DEPARTMENT OF MECHANICAL ENGINEERING

34421C16- HEAT AND MASS TRANSFER LAB (THEORY AND PRACTICALS)

LAB MANUAL

Prepared by

MR.C.THIAGARAJAN, B.E., M.E., MISTE.,(PHD)

ASSOCIATE PROFESSOR/MECH

Approved by

DR. M.PRABHAHAR, B.E., M.E., PHD

HOD/MECH

34421C16- HEAT AND MASS TRANSFER LAB(THEORY AND PRACTICALS)

LIST OF EXPERIMENTS

1. DETERMINATION OF THE THERMAL CONDUCTIVITY

(TWO SLABS GUARDED HOT PLATE METHOD)

AIM:

To find the thermal conductivity of the specimen by two slab guarded hot plate method.

APPARATUS REQUIRED:

1) Experimental setup of two slab guarded hot plate method.
2) Stabilized Power supply
3) Stop clock

PROCEDURE:

- Switch on the heater and set an input voltage (60V) using the Voltage regulator
- The main heater transfer heat by conduction to the wood disc specimen placed on both sides.
- Observe the readings of thermocouples T_1, T_2, T_3 & T_4 fixed on both sides of the heater plate & tabulate them after few minutes of start of heat transfer.
- Observe the reading of thermocouples of T_5 & T_6 fixed on the water side of wooden disc specimen and tabulate them.
- Take readings until the system reaches steady state and use the steady state reading for calculation.
- Calculate the thermal conductivity of the wooden disc specimen by applying Fourier's law of conduction.

OBSERVATIONS :

SL.NO	V_1	I_1	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
	Volts	Amps	(º C)	(º C)	(º C)	(º C)	(º C)	(º C)	(º C)	(º C)

FORMULA USED:

Applying the Fourier's Law of conduction for a Composite wall structure.

1. Thermal conductivity (K) = $\frac{qL}{2A\,(T_h - T_c)}$ W/mK

T_h	=	Specimen bottom temperature in (°C)
T_c	=	Specimen top temperature in (°C)
q	=	heat input to central heater in watts
L	=	Thickness of specimen in m
A	=	Metering area of specimen in m^2

2. Central heater input (q) = V * I Watts

3. Metering area (A) = $\frac{\pi}{4}(10 + x)^2$ in m

Where, X = gap between heater plate = 0.003 m.

4. Specimen hot side temperature (T_h) = [T_1+T_2 / 2] (°C)

5. Specimen cold side temperature (T_c) = [T_5+T_6 / 2] (°C)

6. Thermal conductivity of specimen (K) = q*L /2A ($T_h - T_c$) in W/ mK

RESULT :

The thermal conductivity of insulating slab is ………………… W/mK

VIVA –VOCE Questions

1) What is effect of temperature on thermal conductivity of gases?

   Thermal conductivity of gases increases with increasing temperature

2) State Fourier law?

   Fourier law: the rate of heat conduction through a material depends on geometry of medium, its thickness & material of the medium as well as temperature across the medium.

3) What is effect of temperature on thermal conductivity of metals?

   Thermal conductivity of the metals decreases with increase in temperature.

4) What are the factors affecting the thermal conductivity?

   a.Moisture b. Density of material c. Pressure d. Temperature e. Structure of material

5) What is thermal conductivity?

   Thermal conductivity is the rate of heat transfer through a unit thickness of material per unit area per unit temperature difference

6) Name the material having highest & least thermal conductivity?

   Diamond & Freon-12.

7) Write down the equation for conduction of heat through a hollow cylinder.

   Heat conduction is a mechanism of heat transfer from a region of high temperature to a region of low temperature within a medium [solid, liquid or gases] or different medium in direct physical contact.

2. DETERMINATION OF THE THERMAL CONDUCTIVITY OF THE COMPOSITE WALL

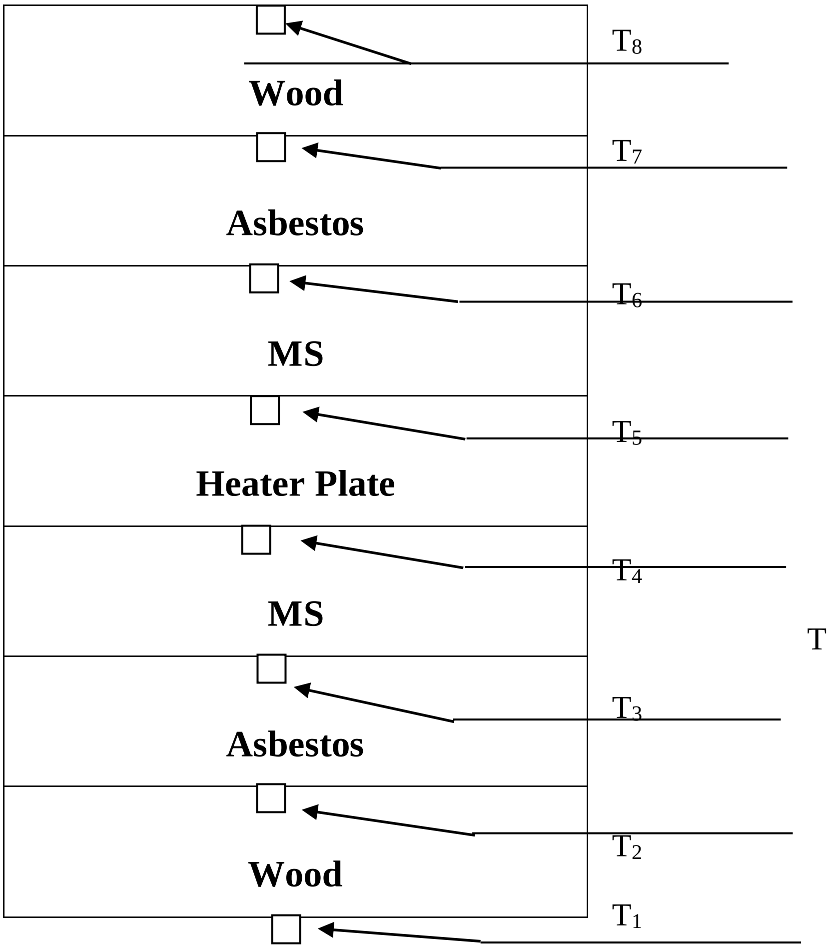
AIM:

To determine the thermal conductivity of the composite wall.

