1.THERMAL CONDUCTIVITY OF A METAL ROD

AIM OF THE EXPERIMENT:

a) To measure the temperature gradient along the length of the metal (copper) rod.

b) To determine the co-efficient of thermal conductivity of the metal (copper).

INTRODUCTION:

Conduction is a process of heat transfer through solids. When a temperature gradient exists in a body, experience has shown that there is a transfer of heat from the high temperature region to the low temperature region. The heat transfer rate per unit area is proportional to the temperature gradient given by:

$$\frac{q}{A} \propto \frac{\Delta T}{\Delta X} \qquad \text{--- Eq (1)}$$

Where, 'q' is the heat transfer rate (watts), A is the area of heat transfer (m^2), $\Delta T / \Delta X$ is the temperature gradient in the direction of heat flow (°C/m). When the proportionality constant is inserted, we get,

$$\frac{q}{A} = \frac{-K \Delta T}{\Delta X} \qquad \text{---Eq (2)}$$

The positive constant 'k' is called the co-efficient of thermal Conductivity of the material. The negative sign indicates that heat transfer takes place in the direction of decreasing temperature. Co- efficient of thermal conductivity has the units of watts/m°C. Note that heat flow rate is involved and the numerical value of the co- efficient of thermal conductivity indicates how fast heat will flow in a given material.

Thermal conductivity co- efficient is a physical property of the material. Although it is fairly constant in a narrow temperature range, it varies over a wide temperature range. Metals which are good conductors of heat have high values of co-efficient of thermal conductivity; for example, 385 watts/m°C for copper. Insulating materials have low values of co-efficient of thermal conductivity – for example 0.048 watt/m°C for fiber insulating board.

In any conduction heat transfer problem, it is essential to have the knowledge of co-efficient of thermal conductivity of the material involved in the heat transfer process. This set-up has been designed to measure the temperature gradient along the length of the rod and to determine its co- efficient of the thermal conductivity.

APPARATUS:

It consists of a copper rod one end of which is heated by an electric heater and the other end projects inside the cooling water jacket. The middle portion of the rod is thermally insulated from the surroundings using asbestos rope. The temperature of the rod is measured at four different locations along its length. Following are the important features of the experimental setup.

a) Copper rod, Length : 450mm
   Diameter : 20mm.
   No. of thermocouples mounted : 4 (at the interval of 58 mm) a long the length

b) Band heater used to heat up one end.

c) Thermal insulation covering the copper rod to reduce heat losses to the surroundings.

d) Cooling water jacket at the other end with water supply connections and thermocouples at both inlet T_5 and outlet T_6.

e) Heat controller or regulator to vary input power to the heater.

f) Measuring jar to measure water flow rate in the cooling water jacket.

g) Thermocouples to measure temperatures at 1, 2, 3 & 4 along the length of the copper rod and 5 & 6 to measure temperatures at inlet & outlet of water jacket.

h) Digital temperature indicator and channel selector.

PROCEDURE:

a) Switch ON the mains.

b) Open the valve at the inlet of the cooling water jacket and maintain constant water flow rate.

c) Switch ON the heater.

d) Set the heat control or regulator and adjust the power input to the heater.

e) Wait for reasonable time till the temperatures T_1 toT_4 are fairly constant with time that is steady state is reached.

f) Read the temperatures T_1 to T_4 on the metal rod using channel selector and digital temperature indicator.

g) Read inlet and outlet water temperatures (T_5 & T_6) of the cooling water jacket.

h) Measure the cooling water flow rate using measuring jar and stop watch.

i) Using the measured temperatures and water flow rate, the temperature gradient along the length of the brass rod and co- efficient of thermal conductivity of copper are calculated using the procedure given below.

Formulae:

The heat balance equation is given by,

$q_i = q_o + q_1$ ---Eq (2)

Where,

q_i = Input heat rate from the heater to the copper rod (Watts).

q_o = Output heat flow rate from the rod.

= Heat flow rate absorbed by water in the cooling water jacket (Watts).

q_1 = Heat loss from the rod to the surrounding s through thermal insulation, watts (Watts), Assumed to be zero.

We can assume that $q_1 = 0$, because of good thermal insulation. Therefore, we get heat flow rate through the rod given by:

$$q_i = q_o = m\, C_p .\ \Delta T_w \qquad \text{--- Eq (3)}$$

Where,

m = Water flow rate in Kg/ sec. in the cooling water jacket.

C_p = Specific heat of water, 4.18 KJ / Kg°C

= 4180 J / Kg°C.

ΔT_w = Rise in temperature of the cooling water in the cooling water jacket.

= T_6-T_5 (°C).

T_6 = Water temperature at the outlet (°C).

T_5 = Water Temperature at the inlet (°C).

Determination of temperature gradient (dT/dX) along the length of the Copper rod:

From the measured temperatures T_1, T_2, T_3, T_4 surface temperature distribution along the length of the rod can be determined by plotting a graph of distance along the rod (X) on the X-axis and temperature (°C) on the Y-axis as shown.

Thus, the temperature gradient (dT/dX) at the centre of the brass rod in °C /m can be determined from the slope of the curve (by drawing a tangent).

Determination of Co-efficient of Thermal Conductivity**:**

The heat conduction equation is given by

$$q = kA\left(\frac{dT}{dX}\right) \qquad \text{---Eq (4)}$$

Where,

Q = Heat flow rate through the Copper rod, watts

k = Co-efficient of thermal conductivity of copper, Watts/m^2 °C.

A = Area of heat transfer, m^2

$= (\pi d^2) / 4.$

$= (\pi \times 0.02^2) / 4$

$= 3.14 \times 10^{-4}\ m^2.$

d = Diameter of the Copper rod (m). = 0.02 m

From EQ (3) & (4), we get,

$$k A \left(\frac{dT}{dX}\right) = m \cdot C_p \cdot \Delta T_w \qquad \text{---- Eq (5)}$$

$$k = \frac{m \times C_p \times \Delta T_w}{A\left(\frac{dT}{dX}\right)} \quad \text{in} \quad w/m^0 c$$

The co-efficient of thermal conductivity (k) can be obtained by substituting the measured values of m, ΔT_w, (dT /dX), A and C_p.

The above analysis assumes that the heat loss from the brass rod is negligible due to thermal insulation.

OBSERVATION TABLE:

Power meter reading, in Watts	**T_1**	**T_2**	**T_3**	**T_4**	**T_4**	**T_5**	**T_6**	**Time duration for steady state**

T_1 – FIRST POINT TEMPERATURE
T_2 – SECOND POINT TEMPERATURE
T_3 – THIRD POINT TEMPERATURE
T_4 – FOURTH POINT TEMPERATURE
T_5 –WATER INLET TEMPERATURE
T_6 –WATER OUTLET TEMPERATURE

GRAPHS: Temp Vs Distance

RESULTS:

2.THERMAL CONDUCTIVITY OF COMPOSITE WALLS

INTRODUCTION:

Conduction is a process of heat transfer through solids For a given temperature difference between the surfaces, the rate of heat transfer (q watts) depends upon the co-efficient of thermal conductivity of the substance (k, watts/ m^{o}C), area of heat transfer (A, m^{2}) and temperature differences (ΔT, ^{o}C) between the surfaces and thickness of the material (ΔX, m) according to the equation,

$$Q = k A (\Delta T / \Delta X) \qquad \text{----Eq (1)}$$

Substances such as metals conduct more heat and have high values of co-efficient of thermal conductivity , as high as about 200 watts / m^{o} C. Insulating materials conduct less heat and have low values of co-efficient of thermal conductivity, say about 0.1 to 1 watts / m^{o} C. In circumstances where heat loss from the system has to be minimized, such as in power plant transmission lines, furnaces, etc. It is essential to cover heat carrying systems with proper materials. This set-up has been designed to study heat transfer through composite materials.

AIM OF THE EXPERIMENT:

To determine rate of heat transfer co efficient through composite material consisting of Copper, Asbestos and Mild Steel, Alluminium.

SPECIFICATION AND DESCRIPTION:

The set-up consists of the following items:

a) Composite Walls:

It consists of a Heater at one end with Mild Steel, Asbestos, Alluminium and Copper plates composited to form heat flow path. The test pieces are covered with MS Sheet Guard to prevent heat loss.

b) Flat Heater:

Provided to heat the composite walls at one end.

* Capacity : 250 watts
* Diameter of copper, Asbestos & Mild Steel plates : 150 mm.
* Thickness of test plates : 6 mm

c) Thermocouples: K- Type to measure temperature

T1	:	On Heater plate
T2	:	On Copper plate
T3	:	On Asbestos plate
T4	:	On Mild Steel plate
T5	:	On Aluminum plate
T6 & T7	:	Water inlet and outlet temperatures

d) Channel Selector and Digital Temperature Indicators.

e) Heat control or Regulator : To vary input power to the heater.

f) Control Panel : To switch on / off the console and the heater.

g) Digital Wattmeter is used for heat input measurement.

OPERATIONAL PROCEDURE:

a) Switch-ON the Mains and the console

b) Switch-ON the heater

c) Set the heat controller / regulator

d) Wait for some time, till the temperature stabilize with time, i.e. steady state is reached

e) Read the temperatures T1 to T5 using channel selector and digital Temperature indicator

f) Note down the wattmeter reading and water flow rate by rotameter.

g) Using the temperatures, calculate rate of heat transfer co-efficient through composite wall using procedure given below

WORKING PRINCIPLE

The heat balance equation for one dimensional flow is given by, (neglecting losses in stable condition),

$$Q = Q_i = Q_{aluminum} = Q_{mild\ steel} = Q_{asbestos} = Q_{copper}$$

Where $Q_{al,}$ $Q_{M,}$ $Q_{as,}$ Q_C are the same heat flowing across Aluminum, Mild Steel Asbestos, and Copper respectively. Q_i is the overall heat flow across composite material. Considering the individual material, the heat transmitted across each of the material is equal to heat input through heater.

$$Q = \frac{K1\,A(\Delta Ta)}{L1} = \frac{K2\,A(\Delta Ta)}{L2} = \frac{K3\,A(\Delta Ta)}{L3} = \frac{K4\,A(\Delta Ta)}{L3}$$

Where, L = Length of heat flow in m. = 0.024 m

A = Area of heat flow in $m^2 = \pi d^2/4$

ΔT = Temperature Difference of particular material in °C.

