P.A. HILTON LTD.

EXPERIMENTAL

OPERATING

AND

MAINTENANCE MANUAL

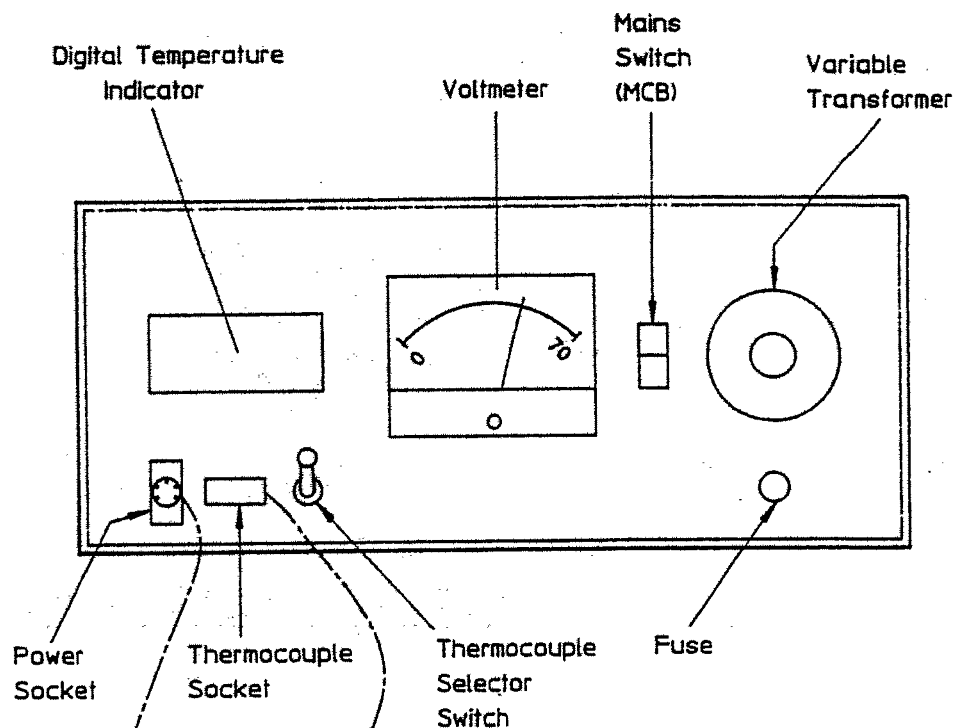
THERMAL CONDUCTIVITY OF LIQUIDS AND GASES UNIT

