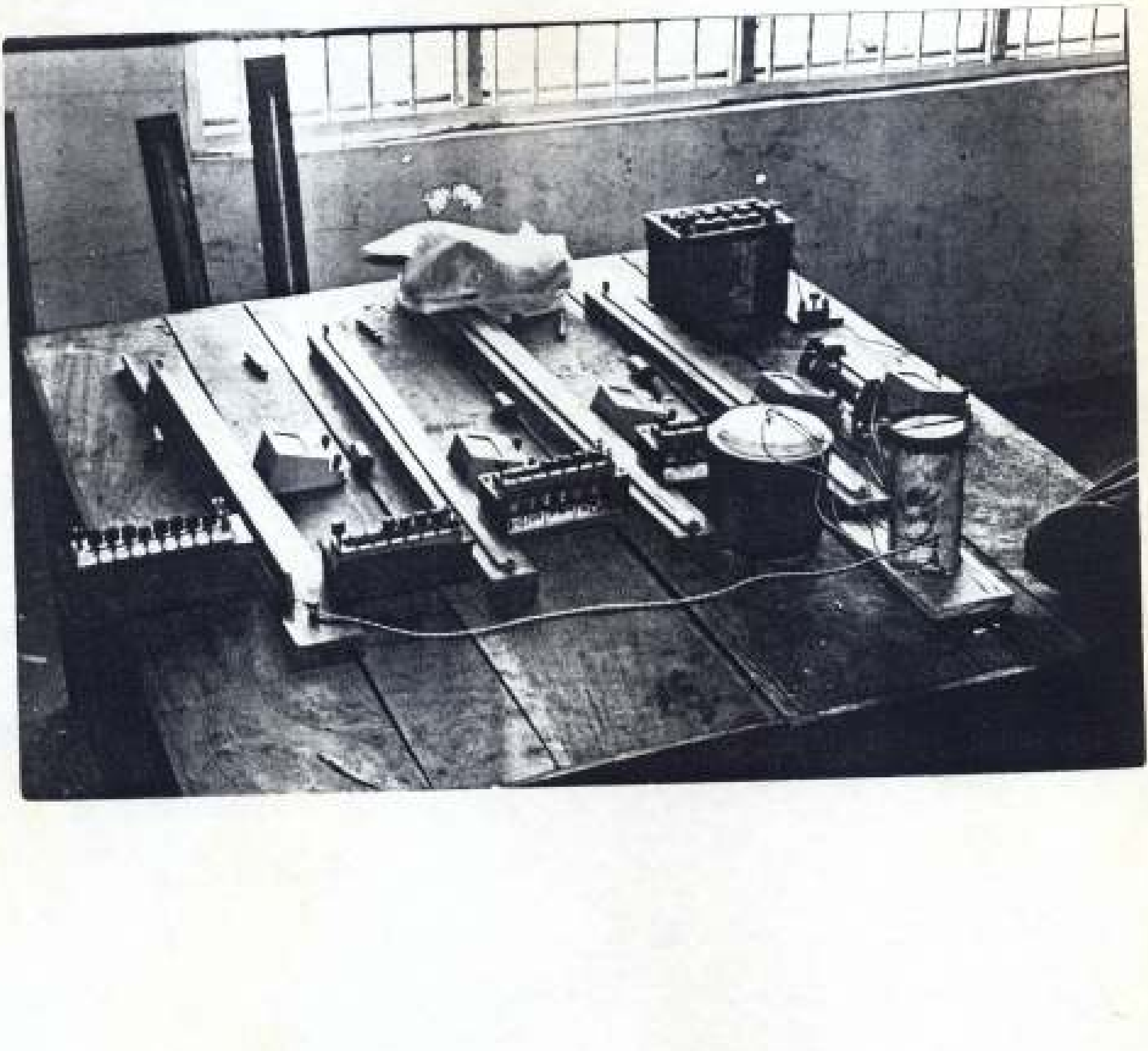
v) The incorporation of a potentiometer circuit to measure the thermally induced emf registered by the thermocouples

Modifications (i) and (ii), although entails the use of more brass discs and the preparation of more samples of the specimens, have helped to simplify the calculations involved to obtain the value of thermal conductivity.

The insulation, by glass wool of the interior of the box containing the brass disc - specimen assembly ensures a uni-directional heat flow.

Temperature measurements by thermometers are characterised by errors due to conduction along the thermometer stem. Again, according to Peter (1979), any sensor with an access hole, stem or lead introduces some degree of disturbance in the heat-paths in a solid. These have necessitated the use of fine wire thermocouples for temperature measurements and small access holes in the present apparatus.

Plate 1 shows all the three units. Fig. 3.5, shows the various parts of the first unit of the apparatus whilst Fig. 3.6 shows the assembly.



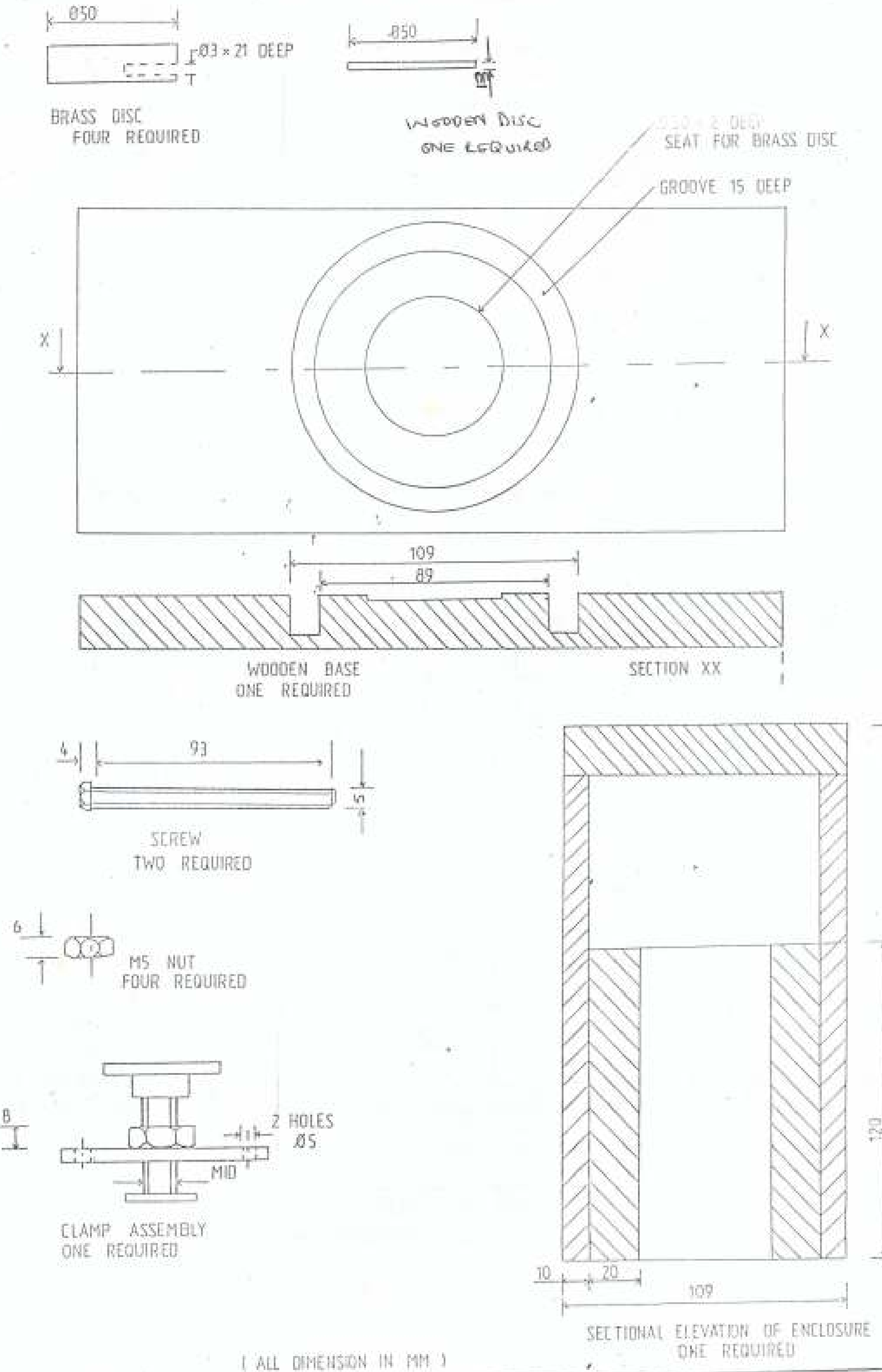


Fig 3.5 Parts drawing of the thermal conductivity measurin
apparatus .