K1 = Thermal Conductivity of copper

K2 = Thermal Conductivity of aluminum.

K3 = Thermal Conductivity of asbestos

K4 =Thermal Conductivity of mild steel.

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Also the heat conducted through composite wall is given by

$$Q = m\,Cp\,(T_7 - T_6)$$

Therefore, Overall thermal conductivity practical, K_{exp}

$$K_{exp} = \frac{Q \times L_0}{A\,(T_2 - T_5)} \text{ in W/m}^oC$$

Where,

m = mass flow rate of water in Kg/s

A = Area of heat flow in m^2

Theoretical Overall heat transfer co-efficient K_{the} is given by,

$$K_{the} = \frac{L_O}{(L1/K1) + (L2/K2) + (L3/K3) + (L4/K4)}$$

L1 = L2 = L3 = L4=0.006 m.

L_O= 0.024 m

A= $\pi \times 0.15^2/4 = 0.017\ m^2$.

TABULAR COLUMN:

Power Input in KW	**Water flow rate in kg/sec**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**Time to reach steady state**	**Theoretical overall heat transfer coefficient**	**Practical overall heat transfer coefficient**

$$K_{exp} = \frac{Q\,L_o}{A\,(T_2 - T_5)} \quad \text{in W/m}^oC \qquad Q = m\,Cp\,(T_7 - T_6)$$

$$K1 = \frac{Q\,L1}{A\,(T_1 - T_2)} =$$

$$K2 = \frac{Q\,L2}{A\,(T_2 - T_3)}$$

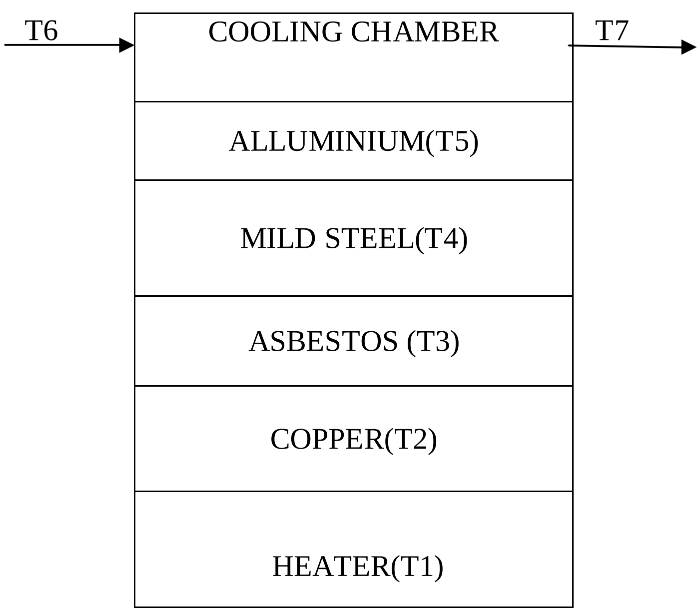
Q L3

$$K3 = \frac{\quad}{A\,(T_3 - T_4)}$$

$$K4 = \frac{Q\,L4}{A\,(T_4 - T_5)}$$

$$K_{the} = \frac{L_O}{(L1/K1) + (L2/K2) + (L3/K3) + (L4/K4)}$$

SCHEMATIC DIAGRAM



<u>RESULTS:</u>

3.<u>THERMAL CONDUCTIVITY OF INSULATING POWDER</u>

AIM:

To determine the thermal conductivity of insulating powders using **'sphere in sphere'** method.

APPARATUS & SPECIFICATIONS:

1. Inner sphere-200mm O.D., halved construction.
2. Outer sphere-254mm O.D., halved construction.
3. Heater-Mica flat heater ,fitted inside inner sphere
4. Controls :-
   a) Main Swith-10A , DPDT Switch
   b)Dimmerstat-0-230 volts,2A capacity
5. Multichannel digital temperature indicator, calibrated for Cr/Al thermo couples.

THEORY:
Conduction of heat is flow of heat which occurs due to exchange of energy from one molecule to another with out appreciable motion of molecules. In any heating process heat is flowing out words from heat generation point. in order to reduce losses of heat, various types of insulations are used in practice. Various powders example asbestos powder, plaster of fairs etc. are used for heat insulation in order to determine the appropriate thickness of insulation, knowledge of thermal conductivity of heat insulation material is essential.

<u>EXPERIMENTAL PROCEDURE:</u>

1. Keep dimmer stat knob at ZERO position and switch ON the equipment.
2. Slowly rotate the dimmer stat knob, so that voltage is applied across the heater .Let the temperature rise.
3. Wait until steady state is reached.
4. Note down all the temperatures and input of heater in terms of volts and current.

5. Repeat the procedure for different heat inputs.

OBSERVATIONS;

Sl No				Temperature ^0C			Heater Input
T1	T2	T3	T4	T5	T6	T7	

CALCULATIONS:

1. Heater input = q = V x I Watts
2. Average inner sphere surface temperature
   Ti = (T1+T2+T3+T4) / 4 °C
3. Average outer sphere temperature
   To = (T5+T6+T7+T8+T9+T10) / 6 °C
4. Inner sphere radius =100mm
5. Outer sphere radius=127mm
6. Thermal conductivity K = q (r_i-r_o) / 4π. $r_i.r_o(T_i-T_o)$ W/m.K at T_i+T_o /2 °C

SAMPLE CALCULATION :

Insulating powder = **Chalk powder**
Oil **= SAE 40 W 20**

$$K = \frac{Q}{R \Delta T}$$

Where K = Thermal conductivity of the powder in w/m°c

Q = Total heat transfer rate in watts.

R = Shape factor

$$= \frac{4\pi \times R \times r}{R \times r}$$

r_i = Radius of inner sphere = 100 mm

r_o = Radius of outer sphere = 127 mm

$\Delta T = Ti - To$ in°c

$Ti = T_7 = 50°c$ Oil Temperature

PRECAUTIONS :

- Do not start the equipment without proper electrical supply.
- Handle the switches gently.
- Always ensure that there is oil with in the sphere.
- After the experiment is over, switch off all the indicators and heaters.
- At least for every two weeks, operate the unit for five minutes.
- In case of any major faults, Please write to manufacture, and do not attempt to repair.

RESULT: Thermal conductivity of the insulating powder is ------ W/m.K

4.DETERMINATION OF STEFAN BOLTZMAN'S CONSTANT

1. INTRODUCTION:

The most commonly used relationship in radiation heat transfer is the Stefan Boltzmann's law which relates the heat transfer rate to the temperatures of the hot and cold surfaces,

$$q = \sigma A (T_h^4 - T_c^4)$$

Where, q = Rate of heat transfer, watts.

σ = Stefan Boltzmann's constant.

= 5.669×10^{-8} watts / m^2 $^0K^4$.

A = Surface area, m^2

D = Dia of the disc 15mm

M = Mass of the disc 4grams

T_h = Temperature of the hot body, ^{0}K.

T_c = Temperature of the cold body, ^{0}K.

The above equation is applicable only to black bodies (for example, a piece of metal covered with carbon black approximates this behavior) and is valid only for thermal radiation .Other types of bodies (like a glossy painted surface or a polished metal plate) do not radiate as much energy as the black body but still the total radiation emitted generally follow T^4 proportionality .

This Setup has been designed to determine the value of the Stefan Boltzmann's constant .

$$q_a = \sigma A_d T_a^4 \qquad \text{............Eq (1)}$$

2. AIM OFTHE EXPERIMENT:

To determine the Stefan Boltzmann's constant.

3. APPARATUS:

The schematic of the setup consists of the following important parts:

a) Copper hemispherical enclosure.

b) Jacket to hold the hot water.

c) Outside surface of the enclosure is filled with insulating material to prevent heat loss .

d) Thermocouples to measure temperature on the copper hemisphere

e) Disc made of copper mounted in an insulating plastic sleeve . Disc Dia: 20 mm, Mass = 4 grams.

f) Digital temperature of the water to a safe value

g) Overhead water container along with necessary fittings to heatup the water and dump it to the jacket of the container .

h) Thermostat to set the temperature of the water to a safe value.

4. WORKING PRINCIPLE:

The enclosure is maintained at a higher temperature (fairly constant and uniform over the enclosure surface) using water jacket . The disc or the test piece is inserted into is place along with the sleeve and the variation in its temperature (T_d) with time is recorded .

The radiation energy falling on the disc (D) from the enclosure is given by,

$$q_e = \sigma A_d T_e^4$$

Where,

q_e = Rate of radiation emitted by the enclosure falling on the disc (watts)

A_d = Area of the disc, m^2.

T_e = Average temperature of the enclosure recorded by

Thermocouples (^{0} K).

The emissivity of the enclosure and the disc are assumed unity of black surface characteristics .

The radiation energy absorbed by the disc from the enclosure is given by ,

$$Q_a = \sigma A_d T_a^4 \qquad \text{............Eq (1)}$$

Where,

Q_a= Rate of radiation absorbed by the disc onto the enclosure (watts)

T_d =Temperature of the disc (^{0} K).

If the disc has mass (m, Kgs) and specific heat (C_p in J / K g^0 C),increase in temperature of the disc is related to radiation heat transfer using the relationship,

$$m\ C_p\ (dT / dt)_{t=0} = \sigma\ A_d\ (T_e^4 - T_a^4) \quad .....Eq\ (2)$$

where (dT/ dt)is the rate of increase in temperature (^{0} C/Sec)at the instant when the disc is inserted into the Set-up . The Stefan Boltzmann's constant is obtained using the relationship,

$$\sigma = \frac{mC_p(dT_a / dt)_{t=0}}{A_D\ (T_e^4 - T_a^4)} \quad ....Eq\ (3)$$

$(dT_a / dt)_{t=0}$ is obtained by plotting the temperature of the disc (T_d) versus time and measuring the slope of temperature variation with time at time t=0 that is , at the instant of inserting the disc into the Set-up .

5. OPERATIONAL PROCEDURE:

1. Switch- ON the Main and the Console.
2. Remove the disc (d) or test piece.
3. Switch-ON the Water Heater.
4. After water attains the maximum temperature, open the valve and dump the water to the enclosure jacket .
5. Wait for about few seconds to allow hemispherical enclosure to attain uniform temperature - the enclosure will soon reach thermal equilibrium.
6. Measure the enclosure temperature T_e using Channel Selector and digital temperature indicator .

