P.A. HILTON LTD.

EXPERIMENTAL
OPERATING
AND
MAINTENANCE MANUAL

HEAT CONDUCTION UNIT
H940

H940M/E/5/076

AUG 91

H940 HEAT CONDUCTION UNIT

INTRODUCTION

Thermal conduction is the mode of heat transfer which occurs in a material by virtue of a temperature gradient within it. A solid is chosen for the demonstration of pure conduction since both liquids and gases exhibit excessive convective heat transfer.

In a practical situation, heat conduction occurs in three dimensions, a complexity which often requires extensive computation to analyse. In the laboratory, a single dimensional approach is required to demonstrate the basic law that relates rate of heat flow to temperature gradient and area.

The Hilton Heat Conduction Unit consists of two electrically heated modules mounted on a bench support frame. One module contains a cylindrical metal bar arrangement for a variety of linear conduction experiments while the other consists of a disc for radial profile studies. Both test sections are equipped with an array of temperature sensors. Cooling water, to be supplied from a standard laboratory tap, is fed to one side of the test pieces in order to maintain a steady gradient.

The instrumentation provided permits accurate measurement of temperature and power supply. Fast response temperature probes, with a resolution of 0.1°C, give direct digital readout in °C. The power control circuit provides a continuously variable electrical output of 0-100 Watts with direct readout.

The test modules are designed to minimise errors due to true three-dimensional transfer. The basic principles of conduction can be taught without knowledge of radiation or convective heat transfer. The linear test piece is supplied with interchangeable samples of conductors and insulators to demonstrate the effects of area, conductivity and series combinations. Contact resistance may also be investigated, and the important features of unsteady state conditions may be demonstrated.

The apparatus may also be used to measure thermal conductivity of various solid materials by clamping a sample of specific dimensions between the hot and cold elements.

RECEIPT OF EQUIPMENT

Sales in the United Kingdom

The apparatus should be carefully unpacked and the components checked against the Packing List.

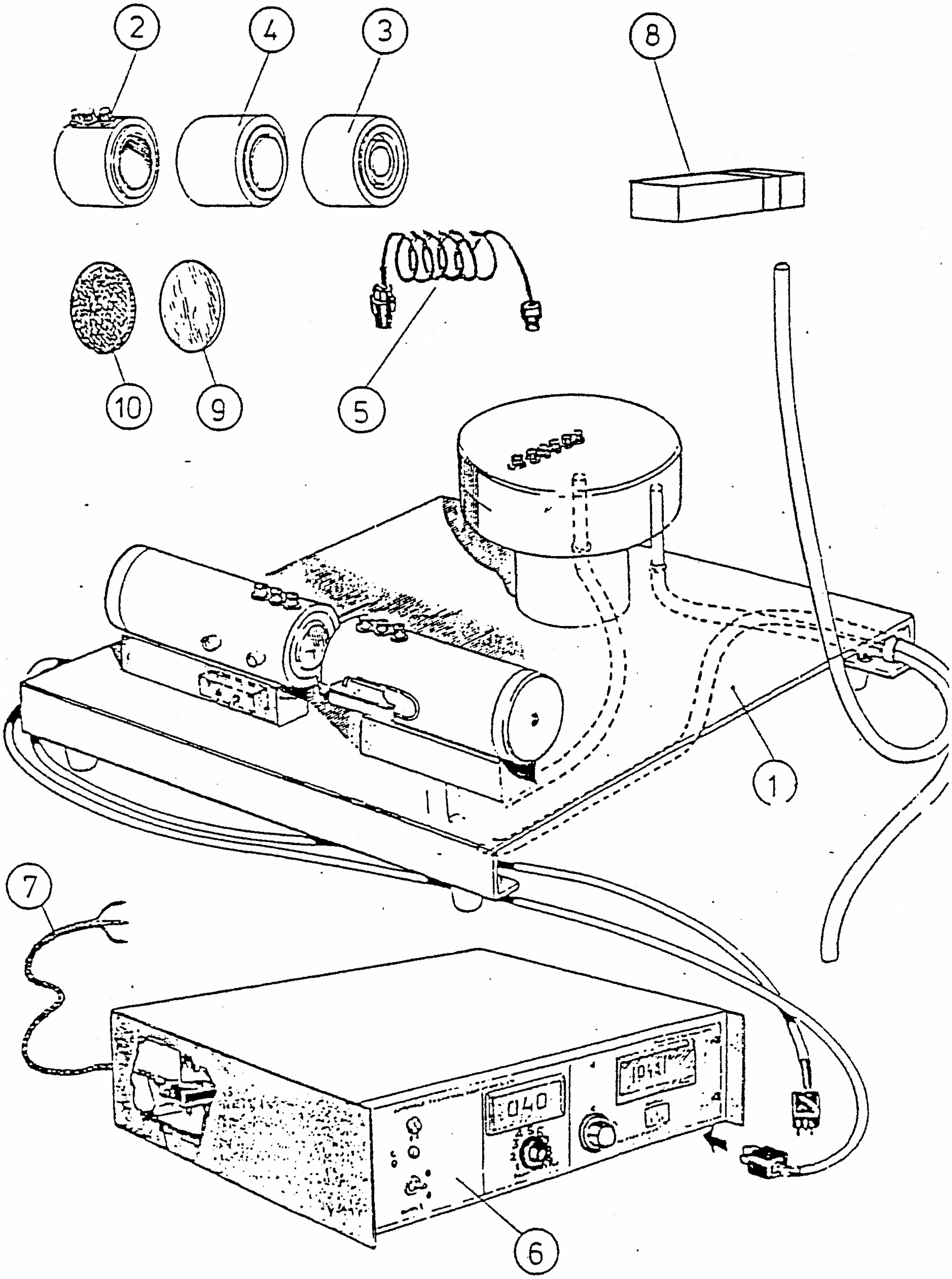
Any omissions or breakages should be notified to P.A. Hilton Limited within three days of receipt.

