EXPERIMENT NO: 1

Date of Conduct:

THERMAL CONDUCTIVITY OF INSULATING POWDER

AIM: To determine thermal conductivity of insulating powder.

THEORY: Thermal insulation is of great importance because it involves considerable cost in industries in minimizing the heat losses. Different materials are used as insulating materials. These materials used may be of solid (sheet or powder or yarn etc) , liquid and gases. Solid insulating materials are popular as they can be easily used in many situations. One of the desirable property of insulating materials is low thermal conductivity or high thermal resistance.

Thermal conductivity is defined as the ' rate of heat transfer by conduction per unit area per unit temperature gradient' and its S.I unit is W/mK or W/m^{0}C . While calculating the thermal conductivity experimentally Fourier's law of heat conduction is used. It can be stated as:

' **Rate of heat transfer by conduction in steady state is directly proportional to the normal area and temperature gradient**'.

Mathematically

$$\mathbf{Q} \propto A\frac{dT}{dx};$$

where Q = heat transfer rate in W

T = Temperature in ^{0}C or K

A = Area normal to heat transfer in m^2

Removing proportionality the law can be written as

$$\mathbf{Q} = -kA\frac{dT}{dx};$$

where k = constant of proportionality called as 'Thermal conductivity'. Negative sign here indicates that the there is decrease in temperature in the direction of heat transfer.

Insulating materials need to have high thermal resistance. Thermal resistance can be calculated using electrical analogy as given below.

$$\text{Heat transfer rate} = \frac{Thermal\,Potential\ Difference}{Thermal\,Resistance}; \qquad Q = \frac{\Delta T}{R_{th}}$$

Where Q is analogous to Current I , ΔT analogous to Voltage V and R_{th} analogous to Electrical Resistance R. S.I unit of thermal resistance is ^{0}C/w or K/W. Expression for thermal resistance depends on the geometry for heat conduction. R_{th} expression for slab, hollow cylinder and hollow sphere is given below.

Slab:

$$R_{th} = \frac{L}{kA};$$

where L =thickness of slab, k = thermal conductivity and A = normal area.

Hollow Cylinder:

$$R_{th} = \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi kL};$$

where r_2 = outer radius , r_1= inner radius, k= thermal conductivity and L=length of cylinder.

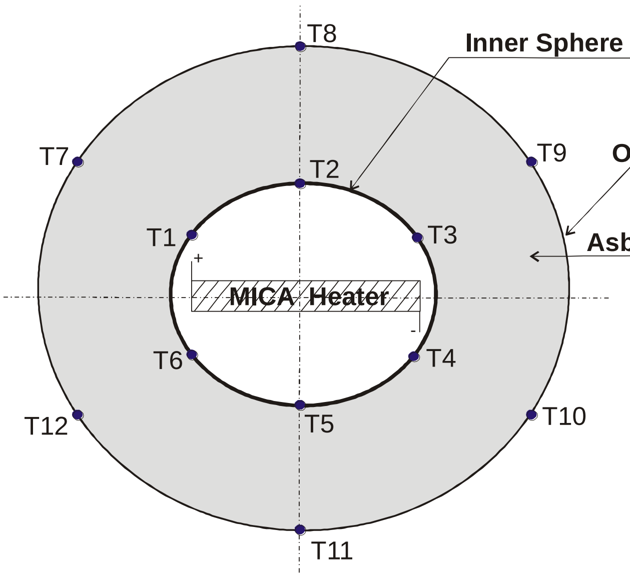
Hollow Sphere:

$$R_{th} = \frac{r_2 - r_1}{4\pi k r_1 r_2};$$

where r_2 = outer radius , r_1= inner radius, k= thermal conductivity

DESCRIPTION OF APPARATUS:

The experimental setup consists of two concentric spheres as shown in figure. The gap between the sphere is filled with asbestos powder whose thermal conductivity is to be found out. Six thermocouples of k-type are attached on inners sphere and six on outer sphere for measuring the temperature. Mica heater is kept inside the inner sphere. With the help of dimmerstat heat input can be controlled. Voltmeter. Ammeter and Selector switch with temperature indicator are provided on the console.



Thermal Conductivity of Insulating Powder Setup Diagram

Designed By Mr.Amit Kopardekar
Department of Mechanical Engg.

SPECIFICATIONS:

1. Radius of inner sphere = r_i=50mm
2. Radius of outer sphere = r_o=100mm
3. Mica heater: 1000 W
4. Dimmerstat: 2 - 5 kW
5. Voltmeter: 0 - 300 Volts
6. Ammeter: 0 - 5 Amperes
7. Multi channel digital temperature indicator: 0 - 400°C
8. Thermocouples: k-type (12 Nos.)

PROCEDURE:

1. Check all the electrical connections.
2. Keep the dimmerstat at zero position before switching ON the power supply.
3. Switch ON the heater and adjust the dimmerstat position to required value of voltmeter by gradually operating the dimmerstat.
4. Note the thermocouple readings T_1 to T_{12} and voltmeter and ammeter readings in the observation table as shown **after steady state is reached**.
5. Repeat the above steps for different heat inputs.
6. Turn dimmerstat to zero position and switch OFF the main supply.

PRECAUTIONS:

1. Operate the selector switch and dimmerstat gently.

2. Note thermocouple readings with an interval of atleast 5 seconds.

OBSERVATION TABLE:

Trial	Heat Input		Inner Surface temperature (^{0}C)						Outer Surface temperature (^{0}C)					
No.	V	I	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}

RESULTS TABLE:

Trial No.	Heat Input	Average Surface Temperature (^{0}C)		Thermal Conductivity k (W/mK)
		Inner	Outer	
	Q (W)	T_i	T_o	

CALCULATIONS:

1. Heat Input = Q = V x I (W)

2. Average surface temperatures:

$$T_i = \frac{T_1 + T_2 + T_3 + T_4 + T_5 + T_6}{6}\ ;\ T_o = \frac{T_7 + T_8 + T_9 + T_{10} + T_{11} + T_{12}}{6}\ ;$$

3. Thermal Conductivity of Insulating Powder:

$$Q = \frac{\Delta T}{R_{th}} = \frac{T_i - T_o}{\left(\frac{r_o - r_i}{4\pi k r_i r_o}\right)}\ ; \quad \text{therefore } k = \left(\frac{Q(r_o - r_i)}{4\pi r_i r_o (T_i - T_o)}\right)$$

RESULTS: Average k =

SAMPLE CALCULATION SHEET:

ORAL QUESTIONS

1. Define thermal conductivity.
2. Write SI unit of thermal conductivity. Derive the same.
3. What do you mean by thermal conductivity?
4. What is the difference between the conducting and insulating materials?
5. Name atleast five conducting and insulating materials.
6. Which material has highest thermal conductivity?
7. What is the thermal conductivity of perfect insulator?
8. What is the thermal conductivity of perfect conductor?
9. What is superconductivity?
10. How does thermal conductivity vary with temperature for solids, liquids and gases? and why?
11. Give atleast five practical applications where you use good thermal conductors and insulators.
12. Give values of thermal conductivity of atleast five good conductors and insulators.
13. Explain the mechanism of heat conduction.
14. State Fourier's law of conduction. or Which is the governing law for conduction and state the same
15. What do mean by steady state? what is required in the lab to achieve the same.
16. Differentiate between steady state and unsteady state conduction.
17. What do mean by thermal resistance?
18. What is SI unit of thermal resistance? derive the same.
19. Explain working of thermocouple. What are their types? and which type is used in the setup?
20. Derive and write the expression for heat transfer through composite sphere.
21. How does temperature vary in slab, cylinder and sphere and why? plot the nature.
22. Hot or cold water is to be stored in rectangular, cylindrical and spherical container of same volume and same thickness; which container you would choose and why?
23. Write generalized heat conduction equation in cartesian , cylindrical and spherical coordinate system.

EXPERIMENT NO: 2

Date of Conduct:

HEAT TRANSFER THROUGH LAGGED PIPE

AIM:

To determine thermal conductivity of insulating material used in lagged pipe and plot the radial temperature distribution.

THEORY:

Many engineering applications related to heat transfer need insulation over a pipe or cylinders. Popular examples are steam pipe, electrical wires, hot water pipes refrigerant pipes etc. In these cases the pipe is lagged with insulation material like asbestos, glass wool, plastic etc. It is necessary know the effect of thickness of these insulation and temperature distribution before using them. Thermal conductivity of these material play important role in minimizing and increasing heat transfer rate.

Thermal conductivity is defined as the ' rate of heat transfer by conduction per unit area per unit temperature gradient' and its S.I unit is W/mK or W/m^{0}C . While calculating the thermal conductivity experimentally Fourier's law of heat conduction is used. It can be stated as:

' **Rate of heat transfer by conduction in steady state is directly proportional to the normal area and temperature gradient**'.

Mathematically

$$\mathbf{Q} \propto A\frac{dT}{dx} \text{;}$$

where Q = heat transfer rate in W

T = Temperature in ^{0}C or K

A = Area normal to heat transfer in m^2

Removing proportionality the law can be written as

$$\mathbf{Q} = -kA\frac{dT}{dx} \text{;}$$

where k = constant of proportionality called as 'Thermal conductivity'. Negative sign here indicates that the there is decrease in temperature in the direction of heat transfer.

Thermal resistance can be calculated using electrical analogy as given below.

$$\text{Heat transfer rate} = \frac{\text{Thermal Potential Difference}}{\text{Thermal Resistance}}; \qquad Q = \frac{\Delta T}{R_{th}}$$

Where Q is analogous to Current I , ΔT analogous to Voltage V and R_{th} analogous to Electrical Resistance R. S.I unit of thermal resistance is ^{0}C/w or K/W. Expression for thermal resistance depends on the geometry for heat conduction. R_{th} expression for hollow cylinder is given below.

Hollow Cylinder:

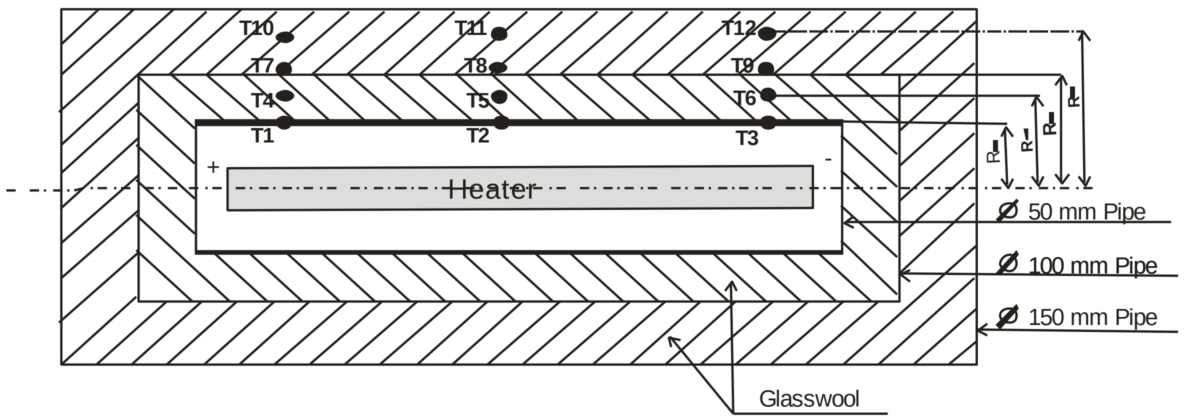
$$R_{th} = \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi kL};$$

where r_2 = outer radius , r_1= inner radius, k= thermal conductivity and L=length of cylinder.

DESCRIPTION OF APPARATUS:

The experimental setup consists of three concentric cylinders as shown in figure. The gap between the cylinders is filled with glass wool insulation whose thermal conductivity is to be found out. Heating coil is inserted inside of inner cylinder. With the help of dimmerstat heat input can be controlled. Voltmeter. Ammeter and Selector switch with temperature indicator are provided on the console. K-type thermocouples are used for measuring temperature. Three thermocouples each are used at four different radii.