7. Insert the disc (d) with the sleeve into its position and record the temperature of the disc (T_d) at different instants of time using stop watch .

8. Plot the variation of disc temperature (T_d) with time (sec) as shown and get the slope of temperature versus time variation (^0C/sec) at the time t=0 sec .

9. Using Eq (3), calculate the Stefan Boltzmann's constant.

10. Repeat the experiment and calculate the average value to obtain the better value of the Stefan Boltzmann's constant .

T_e = ^{0} K

T_d = ^{0} K

T_d is the disc temperature when it is inserted in the set-up and increases with time . T_e=Emitter temperature in ^{0}K

Mass of the test disc (m) =0.004 Kg.

Specific heat of the disc (cu) material C_p

C_p =385 J/kg- k

CALCULATIONS:

Time 't' (min)	**Emitter Temperature 'T_e'(^{0}C)**	**Disc Temperature 'T_d'(^{0}C)**
1		
2		
3		
4		
5		
6		
7		
8		

9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
21		
22		
23		
24		
25		

Obtain $(dT_a / dt)_{t=0}$ using the plot of T_a Vs t and determining the slope .
Calculate Stefan Boltzmann's constant using the relationship,

$T_e = 64.1+273 = 337.1^0k$ $T_d = 44.9+273 = 317.9^0k$

$$\sigma = \frac{m\,C_p\,(dT_a/dt)_{t=0}}{A_D\,(T_e^4 - T_d^4)} = \quad w/m^2k$$

RESULT:

5.PIN-FIN APPARATUS

INTRODUCTION:

A spine or pin-fin is an extended surface of cylindrical or conical shape used for increasing the heat transfer rates from the surfaces, whenever it is not possible to increase the rate for heat transfer either by increasing heat transfer co-efficient or by increasing the temperature difference between the surface and surrounding fluids .
The fins are commonly used on engine heads of scooter, motorcycles , as well as small capacity compressors. The pin type fins are used on the condenser of a domestic refrigerator.

AIM OF THE EXPERIMENT:

a) To find out the temperature distribution along the given fin for constant base temperature under natural and force flow conditions.

b)To find out effectiveness of the fin under both conditions.

DESCRIPTION OF THE APPARATUS:

An Aluminum fin of circular cross section of length ‘L’ is fitted in the rectangular duct. The base of the fin is fixed to a heater plate for heating the fin. Thermocouples are provided on the surface of the fin. The duct is provided with a suction fan to control the airflow with the help of regulator .

A multichannel temperature indicator has been provided to monitor different temperature points. An anemometer has been provided to measure the air velocity through the duct. Digital wattmeter has been provided to measure power input to the heater. Heat Regulator to vary input power to the heater.

PROCEDURE:

1) Switch on the mains, and console after ensuring the given model has fitted in the duct .

2) Open the windows provided on the top and bottom of the duct for conducting experiment in Natural convection.

3) Switch on the heater and adjust the power input the power input to approx. 50 Watts .

4) Wait for some time till steady state is reached.

5) Note down the following readings:
Power in watts
Temperature reading in ^{0}C

6) After conducting experiment in natural convection mode, start the Blower and adjust the flow as required for Forced convection.

7) Increase the power supplied to the heater as to maintain the same temperature before starting the blower .

8) Wait till steady state condition is reached and Note down the temperature readings, power and velocity of air flow.

9) Repeat the procedure for different heat inputs.

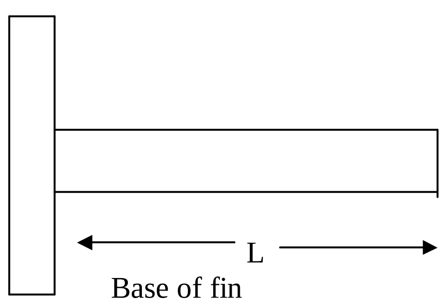
SPECIFICATIONS :

Length of the pin fin (1) = 195mm = 0.195 m
Diameter of the pin fin (d) = 12 mm=0.012 m
Thermal conductivity of fin material (k) Al = 205 W/m-K

FORMULAS:

The temperature distribution along the fin is given by,

$$\frac{T_x - T_a}{T_o - T_a} = \frac{\text{Cosh } m\,(L - x)}{\text{Cosh }(mL)} \quad \text{.......Eqn (1)}$$



Where 'T_x' is the temperature along the fin at a distance 'x '
Measured from the base,
'T_0' is the base temperature,
'Ta' is surrounding air temperature and

'L' is the length of the fin.

$$m = \sqrt{\frac{h\,p}{K_f\,Ac}}$$

Where 'Ac' is the Cross-section area of the fin $= \dfrac{\pi D^2}{4}$

' p ' is perimeter of the fin $= \pi D$,
'Ta' is conductivity of fin material and
'h' is the heat transfer co-efficient of fin.

1. **Free convection condition,**

T_w = Average surface temperature

$$= \frac{(T1 + T2 + T3)}{3}$$

$\Delta T = T_w - T_a$

T_a = Ambient temperature $= {}^0C$

$$T_{mf}\ (\text{Film temp}) = \frac{T_w + T_a}{2}$$

β = Coefficient of thermal expansion

$$= \frac{1}{T_{mf} + 273}$$

All the properties are to be evaluated at the mean film temperature. The mean film temperature is to arithmetic average of the fin temperature and air temperature.

D = Diameter of pin-fin, m

μ = Dynamic viscosity, N-sec/m^2
C_p = Specific heat, KJ/Kg-k
ν = Kinematic viscosity, m2/Sec
K = Thermal conductivity of air, W/m ^0C
g = Acceleration due to gravity, 9.81m/sec^2

$Nu = 1.1 \ (Gr.\ Pr)^{1/6}$ $10^{-1} < Gr.\ Pr. < 10^4$
$Nu = 0.53\ (Gr.\ Pr)^{1/4}$ $10^4 < Gr.\ Pr. < 10^9$
$Nu = 0.13\ (Gr.\ Pr)^{1/4}$ $10^9 < Gr.\ Pr. < 10^{12}$

Where, $$Nu = \frac{h.\ D}{A}$$

$$G_r = \frac{g.\ \beta.\ D^3\ \Delta T}{\nu^2} \quad = \text{Grashoff Number.}$$

$$P_r = \frac{Cp\mu}{K_{Air}} \quad = \text{Prandt1 Number}$$

1) The rate of heat transfer from the fin can be calculated as,

$$Q = \sqrt{h.\ c.\ k.\ A\ \ x\ (T1–Tf)\ tanh\ mL}$$

$$m = \sqrt{\frac{hp}{KA}}$$

H-heat transfer co-efficient W/ m^2 k
P -perimeter = πd
K – Thermal conductivity of fin material (Al) =205 W/m-K
A – Cross sectional area of fin

$$A = \frac{\pi d^2}{4}$$

D = dia of fin = 12 mm

2. Efficiency of the fin can also be calculated as,

$$\eta = \frac{\text{Tanh } mL}{mL}$$

3. Effectiveness of the fin

$$\phi(\text{Fin}) = \frac{\text{Tanh }(ml)}{\sqrt{\dfrac{hp}{KA}}}$$

2. **<u>Forced convection condition,</u>**

T_w= Average surface temperature

$$= \frac{(T1 + T2 + T3)}{3}$$

$\Delta T = T_w - T_a$

T_a = Ambient temperature

$$T_{Mf} \text{ (Film temp)} = \frac{T_w + T_a}{2}$$

All the properties are to be evaluated at the mean film temperature. The mean film temperature is to arithmetic average of the fin temperature and air temperature.

ρ = Density of air, Kg / m^3
D = Diameter of pin-fin, m
μ = Dynamic viscosity, N.sec/m^2
C_p = Specific heat, KJ/Kg k

ν = Kinematic viscosity, m2/Sec
K = Thermal conductivity of air, W/m ^{0}C
g = Acceleration due to gravity, 9.81m/sec^2

$$R_e = \frac{\rho VD}{\nu} = \text{Reynolds's Number.}$$

$Nu = 0.615 (R_e)^{0.466}$ $40 < R_e < 4000$
$Nu = 0.174 (R_e)^{0.618}$ $4000 < R_e < 400$

$$Nu = \frac{h. D}{K_{Air}}$$

1. **The rate of heat transfer from the fin can be calculated as,**

$$Q = \sqrt{h. c. k. A \quad x (T1 – Tf) \tanh mL}$$

$$m = \sqrt{\frac{hp}{KA}}$$

H - Heat transfer co-efficient W/ m^2 k
P - Perimeter = πd
K – Thermal conductivity of fin material (Al) =205 W/m-K
A – Cross sectional area of fin

$$A= \frac{\pi d^2}{4}$$

D = dia of fin = 12 mm

2. Efficiency of the fin can also be calculated as,

$$\eta = \frac{\text{Tanh } mL}{mL}$$

3. Effectiveness of the fin

$$\phi(Fin) = \frac{\tanh(ml)}{\sqrt{\dfrac{hp}{KA}}}$$

TABLE OF READINGS AND CALCULATIONS

NATURAL CONVECTION:

FIRST POINT SURFACE TEMPERATURE T1	SECOND POINT SURFACE TEMPERATURE T2	THIRD POINT SURFACE TEMPERATURE T3	AIR INLET TEMPERATURE T4	AIR OUTLET TEMPERATURE T5	POWER IN WATTS

FORCED CONVECTION:

FIRST POINT SURFACE TEMPERATURE T1	SECOND POINT SURFACE TEMPERATURE T2	THIRD POINT SURFACE TEMPERATURE T3	AIR INLET TEMPERATURE T6	AIR OUTLET TEMPERATURE T7	VELOCITY IN M/SEC	POWER IN WATTS

RESULT:

6.UNSTEADY STATE HEAT TRANSFER

INTRODUCTION:

An understanding of unsteady state heat conduction (both transient and periodic) is very essential since it plays an important role in many heat transfer processes. For example, designers in technological areas are often faced with start-up and other operating transients which need careful and critical evaluation. Unsteady conduction is involved in the quenching of billets, the annealing of solids, manufacture of glass, burning of bricks, steaming of wood and rubber vulcanizing. When a body is heated continuously, the temperature at a given point within the body asymptotically reaches the temperature of the heating medium. The points near the surface quickly approach the temperature of the surroundings and those in the interior lab far behind.

OBJECTIVE OF THE EXPERIMENT:

To estimate the heat transfer co-efficient (h) between the medium and the body being cooled or heated.