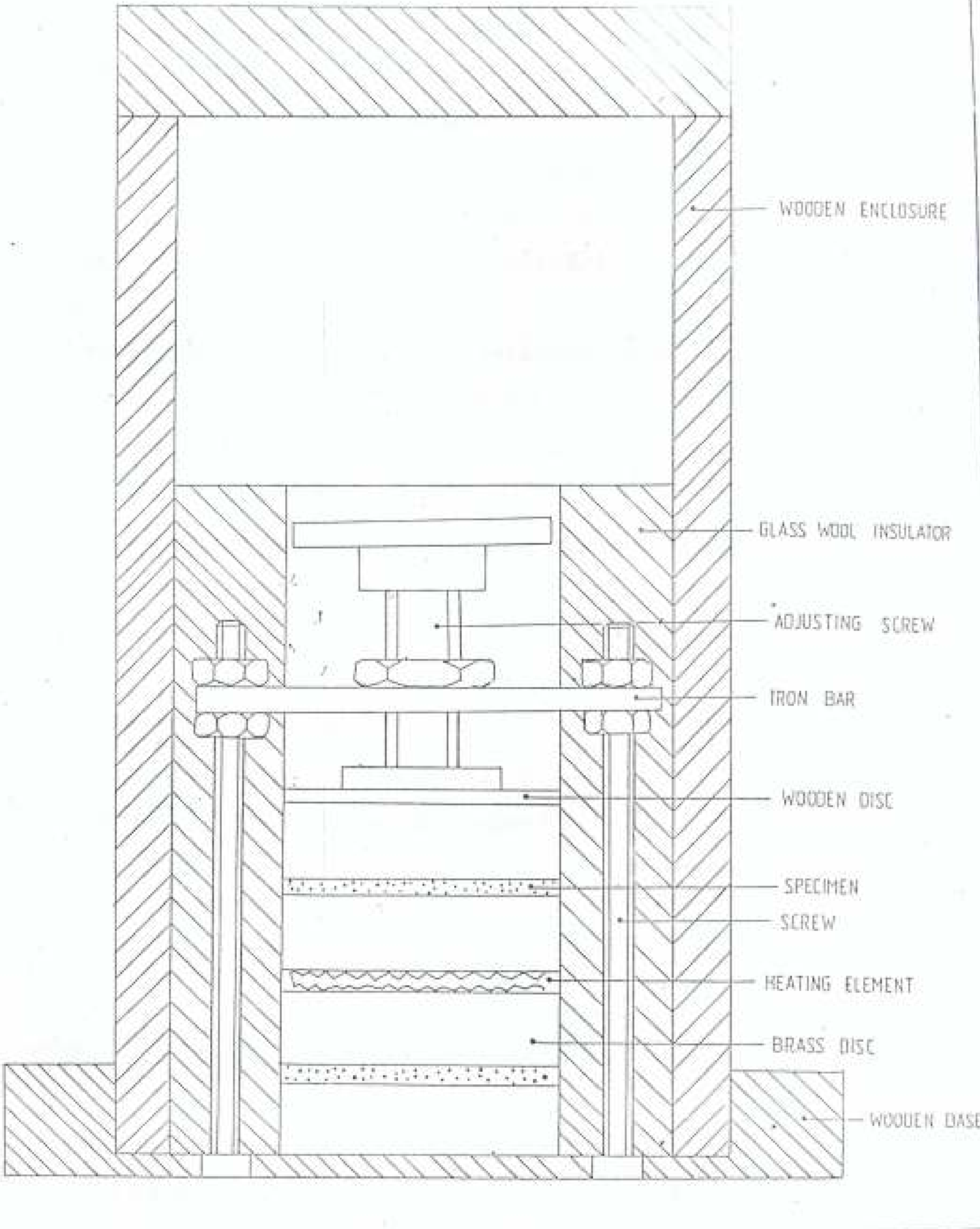


Fig 2·3 Sectional elevation of the assembled components within the enclosure.

3.3 PREPARATION OF SPECIMENS FOR THERMAL CONDUCTIVITY MEASUREMENTS ON THE APPARATUS

The following materials were collected and their thermal conductivities were determined using the constructed apparatus. Concrete, glass, asbestos sheet, Portland cement and corrugated cardboard.

The specimens of glass, asbestos sheet and corrugated cardboard were cut and filed to discs of 50mm diameter each. The thicknesses of each of the first two specimens being 2mm while the thickness of corrugated specimen was 3mm.

Portland cement and concrete were made into paste, moulded and were allowed to dry. They were later filed to discs of 50mm diameter each and thicknesses 5mm and 2mm respectively.

3.4 EXPERIMENTAL TECHNIQUE

The substance under test was taken in the form of two thin discs M_1 and M_2 Each of them was passed between two brass discs, M_1 between B_1 and B_2 and M_2 between B_3 and B_4 . The heater coil H was arranged at the centre between the brass discs B_2 and B_3 as shown in fig 3.7.

Thermocouples T_1 , T_2 , T_3, T_4 were used to measure the temperature of the two faces of each of the discs M_1 and M_2 , one junction of each thermocouple being inserted in a small hole, about 2 mm, drilled in the edge of the respective brass discs. Each brass disc is of diameter 50mm and thickness 13mm. The whole apparatus was clamped within an insulated cylindrical box (a constant temperature enclosure) which is split into two halves but brought together by means of a clip.

The heater, a 1.4Ω constantan wire, was connected into the circuit given (Fig. 3.7).

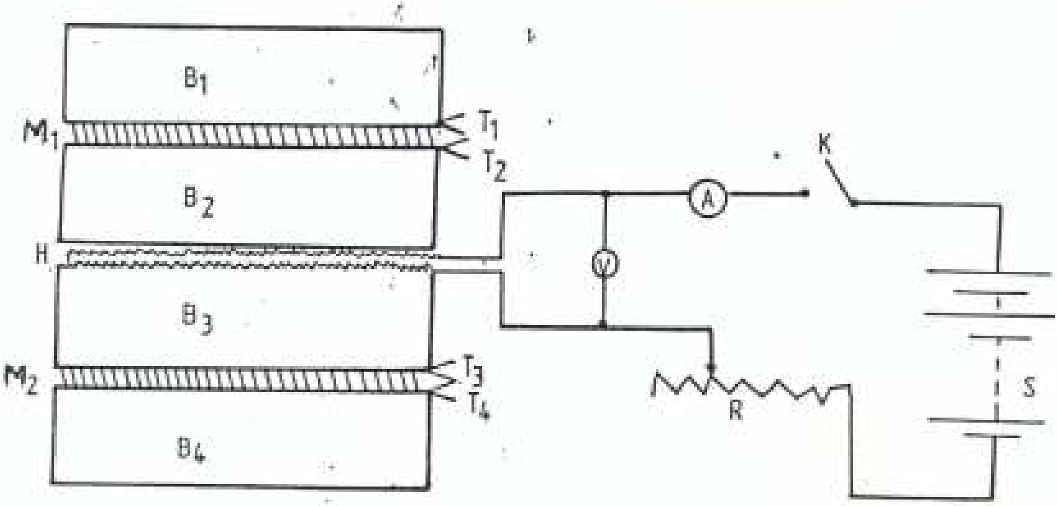


Fig 3.7 An arrangement for supplying heat to the brass - specimen assembly.

M_1, M_1 - Specimens

B_1, B_2, B_3, B_4, - Brass discs

T_1, T_2, T_3, T_4, - Thermocouples

A - Ammeter

K - Plug key

V - Voltmeter

R - Rheostat

S - Source of Power Supply

H - Heating element

Fig. 3.8 shows one of the set of circuits used for measurements of potential difference across the thermocouples. Four of such circuits were set up to measure the temperature at the four locations where the thermocouple wires were inserted. The first junctions of the thermocouples were dipped into a mixture of crushed ice and water maintained at about 0°C in a thermos flask. These junctions were connected to the sliding contact through sensitive centre reading galvanometers. The other set of junctions were placed within the holes drilled in the edges of the brass discs.

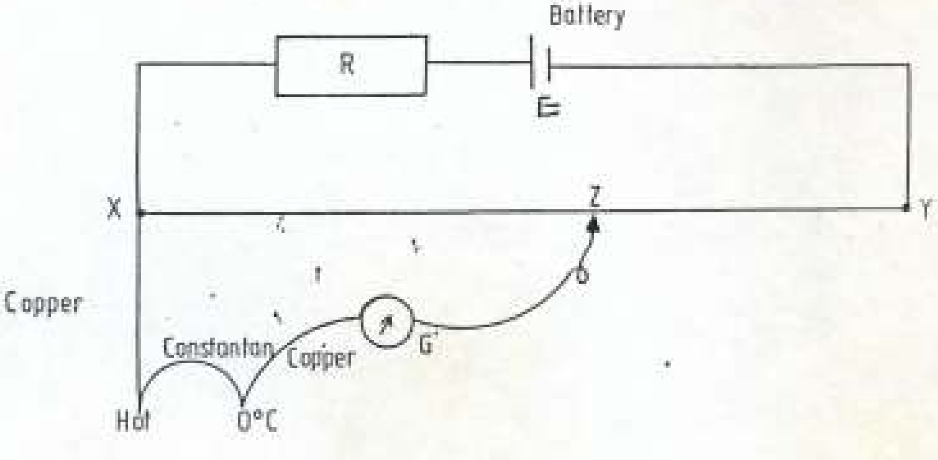


Fig 3.8 : Potentiometer circuit for measuring thermal emf.

R - Series resistance

E - Voltage of battery

L - length of the resistance wire

l - balance point length

XY - Potentiometer wire

G - Centre reading sensitive galvanometer

R was adjusted to obtain various values of current and voltage. Each value of the current obtained was maintained constant for five minutes until balance points on the potentiometer wire were found constant. Thermal electromotive forces were computed for these balance points. The temperatures of the faces of the discs were found using Table 3.1 which shows calibration data of thermal electromotive force against temperature of hot junction for copper/constantan thermocouple based on a cold junction at 0°C.

Table 3.1: CALIBRATION DATA OF COPPER - CONSTANTANT THERMOCOUPLES (FOR A COLD JUNCTION AT 0°C) - ADAPTED FROM SUMMER (1966)

E.M.F	Temperature of (Hot junction (°C))
0	0
1	25
2	49
3	72
4	94
5	115

CALCULATION OF THERMAL CONDUCTIVITY

Considering the circuit in fig 3.7.

$$P = I^2R = kA\left[\frac{(t_2 - t_1)}{x_1} + \frac{(t_3 - t_4)}{x_2}\right] \quad \text{........(3.4)}$$

P = electrical power

x_1, x_2 = specimens' thickness

R = Resistance of the heating element

t_1, t_2, t_3, t_4 = temperatures indicated by the respective thermocouples shown in fig. 3.7

A = Area of a flat face of the specimen

I = Current passed to the heating element

Now, $x_2 = x_1 = x$

$$k = \frac{I^2Rx}{A[(t_2 - t_1) + (t_3 - t_4)]}$$

but $A = \frac{\pi d^2}{4}$

where

d = diameter of specimen

$$\therefore k = \frac{4I^2Rx}{\pi d^2[(t_1 - t_2) + (t_3 - t_4)]} \quad .... (3.5)$$

Equation (3.5) was used to calculate the thermal conductivity of the specimens. It is assumed that radiation from the edges B_2, B_3, M_1 and M_2 is almost negligible by reason of the thermal insulation provided.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 RESULTS

Table 4.1 shows the average values of thermal conductivity k, obtained over a heat source temperature range of 25 - 60°C for asbestos, glass, corrugated cardboard, concrete and portland cement.