H470

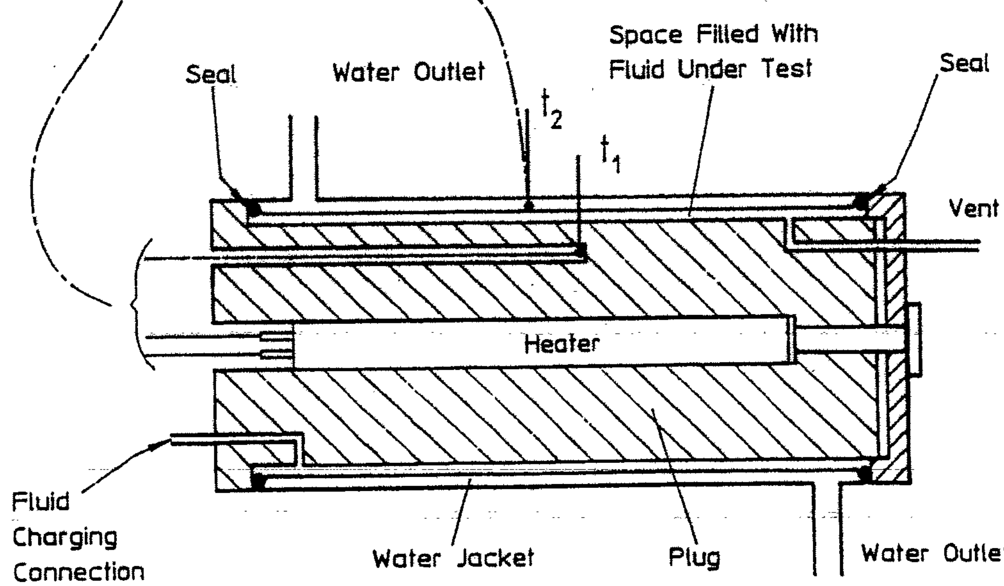
H470M/E/3/066

AUG 94

Thermal Conductivity of Liquids and Gases
Unit H470



Console



Plug / Jacket Assembly

SYMBOLS AND UNITS

Symbol	Quantity	Fundamental Unit
A	Area of Conducting Path	m^2
$\dot{Q}_c$	Conduction Heat Transfer Rate	W
$\dot{Q}_e$	Electrical Power Input	W
$\dot{Q}_i$	Incidental Heat Transfer Rate	W
R	Electrical Resistance	Ω
t	Temperature (Customary)	°C
Δt	Temperature Difference	K
V	Potential Diference	V
Δx	Length of Conducting Path	m
Δr	Radial Clearance (= Δx for the curved lamina)	m

Subscript

1	Plug
2	Jacket

Presentation of Numerical Data

In this manual, numerical quantities obtained during experiments, etc., are expressed in a non-dimensional manner. That is, the physical quantity involved has been divided by the units in which it has been measured.

As an example:

Pressure	$\frac{p}{10^3\ Nm^{-2}}$	150	

This indicates that $$\frac{p}{10^3\ Nm^{-2}} = 150$$

or $$p = 150 \times 10^3\ N\ m^{-2}$$

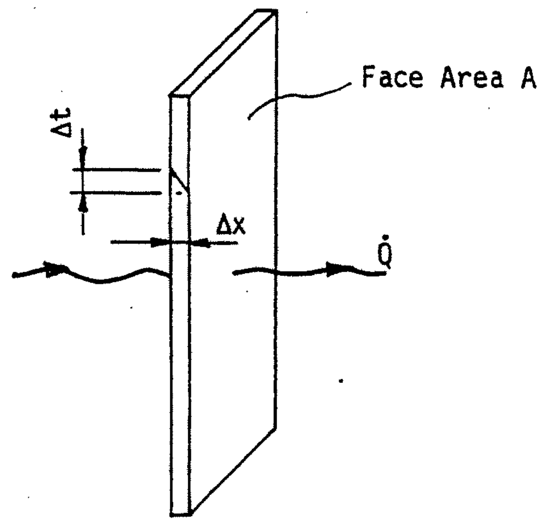
alternatively $$p = 150\ kN\ m^{-2}$$

INTRODUCTION

Conduction is the mode by which heat is transferred from a hot to a colder region in a solid or in a fluid (gas or liquid) whose movement is supressed.

Thermal Conductivity

Consider a lamina of conducting material of face area A and thickness Δx. Let a temperature difference Δt exist between opposite faces of the lamina as shown.



By inspection,

$$\left.\begin{aligned} \dot{Q}_c &\propto A \\ \dot{Q}_c &\propto \Delta t \\ \dot{Q}_c &\propto \frac{1}{\Delta x} \end{aligned}\right) \quad \dot{Q}_c \propto A\frac{\Delta t}{\Delta x}$$

or

$$\dot{Q}_c = kA\frac{\Delta t}{\Delta x}$$

(This is usually written $\dot{Q}_c = -kA\frac{\Delta t}{\Delta x}$ because, mathematically, the direction of heat transfer is opposite to that of the temperature gradient $\frac{\Delta t}{\Delta x}$.)

The Hilton Thermal Conductivity of Liquids and Gases Unit H470 has been designed to enable the thermal conductivity of a wide range of fluids to be determined.

DESCRIPTION
(Please refer to the schematic diagram)

The fluid whose thermal conductivity is to be determined fills the small radial clearance between a heated plug and a water cooled jacket. The clearance is small enough to prevent natural convection in the fluid and the fluid is presented as a lamina of face area $\pi d_m l$ and thickness Δr to the transfer of heat from the plug to the jacket.

The plug is machined from aluminium (to reduce thermal inertia and temperature variation) and contains a cylindrical heating element whose resistance at the working temperature is accurately measured. A thermocouple is inserted into the plug close to its external surface, and the plug also has ports for the introduction and venting of the fluid under test.