THEORY:

Consider an arbitrary solid object of volume 'V' surface area A, density ρs and specific heat C_p. It is assumed to be initially at a temperature of the specimen T_o. This object is exposed suddenly to an environment at temperature T greater than T_o. At any time θ the rate of increase in energy content in the solid material is equal to the rate of heat transport from the surroundings at $T\infty$.

The energy balance equation is given by:

$$\rho_s, C_p, V \frac{dT}{d\theta} \; h.A\,(T\infty-T) \qquad (1)$$

$$\text{Thus} \quad \frac{dT}{d\theta} = \frac{hA}{\rho_s, C_p, V}\,(T\infty-T) \qquad (2)$$

Assuming the quantity $\dfrac{hA}{\rho_s, C_p, V}$ remains constant during the time interval θ, eqn (2)

is integrated with the following initial and boundary conditions.

$T = T_o$ and $T = T$

$$\int_{T_o}^{T} \frac{dT}{(T\infty - T)} = \frac{hA}{\rho_s C_p V} \, d\theta \quad \text{------------ (3)}$$

$$\ln \left(\frac{T\infty - T}{T\infty - To} \right) = \frac{hA\,\theta}{\rho_s C_p V} \quad \text{----------- (4)}$$

In the case of an infinitely long cylinder the dimension less temperature profile is given by,

$$\frac{T\infty - T}{T\infty - T_o} = f\left(\frac{\alpha\theta}{R^2} \quad \frac{k}{hR} \quad \frac{r}{R} \right) \quad \text{----------- (5)}$$

When the temperature is measured at the centre of the cylinder, Eqn (5) reduces to,

$$\frac{T\infty - T}{T\infty - T_o} = f\left(\frac{\alpha\theta}{R^2} \quad \frac{k}{hR} \right) \quad \text{----------- (6)}$$

where θ = time increase
α = thermal diffusion
h = heat transfer coefficient
R = radius ‘r’
ρ_s = density
C_p = Specific heat

f (Fo, Bi) ------------ (6.a)

$$= \frac{k}{\rho_s C_p}$$

For much theory see text book Domkundwar Chapter-8.

SPECIFICATIONS OF DIFFERENT SPECIMEN:

RADIUS OF THE CYLINDER (BRASS) = R = 30mm = 0.03m DENSITY OF BRASS = 8522 kg/m^3 Cp = 0.385 KJ/Kg^{0}K Thermal conductivity = k = 111 w/m ^{o}k
RADIUS OF THE SPHERE (M.S) = R = 15 mm = 0.015m DENSITY OF M.S = 7883 Kg/m^3 Cp = 0.465 kJ/kg ^{0}K Thermal conductivity = k = 54 w/m ^{o}k
DEPTH OF THE RECTANGLE SLAB (COPPER) = D = 16mm = 0.016m DENSITY OF COPPER = 8954 Kg/m^3. Cp = 0.381 KJ/Kg^{0}K Thermal conductivity = k = 386.0 w/m ^{o}k

EXPERIMENTAL SET-UP

The experimental set-up is shown in Fig. constant temperature water bath serves as the hot environment. A specimen height and diameter of the solid object are known. This specimen is provided at the centre with an iron – constantan thermocouple located at half of the specimen height. This measures the centre temperature of the specimen. The both temperature is measured

Unsteady State heat transfer studies

EXPERIMENTAL PROCEDURE:

1. Switch on the heater and mean while switch on and off Pump for stirring purpose.
2. Set the thermostat up to 40^0 and note down the water bath temperature in thermometer.
3. The specimen is suddenly immersed in the constant temperature bath. Immediately the thermocouple output and the corresponding time are noted.
4. Readings are taken until there are no further temperature changes. Then the specimen is suddenly removed and allowed to cool in ambient air. Once again temperature Vs time data is recorded.

5. Repeat the same for different specimen.

PRESENTATION OF DATA

The height, diameter, depth of specimen are measured. The following data is tabulated both for heating and cooling runs.

OBSERVATIONS

T_O = INITIAL TEMPERATURE OF SPECIMEN =

T_∞ = TEMPERATURE OF THE SURROUNDING (BATH TEMP) =

T = SPECIMEN TEMPERATURE AT ANY TIME =

HEATING COOLING

Temperature (T)	Time Secs (θ)	Temperature (T)	Time Secs (θ)

Formulae:

A plot of $\dfrac{T_\infty - T}{T_\infty - T_o}$ (in Y axis) Vs $\dfrac{\alpha\theta}{R^2}$ (in X axis) ⟶ (a)

Where $\alpha = \dfrac{k}{\rho C_p}$

To calculate h,

$$Bi = \frac{h\,R}{k}$$

$$h = \frac{Bi\,k}{R} \quad \text{in } w/m^2\,{}^{o}k$$

Where, h = heat transfer coefficient in $w/m^2\,{}^{o}k$.
k = Thermal conductivity of the material = $w/m\,{}^{o}k$
Bi = Biot number from Slope of graph (a).
R = Radius of specimen in m.

For Steady temperature T, the slope of the line is compared with the Heisler charts for central temperature. Thus the value for the parameter 1/Bi is obtained. Knowing the physical properties of the material, heat transfer co-efficient h is calculated. A similar evaluation is done for cooling in ambient air.

Graph for heating and cooling of a solid specimen by Heisler chart.

NOMENCLATURE

A	Heat transfer area, m^2
C_p	Specific heat of material, J/Kg K
h	Heat transfer co-efficient, $w/m^2\,{}^{o}K$.
k	Thermal conductivity of material, W/m K.
L	Height of material, m
r	Distance in radial direction, m
R	Radius of specimen, m
D	Depth of rectangle slab, m
T	Specimen temperature at any time, °C.
T_o	Initial temperature of specimen °C.

T_∞ Temperature of surroundings (bath temperature), °C.

V Volume of cylinder, m^3.

Bi Biot number, (k/hR)

α Thermal diffusivity, $(K/\rho_s\ Cp)$

ρ_s Density of material, kg/m^3.

θ Time, sec.

RESULTS

7.HEAT TRANSFER THROUGH NATURAL CONVECTION

INTRODUCTION:

Heat transfer can be defined as the transmission of energy from one region to another as a result of temperature difference between them. There are three different modes of heat transfer; namely,

HEAT CONDUCTION : The property which allows the passage for heat energy, even though its parts are not in motion relative to one another.

HEAT CONVECTION : The capacity of moving matter to carry heat energy by actual movement.

HEAT RADIATION : The property of matter to emit or to absorb different kinds of radiation by electromagnetic waves.

Out of these types of heat transfer the convective heat transfer which of our present concern, divides into two categories, Viz.,

NATURAL CONVECTION : If the motion of fluid is caused only due to difference in density resulting from temperature gradients without the use of pump or fan, then the mechanism of heat transfer is known as "Natural or Free Convection".

FORCED CONVECTION : If the motion of fluid is induced by some external means such as a pump or blower, then the heat transfer process is known as "Forced Convection".

The newton's law of cooling in convective heat transfer is given by,

$$\mathbf{Q = h\,A\,\Delta T}$$

Where, **Q** = Heat transfer rate, in watts

A	=	Surface area of heat flow, in m^2
ΔT	=	Overall temperature difference between the wall and fluid, in ^oC
h	=	Convection heat transfer co-efficient, in watts/m^2 ^oC

This setup has been designed to study heat transfer by natural or free convection.

AIM OF THE EXPERIMENT:

To determine the natural heat transfer co-efficient 'h' from the surface of the tube in both vertical and horizontal position.

DESCRIPTION OF THE APPARATUS:

The arrangement of the experimental setup is shown in the schematic enclosed. Important components of the setup are as follows:

1. A chromium plated copper tube of diameter (d) 32 mm and length (L) 450 mm with an electrical heater coil along the axis of the tube.

2. Four thermocouples are fixed on the tube surface with a phase of 90^o.

3. An arrangement to change the position of the tube to vertical and horizontal position.

4. Control panel instrumentation consists of multi-channel digital display.

   a) Temperature indicator to measure surface temperatures T_1 - T_4 of the tube and ambient temperature T_5.

   b) Digital Wattmeter to measure power input to the heater.

   c) Regulator to control the power input to the heater.

5. Front transparent acrylic enclose for safety of the tube when not in use.

OPERATIONAL PROCEDURE:

1. Keep the tube in vertical position.

2. Switch ON the mains and the console.

3. Set the regulator to adjust the heat input to approximately .

4. Wait for sufficient time to allow temperature to reach steady values.

5. Note down temperatures T_1 to T_5 using channel selector and digital temperature indicator.

6. Note down the wattmeter readings.

7. Tabulate the heat input and measured temperatures.

8. Calculate the convection heat transfer co-efficient using the procedure given below.

9. Repeat the experiment by changing the tube to horizontal position with different heat input.

NOTE:

1) The experiment should be carried out in the absence of wind flow through the window as well as in the absence of fan for better results.

2) For better result, the horizontal and vertical experiments should be conducted after the tube is cooled down to almost room temperature.

3) For comparison of results in horizontal and vertical position the temperatures should be considered for equal interval of time, in both cases.

TABLE OF MEASUREMENTS AND CALCULATIONS

Heat Input ' W ' In Watts	Temperature In °C					'h' Practically calculated		'h' Theoretically calculated	
	T1	**T2**	**T3**	**T4**	**T5**	**Vertical Position**	**Horizontal Position**	**Horizontal Position**	**Horizontal Position**

CALCULATIONS:

PRACTICAL:

For steady state condition,

Heat given to heater = Heat lost from the tube surface by natural convection

Therefore,

$$\mathbf{W = h\, A_s\, (T_m - T_a)}$$

Where,

W = (Wattmeter reading), in watts

A_s = Tube surface = π d l

d = Diameter of the tube = 32mm

l = length of the tube= 450mm

$$T_m = (T_1 + T_2 + T_3 + T_4) / 4$$

T_a = Ambient air temperature

Therefore,

$$\text{Heat transfer co-efficient 'h'} = \frac{W}{A_s (T_m - T_a)}$$

THEORETICAL:

The theoretical value of the natural heat transfer co-efficient is given by,

$$\frac{h_v Lc}{k} = 0.59\,(Gr.\ Pr)^{0.25} \text{ for } 10^4 < Gr\ Pr < 10^9 \text{ (for vertical position).}$$

$$\frac{h_v L_c}{k} = 0.53\,(Gr.\ Pr)^{0.25} \text{ for } 10^4 < Gr\ Pr < 10^9 \text{ (for horizontal Position).}$$

Where,

$$Pr = \frac{\mu C_p}{k} \quad \text{and} \quad Gr = \frac{ß\, g\, (T_m - T_a)\, L_c^3}{\gamma 2}$$

Where, $ß = 1/T$

All the properties of air should be taken as $(T_m + T_a)/2$ from the property table. h_v and h_v represent the heat transfer co-efficient for vertical and horizontal tubes.