Sales Overseas

The apparatus should be carefully unpacked and the components checked against the Packing List.

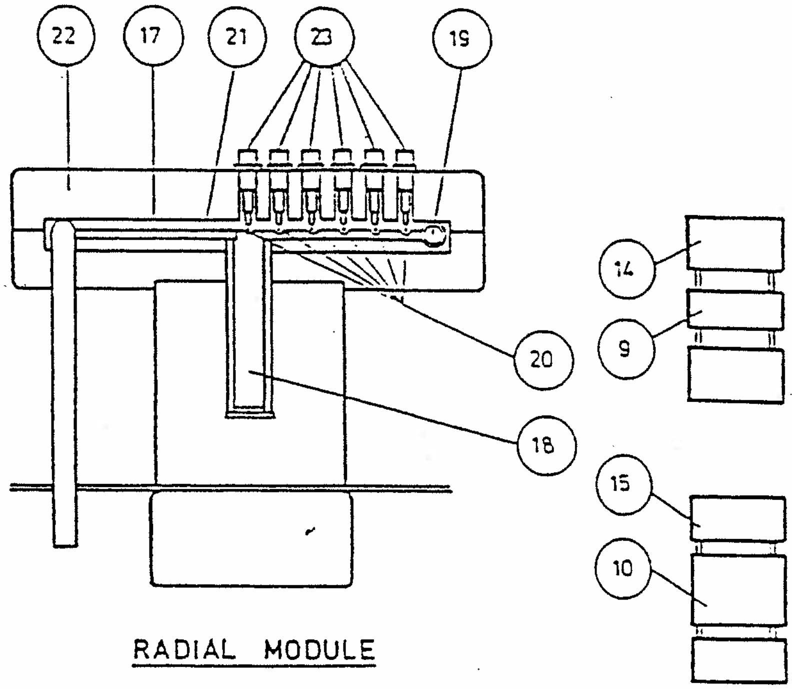
Any omissions or breakages should be notified immediately to the Insurance Agent stated on the Insurance Certificate if the goods were insured by P.A. Hilton Ltd.