The plug is held centrally in the water jacket by 'O' rings which seal the radial clearance, but which allow quick dismantling for cleaning.

The jacket is constructed from nickel plated brass and has water inlet and drain connections and thermocouple t_2 is carefully fitted to the inner sleeve.

Due to the positioning of the thermocouples and the high thermal conductivities of the materials involved, the temperatures measured are effectively the temperatures of the hot and cold faces of the fluid lamina.

A small console is connected by flexible cables to the plug/jacket assembly and provides for the control of the voltage supplied to the heating element. An analogue voltmeter enables the power input to be determined and a digital temperature indicator with 0.1K resolution displays the temperatures of the plug and jacket surfaces.

USEFUL DATA

Nominal Resistance of Heating Element:	55 Ω *
Nominal Radial Clearance Between Plug and Jacket:	0.30mm *
Effective Area of Conducting Path through Fluid:	$0.0133 m^2$

*The actual values to be used are engraved on the head of the plug.

OPERATION

(i) Ensure that the mains switch is off.

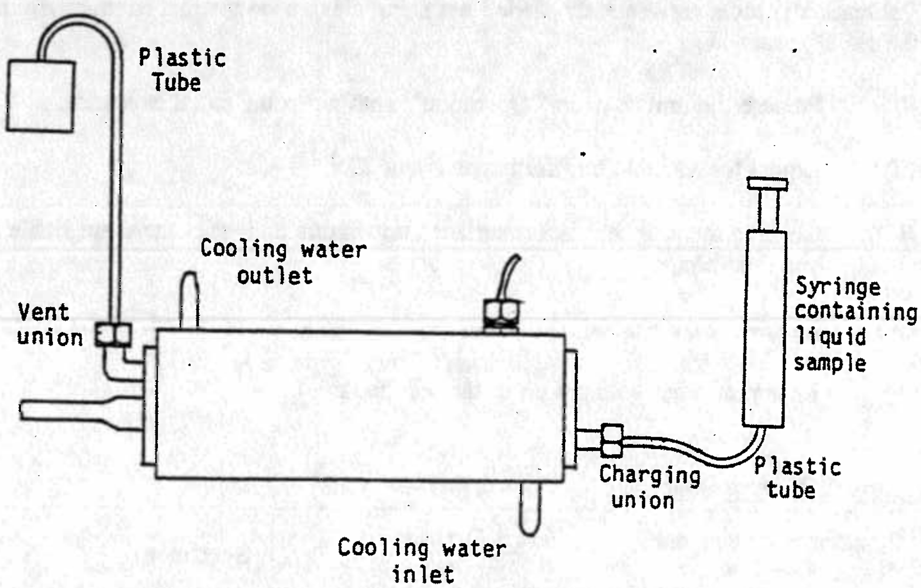
(ii) Remove the hexagonal bolt from the end of the plug and remove the end cap.

(iii) Push plug out of the jacket (taking care not to lose the 'O' rings) and ensure that they are clean.

(iv) Re-assemble plug jacket and end cap making sure that there is an 'O' ring seal at each end.

(v) Pass water through the jacket at about 3 litres per minute (the actual quantity is unimportant but a copious supply is necessary so that the jacket will operate at a sensibly constant temperature).

(vi) Connect the small flexible tubes to the charging and vent unions at either end of the plug and then introduce the liquid or gas to the radial clearance between the plug and jacket (see sketch).



Note: (a) When using a liquid it is important that sufficient is passed through the clearance space to ensure that air pockets are eliminated.

In addition, when injecting low viscosity liquids, such as water, it is <u>essential</u> that the liquid is injected <u>slowly</u> with the vent plug held higher than the charging point. Injecting the liquid rapidly causes bubbles that will remain in position during the test resulting in an apparently lower thermal conductivity than expected.

(b) When using a gas, the space must be thoroughly purged with the gas, and the flexible tubes must be closed off to prevent leakage.

(vii) Switch on the electrical supply and adjust the variable transformer to give about 40V for gases, or about 60V for liquids.

