P.A.Hilton Ltd

H112H MANUAL

INSTRUCTION MANUAL

EXPERIMENTAL

OPERATING

AND

MAINTENANCE PROCEDURES

OPTIONAL

THERMAL CONDUCTIVITY OF LIQUIDS AND GASES UNIT

H112H

H112H_E_1_024
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TABLE OF CONTENTS

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
I	Heater Current	A
t	Temperature (Customary)	^oC
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:

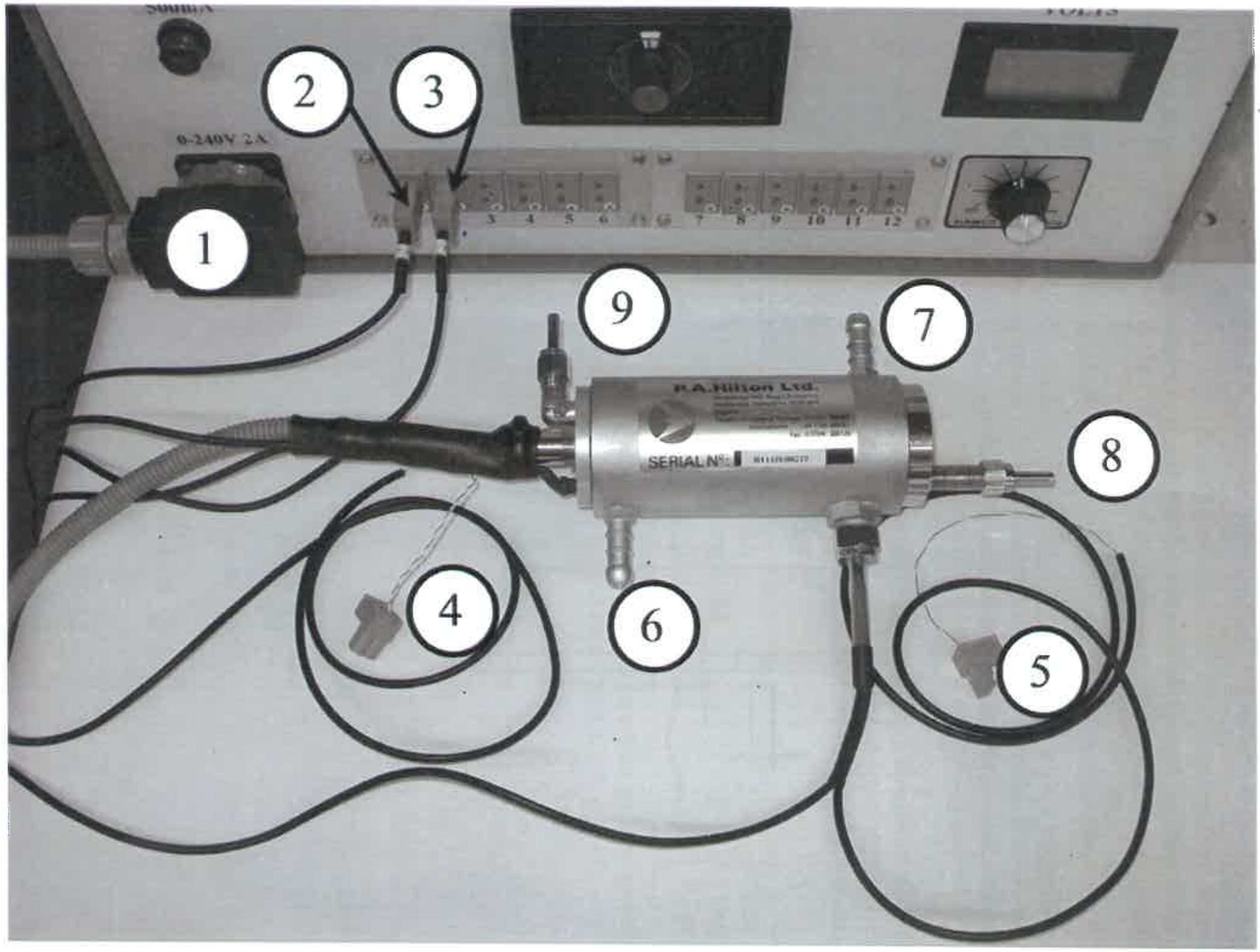
Pressure	$\dfrac{p}{10^3\ Nm^{-2}}$	150	

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

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

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

Thermal Conductivity of Liquids and Gases H111H



Key

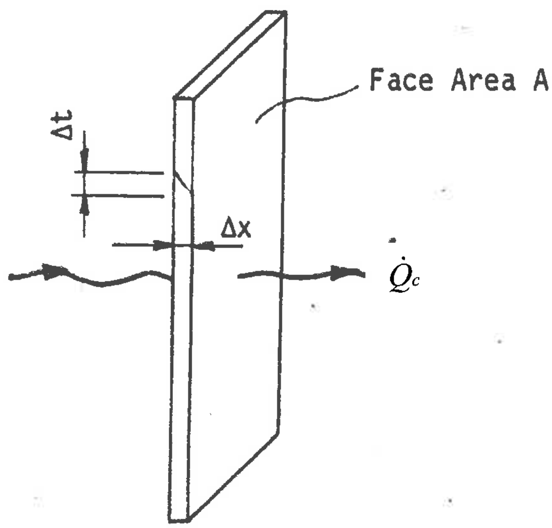
1. **Power Plug**
2. **Thermocouple t1**
3. **Thermocouple t2**
4. **Logger Thermocouple t1**
5. **Logger thermocouple t2**
6. **Cooling water in/out**
7. **Coolling water in/out**
8. **Test fluid inlet**
9. **Test fluid vent**

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,

$$\dot{Q}_c \propto A$$
$$\dot{Q}_c \propto \Delta t$$
$$\dot{Q}_c \propto A\frac{\Delta t}{\Delta x}$$
$$\dot{Q}_c \propto \frac{1}{\Delta x}$$

or