SPECIFICATIONS:

Thickness of wood (L_1)	=	10 mm
Thickness of Asbestos (L_2)	=	6 mm
Thickness of MS Plate (L_3)	=	10 mm
Diameter of the Plate (D)	=	300 mm

DIAGRAM :



PROCEDURE:

- This Apparatus is designed and fabricated mainly to study the characteristics of the composite structure. Here three slabs of different materials are provided, namely asbestos, wood & mild steel.

- Heat input to this composite wall is given by a nichrome wire heater bounded in mica. On both sides of the heater identical structure of composites, walls are placed. Thermocouples (Iron – Constantine) are provided at proper positions in the composite wall to record the temperature.

- A small hand press is binding the plates together. A digital temperature indicator with room temperature compositions is provided with selector switch.

- Heat input to the heater is given through a variac and measured by a wattmeter. An enclosure is given around the composite walls to ensure steady atmosphere conditions with transparent windows for visualization.

- The Heater is switched on after making sure that hand press applies sufficient pressure on the slabs so that they make proper contact with each other. The Heating value can be adjusted to a suitable level.

- Thermocouples reading are taken at regular intervals till consecutive readings are same indicating that steady state has been achieved. After establishing the steady state, the readings are tabulated and the power supply to the equipment is switched off.

OBSERVATIONS:

SL. NO	Heat input (Q) Watts			T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	T_6 (°C)	T_7 (°C)	T_8 (°C)	Themal Conductivity W/m K		
	V volts	I Amperes	Q=V*I Watts									K_A	K_B	K_C

FORMULA USED:

Wood Temperature (T_A) = $\frac{T_1+T_8}{2}$ °C

Asbestos Temperature (T_B) = $\frac{T_2+T_7}{2}$ °C

Mild steel Temperature (T_C) = $\frac{T_3+T_6}{2}$ °C

Heater Temperature (T_D) = $\frac{T_4+T_5}{2}$ °C

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

L = $L_1+L_2+L_3$ in m

Thermal conductivity of Wood (K_A) = $\frac{QL_1}{A(T_A-T_B)}$ W/ mK

Thermal conductivity of Asbestos (K_B) = $\frac{QL_2}{A(T_B-T_C)}$ W/ mK

Thermal conductivity of Mild Steel (K_C) = $\frac{QL_3}{A(T_C-T_D)}$ W/ mK

RESULT:

Thermal conductivity of wood is (K_A) ___________________ W/ mK

Thermal conductivity of Asbestos is(K_B)___________________ W/ mK

Thermal conductivity of Mild steel Plate is (K_C) ___________________ W/ mK

VIVA –VOCE Questions

1) What is effect of temperature on thermal conductivity of gases?

   Thermal conductivity of gases increases with increasing temperature

2) State Fourier law?

   Fourier law: the rate of heat conduction through a material depends on geometry of medium, its thickness & material of the medium as well as temperature across the medium.

3) What is effect of temperature on thermal conductivity of metals?

   Thermal conductivity of the metals decreases with increase in temperature

4) What is steady-state condition?

   Steady state implies that temperature at each point of system remains constant in due course of time.

5) What is heat conduction?

   Conduction is the transfer of heat from one part of a substance to another part or to another substance in physical contact with it.

6) What is thermal conductivity?

   Thermal conductivity is the rate of heat transfer through a unit thickness of material per unit area per unit temperature difference

7) Name the material having highest & least thermal conductivity?

   Diamond & Freon-12.

3. DETERMINATION OF HEAT TRANSFER COEFFICIENT THROUGH PIN- FIN

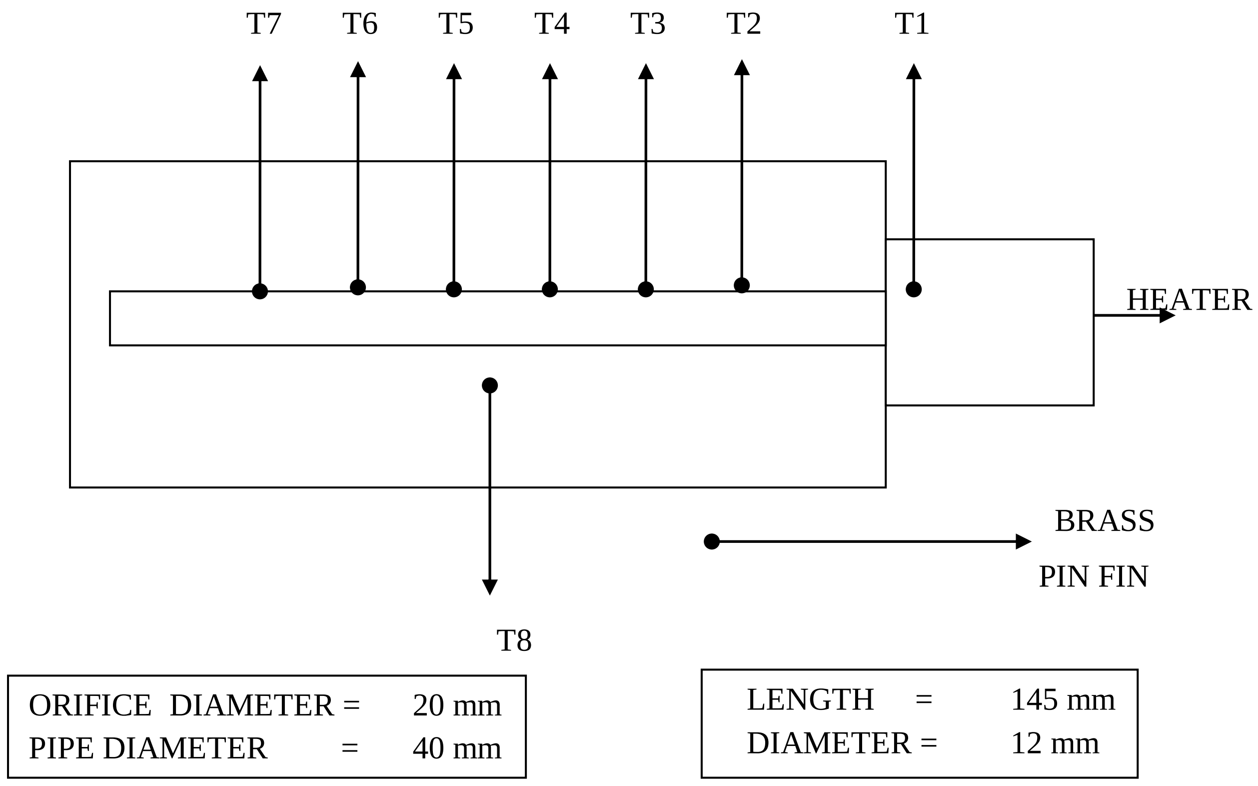
AIM:

To determine the temperature distribution of the PIN - FIN for forced convection and to find the FIN efficiency.

