HEAT TRANSFER LAB REPORTS

Experiments:

1) Determination of Thermal Conductivity of metal.

2) Determination of Thermal Conductivity of liquid.

3) Studies on heat transfer on the pin-fin heat exchanger.

4) Studies on heat transfer through composite wall

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Determination of Thermal Conductivity of metal

AIM

- To determine the thermal conductivity of a given metal bar.

THEORY

The thermal conductivity of a substance is a physical property defined as the ability of a substance to conduct heat. The thermal conductivity of metal depends on chemical composition, state of matter, the crystalline structure of a solid, temperature, pressure and whether or not it is a homogenous material. The heater will heat the bar on its end one and heat will be conducted through the bar to the other end. Since the rod is insulated from outside, it can be safely assumed that the heat transfer along the copper rod is mainly due to axial conduction and steady-state the heat conducted shall be equal to the heat absorbed by water at the cooling end. The heat conducted at a steady-state shall create a temperature profile within the rod (T=f(x)).

Heat absorbed by cooling water,

$$Q = mC_p\Delta T$$

Where,
M is the Mass flow rate of cooling water
C_p is Specific heat of water
ΔT is the Temperature rise of cooling water (T11 – T12)

Heat conducted through the rod in axial direction:

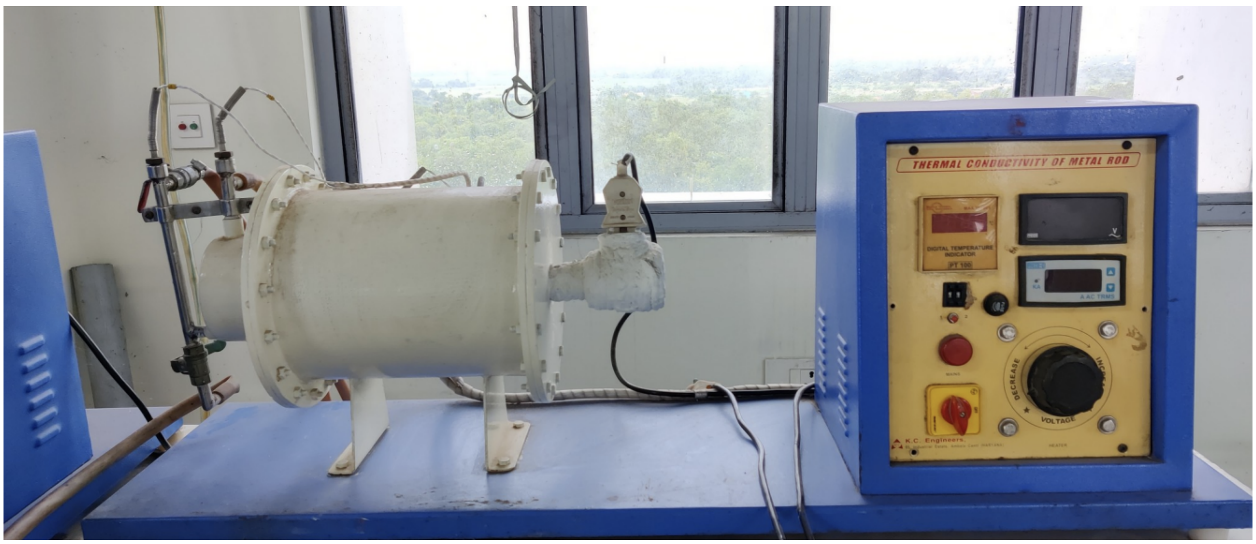
$$Q = -A\frac{dT}{dx}$$

$$k = \frac{mC_p\Delta T}{-\left(A\frac{dT}{dx}\right)}$$

At steady state,

The assumption that at a steady state, the heat flow is mainly due to axial conduction can be verified by the readings of temperature sensors fixed in the insulation material around the rod in the radial direction. Less variation in the reading shall confirm the assumption. The value of dT/dX is obtained as the slope of the graph between T and X.

EXPERIMENTAL SET-UP



The apparatus consists of a metal bar, one end of which is heated by an electric heater while the other end of the bar projects inside the cooling water jacket. The middle portion of the bar is surrounded by a cylindrical shell fitted with asbestos insulating powder. The temperature of the bar is measured at different sections while the radial temperature distribution is measured by separate temperature sensors at two different sections of the insulating shell. The heater is provided with a dimmer stat for controlling the heat input. Water under constant head conditions is circulated through the jacket and its flow rate and temperature rise are noted by two temperature sensors provided at the inlet and outlet of the water.