$$\dot{Q}_c = kA\frac{\Delta t}{\Delta x}$$ Where k is a constant

This constant k is a property of the material and is known as the **Thermal Conductivity**

(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 H112H Thermal Conductivity of Liquids and Gases Unit has been designed to enable the thermal conductivity of a wide range of fluids (liquids and gases) to be determined.

SPECIFICATION

General:

Bench top accessory for the determination of thermal conductivity of liquids and gases; complete with a console for the control and display of temperature and heat input.

Detailed:

Plug/Jacket Assembly

Cylindrical water jacket, constructed from nickel plated brass and fitted with K type thermocouple to measure inner surface temperature (t2). Mounted on stainless steel stand.

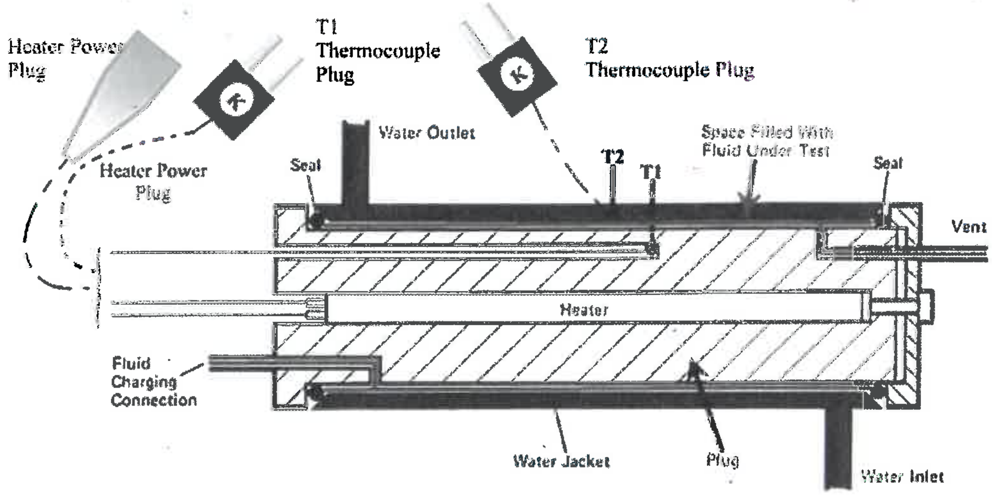
Cylindrical plug, machined from aluminium and anodised. Housing heating element and K type thermocouple(t1) close to the plug surface. Provided with ports for introduction and venting of fluid under test.

Plug diameter	(dm)	39mm.
Effective length	(l)	110mm.
Radial clearance (nominal)	(Δr)	0.3mm.

(Note: The actual radial clearance and the resistance of the element are stated on the plug.)