SPECIFICATIONS:

Duct width	(b)	=	150mm
Duct height	(w)	=	100mm
Orifice Diameter (d_o)		=	24mm
Orifice coefficient (C_d)		=	0.6
Fin length	(L)	=	14.5cm
Fin diameter (D_f)		=	12mm
(Characteristic length)			

DIAGRAM:



APPRATUS REQUIRED:

1) Experimental set up of a Pin-Fin inside a horizontal tube with forced convection Environment
2) Stabilized power supply
3) Stop Clock

PROCEDURE:

- Switch on the heater and set an input voltage of (60V) Using the voltage regulator.
- The heater starts to conduct heat through the pin-fin. Allow the heater to heat the Pin-Fin to a sufficient temperature.
- Switch on the blower for a set the flow rate of air for a particular pressure head in the U tube manometer.
- The air forced through the blower removes the heat from the pin-fin by convection.
- Observe the temperature readings of thermocouple at different location on the pin-fin and also the forced air temperature at equal intervals of time and tabulate them.
- Using appropriate formulae calculate the heat transfer coefficient and fin efficiency.
- Plot the temperature distribution along the length of the fin.

OBSERVATIONS :

SL. No	Mode	Manometer reading (cm)			Power (watts)			Temperature							Amb temp
		h_1	h_2	h= (h_1-h_2)	V	I	Q= VxI	T_1 (ºC)	T_2 (ºC)	T_3 (ºC)	T_4 (ºC)	T_5 (ºC)	T_6 (ºC)	T_7 (ºC)	T_8 (ºC)
1	Forced convection														

FORMULA USED:

Ref :- Heat and Mass Transfer Data book by C.P Kothandaraman & Subramannian , New Age publishers.

Flim Temperature (T_f) = --------------

1. Volume of air flowing through the duet

   $Vo = Cd*a_1*a_2*\sqrt{2gh_a}/(a_1^2 - a_2^2)$

   Where Cd = Co – efficient of orifice = 0.6

   g= Gravitational constant = 9.81 m/sec^2

   h = heat of pipe (p_w/p_a)h

   a_1= area of the Pipe

   a_2 = area of the orifice

2. Velocity of air in the pipe = V / (W +B)

   W = width of duct

   B = Breadth of the duct

3. Reynold's Number = Va x ρ_a / μ_a

   Where Va - Velacity of the duct

   ρ_a = Density of the duct

   μ_a = Viscosity of air at T_8 ºC

4. Prandltl Number = (C $p_a * \mu_a$) / K_a

   Where C_{pa} = Specific heat of air

   μ_a = Viscosity of air

   K_a = Thermal conductivity of air

5. Heat Transfer Coefficient Calculation

   Nusselt number (N_{nu})

   For 40 < NRe < 4000

   $N_{nu} = 0.683 (NRe) * 0.466 (N_{pr})^{0.331}$

   For 1 < NRe < 4

   $N_{nu} = 0.989 (NRe)^{0.33} (N_{pr})^{0.33}$

   For 4< NRe < 40

   $N_{nu} = 0.911 (NRe)^{0.385} (N_{pr})^{0.333}$

For 4000 < NRe < 40000 NRe

$N_{nu} = 0.193\ (NRe)^{0.618}\ (N_{pr})^{0.33}$

For NRe > 40000

$N_{nu} = 0.0266\ (NRe)^{0.805}\ (N_{pr})^{0.333}$

Heat transfer co - efficient $h = N_{nu} * (K_a / L)$

K_a = Thermal conductivity of air

L = Length of Fin

6. Efficiency of the Pin –fin = [(tan h mL) /mL]

   Where,

   H= heat transfer co-efficient

   L = Length of the fin

   $m = \sqrt{(hp / (K_b \times A))}$

   P = Perimeter of the fin = (π* Diameter of the fin)

   A = cross section area of the fin

   K_b = Themal conductivity of brass rod

Temperature distribution = T_x = { [(Cosh m(L-X) /Cosh (M)] * (To –Ta)} + T

X= distance between thermocouple and heater

Distance between thermocouples = 20 mm

7. Evaluation of the heat transfer co -efficient (h)

   Natural Convection

   $N_{nav} = (hD)/K = 1.1\ (Gr\ Pr)^{1/6}$ for 1/10 < Gr Pr < 104

   $N_{nav} = 0.53\ (Gr\ Pr)^{1/4}$ for 104 < Gr Pr < 109

   $N_{nav} = 0.13\ (Gr\ Pr)^{1/3}$ for 109 < Gr Pr < 1012

Where Nnav = average Nusselt Number = (h D)/K

D= Diameter of fin

K = Thermal conductivity of air

Gr= Grashof number - $g\ \beta\ \Delta T\ D^3 / \gamma^2$

β = Coefficient of thermal expansion - $1/(T_{av} + 273)$ $\Delta T = (T_{av} - T_{amb})$

Pr = Prandtl number = (μ Cp / K)

RESULT :

The heat transfer rates of the fin is determined and the values are

i) Temperature distribution

ii) Fin efficiency

VIVA –VOCE Questions

1) What is Orifice - meter?

   Orifice- meter is used to measure discharge.

2) What is the function of blower?

   Blower is an external mechanical device which is essential for forced convection process

3) What is Newton's law of cooling?

   The rate equations for convective heat transfer between a surface and an adjacent fluid is prescribed by Newton's law of cooling

4) What is the range of 'h' for Natural convection in gases & liquids?

   Range of 'h'for natural convection in gases is 3-25W/m2 -k & for liquids it is 50-350W/m2 -k.. Boundary layer is a thin layer at the surface where gradients of both velocity& temperature are large.

5) What is Nusselt Number?

   Nusselt Number represents the enhancement of heat transfer through a fluid layer as a result of convection relative to conduction across a same layer. Larger the Nu, more effective is convection.

6) What is a boundary layer?

   Boundary layer is a thin layer at the surface where gradients of both velocity & temperature are large.