EXPERIMENTAL SETUP FIGURE:



Heat Transfer Through Lagged Pipe Setup Diagram

Designed By Mr. Amit Kapardekar
Department of Mechanical Engg

SPECIFICATIONS:

1. M.S.Pipe (1) : 50mm I.D
2. M.S.Pipe (2) : 100mm I.D
3. M.S.Pipe (3) : 150mm I.D
4. Location of thermocouples in the insulation

   r_1=28mm

   r_2=37.5mm

   r_3=53mm

   r_4=62.5mm
5. Heater Coil: 500 W
6. Dimmerstat: 2 - 5 kW
7. Voltmeter: 0 - 300 Volts
8. Ammeter: 0 - 5 Amperes
9. Multi channel digital temperature indicator: 0 - 400°C
10. Thermocouples: k-type (12 Nos.)

PROCEDURE:

1. Check all the electrical connections.
2. Keep the dimmerstat at zero position before switching ON the power supply.
3. Switch ON the heater and adjust the dimmerstat position to required value of voltmeter by gradually operating the dimmerstat.
4. Note the thermocouple readings T_1 to T_{12} and voltmeter and ammeter readings in the observation table as shown after steady state is reached.
5. Repeat the above steps for different heat inputs.
6. Turn dimmerstat to zero position and switch OFF the main supply.

PRECAUTIONS:

1. Operate the selector switch and dimmerstat gently.

2. Note thermocouple readings with an interval of atleast 5 seconds.

OBSERVATION TABLE:

Trial No	Heat Input		Thermocouple Readings (0C)											
			at r_1=28mm			at r_2=37.5mm			at r_3=53mm			at r_7=62.5mm		
	V	I	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}

RESULTS TABLE:

Trial No.	Heat Input	Average Surface Temperature (^{0}C)				Thermal Conductivity k (W/mK)
		at r_1=28mm	at r_2=37.5mm	at r_3=53mm	at r_4=62.5mm	
	Q (W)	T_A	T_B	T_C	T_D	

CALCULATIONS:

1. Heat Input = Q = V x I (W)
2. Average surface temperatures:

$T_A = \frac{T_1+T_2+T_3}{3}$; $T_B = \frac{T_4+T_5+T_6}{3}$; $T_C = \frac{T_7+T_8+T_9}{3}$; $T_D = \frac{T_{10}+T_{11}+T_{12}}{3}$;

3. Thermal Conductivity of Insulating Material:

$$Q=\frac{\Delta T}{R_{th}}=\frac{T_A-T_D}{\left(\frac{\ln\left(\frac{r_4}{r_1}\right)}{2\pi kL}\right)}; \quad \text{therefore } k=\left(\frac{Q\ln\left(\frac{r_4}{r_1}\right)}{2\pi L(T_A-T_D)}\right)$$

RESULTS:

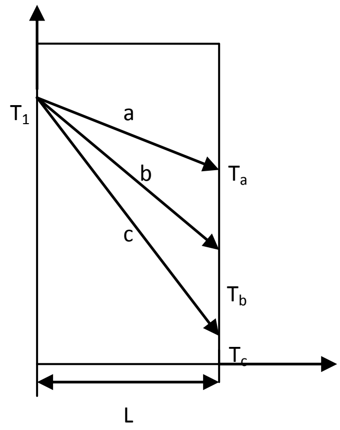
1. Average thermal conductivity of glass wool = k =
2. Plot the radial temperature distribution T v/s Radius
3. Compare the thermal conductivity of glass wool obtained with its standard value.

PASTE GRAPH SHEET HERE

SAMPLE CALCULATION SHEET:

ORAL QUESTIONS

1. What do you mean by lagged pipe?
2. Give examples for lagged pipes.
3. What do you mean by critical radius of insulation?
4. Write expression for critical radius of insulation for cylinder and sphere.
5. What do mean by diffusivity? give its significance and SI units.
6. Shown in figure the plot of T vs L for heat conduction. Which has more thermal conductivity and why?



EXPERIMENT NO: 3

Date of Conduct:

(A) HEAT TRANSFER THROUGH COMPOSITE WALL

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

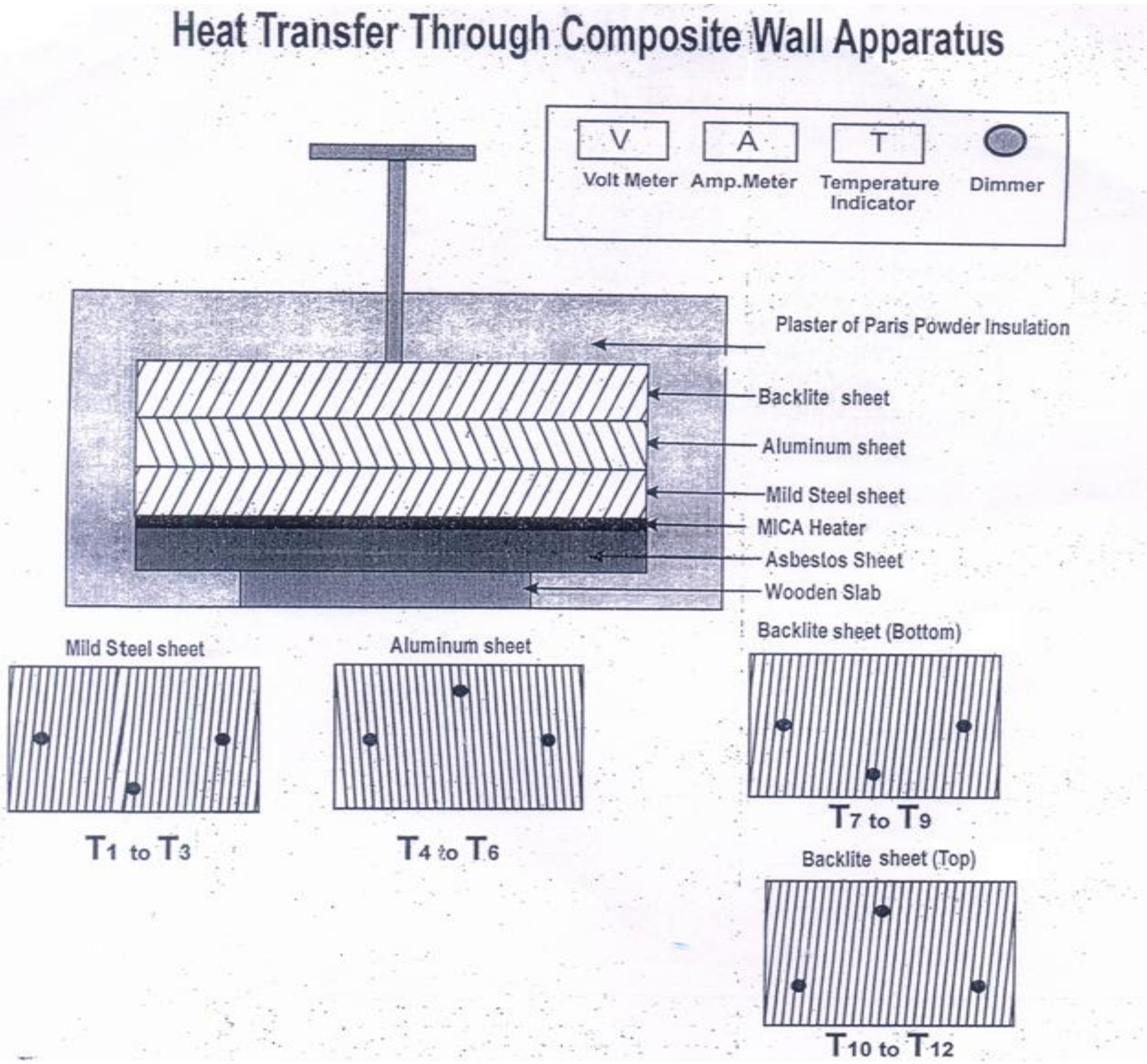
THEORY:

Many engineering applications of practical utility involve heat transfer through a medium composed of two or more materials of different thermal conductivities arranged in series or parallel. Consider examples like the walls of a refrigerator, hot cases, cold storage plants, hot water tanks, etc., which always have some kind of insulating material between the inner and outer walls. A hot fluid that flows inside the tube covered with a layer of thermal insulation is another example of composite system because in this case the thermal conductivities of tube material and insulation are different. The problem of heat transfer through the composite system can be solved by the application of the thermal resistance concept.

DESCRIPTION OF APPARATUS:

The experimental setup consists of three slabs, (Mild steel, Aluminium and Bakelite) of identical size and thickness as shown in figure. Mica heater is provided to supply heat input across these composite walls. Total assembly comprises of a heater bound between asbestos plates. Small hand press is provided to press the wall on each other and to ensure no air gap between two plates. The heater input can be varied with the help of dimmerstat and is measured by voltmeter and ammeter. Thermocouples of k-type (Chromel-Alumel) are provided at proper position in the composite wall to measure desired inside temperature of composite wall. Multi channel temperature indicator is used to measure these temperatures.

EXPERIMENTAL SETUP FIGURE:



SPECIFICATIONS:

1. Size of each slab = 0.150 x 0.150 m
2. Thickness of each slab = L = 12 mm
3. Mica heater: 400 W
4. Dimmerstat: 0 - 230 Volts
5. Voltmeter: 0 - 300 Volts
6. Ammeter: 0 - 30 Amp
7. Multi channel digital temperature indicator: 0 - 300°C
8. Thermocouples: k-type (12 Nos.)

PROCEDURE:

1. Check the pressure applied to the plates manually.
2. Check all the electrical connections.
3. Keep the dimmerstat at zero position before switching ON the power supply.
4. Switch ON the heater and adjust the dimmerstat position to required value of voltmeter by gradually operating the dimmerstat.
5. Note the thermocouple readings T_1 to T_{12} and voltmeter and ammeter readings in the observation table as shown after steady state is reached.
6. Repeat the above steps for different heat inputs.
7. Turn dimmerstat to zero position and switch OFF the main supply.

PRECAUTIONS:

1. Operate the selector switch and dimmerstat gently.

2. Note thermocouple readings with an interval of atleast 5 seconds.

OBSERVATION TABLE:

Trial No	Heat Input		Thermocouple Readings (0C)											
	V	I	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}

RESULTS TABLE:

Trial No.	Heat Input	Average Surface Temperature (^{0}C)				$\sum(R_{th})_{Exp}$ (^{0}C/W)	%Error
	Q (W)	T_A	T_B	T_C	T_D		

CALCULATIONS:

1. Heat Input = Q = V x I (W)

2. Average surface temperatures:

$T_A = \frac{T_1 + T_2 + T_3}{3}$; $T_B = \frac{T_4 + T_5 + T_6}{3}$; $T_C = \frac{T_7 + T_8 + T_9}{3}$; $T_D = \frac{T_{10} + T_{11} + T_{12}}{3}$;

3. $\sum (R_{th})_{Exp} = \frac{T_A - T_D}{Q}$ (^{0}C/W)

4. $\sum (R_{th})_{Std}$ = Equivalent Thermal Resistance using Standard Values of Thermal Conductivities

$$= \frac{L}{A}\left[\frac{1}{k_M} + \frac{1}{k_A} + \frac{1}{k_B}\right] (^0\text{C/W})$$

Where

A = Area of each slab

k_M = Thermal Conductivity of Mild Steel = 48 W/mK

k_A = Thermal Conductivity of Aluminium = 250 W/mK

k_B = Thermal Conductivity of Bakelite = 0.7 W/mK

5. %Error = $\frac{\sum (R_{th})_{Std} - \sum (R_{th})_{Exp}}{\sum (R_{th})_{Std}} x100$

6. Plot the variation of temperature (T) v/s Slab thickness (L)

RESULTS:

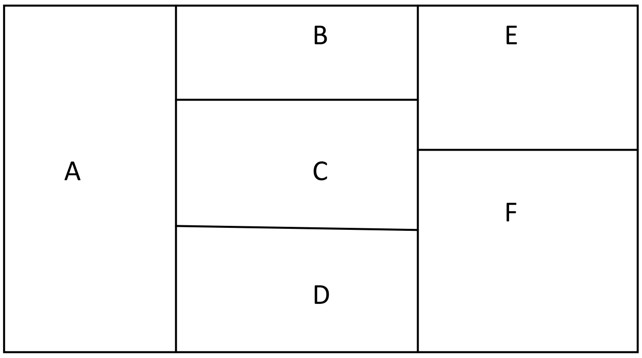
1. Average $\sum (R_{th})_{Exp}$ =

2. Average %Error =

SAMPLE CALCULATION SHEET:

ORAL QUESTIONS

1. What do mean by composite wall? Give examples.
2. Draw equivalent circuit diagram for the composite wall.
3. Write expression for equivalent thermal resistance.
4. What do you mean by electrical analogy? write expression for thermal resistance for a slab, cylinder and sphere.
5. Draw electrical analogy circuit for the following composite wall.