The thermal emf, e, corresponding to length of potentiometer wire for no deflection in the galvanometer, G show in Fig. 3.8 was computed using the formula

$$e = \frac{E\rho l}{R + \rho L} \ldots\ldots\ldots\ldots\ldots (4.1)$$

where ρ is the resistance per unit length of the potentiometer XY

Once the thermal emfs have been determined Table 3.1 was used to find the temperatures that correspond to the various electromotive force (emfs).

TABLE 4.1: VALUES OF THERMAL CONDUCTIVITY DETERMINED WITH THE APPARATUS

Materials	Average thermal Conductivity k, ($Wm^{-1}K^{-1}$)	Average Temperature of heat source, t_h (°C)
Concrete	1.285	35
Glass	0.737	38
Portland Cement	0.327	42
Asbestos	0.121	41
Corrugated cardboard	0.072	34

The temperature of the heat source is given by

$$t_h = \frac{t_2 + t_3}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.2)$$

t_2 and t_3 were measured using the thermocouple arrangement installed within the drilled holes (Fig 3.7).

Graphs of the variation of thermal conductivity with temperature for the specimens are shown in Figs. 4.1 - 4.5. Each sample showed a gradual linear increase in thermal conductivity with temperature except glass which showed a non linear dependence of thermal conductivity with temperature.

Asbestos' thermal conductivity rose from 0.111 to 0.133 w/mK between 26°C, portland cement's from 0.315 to 0.336 w/mK between 25°C and 60°C, cardboard's from 0.070 to 0.076 w/mK between 24°C and 44°C and concrete from 0.259 to 0.300 w/mK between 34°C and 48°C.

Figs 4.6 - 4.10 show the variation of the electrical power, p, associated with the total electromotive force (emf) drop across the two specimens of each material whose thermal conductivity is being determined based on a reference junction 0°C. The total emf drop which is a measure of temperature gradient across the specimens, increased linearly with the electrical power for all the samples.

4.2 DISCUSSIONS

In the literature, various values of thermal conductivities were given for the different materials. The thermal conductivity of glass, for instance, was given as 1.09, 0.81, 0.744, 0.78 - 0.88 and 0.779 W m^{-1} K^{-1} according to Eckert (1972), Frank et al (1986), Subramayan and Kothandaraman (1992), Isachenko and Osipova (1977) and Frank (1986) respectively. The current value of 0.737 W m^{-1} K^{-1} therefore compares favourably with those obtained in the literature since it falls within the range of values of thermal conductivity given for glass. Eckert (1972) gave varying values of thermal conductivities for glass, corrugated cardboard and asbestos. These varying values might not have been unrelated to the different conditions under which the thermal conductivities were determined and the method of measurement although these were not stated by the authors.

According to Choy and Leung (1989) thermal conductivity is dependent on density and moisture content. These factors were not considered in the course of determining the thermal conductivities of the various samples. The values of thermal conductivities obtained might not be without error due to the non-consideration of these factors.

The average values of thermal conductivities for the materials as given in the literature were used as a basis of determining the accuracies of the present result. The errors involved ranged between 1.55 - 11.03%.

Thermal conductivities of asbestos, portland cement, concrete and corrugated cardboard samples were found to be linearly dependent on temperature. This finding is in perfect agreement with what obtains in Folayan and Marona (1988) and Bhalchandra and

Robert (1989).

The non-linear dependence of thermal conductivity on temperature found in glass is corroborated by Frank (1978) who drew a graph which depicted a non linear thermal conductivity - dependence on temperature dependence for some poor heat conducting materials typical of which is silica brick.

Statistical analysis revealed that the estimated uncertainties in the calculated mean value of thermal conductivity are 0.121 ± 0.015, 0.737 ± 0.042, 0.327 ± 0.015, 0.072 ± 0.006 and 1.285 ± 0.027 w/mK at the 99% significance level for Asbestos, glass, portland cement, corrugated cardboard and concrete respectively.

Significance test revealed that the difference between the mean values of thermal conductivity from the literature and the mean values obtained using the developed apparatus is not significantly different at the 99% level for glass, corrugated cardboard and concrete but the difference is significant for Asbestos and portland cement. This is expected since there is no absolute value for thermal conductivity which depends on factors which included moisture content, temperature, density and grain size.

According to Peter (1979) the most serious and least suspected errors arise in temperature measurement. Conduction along thermocouple wires can cause very large differences between the observed temperature and the temperature intended to be observed. Sleeves were provided to cover the thermocouple wire therefore errors arising from conduction along the wires were minimized.

Chromel/Alumel thermocouples give more accurate temperature readings than copper/constantan thermocouples. According to Peter (1979) the finer the thermocouple wires the less the error incurred in temperature measurement. Copper/constantan thermocouples of 0.5mm diameter wires gives an error of about 12 per cent in the temperature reading when its immersed length is 20mm. Therefore the temperature recorded in this report might have been underestimated by 12 percent.

A uni-directional flow of heat across the samples is ensured by a thermal insulation provided by glass wool which minimized heat loss from the surfaces of the brass discs.

Factors that might have affected the thermal conductivities as determined in the present work include: moisture content of the cement and concrete samples the grain size of the concrete and the asbestos sheet and the densities of the various samples. Other sources of error include: Mechanical inhomogeneities caused by pulling or bending the thermocouple wires. Parasitic thermoelectric forces, according to Summer (1966), can originate in the external circuit where different metals make contact. soldered joints, according to Avery and Ingram (1976) offer resistance which leads to error in the potentiometer reading. Extreme care was taken to ensure that correct balance points were obtained on the potentiometer wire but these sources of error might have affected the accuracy of the results obtained.

Folayan and Marona (1988) used the modified Fitch apparatus to obtain a thermal coductivity value of 0.151 $Wm^{-1} K^{-1}$ for asbestos at 60°C. A value of 0.133 $Wm^{-1} K^{-1}$ was obtained in the present work. This shows a 12 percent difference from Folayan's result. However, at 30°C the result from the present work differs from Folayan's by 4.9 percent. It is therefore evident that the present value for the thermal conductivity of asbestos compares favourably with that obtained by Folayan and Marona (1988) not withstanding the difference in the apparatus used for the measurements.

The average value of thermal conductivity of glass over an average heat source temperature of 37.5°C was found to be 0.737 W m^{-1} K^{-1}. This shows a difference of 0.90 percent when compared with values given by Subramayan and Kothandaraman (1992). Again, this gives credence to the effectiveness of the present Apparatus.