4. DETERMINATION OF HEAT TRANSFER COEFFICIENT THROUGH FORCED CONVECTION

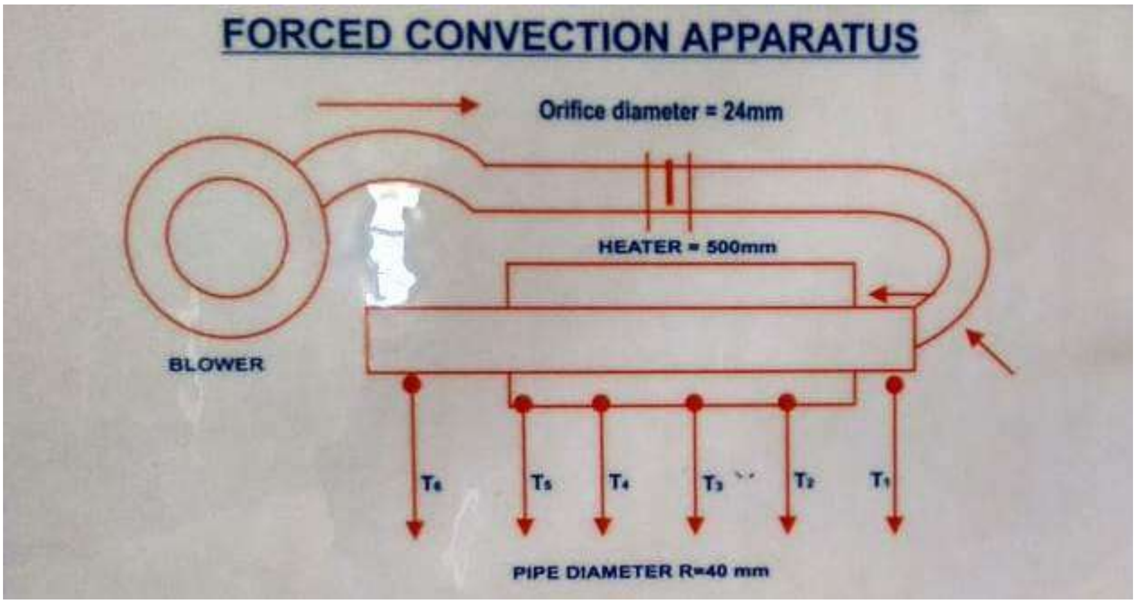
AIM:

To determine the heat transfer coefficient of a steel pipe in a forced convection environment.

APPARATUS REQUIRED:

1. Forced convection experimental setup
2. Stabilized power supply
3. Stop clock

DIAGRAM:



PROCEDURE:

- Switch on the heater and set an input voltage (50V) using the regulator
- After a short interval of time, Switch on the blower to establish a forced convection environment.
- Set the blower speed regulator to a desired flow rate of air.
- The heating coil transfers heat to the surface of the steel pipe through conduction. As the blower blows air inside the pipe, the inner surface of the pipe loses heat through convection.
- Allowing the heater to continuously heat the pipe and also the blower to convect the heat, observe the temperatures at specific locations at equal internals of time until the system reaches steady state and tabulate them.
- Observe the pressure load readings on the u - Tube manometer to calculate the flow rate of air.
- Using heat and mass transfer data book choose formula for forced convection internal flow heat transfer and calculate the heat transfer co- efficient for the surface.

OBSERVATIONS:

SL.No	Voltage (V) Volts	Current (I) Amps	Temperature (°C)						Manometer head (Cm)		
			T_1	T_2	T_3	T_4	T_5	T_6	h_1	h_2	$h_1 - h_2$

FORMULA USED:

Ref: Heat and Mass Transfer Data book by C.P. Kothandaraman & Subramanian, New Age Publishers.

1. Heat input (q) V*I Watts
2. Average air temperature (T_a) = $(T_1+T_6)/2$ (°C)
3. Average surface temperature (T_s) = $(T_2+T_3+T_4+T_5)/4$ (°C)
4. Volume of air flow (Q_B) = $C_d (\pi d^2/4)(\sqrt{2g h_w})(P_w/P_a)$ m^3

Where

C_d - Co –efficient of discharge = 0.64

h_w - Difference of water level in manometer in meter

d - Diameter of orifice = 0.0.14 m

5. Velocity of air in Pipe (V) = Q_B / cross section of pipe in m/sec
6. Reynolds number = VD / γ

   Where,

   γ = Kinematic viscosity of air from HMT DATA BOOK
7. Nusselt Number (Nu) = $0.023 (Re)^{0.8} (Pr)^{0.4}$

   Prandtl no from HMT Data Book of (T_a)
8. Heat transfer co-efficient = Nu K /D Wm^2/K

RESULT:

The convective heat transfer coefficient is (ha) ____________ Wm^2/K

VIVA –VOCE Questions

1) What is Orifice - meter?

   Orifice- meter is used to measure discharge.

2) What is the function of blower?

   Blower is an external mechanical device which is essential for forced convection process

3) What is Newton's law of cooling?

   The rate equations for convective heat transfer between a surface and an adjacent fluid is• prescribed by Newton's law of cooling.

4) What is meant by free or natural convection?

   It is fluid motion is produced due to change in density resulting from temperature gradients, the mode ofheat transfer is said to be free or natural convection.

5) Define Grashof number [Gr].

   It is defined as the ratio of product of inertia force and buoyancy force to the square of viscous force. Gr =Inertia force x Buoyancy force / [Viscous force]

6) Define Stanton number [St].

   It is the ratio of Nusselt number to the product of Reynolds number and Prandtl number. St = Nu / Re x Pr.

7) Define Reynolds number [Re].

   It is defined as the ratio of inertia force to viscous force. Re = Inertia force / Viscous force

5. DETERMINATION OF HEAT TRANSFER COEFFICIENT THROUGH NATURAL CONVECTION

AIM

To determine the surface Heat transfer coefficient along the length of the tube by Natural convection.

SPECIFICATIONS:

Diameter of the cylinder (D)	:	35mm
Length of the tube (L)	:	500mm
Duct size	:	250 mm x 250 mm x 700 mm
No. of thermocouples	:	8
Temperature indicator	:	0-400^{o}C

APPARATUS REQUIRED:

1) Natural convection experimental setup
2) Stabilized power supply
3) Stop clock

PROCEDURE:

- Switch 'ON' The heater and Set an input Voltage (60V) Using the voltage regulator.
- The heater inside the vertical tube heats the steel tube through the conduction. As the tube gets heated, the heat from the outer surface of tube transfer to the surrounding by natural convection.
- Allowing the heater to heat the tube, observe the readings of thermocouple at different locations at equal intervals of time until the system reaches steady state and tabulate them.
- Choosing appropriate formulae for a natural convection of a horizontal tubes, external surface from HMT data book, calculate the heat transfer coefficient.