L_c is the characteristic length which is,

L_c = L for vertical position
L_c = d for horizontal position.

RESULTS AND CONCLUSION:

Draw the graph of ‘h’ versus ‘T_m’ for vertical and horizontal position of the tube actually and theoretically calculated and compare the results.

8.HEAT TRANSFER IN FORCED CONVECTION

AIM OF THE EXPERIMENT:

To determine the convective heat transfer co-efficient in forced convection.

INTRODUCTION:

It is well known that a hot plate of metal will cool faster in front of a fan than when exposed to still air. We say that heat is convicted away and we call the process as convective heat transfer. The velocity at which the air blows over the hot plate obviously influences the heat transfer rate.

The Newton's law of cooling in convective heat transfer is given by,

$$q = hA\Delta T \qquad \text{--- Eq (1)}$$

Where, q = Heat transfer rate, Watts

A = Surface Area of heat flow, m^2

ΔT = Average temperature difference between the tube Heater and the surrounding air (°C).

h = Convective heat transfer co-efficient (Watts/m^2°C).

The convective heat transfer co-efficient depends upon the viscosity of the fluid in addition to its dependence on the thermal properties of the fluid (thermal conductivity, specific heat, density etc).

If a heated plate is exposed to ambient room air without an external source of motion, movement of air would be experienced as a result of the density gradient near the plate. We call this natural or free convection. If the convection is experienced the case of the fan blowing air over a plate, we call this **Forced Convection.** The approximate ranges of convection heat transfer co-efficient are given in the table below:

This set-up has been designed to study forced convective heat transfer.

Mode	'h' Watts / m^2°C
Free convection (air)	5-25
Forced convection : Air Water	10-500 100-15000
Boiling water	2500-25000
Condensation of water vapour	5000-100000

APPARATUS:

The important components of the set-up are:

(a) **Heat exchanger tube** – the tube is thermally insulated outside to prevent heat transfer losses to the atmosphere.

(b) **Band heater**, Wattage: 500 watts (approx.).

(c) **Regulator** to control the power input to the heater.

(d) **Wattmeter** to measure power input to the heater.

(e) **Thermocouples**

T_1, T_2, T_3 to measure heater surface temperatures.

T_4 and T_5 to measure air temperature at the inlet and outlet of the duct.

(f) **Channel selector.**

(g) **Digital temperature indicator.**

(h) **Blower:** To blow air through the heat exchanger.

(i) **Orifice meter and Manometer** to air flow rate from the blower.

(j) **Control panel** to house the whole instrumentation.

OPERATIONAL PROCEDURE:

a) Switch-ON the mains.
b) Start the blower first.
c) Control blower flow rate to a suitable value.
d) Measure the pressure drop across the manometer and calculate air mass flow rate.
e) Switch-ON the heater and adjust the power input to the heater to a suitable value using the regulator.
f) Wait for reasonable time to allow temperatures to reach steady value.
g) Note temperatures T_1 to T_5 using channel selector and digital temperature indicator.

   T_4 = Temperature of air at heat exchanger inlet °C.

   T_5 = Temperature of air at heat exchanger outlet °C.

   T_1, T_2 and T_3 = Surface temperatures at three locations on the heater (°C).

h) Measure power input (P, watts) to the heater.
i) Tabulate the measured temperatures and power input to the heater.
j) Calculate the convective heat transfer co-efficient using the procedure given.
k) Repeat the experiment for different values of power input to the heater and blower air flow rates.

WORKING PRINCIPLE*:*

The air flows from bottom to the top of the heat exchanger because of the blower action. In a steady state, power input to the heater is equal to the heat transferred to the air. This is used as the base for calculation of heat transfer co-efficient.

$$q = h\,A\,\Delta T \qquad \text{--- Eq (1)}$$

Where, q = Power input to the heater = P, Watts

h = Convective heat transfer co-efficient watts/m^2°C.

A = Surface area of the tube heater, $\pi\, d\, L$ (m^2)

L = Length of the tube heater, = 0.45m.

d = Diameter of the tube heater, = 0.03m.

ΔT = $T_i - T_o$ = Average temperature difference Between the tube heater and the Surrounding air (°C)

From the measurement of T_1, T_2, T_3, T_4 & T_5 and P the convective heat transfer co-efficient can be calculated using Eq. (1).

Experiments can be repeated for different heater input power and air mass flow rates. The table of measurements and results are given below.

TABULAR COLUMN:

Sl. No.	Power in watts	Air mass flow rate in mm	T_1°C	T_2°C	T_3°C	T_4°C	T_5°C	h watts/m2°C

FORMULAE

1) Mean Temperature

$$T_{ma} = \frac{T_4 + T_5}{2} \quad {}^0k$$

2) Velocity in m/s

$$V = \sqrt{2\,g\,h\,\frac{\rho_w}{\rho_a}} \quad \text{in m/sec}$$

g	=	Specific gravity = 9.81 m^2/sec
h	=	Manometer difference in m.
ρ_w	=	Density of water = 1000 kg/m^3
ρ_a	=	Density of air = 1.147 kg/m^3

3) Mass flow rate in, kg/s

$$m = \rho_a A V$$

Where, ρ_a = Density of air = 1.147 kg/m^3

$A = \pi \times d^2 / 4 = 7.07 \times 10^{-4}\ m^2$

d = diameter of the surface = 0.03 m

V = Velocity in m/sec. = from equation (2)

4) Reynolds Number

$$R_e \quad \frac{V \times d}{\upsilon}$$

V = Velocity in m/sec

d = diameter of copper tube = 0.03 m

Heat transfer co-efficient

$$h_{theoretical} = 0.023\,(Re)^{0.8}\,(Pr)^{0.4}\left(\frac{K_{air}}{0.03}\right) \quad \text{in } W/m^2\,{}^0C$$

$$h_{practical} = \frac{m\,Cp\,dt_{air}}{A\,(dt)} = \frac{m\,Cp\,dt_{air}}{A\,(T_{mt}-T_{ma})} \quad \text{in } W/m^2\,{}^0C$$

m = mass flow rate in kg/sec = from formulae (3)

Cp = 1005 J/kg ^{o}k

A = Surface area of the tube heater, π d L in m^2

d = diameter of tube = 0.030 m

L = Length of tube = 0.45m

dt_{air} = Difference of temperature air inlet and outlet in ^{0}C

dt = Difference of mean surface temperature and mean air temperature

PRECAUTIONS:

1. Keep the variac to Zero voltage position before starting the experiment.
2. Take sufficient amount distilled water in the container so that both the heaters are completely immersed.
3. Connect the test heater wire across the studs tightly.
4. Do not touch the water or terminal points after putting the switch in ON position.
5. Very gently operate the variac in steps and allow sufficient time in between.

RESULTS:

9.CRITICAL HEAT FLUX APPARATUS

AIM:

To determine the axial heat flux for given wire.

INTRODUCTION:

When heat is added to a liquid from a submerged solid surface, which is at a temperature higher than the saturation temperature of the liquid, it is usual for a part of the liquid to change phase. This change of phase is called boiling.

Boiling is of various types, the type depends upon the temperature difference the surface and the liquid. The different types are indicated in which a typical experimental boiling curve obtained in a saturated pool of liquid is down.

DESCRIPTION:

The apparatus consists of a container housing the test heater and heater coil for initial heating of the wire. Heater coil is directly connected to mains and the test heater (Nichrome wire) is also connected the mains via a dimmer stat and an ammeter is connected in series while a voltmeter across it to read the current and voltage. The micro controller based peak detector has been provided to measure the maximum current during the process.

SPECIFICATION:

- Nichrome wire size : 0.2 ϕ mm
- Dimmer stat : 10 Amp, 230 volts.
- Power indicator : **200 w**
- Nichrome wire resistance : 6.4 ohms.
- Length of wire (L) : 50 mm

THEORY:

The heat flux supplied to the surface is plotted against (Tw - Ts) the difference between the temperature of the surface and the saturation temperature of the liquid. It is seen that the boiling curve can be divided into three regions:

- ✓ Natural Convection Region
- ✓ Nucleate Boiling Region
- ✓ Film Boiling Region

The region of natural convection occurs at low temperature differences (of the order of 10 ^{o}C or less). Heat transfer from the heated surface to a liquid in its vicinity causes the liquid to be superheated.

The superheated liquid rises to the free liquid surface by natural convection, where vapour is produced by evaporation. As the temperature difference (Tw – Ts) is increased, nucleate boiling starts. In this region, it is observed that bubbles start to form at certain locations on the heated surface.

Region II consists of two parts. In the first part, II – a, the bubbles formed are very few in number. They condense in the liquid and do not reach the free surface. In the second part, II – b, the rate of bubbles formation and the number of locations where they are formed increase. Some of the bubbles now rise all the way to the free surface. With increasing temperature difference, a stage is finally reached when the rate of formation of bubbles is so high, that they start to coalesce and blanket the surface with a vapour film. This is the beginning of the region III viz film boiling.

In the first part of this region III-a, the vapour film is unstable, so that the film boiling may be occurring on a portion of the heated surface area, while nucleate boiling may be occurring on the remaining area. In the second part, III-b, a stable film covers the entire surface. The temperature difference in this region is of the order of 1000°C and consequently radiative heat transfer across the vapour film is also significant.

It will be observed that the heat flux does not increase in a regular manner with the temperature difference. In region I, the heat flux is proportional to (Tw – Ts) ^{n}, where ‘n’ is slightly greater than unity. When the transition from natural convection to nucleate boiling occurs the heat flux starts to increase more rapidly with temperature difference, the value of n increasing to about 3.at the end of region

II, the boiling curve reaches a peak. Beyond this, in the region II-A, in spite of increasing temperature difference, the heat flow increases with the formation of a vapour film. The heat flux passes through a minimum at the end of region III-a. it starts to increase again with (Tw – Ts) only when stable film boiling begins and radiation becomes increasingly important.