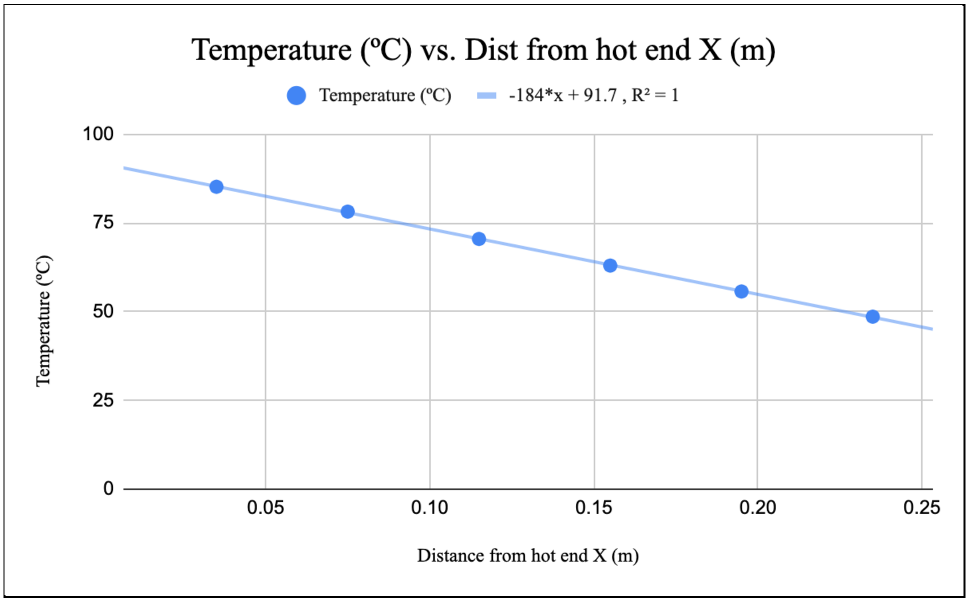
OBSERVATIONS

Sensor	1	2	3	4	5	6	7	8	9	10	11	12
Temp in ^{o}C	84.9	77.8	70.2	62.8	55.6	48.7	44.3	44.3	39.2	37.8	38	38.2
	85.4	78.4	70.7	63.3	56	49.1	44.6	44.7	39.6	38.1	39.2	39.7
	85.5	78.3	70.6	63.1	55.1	48.8	44.6	44.7	39.2	37.6	36.9	37.1
	85.6	78.4	70.8	63.3	55.9	44.8	44.8	44.8	39.2	32.7	38.9	39.1
Steady State Temp	85.2	78.2	70.5	63	55.7	48.6	44.7	44.8	39	37.5	38.1	38.3

Dist from hot end X (m)	**Temp sensor**	**Temperature (^{o}C)**
0.035	T1	85.2
0.075	T2	78.2
0.115	T3	70.5
0.155	T4	63
0.195	T5	55.7
0.235	T6	48.6

*All mentioned temperatures are in ^{0}C

GRAPH



CALCULATIONS

Flow rate of water = 2LPM

ρ_{water} at 38°C = 0.993 kg/L

Mass flow rate of water = 2 × 0.993 × 60

= 119.76 kg/hr

= 0.33 kg/sec

C_p of water = 4.13 kJ/kg°c

$\Delta T = T_{12} - T_{11} = 0.2^{\circ}C$

$Q = M C_p \Delta T = 0.33 \times 0.2 \times 4.13 = 27.341$ J/S

Copper rod diameter = 25mm

Cross section Area (A) = $\frac{\pi}{4} d^2 = 4.91 \times 10^{-4} m^2$

$\frac{dT}{dx}$ (from graph) = -184.283 °C/m

$$\therefore k_{copper} = Q\left(-A\frac{dT}{dx}\right)^{-1} = 27.341 \times (4.91 \times 10^{-4} \times 184.283)^{-1}$$

$$= 302.163 \ W/m^{\circ}c$$

Actual value of $k_{copper} \approx 380 \ W/m^{\circ}c$

$$\% \text{ error} = \left|\frac{302.163 - 380}{380}\right| \times 100 = 20.483$$

DISCUSSION

While equating the heat given input and heat taken up by the liquid, we assume all the insulation conditions. However, there might be some loss of heat, and as we move away from the ideality, there will be a heat loss and correspondingly k measured will be decreased. This is the reason for the error in the result compared to the real value of copper's thermal conductivity. The assumption that at a steady state, the heat flow is mainly due to axial conduction can be verified by the readings of temperature sensors fixed in the insulation material around the rod in the radial direction. Lesser the variation is truer the confirmation of our assumption. Mass flow rate considered cannot be increased to make the k value reach closer to its actual value because, the rise in flow rate can also have an influence on other parameters, changing heat and temperature values if altered. While calculating, we need to make sure the length used in the formula is test length because only that is responsible for the effective heat transfer area. Water under constant head conditions is circulated through the jacket and its flow rate and temperature rise are noted by two temperature sensors provided at the inlet and outlet of the water. These temperatures should not be confused with the other temperature notations. All necessary precautions should be taken care of while performing experiments to avoid risks, such as stabilized current supply, gradual increment of voltages, gentle operation of power supply instruments, etc.