OBSERVATIONS:

SL. No	Voltage (V) Volts	Current (I) Amps	Temperature (^{0}C)							Ambient Temp	Heat transfer coefficient (h_a) W/m^{2}K
			T_1 (ºC)	T_2 (ºC)	T_3 (ºC)	T_4 (ºC)	T_5 (ºC)	T_6 (ºC)	T_7 (ºC)	$T_8=T_a$ (ºC)	

FORMULA USED:

Ref: Heat and Mass Transfer Data book by Kothandaraman & Subramaian, New Age Publishers.

Heat input: $(q) = V*l$ Watts

Average surface temp $(T_s) = \dfrac{T_1+T_2+T_3+T_4+T_5+T_6+T_7}{\mathbf{7}}$

= ------------------- ^oC

Ambient air temp $(T_a) = T_8\ ^oC$

Mean film temp $(T_f) = \dfrac{T_s + T_a}{2}\ ^oC$

$= \dfrac{1}{T_f \text{ in K}}$

Properties of air at 'T_f' from the at and Mass Transfer data book

Grashof No $Gr = \dfrac{g\beta \triangle TL^3}{\gamma^2 \triangle}$

$\triangle T = T_s - T_a\ (^oC)$

$Gr\ Pr =$ ___________

Nusselt No, $Nu = 0.13\ (Gr\ Pr)^{1/3}$

Heat transfer coefficient, $(h_a) = \dfrac{NuK}{D}$ W/m^{2}K

RESULT :

The surface of Heat transfer coefficient along the length of the tube is (h_a) ___________

VIVA –VOCE Questions

1) What is the range of 'h' for Natural convection in gases & liquids?

   Range of 'h'for natural convection in gases is 3-25W/m2 -k & for liquids it is 50-350W/m2 -k.. Boundary layer is a thin layer at the surface where gradients of both velocity & temperature are large.

2) What is Nusselt Number?

   Nusselt Number represents the enhancement of heat transfer through a fluid layer as a result of convection relative to conduction across a same layer. Larger the Nu, more effective is convection.

3) What is a boundary layer?

   Boundary layer is a thin layer at the surface where gradients of both velocity & temperature are large.

4) What is meant by laminar flow ?Laminar flow:

   Laminar flow is sometimes called stream line flow. In this type of flow, the fluid moves inlayers and each fluid particle follows a smooth continuous path. The fluid particles in each layer remain inan orderly sequence without mixing with each other.

5) Define Convection.

   Convection is a process of heat transfer that will occur between a solid surface and a fluid medium when they are at different temperatures.

6) What is meant by Newtonion and non-newtonion fluids?

   The fluids which obey the Newton's law of viscosity are called Newtonion fluids and those which do not obey are called no-newtonion fluids.

6. DETERMINATION OF EMISSIVITY

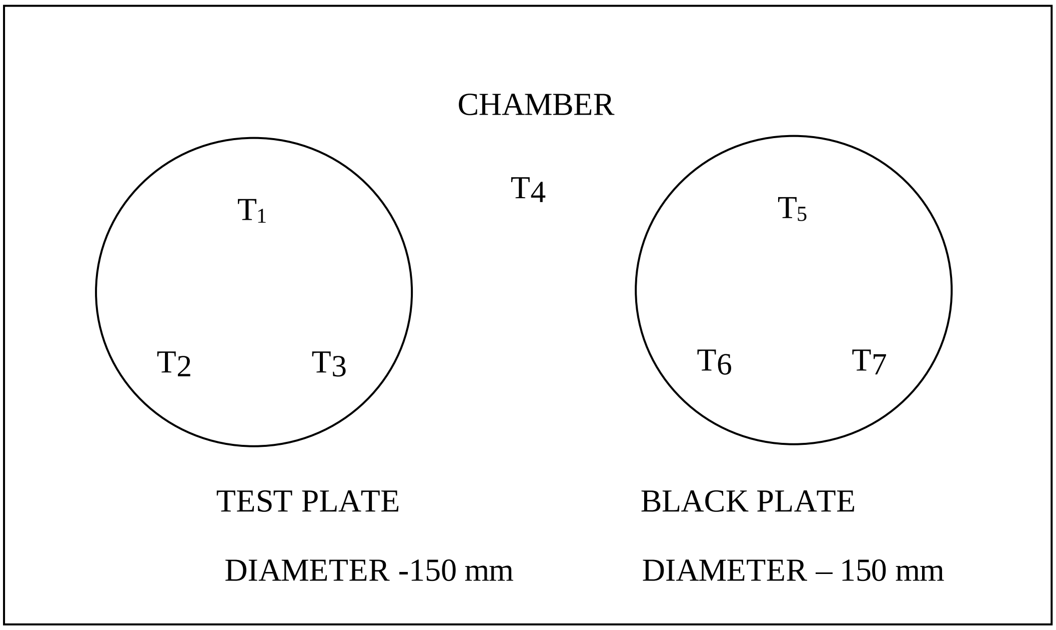
AIM:

To determine the Emissivity of a surface in a closed radioactive heat transfer environment.

APPARATUS REQUIRED:

1. Experimental setup with plates and heater for irradiative heat exchange
2. Stabilized power supply
3. Stop clock

DIAGRAM:



PROCEDURE:

- Switch on the heater and set an input voltage (50V) using the regulator.
- The Heater transfers heat to the plate through conduction and once a temperature difference establishes, heat transfer occurs through radiation from black plate to test plate.
- Allow the plates to get heated for a reasonable time so the temperatures on the plate reaches a steady state
- Measure the temperatures from 1 to 7 at equal intervals of time until the system reaches steady state.
- Calculate the emissivity of the test plate in applying Stefan’s Boltzmann Law.