Your own insurers should be notified immediately if insurance was arranged by yourselves.

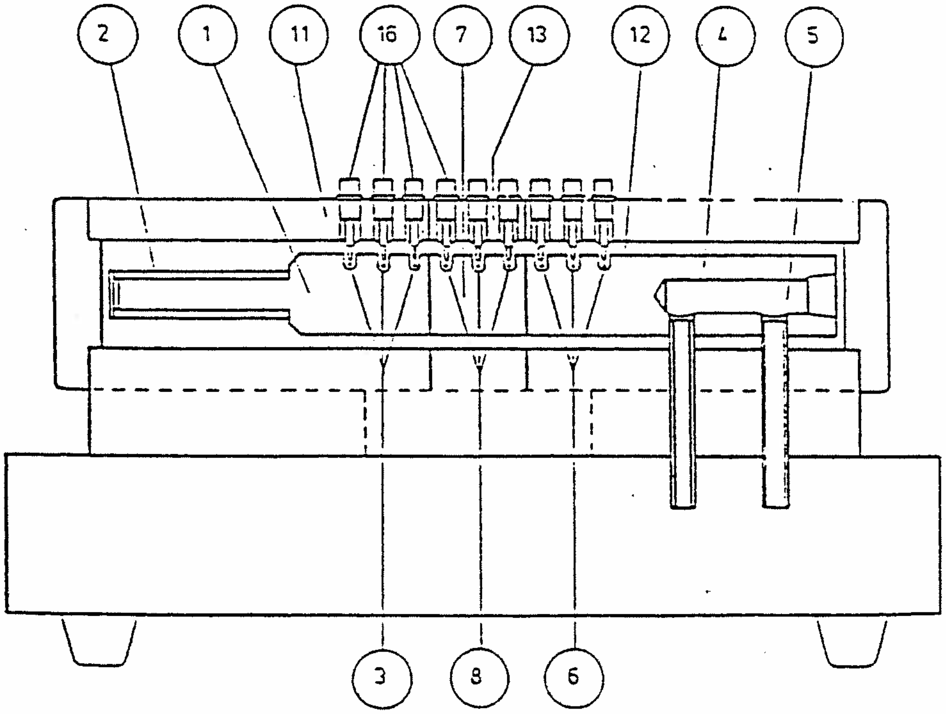


IDENTIFICATION DIAGRAM

Fig 1



RADIAL MODULE



LINEAR MODULE

HEAT CONDUCTION APPARATUS

Fig. 2

DESCRIPTION

(Refer to Fig.2, Page 8)

General

The equipment comprises two heat conducting specimens, a multi-section bar for the examination of linear conduction and a metal disc for radial conduction. An electrical console provides electrical power for heaters in the specimens and digital readout of the temperature at any of the selected points along the heat-conducting paths.

A small flow of cooling water provides a heat sink at the end of the conducting path in each specimen.

Linear Module

Fourier's Law of Heat Conduction is most simply demonstrated with the linear conduction module. This comprises a heat input section (1) manufactured from brass fitted with an electrical heater (2). Three thermistor temperature sensors (3) are installed at 10mm intervals along the working section which has a diameter of 25mm. A separate heat sink section (4), also of brass, is cooled at one end by running water (5) whilst its working section is also fitted with thermistor temperature sensors (6) at 10mm intervals. The heat input section (1) and the heat sink section (4) may be clamped directly together to form a continuous brass bar with temperature sensors at 10mm intervals. Alternatively any one of three intermediate sections can be fitted between these two. The first of these (7) is a 30mm length of the same material (brass) and is the same diameter as the heat input and heat sink sections, and is again fitted with thermistor sensors (8) at 10mm intervals. This section (7) is shown clamped between the two basic sections in Figure 1 and so forms a relatively long uniform bar with nine regularly spaced temperature sensors.