RESULTS

- Thermal conductivity of the metal bar (k) = 302.163 W/m ^{0}C
- Error in Result: 20.483%

Determination of Thermal Conductivity of liquid

AIM

- To find the thermal conductivity of the liquid.

THEORY

The heat transferred by conduction through the liquid layer is given by:

$$Q = -A\frac{\Delta T}{\Delta x}$$

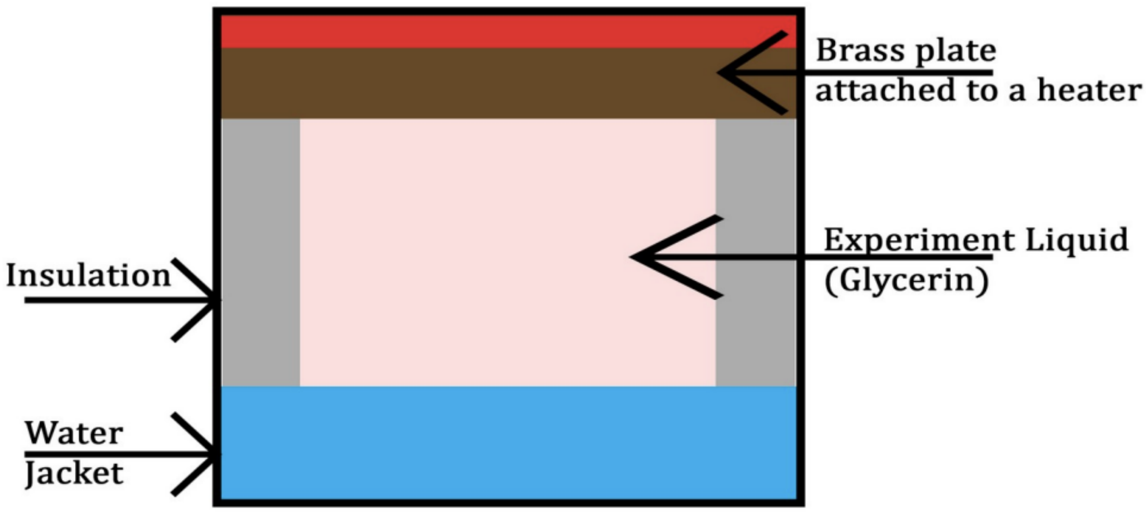
Where,
Q is the rate of heat transfer as measured by input to the heater.
A is the area of the test substance, normal to the direction of heat flow.
ΔT is the temperature drop across the bottom and top surfaces of liquid.
ΔX is the thickness of the test layer along the direction of heat transfer.
K is the thermal conductivity of the test substance.

If M_w is the rate of water flow through calorimeter and ‘T_{in}’ and ‘T_{out}’ are the temperatures at inlet and outlet, then the heat carried away by cooling water:

$$Q = M_w C_P \Delta T$$

Where, $\Delta T = T_{out} - T_{in}$
Q is in kcal/hr
Mw is water flow rate, kg/hr
Cp is the specific heat of water at a temperature $(T_{in} + T_{out})/2$, kcal/kg ℃
T_{out} is water outlet temperature, ℃
T_{in} is water inlet temperature, ℃

Schematic and Experimental Setup:



Schematic of the experiment

Experimental Set-Up

OBSERVATIONS

S. no.	Flow rate	Volts	Amps	T1	T2	T3	T4	T5	T6	T7	T8
1	10	47	0.2	79.1	62.8	39.5	41.7	38.7	38.1	21.1	35
2	10	46	0.19	87.8	70.8	45.5	47.7	45.8	45.5	21.3	41
3	10	47	0.2	88.9	73.9	49	50.7	50.6	50.6	21.6	45.4

*All mentioned temperatures are in ^{0}C

CALCULATIONS

S. no.	T_1	T_2	T_3	T_{top}	T_4	T_5	T_6	T_{bottom}	k(kcal/hm ^{0}C)
1	79.1	62.8	39.5	60.47	41.7	38.7	38.1	39.50	0.61
2	87.8	70.8	45.5	68.03	47.7	45.8	45.5	46.33	0.59
3	88.9	73.9	49	70.60	50.7	50.6	50.6	50.63	0.64