OBSERVATIONS:

SL.No	Heat Input (Q) Watts			Temperature of test plate (^0C)			Temperature of black Body (^0C)			Chamber temperature (^0C) $T_a = T_4$	Emissivity
	V	1	Q = V * I	T_1	T_2	T_3	T_5	T_6	T_7		

FORMULA USED:

Ref : Heat and Mass Transfer Date book by C P Kothandaraman & Subramanian New Age Publishers

Stefan's Boltzmann's Law

Heat transfer through `radiation i.e

Emissive Power (E) = £ A $\sigma(T_1^4 - T_2^4)$

Heat Input (q) = V* I Watts

Average of Test Plate Surface temperature (T_{tp}) = ($T_1+T_2+T_3$) /3 º C ____________ K

Average of Black Plate Surface temperature (T_{bp}) = ($T_5+T_6+T_7$) /3 º C ____________ K

Surface Area (A) = $\pi D^2 / 4$ in m^2

Emissive Power of the black Plate (E_{bp}) = $£_{bp}\ A_{bp}\ \sigma\ (T_{bp}^4 - T_a^4)$

Emissive Power of the test Plate (E_{tp}) = $£_{tp}\ A_{tp}\ \sigma\ (T_{tp}^4 - T_a^4)$

Equating the emissive power of a both Plates as it reaches a steady State.

$$E_{bp} = E_{tp}$$

$$£_{bp}\ A_{bp}\ \sigma\ (T_{bp}^4 - T_a^4) = £_{tp}\ A_{tp}\ \sigma\ (T_{tp}^4 - T_a^4)$$

Since $A_{bp} = A_{tp}$

$$£_{tp} = £_{bp} \frac{(T_{bp}^4 - T_a^4)}{(T_{tp}^4 - T_a^4)}$$

Where

Q – Heat input in watts

A – Area of the Plate in m^2

T_{tp} – Teat Plate surface temperature in K

T_{bp} – Black Plate surface temperature in K

T_a – Chamber temperature in K

$£_{bp}$ – Emissivity of Block Plate Surface – 1

$£_{tb}$ - Emissivity of Test Plate Surface

σ - Stefan Boltzmann's Constant = $5.67x10^{-8}\ m^2\ k^4$

RESULT :-

The emissivity of the test Plate is determined as ($£_{tp}$) ______________

VIVA –VOCE Questions

1) What is the effect on internal energy of an object during radiation?

   In radiation, internal energy of an object decreases.

2) Define Emissive Power.

   It is defined as the total amount of radiation emitted by the body per unit time and unit area.

3) Define Monochromatic emissive Power.

   The energy emitted by the surface at a given length per unit time per unit area in all dimensions is known as monochromatic emissive power.

4) Define Radiation.

   The heat transfer from one body to another without any transmitting medium is known as radiation

5) Define Emissivity.

   It is defined as the ability of the surface of a body to radiate the heat.

6) What is meant by Gray body?

   If a body absorbs a definite percentage of incident radiation irrespective of their wavelength, the body is known as Gray body.

7) Define intensity of Radiation.

   It is defined as the rate of energy having a surface in a given direction per unit solid angle per unit area of the emitting surface normal to the mean direction in space.

8) Define Max emissive power.

   A combination of Planck's law & Wien's displacement law yields the condition for the max monochromatic emissive power of a black body.

7. DETERMINATION OF EFECTIVENESS OF A HEAT EXCHANGER BY PARALLEL FLOW

AIM:

To determine the overall heat transfer co-efficient in Parallel flow heat exchanger.

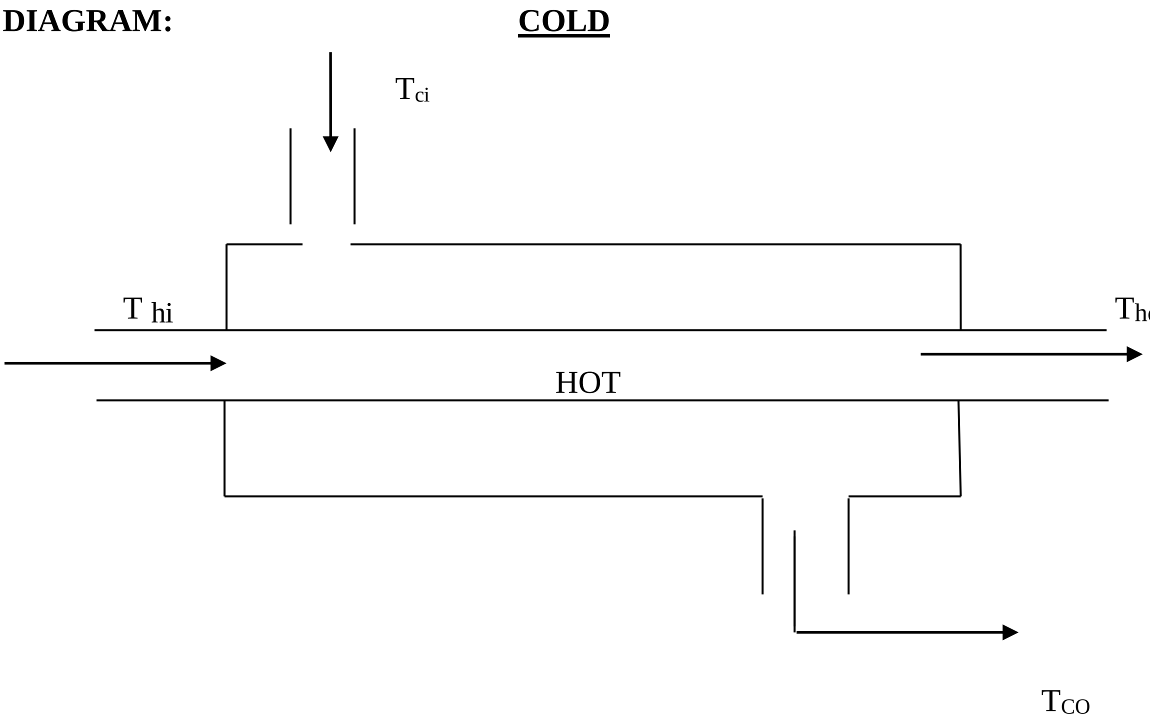
SPECIFICATIONS:

Length of the heat exchanger	=	1800 mm
Inner Copper Tube (ID)	=	12 mm
Inner Copper tube (OD)	=	15 mm
Outer GI tube Id	=	40 mm

APPARATUS REQUIRED:

1) Experimental setup of heat exchanger
2) Stabilized power Supply
3) Stop clock

DIAGRAM:



PROCEDURE :

- Connect water supply to the pipe arrangement.
- Adjust the water supply on hot and cold sides by opening the valves, so that cold water flows parallel to the hot water.
- Set a constant flow rate of 2 lit / min for hot water and 5 lit / min for cold water by controlling the valves.
- Switch on the water heater and allow the water to get heated to a higher temperature and reach a steady state.
- Observe the temperature of water at the inlet and exit of gold water & hot water after a steady state is reached.
- Measure time taken for flow of water by collecting water in a 500 ml flask.