The second centre section (9), which may be fitted, is again brass and 30mm long, but has a diameter of 13mm and is not fitted with temperature sensors. This section allows a study of the effect of a reduction in the cross-section of the heat-conducting path.

The third centre section (10), which may be fitted, is of stainless steel and has the same dimensions as the first brass section. No temperature sensors are fitted. This section allows the study of the effect of a change in the material while maintaining a constant cross-section.

The mating ends of the five sections are finely finished to promote good thermal contact although heat-conducting compound may be smeared over the surfaces to reduce thermal resistance.

The heat-conducting properties of insulators may be found by simply inserting a thin specimen between the heated and cooled metal sections. An example of such an insulator is a piece of paper.

Construction of the modules is shown in Figure 2.

Heat losses from the linear module are reduced to a minimum by a heat-resistant casing (11) enclosing an air space (12) around the module. The interchangeable centre sections (7, 9 and 10) have their own attached casing pieces (13, 14 and 15) which fit with those of the heat input and heat sink sections.

The thermistor temperature sensors (3, 8 and 6) are connected to miniature plugs (16) fitted to the casing and connection from the sensors to the digital temperature readout are made via nine sensor leads fitted with appropriate sockets. Therefore temperature gradients can be readily plotted from rapidly acquired data.

The temperature selector switch on the front panel of the electrical console permits any of the nine temperatures to be displayed.

Radial Module

The radial conduction module comprises a brass disc (17) 110mm diameter and 3mm thick, heated in the centre by an electrical heater (18) and cooled by cold water in a circumferential copper tube (19). Thermistor temperature sensors (20) are fitted to the centre of the disc at 10mm intervals along a radius, there being six in all. Again heat losses are minimised by preserving an air gap (21) around the disc with a heat-resistant casing (22). As in the linear module, the thermistor connections are brought out to plugs in the casing (23) to which six sensor leads fitted with appropriate sockets may be connected to obtain individual temperature readings.

Electrical Console

Either of the heat-conduction modules may be connected to an electrical console which allows the heater input power to be set and the temperature at any of the sensors to be shown in °C on a digital readout.

Heater power is controlled by a variable auto transformer and displayed on a wattmeter with digital readout. Power outputs from 0 to 100 Watts may be obtained.

A nine position selector switch permits the temperature gradient along the specimen to be displayed.

INSTALLATION REQUIREMENTS

The equipment should be installed on a firm, level work surface adjacent to a water supply and drain.

A single phase electrical supply is required.

No other services are necessary.

H940 HEAT CONDUCTION UNIT

Experiments:

1. Conduction along a Simple Bar
   To investigate Fourier's Law for the linear conduction of heat along a simple bar.

2. Conduction along a Composite Bar
   To study the conduction of heat along a composite bar and evaluate the overall heat transfer coefficient.

3. Effect of Cross-Sectional Area
   To investigate the effect of a change in the cross-sectional area on the temperature profile along a thermal conductor.

4. Radial Conduction
   To examine the temperature profile and determine the rate of heat transfer resulting from radial steady conduction through the wall of a cylinder.