Heat Input, $Q = V \times I \times 0.86$
$= 47 \times 0.2 \times 0.86$
$= 8.084$ kcal/hr

Heat removed through water (Q) $= 10 \times 6 \times 1000\,(T_8 - T_7)$
$= 10 \times 6 \times 1000\,(35 - 21.1)$
$= 8.04$ kcal/hr

Thermal counductivity of glycerin (k) $= Q \dfrac{\Delta x}{A} \cdot \dfrac{1}{(T_{top} - T_{bot})}$

$= \dfrac{8.048 \times 6 \times 10^{-3}}{0.0038} \times \dfrac{1}{60.47 - 39.5}$
$= 0.61$ kcal/hr m °C

Taking avg. k for three readings, $\frac{1}{3}(0.61 + 0.59 + 0.64) = 0.61$

∴ Thermal conductivity of glycerin (experimental liquid)
$= 0.61$ kcal/hr m °C
$= 0.71$ W/hr m °C

DISCUSSION:

We keep the heated plate on top of the liquid and the cooling water on the bottom to ensure that only 1-dimensional conduction occurs. We must keep the liquid height as low as possible to ensure that only one-dimensional conduction occurs. We kept it at 6mm in our testing. Throughout the length of the experiment, the flow rate of coolant water should be kept constant.At steady state, the temperature sensors' values should be recorded.

The following precautions should be taken:

- Using a stabilized single phase A.C supply.
- Voltage must be increased slowly.
- Power supply should be between 180V to 240V.
- The apparatus should be free from dust.

All necessary precautions should be taken care of while performing experiments to avoid risks, such as stabilized current supply, gradual increment of voltages, gentle operation of power supply instruments, etc.

RESULTS

- Thermal conductivity of the experimental liquid (glycerin) is 0.61 kcal/hr m ^{o}C

Studies on heat transfer on the pin-fin heat exchanger

AIM

- To plot the variation of temperature along the length of pin under forced convection.
- To determine the value of heat transfer coefficient under forced convection condition and to find:
    - Theoretical values of temperatures along the length of the fin.
    - Effectiveness and efficiency of the pin fin for insulated end condition.

THEORY

The heat transfer phenomenon from a heated surface to its ambient is given by the relation:

$$q = hA\Delta T$$

Where,
h is the heat transfer coefficient (W/m2 .K),
ΔT is the temperature difference (K)
A is the area of heat transfer normal to the heat flow

To increase q, heat transfer coefficient 'h' or temp difference 'ΔT' or surface area 'A' may be increased. In some cases, it is not possible to increase the value of the heat transfer coefficient or the temperature difference 'ΔT'. Then, the only option is to increase the surface area of heat transfer. The surface area is increased by attaching extra material in the form of the rod on the surface whose heat transfer rate is to be increased. This extra material attached is called the 'extended surface' or 'Fin'. The fins attached to a plane surface are called plane surface fins. If the fins are attached to a cylindrical surface, they are called circumferential fins. The cross-section of the fin may be circular, rectangular, triangular or parabolic.

Temperature distribution along the length of the fin is:

$$\frac{\theta}{\theta_0} = \frac{T - T_\infty}{T - T_0} = \frac{\cosh\left(m\left(L - x\right)\right)}{\cosh\left(mL\right)}$$

Where

$\theta_0 = (T_0 - T_\infty)$ (°C)

$\theta = (T - T_\infty)$ (°C)

T = Temperature at any distance x from the base on the fin (°C)

T_0 is the Temperature at x = 0 (°C)

T_∞ is the Ambient temperature (°C)

L is the length of the fin (m)

m = √ hcP/kA

h_c = convective heat transfer coefficient (W/m^2K)

P = perimeter of the fin (m)

A = area of the fin (m2)

k = Thermal conductivity of the fin material (W/m.K)

Amount of heat flow,

$$q = \theta_0 \sqrt{h_c PKA} \tanh\left(mL\right)$$

The effectiveness of a fin is defined as the ratio of the heat transfer with a fin to the heat transfer from the surface without fin. For end insulated condition,

$$\varepsilon = \sqrt{\frac{P \cdot k}{h \cdot A} \tanh\left(mL\right)}$$

The efficiency of a fin is defined as the ratio of the actual heat transferred by the fin to the maximum heat transferred by the fin if the entire fin area is at the base temperature.