OBSERVATIONS:

Flow type	Hot water Temperature (°C)		Cold water Temperature (°C)		Time for 500 ml water collection (t) Sec		Flow rate (m) Kg / Sec	
	Inlet (T_{hi})	Outlet (T_{ho})	Inlet (T_{Ci})	Outlet (T_{Co})	Hot water	Cold water	Hot water	Cold water
Parallel Flow								

FORMULA UESD:

Heat content of Hot Water

$Q_h = m_h\, Cp_h\ (T_{hi} - T_{ho})$ watts

Where,

m_h - Mass flow rate of hot water, kg,/sec

T_{hi} - Temperature of hot water inlet (°C)

T_{ho} - Temperature of hot water outlet (°C)

C_{ph} - Specific heat of hot water in kJ/kg K

Heat content of cold water:

$Q_c = m_c\, Cp_c\ (T_{co} – T_{ci})$ watts

Where,

m_c - Mass flow rate of cold water, kg,/sec

T_{ci} - Temperature of inlet cold water (°C)

T_{co} - Temperature of outlet cold water (°C)

C_{pc} - Specific heat of cold water in kJ /Kg K

$$Q = \frac{Q_h + Qc}{2} \quad \text{KJ / Sec}$$

Logarithmic Mean Temperature Difference (LMTD):

$$\text{LMTD } (\Delta T_m) = \frac{(\Delta T_i - \Delta T_o)}{\ln(\Delta T_i - \Delta T_o)}$$

$$= \frac{(T_{ho} - T_{co}) - (T_{hi} - T_{ci})}{\ln(T_{ho} - T_{co} / T_{hi} - T_{ci})}$$

Where,

$\Delta T_i = T_{ho} - T_{co}$

$\Delta T_o = T_{hi} - T_{ci}$

Overall Heat Transfer Co-Efficient

$$U_i - = \frac{Q}{A_i \; \Delta T_m} \quad W/m^{2\ 0}C$$

Where,

U_i - Overall heat transfer coefficient based on inner surface area in $W/m^2\ {}^oC$

A_i - Inner surface area in m^2

ΔT_m – Logarithmic mean temperature difference

$$U_0 - = \frac{Q}{A_o \; \Delta T_m} \quad W/m^{2\ 0}C$$

Where,

U_o - Overall heat transfer coefficient based on outer surface area in $W/m^2\ {}^oC$

A_o - Outer surface area in m^2

ΔT_m – Logarithmic mean temperature difference

$$\text{Effectiveness of Heat Exchanger} = \frac{m_c\, C_{po}(T_{co} - T_{ci})}{m_h\, C_{ph}\,(T_{hi} - T_{ho})}$$

RESULT :

The effectiveness of heat exchanger for Parallel flow is ______________

The overall heat transfer co –efficient based on inner surface area of heat exchanger is ___

The overall heat transfer co –efficient based on outer surface area of heat exchanger is ___

VIVA –VOCE Questions

1) What is heat exchanger?

   Heat exchanger is equipment which transfers the energy from a hot fluid to cold fluids, with maximum rate & minimum investment

2) Explain LMTD?

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

3) For evaporators & condensers, what is the value of LMTD for parallel & counter flow?

   For evaporators & condensers, LMTD for parallel & counter flow is equal/same.

4) What is the value of LMTD if heat capacity of both fluids is same?

   If heat capacity of both fluids is same, then LMTD is equal to temperature difference at either ends.

5) What is Relative direction of motion of fluids?

   Relative direction of motion of fluids: Parallel, Counter & Cross flow.

6) When NTU method is particularly useful in design of heat exchangers?

   NTU method is necessary if outlet temperature of both fluids is not known as priority.

8. DETERMINATION OF EFFECTIVENESS OF A HEATEXCHANGER BY COUNTER FLOW

AIM:

To determine the overall heat transfer co –efficient in Counter flow heat exchanger.

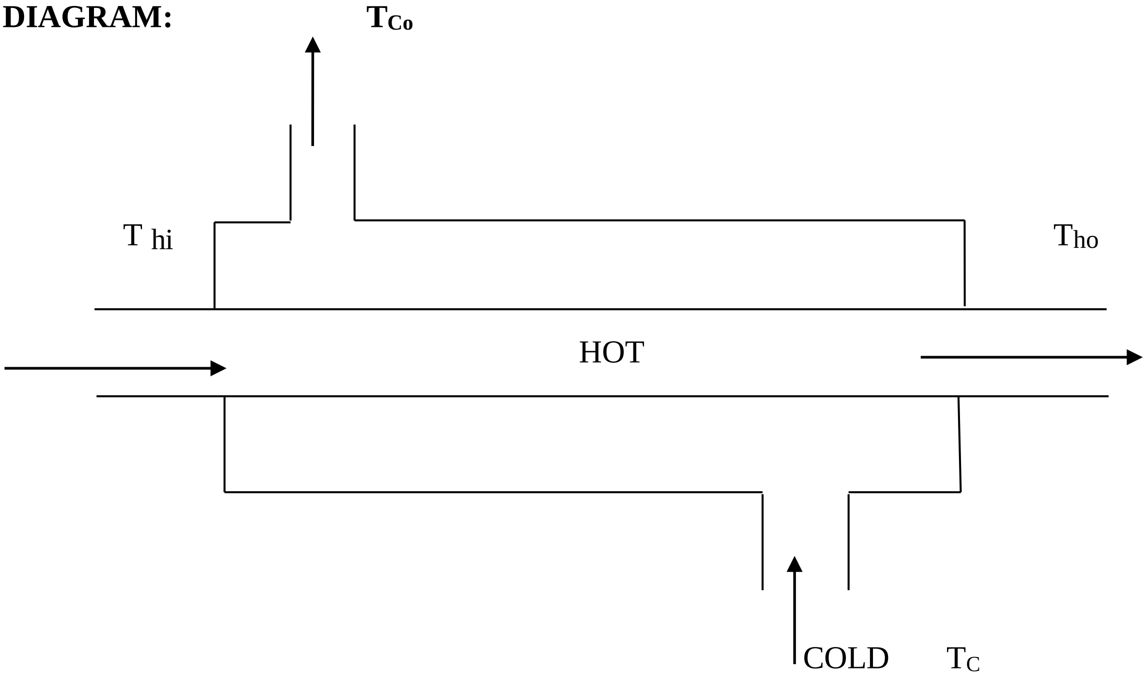
SPECIFICATIONS:

Length of the heat exchanger	=	1800 mm
Inner copper tube (ID)	=	12 mm
Inner copper tube (OD)	=	15 mm
Outer GI tube ID	=	40 mm

APPARATUS REQUIRED:

1) Experimental setup of heat exchanger.
2) Stabilized Power Supply.
3) Stop clock.