It is of interest to note how the temperature of the heating surface changes as the heat flux is steadily increased from zero. Up to point A, natural convection boiling and nucleate boiling occur and the temperature of the heating surface is obtained by reading off the value of (Tw – Ts) from the boiling curve and adding to it the value of Ts.

If the heat flux is increased even a little beyond the value of A, the temperature of the surface will shoot up to the value corresponding to the point C. it is apparent from figure 1 that the surface temperature corresponding to point C is high.

For most surfaces, it is high enough to cause the material to melt. Thus in most practical situations, it is undesirable to exceed the value of heat flux corresponding to point A. This value is therefore of considerable engineering significance and is called the critical or peak heat flux. The pool-boiling curve as described above is known as Nukiyam pool Boiling Curve. The discussions so far has been concerned with the various type of boiling which occur in saturated pool boiling. If the liquid is below the saturation temperature we say that sub-cooled pool boiling is taking place. Also in many practical situations, e.g. steam generators; one is interested in boiling in a liquid flowing through tubes. This is called forced convection boiling, may also be saturated or sub-cooled and of the nucleate or film type.

Thus in order to completely specify boiling occurring in any process, one must state

- ✓ Whether it is forced convection boiling or pool boiling,
- ✓ Whether the liquid is saturated or sub cooled, and

- ✓ Whether it is in the natural convection nucleate or film boiling region.

PROCEDURE:

- Fill the tank with water.
- Dip the Nichrome wire into the water and make the electrical connections
- Note the current reading in steps of 1 amp till a maximum current of 10 ampere.
- Between each reading the time interval of two min is allowed for steady state to establish.
- Water temperature is noted with a temperature indicator at the beginning and the end of the experiment. The average of these two is taken as the bulk liquid average temperature.
- Note down the power and temperatures from the indicators.

OBSERVATIONS:

- ✓ d = Diameter of test heater wire, = **2×10^{-4} m**
- ✓ L= Length of the test heater = **0.050 m**
- ✓ A = Surface area = πdL = 5.026×10^{-5} m^2

OBSERVATIONS TABLE:

Sr. No.	Water / Bulk Temp T in ^{0}C	Voltage input to test wire (volts)	Current input to test wire (amps)	Actual critical heat flux (watts / m^2)	Theoretical critical heat flux (watts / m^2
1					
2					

3					
4					
5					
6					

FORMULAE:

I. Critical Heat Flux, $q_c = \dfrac{Q_c}{\pi D L}$ Watts / m^2

Where, QC = V x I Watts,

D = Diameter of the test wire,

L = Length of the test wire.

II Theoretical Critical Heat Flux, q_{ct}

$$q_{ct} = \frac{\pi}{24} \times hfg \times \rho_v \times \left(\frac{\sigma_V L g (\rho_l - \rho_v)}{\rho_v^2} \right)^{1/4} \times \left(1 + \frac{\rho_v}{\rho_l} \right)^{1/2}$$

Where hfg = Latent Heat of Evaporation in KJ / Kg

ρ_v = Density of vapor in Kg / m^2

σ_v = Surface tension of the Vapor – Liquid in N / m

ρ_l = Density of liquid Kg / m^3

From table 1.1 take readings of hfg, σ_v, ρ_v and ρ_l

CONSTANTS:

Temperature co-efficient of resistance of Nichrome Wire = 0.00013

Resistance of Nichrome Wire at room temperature R_O = 4 Ω

Diameter of Nichrome wire =0.2mm

Length of Nichrome wire =50mm

PRECAUTIONS:

- Keep the variac to zero voltage position before starting the experiment.
- Take sufficient amount of distilled water in the container so that both the heaters are completely immersed.
- Connect the test heater wire across the studs tightly.
- Do not touch the water or terminal points after putting the switch in ON position.
- Very gently operate the variac in steps and allow sufficient time in between.
- After the attainment of critical heat flux condition, slowly decrease the voltage and bring it to zero.

RESULT:

10.HEAT PIPE DEMONSTRATION APPARATUS

INTRODUCTION:

One of the main objectives of energy conversion systems is to transfer energy from a receiver to some other location where it can be used to heat a working fluid. The heat pipe is a novel device that can transfer large quantities of heat through small surface areas with small temperature differences. The method of operation of a heat pipe is shown in the Schematic. The device consists of a circular pipe with an annular layer of wicking material covering the inside. The core of the system is hollow in the center to permit the working fluid to pass freely from the heat addition end on the left to the heat rejection end on the right. The heat addition end is equivalent to an evaporator, and the heat rejection end corresponds to a condenser. The condenser and the evaporator are connected by an insulated section of length L. The liquid permeates the wicking material by capillary action, and when heat is added to the evaporator end of the heat pipe, liquid is vaporized in the wick and moves through the central core to the condenser end, where heat is removed. Then the vapor condenses back into the wick and the cycle repeats.

AIM OF THE EXPERIMENT:

To determine the axial heat flux in a heat pipe using water as the working fluid with that in a solid copper rod with different temperatures.

DESCRIPTION:

The Heat Pipe Demonstration Set-up consists of the following:

1) Solid Copper Rod of length 500mm with Evaporator at one end and Condenser at the other end.

2) Wickless Water Heat Pipe made of Copper Tube of length 500mm with Evaporator at one end and Condenser at the other end.

3) Water Heat Pipe with Wick (Stainless Steel Mesh 180 microns, 1 layers) made of Copper Tube of length 500mm with Evaporator at one end and Condenser at the other end.

4) Digital Temperature Indicator with 8- Channel Selector Switch for measuring temperatures on the surface of the Heat Pipe.

5) Digital Ammeter and Voltmeter to measure power input to the heater.

6) Dimmerstat to control the power input to the heater.

SPECIFICATION:

* Diameter of the specimen : 30 mm.

* Length of the specimen : 450 mm.

<u>TEMPERATURE POINTS</u>

T5,T6 : Temperature on the water heat pipe with wick at a distance of 150 mm and 350 mm from bottom.

T3,T4 : Temperature on the water heat pipe without wick at a distance of 150 mm and 350 mm from bottom.

T1,T2 : Temperature on the solid copper rod at a distance -of 150 mm and 350 mm from bottom.

* Band heater : Of capacity 150 watts.(3 Nos).

* Electrical Supply : 1 ph,230 Volts,16 amps with ground.

OPERATIONAL PROCEDURE:

1) Switch-ON the Mains and Console.

2) Check the water level within the pipes and at top.

3) Switch-ON all the Three Heaters and regulate the power to desired value.

4) Wait for considerable time to allow the temperature to reach the steady value.

5) Note down the temperatures T1 to T6 using Channel Selector and Digital Temperature Indicator.

T5,T6 : Temperature on the water heat pipe without wick at a distance of 150 mm and 350 mm from bottom.

T3,T4 : Temperature on the water heat pipe with wick at a distance of 150 mm and 350 mm from bottom.

T1,T2 : Temperature on the solid copper rod at a distance -of 150 mm and 350 mm from bottom.

6) Note down the voltmeter and ammeter readings.

7) Calculate Axial Heat Flux for all the Pipes.

8) Repeat the above procedure for different heat inputs and compare the results.

PROCEDURE FOR CALCULATION:

$$\text{Axial Heat Flux} \quad q = \frac{Q}{A} = K \frac{\Delta T}{\Delta X}$$

Thermal Conductivity of Copper = 374 W / m^{o}C

References :

1) Principles of Heat Transfer (6th Edition) by
Frank Kreith and Mark S. Bohn.

2) Heat Transfer by Holman, J.P.

TEMPERATURE POINTS:

T1, T2 : Temperature on the copper rod at a distance of 150 mm and 350 mm from bottom.

T3, T4 : Temperature on the water heat pipe with wick at a distance of 150 mm and 350 mm from bottom.

T5, T6 : Temperature on the water heat pipe without wick at a distance of 150 mm and 350 mm from bottom.

OBSERVATIONS:

1. **Watt meter readings = 150 watts**
2. **T1 =**
3. **T2 =**
4. **T3 =**
5. **T4 =**
6. **T5 =**
7. **T6 =**

FORMULA:

$$\text{Axial Heat Flux} \quad q = K \frac{\Delta T}{\Delta X}$$

Thermal Conductivity of Copper = 370-410 W / m^{o}C

Δ T = Temperature difference in ^{0}c

PRECAUTIONS:

* Donot start the equipment without proper elctrical supply.
* Handle the switchs gently.
* Before starting ensure that water level is maintained.
* Atfer the experiment is over, switch off all the indicators and heaters.
* At least for every two weeks, operate the unit for five minutes.
* In case of any major faults, Please write to manufacture, and do not attempt to repair.

RESULT:

11.HEAT TRANSFER THROUGH LAGGED PIPE

INTRODUCTION:

The costs involved in insulating either heated or refrigerated equipment, air-conditioned rooms, pipes, ducts, tanks and vessels are of a magnitude to warrant careful consideration of the type and quantity of insulation to be used. Economic thickness is defined as *the* minimum annual value of the sum of the cost of heat loss plus the cost of insulation, or, in more general terms, as the thickness of a given insulation, or, in more general terms, as the thickness of a given insulation that will save the greatest cost of energy while paying for itself within an assigned period of time. At low values of thickness, the amortized annual cost of insulation is low, but the annual cost of heat energy is high. Additional thickness adds to the cost of insulation but reduces the loss of heat energy, and therefore, its cost. At some value of insulation thickness, the sum of the cost of insulation and the cost of heat loss will be a minimum. Beyond the minimum, curve C rises because the increased cost of insulation is no longer offset by the reduced cost of heat loss.

The calculation of economic thickness for an industrial installation is not easy, owing to the large number of variables and separate calculations involved. This has all been reduced to manual form in “How to determine Economic Thickness of Insulation”, published by National Insulation Manufacturers Association, New York.

Insulation is defined as a material which retards heat flow with reasonable effectiveness.

- One has to note here that, it is not always necessary to have low thermal conductivity of material (insulation) because even aluminum with its high value of thermal conductivity than low temperature insulator, also works as an insulator when used in air spaces.

- Heat is transferred through insulation by conduction, convection & radiation or by combination of the all three.

- There is no insulation which is 100% efficient to prevent heat flow under temperature gradient.