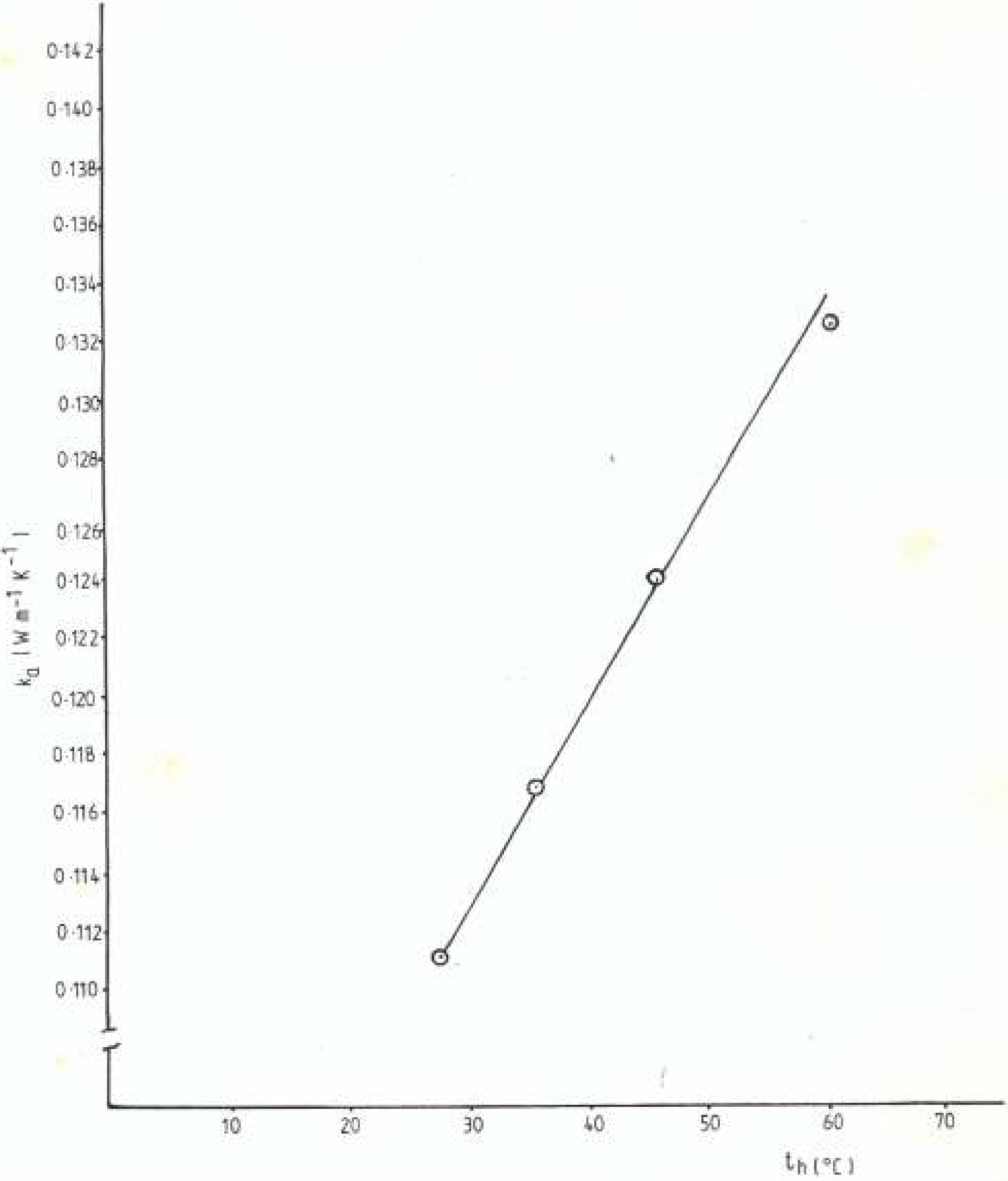


Fig 4·1 : Variation of thermal conductivity with temperature for Asbestos

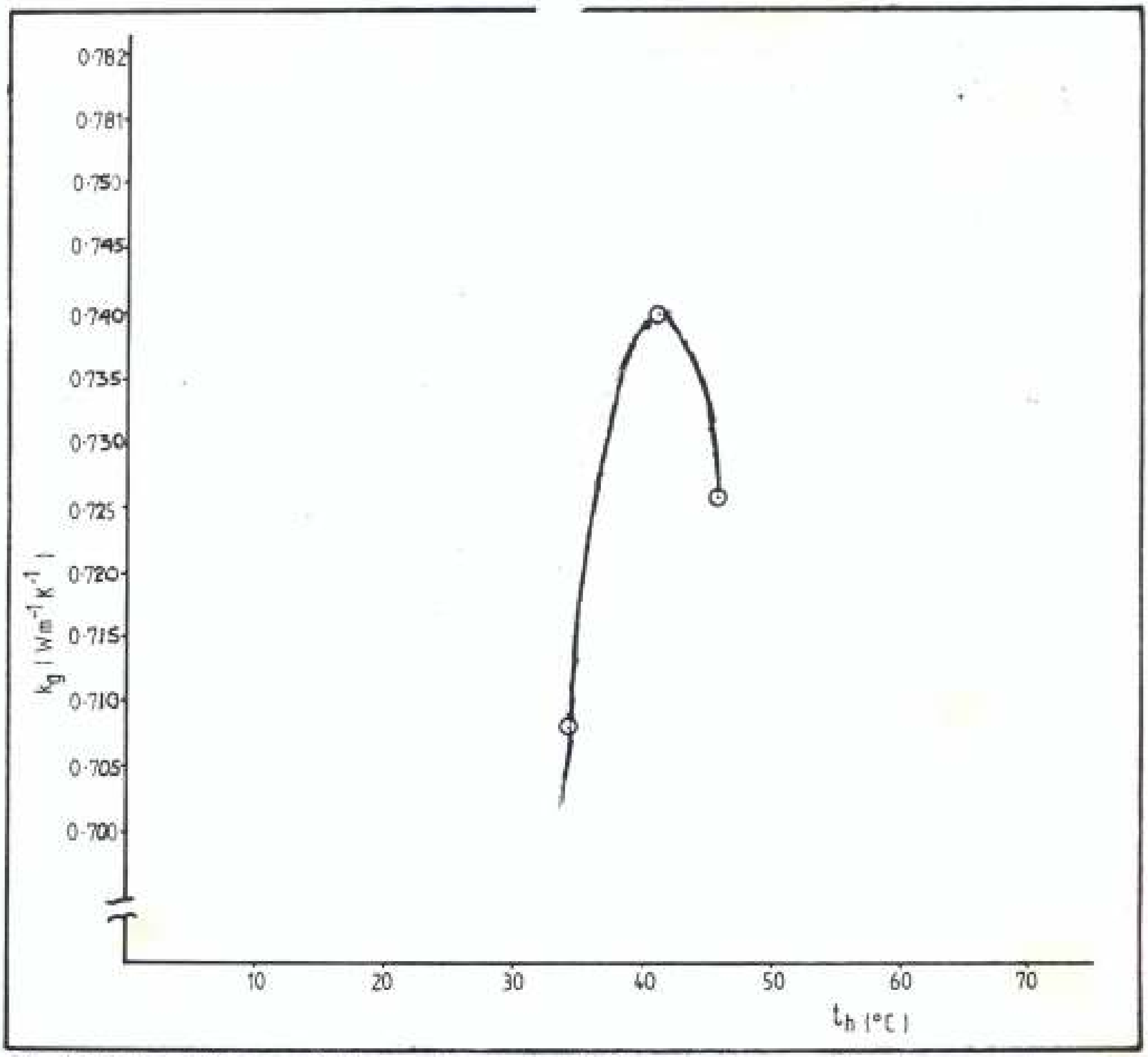


Fig 4·2: Variation of thermal conductivity of glass with temperature

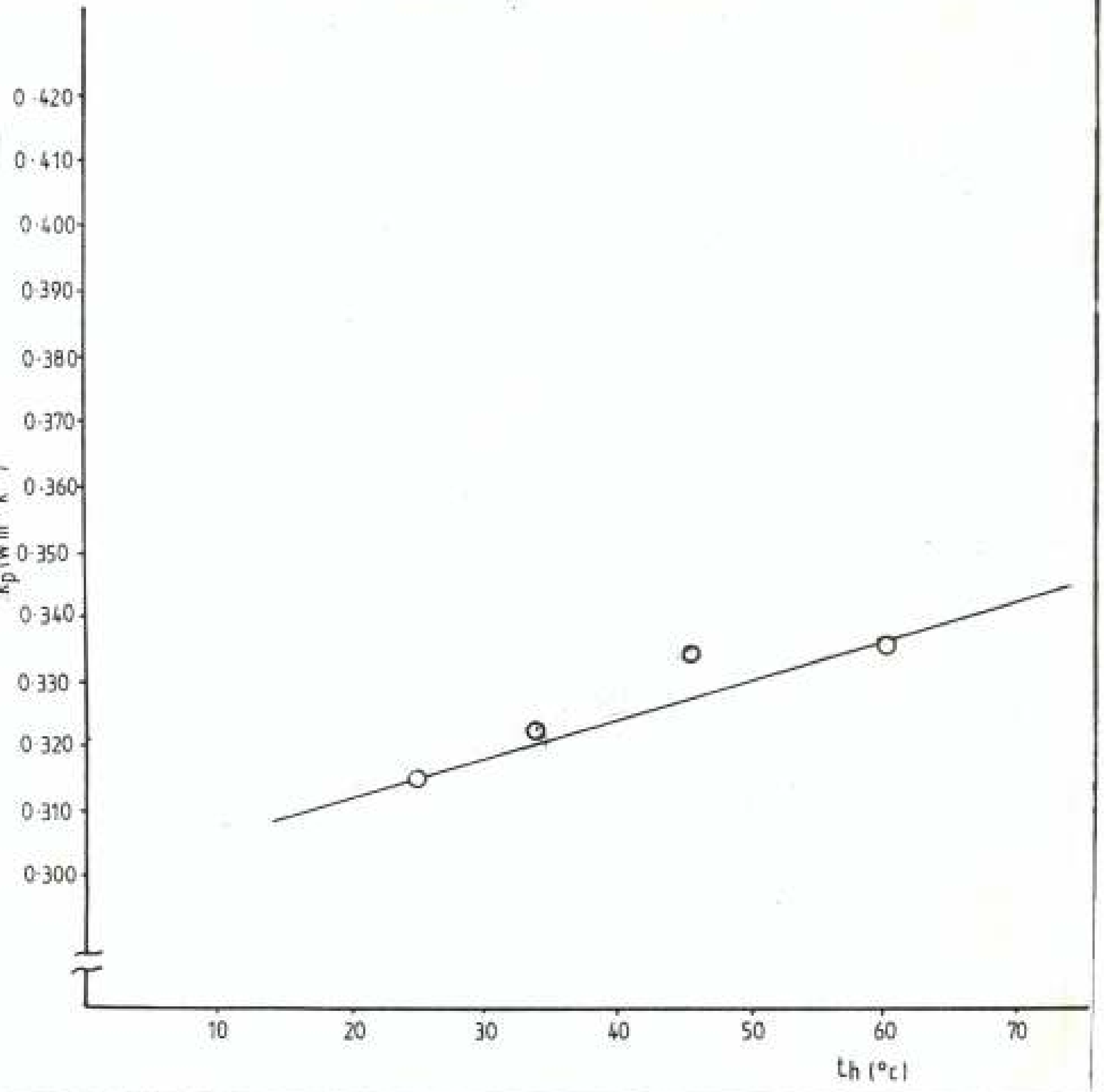


Fig 4·3: Variation of thermal conductivity of portland cement with portland cement