(viii) At intervals check the temperature of the plug and jacket surfaces and when they are stable, note their values and also the voltage.

Note: The toggle switch just below the temperature indicator will select either plug or jacket temperature.

DETERMINATION OF THE INCIDENTAL HEAT TRANSFER

Before using the unit to determine a thermal conductivity, it is necessary to determine the extent of the "incidental" heat transfer. This includes all heat transfers from the element in the plug OTHER than that transferred by conduction through the fluid under test.

The incidental heat transfer includes,

(a) Heat conducted from the plug to the jacket by the 'O' ring seals.

(b) Heat radiated from the plug to the jacket.

(c) Heat losses to the surroundings from the exposed ends of the plug.

Calibration

Calibration is most conveniently carried out using air (whose thermal conductivity is well known) in the radial space:

(i) Prepare the unit as under "Operation", with air in the radial clearance.

(ii) Adjust the variable transformer to about 20V.

(iii) Observe the plug and jacket surface temperature and when these are stable, note their values and the voltage.

(iv) Increase the electrical input to about 35V and when stable repeat the observations.

(v) Repeat at other voltages up to the maximum.

Typical Observations

Resistance of element Radial clearance	54.8 Ω * 0.34mm *		Specimen		
Voltage	/ V		41.0		
Plug surface temperature	t_1 / °C		41.9		
Jacket surface temperature	t_2 / °C		16.2		

*The values engraved on the plug must be used.

Calculations (for specimen)

Mean temperature of air

$$= \frac{41.9 + 16.2}{2} \ {}^\circ C$$

$$= \underline{29^\circ C}$$

From Page 13 the thermal conductivity of air at 29°C is 0.0265 W m^{-1} K^{-1}.

Temperature difference

$$\Delta t = 41.9 - 16.2$$

$$= \underline{25.7\ K}$$

Heat conducted through air

$$\dot{Q}_c = \frac{kA\,\Delta t}{\Delta r}$$
$$= \frac{0.0265 \times 0.0133 \times 25.7}{0.34 \times 10^{-3}}\ W$$
$$= \underline{26.64}\ W$$

Electrical Input

$$\dot{Q}_e = \frac{V^2}{R}$$
$$= \frac{41^2}{54.8}$$
$$= \underline{30.67}\ W$$

Incidental Heat Transfer

$$\dot{Q}_i = \dot{Q}_e - \dot{Q}_c$$
$$= 30.67 - 26.64$$
$$= \underline{4.03}\ W$$

Similar calculations at other voltages will yield results from which a graph of incidental heat transfer against temperature difference can be drawn.

This graph may then be kept safely and used when a thermal conductivity is to be determined.

A typical graph is shown on Page 14, but it must be stressed that the graph will vary from unit to unit.

DETERMINATION OF THE THERMAL CONDUCTIVITY OF A LIQUID OR A GAS

(i) Ensure that the unit has been calibrated (see Page 10), is clean and correctly assembled.

(ii) Prepare the unit as under Operation (Page 9) and introduce the test fluid to the radial clearance.

(iii) Switch on and adjust the variable transformer to give the desired voltage.

(iv) When stable, note the temperatures and the voltage.

Specimen Results

Resistance of Element:	54.8 Ω
Radial Clearance:	0.34 mm
Fluid:	Mineral Oil
Plug Surface Temperature:	28.4°C
Jacket Surface Temperature:	16.2°C
Heater Voltage:	60.5V