PURPOSE OF INSULATION:

The purpose of insulation is of two fold -

- To prevent the flow of heat from the system to surroundings.

  e.g.: Steam turbines & Hot water pipes used in Air conditioning in winter.

- To prevent the flow of heat from the surroundings to the system.
  e.g.: Brine pipes which are used for Air conditioning in summer & domestic refrigerators & water coolers.

- **INSULATION ARE COMMONLY USED FOR FOLLOWING INDUSTRIAL PURPOSES :**

  - Air Conditioning Systems
  - Refrigeration & Food Preserving Stores
  - Preservation of Liquid gases
  - Boilers & Steams Pipe
  - Insulating bricks in all types

CLASSIFICATION OF INSULATION:

- **Loose Fill Insulation:** -which includes glass wool, slag wool, koolm wool, diatomaceous earth, silica aerogel, crushed bricks etc.

- **Slab Insulation:** - available in the form of pad & slabs of different thickness or in form of pipes made of foam glass, celotex, hair felt, insulating papers & so on.

- **Reflective Insulation: -** available in the form of foils of aluminum, platinum, nickel & so on.

TYPES OF INSULATING MATERIAL

Insulating Material can be classified for:-

- Low temperature insulations
- Medium temperature insulations
- High temperature insulations

PROPERTIES OF INSULATING MATERIALS

Insulating material used either for heating system or cooling systems should have following desirable properties: -

- Low weight
- Resistance to vermin
- Resistance to fire
- Resistance to moisture absorption
- Free from odor
- Long life

COSTS INVOLVED FOR INSULATION

The costs involved in insulation is very much dependent on the type of material being insulated, thickness of insulation made, heat flow in the material that is to be insulated & other physical & chemical properties of insulating material.

Among all these variables, the thickness of insulation is important & is a function of cost & Heat flow.

When the thickness is Low, the cost is low but the heat flow to the surrounding more.

As the thickness is increased beyond certain thickness, then the cost & heat flow also increases.

So, at one particular thickness, the cost insulation & the thickness of insulation is such that they balance each other. In the sense, that, beyond this thickness the cost is more also, the flow of heat also increases to surroundings & below this thickness, through the cost decreases, the heat flow through material inside is less.

Thus, this thickness is considered to be as:-
Economic Thickness of Insulation or
Critical Thickness of Insulation.

*** Note:** Considering the 1st purpose of Insulation.

<u>CRITICAL THICKNESS OF INSULATION</u> {CTI}

Critical thickness of insulation is defined as the thickness of insulation at which the cost of insulation will save the greatest cost of energy losses.

That is, at this thickness more heat energy is transferred through the material than to the surroundings.

That calculation of CTI is done for different shapes. Our present concern of interest is for hollow cylinder.

So, heat transferred in a hollow cylinder of diameter d, & insulation of thickness of 't' -

$$Q = \frac{2 \pi L (T_i - T_0)}{1/K_2 \ln (R_2/R_1)}$$

Where, R_1 = Radius of the hollow cylinder
R_2 = Radius from center of cylinder to the outer surface of insulation.
L = Length of zone =110 mm
K_2= Thermal conductivity of insulation material
T_i = Inside Surface temperature
T_o = Outside surface temperature of the insulation.
t = Thickness of insulation ($R2-R_1$)

At critical thickness of insulation, the flow of heat through the pipe is more & to the surroundings is minimum.

The other way to say is, the flow of heat through the insulation is minimum.

*Neglecting the Convective and Radiation heat transfers co-efficient.
i.e. Considering heat transfer through the insulations purely of conduction.

DESCRIPTION OF THE APARATUS

Apparatus consists of four Zones, they all

* BARE ZONE, dia =32mm
* ZONE - I of dia, d_1 = 65mm
* ZONE - II of dia, d2 = 75mm
* ZONE - III of dia, d_3 = 85mm

All the zones are on one single pipe of length 450mm.
Each zone is equally divided i.e. each zone is of <u>110mm</u>.

To measure the temperatures, thermocouples are provided at the inside & outside surface & are read on temperature indicator [digital]

To measure input, wattmeter is provided [digital]

The pipe is of copper of dia, d = 32mm & thickness of 1mm with an in built coil as heater of capacity 500 watts.

PROCEDURE TO CONDUCT THE EXPERIMENT

- ❖ Switch on the heater.
- ❖ Adjust the wattmeter reading by using regulator, say 50 watts
- ❖ Allow the system to attain steady state.
- ❖ Note down the Readings, such as temperature & wattage.
- ❖ Repeat the experiment for different values of power.
- ❖ Tabulate all the readings & calculate the Critical Radius.

OBSERVATION TABLE:

Power Watts	Temperature ^{O}C							
	Bare	Zone 1		Zone 2		Zone 3		Ambient
	T1	T2	T5	T3	T6	T4	T7	T8

Zone - 1

R1= 16mm=0.016m

R2 = 32.5mm=0.0325m Kasb = 0.195

Overall length L= 450mm=0.45m

Length of each Zone = 110mm = 0.11m

$$Qbare = \frac{2 \Pi L (T_1 - T_8)}{1/K}$$

For ZONE–I,

$$Qasb1 = \frac{2 \Pi L (T_2 - T_5)}{1/K \ln (R_2 / R_1)}$$

For ZONE–II,

$$Qasb2 = \frac{2 \Pi L (T_3 - T_6)}{1/K \ln (R_3 / R_1)}$$

For ZONE – III,

$$Qasb3 = \frac{2 \Pi L (T_4 - T_7)}{1/K \ln (R_3 / R_1)}$$

RESULTS:

12.PARALLEL AND COUNTER FLOW HEAT EXCHANGER

INTRODUCTION:

Heat exchanger is a device in which heat is transferred from a hot to a cold fluid across a separating wall. This is an important component of any thermal system; such as condenser in a thermal power plant, evaporators and condensers in refrigerator, radiator of a motor car etc. The heat transfer process is dominated by convection in fluid -solid boundaries and conduction through the separating wall.

The size and weight are the important aspects in the design of heat exchangers. The important performance parameter is the overall heat transfer co-efficient which determines the heat transfer rate in the equipment.

The heat transfer rate in a typical heat exchanger is given by,

$$q = U \ A \Delta T_M$$

Where,

q = Heat transfer rate in watts

U = Overall heat transfer co-efficient in $W/m^2 {}^\circ C$

A = Surface area of heat transfer in m^2

ΔT_M = Suitable mean temperature difference across the Heat exchanger surface in $^\circ C$.

One of the major classifications of heat exchangers is based on the direction of flow of hot and cold fluids. In the parallel flow heat exchanger, both hot and cold fluids flow in the same direction, whereas in the counter flow type, fluids flow in opposite direction.

CLASSIFICATION OF HEAT EXCHANGERS:

I BASED ON THE NATURE OF HEAT EXCHANGER PROCESS

i Direct Contact Type: The heat exchangers in which the process of heat transfer occurs through direct contact and mixing of the hot and cold fluid. The heat transfer is usually accompanied by mass transfer in such cases. Water cooling towers, Jet condensers are the two examples.

ii Indirect Contact Type: Those are devices in which hot and cold fluid alternatively flow over the surface. The heat carried by the hot fluid is accumulated in the walls of the equipment and is then transferred to the cold fluid when it passes over the surface next. Regenerators, Recuperates etc.

II BASED ON THE RELATIVE DIRECTION OF FLUID FLOW

i **Parallel flow heat exchanger** : In this type of heat exchanger the hot and cold fluids flow in same direction , hence the name parallel flow. In parallel flow exchanger, the temperature difference between hot and cooled fluids keeps on decreasing from inlet to exit. Many devices, such as water heaters, oil heaters and coolers belong to this class.

ii **Counter flow heat exchanger**: In this type of heat exchanger the hot and cold fluids flow parallel to each other but in opposite direction hence the name counter flow. Counter flow exchanger are the most favorable device for heating or cooling of fluids because, for a given surface area, these exchangers give the maximum heat transfer rate.

iii **Cross flow heat exchangers**: Here the two fluids flow at right angle to each other. Automobile radiators an example for this type of heat exchanger.

TEMPERATURE DIFFERENCE :

This is defined as that temperature difference which, if constant, would give the same rate of heat transfer as usually occurs under variable conditions of temperature difference.

Description of Apparatus:

One small diameter tube is fixed in another bigger diameter tube concentrically and outer tube is insulated to reduce the heat losses from its surface to the surroundings.

The fluids which are used for transferring the heat are cold water and hot water. The cold water is supplied connecting the inlet to the common tap supply and its flow is controlled by providing inlet and outlet values as shown in the figure. For providing the hot water, a small water tank is provided with heater immersed in it and heated water flow is controlled by inlet and outlet valves as shown in the figure. The water level in the hot water tank and its temperature is maintained constant as required by controlling the power supply and a valve through which cold water tank.

The valves arrangement is made in such a way, that the flow can be made parallel or counter as desired. The direction of hot water flow through the inner pipe is maintained same and the direction of cold water flow is made parallel or counter as desired by changing the valve positions.

The two thermometers are provided to measure the inlet and outlet temperatures of hot water (T_{hi} and T_{ho}) and other two measure the inlet and outlet temperatures of cold water (T_{ci} and T_{co})

OVERALL HEAT TRANSFER COEFFICENT:

The rate of heat transfer between hot and cold fluid is given by

$$Q = Uo\ Ao\ LMTD$$

Where Uo = Overall heat transfer coefficient based on outer surface area of tubes. $W/m^2\text{-}^0K$.

Ao = Total outer surface area of tubes, m^2.

DESCRIPTION:

The apparatus of a concentric tube heat exchanger. The hot fluid namely hot water is obtained from an electric geyser and it flows through the inner tube. The cold fluid is, cold water can be admitted at any one of the ends enabling the heat exchanger to run as a parallel flow or as a counter flow exchanger. This can be done by operating the valves provided. Temperature of the fluid can be measured using thermocouples with digital display. Flow rates can be measured by rotameter and a measuring flask. The outer tube is provided with insulation to minimize heat losses. A valve is provided at rotameter to vary the flow rate of water.

SPECIFICATION:

Inner tube material: Copper

I.D : 21 mm

O.D : 25 mm.

Outer tube material: Stainless Steel

I.D : 32 mm

O.D : 38 mm

Length of the Heat Exchangers : 1100 mm

Temperature Points**:**

T_{ci}: Cold water inlet temperature.

T_{co}: Cold water outlet temperature.