EXPERIMENT NO: 3

Date of Conduct:

(B) THERMAL CONDUCTIVITY OF METAL ROD

AIM : To Determine Thermal Conductivity of Metal Rod

THEORY: Thermal conductivity is the physical property of the material denoting the case with a particular substance can accomplish the transmission of a thermal energy by molecular motion.

Thermal conductivity of the material is found to depend on chemical composition of the substance or substances of which it is composed the phase (i.e gas, Liquid or solid) in which it exist, its crystalline structure if a solid, the temperature and pressure to which it is subjected, and whether or not it is a homogeneous material.

DESCRIPTION OF APPARATUS:

The experimental set up consist of a metal bar, one end of which is heated by an electric heater while the other end of bar projects insides the cooling water jacket. The middle portion of the bar is surrounded by cylindrical shell filled with insulating material. The temperature of the bar is measured at six different equidistant locations along the length of bar, as shown in figure. Two thermocouples are used to measure inlet and outlet temperature of circulating water

The heater is provided with a dimmer for controlling the heat input. Water circulated through the jacket and flow rate and temperature rise are noted.

SPECIFICATIONS:

1. Length of metal bar (Total) = 460 mm (0.460 m)
2. Material Used for bar – Copper
3. Diameter of metal bar = 25 mm
4. Distance between each thermocouple = 25 mm (0.025 m)
5. Number of thermocouples mounted on the bar = 06
6. Heater = Band type 1000 Watt
7. Thermocouple Type : Chromel Alumel (K-Type)

   Position 1 to 6 – on the bar

   Position 7 = Inlet Water Temperature

   Position 8 = Outlet Water Temperature

8. Dimmer stat for heat input = 0 to 240 V
9. Voltmeter: 0- 240 V
10. Ammeter: 0- 06 A

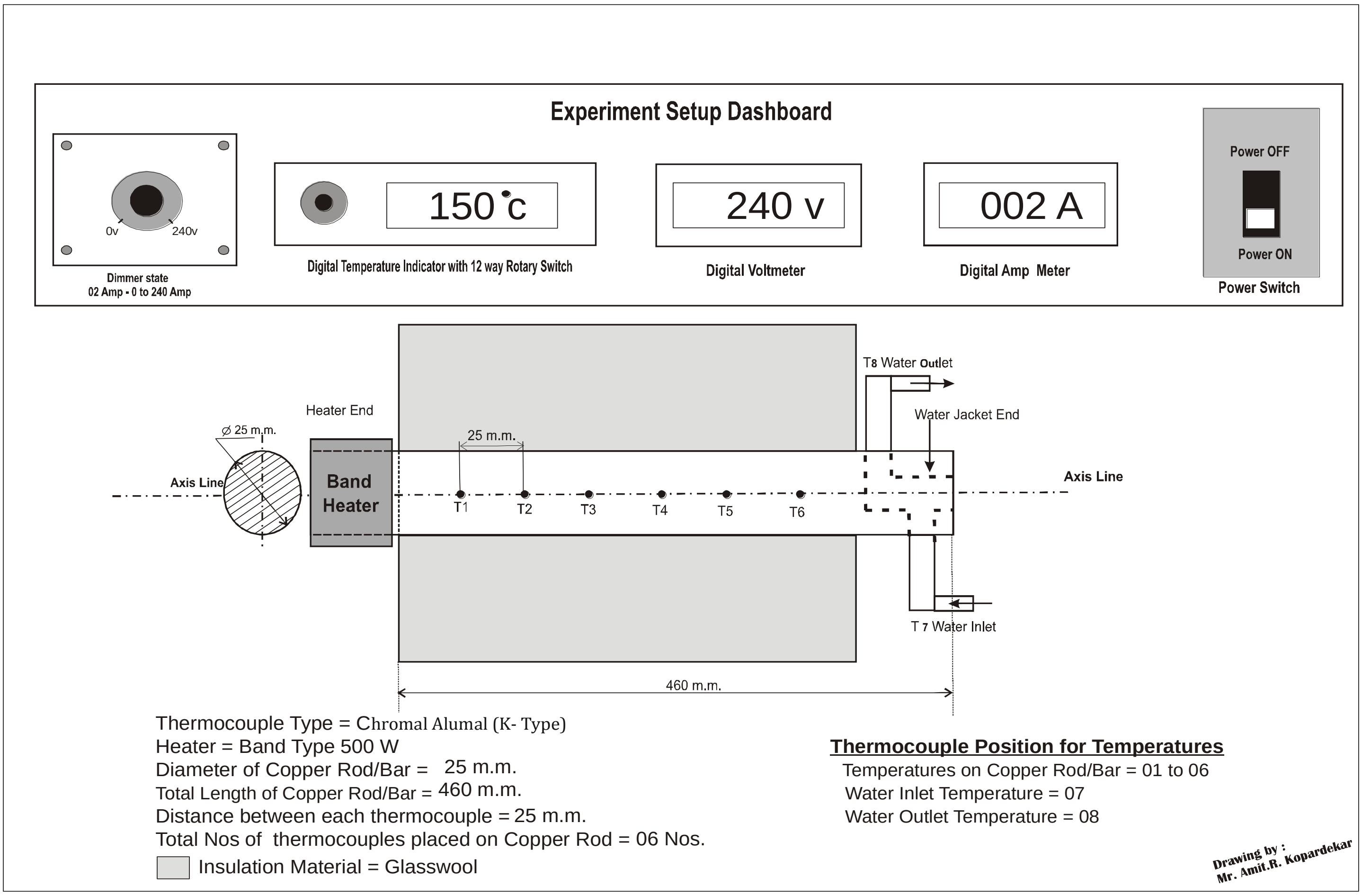
PROCEDURE :

1. Start the supply.
2. Give input to heater by slowly rotating the dimmer stat and adjust it to 50 V – 100 V
3. Start the cooling water supply through the jacket and adjust suitable flow rate so that minimum 2^{0}C temperature rise exists.
4. Go on checking the temperatures after time intervals of 10 min. and continue this till a steady state condition is reached.
5. Note the temperature readings 01 to 08
6. Note the mass flow rate of the water.

PRECAUTIONS:

1. Operate the selector switch of the temperature indicator gently.
2. See the dimmer stat knob is on Zero before starting the unit.
3. Never exceed dimmer above 100 V

EXPERIMENTAL SETUP FIGURE:



OBSERVATION TABLE :

Trial No.	V	I	Rod Surface Temperature (^{0}C)						Water jacket temperature (^{0}C)		Water Flow Rate	
											LPM	Kg/sec
			T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8		

CALCULATIONS:

After steady state condition

Axial Heat Condition through Rod = Heat Gained by water

$-KA\ (dt/dx) = m_w\ cp_w\ (T_{wo}\ T_{wi})$

Where :

K= Thermal Conductivity of metal Rod.

A = Cross-sectional area of Metal Rod.

(dt/dx) = Temperature

RESULTS:

Thermal conductivity K =______

Plot Graph of Temperature distribution along the Length

Comment on graph and results

SAMPLE CALCULATION SHEET:

PASTE GRAPH SHEET HERE

EXPERIMENT NO: 4

Date of Conduct:

HEAT TRANSFER THROUGH NATURAL CONVECTION

AIM:

To determine heat transfer coefficient for a vertical heated cylinder loosing heat by natural/free convection.

THEORY:

Convection is that mode of heat transfer where heat is transferred from high temperature region to low temperature region with appreciable movement of molecules. Hence convection can occur only in fluids. Most of the thermal problems involve convection mode of heat transfer. Convection can occur in three different ways namely; Forced convection, Natural or Free convection and combined Forced & Free convection. When movement of molecules is established by buoyancy effects due to density difference within the fluid then that mode of convection is called Free or Natural convection.

If the molecular movement is due to external agent like pump, blower, fan, gravity force etc, then the mode is called Forced convection.

There are situations where Free and Forced Convection contribute equally in heat transfer then such case is called Combined Free & Forced Convection.

There are many examples for convection mode. Heating water in container, Cooling of liquids, Heating of water in gas geyser, electric geyser, condensation, boiling etc. The heat transfer in convection is governed by Newton's Law of cooling which can be stated as follows;

' Rate of heat transfer by convection is directly proportional to the surface area and the temperature difference between the hot surface and cold fluid'.

Mathematically

$$\mathbf{Q} \propto A(T_s - T_f);$$

where Q = heat transfer rate in W

T_s = Surface Temperature in ^{0}C or K

T_f = Fluid Temperature in ^{0}C or K

A = Surface Area in m^2

Removing proportionality the law can be written as,

$$Q = hA(T_s - T_f);$$

where h = constant of proportionality called as 'heat transfer coefficient or film coefficient'. Heat transfer coefficient depends on seven to eight variables and sometimes more than that, hence it is difficult to determine the same. Many researchers have proposed empirical relations to determine the heat transfer coefficient. These empirical relations involve dimensionless numbers.

Heat transfer coefficient in Natural convection depends on three numbers namely

Nusselt Number (Nu), Grashof Number (Gr) and Prandtl Number (Pr). Generally it is expressed as follows

Nu = f (Gr, Pr)

The physical significance of these Numbers is as given below

Nusselt Number (Nu): Ratio of temperature gradients by conduction and convection at the surface. It can also be written at the surface as

$$Nu = \left(\frac{Resistance\ for\ conduction}{Resistance\ for\ convection}\right) = \left(\frac{Heat\ transfer\ by\ convection}{Heat\ transfer\ by\ conduction}\right)$$

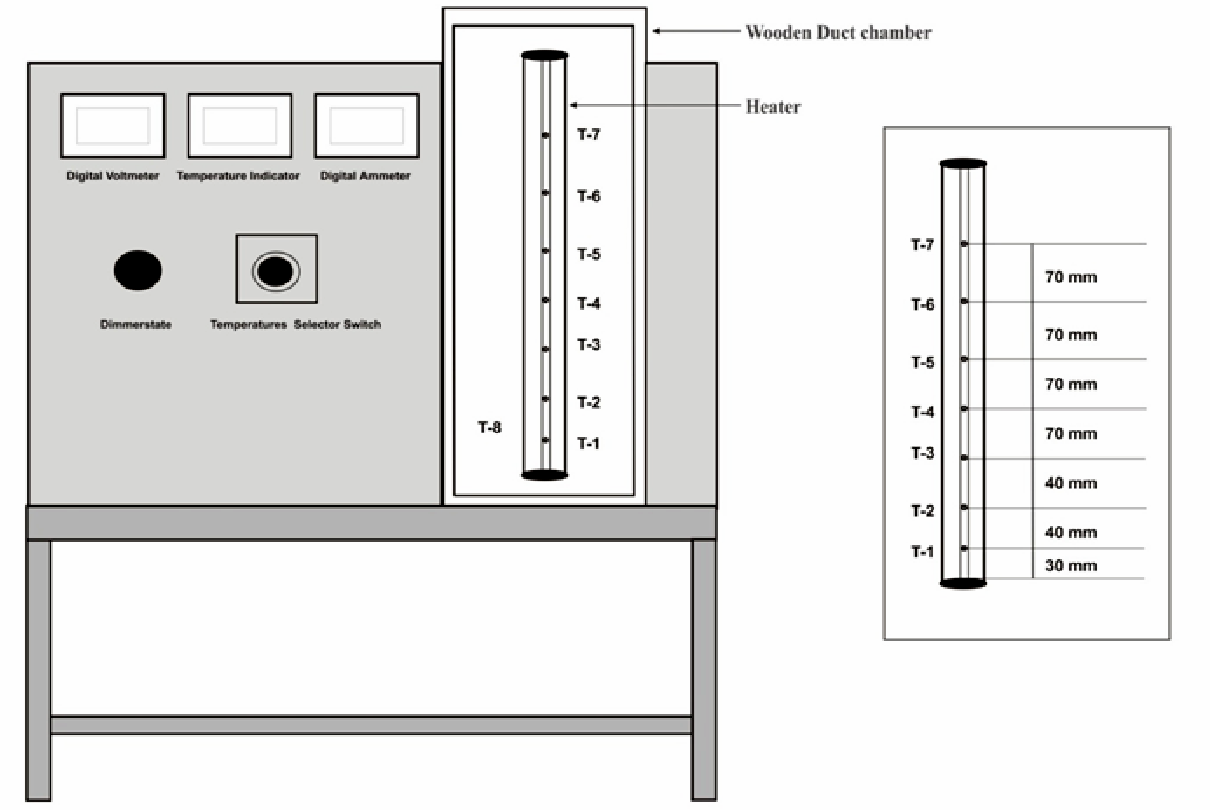
Grashof Number (Gr): $\left(\frac{Buoyant\ Force}{Viscous\ Force}\right)\left(\frac{Inertia\ Force}{Viscous\ Force}\right)$

Prandtl Number (Pr): $\left(\frac{Molecular\ Diffusivity\ of\ Momentum}{Molecular\ Diffusivity\ of\ Heat}\right)$

DESCRIPTION OF APPARATUS:

The experimental setup consists of vertical stainless steel tube enclosed in a rectangular duct on as shown in figure. Duct serves the purpose of undisturbed surroundings. The front side has transparent acrylic sheet for visual inspection. Bottom and top side is open for air movement. There are eight thermocouples of k-type, seven on cylinder and one in the duct for ambient temperature of air. The location of each thermocouple is also indicated in the figure. The heater coil is kept all along the cylinder from inside. With the help of dimmerstat heat input can be controlled. Voltmeter. Ammeter and Selector switch with temperature indicator are provided on the console.

EXPERIMENTAL SETUP FIGURE:



Heat Transfer Through Natural Convention

SPECIFICATIONS:

1. Diameter of cylinder =D= 45mm
2. Length of the cylinder = L= 500mm
3. Duct size: 200 x 200 x 600 x12 mm Thick
4. Heater Coil: 500 W
5. Dimmerstat: 2 - 5 kW
6. Voltmeter: 0 - 300 Volts
7. Ammeter: 0 - 5 Amperes
8. Multi channel digital temperature indicator: 0 - 400°C
9. Thermocouples: k-type (8 Nos.)
10. Distance of thermocouple from bottom end:

L_1=30mm; L_2=70mm; L_3=110mm; L_4=180mm; L_5=250mm; L_6=320mm; L_7=390mm

PROCEDURE:

1. Check all the electrical connections.
2. Keep the dimmerstat at zero position before switching ON the power supply.
3. Switch ON the heater and adjust the dimmerstat position to required value of voltmeter by gradually operating the dimmerstat.
4. Note the thermocouple readings t_1 to t_8 and voltmeter and ammeter readings in the observation table as shown after steady state is reached.
5. Repeat the above steps for different heat inputs.
6. Turn dimmerstat to zero position and switch OFF the main supply.

PRECAUTIONS:

1. Operate the selector switch and dimmerstat gently.

2. Note thermocouple readings with an interval of atleast 5 seconds.

OBSERVATION TABLE:

Trial No.	Heat Input		Thermocouple Readings (^{0}C)							
			Surface							Ambient
	V	I	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8

RESULTS TABLE:

(A) Average heat transfer coefficient (h_{avg})

Trial No.	Heat Input	Average Surface Temperature (^{0}C)	Air Temperature (^{0}C)	Heat transfer by Radiation (W)	Heat transfer by Convection (W)	Experimental Average Heat transfer Coefficient (W/m^2 K)	Empirical Average Heat transfer Coefficient (W/m^2 K)
	Q (W)	t_s	t_f=t_8	Q_{rad}	Q_{conv} = Q- Q_{rad}	$[h_{avg}]_{exp}$	$[h_{avg}]_{emp}$

(B) Local heat transfer coefficient (h_x)

Trial No.	Heat Input	Air Temperature (^0C)	Heat transfer by Radiation (W)	Heat transfer by Convection (W)	Local Heat transfer Coefficient (W/m^2 K)						
	Q (W)	$t_f = t_8$	Q_{rad}	Q_{conv} = Q-Q_{rad}	h_1	h_2	h_3	h_4	h_5	h_6	h_7

CALCULATIONS:

1. Heat Input = Q = V x I (W)

2. Average surface temperature= t_s = $\dfrac{t_1 + t_2 + t_3 + t_4 + t_5 + t_6 + t_7}{7}$

3. Heat transfer by radiation using Stefan-Boltzmann law:

Q_{rad} = $\varepsilon\sigma$ A_s $[T_s^4 - T_f^4]$

where $\varepsilon =$ Emissivity of stainless tube polished=0.075

$\sigma =$ Stefan-Boltzmann constant = 5.667 x10^{-8} W/m^2 K^4

$T_s = t_s + 273$

$T_f = t_f + 273$

4.Heat transfer by convection only = Q_{conv} = Q - Q_{rad}

5. Average heat transfer coefficient from Experiment= $[h_{avg}]_{exp} = \dfrac{Q_{conv}}{A_s(t_s - t_f)}$

A_s = Surface area of cylinder = πDL

6. Average heat transfer coefficient experimentally at x=L_x:

$[h_{avg}]_x = \dfrac{Q_{conv}}{A_x(t_{sx} - t_f)}$;where A_x = πDL_x , x = 1,2,3,4,5,6,7 *[Note: Convert L_x into meters]*

where t_{sx}= average tempearture upto location 'x'.

7. Local heat transfer coefficient experimentally at $x=L_x$:

$$h_x = \frac{[h_{avg}]_x}{2}$$

7. Average heat transfer coefficient from Empirical relation:

Nu = 0.59 $Ra_L^{1/4}$ if $10^4 < Ra_L < 10^8$

Nu = 0.13 $Ra_L^{1/3}$ if $10^8 < Ra_L < 10^{12}$

Where Ra_L = Rayleigh Number = Gr_L Pr

$Nu = \dfrac{h_{avg}L}{k}$; $Gr_L = \dfrac{g\beta\Delta t L^3}{\nu^2}$; $Pr = \dfrac{\mu C_p}{k}$;

g = local acceleration due to gravity =9.81 m/s²

β= thermal expansion coefficient = $\dfrac{1}{t_m + 273}$

$\Delta t = t_s - t_f$

L = length of the cylinder

ν = Kinematic Viscosity of air

μ = Dynamic Viscosity of air

C_p = Specific heat of air

k = Thermal conductivity of air

Properties of air to be obtained from Handbook at Mean Film Temperature=t_m = $\dfrac{t_s + t_f}{2}$;

Average heat transfer coefficient = $[h_{avg}]_{emp} = \dfrac{Nu\ k}{L}$

RESULTS:

1. Experimental Average Heat transfer coefficient = $[h_{avg}]_{exp}$ =
2. Empirical Average Heat transfer coefficient =$[h_{avg}]_{emp}$ =

3. Plot the variation of local Heat transfer coefficient h_x versus 'L_x'.

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SAMPLE CALCULATION SHEET:

ORAL QUESTIONS

1. What do you mean by convection?
2. Which is the governing law for the convection? State the same
3. Differentiate between natural/free and forced convection.
4. Give atleast five examples for natural convection.
5. In the experimental setup of vertical cylinder why temperature at the top is more than at the bottom?
6. Draw flow patterns for the following natural/free convection cases;

   i) Heated horizontal and vertical plate

   ii) Heated horizontal and vertical cylinder

   iii) Heated sphere

   iv) Cold horizontal and vertical plate

   v) Cold horizontal and vertical cylinder

   vi) Cold sphere
7. What are dimensionless numbers governing natural convection?
8. Give significance of dimensionless numbers governing natural convection.
9. Write expression for dimensionless numbers governing natural convection.
10. Two identical heated metal plates are kept in fluid; one in water and other in air. In which case the cooling rate is faster and why?
11. Two identical hot cylinders are kept in air; one is horizontal and other is vertical. Which cylinder cools faster and why?
12. It is required to heat a cylinder in hot bath. How you would keep the cylinder; horizontally or vertically and why?

EXPERIMENT NO: 5

Date of Conduct:

EMISSIVITY MEASUREMENT APPARATUS

AIM: To Determine Emissivity of Given Gray Plate.

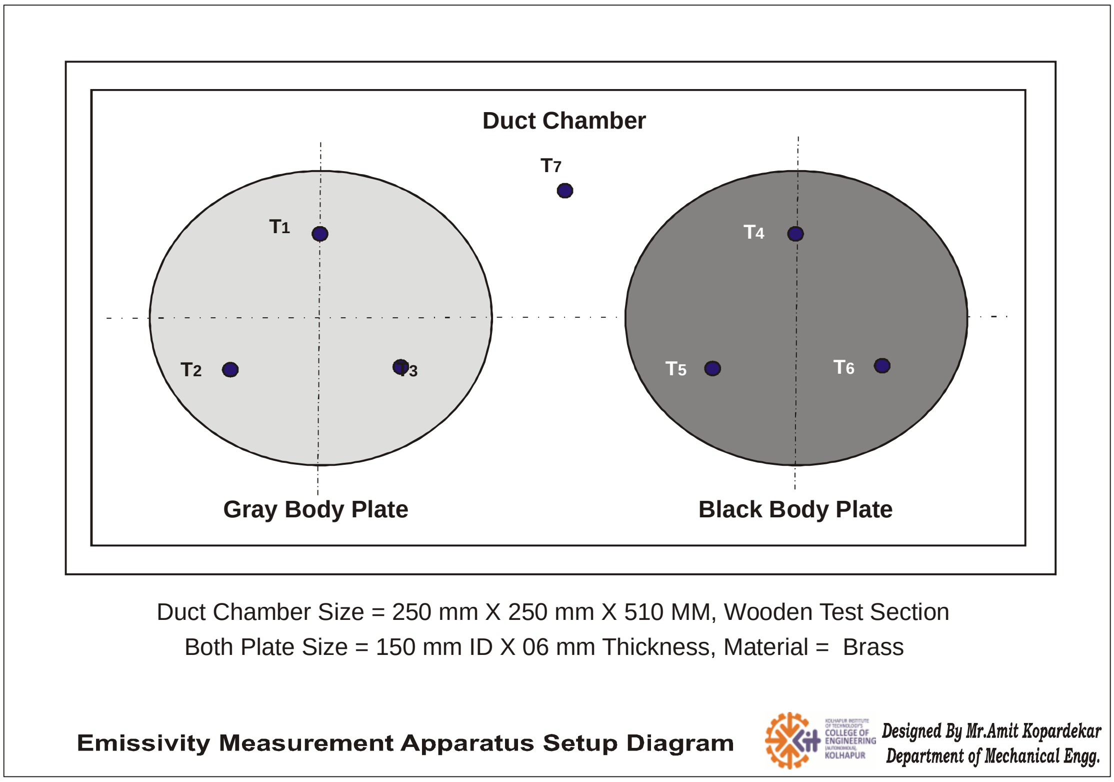
THEORY:

Thermal radiations are emitted by all substances at all temperatures. Thermal radiations are electromagnetic waves and does not require any medium for propagation. All substance or bodies can emit radiations and have also the capacity to absorb all or a part of a radiation coming from surroundings. The emissive power is the radiant energy per unit area from the surface of the body and is denoted by E. Emissivity is the ratio of emissive power of the grey surface to the emissive power of the hypothetical black surface, at the same temperature and is denoted $\varepsilon = \frac{E_g}{E_b}$. The value of emissivity varies from zero to one. For black body $\varepsilon = 1$. For grey surfaces $0 \leq \varepsilon \leq 1$. A black body is one which is capable of absorbing all the incident radiation. At the same time a black body is a perfect emitter. Where as a grey body is one which absorbs only a definite percentage of incident radiation.

DESCRIPTION OF APPARATUS:

The experimental setup consists of two circular brass plates of identical dimensions. One of the plates is made black by applying a thick layer of lamp black so that it behave almost like a black body. The other plate whose emissivity is to be measured in non-black or grey body. Heating cols are provided at the bottom of both plates. The plates are mounted on asbestos cement sheet and kept in an enclosure to provide undisturbed natural convection surroundings. The heat input to the plates is varied by a dimmerstat and is measured by an ammeter and voltmeter. Each plate is having three k-type thermocouples for temperature measurements. One thermocouple is kept in the chamber to read the ambient or chamber temperature. Voltmeter. Ammeter and Selector switch with temperature indicator are provided on the console.