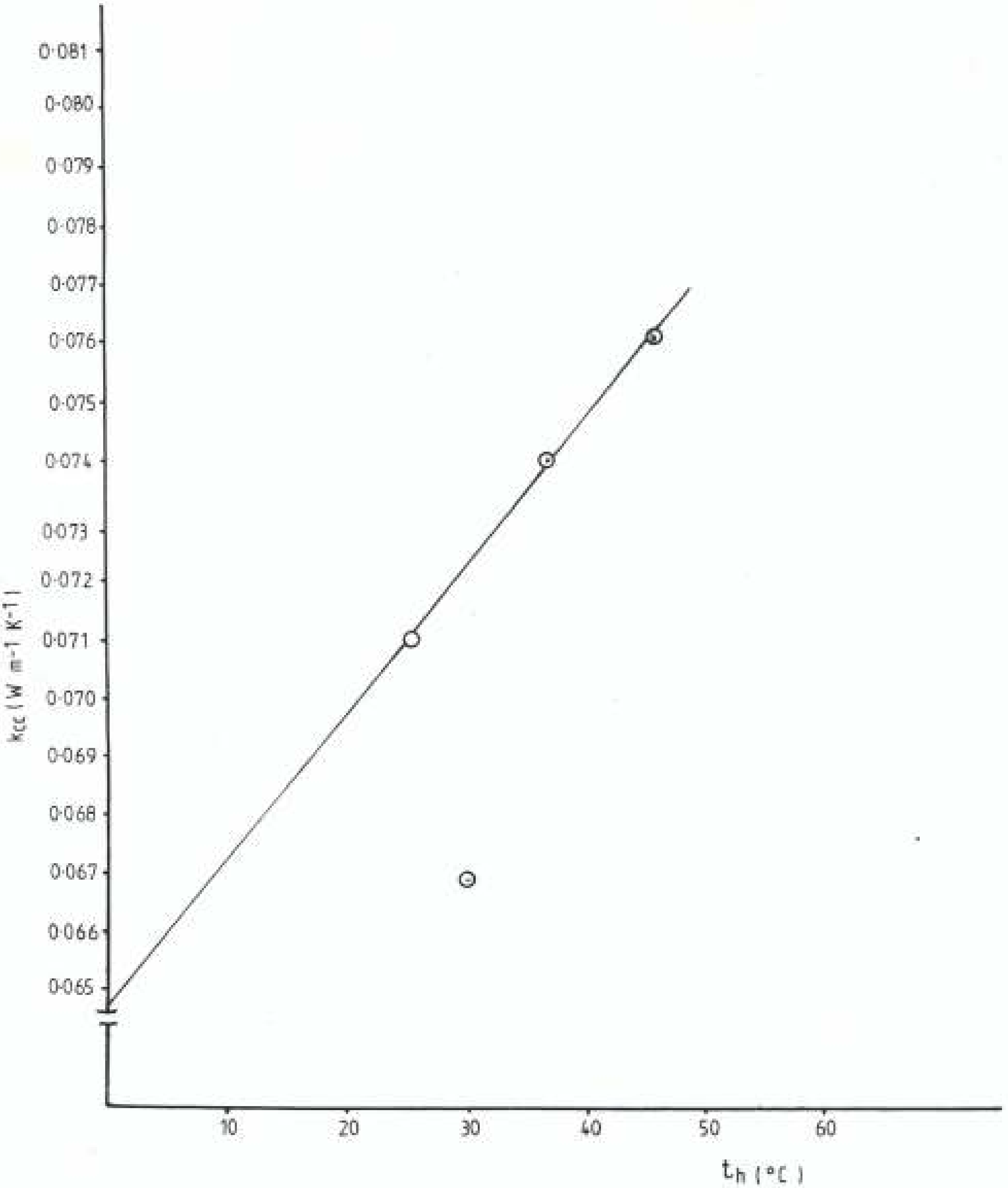


Fig 4·4: Variation of thermal conductivity with temperature for corrugated cardboard

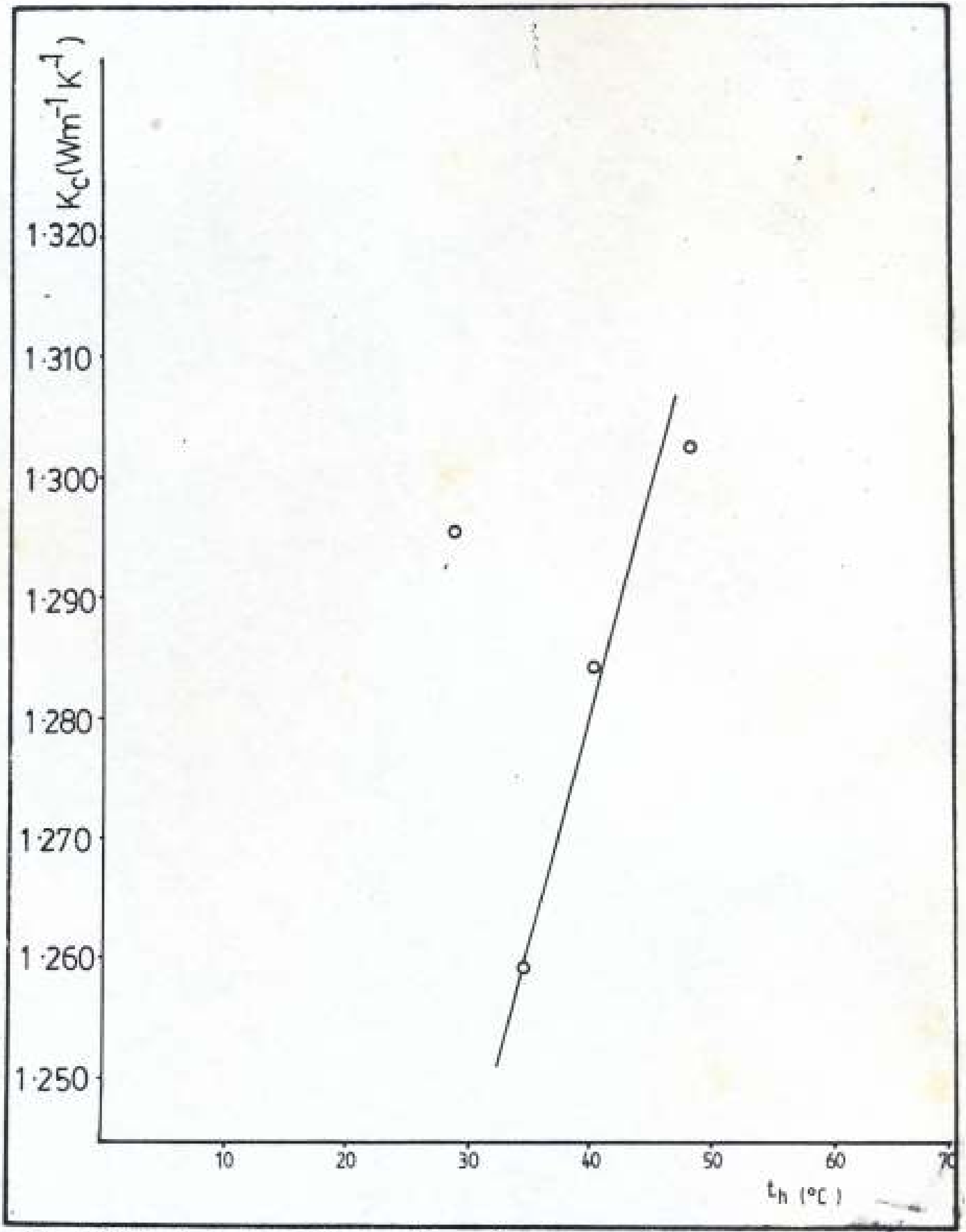
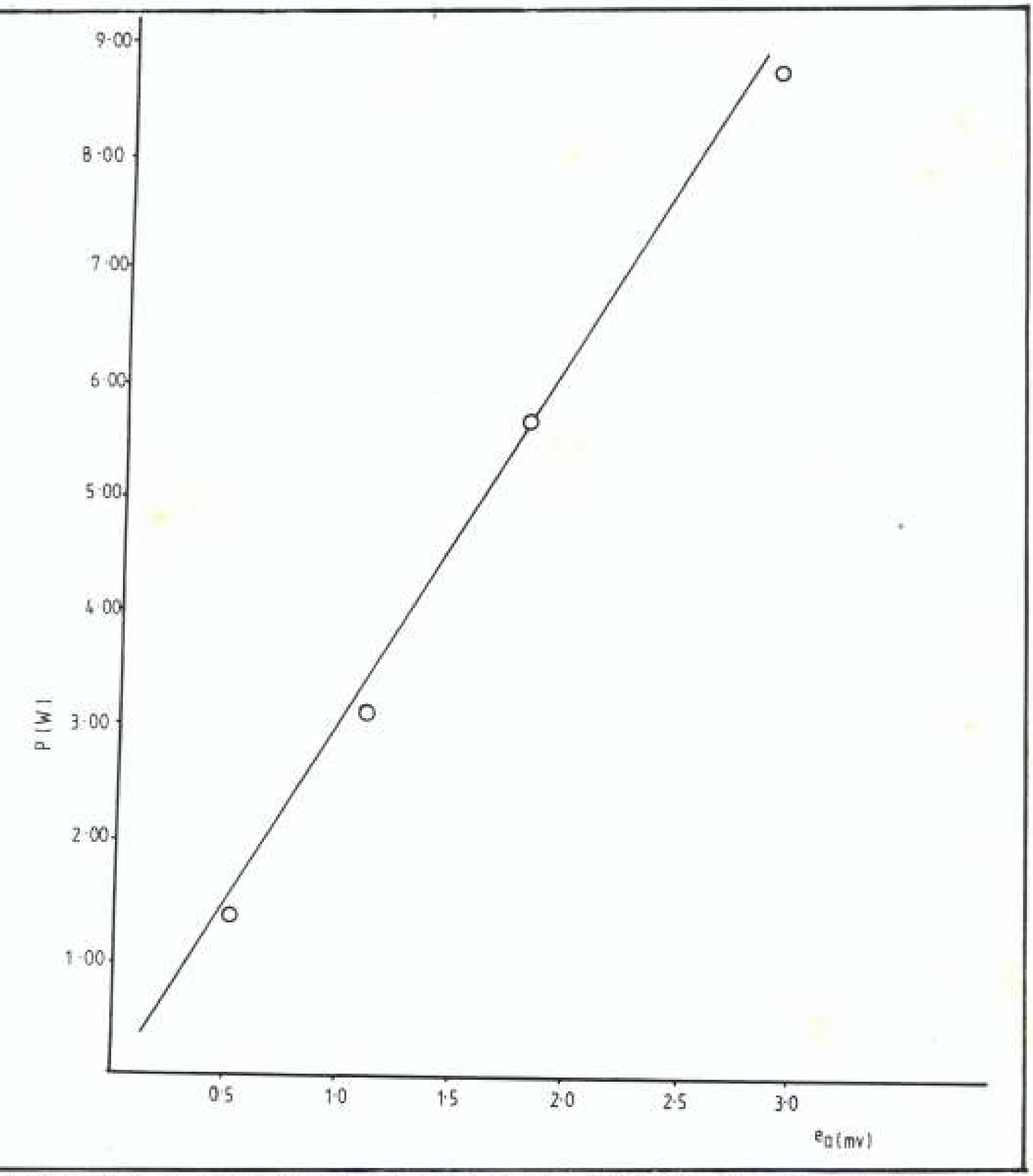