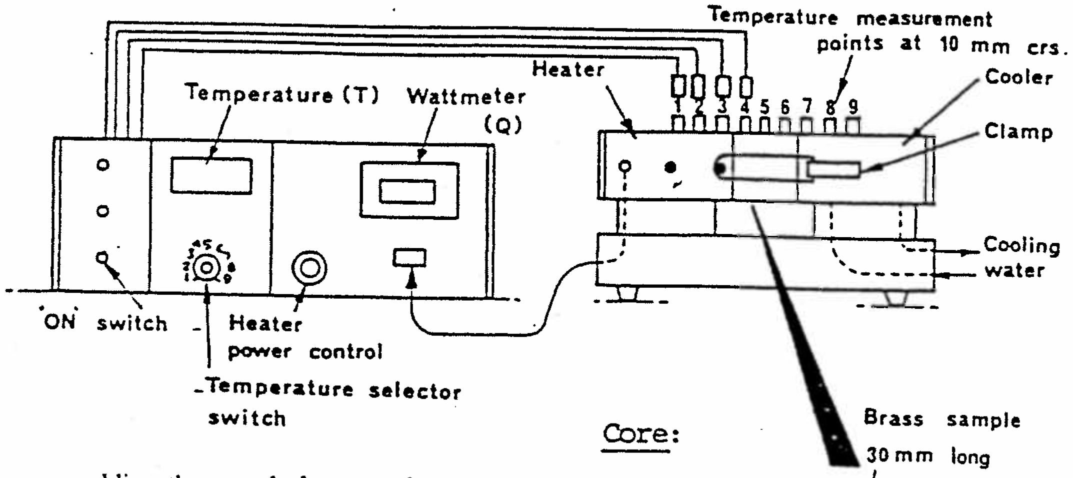
5. Effect of Surface Contact
   To demonstrate the effect of surface contact on thermal conduction between adjacent slabs of material.

6. Insulation Effects
   To investigate the influence of thermal insulation upon the conduction of heat between adjacent metals.

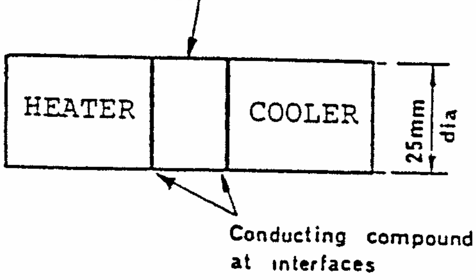
1. CONDUCTION ALONG A SIMPLE BAR

Experiment
To investigate Fourier's Law for the linear conduction of heat along a simple bar.

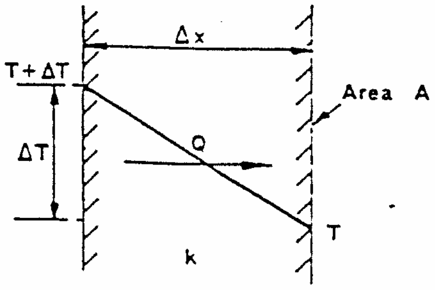
Equipment Set-Up



Note:
1. When assembling the sample between the heater and the cooler take care to match the shallow shoulders in the nylon housings.
2. Ensure that the temperature measurement points are aligned along the longitudinal axis of the unit.



Summary of Theory



If a plane wall of thickness (Δx) and area (A) supports a temperature difference (ΔT) then the heat transfer rate per unit time (Q) by conduction through the wall is found to be:

$$Q \propto A\frac{\Delta T}{\Delta x}$$

If the material of the wall is homogeneous and has a thermal conductivity (k) then:

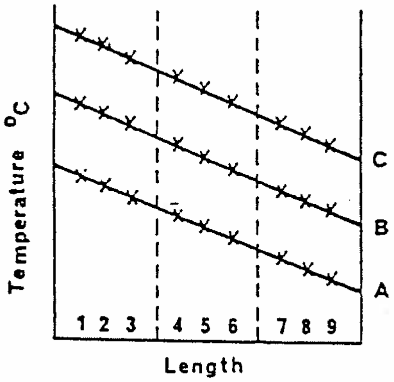
$$Q = kA\frac{dT}{dx}$$

It should be noted that heat flow is positive in the direction of temperature fall.

Readings to be taken
Select a low position for the heater power control (i.e. 20 Watts) and allow sufficient time for a steady state condition to be achieved before recording the temperature (T) at all nine sensor points and the input power reading on the wattmeter (Q). This procedure should be repeated for other input powers up to the maximum permitted (i.e. when T_1 = 100°C). After each change, sufficient time must be allowed to achieve steady state conditions.