EXPERIMENTAL SETUP FIGURE:



SPECIFICATIONS:

1. Diameter of each plate =D=150mm
2. Heater Coil: 500 W (2 Nos)
3. Dimmerstat: 2 - 5 kW (2 Nos)
4. Voltmeter: 0 - 300 Volts
5. Ammeter: 0 - 5 Amperes
6. Multi channel digital temperature indicator: 0 - 400°C
7. Thermocouples: k-type (7 Nos.)

PROCEDURE:

1. Check all the electrical connections.
2. Keep the dimmerstat at zero position before switching ON the power supply.
3. Select the grey plate heater and Switch ON the heater and adjust the dimmerstat position to required value of voltmeter by gradually operating the dimmerstat.
4. Now select the black plate heater and Switch ON the heater and adjust the dimmerstat position approximately same as that of the grey plate by gradually operating the dimmerstat.
5. Check the temperatures of the two plates at small time intervals and adjust the power input of the test plate only by means of the dimmerstat such that the steady state temperature.

6. After attaining the steady state note thermocouple t_1 to t_7 and voltmeter & ammeter readings.
7. Repeat the above steps for different heat inputs.
8. Turn dimmerstat to zero position and switch OFF the main supply.

PRECAUTIONS:

1. Operate the selector switch and dimmerstat gently.

2. Note thermocouple readings with an interval of atleast 5 seconds.

OBSERVATION TABLE:

Trial No.	Heat Input				Thermocouple Readings (^0C)						Average Surface Temperature of both plates (^0C		Chamber temperature (^0C)
	Grey plate		Black plate		Grey plate			Black plate			Grey plate	Black plate	
	V_g (Volts)	I_g (Amp)	V_b (Volts)	I_b (Amp)	t_1	t_2	t_3	t_4	t_5	t_6	t_g	t_b	$t_c=t_7$

RESULTS TABLE:

Trial No.	Heat Input (W)		Average Surface Temperature of both plates (K)		Chamber temperature (K)	Emissivity
	Grey plate	Black plate	Grey plate	Black plate		
	Q_g	Q_b	$T_s=t_s+273$	$T_b=t_b+273$	$T_c=t_c+273$	ε_g

CALCULATIONS:

1. Heat Input to grey plate = $Q_g = V_g \times I_g$ (W)= $\varepsilon_g \sigma A_g (T_g^4 - T_c^4)$

2. Heat Input to black plate = $Q_b = V_b \times I_b$ (W)= $\varepsilon_b \sigma A_b (T_b^4 - T_c^4)$

3. Emissivity of grey plate (ε_g):

$$\frac{Q_g}{Q_b} = \frac{V_g I_g}{V_b I_b} = \frac{\varepsilon_g \sigma A_g (T_g^4 - T_c^4)}{\varepsilon_b \sigma A_b (T_b^4 - T_c^4)}$$

therefore

$$\varepsilon_g = \varepsilon_b \frac{\sigma A_b (T_b^4 - T_c^4)}{\sigma A_g (T_g^4 - T_c^4)}$$

where

ε_b= Emissivity of black plate =1 (assumed)

A_s = Surface area of plate = $\frac{\pi D^2}{4}$

σ = Stefan-Boltzmann constant = 5.667 x10^{-8} W/m^2 K^4

therefore

ε_g =

RESULTS:

Emissivity given grey surface is ε_g =

SAMPLE CALCULATION SHEET:

ORAL QUESTIONS

1. Define Emissivity.
2. Define Reflectivity, Absorptivity And Transmissivity.
3. State governing law for radiation.
4. State Kirchhoff's law.
5. What is a black body and white body explain the concept?
6. Why lamp black is applied on one of the plate in the setup?
7. For same heat input why black plate has less surface temperature?
8. Give examples for materials having good emissivity.

Date of Conduct:

EXPERIMENT NO: 6

STEFAN BOLTZMANN APPARATUS

AIM: To determine experimentally Stefan-Boltzmann constant.

THEORY: The most commonly used law of thermal radiation is the Stefan-Boltzmann' law which states that thermal radiation or emissive power of black body surface is directly proportional to the fourth power of its absolute temperature of the surface and given by Q = $\sigma A T^4$; where σ= Constant of proportionality called as " Stefan-Boltzmann Constant"

$$= 5.667 \times 10^{-8} \text{ W/m}^2\text{K}^4.$$

All equations of heat transfer by radiation whether from a single body or from multiple bodies exchanging radiation will involve σ , the Stefan-Boltzmann constant. Although its value is universally known, yet it will be worthwhile to determine it experimentally in the laboratory.

DESCRIPTION OF APPARATUS:

The experimental setup consists of a flanged copper hemisphere fixed on a flat non conducting plate. A test disc made of copper is fixed to the plate. Thus the test disc is completely enclosed by the hemisphere. Thus outer surface of the hemisphere is enclosed in a vertical water jacket used to heat the hemisphere to a suitable constant temperature. Four Chromel-Alumel (k-type) thermocouples are attached at four strategic places on the surface of the hemisphere to obtain its temperature. The disc is mounted on a Bakelite sleeve which is fitted in a hole drilled at the centre of the base plate. Another Chromel-Alumel thermocouple is fixed to the disc to record its temperature. With the help of dimmerstat heat input can be controlled to heat the water in the jacket. Selector switch with temperature indicator are provided on the console.

SPECIFICATIONS:

1. Diameter of the Test Disc =D = 15mm
2. Thickness of the Test Disc =t = 1.5mm
3. Mass of the Disc = m_d=2.4 gm
4. Emissivity of copper hemisphere =ε=0.072
5. Specific Heat of test disc= C_p=380 J/kg K
6. Heater Coil: 500 W
7. Dimmerstat: 2 - 5 kW
8. Voltmeter: 0 - 300 Volts
9. Ammeter: 0 - 5 Amperes

10. Multi channel digital temperature indicator: 0 - 400°C
11. Thermocouples: k-type (6 Nos.)

PROCEDURE:

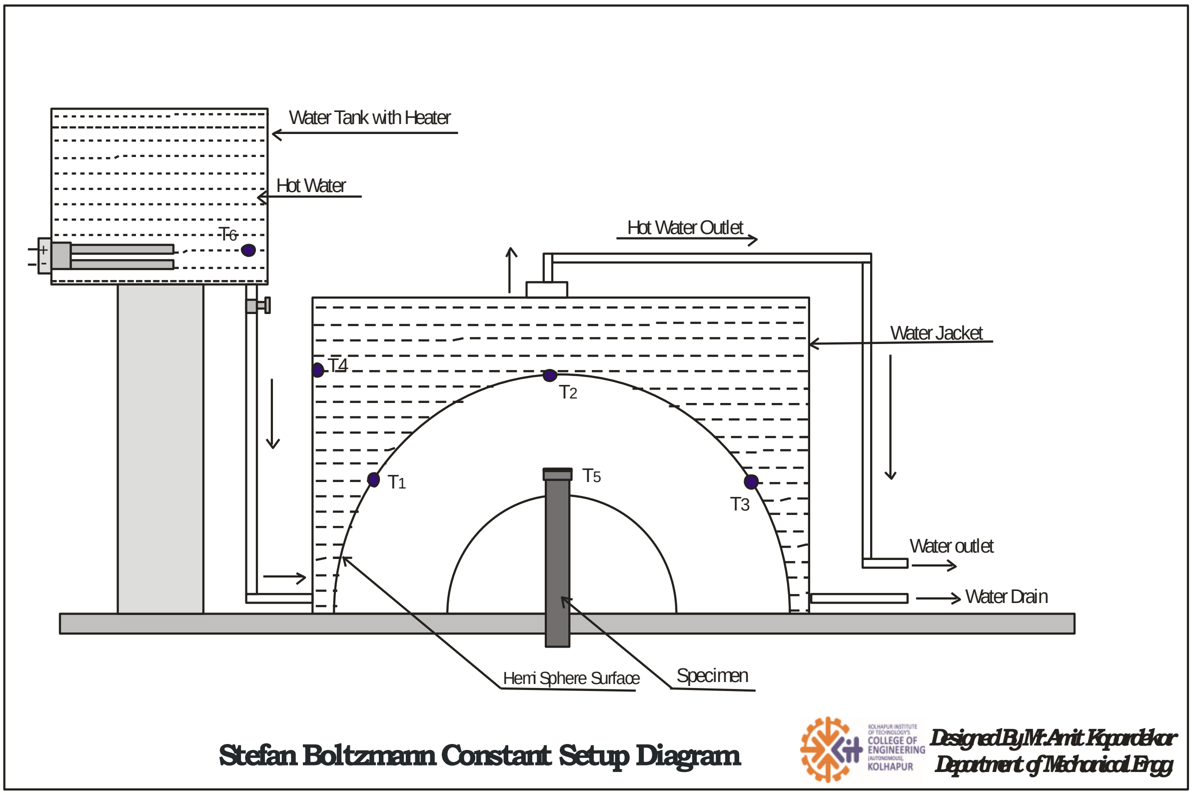
1. Check all the electrical connections.
2. Keep the dimmerstat at zero position before switching ON the power supply.
3. Switch ON the heater and adjust the dimmerstat position to required value of voltmeter by gradually operating the dimmerstat.
4. Remove the test disc before pouring the hot water and also remove water from jacket if it is left before.
5. After attaining required temperature of hot water pour it into the jacket surrounding the hemisphere.
6. Wait for steady state to be reached for the hemisphere surface.
7. Now insert the test disc and position it exactly in the groove and start stop watch immediately.
8. Note the thermocouple reading of test disc every five seconds for about 2 to 3 minutes. Also note the thermocouple readings of hemisphere.
9. Repeat the above steps for different hemisphere surface temperatures
10. Turn dimmerstat to zero position and switch OFF the main supply.

PRECAUTIONS:

1. Operate the selector switch and dimmerstat gently.

2. Note thermocouple readings with an interval of atleast 5 seconds.

Experimental Setup Figure: (Stefan Boltzmann Constant)



OBSERVATION TABLE:

(A) Hemisphere:

Trial No.	Thermocouple Readings (^{0}C)				
	Hot water Tank	Hemisphere Surface			
	T_6	T_1	T_2	T_3	T_4

(B) Test Specimen: (After Inserting Specimen)

Time, t (Seconds)	Temperature, t_d= T_5 (^{0}C)	Temperature, T_d= T_5 (K)	Time, t (Seconds)	Temperature, t_d= T_5 (^{0}C)	Temperature, T_d= T_5 (K)
0			170		
10			180		
20			190		
30			200		
40			210		
50			220		
60			230		
70			240		
70			250		
90			260		
100			270		
110			280		
120			290		
130			300		
140			310		
150			320		
160			330		

RESULTS TABLE:

Trial No.	Hemisphere Surface temperature (K)	Test specimen temperature (K)	Stefan-Boltzmann Constant , σ
	$T_s = t_s + 273$	T_d	

CALCULATIONS:

1. Average Hemisphere surface temperature= $t_s = \frac{t_1 + t_2 + t_3}{3}$

2. For energy balance of the test specimen

Net heat received by the test specimen by radiation = Rate of change of internal energy of the specimen

$$\varepsilon\sigma\, A_d\, [T_s^4 - T_d^4] = m_d\, C_p\, \frac{dT_d}{dt}$$

where $\frac{dT_d}{dt} = \textit{slope of Test Specimen temperature with respect to time}$

Therefore

$$\sigma = \frac{m_d C_p \frac{dT_d}{dt}}{\varepsilon A_d [T_s^4 - T_d^4]}$$

RESULTS:

Experimental Average Stefan-Boltzmann constant $= \sigma =$

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SAMPLE CALCULATION SHEET:

ORAL QUESTIONS

1. State Stefan-Boltzmann law.
2. What is the range of wavelength for thermal radiation?
3. How thermal radiation is established in the setup?
4. Why lamp black is applied on the specimen in the setup?

EXPERIMENT NO: 7

Date of Conduct:

PARALLEL FLOW AND COUNTER FLOW HEAT EXCHANGERS

AIM: To determine experimentally Log Mean Temperature Difference (LMTD), Overall heat transfer coefficient (U) and Effectiveness (ε) of Parallel flow and Counter flow Heat Exchangers.