Fig 4·5: Variation of thermal conductivity with temperature for concrete



4·6: Variation of electrical power with total thermal emf drop across Asbestos specimen

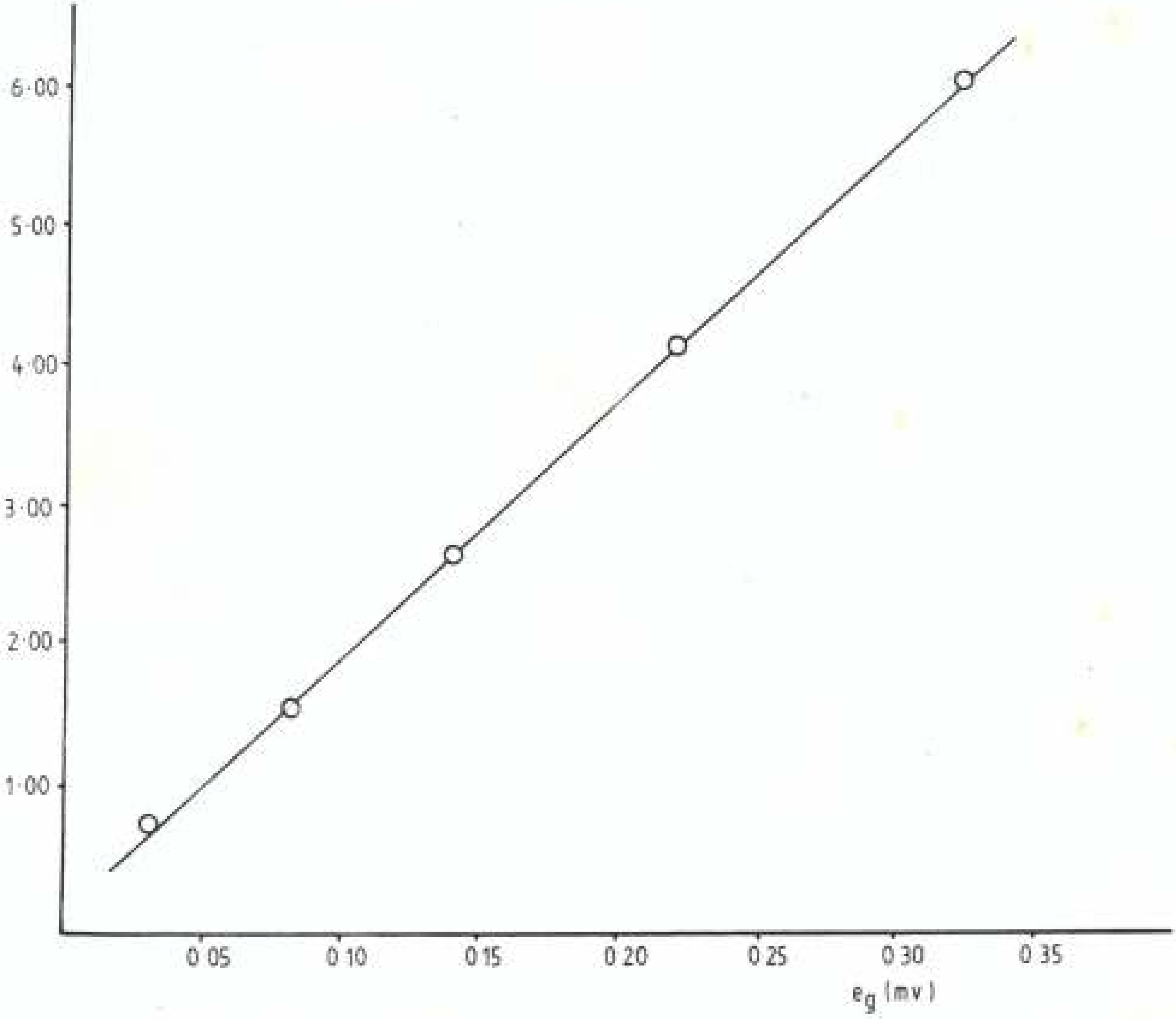


Fig 4·7 : Variation of electrical power with total thermal emf drop across glass specimen

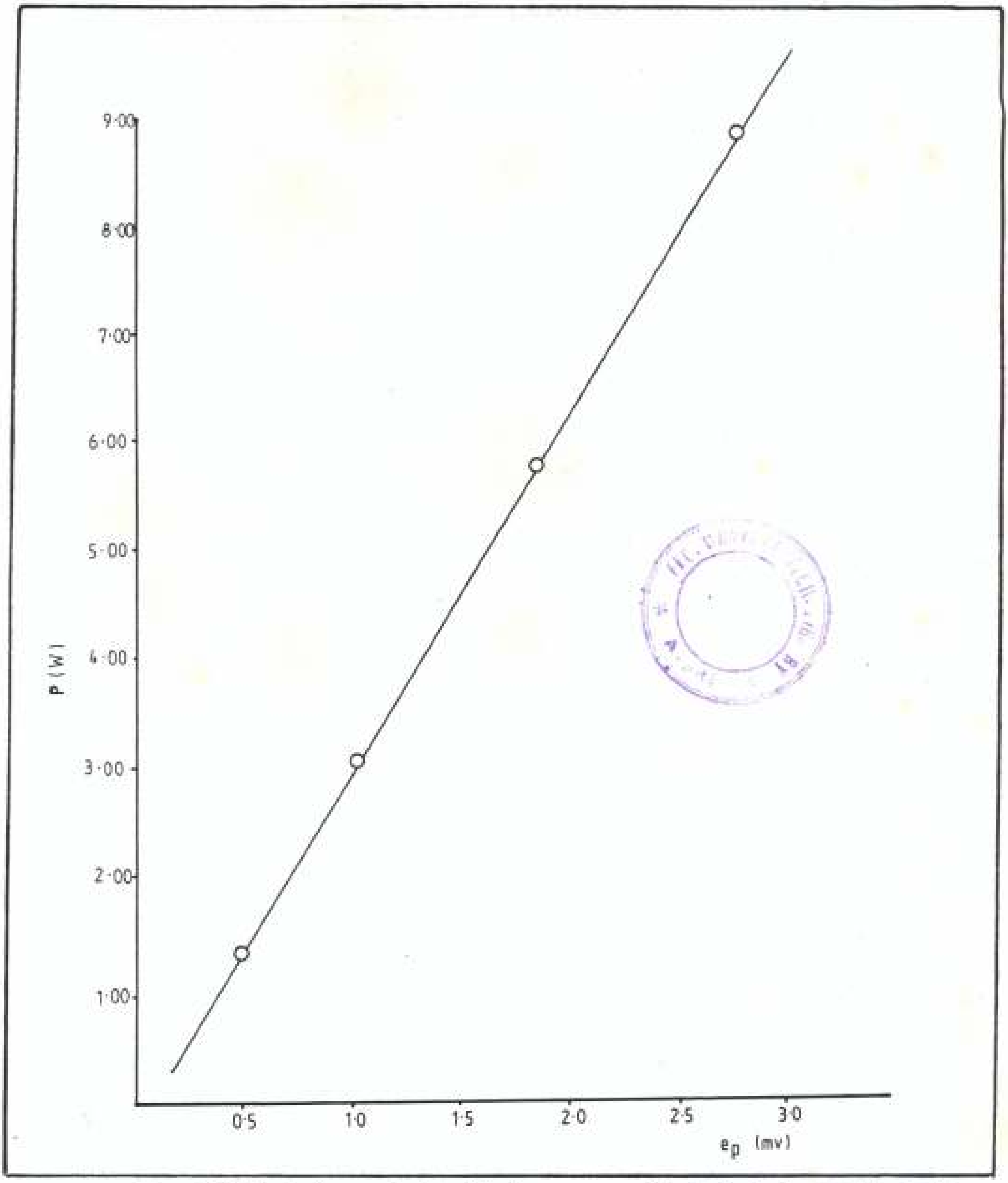


Fig 4·8: Variation of electrical power with total thermal emf drop across portland cement specimen

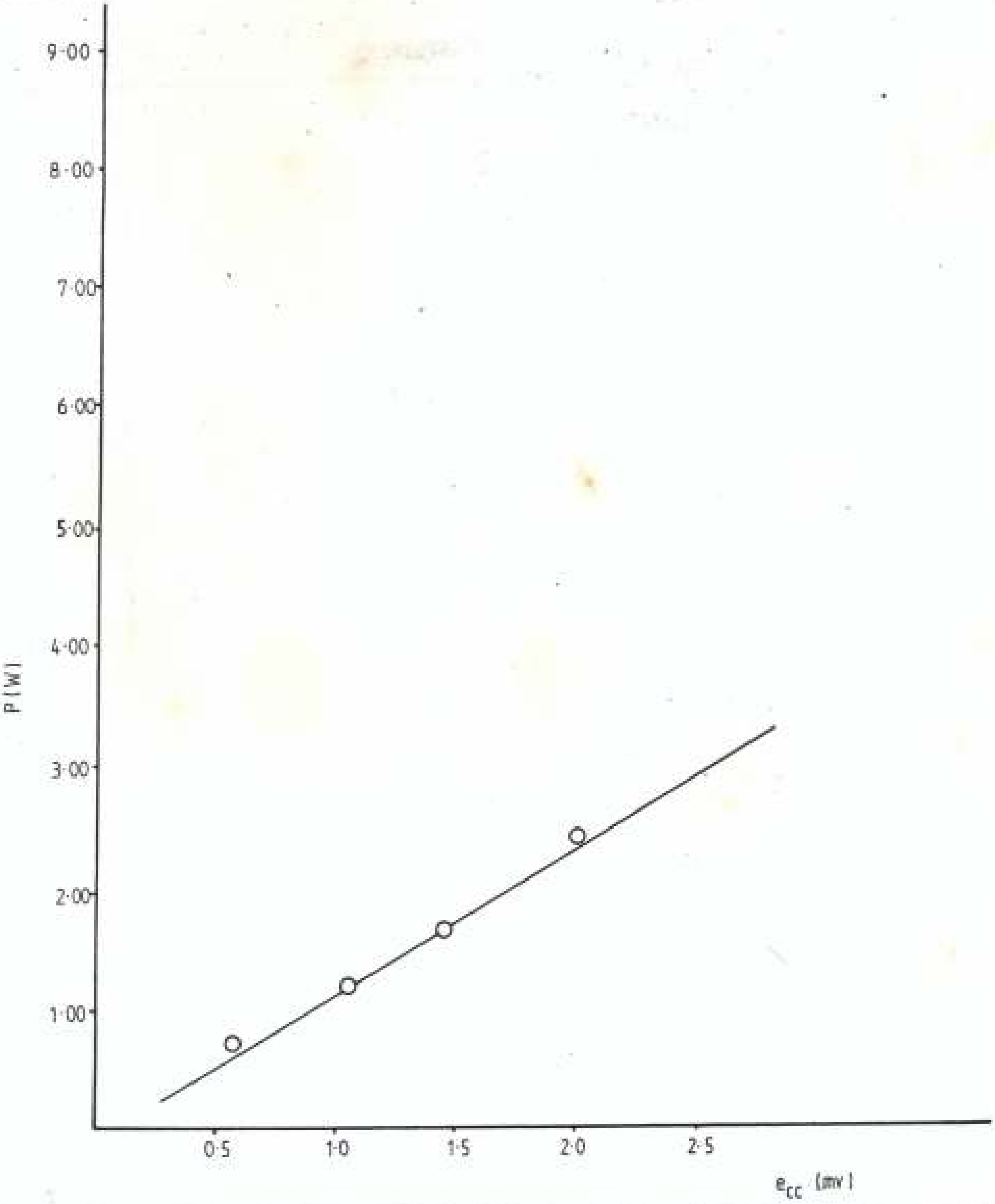


Fig 4·9: Variation of electrical power with total thermal emf drop across corrugated specimens

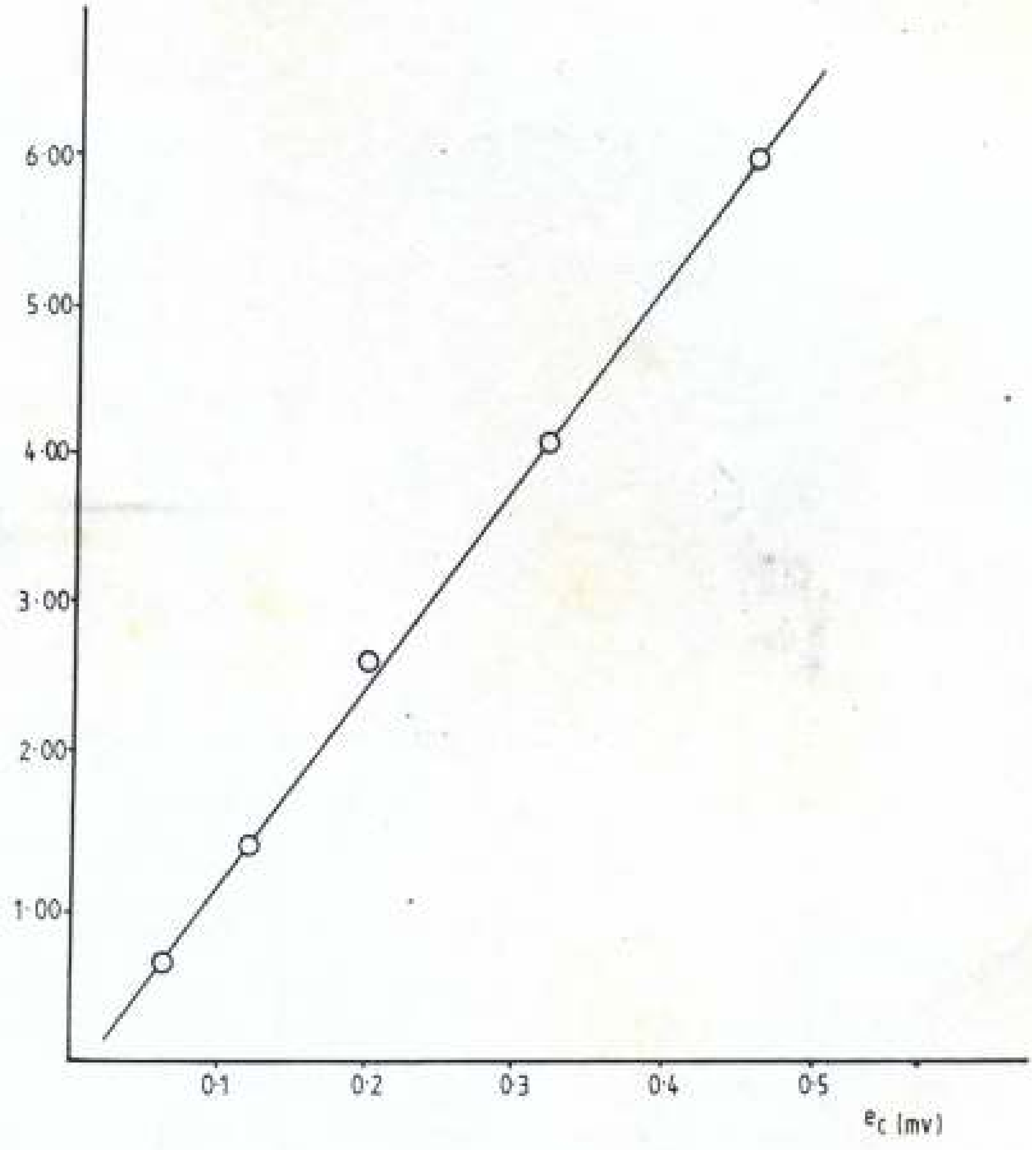


Fig 4·10 : Variation of electrical power with total thermal electromotive force drop across concrete specimen

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

1. Thermal conductivities of the various samples increased linearly with temperature except glass which showed a non linear dependence of thermal conductivity on temperature.
2. The average values of the thermal conductivities of concrete, glass, Portland cement, asbestos and corrugated cardboard over a heat source temperature range of 25°C - 60°C computed using the present apparatus were found to be 1.285, 0.737, 0.327, 0.121 and 0.072 $Wm^{-1} K^{-1}$.
3. The thermal conductivity values obtained for asbestos by Folayan approximates the value obtained in the present work the method of measurement not withstanding. Therefore, the present apparatus is effective.
4. The electrical power for supplying current to the heating element is directly proportional to the total emf drop which is a measure of the temperature gradient across the samples.
5. The maximum error incurred whilst using average quoted values of thermal conductivities from the literature for the various substances as basis is 11.03 per cent. Hence the apparatus can be relied upon to give reasonable value of thermal conductivity.
6. A thermal conductivity measuring apparatus for nonmetallic solids has been developed and found to give values of thermal conductivities, for the respective specimens, which compare favourably with those given in

the literature, since at the 99% significance level the difference between the mean values of thermal conductivity in the literature is not significantly different from those obtained for glass, corrugated cardboard and concrete.

7. There is a significant difference between the average values of thermal conductivity for asbestos and portland cement in the literature and the average values obtained using the present apparatus. This difference may be attributed to certain factors such as moisture content, grain size, density and temperature which modulate thermal conductivity.

5.2 RECOMMENDATIONS

The following recommendations are made for temperature measurements since the major parameter that determine accurate measurement of thermal conductivity is centred on precision measurement of temperature.

1. Differential thermocouples are recommended for measurement of temperature differences rather than installing thermocouples which measure absolute temperatures at the four faces of the discs. This will minimise errors in temperature measurement.
2. Galvanometers graduated directly in millivolts or degrees should be preferred to sensitive centre reading galvanometers which require potentiometer circuits. This will help to minimise errors due to potentiometer reading and effects of soldering.

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c) VALUES OF CURRENT AGAINST BALANCE POINTS ON THE POTENTIOMETER WIRES FOR PORTLAND CEMENT

I(Amperes)	V(volts)	l_1(Cm)	l_2(Cm)	l_3(Cm)	l_4(Cm)
1.00	1.40	18.90	26.00	27.00	20.80
1.50	2.09	22.10	36.00	37.00	23.80
2.00	2.85	26.20	48.00	50.90	24.70
2.50	3.50	26.50	61.00	72.90	32.00

Data: Thickness of Portland Cement specimen = 5mm
Diameter of specimen = 50mm
Series resistance with battery = 1100Ω
Battery driving potentiometer = 1.5V
Resistance of potentiometer wire associated
with $l_1, l_2,$ = 3Ω
Resistance of potentiometer wire associated with l_3, l_4 = 2.5Ω

d) VALUES OF CURRENT AGAINST BALANCE POINTS ON THE POTENTIOMETER WIRES FOR CORRUGATED CARDBOARD

I(Amperes)	V(volts)	l_1(Cm)	l_2(Cm)	l_3(Cm)	l_4(Cm)
0.70	1.00	16.60	24.00	23.00	18.80
0.90	1.30	16.90	25.00	25.10	20.60
1.10	1.50	17.40	27.00	26.00	21.50
1.30	1.80	18.40	27.10	29.20	24.40

Data: Thickness of Corrugated Cardboard specimen = 3mm
Diameter of specimen = 50mm
Series resistance with battery = 1100Ω
Battery driving potentiometer = 1.5V
Resistance of potentiometer wire associated
with l_1, l_2, l_3 = 3Ω
Resistance of potentiometer wire associated with l_4 = 2.5Ω

APPENDIX - EXPERIMENTAL RESULTS.

a) VALUES OF CURRENT AGAINST BALANCE POINTS ON THE POTENTIOMETER WIRE FOR ASBESTOS SHEET

I(Amperes)	V(volts)	l_1(Cm)	l_2(Cm)	l_3(Cm)	l_4(Cm)
1.0	1.4	20.10	27.90	27.90	20.80
1.5	2.09	22.60	36.90	38.90	18.90
2.01	2.85	24.00	47.80	52.00	28.00
2.5	3.5	27.50	63.90	70.80	30.90

Data: Thickness of Asbestos specimen = 2mm
Diameter of specimen = 50mm
Series resistance with battery = 1100Ω
Battery driving potentiometer = 1.5V
Resistance of potentiometer wire associated with l_1, l_2 = 3Ω
Resistance of potentiometer wire associated with l_3, l_4 = 2.5Ω

b) VALUES OF CURRENT AGAINST BALANCE POINTS ON THE POTENTIOMETER WIRE FOR GLASS

I(Amperes)	V(volts)	l_1(Cm)	l_2(Cm)	l_3(Cm)	l_4(Cm)
1.0	1.5	26.70	27.70	28.20	32.60
1.3	2.0	31.90	33.70	34.10	38.80
1.65	2.5	37.50	40.20	41.00	45.90
2.0	3.0	42.40	46.00	47.50	52.00

Data: Thickness of Glass specimen = 2mm
Diameter of specimen = 50mm
Series resistance with battery = 1100Ω
Battery driving potentiometer = 1.5V
Resistance of potentiometer wire associated
with l_1, l_2, l_3 = 3Ω
Resistance of potentiometer wire associated with l_4 = 2.5Ω

e) VALUES OF CURRENT AGAINST BALANCE POINTS ON THE POTENTIOMETER WIRES FOR CONCRETE

I(Amperes)	V(volts)	l_1(Cm)	l_2(Cm)	l_3(Cm)	l_4(Cm)
0.70	1.00	24.52	25.20	24.60	28.50
1.00	1.50	26.70	28.10	27.50	31.20
1.30	2.00	30.90	33.40	35.10	39.10
1.65	2.50	35.80	39.60	40.10	43.50
2.00	3.00	41.70	47.20	49.00	52.00

Data: Thickness of Concrete specimen = 2mm
Diameter of specimen = 50mm
Series resistance with battery = 1100Ω
Battery driving potentiometer = 1.5V
Resistance of potentiometer wire associated
with l_1, l_2, l_3 = 3Ω
Resistance of potentiometer wire associated with l_4 = 2.5Ω

f) VALUES OF CURRENT AGAINST COMPUTED VALUES OF THERMAL CONDUCTIVITY FOR ASBESTOS

I (Amp)	V Volts	e_1 mv	t_1 (°C)	e_2 (mv)	t_2 (°C)	e_3 (mv)	t_3 (°C)	e_4 (mv)	t_4 (°C)	k(Wm^{-1}K^{-1}
1.00	1.40	0.82	20.50	1.10	27.40	0.95	23.75	0.71	17.8	0.111
1.50	2.09	0.92	23.00	1.49	36.76	1.33	32.92	0.71	19.25	0.117
2.00	2.85	0.98	24.50	1.95	47.80	1.77	43.48	0.98	23.50	0.124
2.50	3.50	1.12	27.88	2.61	63.03	2.41	58.43	1.05	26.20	0.133

Average k = 0.121 W m^{-1} K^{-1}

Error = 11.03 percent based on an average
value of k = 0.136 W m^{-1} K^{-1}, from literature

g)

VALUES OF CURRENT AGAINST COMPUTED VALUES OF THERMAL CONDUCTIVITY FOR GLASS

I (Amp)	V Volts	e_1 mv	t_1 (°C)	e_2 (mv)	t_2 (°C)	e_3 (mv)	t_3 (°C)	e_4 (mv)	t_4 (°C)	k $(Wm^{-1}K^{-1}$
1.07	1.50	1.09	27.10	1.13	28.12	1.15	28.60	1.11	27.65	0.775
1.30	2.00	1.30	32.28	1.37	33.88	1.39	34.36	1.32	32.56	0.708
1.65	2.50	1.53	37.64	1.64	40.36	1.67	41.08	1.56	38.41	0.740
2.00	3.00	1.73	42.44	1.89	46.36	1.94	47.56	1.78	43.64	0.726

Average k = 0.737 W/mK

Error = 4.66 percent based on an average value of k = 0.773 W m^{-1} K^{-1}, from literature

h)

VALUES OF CURRENT AGAINST COMPUTED VALUES OF THERMAL CONDUCTIVITY FOR PORTLAND CEMENT

I (Amp)	V Volts	e_1 (mv)	t_1 (°C)	e_2 (mv)	t_2 (°C)	e_3 (mv)	t_3 (°C)	e_4 (mv)	t_4 (°C)	k $(Wm^{-1}K^{-1})$
1.00	1.40	1.78	19.38	1.06	26.44	0.98	23.00	0.71	17.75	0.315
1.50	2.09	0.90	22.50	1.47	36.28	1.26	31.24	0.81	20.25	0.323
2.00	2.85	1.07	26.74	1.96	48.04	1.73	42.52	0.84	21.00	0.334
2.50	3.50	1.08	26.92	2.49	60.27	2.48	60.04	1.09	27.16	0.336

Average k = 0.327 W/mK

Error = 10.09 percent based on an average

value of k = 0.294 W m^{-1} K^{-1}, from literature

i)

VALUES OF CURRENT AGAINST COMPUTED VALUES OF THERMAL CONDUCTIVITY FOR CORRUGATED CARDBOARD

I (Amp)	V Volts	e_1 (mv)	t_1 (°C)	e_2 (mv)	t_2 (°C)	e_3 (mv)	t_3 (°C)	e_4 (mv)	t_4 (°C)	k $Wm^{-1}K^{-1}$
0.70	1.00	0.68	16.98	0.98	24.48	0.94	23.46	0.64	15.93	0.070
0.90	1.30	0.69	17.36	1.21	30.00	1.23	30.60	0.70	17.50	0.067
1.10	1.50	0.71	17.84	1.43	35.32	1.46	36.00	0.73	18.26	0.074
1.34	1.80	0.75	18.82	1.76	43.31	1.84	45.15	0.83	20.75	0.076

Average k = 0.072 W/mK

Error based on average k of 0.079 W m^{-1} K^{-1}, from literature

= [(0.071 - 0.072)/0.079] x 100% = 8.9%

j) VALUES OF CURRENT AGAINST COMPUTED VALUES OF THERMAL CONDUCTIVITY FOR CONCRETE

I (Amp)	V Volts	e_1 (mv)	t_1 (°C)	e_2 (mv)	t_2 (°C)	e_3 (mv)	t_3 (°C)	e_4 (mv)	t_4 (°C)	k (Wm^{-1}
0.70	1.00	1.00	25.00	1.03	25.72	1.00	25.00	0.97	24.36	1.375
1.00	1.50	0.09	27.26	1.15	28.60	1.12	27.88	1.06	26.47	1.295
1.30	2.00	1.26	31.30	1.36	33.64	1.43	35.32	1.33	32.88	1.259
1.65	2.50	1.46	36.08	1.62	39.88	1.64	40.36	1.48	36.60	1.284
2.00	3.00	1.70	41.79	1.93	47.32	2.00	49.00	1.77	43.58	1.300

Average k = 1.285 W/mK

Error based on average k of 1.287 W/mK from literature

= [(1.287 - 1.285)/1.287] x 100%

= 1.55%

LITERATURE VALUES OF THERMAL CONDUCTIVITY
VALUE OF THERMAL CONDUCTIVITY FOR THE VARIOUS MATERIALS GIVEN BY DIFFERENT AUTHORS

AUTHOR	MATERIALS THERMAL CONDUCTIVITY (K) W/mK				
	Asbestos	Glass	Portland cement	Corrugated cardboard	Concrete
Eckert and Drake (1972)	0.156	0.760	-	0.064	1.460
Isackenlo and asipova (1977)	-	0.780	-	-	1.280
Frana (1978)	0.151	0.779	-	-	0.935
Frank and Mark (1986)	0.113	0.810	-	0.140	-
Holman (1977)	0.116	0.780	0.290	0.064	1.370
Alna (1984)	0.166	0.760	0.290	0.64	1.400
Subramayan and Kothandaraman (1972)	0.116	0.744	0.302	0.064	1.279
Present work	0.121	0.737	0.327	0.072	1.285