With end insulated condition,

$$\eta = \left(\frac{\tanh{(mL)}}{mL} \times 100 \right) \%$$

EXPERIMENTAL SET-UP

Specifications:

Length of the fin: 150 mm

Diameter of the fin: 12 mm

Thermal conductivity of the material: 110 W/m.K

Diameter of the orifice: 0.02 m

Width of the duct: 0.15 m

The breadth of the duct: 0.1 m

Coefficient of discharge of the orifice: 0.61

The density of the manometric fluid: 1000 kg/m3

OBSERVATIONS

S.No	Heat Input			Pressure Drop of Water (cm)	Temperatures					
	Volt (V)	Current (I)	Power (W)		T1	T2	T3	T4	T5	T6
1	40	0.2	8	1.5	78.2	59.4	54.8	51.6	49.3	40.9
	50	0.25	12.5		78.7	59.2	54.8	51.7	49.3	40.9
	60	0.3	18		80.7	59.6	55.1	51.8	49.4	41
2	40	0.2	8	2	72.7	56.3	52.5	49.9	47.9	40.4
	50	0.25	12.5		73.7	56.3	52.6	50	48	40.4
	60	0.3	18		78.2	58	53.5	50.5	48.3	40.6
3	40	0.2	8	2.5	78.4	59.7	55.2	52.2	49.8	41
	50	0.25	12.5		78.7	59.6	55.1	52.3	49.7	41.1
	60	0.3	18		82.2	60.6	55.7	52.4	49.9	41.2

*All mentioned temperatures are in ^{0}C

CALCULATIONS

Consider the following case,

Avg. surface Temp;

$$T_s = \frac{1}{5}(T_1 + T_2 + T_3 + T_4 + T_5) = 58.66°c$$

Ambient Temp, $T_\infty = 40.9°c$

Mean Temp, $T_m = \frac{T_s + T_\infty}{2} = 49.78°c$

At $T = 49.78°c$, propercitie of air,

$\nu = 16.96 \times 10^{-6}$ m^2/s
$Pr = 0.699$
$k = 26.56 \times 10^{-3}$ w/mK

Velocity at orifice, $v_0 = C_d \sqrt{\frac{2gh(\rho_m \rho_a)}{\rho_a(\beta^4)}}$

$C_d \rightarrow$ co-efficient of discharge
$h \rightarrow$ Pressure drop of water
$\rho_m \rightarrow$ Density of manometric fluid
$\rho_a \rightarrow$ Density of air

On solving, $v_0 = 10.058$ m/s

Velocity in air duct, $v_0 = \pi d^2 / 4bw$
$= 10.058 \times \pi \times 0.02^2 / 4 \times 0.15 \times 0.1$
$= 0.211$ m/s

$Re = 0.211 \times 0.012 / 16.96 \times 10^{-6}$
$= 149.294$

$Nu = 0.683\ Re^{0.466}\ P_r^{1/3}$
$= 6.247$

$Nu = \frac{h_c d}{k} = 6.247 \Rightarrow h_c = 13.827\ W/m^2K$

Thermal conductivity of fin material = 110 W/mK

$m = \left(\frac{h_c P}{kA}\right)^{0.5} = 6.473$

Temperature distribution is given by

$$\theta/\theta_0 = \frac{(T - T_\infty)}{(T_b - T_\infty)} = \frac{\cosh(m(L-x))}{\cosh(mL)}$$

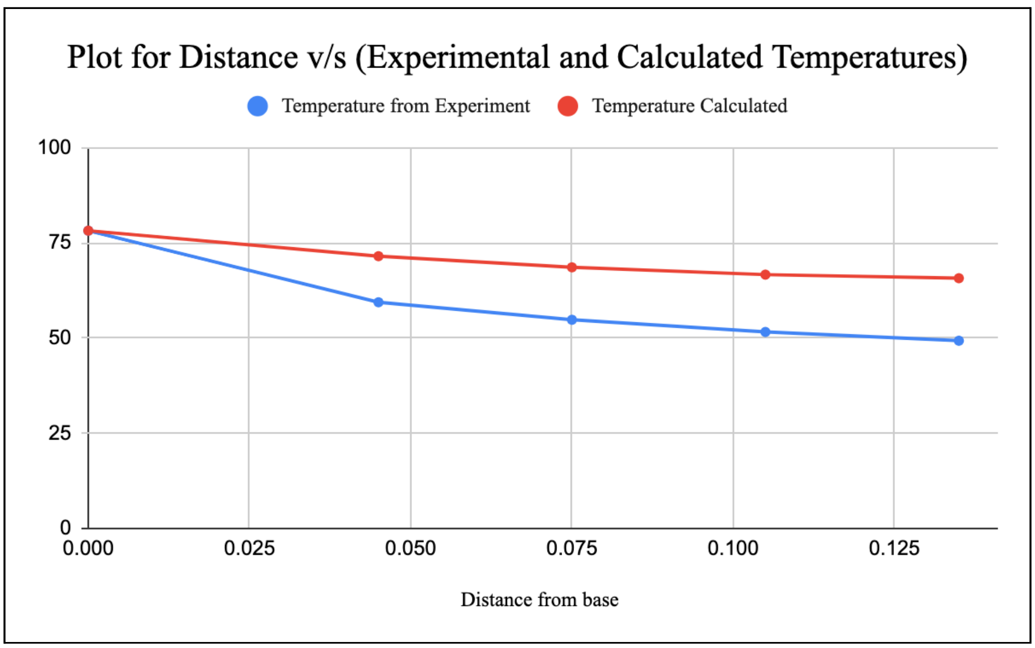
$$T = 40.9 + (78.2 - 40.9)\frac{\cosh(6.473(0.15-x))}{1.5096}$$

