राज्य अभियांत्रिकी एवं प्रौद्योगिकी संस्थान, नीलोखेड़ी

State Institute of Engineering & Technology, Nilokheri

(Formerly Govt. Engineering College)

LABORATORY MANUAL

HEAT TRANSFER LAB

MEC 307LA

Department of Mechanical Engineering

STATE INSTITUTE OF ENGINEERING AND TECHNOLOGY

(Affiliated to K.U. University)

NILOKHERI – 132117, KARNAL

Experiment-1

Aim: To determine the thermal conductivity of a metal rod.

Apparatus: Apparatus for thermal conductivity of metal rod, water supply, cylindrical jar

Theory:

The thermal conductivity of a substance is a physical property, which is defined as the ability of a substance to conduct heat. Thermal conductivity of material depends on chemical composition; state of matter, crystalline structure of a solid, the temperature, pressure and weather or not it is a homogeneous material. The heater will heat the rod on its one end and heat will be conducted through the rod 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 at steady state, the heat conducted will be equal to the heat absorbed by water at the cooling end. The heat conducted at steady state will create a temperature profile within the rod. (T = f (x))The steady state heat balance at the rear end of the rod is:

Heat absorbed by cooling water,

$$Q = M\,C_p\,\Delta T$$

Heat conducted through the rod in axial direction:

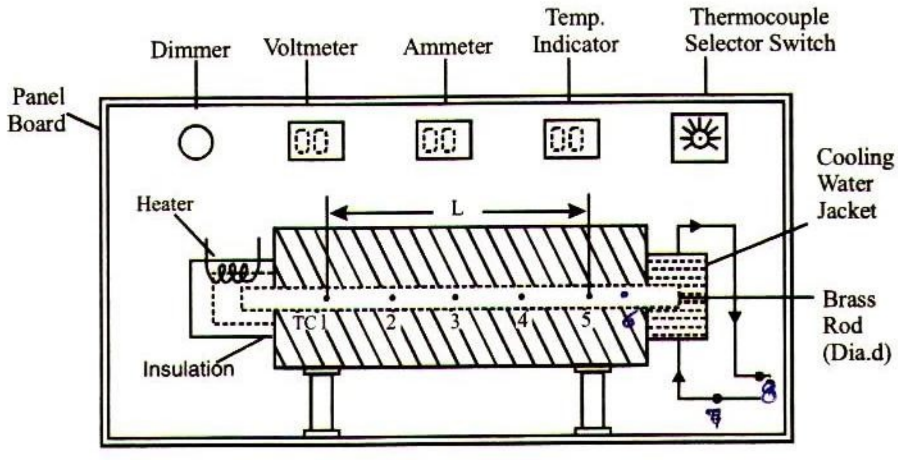
$$Q = -KA\,\frac{dt}{dx}$$

At steady state

$$Q = -KA\,\frac{dt}{dx} = M\,C_p\,\Delta T$$

So thermal conductivity of rod may be expressed as:

$$K = \frac{MC_p\,\Delta T}{-A\left(\frac{dT}{dX}\right)}$$



Thermal Conductivity of Metal Rod

The apparatus consists of a metal rod, one end of which is heated by an electric heater while the other end of the rod projects inside the cooling water jacket. The middle portion of the rod is surrounded by a cylindrical shell filled with the asbestos insulating powder. The temperature of the rod is measured at different section. The heater is provided with a dimmerstat 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 the two temperature sensors provided at the inlet and outlet of the water.

Procedure:

Starting Procedure:

1. Connect continuous water supply to the inlet of water chamber.
2. Connect outlet of chamber to drain.
3. Ensure that Mains ON/OFF switch given on the panel is at 'OFF' position & dimmer stat is at zero position.
4. Connect electric supply to the set up.
5. Switch 'ON' the Mains ON / OFF switch.
6. Set the heater input by the dimmer stat and the voltmeter in the range of 40 to 100 V.
7. Start water supply at low flow rate.
8. Measure the flow of water through chamber by measuring cylinder and stop watch.
9. After 1.5 hrs., note down the readings of voltmeter, ampere meter and temperature sensors in the observation table after every 10 minutes interval till observing change in consecutive readings of temperatures (± 0.2 oC) .

Closing Procedure:

1. After experiment is over set the dimmer stat to zero position.
2. Switch 'OFF' the Mains ON/OFF switch.
3. Switch 'OFF' the electric supply to the set up.
4. Stop cold water flow by closing the valve.

4.1 <u>GIVEN</u>:

d = 0.025 m
ρ = 1000 kg/m3
Cp = 4186 J/kg K

OBSERVATION & CALCULATION

S.No.	V, ml	t, sec	T_1 °C	T2 °C	T3 °C	T4 °C	T5 °C	T6 °C	T7 °C	T8 °C

$A = \frac{\pi}{4} d^2$ (m²)`

$M = \frac{V}{t} \times 10^{-6} \times \rho$ (kg / s) V = Volume

$Q = M C_p (T_8 - T_7)$ (Watts)

Temp. Sensor No.	X , m	T , °C
T1	0.035	
T2	0.075	
T3	0.115	
T4	0.155	
T5	0.195	
T6	0.235	

Plot T vs. X. draw a smooth curve through all the points and obtain the slope dT/dX.

$$K = \frac{Q}{-A\left(\frac{dT}{dX}\right)} \text{ (W/m °C)}$$

Nomenclature:

A	=	Cross-sectional area of the metal rod, m2
Cp	=	Specific heat of water, kJ /kg oC
D	=	Diameter of rod, m
dT/dx	=	Slope of the graph b/w temperature vs length of the rod, oC/m
k	=	Thermal conductivity of metal rod, W/m oC
M	=	Mass flow rate of cooling water, kg/s
Q	=	Heat Gained by water, W
T	=	Time taken to collect V ml of water for flow measurement, sec.
T	=	Temperature, oC
T7	=	Inlet temp of cold water, oC
T8	=	Outlet temp of cold water, oC
V	=	Volume of water collected for flow measurement, ml.
X	=	Length of rod, m
ρ	=	Density of water, kg/m3

PRECAUTIONS & MAINTENANCE INSTRUCTIONS:

1. Never run the apparatus, if power supply is less than 180 volts and above than 230volts.
2. Never switch ON' mains power supply before ensuring that all the ON/OFF switches given on the panel is at 'OFF' position.
3. Operator selector switch off temperature indicator gently.
4. Always keep the apparatus free from dust.
5. If electric panel is not showing the input on the mains light, check the main supply.
6. If voltmeter showing the voltage given to heater but ampere meter does not, check the connection of heater in control panel.

RESULT: Thermal conductivity of the metal rod is …………….

Experiment-2

AIM: To determine the thermal conductivity of an insulated powder.

APPARATUS: Apparatus for thermal conductivity of an insulating powder

THEORY:

In many heat transfer equipments, heat loss to surroundings is to be minimized to achieve maximum economy. In such cases, they are lagged by materials of lower thermal conductivity, which are referred as insulators. Because of demand of such insulating materials, many industries have come up to produce such material. Preference is given to produce materials having lower and lower thermal conductivities. Also, their material is available in different shapes, sizes and forms of powders. Powders have the advantage that they can take any complicated shape between any two confirming surfaces. In addition, its conductivity will be much lower than that of the basic solid from which the powder has been made. This is because of a very large number of air spaces in between particles, which have much lower thermal conductivity values. Thermal conductivity of such material is a complicated function of the geometry of the particles, the nature of heat transfer, conduction, convection and radiation in air spaces, which is determined by the air space size and temperature level etc. Thus it is very difficult quantity to estimate and almost in all practical cases it is measured experimentally. The set-up provided is one such apparatus to find the thermal conductivity values.