Results

Test No	Wattmeter Q Watts	T_1 °C	T_2 °C	T_3 °C	T_4 °C	T_5 °C	T_6 °C	T_7 °C	T_8 °C	T_9 °C
A										
B										
C										



Plots of the temperature profile along the length of the core will result in a set of straight lines having approximately the same slope $\frac{dT}{dx}$

This slope may be used to determine the thermal conductivity of brass:

$$k = \frac{Q}{A}\frac{dx}{dT}$$

Appropriate multiplication factors should be introduced to convert the result to normally accepted units for thermal conductivity, i.e. W/m K

The result obtained should be compared with typical values for brass contained in tables of published data.

Students should comment upon the effect of average temperature on the values of thermal conductivity - k increases with T for brass. How does the factor influence the shape of the temperature profile.

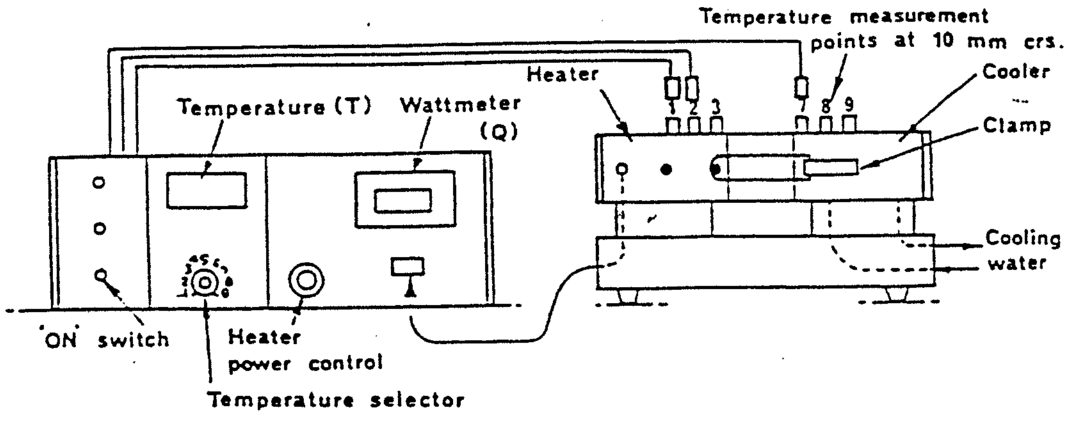
Note:
It is often necessary to evaluate the heat flow through a solid when the flow is not steady, e.g. through the wall of a furnace that is being heated or cooled. To calculate the heat flow under these conditions it is necessary to find the temperature distribution through the solid and how the distribution varies with time. Using the equipment set-up already described, it is a simple matter to monitor the temperature profile variation during either a heating or cooling cycle thus facilitating the study of unsteady state conduction.

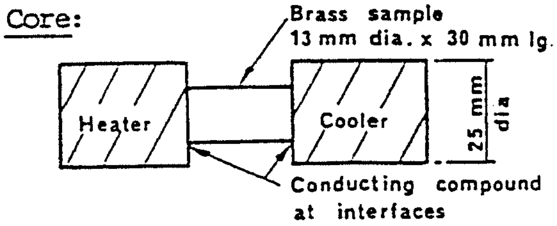
3. EFFECT OF CROSS-SECTIONAL AREA

Experiment

To investigate the effect of a change in the cross-sectional area on the temperature profile along a thermal conductor.

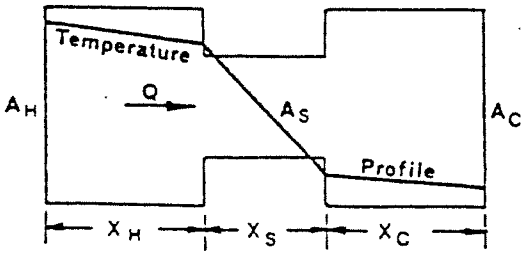
Equipment Set-Up





Note:
When assembling the sample between the heater and the cooler take care to match the shallow shoulders in the nylon housings.

Summary of Theory



Fourier's Law states that:

$$Q = kA\frac{dT}{dx}$$

From continuity the heat flow rate (Q) is the same for each section of the conductor. Also the thermal conductivity (k) is constant (assuming no change with average temperature of the material).