$$\therefore T = 40.9 + 24.71\cosh(6.473(0.15-x))$$

Distance from base	Temperature from Experiment	Temperature calculated
0	78.2	78.2
0.045	59.4	71.5
0.075	54.8	68.58
0.105	51.6	66.66
0.135	49.3	65.72

*All mentioned temperatures are in ^{0}C

GRAPH



Effectiveness of fin

$$\varepsilon = \sqrt{\frac{Pk}{h_c A}} \tanh(mL)$$

$$\therefore \varepsilon = 38.577$$

Efficiency of fin, $\eta = \frac{\tanh(mL)}{mL} \times 100$

$$\therefore \eta = 77.15\%$$

In a similar way, we can do the calculations for other readings.

DISCUSSION

Pin fins are used to increase heat transfer from heated surfaces to air. Normally pin fins, by its orientation, promote turbulence within the flow channel and enhances convective heat transfer. Natural convection and radiation are used to move heat from the expanded surface in this experiment. Fins are expanded surfaces that are used to accelerate the rate of heat transfer to or from the environment via increasing convection. An ideal fin is the one whose temperature is equal to temperature of the surface. This is possible only if the thermal conductivity of fin material is infinitely high. The effectiveness of an actual fin material is always lower than an ideal fin.The fins increase the surface area, making heat transfer problems in both natural and forced convection more cost-effective and efficient. For the forced convection experiment, we should fill the manometer with water and close the duct cover, as well as guarantee correct earthing to the unit. We must be cautious when installing the thermocouples, as improperly installed thermocouples may produce inconsistent readings.We should fill up water in the manometer and close duct cover for forced convection experiment and ensure proper earthing to the unit. We should be careful while fixing the thermocouples as incorrectly fixed thermocouples may show erratic readings

RESULTS

- Heat Transfer coeff under forced convection =13.827 W/m^2K
- Efficiency of the fin : 77.15%
- Effectiveness of the fin : 38.577

Studies on heat transfer through composite wall heat transfer

AIM

- Study of conduction heat transfer through composite wall.
- To determine total thermal resistance and thermal conductivity of composite wall.
- To plot the temperature profile along the composite wall.

THEORY

When a temperature gradient exists in a body, there is an energy transfer from the high temperature region to the low temperature region. Energy is transferred by conduction and heat transfer rate per unit area is proportional to the normal temperature gradient:

$$q = -kA\frac{\Delta T}{\Delta x}$$

Where,
q is the heat transfer rate
$\Delta T/ \Delta X$ is the temperature gradient in the direction of heat flow
The proportionality constant k is called thermal conductivity of the material

A direction of Fourier's law is the plane wall. Fourier's equation:

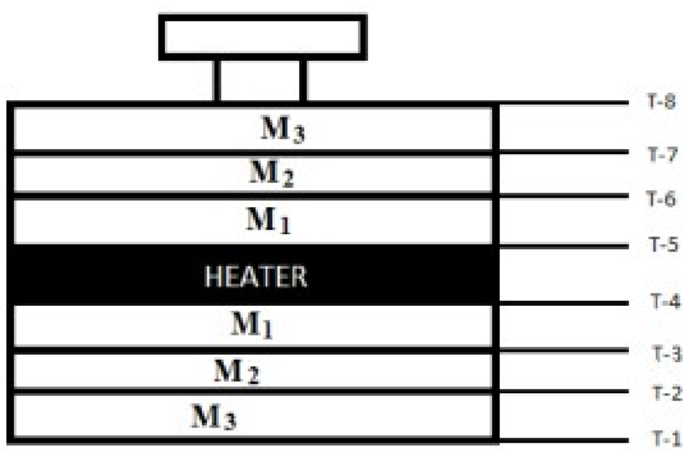
$$q = -kA\frac{(T_2 - T_1)}{\Delta x}$$

Where, the thermal conductivity is considered constant. The wall thickness is Δx, and T_1 and T_2 are surface temperatures.The temperature gradients in the three materials (M_1, M_2, M_3), the heat flow may be written as

$$q = - kM_1A\Delta T_1/\Delta x_1 = - kM_2A\Delta T_2/\Delta x_2 = - kM_3A\Delta T_3/\Delta x_3$$

EXPERIMENTAL SET-UP

Experimental Set-Up



Schematic Diagram of Composite Wall

OBSERVATIONS

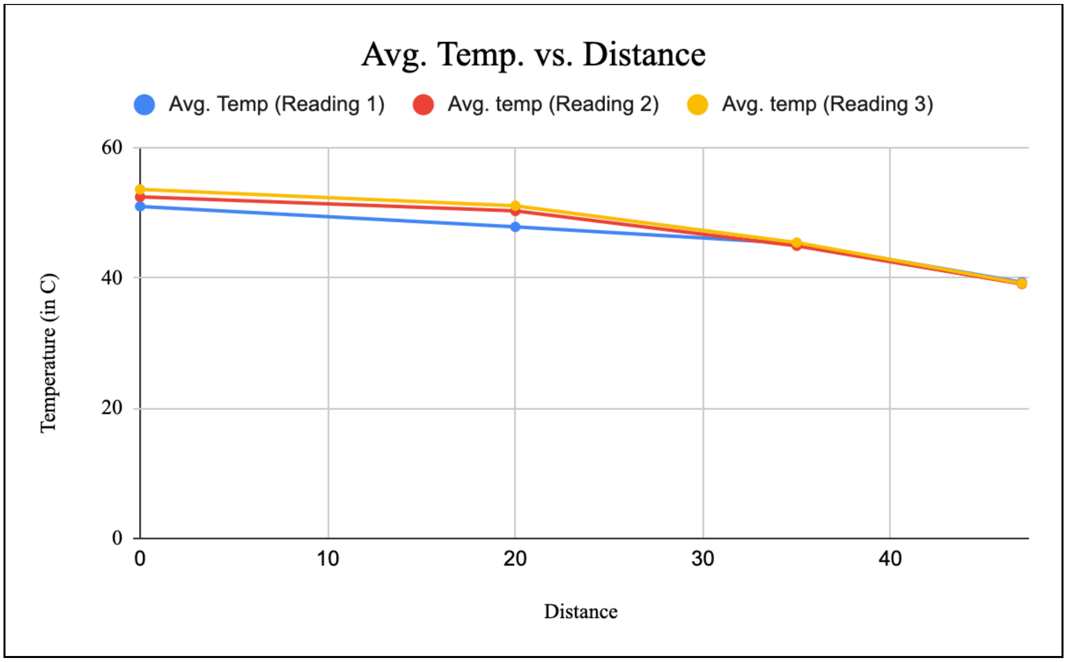
S. No.	V (Volt)	I (Amp)	T1	T2	T3	T4	T5	T6	T7	T8
1	45	11.08	39.5	45.9	48.1	50.5	51.4	47.5	44.6	39.1
2	55	12.36	39.2	45.1	50.5	52.6	52.2	50	44.7	38.9
3	65	14.66	39.2	45.5	51.5	54.1	53	50.6	45.3	39.1

X1=0.02m,X2=0.015m,X3=0.012m

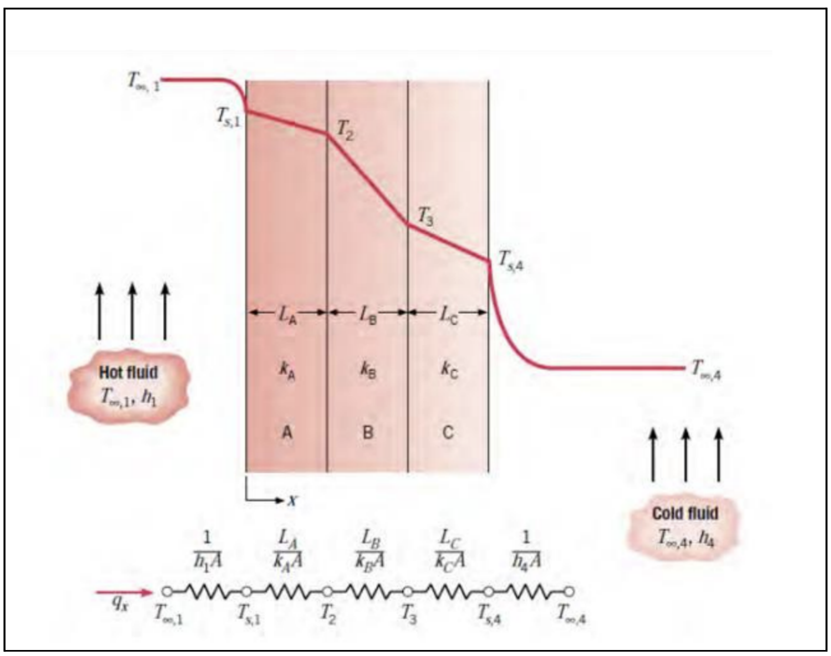
GRAPH

Distance	0	20	35	47
Avg. Temp. (Reading 1)	50.95	47.8	45.25	39.3
Avg. temp (Reading 2)	52.4	50.25	44.9	39.05
Avg. temp (Reading 3)	53.55	51.05	45.4	39.15

*All mentioned temperatures are in ^0C



CALCULATIONS



Principle involved in Composite Wall

Let's consider,

$$Q = V \times I$$
$$= 45 \times 11.08 = 498.6 \text{ W}$$

$$q = Q/2 = 249.3 \text{ W}$$

$$A = \pi d^2/4 = 0.0491 \text{ m}^2$$

$$T_1' = \frac{1}{2}(T_1 + T_8) = 39.3^\circ C$$

$$T_2' = \frac{1}{2}(T_2 + T_7) = 45.25^\circ C$$

$$T_3' = \frac{1}{2}(T_3 + T_6) = 47.8^\circ C$$

$$T_4' = \frac{1}{2}(T_4 + T_5) = 50.95^\circ C$$

Total Thermal Resistance, $R_T = \frac{1}{q}(T_4' - T_1')$

$$\therefore R_T = 0.0467 \ ^\circ C/W$$

$$k_{M_1} = \frac{q x_1}{A} \times \frac{1}{(T_4' - T_3')} = \frac{249.3 \times 20 \times 10^{-3}}{49 \times 10^{-3} (50.95 - 49.8)}$$
$$= 32.303 \text{ W/m}^\circ C$$

$$k_{M_2} = \frac{q x_2}{A} \times \frac{1}{(T_3' - T_2')} = \frac{249.3 \times 15 \times 10^{-3}}{49 \times 10^{-3} \times (47.8 - 45.25)}$$
$$= 29.928 \text{ W/m}^\circ C$$

$$k_{M_3} = \frac{q x_3}{A} \times \frac{1}{(T_2' - T_1')} = \frac{249.3 \times 12 \times 10^{-3}}{49 \times 10^{-3} (45.25 - 39.3)}$$
$$= 10.261 \text{ W/m}^\circ C$$

$$k_{comp} = \frac{q x}{A} \times \frac{1}{(T_4' - T_1')} = \frac{249.3 \times 47 \times 10^{-3}}{49 \times 10^{-3} \times (50.95 - 39.3)}$$
$$= 20.526 \text{ W/m}^\circ C$$

Thermal conductivity of composite wall is 20.526 W/m°C

DISCUSSION

Thermal Heat conductivities of three materials (k_1 , k_2 , k_3) and the composite of them (from plot's slopes, $k_{composite}$) are found at each power rating. k values for the first two power ratings are close whereas third power rating's k values have large errors with respect to first two values. However, as k values are material property and should be independent of heat flux provided.

Increasing Temperature recordings at third power rating and properly ensuring to attain the steady will reduce the error in its k values. $k_{composite}$ obtained are, q/(dT/dx) = k [dT/dx is obtained as the slope of linear fit] . If temperature conventions obtained from thermocouples are unknown, then start assigning highest temperature to the material immediately next to the heater at distance = 0m, and continue till the end of composite material by reducing temperatures on either side of the heater. While taking average, we are essentially replacing the whole system with another system which has composite materials only on one side with averaged temperature readings across it & with flux $q_{total}/2$ provided by the heater. This is done because the dimensions, composition of materials placed on either side of the heater are assumed to be perfectly similar. Before beginning the experiment, rotate the press frame handle present at the top tight enough so as to keep the substrates present as the sandwich is brought close together and hence reducing the contact resistance. Differential dT/dx is replaced with fraction of difference of temperatures by distances while measuring k_1 , k_2 , k_3 , because even though the system is in cylindrical coordinates; no heat generation inside the material will make the temperature profile along the axis linear in nature

RESULTS

- Thermal conductivity of the composite wall is 20.526 W/ m°C.
- Total thermal resistance of the wall is 0.0467 °C/W.
- Individual thermal resistances are 32.303 W/ m°C (M_1), 29.928 W/ m°C (M_2) and 10.261 W/ m°C (M_3).