Consider the transfer of heat by conduction through the wall of hollow sphere formed by the insulating powdered layer packed between two thin copper spheres.
Let r_i = radius of inner sphere in m.
r_o = radius of outer sphere in m
T_i = average temperature of the inner surface in ºC
T_o = average temperature of the outer surface in ºC

where $$T_i = \frac{T_1+T_2+T_3+T_4}{4}$$

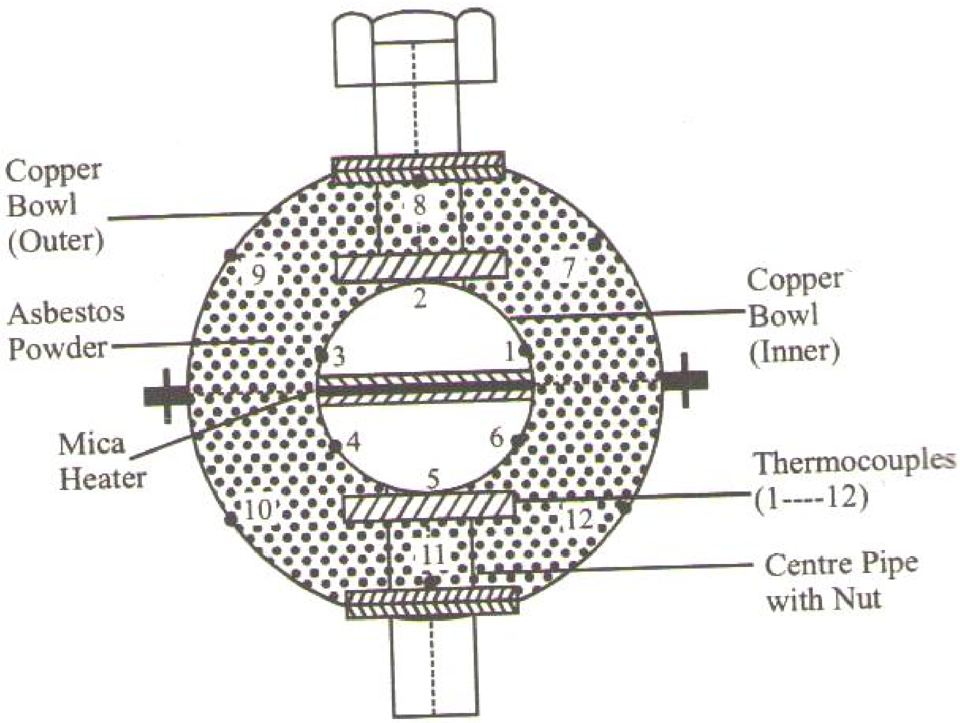
and $$T_o = \frac{T_5+T_6+T_7+T_8+T_9+T_{10}}{6}$$

From the experimental values of q, Ti and To, the unknown thermal conductivity k can be determined as:

$$k = \frac{Q\,(r_o - r_i)}{\quad}$$

$$4\pi \, r_o \, r_i \, (T_i - T_o)$$

The apparatus consists of two thin walled concentric spheres of copper of different size. The small inner copper sphere houses the heater. The insulating powder (Asbestos) is packed between the two spheres. The temperature sensors at proper positions are fitted to measure surface temperature of spheres. The power given to the heating coil is measured by voltmeter and ammeter and can be varied by using dimmer stat.



Thermal conductivity of Insulating Powder

PROCEDURE:

Starting Procedure:

1. Ensure that Mains ON/OFF switch given on the panel is at 'OFF' position & dimmer stat is at zero position.
2. Connect electric supply to the set up.
3. Switch 'ON' the Mains ON / OFF switch.
4. Set the heater input by the dimmer stat and voltmeter in the range of 40 to 100V.

5. After 1.5 hrs., note down the readings of voltmeter, ampere meter and temperature sensors in the observation table after every 10 minutes interval till observing change in consecutive readings of temperatures (± 0.2 °C).

Closing Procedure:

1. After experiment is over, set the dimmer stat to zero position.
2. Switch 'OFF' the Mains ON/OFF switch.
3. Switch 'OFF' electric supply to the set up.

GIVEN:

$r_i = 0.05$ m

$r_o = 0.1$ m

OBSERVATION & CALCULATION:

S.No	V, Volt	I , Amp	T1 °C	T2 °C	T3 °C	T4 °C	T5 °C	T6 °C	T7 °C	T8 °C	T9 °C	T10 °C

$$Q = V \times I, \text{ (W)}$$

$$T_i = \frac{T_1+T_2+T_3+T_4}{4} \quad (°C)$$

$$T_o = \frac{T_5+T_6+T_7+T_8+T_9+T_{10}}{6} \quad (°C)$$

$$k = \frac{Q\,(r_o - r_i)}{4\pi\, r_o\, r_i\,(T_i - T_o)} \quad (W/m\ °C)$$

Nomenclature

I	=	Ammeter reading, amp
K	=	Thermal conductivity of insulating powder, W/m °C
Q	=	Heat Input, W
r_i	=	Inner Radius, m
r_o	=	Outer Radius, m
T_i	=	Inside surface temperature, ºC
T_o	=	Outside surface temperature, ºC
T_1 to T_4	=	Temperature sensors embedded on the inner sphere, ^oC
T_5 to T_{10}	=	Temperature sensors embedded on the outer sphere, ^oC
V	=	Voltmeter reading, volts

PRECAUTIONS & MAINTENANCE INSTRUCTIONS:

1. Never run the apparatus, if power supply is less than 180 volts and above than 230 volts.
2. Never switch 'ON' mains power supply before ensuring that all the ON/OFF switches given on the panel are at 'OFF' position.
3. Operate selector switch of temperature indicator gently.
4. Always keep the apparatus free from dust.

RESULT: Thermal conductivity of an insulating powder is appox……………….

Experiment-3

AIM: To determine the thermal conductivity of a liquid using guard plate method.

APPARATUS: Apparatus for thermal conductivity of liquid, bar

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:

$$\frac{q}{A} \alpha \frac{\Delta T}{\Delta X}$$

When the proportionality constant is inserted,

$$q = -K A \frac{\Delta T}{\Delta X}$$

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

For thermal conductivity of liquids using Fourier's law, the heat flow through the liquid from hot fluid to cold fluid is the heat transfer through conductive fluid medium.

Fourier's equation:

$$q = -K A \frac{(T_2 - T_1)}{\Delta X}$$

Fourier's law for the case of liquid at steady state, the average face temperatures are recorded (T_h and T_c) along with the rate of heat transfer (Q). Knowing, the heat transfer area (A_h) and the thickness of the sample (ΔX) across which the heat transfer takes place, the thermal conductivity of the sample can be calculated using Fourier's Law of heat conduction.

$$Q = K A_h \frac{\Delta T}{\Delta X} = K A_h \frac{T_h - T_c}{\Delta X}$$

The apparatus consists of a heater. The heater heats a thin layer of liquid. A cooling plate removes heat through liquid layer, ensuring unidirectional heat flow. Temperature is measured across the liquid layer and complete assembly is properly insulated. A proper arrangement for changing the liquids is provided. The whole assembly is kept in a chamber.

PROCEDURE:

Starting Procedure:

1. Connect continuous water supply to the inlet of water chamber.
2. Connect outlet of chamber to drain.
3. Ensure that Mains ON/OFF switch given on the panel is at 'OFF' position & dimmer stat is at zero position.
4. Connect electric supply to the set up.
5. Switch 'ON' the Mains ON / OFF switch.
6. Set the heater input by the dimmer stat and voltmeter in the range of 40 to 100 V.
7. After 1.5 hrs. note down the readings of voltmeter, ampere meter and temperature sensors in the observation table after every 10 minutes interval till observing change in consecutive readings of temperatures (± 0.2 °C).

Closing Procedure:

1. After experiment is over set the dimmer stat to zero position.
2. Switch 'OFF' the Mains ON/OFF switch.
3. Switch 'OFF' electric supply to the set up.
4. Stop flow of water by closing the valve provided.

GIVEN:

$\Delta X = 0.018$ m
D = 0.165 m

OBSERVATIONS & CALCULATIONS:

Observations table:

S.NO	V,	I,	T_1	T2	T3	T4	T5	T6

	Volts	amp	°C	°C	°C	°C	°C	°C

Calculations:

Q = $V \times I$, W = -------------- W

A = $\pi D^2 / 4$, m^2 = ------------ m^2

$$T_h = \frac{T_1+T_2+T_3}{3} \ °C$$

$$T_c = \frac{T_4+T_5+T_6}{3} \ °C$$

$$k = \frac{Q \, \Delta X}{A \, (T_h - T_c)} \ W/m \, °C$$

Nomenclature:

A = Heat transfer area, m^2

D = Effective diameter of plate, m

K = Thermal conductivity of liquid, W/m °C

Q = Heat supplied by heater, W

Th	=	Hot face average temperature, °C
Tc	=	Cold face average temperature, °C
T1, T2, T3	=	Temperatures on the hot side, °C
T4, T5, T6	=	Temperatures on the cold side, °C
ΔX	=	Thickness of liquid, m

PRECAUTIONS & MAINTENANCE INSTRUCTIONS:

1. Never run the apparatus, if power supply is less than 180 volts and above 230 volts.
2. Never switch on mains power supply before ensuring that all the ON/OFF switches given on the panel are at 'OFF' position.
3. Operator selector switch 'OFF' temperature indicator gently.
4. Always keep the apparatus free from dust.

RESULT: Thermal conductivity of a given liquid is approx. ……………….

Experiment 4

AIM: To determine the thermal resistance of a composite wall.

APPARATUS: Composite wall apparatus

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:

$$\frac{q}{A} \alpha \frac{\Delta T}{\Delta X}$$

When the proportionality constant is inserted,

$$q = -K A \frac{\Delta T}{\Delta X}$$

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

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

$$q = -K A \frac{(T_2 - T_1)}{\Delta X}$$

Where the thermal conductivity is considered constant. The wall thickness is ΔX, and T1 and T2 are surface temperatures. If more than one material is present, as in the multiplayer wall, the analysis would proceed as follows:
The temperature gradients in the three materials (A, B, C), the heat flow may be written as:

$$q = -K_A A \frac{\Delta T_A}{\Delta X_A} = -K_B A \frac{\Delta T_B}{\Delta X_B} = -K_C A \frac{\Delta T_C}{\Delta X_C}$$

The apparatus consists of a heater sandwiched between two asbestos sheets. Three slabs of different material are provided on both sides of heater, which forms a composite structure. A small press- frame is provided to ensure the perfect contact between the slabs. A dimmerstat is provided for varying the input to the heater and measurement of input power is carried out by a digital voltmeter & digital ammeter. Temperature sensors are embedded between inter faces of the slab, to read the temperature at the surface. The experiment can be conducted at various values of power input and calculations can be made accordingly.

PROCEDURE:

Starting procedure:

1. Ensure that Mains ON/OFF switch given on the panel is at 'OFF' position & dimmer stat is at zero position.
2. Connect electric supply to the set up.
3. Switch 'ON' the Mains ON / OFF switch.
4. Set the heater input by the dimmer stat and voltmeter in the range of 40 to 100 V.
5. After 1.5 hrs. Note down the readings of voltmeter, ampere meter and temperature sensors in the observation table after every 10 minutes interval till observing change in consecutive readings of temperatures (± 0.2 oC).

Closing Procedure:

1. After experiment is over set the dimmer stat to zero position.
2. Switch 'OFF' the Mains ON/OFF switch.
3. Switch 'OFF' electric supply to the set up.

GIVEN:

d = 0.25 m
X1 = 0.02 m
X2 = 0.015m
X3 = 0.012 m
k1 = 52 W /m oC
k2 = 1.4 W /m oC
k3 = 0.12 W /m $_{O}$C

OBSERVATION & CALCULATIONS:

Observation table:

S.No.	V, Volts	I, amp	T_1 °C	T2 °C	T3 °C	T4 °C	T5 °C	T6 °C	T7 °C	T8 °C

Calculations:

To plot the temperature profile,

Distance	0	20	35	47
Avg. Temp.				

At distance 0, average temp $= \dfrac{(T_1 + T_2)}{2}$

At distance 20, average temp $= \dfrac{(T_3 + T_4)}{2}$

At distance 35, average temp $= \dfrac{(T_5 + T_6)}{2}$

At distance 47, average temp $= \dfrac{(T_7 + T_8)}{2}$

$$Q = \frac{W}{2} \quad \text{(Watts)}$$

$W = V \times I$ (Watts)

$$q = \frac{Q}{A} \quad (W/m^2)$$

$A = \pi d^2 / 4$ (m^2)

$(T_1 - T_7) + (T_2 - T_8)$

$$\Delta T = \frac{\qquad\qquad}{2}$$

$$R_t = \frac{\Delta T}{q} \qquad (\ ^\circ C\ m^2/W)$$

$$\Delta X = \square X_1 \square\square + X_2 \square + \square\ X_3 \quad (\ m\ )$$

$$K_{eff} = \frac{q \times \Delta X}{\Delta T} \qquad (\ W/m\ ^\circ C\ )$$

$$K_3 = \frac{X_3}{[(\Delta T/q\ ) - \{(X_1/K_1) + (X_2/K_2)\}]} \qquad (W/m\ ^\circ C)$$

Nomenclature:

A	= Area of heat transfer, m2
d	= Diameter, m
I	= Ammeter reading, amp
K_{eff}	= Thermal conductivity of composite wall, W/m oC
k1	= Thermal conductivity of cast iron, W/m oC
k2	= Thermal conductivity of Bakelite, W/m oC
k3	= Thermal conductivity of Press wood, W/m oC
Q	= Amount of heat transfer, W
q	= Heat flux, W/m2
R_t	= Total thermal resistance of composite wall, oC m2/W
ΔT	= Overall temperature difference, oC
T1 & T2	= Interface temperature of cast Iron and heater, oC
T3 & T4	= Interface temperature of cast Iron and bakelite, oC
T5 & T6	= Interface temperature of bakelite and press wood, oC
T7 & T8	= Top surface temperature of press wood, oC
V	= Voltmeter reading, volts
W	= Heat supplied by the heater, W
ΔX	= Total thickness of wall, m
X1	= Cast Iron thickness, m
X2	= Bakelite thickness, m
X3	= Press wood thickness, m

PRECAUTIONS & MAINTENANCE INSTRUCTIONS:

1. Never run the apparatus if power supply is less than 180 volts and above than 230volts.
2. Never switch on mains power supply before ensuring that all the ON/OFF switches given on the panel is at 'OFF' position.
3. Operator selector switch 'OFF' temperature indicator gently.
4. Always keep the apparatus free from dust.
5. If electric panel is not showing the input on the mains light, check the main supply.
6. If voltmeter showing the voltage given to heater but ampere meter does not, check the connection of heater in control panel.

RESULT: Thermal conductivity of composite wall is appx. ………………

Experiment 5

AIM: To determine the temperature distribution of a pin fin in free and forced convection.

APPARATUS: Pin Fin apparatus**,** temp. sensor

THEORY:

Fins or extended surfaces are used to increase the heat transfer rate from a surface to a fluid wherever, it is not possible to increase the value of the surface heat transfer coefficient or the temperature difference between the surface and the fluid. The use of this is very common and they are fabricated in a variety of shapes or circumferential fins around the cylinder of a motorcycle engine and fins attached to condenser tubes of a refrigerator are few familiar examples. It is obvious that a fin surface stick out from primary heat transfer surface. The temperature difference with surrounding fluid will steadily diminish as one move out along the fin. The design of the fins therefore requires knowledge of the temperature distribution in the fin. The main object of this experimental set up is to study the temperature distribution in a simple pin fin.
Fin effectiveness

$$\varepsilon = \frac{\tanh mL}{mL}$$

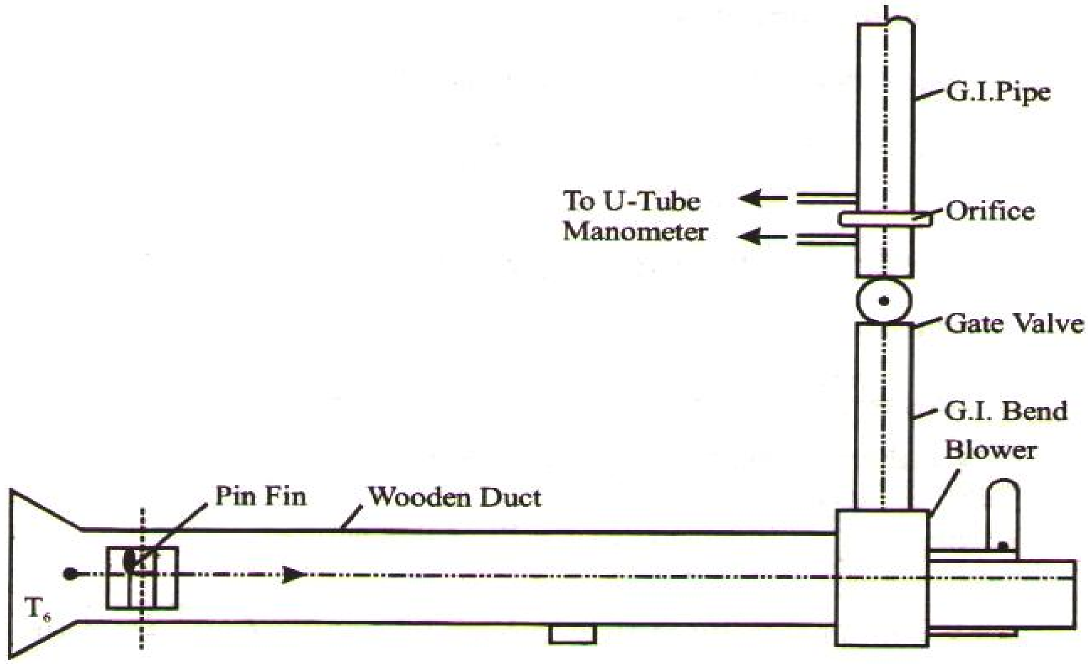
The temperature profile within a pin fin is given by:

$$\frac{\theta}{\theta_0} = \frac{T - T_f}{T_b - T_f} = \left[\frac{\cosh m(L-x) + H \sinh m(L-x)}{\cosh mL + H \sinh mL} \right]$$

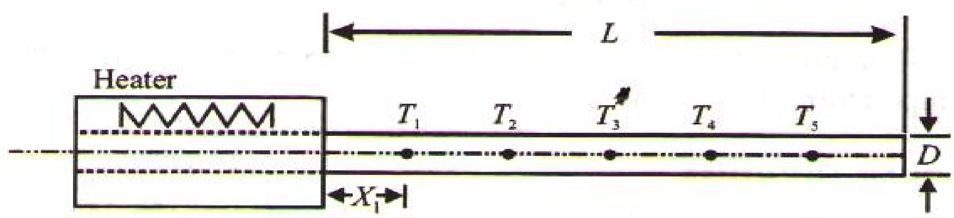
Where T_f is the free stream temperature of air, T_b is the temperature of fin at its base, T is the temperature within the fin at any x, L is the length of the fin and D is the fin diameter. m is the fin parameter defined as:

$m = \sqrt{[hC / k_b A]}$

$\beta = 1 / [T_{mf} + 273.15]$, 1/ K



(a) Layout



(b) Test Section

<u>Diagram of PIN FIN</u>

Velocity of air

$$V = \frac{Q}{A}$$

$$Q_a = \frac{C_0\left(\frac{\pi}{4}\right)a_p a_0\sqrt{2g\Delta H}}{\sqrt{(a_p^2 - a_0^2)}} \quad m^3/s$$

Velocity of air at T_{mg} may be calculated from:

$$V = \frac{V(T_{mf} + 273.15)}{T_f + 273.15}$$

It consists of pin type fin fitted in a duct. A fan is provided on one side of duct to conduct experiments under forced draft conditions. Air flow rates can be varied. A heater heats one end of fin and heat flows to another end. Heat input to the heater is given through dimmerstat. Digital voltmeter and digital ammeter are provided for heat measurement. Digital Temperature Indicator measures temperature distribution along the fin.

PROCEDURE:

Starting Procedure (Free Convection):

1. Ensure that the Mains ON/OFF switch given on the panel is at 'OFF' position & dimmer stat is at zero position.
2. Connect electric supply to the set up.
3. Switch 'ON' the Mains ON / OFF switch.
4. Set the heater input by the dimmer stat and voltmeter in the range of 40 to 100 V.
5. After 1.5 hrs., note down the readings of voltmeter, ampere meter and temperature sensors in the observation table after every 10 minutes interval till observing change in consecutive readings of temperatures (± 0.2 oC).

Starting Procedure (Forced Convection):

1. Ensure that the Mains ON/OFF switch given on the panel is at 'OFF' position & dimmer stat is at zero position.
2. Connect electric supply to the set up.
3. Fill water in manometer up to half of the scale, by opening PU pipe connection from the air flow pipe and connect the pipe back to its position after doing so.

4. Switch ‘ON’ the Mains ON / OFF switch.
5. Set the heater input by the dimmer stat and voltmeter in the range of 40 to 100 V.
6. Switch ‘ON’ the blower.
7. Set the flow of air by operating the valve.
8. After 0.5 hrs., note down the readings of voltmeter, ampere meter, manometer and temperature sensors in the observation table after every 10 minutes interval till observing change in consecutive readings of temperatures (± 0.2 oC).

Closing Procedure:

1. After experiment is over, set the dimmer stat to zero position.
2. Switch ‘OFF’ the blower.
3. Switch ‘OFF’ the Mains ON/OFF switch.
4. Switch ‘OFF ‘electric supply to the set up.

GIVEN:

d_P = 0.052 m
d_o = 0.026 m
D = 0.0127 m
L = 0.150 m
C_o = 0.64
P_r = 0.698
g = 9.81 m/s^2
x = 2.5cm (For T_1) (Centimeter should be convert into meter)
= 5cm (For T_2)
= 7.5cm (For T_3)
= 10cm (For T_4
= 12.5cm (For T_5)
h = 6
ρ_a = 1.093 kg/m^3
ρ_w = 1000 kg/m^3

μ = 19.61 $x10^{-6}$ kg/m-s
ν = 17.95 $x10^{-6}$ m^2/s
k_{air} = 28.215 $x10^{-3}$ W/m °C
k_b = 111 W/m °C

OBSERVATIONS & CALCULATIONS:

Observation table:

Table for Free convection:

S.No.	V, volts	I, amp	T_1 °C	T_2 °C	T_3 °C	T_4 °C	T_5 °C	T_6 °C

Table for Forced convection:

S.No.	V, volts	I, amp	T_1 °C	T_2 °C	T_3 °C	T_4 °C	T_5 °C	T_6 °C	h_1, cm	h_2, cm

Calculations:

Free Convection:

Experimentally

$$T_m = \frac{T_1+T_2+T_3+T_4+T_5}{5}$$

$\Delta T = T_m - T_f$ (°C) $T_f = T_6$

$Q = \square V \times I$, (W)

$A_s = \pi DL$ (m^2)

$$h_{exp} = \frac{Q}{A_s \, \Delta T} \quad (W/m^{2\circ}c)$$

Theoretically

$$T_m = \frac{T_1+T_2+T_3+T_4+T_5}{\quad}$$

$\Delta T = T_m - T_f$ (°C)

$$T_{mf} = \frac{T_m + T_f}{2} \quad (\,°C)$$

$\beta = 1 / [\, T_{mf} + 273.15 \,]$, (1/K)

$$Gr = \frac{g\, \beta\, D^3\, \Delta T}{\nu^2}$$

$Nu = 0.53\, (Gr \times Pr\,)^{1/4}$

$$h_{theo} = \frac{N_u \times k_{air}}{D} \;(\, W/m^{\circ}C)$$

$m = \sqrt{[hC / k_b\, A\,]}$

$C = \pi D$

$$A \;=\; \frac{\pi\, D^2}{4}$$

$$\varepsilon = \frac{\tanh mL}{mL}$$

$$H = \frac{h}{K_b\, m}$$

$$\frac{\theta}{\theta_0} = \frac{T - T_f}{T_b - T_f} = \left[\frac{\cosh m(L-x) + H \sinh m(L-x)}{\cosh mL + H \sinh mL} \right]$$

Taking base temperature, $T_b = T_1$

FORCED CONVECTION:

EXPERIMENTALLY

$$T_m = \frac{T_1+T_2+T_3+T_4+T_5}{5}$$

$\Delta T = T_m - T_f$ (°C)

$Q = V \times I$ (Watts)

$A_s = \pi\, d\, l$

$$h_{exp} = \frac{Q}{A_s\, \Delta T} \qquad (\text{ W/m}^2\,°\text{C })$$

THEORETICALLY

$$Tm = \frac{T_1+T_2+T_3+T_4+T_5}{5}$$

$$T_{mf} = \frac{T_m + T_f}{2} \qquad (°\text{C})$$

$$a_p = \frac{\pi d_p^{\,2}}{4} \text{ , m}^2$$

$$a_0 = \frac{\pi d_0^{\,2}}{4} \text{ , m}^2$$

$$\Delta H = \frac{h_1 - h_2}{100}\ [\ (\rho_w / \rho_a) - 1\ ] \quad \text{, (m)}$$

$$Q_a = \frac{C_0 a_p a_0 \sqrt{2g\Delta H}}{\sqrt{(a_p^{\,2} - a_0^{\,2})}} \qquad \text{m}^3/\text{s}$$

$V' = Q_a / A$ (m/s)

$A = \pi D^2 / 4$

$$V = \frac{V(T_{mf} + 273.15)}{T_f + 273.15}$$

$Re = (DV_1 \rho_a) / \mu$

$N_u = 0.615 (R_e)^{0.466}$

$$h_{theo} = \frac{N_u \times k_{air}}{D} \quad (W/m^{\circ}C)$$

$m = \sqrt{[hC / k_b A]}$

$C = \pi D$

$$\varepsilon = \frac{\tanh mL}{mL}$$

$H = h / (k_b m)$

$$\frac{\theta}{\theta_0} = \frac{T - T_f}{T_b - T_f} = \left[\frac{\cosh m(L-x) + H \sinh m(L-x)}{\cosh mL + H \sinh mL}\right]$$

Taking base temperature, $T_b = T_1$

NOMENCLATURE:

a_p = Area of pipe, m^2

a_o = Area of orifice, m^2

A = Cross sectional area of fin, m^2

A_S = Surface heat transfer area, m^2

C = Perimeter, m

C_o = Orifice coefficient

D = Fin diameter, m

d_o = Orifice diameter, m

d_p = Diameter of pipe, m

g = Acceleration due to gravity, m/s^2

Gr = Grashoff's number

h_1, h_2 = Manometer reading, cm

H = Parameter, m

ΔH = Head loss, m

h_{Exp} = Experimental heat transfer coefficient, $W/m^2\ ^oC$

h_{Theo} = Theoretical heat transfer coefficient, $W/m^2\ ^oC$

I = Ammeter reading, amps

K_b = Thermal conductivity of brass fin, $W/m\ ^oC$

K_{air} = Thermal conductivity of air, $W/m\ ^oC$

L = Fin length, m

m = Fin parameter, m

Nu = Nusselt number

Pr = Prandtl number

Q = Amount of heat transfer, W

Q_a = Volumetric flow rate of air through the duct, m^3/s

T = Fin surface temperature, ^oC

T_{mf} = Fluid mean temp, ^oC

T_m = Fin mean temperature, ^oC

T_f = Fin temperature at any point, ^oC

T_b = Fin base temperature, ^oC

V = Voltmeter reading, volts

V' = Velocity of air, m/s

V_1 = Velocity of air at T_{mf}, m/s

ε = Fin effectiveness

ρ_a = Density of air, kg/m^3

μ = Dynamic viscosity of air, kg/m s

ν = Kinematic viscosity of air, m^2/s

ρ_w = Density of air, kg/m^3

$\frac{\theta}{\theta_0}$ = Theoretical temperature profile within the fin

PRECAUTIONS & MAINTENANCE INSTRUCTIONS:

1. Never run the apparatus, if power supply is less than 180 volts and above 230volts.
2. Never switch on mains power supply before ensuring that all the ON/OFF switches given on the panel is at ‘OFF’ position.
3. Operator selector switches OFF temperature indicator gently.
4. Always keep the apparatus free from dust.
5. If electric panel is not showing the input on the mains light, check the main supply.

RESULT:

h_{Exp} = Experimental heat transfer coefficient, is ………… $W/m^2\ ^oC$

h_{Theo} = Theoretical heat transfer coefficient, is ………….. $W/m^2\ ^oC$

Experiment 6

AIM: To study forced convection heat transfer from a cylindrical surface.

APPARATUS: Forced Convection Apparatus

THEORY:

Convection is defined as a process of heat transfer by combined action of heat conduction and mixing motion. The convection heat transfer is further classified as Natural Convection and Forced Convection. If the mixing motion takes place due to density difference caused by temperature gradient, then Natural or Free Convection knows the process of heat transfer as heat transfer. If the mixing motion is induced by Forced Convection knows some external means such as a pump or blower, then the process is known as heat transfer. If the air is flowing into the heated pipe with very high flow rate then the heat transfer rate increases. The temperature taken by the cold air from the bulk temperature and rises its temperature. Thus, for the tube the total energy added can be expressed in terms of a bulk-temperature difference by:

$q = m\ C_p\ (\ T_{b2} - T_{b1}\ )$

Bulk temperature difference in terms of heat transfer coefficient

$q = h\ A\ (\ T_{b2} - T_{b1}\ )$

The apparatus consists of blower unit fitted with the test pipe. The test section is surrounding by nichrome heater. Four temperature sensors are embedded on the test section and two temperature sensors are placed in the air stream at the entrance and exit of the test section. Test Pipe is connected to the delivery side of the blower along with the Orifice. Input to the heater is given through a dimmerstat and measured by volt meter & ampere meter. The digital temperature indicator is provided to measure the temperature. The airflow is measured with the help of orifice meter and the water manometer which is fitted on the board.

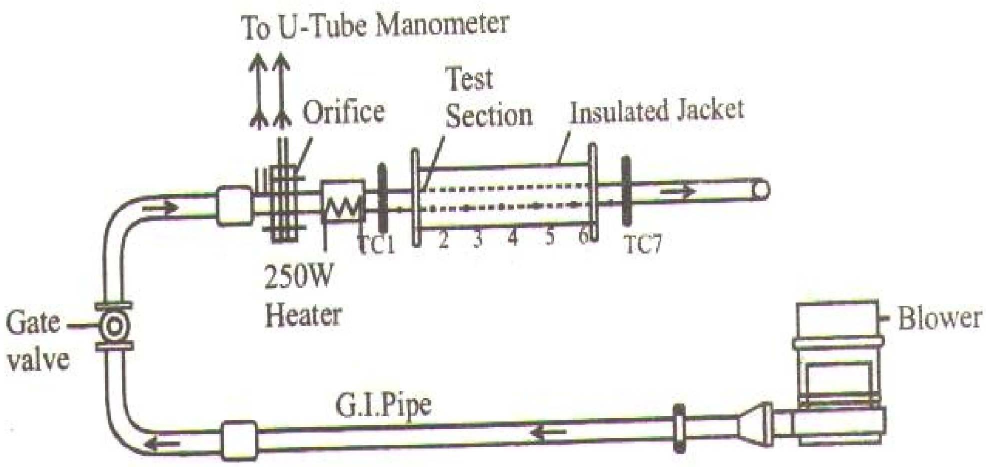


Diagram of Forced Convection

PROCEDURE:
Starting Procedure:

1. Ensure that the Mains ON/OFF switch given on the panel is at 'OFF' position & dimmer stat is at zero position.
2. Connect electric supply to the set up.
3. Fill water in manometer up to half of the scale, by opening PU pipe connection from the air flow pipe and connect the pipe back to its position after doing so.
4. Switch 'ON' the Mains ON / OFF switch.
5. Set the heater input by the dimmer stat and voltmeter in the range of 40 to 100 V.
6. Switch 'ON' the blower.
7. Set the flow of air by operating the valve.
8. After 0.5 hrs., note down the readings of voltmeter, ampere meter, manometer and temperature sensors in the observation table after every 10 minutes interval till observing change in consecutive readings of temperatures (± 0.2 ^oC).

Closing Procedure:

1. After the experiment is over, set the dimmer stat to zero position.
2. Switch 'OFF' the blower.
3. Switch 'OFF' the Mains ON/OFF switch.
4. Switch 'OFF' the electric supply to the set up.

GIVEN:

D_i = 0.028 m

D_o = 0.038 m

L = 0.4 m

d_o = 0.014 m

d_p = 0.028 m

C_p = 1.003 kJ/kg ^oC

ρ_a = 1.205 kg/m^3

ρ_w = 1000 kg/m^3
C_o = 0.64

OBSERVATIONS & CALCULATIONS:

Observation table:

V volts	I amp	T_1 °C	T_2 °C	T_3 °C	T_4 °C	T_5 °C	T_6 °C	h_1 cm	h_2 cm

$$T_s = \frac{T_2 + T_3 + T_4 + T_5}{4}$$

$$T_a = \frac{T_1 + T_6}{2}$$

$$A = \pi D_i L \quad , m^2$$

$$\Delta H = \frac{h_1 - h_2}{100} \left[\left(\rho_w / \rho_a \right) - 1 \right] \ , m$$

$$Q_a = \frac{C_0 \, a_p \, a_0 \sqrt{(2g\Delta H)}}{\sqrt{(a_p^2 - a_0^2)}} \quad m^3/s$$

$$m = Q \times \rho a \ , kg/s$$

$$Q_a = m \, Cp \, (T6 - T1) \ , \ W$$

$$U = \frac{Qa}{A (Ts - Ta)} \quad , W/m^2$$

Nomenclature:

A = transfer area, m2
C_p = Specific heat of air, kJ/kg ^oC
C_o = Coefficient of discharge
D_i = Inner diameter of test section, m
D_o = Outer diameter of test section, m
d_p = Diameter of pipe, m
d_o = Diameter of orifice, m
ΔH = Head loss, m of air
I = Ammeter reading, amp
L = Length of test section, m
m = Mass flow rate of air, kg/s
Q_a = Heat taken by air, W
Q = Flow rate of air, m3/s
h_1,h_2 = Manometer readings, cm
T_1 = Air inlet temperature, ^oC
T_2,T_3,T_4,T_5 = Surface temperature of test section, ^oC
T_6 = Air outlet temperature, ^oC
T_s = Average surface temp, ^oC
T_a = Average temperature of air, ^oC
U = Heat transfer coefficient, Watt/m^2°C
V = Voltmeter reading, volts
ρ_w = Density of water, kg/m^3
ρ_a = Density of air, kg/m^3

PRECAUTIONS & MAINTENANCE INSTRUCTIONS:

1. Never run the apparatus, if power supply is less than 180 volts and above 230 volts.
2. Never switch 'ON' mains power supply before ensuring that all the ON/OFF switches given on the panels are at 'OFF' position.
3. Operate the selector switch of temperature indicator gently.
4. Always keep the apparatus free from dust.
5. If electric panel is not showing the input on the mains light, check the main supply.
6. If voltmeter showing the voltage given to heater but ampere meter does not, check the connection of heater in control panel.

RESULT: Heat transfer coefficient is approx. ………………… Watt/m^2°C

Experiment-7

AIM: To find the effectiveness of a heat exchanger.

.

APPARATUS:

1. Electricity Supply: Single Phase, 220 VAC, 50Hz, 5-15Amp socket with earth connection.
2. Water Supply: Continuous @ 5 LPM at 1 Bar.
3. Drain Required.
4. Bench Area Required: 1.75 m x 0.5 m

THEORY:

Heat Exchanger is a device in which heat is transferred from one fluid to another. The necessity for doing this arises in a multitude of industrial applications. Common examples of heat exchangers are the radiator of a car, the condenser at the back of a domestic refrigerator and the steam boiler of a thermal power plant. The heat exchangers are classified in three categories:
1) Transfer Type.
2) Storage Type.
3) Direct Contact Type
A transfer type of heat exchanger is one on which both fluids pass simultaneously through the device and heat is transferred through separating walls. In practice, most of the heat exchangers used are of transfer type. The transfer type exchangers are further classified according to flow arrangement as -
1. Parallel flow in which fluids flow in the same direction.
2. Counter flow in which fluid flow in opposite direction and
3. Cross flow in which fluid flow at right angles to each other.
A simple example of transfer type of heat exchanger in the form of a tube type arrangement in which one of the fluids is flowing through the inner tube and the other through the annulus surroundings it. The heat transfer takes place across the walls of the inner tube.

The apparatus consists of a tube in tube type concentric tube heat exchanger. The hot fluid is hot water which is obtained from an insulated water bath using a magnetic drive pump and it flow through the inner tube while the cold fluid is cold water flowing through the annuals. The hot water flows always in one direction and the flow rate of which is controlled by means of a valve. The cold water can be admitted at one of the end enabling the heat exchanger to run as a parallel flow apparatus or a counter flow apparatus. This is done by valve operations. For flow measurement rota meters are provided at inlet of cold water and outlet of hot water line. A magnetic drive pump is used to circulate the hot water from a recycled type water tank, which is fitted with heaters and Digital Temperature Controller.

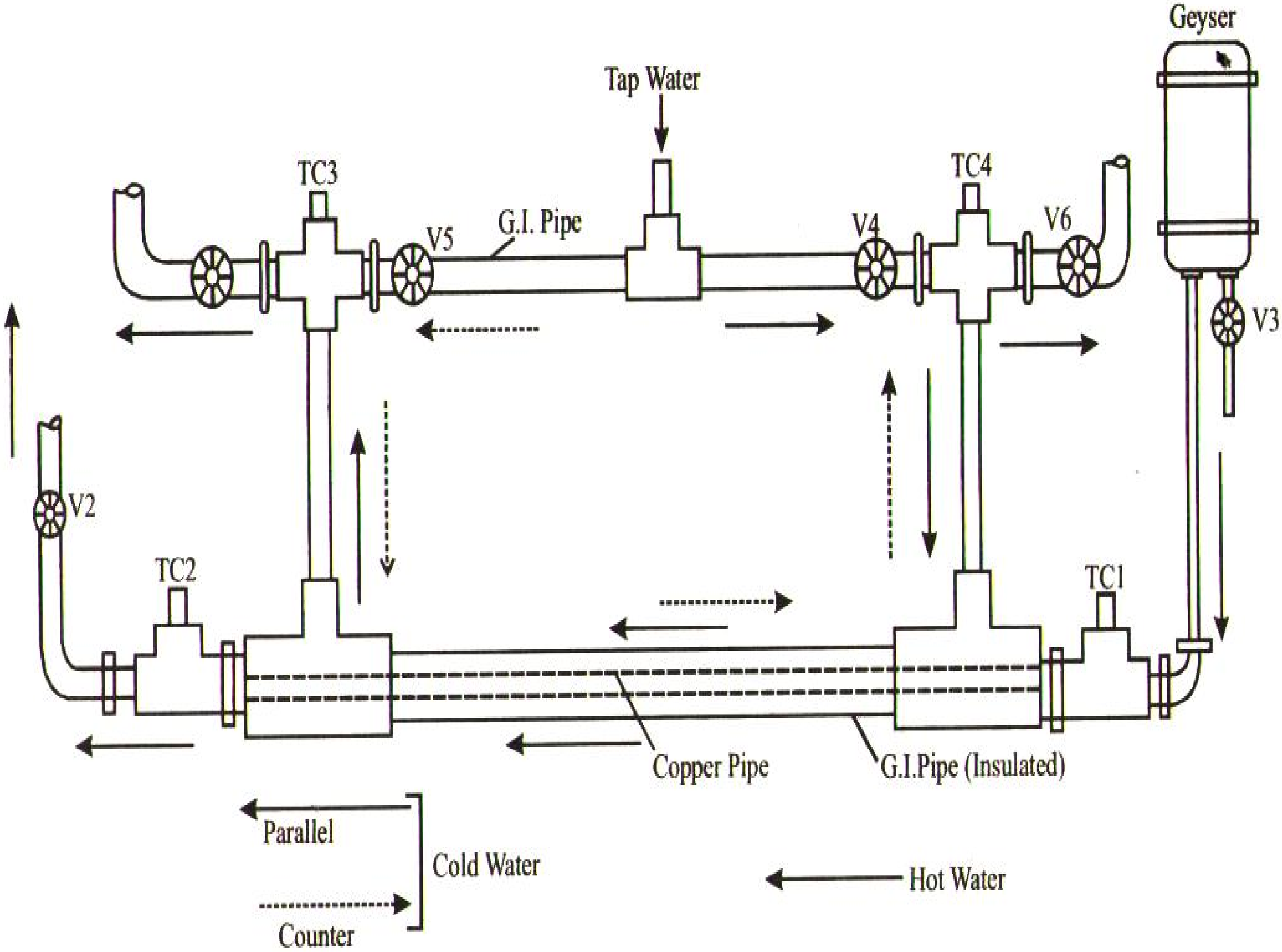


Diagram of Heat Exchanger

PROCEDURE:

Starting procedure:

1. Close all the valves provided on the set up.
2. Open the lid of hot water tank, fill the tank with water and put the lid back to its position.
3. Ensure that switches given on the panel are at 'OFF' position.
4. Connect electric supply to the set up.
5. Set the desired water temperature in the DTC by operating the increment or decrement and set button of DTC.
6. Open by pass valve and Switch 'ON' the pump.
7. Switch ON the heater and wait till desired temperature achieves.
8. Connect cooling water supply to the set up.
9. Connect both the outlet (parallel / counter) of cooling water to drain.
10. Open the inlet & outlet valve for cold water as per desired mode (parallel/counterflow).
11. Allow cold water to flow through heat exchanger and adjust the flow rate by rotameter and control valve.
12. Allow hot water to flow through heat exchanger and adjust the flow rate by Rotameter, control valve and by pass valve.
13. At steady state (constant temperature) record the temperatures & flow rate of hot and cold water.
14. Repeat the experiment for different flow rate of hot & cold water.
15. Repeat the experiment for different bath temperature.
16. Repeat the experiment for other mode (counter/parallel flow).

Closing procedure:

1. When experiment is over switch 'OFF' heaters.
2. Switch 'OFF' pump.
3. Switch 'OFF' Power Supply to Panel.
4. Stop cooling water supply.
5. Drain hot water tank by the drain valve provided.

GIVEN:

D_i = 0.0095 m
D_o = 0.0127 m
L = 1.6 m

OBSERVATION & CALCULATION:

Observation table:

S. No.	Mode Parallel / Counter	F_h LPH	T_1 °C	T_2°C	F_c LPH	T_3°C	T_4/T_5 °C

Calculations:

Find the properties of water (C_{ph}, ρ_h) at $T_h = \dfrac{T_1+T_2}{2}$ and (C_{pc}, ρ_c) at

$T_c = \dfrac{T_3+T_4}{2}$ or $\dfrac{T_3+T_5}{2}$ (as per mode selected) from data book.

C_{ph} = ----------- kJ/kg °C

C_{pc} = ----------- kJ/kg °C

ρ_h = ----------- kg/m³

ρ_c = ----------- kg/m³

$M_h = \dfrac{F_h \times \rho_h}{3600 \times 1000}$, kg/s = ---------------- kg/s

$Q_h = M_h C_{ph} (T_1 - T_2)$, W = ---------------- W

$M_c = \dfrac{F_c \times \rho_c}{3600 \times 1000}$, kg/s = ---------------- kg/s

$Q_c = M_c C_{pc} (T_4 - T_3)$, W (for parallel flow) = ---------------- W

$Q_c = M_c C_{pc} (T_5 - T_3)$, W (for counter flow) = ---------------- W

$$Q = \frac{Q_h + Q_c}{2}, \text{ W} = \text{-------------------------- W}$$

$\Delta T_1 = T_1 - T_3$ °C (for parallel flow) = ----------------- °C

$\Delta T_1 = T_1 - T_5$ °C (for counter flow) = ----------------- °C

$\Delta T_2 = T_2 - T_4$ °C (for parallel flow) = ----------------- °C

$\Delta T_2 = T_2 - T_3$ °C (for counter flow) = ----------------- °C

$$\Delta T_m = \frac{\Delta T_1 - \Delta T_2}{\text{Ln}\,(\Delta T_1 / \Delta T_2)}, \text{ °C} = \text{------------------- °C}$$

$A_i = \pi D_i L$, m^2 = --------------------- m^2

$A_o = \pi D_o L$, m^2 = --------------------- m^2

$$U_i = \frac{Q}{A_i \Delta T_m}, \text{ W/m}^2\text{ °C} = \text{------------ W/m}^2\text{ °C}$$

$$U_o = \frac{Q}{A_o \Delta T_m}, \text{ W/m}^2\text{ °C} = \text{------------ W/m}^2\text{ °C}$$

Nomenclature:

A_i = Inside heat transfer area, m^2

A_o = Outside heat transfer area, m^2

C_{ph} = Specific heat of hot fluid at mean temperature, kJ/kg °C

C_{pc} = Specific heat of cold fluid at mean temperature, kJ/kg °C

D_o = Outer diameter of tube, m

D_i = Inner diameter of tube, m

F_h = Flow rate of hot water, LPH

F_c = Flow rate of cold water, LPH

L = Length of tube, m

M_h = Mass flow rate of the hot water, kg/s

M_c = Mass flow rate of the cold water, kg/s

Q = Average heat transfer from the system, W

Q_c = Heat gained by the cold water, W

Q_h = Heat loss by the hot water, W

T_h = Mean temperature of hot water, ^oC

T_c = Mean temperature of cold water, ^oC

T_1 = Inlet temperature of the hot water, ^oC

T_2 = Outlet temperature of the hot water, ^oC

T_3 = Inlet temperature of the cold water, ^oC

T_4 = Outlet temperature of the cold water for parallel flow, ^oC

T_5 = Outlet temperature of the cold water for counter flow, ^oC

ΔT_m = Log mean temperature difference, ^oC

U_i = Inside overall heat transfer coefficient, $W/ m^2\ ^oC$

U_o = Outside overall heat transfer coefficient, $W/ m^2\ ^oC$

ρ_c = Density of cold water at mean temp, kg/m^3

ρ_h = Density of hot water at mean temp, kg/m^3

PRECAUTIONS & MAINTENANCE INSTRUCTIONS:

1. Never run the apparatus, if power supply is less than 180volts and above 230volts.
2. Never switch 'ON' mains power supply before ensuring that all the ON/OFF switches given on the panel is at 'OFF' position.
3. Operate the selector switch of temperature indicator gently.
4. Always keep the apparatus free from dust.

RESULT:

U_i = Inside overall heat transfer coefficient is ………….. $W/ m^2\ ^oC$

U_o = Outside overall heat transfer coefficient is …………… $W/ m^2\ ^oC$

Experiment-8

AIM: To find the Stefan- Boltzman constant.

APPARATUS: Stefan Boltzmann Apparatus, Beaker

THEORY:

All substances at all temperature emit thermal radiation. Thermal radiation is an electromagnetic wave and does not require any material medium for propagation. All bodies can emit radiation and also the capacity to absorb all the part of the radiation coming from the surrounding towards it. The most commonly used law of thermal radiation is the Stefan Boltzmann law which states that thermal radiation heat flux or emissive power of a black surface is proportional to the fourth power of absolute temperature of the surface and is given by

$$\frac{Q}{A} = Eb = \sigma T^4 \quad W/mK^4$$

The constant of proportionally is called the Stefan Boltzmann constant and has the value of 5.67×10^{-8} $W/m^2 K^4$. The Stefan Boltzmann law can be derived by integrating the Planck's law over the entire spectrum of wavelength from 0 to ∞. The objective of this experimental set up is to measure the value of this constant fairly closely, by an easy arrangement.

The apparatus consists of a hemisphere fixed to a Bakelite Plate, the outer surface of which forms the jacket to heat it. Hot water to heat the hemisphere is obtained form a hot water tank, which is fixed above the hemisphere. The copper test disc is introduced at the center of hemisphere. The temperature of hemispheres and test disc are measured with the help of temperature sensors.

PROCEDURE:

Starting Procedure:

1. Close all the valves.
2. Fill heater tank 3/4th with water by removing the lid of the tank and put the lid back to its position after doing so.
3. Ensure that switches given on the panel are at 'OFF' position.
4. Connect electric supply to the set up.
5. Switch 'ON' the Mains ON / OFF switch.

6. Set the desired water temperature in the DTC by operating the increment or decrement and set button of DTC.
7. Switch ON the heater and wait till desired temperature achieves.

8. Remove the disc from the bottom of test chamber by removing the support provided to hold it.
9. Switch 'OFF' the heater.
10. Fill test chamber with hot water of heater tank by opening the valve provided at the top of the chamber, till observing the overflow of water through chamber outlet and then close the valve.
11. Note the readings of water temperature (T1) and initial temperature of the disc (T2i).
12. Insert the disc to the bottom of the chamber and note the reading of temperature T2 after 5-10 sec interval.

Closing Procedure:
1. After the experiment is over, switch OFF the Mains ON/OFF switch.
2. Switch OFF the electric supply to the set up.
3. Drain the water from chamber and heater tank by the drain valve provided.

GIVEN:

D = 0.02 m
m = 0.0051 kg
s = 4186 J/kg-^{o}C

OBSERVATION & CALCULATION:

Observation:

T_1 = ----------- ^{o}C
T_2 = ----------- ^{o}C

Time , t (sec.)	Temp. , T

PRECAUTIONS & MAINTENANCE INSTRUCTIONS:

1. Never run the apparatus, if power supply is less than 180volts and above 230volts.
2. Never switch 'ON' mains power supply before ensuring that all the ON/OFF switches given on the panel is at 'OFF' position.

3. Operate the selector switches of temperature indicator gently.

4. Always keep the apparatus free from dust.

RESULT: Value of Stefan Boltzmann constant is approx. ……………..