THEORY:

A heat exchanger is a device used for effecting the process of heat exchange between two fluids that are at different temperatures without coming in direct contact. In parallel flow heat exchanger hot and cold fluid flow in the same direction. But in counter flow heat exchanger hot and cold fluid flow in opposite direction. The thermal analysis of any heat exchanger involves the variable like inlet and outlet temperature of fluid. The hot fluid is that fluid which losses the heat and cold fluid is that fluid which gains the heat.

DESCRIPTION OF APPARATUS:

The apparatus consists of a tube-in-tube concentric tube heat exchanger. In the heat exchanger, the hot fluid flows through the inner tube, while the cold fluid flows through the annulus. The fluid used is water. The apparatus is supported on a rigid stand, and is provided with a system of pipes and valves, to change the heat exchanger operation from parallel flow mode to counter flow mode and vice versa. It is to be noted that the hot fluid always flows in one direction only, while the direction of flow of the cold fluid can be changed according to the need.

Thermocouples are provided for measuring the temperature of the fluid at the inlets and outlets of the hot and cold fluids. An electric geyser is used to heat the water. The flow rates of the hot and cold fluids are measured with the help of measuring flask and a stop clock. The outer tube of the heat exchanger is provided with adequate insulation to minimize the heat losses and thus prevent inaccuracy in calculations. With the help of dimmerstat heat input can be controlled to heat the water in the jacket. Selector switch with temperature indicator are provided on the console.

SPECIFICATIONS:

1. Thermocouples : 0-300°C (4 Nos).
2. Geyser : 1 No.
3. Measuring flask :1 No.
4. Stop Clock :1 No.

5. Inner Pipe(M.S.) : I.D = 6.25mm, O.D= 12.5mm
6. Outer Pipe (G.I.) : I.D = 25mm, O.D = 32mm
7. Length of Heat exchanger = 2m

PROCEDURE:

1. Check all the electrical connections.
2. Switch ON the heater on geyser.
3. Open the valves such that the flow becomes parallel.
4. Measure the flow rate of hot fluid and cold fluid by collection the known quantity of water for a specified time and maintain this throughout the flow.
5. Measure the temperature for inlet and outlet for hot and cold fluid with the help of thermocouples after steady state is reached.
6. Repeat the above procedure for counter flow also.
7. Repeat the above steps for different flow rates.
8. Switch OFF the main supply.

PRECAUTIONS:

1. Operate the selector switch gently.

2. Note thermocouple readings with an interval of atleast 5 seconds.

OBSERVATION TABLE:

(A) Parallel flow Arrangement:

Trial No.	Flow rate lpm	Hot water temperature, °C		Cold water temperature, °C	
		Inlet($T_{h,i}$)	Outlet($T_{h,o}$)	Inlet($T_{c,i}$)	Oulet($T_{c,o}$)

(B) Counter flow Arrangement:

Trial No.	Flow rate lpm	Hot water temperature, °C		Cold water temperature, °C	
		Inlet($T_{h,i}$)	Outlet($T_{h,o}$)	Inlet($T_{c,i}$)	Oulet($T_{c,o}$)

RESULTS TABLE:

(A) Parallel flow Arrangement:

Trial No.	LMTD (^{0}C)	Effectiveness, ε	Overall Heat transfer coefficient (W/m^{2}K)	
			U_i	U_o

(B) Counter flow Arrangement:

Trial No.	LMTD (^{0}C)	Effectiveness, ε	Overall Heat transfer coefficient (W/m^{2}K)	
			U_i	U_o

CALCULATIONS:

1. Logarithmic Mean temperature Difference (LMTD) :

$$LMTD = \frac{(\Delta T_1 - \Delta T_2)}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$$

Where ΔT_1 and ΔT_2 are the differences in temperatures of the hot and the cold fluids as found at left and right sides of the heat exchanger, and further:

For Parallel Flow Mode:

$$\Delta T_1 = (T_{h,i} - T_{c,i}) \text{ and } \Delta T_2 = (T_{h,o} - T_{c,o})$$

For Counter Flow Mode:

$$\Delta T_1 = (T_{h,i} - T_{c,o}) \text{ and } \Delta T_2 = (T_{h,o} - T_{c,i})$$

2. Heat lost by hot water , $Q_h = m_h c_h (T_{hi} - T_{ho})$
3. Heat gained by cold water, $Q_c = m_c c_c (T_{co} - T_{ci})$

4. Average heat transfer between hot and cold water = Q = $\dfrac{Q_h + Q_c}{2}$
5. Maximum possible heat transfer between the hot and cold water = Q_{max} = C_{min} ($T_{hi} - T_{ci}$)

   where C_{min} = minimum of heat capacities of hot and cold water $C_h = m_h c_h$ and $C_c = m_c c_c$
6. Effectiveness = $\varepsilon = \dfrac{Q}{Q_{max}}$
7. Overall heat transfer coefficient:

   Based on inner area of inner pipe:

   $$U_i = \frac{Q}{A_i(LMTD)}\text{; where } A_i = \pi D_i L$$

   Based on outer area of inner pipe:

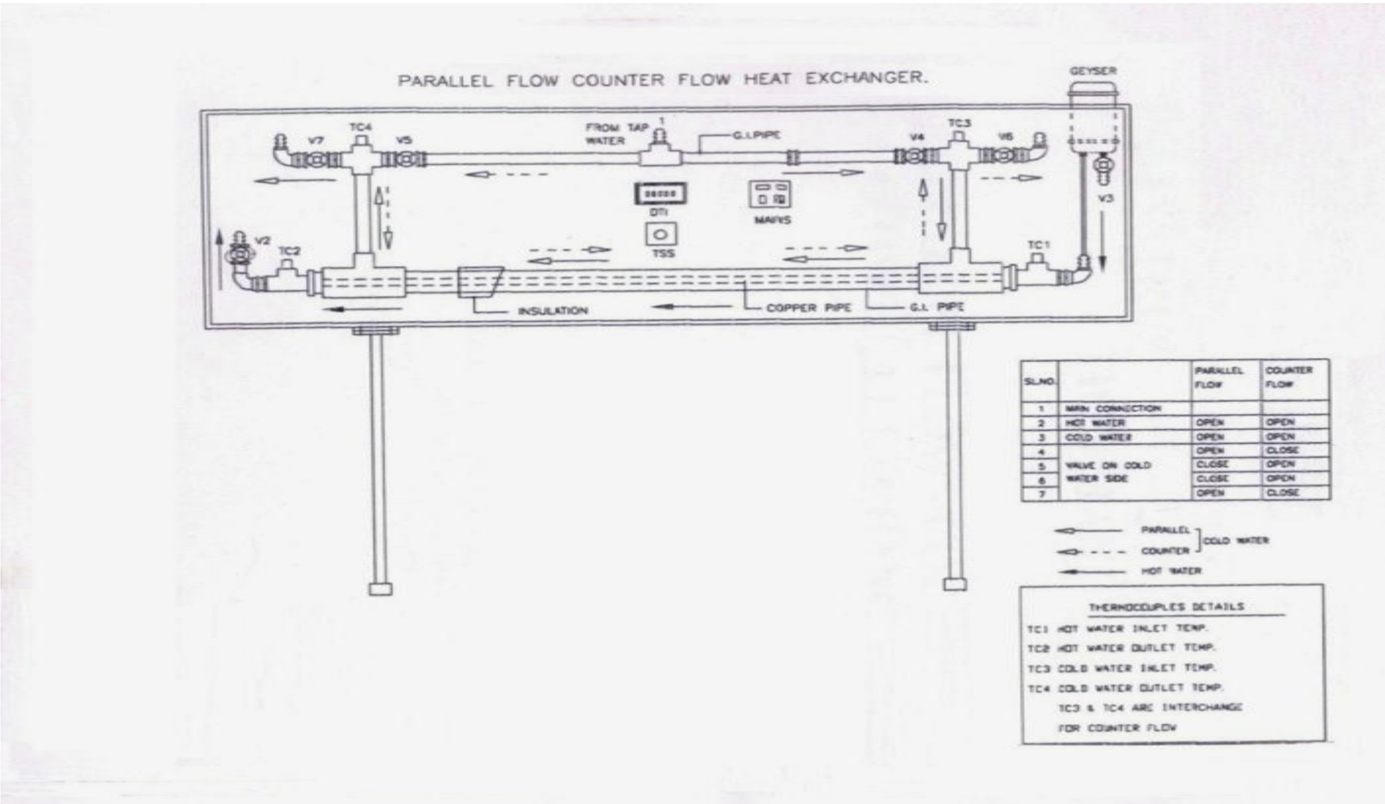
   $$U_o = \frac{Q}{A_o(LMTD)}\quad\text{where } A_o = \pi D_o L$$

Results :

1. LMTD for Parallel flow Heat Exchanger =
2. LMTD for Counter flow Heat Exchanger =
3. Effectiveness of parallel flow & counter flow =

Experimental Figure setup

Trial on Heat Exchangers- Parallel flow and Counter flow



SAMPLE CALCULATION SHEET:

ORAL QUESTIONS

1. What is a heat exchanger?
2. How do you classify heat exchanger?
3. Give examples for different types of heat exchangers.
4. Draw temperature profile for parallel and counter flow heat exchanger.
5. What assumptions are made for heat exchanger analysis using LMTD and NTU method?
6. What is LMTD and when to use LMTD method of analysis?
7. Define effectiveness of heat exchanger?
8. What is NTU? give its significance.
9. Write expression for overall heat transfer coefficient for double pipe heat exchanger.
10. Compare parallel and counter flow heat exchanger.

EXPERIMENT NO: 8

Date of Conduct:

HEAT TRANSFER THROUGH FORCED CONVENTION

AIM: To determine average heat transfer coefficient in forced convection between hot air and cylinder during internal flow.

THEORY:

Convection is that mode of heat transfer where heat is transferred from high temperature region to low temperature region with appreciable movement of molecules. Hence convection can occur only in fluids. Most of the thermal problems involve convection mode of heat transfer. Convection can occur in three different ways namely; Forced convection, Natural or Free convection and combined Forced & Free convection. When movement of molecules is established by buoyancy effects due to density difference within the fluid then that mode of convection is called Free or Natural convection.

If the molecular movement is due to external agent like pump, blower, fan, gravity force etc, then the mode is called Forced convection.

There are situations where Free and Forced Convection contribute equally in heat transfer then such case is called Combined Free & Forced Convection. This is determined by the ratio [Gr/Re^2].

If [Gr/Re^2] >>1then the mode is assumed to be natural convection

If [Gr/Re^2] <<1then the mode is assumed to be forced convection and

If [Gr/Re^2] =1 (approximately) then the mode is assumed to be combined free and forced convection.

There are many examples for convection mode. Heating water in container, Cooling of liquids, Heating of water in gas geyser, electric geyser, condensation, boiling etc. The heat transfer in convection is governed by Newton's Law of cooling which can be stated as follows;

' Rate of heat transfer by convection is directly proportional to the surface area and the temperature difference between the hot surface and cold fluid'.

Mathematically

$$\mathbf{Q} \propto A(T_s - T_f);$$

where Q = heat transfer rate in W

T_s = Surface Temperature in ^{0}C or K

T_f = Fluid Temperature in ^{0}C or K

A = Surface Area in m^2

Removing proportionality the law can be written as

$$\mathbf{Q} = hA(T_s - T_f);$$

where h = constant of proportionality called as 'heat transfer coefficient or film coefficient'. Heat transfer coefficient depends on seven to eight variables and sometimes more than that, hence it is difficult to determine the same. Many researchers have proposed empirical relations to determine the heat transfer coefficient. These empirical relations involve dimensionless numbers.

Heat transfer coefficient in forced convection depends on three numbers namely

Nusselt Number (Nu), Reynolds Number (Re) and Prandtl Number (Pr). Generally it is expressed as follows

Nu = f (Re, Pr)

The physical significance of these Numbers is as given below

Nusselt Number (Nu): Ratio of temperature gradients by conduction and convection at the surface. It can also be written at the surface as

$$\text{Nu} = \left(\frac{Resistance\ for\ conduction}{Resistance\ for\ convection}\right) = \left(\frac{Heat\ transfer\ by\ convection}{Heat\ transfer\ by\ conduction}\right)$$

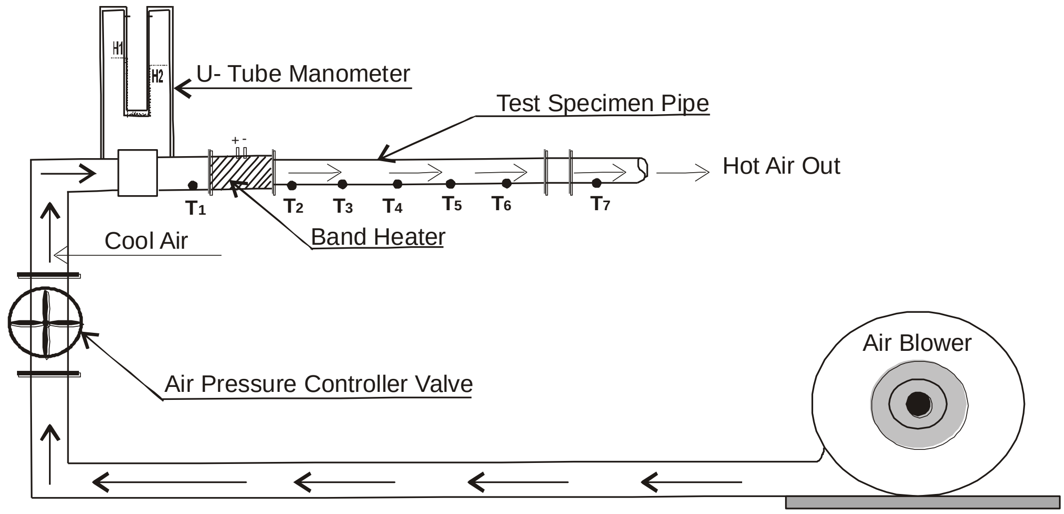
Reynolds Number (Re): $\left(\frac{Inertia\ Force}{Viscous\ Force}\right)$

Prandtl Number (Pr): $\left(\frac{Molecular\ Diffusivity\ of\ Momentum}{Molecular\ Diffusivity\ of\ Heat}\right)$

DESCRIPTION OF APPARATUS:

The experimental setup consists of horizontal tube which is insulated from outside. This tube receives hot air from one side through blower and heater as shown in figure. The rate of flow is measured by orifice meter with mercury manometer. Two thermocouples read the temperature of air entering and leaving the test length of tube. Five thermocouples measure the temperature along the tube surface. The flow rate of air can be adjusted by the valve on delivery pipe of blower and speed of the blower. With the help of dimmerstat heat input can be controlled. Voltmeter. Ammeter and Selector switch with temperature indicator are provided on the console.

EXPERIMENTAL SETUP FIGURE:



T_1 = Air Inlet Temp.
T_2 to T_6 = Specimen Pipe Temp.
T_7 = Air Outlet Temp.

Heat Transfer through Forced Convention Setup Diagram

KOLHAPUR INSTITUTE OF TECHNOLOGY'S COLLEGE OF ENGINEERING (AUTONOMOUS), KOLHAPUR

Designed By Mr.Amit Kopardekar
Department of Mechanical Engg.

SPECIFICATIONS:

1. Inner diameter of tube =d= 25mm=0.025m
2. Test Length of the tube = L= 400mm=04m
3. Orifice diameter = d_0 = 20mm=0.02m ; C_d =0.62
4. Heater Coil: 500 W
5. Dimmerstat: 2 - 5 kW
6. Voltmeter: 0 - 300 Volts
7. Ammeter: 0 - 5 Amperes
8. Multi channel digital temperature indicator: 0 - 400°C
9. Thermocouples: k-type (7 Nos.)

PROCEDURE:

1. Check all the electrical connections.
2. Keep the dimmerstat at zero position before switching ON the power supply.
3. Switch ON the blower & heater and adjust the dimmerstat position to required value of voltmeter by gradually operating the dimmerstat. Also adjust the speed of the blower using regulator.
4. Note the thermocouple readings t_1 to t_7 and voltmeter and ammeter readings in the observation table as shown after steady state is reached.
5. Repeat the above steps for different heat inputs.
6. Turn dimmerstat to zero position and switch OFF the main supply.

PRECAUTIONS:

1. Operate the selector switch and dimmerstat gently.

2. Note thermocouple readings with an interval of atleast 5 seconds.

OBSERVATION TABLE:

Trial No.	Manometer Reading		Air temperature(^{0}C)		Thermocouple Readings (^{0}C) Tube Surface				
	h_{Hg} (mm)	h_a(m)	Inlet t_1	Outlet t_7	t_2	t_3	t_4	t_5	t_6

RESULTS TABLE:

Average heat transfer coefficient (h_{avg}):

Trial No.	Bulk mean temperature	Average Tube Surface Temperature (^{0}C)	Heat transfer Rate (W)	Experimental Average Heat transfer Coefficient (W/m^2 K)	Empirical Average Heat transfer Coefficient (W/m^2 K)	% difference
	$t_{bm} = [t_1+t_7]/2$	$t_s = [t_2+t_3+t_4+t_5+t_6]/5$	Q	$[h_{avg}]_{exp}$	$[h_{avg}]_{emp}$	

CALCULATIONS:

1. Heat transfer by Forced convection = Q

2. Average heat transfer coefficient from Experiment= $[h_{avg}]_{exp} = \dfrac{Q}{A_s(t_s - t_f)}$

A_s = Surface area of cylinder = πd L

3. Average heat transfer coefficient from Empirical relation:

Using Dittus-Boelter equation for forced convection through tube

Nu = 0.023 $Re^{0.8}$ $Pr^{0.33}$

Where Nu = $\dfrac{[h_{avg}]_{emp} d}{k}$; Re = $\dfrac{\rho V d}{\mu}$; Pr = $\dfrac{\mu C_p}{k}$;

Properties of air at t_{bm} from hand book

μ = Dynamic Viscosity of air

C_p = Specific heat of air

k = Thermal conductivity of air

V = Q_a/A_t ; $Q_a = C_d A_o \sqrt{2gh_a}$; A_o = Orifice area

Average heat transfer coefficient = $[h_{avg}]_{emp} = \dfrac{Nu\, k}{d}$

RESULTS:

1. Experimental Average Heat transfer coefficient = $[h_{avg}]_{exp}$ =

2. Empirical Average Heat transfer coefficient =$[h_{avg}]_{emp}$ =

SAMPLE CALCULATION SHEET:

ORAL QUESTIONS

1. What do you mean by convection?
2. Which is the governing law for the convection? State the same
3. Differentiate between natural/free and forced convection.
4. Give atleast five examples for forced convection.
5. What are dimensionless numbers governing forced convection?
6. Give significance of dimensionless numbers governing forced convection.
7. Write expression for dimensionless numbers governing forced convection.
8. Two identical plates of copper material are cooled by two different fluid. One plate is cooled by air and other by water . In both cases fluid flow velocity and direction is same. In which case the plate gets cooled faster and why?
9. Compare Nusselt number and Biot number.

EXPERIMENT NO: 9

Date of Conduct:

HEAT TRANSFER THROUGH PIN FIN APPARATUS

AIM: To determine the following for the heat transfer through given Pin fin;

a) temperature distribution experimentally and theoretically
b) heat transfer rate theoretically and
c) fin efficiency and fin effectiveness

THEORY:

There are three possible ways to improve the heat transfer rate by convection

- to increase the heat transfer coefficient
- to increase the surface area for convection
- to increase the temperature difference between the fluid and the surface.

In many situations the heat transfer coefficient and temperature difference cannot be altered due to practical limitations. If suitable surface area is increased then heat transfer by convection can be increased. Such surfaces which are attached for increasing heat transfer are called as " Extended surfaces or Fins". Examples of such applications are;

I.C. Engine surfaces. High tension electrical conductors , transformers, motors, generators. compressors etc,.

A general governing differential equation for one dimensional steady state heat transfer through can be written as

$$\frac{d^2\theta}{dx^2} - m^2\theta = 0 \qquad (1)$$

where θ $= T - T_\infty$;

T = Temperature at any location x on the fin

T_∞ = Ambient or fluid temperature

$m = \sqrt{\frac{hP}{kA}}$

h = heat transfer coefficient between fin surface and fluid

P = Perimeter of the fin

k = thermal conductivity of the fin

A = Area normal or cross sectional area of the fin

A general solution to equation (1) can be written as

$\theta = C_1 e^{-mx} + C_2 e^{+mx}$ OR

$\theta = C_1 \cosh m(L-x) + C_2 \sinh m(L-x)$

where L = length of the fin.

The constants C_1 and C_2 are evaluated for two boundary conditions depending on fin tip conditions. There are three different types of fin tip conditions are considered generally and they are

a) Very long fin with fin tip temperature approaching ambient value and solution becomes

$$\frac{\theta}{\theta_0} = e^{-mx}$$

$$Q_f = \theta_0 \sqrt{hPkA}$$

b) Fin with tip insulated or with negligible heat transfer because of the tip area being very small compared to the lateral area. The temperature gradient is zero at the tip and the solution becomes

$$\frac{\theta}{\theta_0} = \frac{\cosh m(L-x)}{\cosh mL}$$

$$Q_f = \theta_0 \sqrt{hPkA} \tanh mL$$

c) Short fin with convection off the end and solution becomes

$$\frac{\theta}{\theta_0} = \frac{\cosh m(l-x) + [h/mk] + \sinh m(L-x)}{\cosh mL + [h/mk]\sinh mL}$$

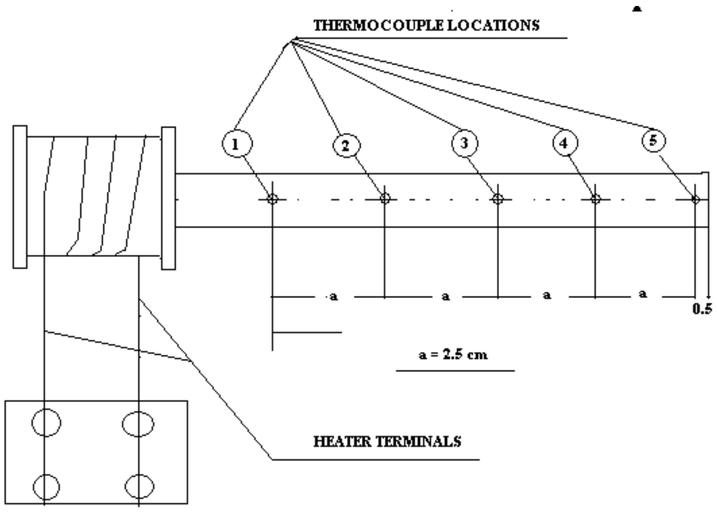
$$Q_f = \theta_0 \sqrt{hPkA}\, \frac{\tanh mL + [h/mk]}{1 + [h/mk]\tanh mL}$$

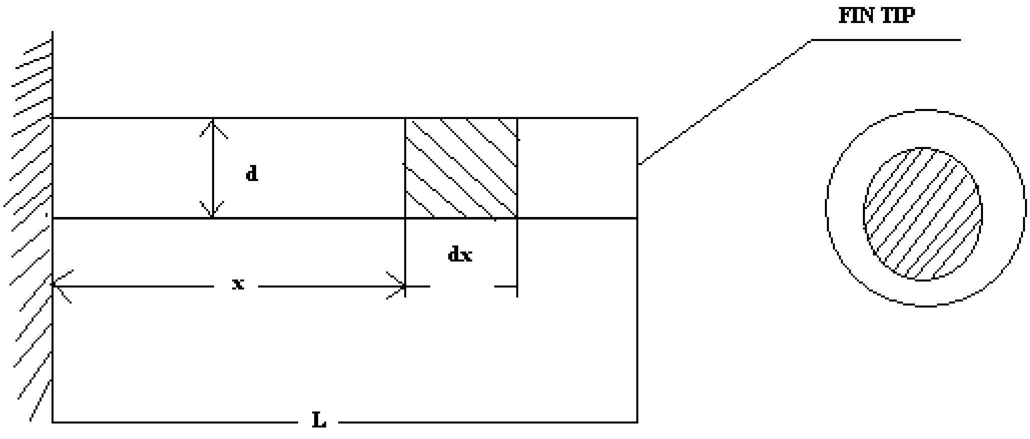
DESCRIPTION OF APPARATUS:

The experimental setup consists of horizontal rectangular duct in which pin fin of given material is attached as shown in figure. One end of the pin fin is heated with band type heater. Heat input can be adjusted using dimmerstat. Five thermocouples are attached on pin fin at equidistant to measure temperature distribution and one thermocouple in the duct to measure temperature of ambient air. To increase the heat transfer by convection air is forced over the pin fin surface using blower. Flow rate of air can be adjusted by valve on the blower pipe and is measured by orifice meter and water manometer. Selector switch is used for the temperature indicator provided on the console.

EXPERIMENTAL SETUP FIGURE:

Schematic Diagram





SPECIFICATIONS:

1. Pin fin diameter =d= 12.7mm=0.0127m
2. Length of pin fin =L = 11cm=0.11m
3. Distance between each thermocouple = Δx =2.5cm=0.025m
4. Location for temperature measurement:

   $x_1 = \Delta x$ =0.025m; $x_2 = x_{1+}\ \Delta x$ =0.05m; $x_3 = x_{2+}\ x_1$ =0.075m; $x_4 = x_{3+}\ x_2$ =0.01m;

5. Thermal conductivity of

Aluminium fin = k= 175 W/mK

Brass fin = k = 95 W/mK

6. Duct size = 15 x10 cm^2
7. Orifice diameter = d_0 = 13mm=0.013m ; C_d =0.64
8. Heater Coil: 500 W
9. Dimmerstat: 2 - 5 kW
10. Voltmeter: 0 - 300 Volts
11. Ammeter: 0 - 5 Amperes
12. Multi channel digital temperature indicator: 0 - 400°C
13. Thermocouples: k-type (6 Nos.)

PROCEDURE:

1. Check all the electrical connections.
2. Select the aluminium or brass fin for the experiment and connect all thermocouple and heater.
3. Keep the dimmerstat at zero position before switching ON the power supply.
4. Switch ON the blower & heater and adjust the dimmerstat position to required value of voltmeter by gradually operating the dimmerstat.
5. Note the thermocouple readings t_1 to t_6 readings in the observation table as shown after steady state is reached.
6. Repeat the above steps for different heat inputs and flow rate of air.
7. Turn dimmerstat to zero position and switch OFF the main supply.

PRECAUTIONS:

1. Operate the selector switch and dimmerstat gently.

2. Note thermocouple readings with an interval of atleast 5 seconds.

OBSERVATION TABLE:

Trial No.	Manometer Reading		Air temperature(^0C)	Thermocouple Readings (^0C) Experimental temperature distribution on Fin Surface				
	h_w (mm)	h_a(m)	t_a=t_6	t_1=t_0	t_2	t_3	t_4	t_5

RESULTS TABLE:

(A) Theoretical heat transfer rate (Q_f), Fin efficiency (η_f) and Fin effectiveness (ε)

Trial No.	Average fin Surface Temperature (^{0}C)	Mean film temperature	Reynolds Number (Re)	Nusselt Number (Nu)	Heat transfer Coefficient h (W/m^2 K)	Theoretical Heat transfer rate, Q_f (W)	Fin efficiency, η_f	Fin effectiveness, ε
	$t_s = [t_1+t_2+t_3+t_4+t_5]/5$	$t_m = [t_a+t_s]/2$						

(A) Theoretical temperature distribution on fin surface

Trial No.	$T_x = t_a + \theta_0 \frac{\cosh m(L-x)}{\cosh mL}$			
	T_1	T_2	T_3	T_4

[Take $\theta_0 = t_0 - t_a$]

CALCULATIONS:

1. Theoretical heat transfer from the fin (Q_f) :

$$Q_f = \theta_0 \sqrt{hPkA}\,\tanh mL$$

where P = perimeter of fin = πd ; A = $\frac{\pi d^2}{4}$; m= $\sqrt{\frac{hP}{kA}}$

h = $\frac{\mathrm{Nu}\, k}{d}$

Nu= C Re^m $Pr^{0.333}$

Re	C	m
0.4 - 4.0	0.989	0.330
4.0 - 40	0.911	0.385
40.0 -4000	0.683	0.466
4000 - 40,000	0.193	0.618
40,000 - 400,000	0.0266	0.805

$$\mathrm{Re} = \frac{\rho V d}{\mu} \ ; \ \mathrm{Pr} = \frac{\mu C_p}{k_a} \ ;$$

Properties of air at t_m from hand book

μ = Dynamic Viscosity of air

C_p = Specific heat of air

ρ = density of air

k_a = thermal conductivity of air

$V = Q_a/A_d$; A_d = Duct area ; $Q_a = C_d A_o \sqrt{2gh_a}$; A_o = Orifice area

2. Theoretical temperature distribution T(x):

$$T_x = t_a + \theta_0 \frac{\cosh m(L-x)}{\cosh mL}$$

where x = x_1, x_2, x_3, and x_4 for T_1, T_2, T_3 and T_4 respectively.

RESULTS:

a) Plot of Temperature distribution experimentally and theoretically
b) Plot of Theoretical Heat transfer rate (Q_f) versus Reynolds Number (Re)
c) Average fin efficiency
d) Average fin effectiveness

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SAMPLE CALCULATION SHEET:

ORAL QUESTIONS

1. What are fins? give different types.
2. Why fins are used? give atleast five applications.
3. What do you mean by pin fin?
4. What are different fin tip conditions considered for analysis?
5. Write expression for heat transfer rate , and temperature distribution for different fin tip conditions.
6. Define fin effectiveness and efficiency.
7. Write expression for fin effectiveness and fin efficiency for different fins with their tip conditions.

Date of Conduct:

EXPERIMENT NO: 10

STUDY AND DEMONSTRATION OF HEAT PIPE

AIM: To compare the heat transfer through heat pipe with those of mild steel and copper tubes.

THEORY:

Heat pipe allows the transfer of huge amount of heat through small surface areas. Heat pipe is generally a circular pipe, having a layer of wick material covering the inner surface, with hollow core in the centre. A condensable fluid is also contained in the pipe, and the liquid permeates the wick material by capillary action. When heat is supplied to one end of the pipe (the evaporator), the liquid is vaporized in the wick and the vapour moves to the central core due to the resulting pressure difference. At the other end of the pipe, heat is removed (the condenser) and the vapour condenses back into the wick. Liquid is replenished in the evaporator section by capillary action. The evaporation and condensation processes are responsible for nearly isothermal working of heat pipe. Heat pipes have been used for cooling of electronic systems, such as transistors, laptop computers, cell phones, because in such systems heat generation must be dissipated from a small area to a larger areas since the performance of electronic devices is strongly temperature dependent.

DESCRIPTION OF APPARATUS:

The apparatus consists of copper pipe, mild steel pipe and heat pipe of identical geometrical properties, such as diameter and length. All three pipes are mounted vertically with water bath at the top and heater at the bottom. Heat pipe is made up of G.I. pipe. In heat pipe, wire mesh of suitable size is inserted as wick material. Circumferential layers of this mesh have been used. Calculated quantity of distilled water, as working fluid, is introduced in heat pipe after cleaning the pipe and mesh with hydrochloric acid, acetone and distilled water making perfect vacuum as far as possible. A mild steel pipe and copper pipe are taken for comparison. The lengths for three members are kept equal and band type heaters are used and mounted on one end. The surface temperatures along the lengths of pipe are measured by Chromel - Alumel thermocouples while temperature of water in water bath is measured by thermometer.

SPECIFICATIONS:

1. Diameter of pipes (copper, mild steel and heat pipe) = 32 mm ϕ
2. Length of the pipes = 400 mm
3. Water bath = 3 Nos.
4. Water bath capacity = 1 litre
5. Area of Condenser tank = 140mm x 100mm x 100mm
6. Voltmeter – 0 – 300 Volts
7. Ammeter – 0 – 30 Amperes
8. Heater – 3 Nos. Band Type
9. Thermometer: 15 Nos. Chromel alumel
10. Multi channel digital temperature indicator: 0 - 300°C

PROCEDURE:

1. Fill equal amount of water in three Water bath tanks so that the pipes are submerged completely in the water.
2. Start the switch and adjust input suitable voltage to the three heaters with the help of dimmerstat.
3. Take thermocouple readings on the pipes and Water bath temperature by thermometers.
4. Repeat step 3 for every 10 minutes till steady state is achieved.
5. Turn dimmerstat to zero output and then switch off the main supply.

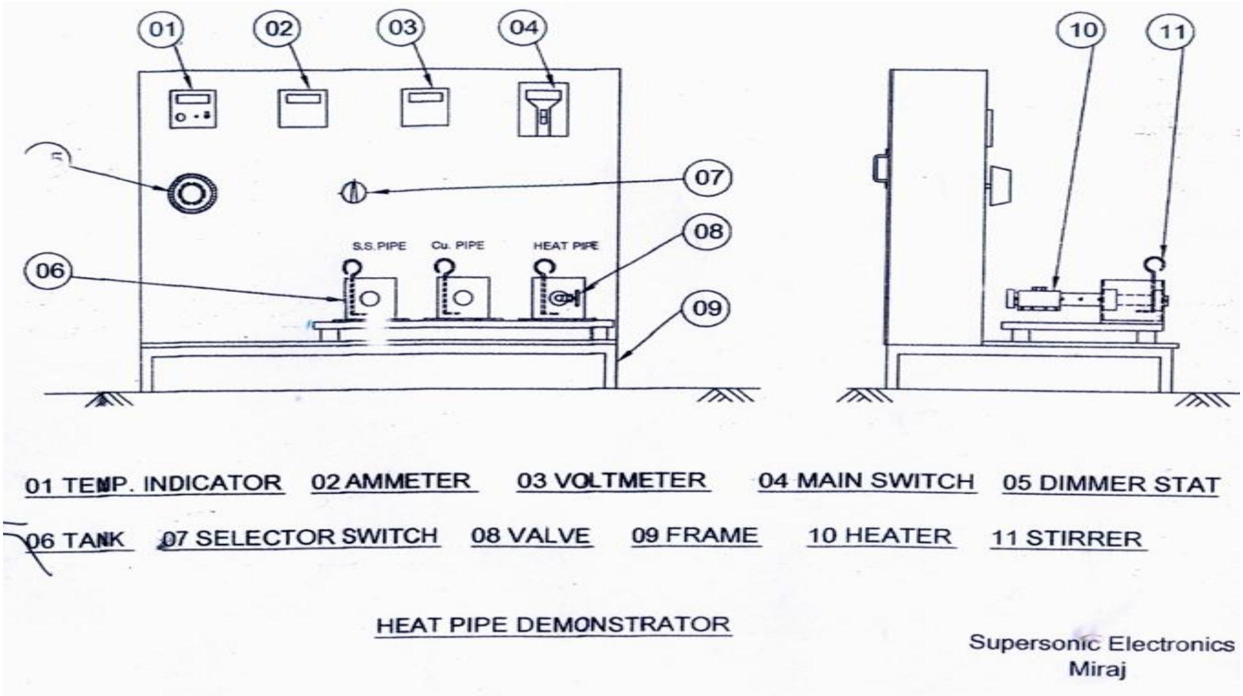
OBSERVATIONS:

Voltmeter reading: ----------Volts.

Ammeter reading: -----------Amperes.

Unit	Temperatures (°C)	Time in minutes					
		10	20	30	40	50	60
Heat Pipe	T_1						
	T_2						
	T_3						
	T_4						
	T_5						
	Water Bath Temp.						
Copper Pipe	T_6						
	T_7						
	T_8						
	T_9						
	T_{10}						
	Water Bath Temp.						
Mild steel Pipe	T_{11}						
	T_{12}						
	T_{13}						
	T_{14}						
	T_{15}						
	Water Bath Temp.						

EXPERIMENTAL SETUP :



RESULTS AND CONCLUSION:

Comment on the observations noted

Plot temperature distribution along the length of all the pipes & Comment on graphs

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ORAL QUESTIONS

1. What is a heat pipe?
2. Describe construction and working of heat pipe.
3. Give applications of heat pipe.
4. What are practical limitations of heat pipe?