DESCRIPTION
(Please refer to the schematic diagram on page H1 and the diagram below)

The optional Thermal Conductivity of Liquids and Gases Unit H112H allow students to simply investigate the thermal conductivity (k) of a wide range of fluids. The H112H is dependent upon the Heat Transfer Service Unit H112, for heater power and temperature measurement.
In common with all of the optional heat transfer units the accessory has additional connections for using the optional HC113B Data Acquisition Upgrade.



Plug/Jacket Assembly

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 heated using a cartridge heater supplied with power by the H112 Heat Transfer Service unit. Power is measured by the standard panel mounted voltmeter and ammeter and controlled using the panel mounted control knob.

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.

USEFUL DATA

Nominal Radial Clearance between Plug and Jacket: 0.30mm *

Effective Area A of Conducting Path through Fluid : $0.0133 m^2$

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

WARNINGS

1. Only liquids and gases compatible with the materials of construction, (i.e. brass, nickel plated brass, anodised aluminium, PVC and Viton), should be used.

2. The unit must not be operated unless water is flowing through the jacket at approximately 3 litres per minute. Note that the flow rate is not important so long as the flow is sufficient to cool the jacket to ambient temperature or below.

3. Always dismantle and clean the plug and jacket after use to prolong the surface finish.

INSTALLATION
THERMAL CONDUCTIVITY OF LIQUIDS AND GASES UNIT H112H
WITH HEAT TRANSFER SERVICE MODULE H112

Refer to the schematic diagram on page H 1

It is assumed that the basic INSTALLATION AND COMMISSIONING procedures for the Heat Transfer Service Unit H112 have been completed as detailed in the H112 manual.

Ensure that the main switch is in the OFF position.

Place the Thermal Conductivity of Liquids and Gases Unit on a flat surface adjacent to the Heat transfer Service Unit H112

Temperature Sensors
The two temperature sensors are type K thermocouples and each lead has a number label (1 and 2).

The miniature plugs on each thermocouple have one wide and one narrow flat blade that match the slots on the thermocouple sockets. Connect the plugs to the corresponding numbered sockets on the Heat transfer service Unit H112.

Heating Element
Connect the 8-pole power lead(1) to the OUTPUT socket on the front panel of the Heat Transfer Service Unit H112.

Cooling Water Supply
The Thermal Conductivity of Liquids and Gases Unit H112H requires connection to a source of clean, cold water with a flow of approximately 1.5 litres/minute. This should be fitted with an isolation valve so that when not in use the supply can be turned off.

Connect to the cold-water inlet(6) or (7) point using the clear PVC tubing supplied. Note that either coupling may be used as inlet or outlet. Orientation is not important.

Cooling Water Drain
Connect the PVC tubing to the outlet nozzle. This should be led to a drain and the tube secured so that it cannot fall out during use.

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 the 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, with 'O' ring seal fitted 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

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 **essential** that the liquid is injected **slowly** 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 turn the voltage control clockwise to give approximately 170 volts for liquids and 110volts for gases. The actual voltage required will depend upon the medium being tested. The most accurate results will be obtained with a larger temperature difference.

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

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 60V.

(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 100V and when stable repeat the observations.

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

Typical Observations

Radial clearance Δr	0.34mm *		**Specimen**		
Voltage	/ V		117		
Current	/ A		0.262		
Plug surface temperature	t_1 / °C		41.9		
Jacket surface temperature	t_2 / °C		16.2		

*The value 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 H13 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

$$\dot{Q}_e = V \times R$$
$$= 117 \times 0.262$$
$$= 30.65W$$

Incidental Heat Transfer

$$\dot{Q}_i = \dot{Q}_e - \dot{Q}_c$$
$$= 30.65 - 26.64$$
$$= 4.01W$$

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 H10), is clean and correctly assembled.

(ii) Prepare the unit as under Operation (Page H8) 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

Radial Clearance: 0.34 mm
Fluid: Mineral Oil

Plug Surface Temperature:	28.4°C
Jacket Surface Temperature:	16.2°C
Heater Voltage:	173V
Heater Current	0.384A

Specimen Calculation

Element Heat Input

$$\dot{Q}_e = V \times R$$
$$= 173 \times 0.384$$
$$= 66.4W$$

Temperature Difference

$$\Delta t = 28.4 - 16.2\ K$$
$$= 12.2K$$

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

$$\dot{Q}_i = 1.8W$$

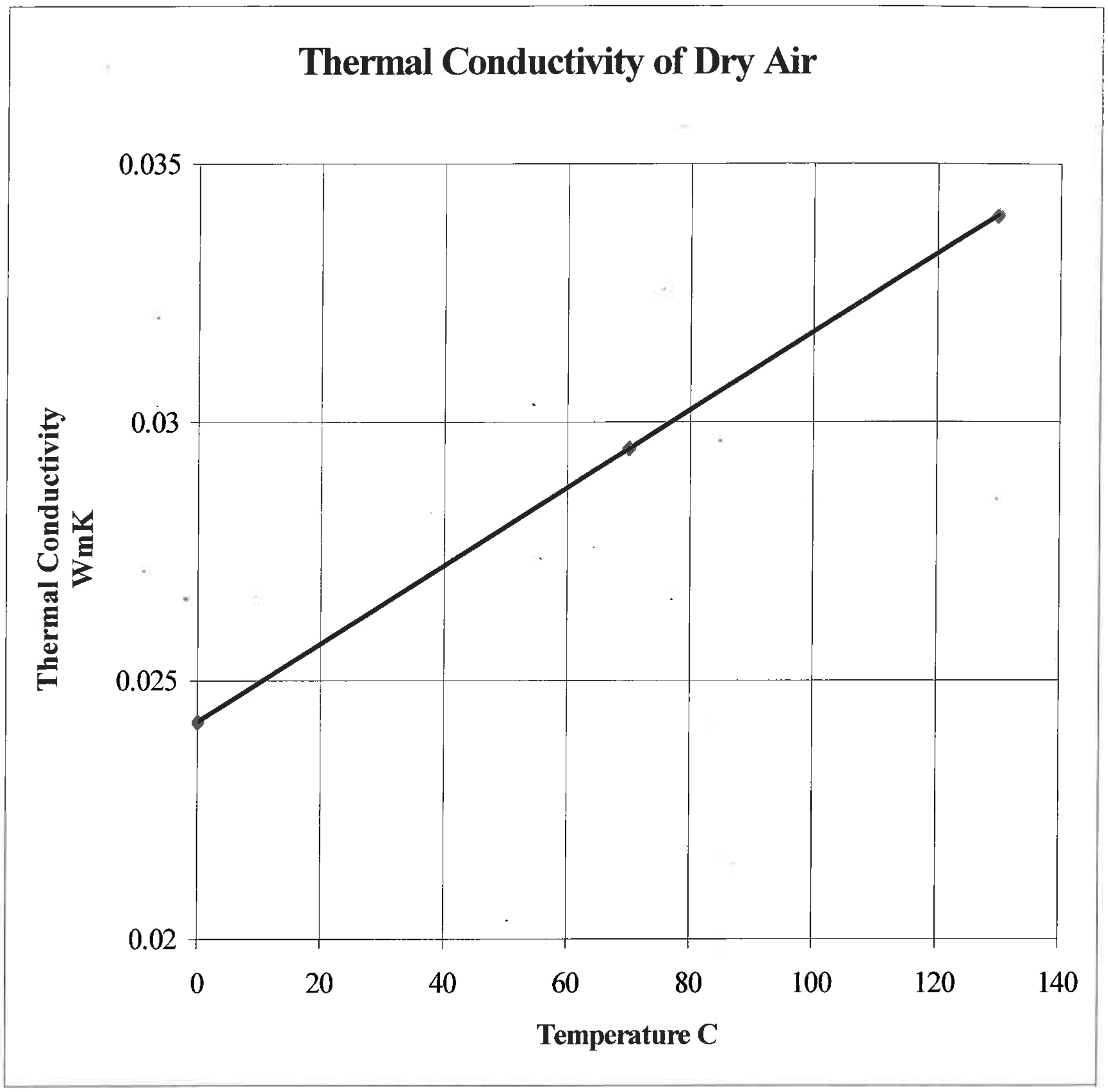
$$\dot{Q}_c = \dot{Q}_e - \dot{Q}_i$$
$$= 66.4 - 1.8\ W$$
$$\dot{Q}_c = 64.6W$$

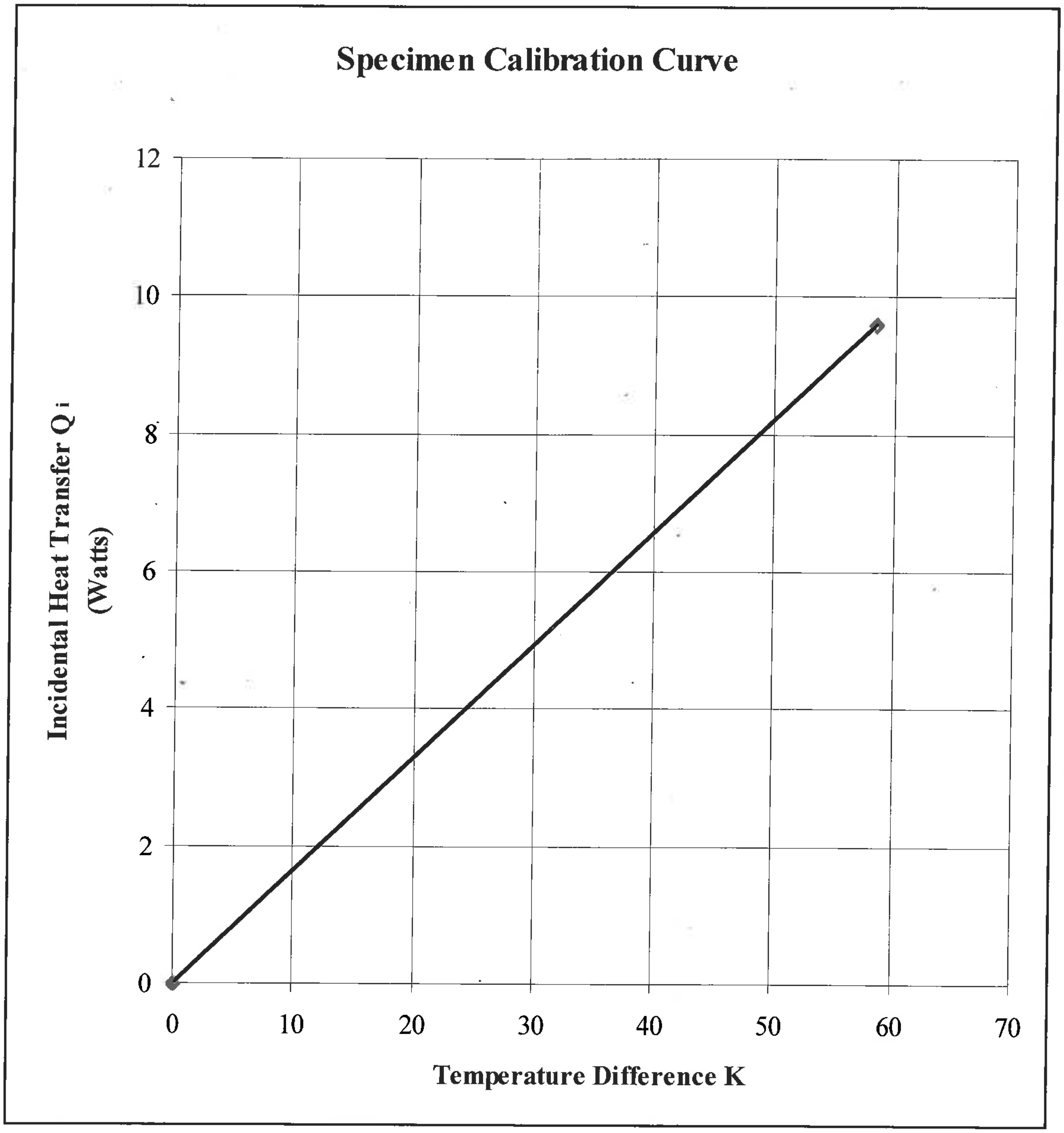
Heat Transfer by Conduction through the Oil,

Thermal Conductivity of Oil Sample,

$$(k_{oil}) = \frac{\dot{Q}_c\,\Delta r}{A\,\Delta t}$$
$$= \frac{64.6 \times 0.34 \times 10^{-3}}{0.0133 \times 12.2}$$
$$k_{oil} = 0.135\,W\,m^{-1}\,K^{-1}$$

Thermal Conductivity Graph




Specimen Calibration Curve
Incidental Heat Transfer Q i (Watts)
Temperature Difference K
0
2
4
6
8
10
12
0
10
20
30
40
50
60
70

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