Hence: $$A_H\left(\frac{dT}{dx}\right)_H = A_S\left(\frac{dT}{dx}\right)_S = A_C\left(\frac{dT}{dx}\right)_C$$

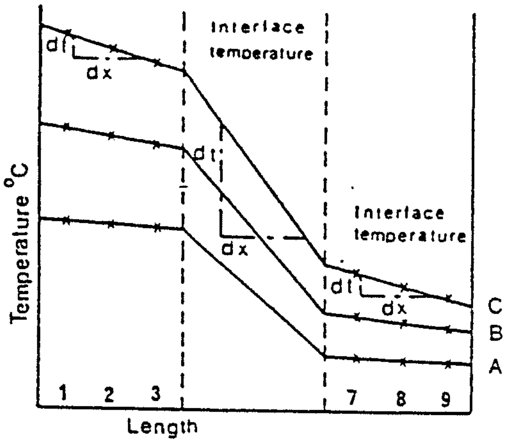
i.e. the temperature gradient is inversely proportional to the cross-sectional area.

Readings to be taken

Select a low position for the heater power control (i.e. 20 Watts) and allow sufficient time for a steady state condition to be achieved before recording the temperature (T) at all six sensor points and the input power reading on the wattmeter (Q). This procedure should be repeated for other input powers up to the maximum permitted (i.e. when T_1 = 100°C). After each change, sufficient time must be allowed to achieve steady state conditions.

Results

Test No	Wattmeter Q Watts	T_1 °C	T_2 °C	T_3 °C	T_7 °C	T_8 °C	T_9 °C
A							
B							
C							



Plots of the temperature profile in the heater and cooler should be extrapolated to the interfaces so as to determine the temperature gradient across the reduced area sample.

Using this graph, students should determine the ratio of the temperature gradient within the heater/cooler to the temperature gradient within the reduced area sample. It will be found that the gradients are in inverse proportion to the respective areas of cross section.

i.e. Gradient ratio

$$\frac{\textit{Area (heater/cooler)}}{\textit{Area (sample)}} = \left(\frac{\textit{Dia. (heater/cooler)}}{\textit{Dia. (sample)}}\right)^2$$

$$= \left(\frac{25}{13}\right)^2$$

$$= \underline{3.70}$$

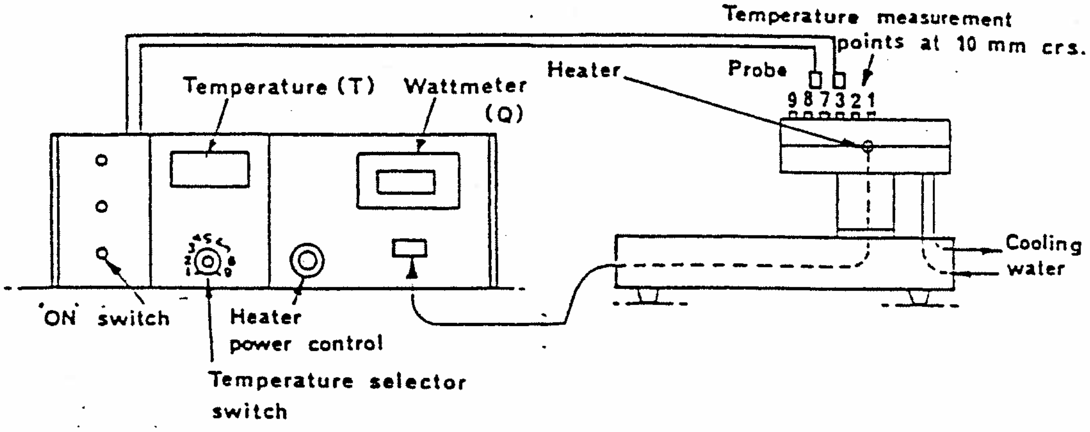
Students should account for any differences between measured and calculated results and comment upon the effects of varying the input power.