T_{hi}: Hot water inlet temperature.

T_h : Hot water outlet temperature.

PROCEDURE:

1. Switch on the M.C.B, Mains on.
2. Start the flow of water to Geyser and switch on the geyser so that hot water starts flowing through the pipe.
3. Now the flow of cold water is started.
4. Using the valves provided the flow can be adjusted to counter / parallel.
5. Keep the flow rate same till the steady state is reached.
6. Repeat the experiment for counter / parallel flow with constant flow rate.
7. Note down all the temperatures, flow rates of water with respect to time.
8. After the experiment is over switch of all the switches.

PRECAUTIONS:

- Do not start the equipment without proper electrical supply.
- Handle the switches gently.
- Before starting ensure that water level is maintained.
- After the experiment is over, switch off all the indicators and heaters.
- At least for every two weeks, operate the unit for five minutes.
- In case of any major faults, Please write to manufacture and do not attempt to repair.

OBSERVATIONS:

FOR PARALLEL FLOW:

1. Cold water flow rate = LPs
2. Hot water flow rate = LPs
3. T_{ci} = ^{O}C
4. T_{co} = ^{O}C
5. T_{hi} = ^{O}C
6. T_{ho} = ^{O}C

FOR COUNTER FLOW:

1. Cold water flow rate
2. Hot water flow rate
3. T_{ci} = ^{O}C
4. T_{co} = ^{O}C
5. T_{hi} = ^{O}C
6. T_{ho} = ^{O}C

FORMULAE TO BE USED:

1. Q_h = $m_h C_{ph} (T_{hi} - T_{ho})$ in watts.
   Where, m_h = mass flow rate of hot water in LPs.
   C_{ph} = Specific heat of water = 4187 J/kg ^{o}K
   T_{hi} = Inlet temperature of hot water
   T_{ho} = Outlet temperature of hot water

2. Q_c = $m_c C_{pc} (T_{co} - T_{ci})$ in watts.
   Where, m_c = mass flow rate of hot water in LPs.
   C_{pc} = Specific heat of water = 4187 J/kg ^{o}K
   T_{ci} = Inlet temperature of hot water
   T_{co} = Outlet temperature of hot water

3. Q = $(Q_h + Q_c) / 2$ in watts

4. LMTD = $\frac{(\theta_2 - \theta_1)}{\ln (\theta_2/\theta_1)}$ ^{o}K

For Parallel flow,

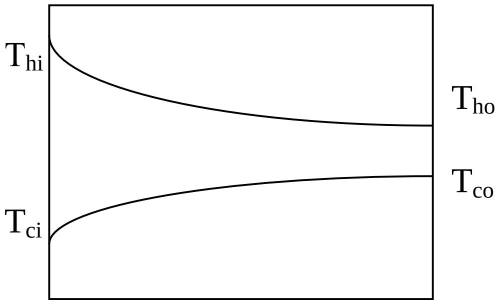
Where, $\theta_1 = (T_{hi} - T_{ci}) =$

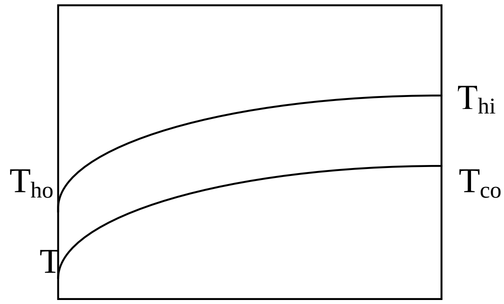
$\theta_2 = (T_{ho} - T_{co}) =$

For Counter flow,

Where, $\theta_1 =$ $(T_{ho} - T_{ci})$ =

$\theta_2 =$ $(T_{hi} - T_{co})$ =





PARALLEL **COUNTER**

5. **<u>Overall Heat transfer coefficient Uo:</u>**

$$U_o = Q / (A_o \times LMTD) \qquad w/m^{2\,o}k$$

FOR COPPER MATERIAL

Where, $A_o = \pi\, d_o\, L$ in m^2.

$= \pi \times 0.025 \times 1.1$

$= 0.0863\ m^2$

do = Outer Diameter of the tube = 25 mm

L = Length of the tube = 1100 mm.

6. **<u>EFFECTIVENESS:</u>**

$$X = Q/Q_{max}$$

if, $m_c C_{pc} > m_h C_{ph}$ $=h= \dfrac{T_{hi} - T_{ho}}{T_{hi} - T_{ci}}$ ⟶ Equ - 1

if, $m_c C_{pc} < m_h C_{ph}$ $=h= \dfrac{Tco - Tci}{T_{hi} - T_{ci}}$ ⟶ Equ - 2

7. **<u>RESULTS</u>:**

13.MEASUREMENT OF SURFACE EMMISSIVITY

AIM OF THE EXPERIMENT:

To determine the emissivity of the radiating surface.

INTRODUCTION:

Radiation is one of the modes of heat transfer which does not require any material medium for its propagation. The mechanism is assumed to be electromagnetic in nature and is a result of temperature difference. Thermodynamic considerations show that an ideal radiator or black body will emit energy at a rate proportional to the fourth power of the absolute temperature of the body. When two bodies exchange heat by radiation, the net heat exchange is given by,

$$q = \sigma A (T_h^4 - T_c^4) \quad ....\text{Eq (1)}$$

Where, 'q' is the heat transfer rate in watts, 'σ' is called the Stefan Boltzmann's Constant having the value of 5.669 3 10^{-8} watts/ m^2 $^0K^4$, 'A' is the surface area (m^2) and T_h and T_c are the temperatures of the hot and cold bodies (^{0}K) respectively. Eq (1) is called the Stefan Boltzmann's law of thermal radiation and equation applies only applies only to black bodies; a piece of metal covered with carbon black approximates this behavior. Other types of surfaces such as glossy painted surface or a polished metal plate do not radiate as much energy as the black body; however the total radiation emitted by these bodies still generally follow the T^4 proportionality. To take account of the grey nature of such surface, the factor called Emissivity (ε) which relates the radiation of the grey surface to that of an ideal black surface is used.

The emissivity of the surface is the ratio of the emissive power of the surface to the emissive power of the black surface at the same temperature. Emissivity is the property of the surface and depends upon the nature of the surface and temperature. The net heat exchange between two bodies is given by,

$$q = \sigma A_1 F \varepsilon_1 (T_h^4 - T_c^4) \quad ....\text{Eq (2)}$$

This equation assumes that all the radiation emitter (body 1) is received by the receiver (body 2). ε_1 is the emissivity of the emiter and A_1 is the area of the emitter. F is the radiation shape factor.
This setup has been designed to determine the emissivity of the given surface.

APPARATUS:

It consists of the following :

a) Black body made of circular aluminium plate with the surface black anodized, mounted on asbestos cement sheet.

Diameter : 150mm.

b) Grey body or Test plate made of circular aluminum plate of same size as the black body with polished surface , mounted on asbestos Cement sheet Diameter : 150 mm.

c) Enclosure : The sides of the enclosure are made up of transparent sheets for better visibility and with lid on the top surface for exhausting the hot air after experiment is over. The bottom is fitted on asbestos sheet to prevent heat loss.

d) Heaters to heat the black body and the grey body to identical temperature.

e) Wattmeter provided to measure input power to the heaters.

f) Thermocouples to measure surface temperatures of Test plate (T_1), Black body (T_2) and the enclosure surface (T_3) .

h) Heat control or Regulator to the heaters.

i) Control panel to switch on/ off the mains and the heater.

PROCEDURE:

a) Switch on the mains.

b) Switch on the heater to the black body and adjust the power Input to the heater to a suitable value using regulator.

c) Switch on the heater to the test plate (Grey body) and keep the power input to a value less than that input to the black body.

d) Observe temperatures of the black body and test surface in close time intervals and adjust power input to the test plate heater such that both black body and test surface temperatures are same .
This procedure requires trial and error method and one has to
Wait Sufficiently long (one hour or longer) to reach a steady state.

e) After attaining steady state, record input powers to heaters by switch off any one regulator (W_1 and W_2) and temperatures T_1, T_2 and T_3 (^0C) of black body, test plate and the enclosure

f) Using the above measurements, calculate the emissivity of the test Surface using the procedure given below.

WORKING PRINCIPLE:

Determine the emissivity of the test surface. The experimental setup is designed in such a way that under steady state conditions, the heat dissipation by conduction and convection, although small, are same for both plates : the difference in power input to the heaters of black surface and test plate which are at the same temperature is due to the difference in radiation characteristics because of Different emissivity. The difference in power inputs to the heaters

Are related to the emissivity by the relationship

$$\mathbf{W_1 - W_2 = \frac{(\varepsilon_b - \varepsilon)\, \sigma\, A\, (T_1^4 - T_3^4)}{0.86}} \quad \text{....... Eq (3)}$$

Where,

W_1 = Heat input to the black surface, watts.

W_2 = Heat input to the test plate, watts.

A = Area of black body & test plate, 2 x (π d^2) /4, m^2

d = Diameter to the test plate & black body, m.

T_1 = Temperature of the Gray plate, ^{0} K

T_2 = Temperature of the black plate, ^{0}K

T_3 = Inside temperature of the enclosure, ^{0}K.

ε_b = Emissivity of black plate (assumed equal to 1).

ε = Emissivity of the test plate.

σ = Stefan Boltzmann's constant.

= 5.669×10^{-8} watts / $m^2\ ^0K^4$.

The constant in the denominator (0.86) takes into account various factors such as radiation shape factor , effect of conduction and free convection losses and other factors (such as non-uniformities in enclosure temperature) which cause deviations from the typical radiation heat transfer experiment . The above analysis requires that the temperatures of black surface and test are same ($T_1 = T_2$).

TABULAR COLUMN:

W_1 watts	W_2 watts	T_1 ^{0}C	T_2 ^{0}C	T_3 ^{0}C	ε

GUIDANCE OF CALCULATIONS:

W_1 = watts (black body)
W_2 = watts (grey body)

$$A = 2 \times \frac{\pi d^2}{4} =$$

σ = 5.669×10^{-8} watts / $m^2\ ^0K^4$.

$$\varepsilon = 1 - \frac{0.86 \; (W_1 - W_2)}{\sigma \times A \times (T_1^4 - T_3^4)}$$

For different values of input power to the heater (W_1 & W_2) Experiment is repeated to determine ε.

RESULTS: