ENE 310 – ENE 320
ENGINEERING LABORATORY I

LINEAR HEAT CONDUCTION

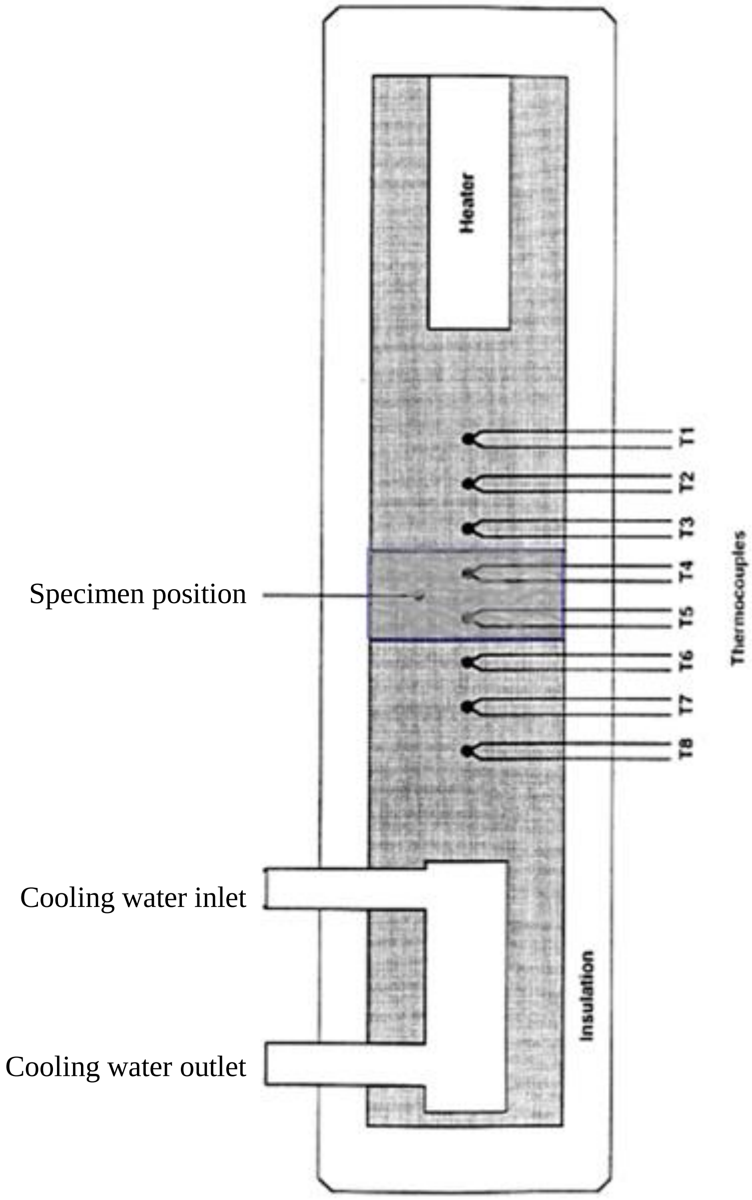
MANUAL

AIM OF THE EXPERIMENT

The Linear Heat Conduction experiment allows the investigation of the basic laws of heat transfer by conduction through a solid. In this experiment, conduction through two different configurations can be demonstrated.

EXPERIMENTAL SET-UP

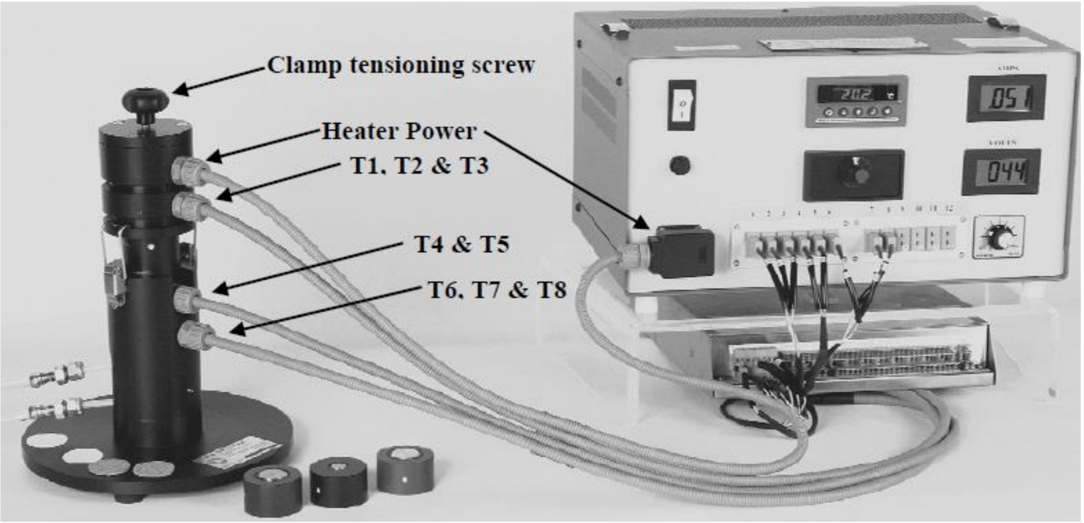
Schematic Diagram H112A

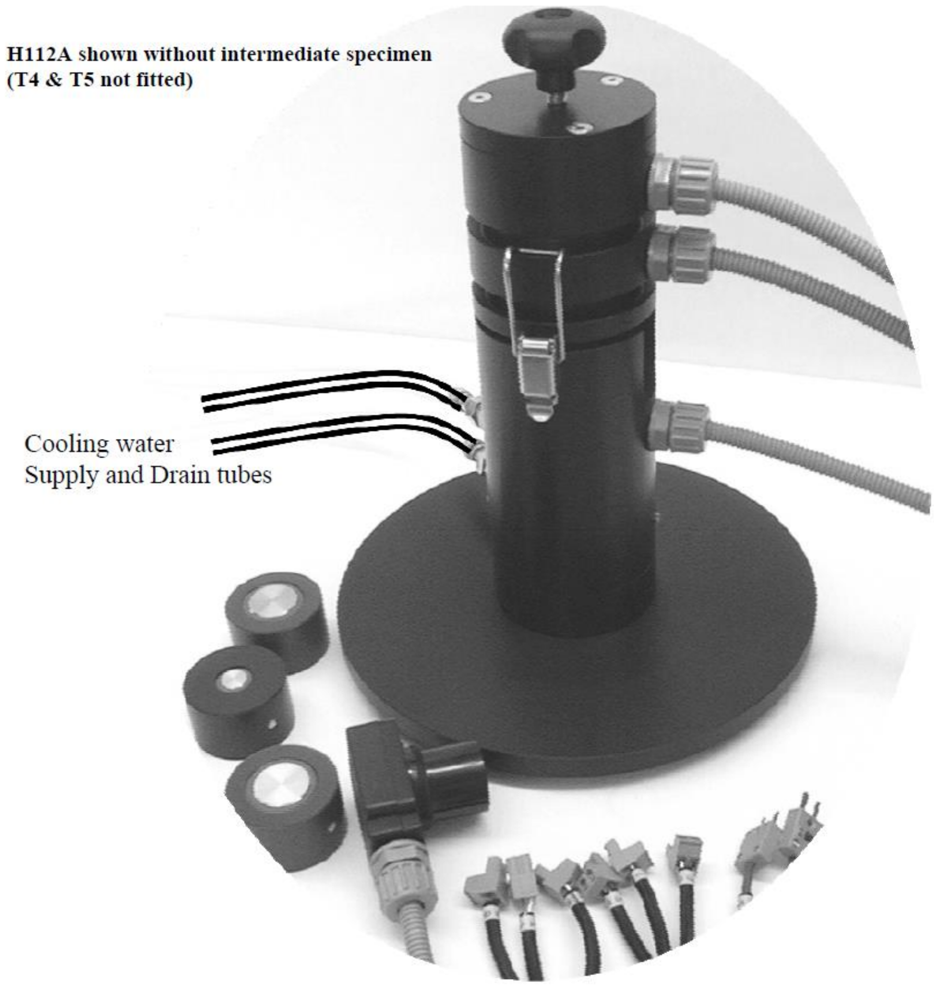


Typical Installation

Heat Transfer service Unit H112 shown with H112A Linear Heat Conduction Unit and HC112A Data Acquisition Upgrade.

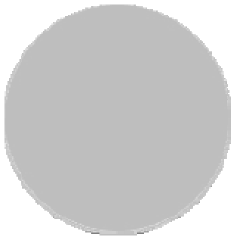
Note that the digital temperature indicator and selector switch shown, have been replaced by a combined indicator and selector



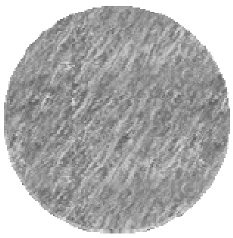


Specimen supplied

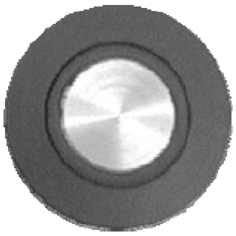
Heat transfer paste



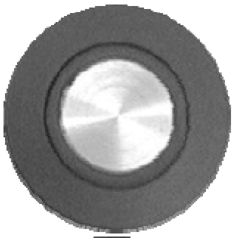
Paper disc insulator



Cork disc insulator



25mm diameter Aluminium



25mm diameter Stainless Steel

13mm (Reduced diameter) Brass

SYMBOLS AND UNITS

Symbol	Quantity	Fundamental Unit
D	Diameter of element	m
A	Heat transfer area	m^2
x	Distance or thickness	m
V	Voltage to heating element	V
I	Current to heating element	A
$\dot{Q}$	Power to heating element and heat transfer rate	W
T	Temperature measured	°C
T	Temperature Difference	K
k	Thermal conductivity	W/mK
U	Overall heat transfer coefficient	W/m^2K
R	Resistance to heat flow	m^2K/W
t	Elapsed time	seconds

Subscripts

hot	Heating section
cold	Cooling section
int	Intermediate section
hotface	Contact face of heated section
coldface	Contact face of cooling section
1,2,3,4....	Thermocouple positions

Description of the Experimental Set-up

The Linear Heat Conduction unit H112A allows the investigation of the basic laws of heat transfer by conduction through a solid. The H112A is dependent upon the Heat Transfer Service Unit H112, for heater power and temperature measurement.

The unit is mounted on a plastic base plate that must be placed on a surface, ideally to the left of the Heat Transfer service Unit H112.

The heat transfer module is cylindrical and mounted with its axis vertical to the base plate. The heating section houses a 25 mm diameter cylindrical brass section with a nominally 65 Watt (at 240 V AC) cartridge heater in the top end. An integral high temperature cut out (automatic reset) prevents overheating. Power is supplied to the heater from the Heat Transfer Service Unit H112 via the 8-pole plug and lead.

Three fixed thermocouples T1, T2, T3 are positioned along the heated section at 15 mm intervals. The cooling section is also manufactured from 25 mm diameter brass to match the heated top section and is cooled at its bottom end by water flowing through a chamber in the material. Three fixed thermocouples T6, T7, T8 are positioned along the cooled section at 15 mm intervals.

The heated section, cooling section and all the intermediate sections are located co-axially inside plastic housings. An annular air gap insulates the specimens from the surroundings and minimise heat losses/gains. The heated and cooled sections incorporate centralising 'O' rings to ensure that each are held concentrically. Similar 'O' rings are fitted to the intermediate sections so that they are installed in alignment.

Toggle clamps ensure that the heated and cooled sections are held tightly together, with or without the intermediate sections installed. Slacken the clamp tensioning screw before releasing the toggle clamps and re-apply tension after fitting a new specimen, thus avoiding over-stressing the clamping device.

Water for the cooled section is supplied from a local tap via the supplied hoses. The water flow rate is adjusted by manual control of the supply tap. After cooling the cooled section, the water is allowed to run to a drain via the outlet hose.

The intermediate sections supplied are as follows: -

Brass Specimen

30 mm long, 25 mm diameter fitted with two thermocouples T4, T5 at 15 mm intervals along the axis. With the brass specimen clamped between the heated and cooled sections a uniform 25 mm diameter brass bar is formed with 8 uniformly spaced (15 mm intervals) thermocouples (T1 to T8). Refer to Figure A3 on page A3. The specimen is marked 'TOP' to ensure T4 precedes T5.

Brass Specimen with Reduced Diameter: 30 mm long, 13 mm diameter. No thermocouples fitted.

Other Specimens: 30 mm long, 25 mm diameter. No thermocouples fitted

In addition, the heat conducting properties of insulators such as cork and paper may be found by clamping the insulating discs between the heated and cooled sections. The effect of good thermal contact between conducting surfaces is demonstrated by experiments with and without toggle clamps.

The value of heat transfer paste may be verified by experiments with and without paste.

The eight temperature sensors are type K thermocouples and each lead has a number label. The miniature plugs on each thermocouple have one wide and one narrow flat blade that match the slots on the thermocouple sockets.

The Linear Heat Conduction H112A 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. Cooling Water drains through 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.

Useful Data

Heated Section
Material: Brass, 25 mm diameter, Thermocouples T1, T2, T3 at 15mm spacing
Thermal Conductivity: Approximately 121 W/m K

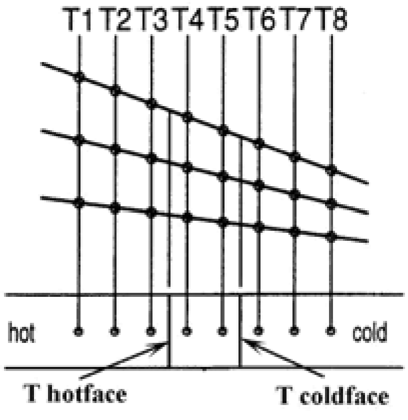
Cooled Section
Material: Brass, 25 mm diameter, Thermocouples T6, T7, T8 at 15mm spacing
Thermal Conductivity: Approximately 121 W/m K

Brass Intermediate Specimen
Material: Brass, 25 mm diameter x 30 mm long. Thermocouples T4, T5 at 15mm spacing centrally spaced along the length.
Thermal Conductivity: Approximately 121 W/m K

Stainless Steel Intermediate Specimen
Material: Stainless steel, 25 mm diameter x 30 mm long. No thermocouples fitted.
Thermal Conductivity: Approximately 25 W/m K

Aluminium Intermediate Specimen
Material: Aluminium Alloy, 25 mm diameter x 30 mm long. No thermocouples fitted.
Thermal Conductivity: Approximately 180 W/m K

Hot and Cold Face Temperature
Due to the need to keep the spacing of the thermocouples constant at 15 mm with, or without the intermediate specimens in position the thermocouples are displaced 7.5 mm back from the end faces of the heated and cooled specimens and similarly located for the Brass Intermediate Specimen.



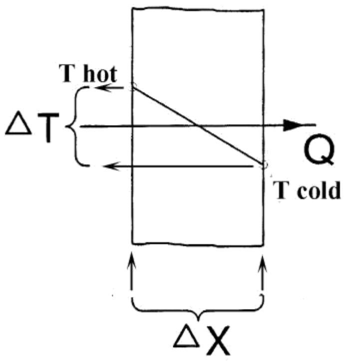
Hence,

$$T_{hotface} = T3 - \frac{(T2 - T3)}{2} \quad \text{and} \quad T_{coldface} = T6 + \frac{(T6 - T7)}{2}$$

These temperature values will be used for temperature values of intermediate specimen faces, except for brass specimen, which has its own thermocouples embedded. Note that the distance between T3 and the hot face and T6 and the cold face are equal to half the distance between the adjacent pairs of thermocouples.

THEORY OF THE EXPERIMENT

If the heated and cooled surfaces are clamped tightly together and are in good thermal contact, then the two sections can be considered as a continuous homogenous sample of uniform cross section and material.



According to Fourier's law of heat conduction: If a plane section of thickness x and constant area A maintains a temperature difference T then the heat transfer rate per unit time $\dot{Q}$ by conduction through the wall is found to be:

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

$$\dot{Q} = C \frac{\Delta T}{\Delta x} \qquad \text{where} \qquad C = \frac{\dot{Q}}{\frac{\Delta T}{\Delta x}}$$

where, C is called thermal conductivity of the wall.

If the material of the wall is homogeneous and has a constant thermal conductivity k then

$$\dot{Q} = -kA \frac{\Delta T}{\Delta x}$$

The negative sign follows thermodynamic convention in that heat transfer is normally considered positive in the direction of temperature fall. In each uniform section, thermal conductivity k of the section material can be found using the following;

$$k = \frac{\Delta x}{\Delta T} \frac{\dot{Q}}{A}$$

The following are the results of a sample test and illustrative calculations showing the application of the above theory.

Sample Test Results

Sample No.	T1	T2	T3	T4	T5	T6	T7	T8	V	I
	ºC	ºC	ºC	ºC	ºC	ºC	ºC	ºC	Volts	Amps
1	30.9	28.4	25.9	–	–	24.5	21.9	20.1	88	0.098
Distance from T1	0.000	0.015	0.030	–	–	0.045	0.060	0.075	–	–

Calculations

For sample No.1 the example calculations are as follows:

Sample No.	$\dot{Q}$	ΔT_{1-3}	ΔT_{6-8}	Δx_{1-3}	Δx_{6-8}	$\frac{\Delta T_{1-3}}{\Delta x_{1-3}}$	$\frac{\Delta T_{6-8}}{\Delta x_{6-8}}$	$\dot{Q}/\left(\frac{\Delta T_{1-3}}{\Delta x_{1-3}}\right)$	$\dot{Q}/\left(\frac{\Delta T_{6-8}}{\Delta x_{6-8}}\right)$
	Watts	˚C	˚C	m	m	K/m	K/m	Wm/K	Wm/K
1	8.6	5.0	4.4	0.03	0.03	166.7	146.7	0.051	0.058

Heat transfer rate from the heater, which will be the same for both heated and cooled sections

$$\dot{Q} = V \times I$$
$$= 88 \text{ x } 0.098 = 8.6 \text{ Watts}$$

Temperature difference in the heated section between T1 and T3

$$\Delta T_{hot} = \Delta T_{1-3} = T_1 - T_3$$
$$= 30.9 - 25.9 = 5.0 \text{ ˚C}$$

Similarly, the temperature difference in the cooled section between T6 and T8

$$\Delta T_{cold} = \Delta T_{6-8} = T_6 - T_8$$
$$= 24.5 - 20.1 = 4.4 \text{ ˚C}$$

The distance between the temperature measuring points, T1 and T3 and T6 and T8, are similar

$$x_{1\text{-}3} = 0.03 \text{ m}$$
$$x_{6\text{-}8} = 0.03 \text{ m}$$

Hence, the temperature gradient along the heated and cooled sections may be calculated from

Heated Section $\frac{\Delta T_{1-3}}{\Delta x_{1-3}} = 166.\ 7$ K/m

Cooled Section $\frac{\Delta T_{6-8}}{\Delta x_{6-8}} = 146.7$ K/m

If the constant rate of heat transfer is divided by the temperature gradients, the value obtained will be similar. Substituting for the heated and cooled sections, respectively, gives the following values.

$$\dot{Q}/\left(\frac{\Delta T_{1-3}}{\Delta x_{1-3}}\right) = \frac{8.6}{166.7} = 0.051 \text{ Wm/K}$$

$$\dot{Q}/\left(\frac{\Delta T_{6-8}}{\Delta x_{6-8}}\right) = \frac{8.6}{146.7} = 0.058 \text{ Wm/K}$$

And, thermal conductivities will be

$$k = \frac{\dot{Q}}{A}/\left(\frac{\Delta T_{1-3}}{\Delta x_{1-3}}\right) = \frac{0.051}{0.00049} = 104.08 \text{ W/mK}$$

$$k = \frac{\dot{Q}}{A}/\left(\frac{\Delta T_{6-8}}{\Delta x_{6-8}}\right) = \frac{0.058}{0.00049} = 118.36 \text{ W/mK}$$

As may be seen from the above example and the tabulated data the function does result in a constant value within the limits of the experimental data. If there are more than one contact surfaces, these calculations can be repeated for each surface, and sections.

EXPERIMENTAL PROCEDURE

General Procedure

(i) Ensure that the main switch is in the off position (the digital displays should not be illuminated). Ensure that the residual current circuit breaker on the rear panel is in the ON position.

(ii) Turn the voltage controller anti-clockwise to set the AC voltage to minimum. Ensure the Linear Heat Transfer Unit H112A has been connected to the Heat Transfer Service Unit H112 as detailed in the INSTALLATION procedure.

(iii) Ensure the cold water supply and electrical supply are turned on at the source. Open the water tap until the flow through the drain hose is approximately 1.5 litres/minute. The actual flow can be checked using a measuring vessel and stopwatch if required but this is not a critical parameter. The flow has to dissipate up to 65 W only.

(iv) Release the toggle clamp tensioning screw and clamps. Ensure that the faces of the exposed ends of the heated and cooled sections are clean. Similarly, check the faces of the intermediate specimen (if in use) to be placed between the faces of the heated and cooled sections. If instructed in the individual procedures for the experiment, coat the mating faces of the heated and cooled sections and the intermediate section (if used) with thermal conduction paste. Ensure the intermediate section to be used is in the correct orientation then clamp the assembly together using the toggle clamps and tensioning screw.

(v) Turn on the main switch and the digital displays should illuminate. Set the temperature selector switch to T1 to indicate the temperature of the heated end of the bar. Rotate the voltage controller to increase the voltage to that specified in the procedure for each experiment.

(vi) Observe the temperature T1. This should begin to increase.

(vii) Allow the system to reach stability, and take readings and make adjustments as instructed in the individual procedures for each experiment.

(viii) When the experimental procedure is completed, it is good practice to turn off the power to the heater by reducing the voltage to zero and allow the system a short time to cool before turning off the cooling water supply.

(ix) Ensure that the locally supplied water supply isolation valve to the unit is closed. Turn off the main switch and isolate the electrical supply.

(x) Note that if the thermal conducting paste is left on the mating faces of the heated and cooled sections for a long period it can be more difficult to remove than if removed immediately after completing an experiment. If left on the intermediate sections it can attract dust and in particular grit which acts as a barrier to good thermal contact.

Experiment 1: To measure the temperature distribution for steady state conduction of energy through a uniform plane wall and demonstrate the effect of a change in heat flow

---

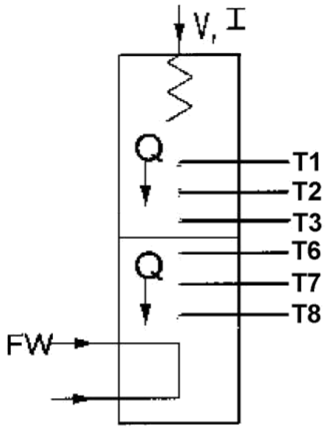
Procedure

(i) Following the basic General Procedure listed previously smear the faces of the heated and cooled sections with thermal conducting paste and clamp them together without any intermediate section in place. Schematically this produces a system as shown below.

(ii) Again, following the above procedure ensure the cooling water is flowing and then set the heater voltage V to given value.

(iii) Monitor temperatures T1, T2, T3, T6, T7, T8 until stable.

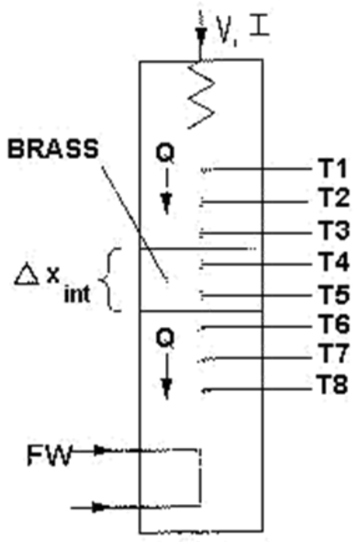
(iv) When the temperatures are stabilised record: T1, T2, T3, T6, T7, T8, V and I.



Experiment 2: To understand the use of the Fourier Rate Equation in determining rate of heat flow through solid materials for one dimensional, steady flow of heat.

Procedure

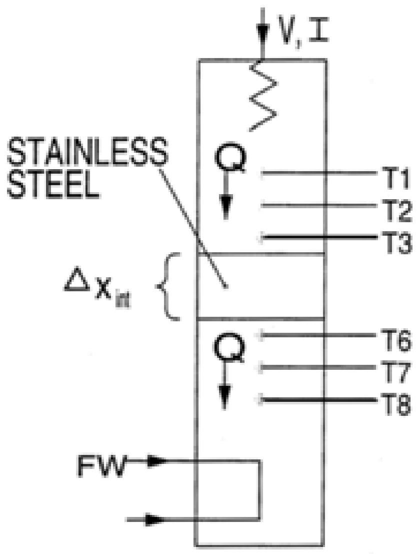
(i) Following the basic General Procedure listed previously smear the faces of the heated and cooled sections with thermal conducting paste and clamp them together with the Brass Intermediate Specimen in place. Schematically this produces a system as shown below.
(ii) Again, following the above procedure ensure the cooling water is flowing and then set the heater voltage V to given value.
(iii) Monitor temperatures T1, T2, T3, T4, T5, T6, T7, T8 until stable.
(iv) When the temperatures are stabilised record: T1, T2, T3, T4, T5, T6, T7, T8, V and I.



Experiment 3: To measure the temperature distribution for steady state conduction of energy through a composite plane wall and determine the Overall Heat Transfer Coefficient for the flow of heat through a combination of different materials in use.

Procedure

(i) Following the basic General Procedure listed previously smear the faces of the heated and cooled sections with thermal conducting paste and clamp them together with the Intermediate Specimen (i.e. stainless steel) in place. Schematically this produces a system as shown below.
(ii) Again, following the above procedure ensure the cooling water is flowing and then set the heater voltage V to given value.
(iii) Monitor temperatures T1, T2, T3, T6, T7, T8 until stable.
(iv) When the temperatures are stabilised record: T1, T2, T3, T6, T7, T8, V and I.
(v) When completed, reduce the heater voltage to zero and shut down the system.



IN YOUR REPORTS

- Calculate thermal conductivity of brass for all sections (hot, cold and intermediate) in experiments and compare them with the real value. Comment on the differences if there is any.
- Calculate thermal conductivity of the intermediate material and determine what is made out of.
- Plot temperature gradients of all experiments using calculated thermal conductivities as a line graph, and mark the thermocouple measurements on the graph. Are there differences between different sections? How measured values distributed compared to plotted lines? Discuss the results.
- Discuss possible sources of discrepancies in the experiment if there is any.
- Show your calculations steps explicitly.