4. RADIAL CONDUCTION

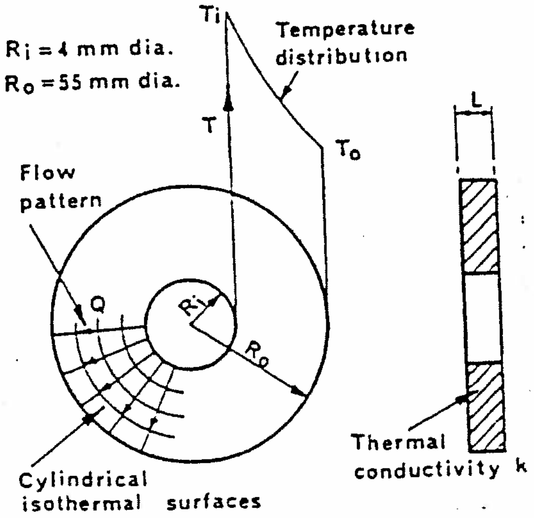
Experiment

To examine the temperature profile and determine the rate of heat transfer resulting from radial steady conduction through the wall of a cylinder.

Equipment Set-Up



Summary of Theory



When the inner and outer surfaces of a thick walled cylinder are each at a uniform temperature, heat flows radially through the cylinder wall. From continuity considerations the radial heat flow through successive layers in the wall must be constant if the flow is steady, but since the area of successive layers increases with radius, the temperature gradient must decrease with radius.

The amount of heat (Q) which is conducted across the cylinder wall per unit time is:

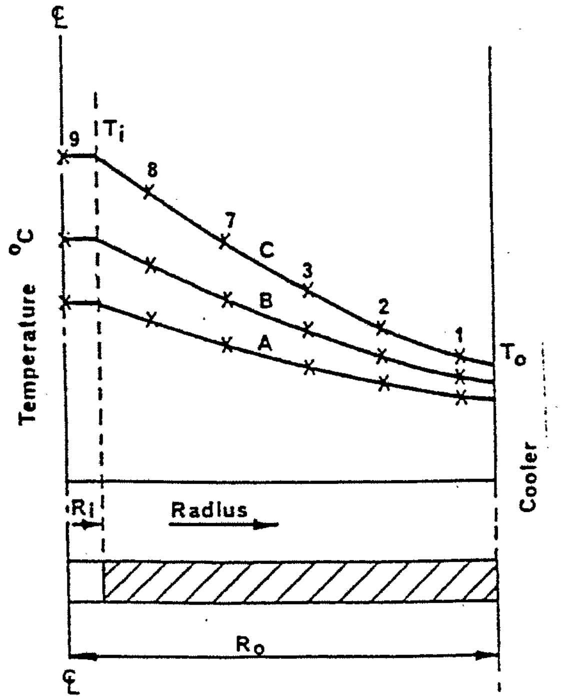
$$Q = 2\pi \ L \ k \left(\frac{T_i - T_o}{\log_e \dfrac{R_o}{R_i}} \right)$$

Readings to be taken

Select a low position for the heater power control (i.e. 20 Watts) and allow sufficient time for a steady state condition to be achieved before recording the temperature (T) at all six sensor points and the input power reading on the wattmeter (Q). This procedure should be repeated for other input powers up to the maximum permitted (i.e. when T_i = 100°C). After each change, sufficient time must be allowed to achieve steady state conditions.

Results

Test No	Wattmeter Q Watts	T_1 °C	T_2 °C	T_3 °C	T_7 °C	T_8 °C	T_9 °C
A							
B							
C							



Plots of the temperature profile along the radius should be drawn and the temperature T_o at the outer radius R_o of the disc should be determined from the curve. This data should be used to calculate the rate of radial heat conduction from the equation and the result compared with the measured heat input (Q) from the wattmeter.

Students should account for any difference between the measured input and the calculated conduction rate. A straight line plot can be obtained on log/linear graph paper with radius on the logarithmic axis and temperature on the linear axis.