Specimen Calculation

Element Heat Input

$$(\dot{Q}_e) = \frac{V^2}{R} = \frac{60.5^2}{54.8}\ W = \underline{66.8}\ W$$

Temperature Difference

$$(\Delta t) = 28.4 - 16.2\ K = \underline{12.2}\ k$$

Incidental Heat Transfer at 12.2K temperature difference (from Page 14),

$$(\dot{Q}_I) = \underline{1.8}\ W$$

Heat Transfer by Conduction through the Oil,

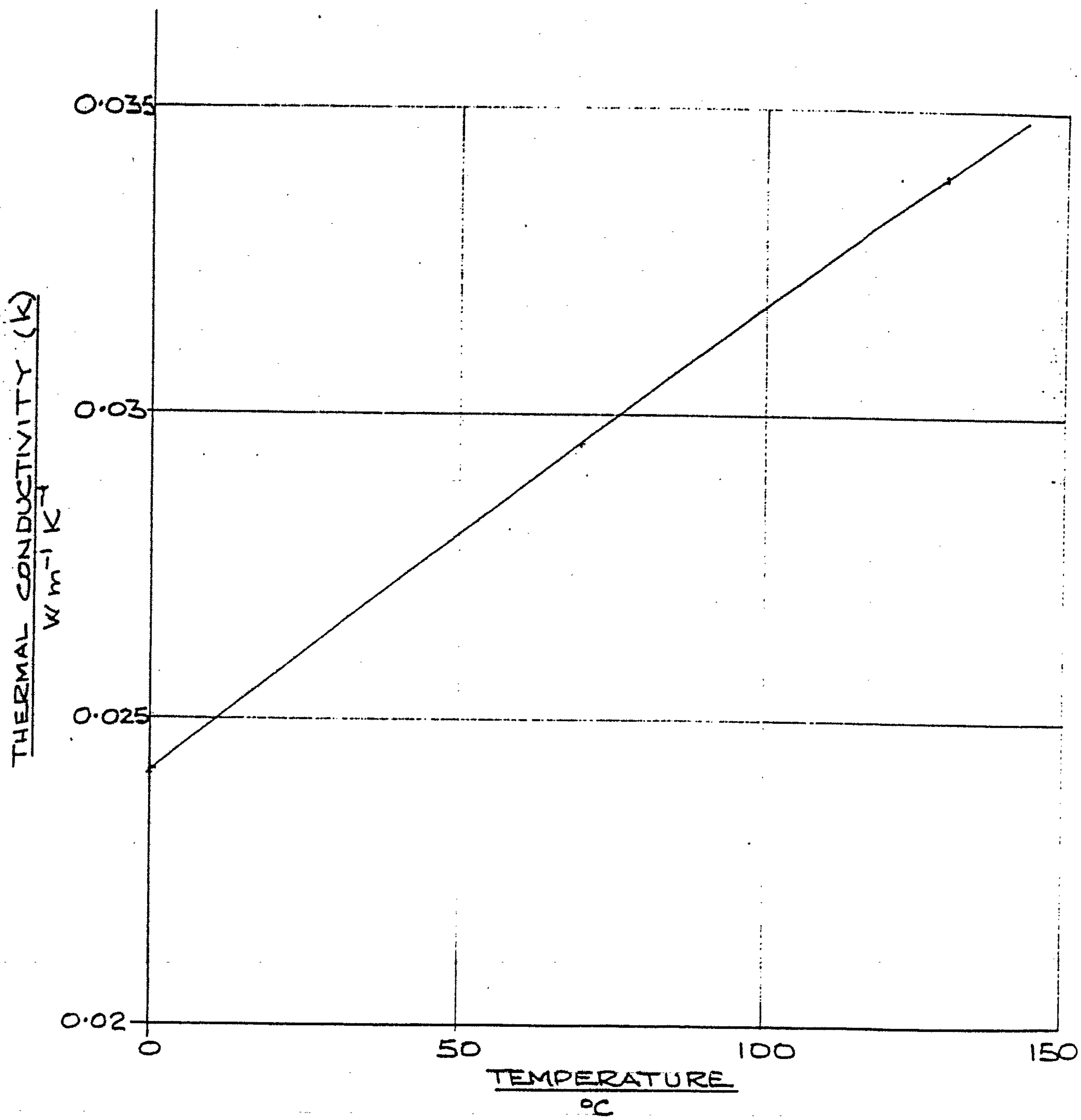
$$(\dot{Q}_c) = \dot{Q}_e - \dot{Q}_I = 66.8 - 1.8\ W$$

$$\dot{Q}_c = \underline{65.0}\ W$$

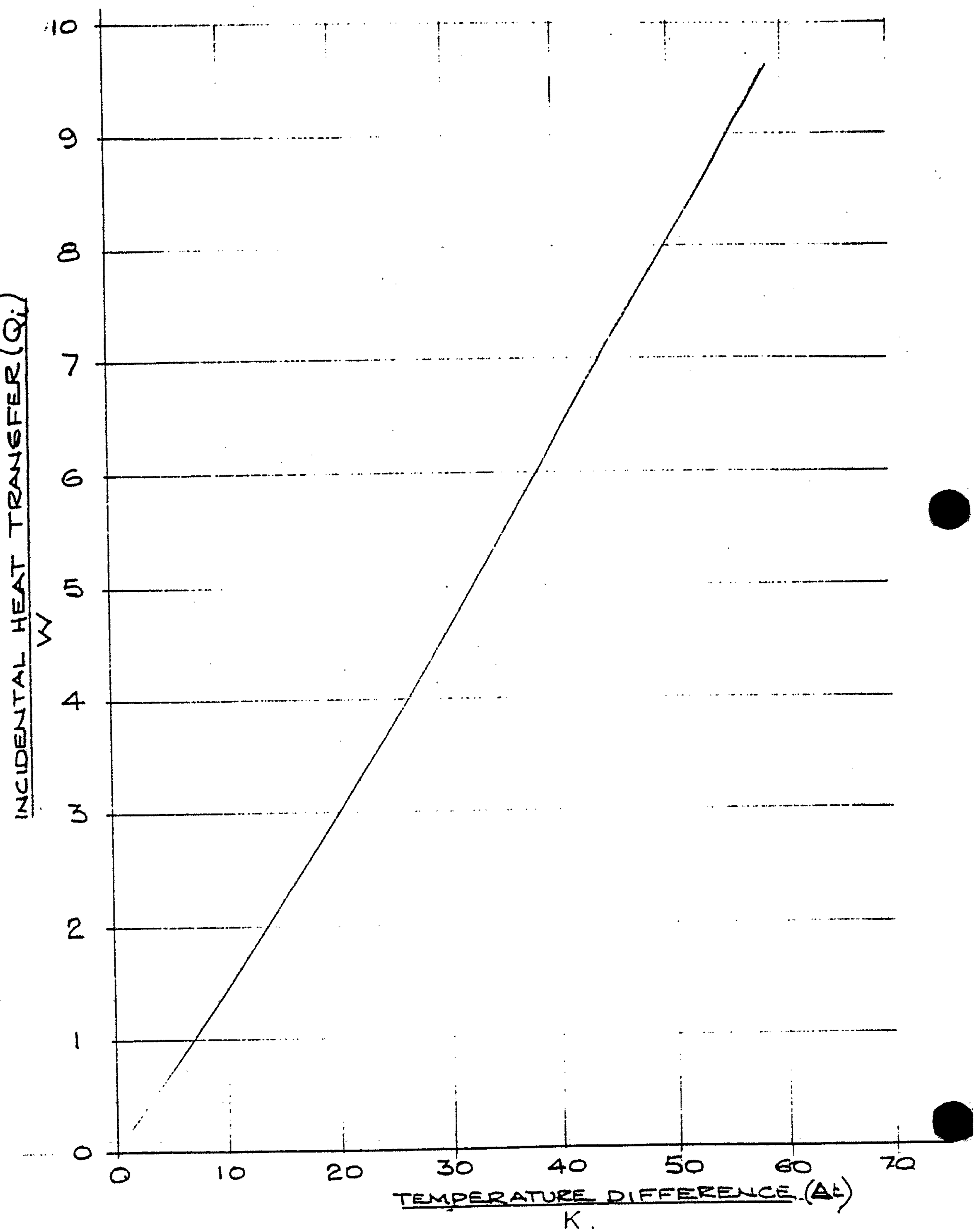
Thermal Conductivity of Oil Sample,

$$(k_{oil}) = \frac{\dot{Q}_c\ \Delta r}{A\ \Delta t} = \frac{65 \times 0.34 \times 10^{-3}}{0.0133 \times 12.2}$$

$$k_{oil} = \underline{0.136}\ W\ m^{-1}\ K^{-1}$$



THERMAL CONDUCTIVITY OF DRY AIR.



SPECIMEN CALIBRATION CURVE.