DIAGRAM:



PROCEDURE :

- Connect water supply to the pipe arrangement.
- Adjust the water supply on hot and cold sides by opening the valves, so that cold water flows counter to the hot water.
- Set a constant flow rate of 2 lit /min for hot water and 5 lit / min for cold water by controlling the valves.
- Switch on the water heater and allow the water to get heated to a higher temperature and reach a steady state.
- Observe the temperature of water at the inlet and exit of cold water & hot water after a steady state is reached.
- Measure time taken for flow of water by collecting water in a 500 ml flask.

OBSERVATIONS:

Flow type	Hot water Temperature (^oC)		Cold water Temperature (^oC)		Time for 500 ml water collection (t) Sec		Flow rate (m) Kg / Sec	
	Inlet (T_{hi})	Outlet (T_{ho})	Inlet (T_{Ci})	Outlet (T_{Co})	Hot water	Cold water	Hot water	Cold water
Counter Flow								

FORMULA UESD:

Heat content of Hot Water

$Q_h = m_h Cp_h \; (T_{hi} - T_{ho})$ watts

Where,

m_h	-	Mass flow rate of hot water, kg,/sec
T_{hi}	-	Temperature of hot water inlet (°C)
T_{ho}	-	Temperature of hot water outlet (°C)
C_{ph}	-	Specific heat of hot water in kJ/kg K

Heat content of cold water:

$Q_c = m_c Cp_c \; (T_{co} - T_{ci})$ watts

Where,

m_c	-	Mass flow rate of cold water, kg,/sec
T_{ci}	-	Temperature of inlet cold water (°C)
T_{co}	-	Temperature of outlet cold water (°C)
C_{pc}	-	Specific heat of cold water in kJ /Kg K

$$Q = \frac{Q_h + Qc}{2} \text{ KJ / Sec}$$

Logarithmic Mean Temperature Difference (LMTD):

$$\text{LMTD } (\Delta T_m) = \frac{(\Delta T_i - \Delta T_o)}{\ln(\Delta T_i - \Delta T_o)}$$

$$= \frac{(T_{ho} - T_{co}) - (T_{hi} - T_{ci})}{\ln(T_{ho} - T_{co} / T_{hi} - T_{ci})}$$

Where,

$\Delta T_i = T_{ho} - T_{co}$

$\Delta T_o = T_{hi} - T_{ci}$

Overall Heat Transfer Co-Efficient

$$U_i - \quad = \quad \frac{Q}{A_i \ \Delta T_m} \quad W/m^{2\,0}C$$

Where,

U_i - Overall heat transfer coefficient based on inner surface area in $W/m^2\,^oC$

A_i - Inner surface area in m^2

ΔT_m – Logarithmic mean temperature difference

$$U_0 - \quad = \quad \frac{Q}{A_o \ \Delta T_m} \quad W/m^{2\,0}C$$

Where,

U_o - Overall heat transfer coefficient based on outer surface area in $W/m^2\,^oC$

A_o - Outer surface area in m^2

ΔT_m – Logarithmic mean temperature difference

$$\text{Effectiveness of Heat Exchanger} = \frac{m_c\, C_{po}(T_{co} - T_{ci})}{m_h\, C_{ph}\,(T_{hi} - T_{ho})}$$

RESULT :

The effectiveness of heat exchanger for Counter flow is ______________

The overall heat transfer co –efficient based on inner surface area of heat exchanger is ___

The overall heat transfer co –efficient based on outer surface area of heat exchanger is ___

VIVA –VOCE Questions

1) What is heat exchanger?

   Heat exchanger is equipment which transfers the energy from a hot fluid to cold fluids, with maximum rate & minimum investment

2) Explain LMTD?

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

3) For evaporators & condensers, what is the value of LMTD for parallel & counter flow?

   For evaporators & condensers, LMTD for parallel & counter flow is equal/same.

4) What is the value of LMTD if heat capacity of both fluids is same?

   If heat capacity of both fluids is same, then LMTD is equal to temperature difference at either ends.

5) What is Relative direction of motion of fluids?

   Relative direction of motion of fluids: Parallel, Counter & Cross flow.

6) When NTU method is particularly useful in design of heat exchangers?

   NTU method is necessary if outlet temperature of both fluids is not known as priority.

9. DETERMINATION OF STEFAN BOLTZMANN'S CONSTANT

AIM :

To determine the value of Stefan Boltzmann's constant.

SPECIFICATIONS:

Hemispherical enclosure diameter	-	200 mm
Size of water jacket for hemisphere	-	260 mm
Base Plate, hylum diameter	-	240 mm
Test disc diameter	-	20 mm
Specific heat of test disc (C_p)	-	0.4168 kJ/kg K
No. of thermocouples mounted of enclosure	-	4
No. of thermocouples mounted on the disc	-	1
No. of thermocouples mounted water heater	-	1
Immersion water heating capacity	-	2000 watts
Mass of test disc	-	0.008 kg

APPARATUS REQUIRED:

1) Experimental setup for Stefan Boltzmann's constant determination, with heater arrangement.
2) Stabilized power supply
3) Stop clock

PROCEDURE:

- Switch on the power supply and set an input voltage (65 V) using the Voltage regulator.
- Fill the Stainless Steel cubical vessel with 7 litres of water and heat the water to 80°C.
- Open the Values & allow the hot water to fill the chamber
- Allow the hot water to stabilize for 10 minutes & measure the temperature of the chamber and three different locations on the inner hemispherical surface.
- Insert the test disc from the bottom exposing it to the hemispherical surface for radioactive of the test disc absorb heat by radiation.
- Measure temperature of test surface to evenly 10 secs until it reaches a steady state
- Calculate the Stefan Boltzmann's constant by applying Stefan Boltzmann's law.

OBSERVATIONS:

Temperature of hot water T_1 = 80°C

SL.NO	Temperature of hemispherical enclosure inner surface		
	T_2 (°C)	T_3 (° C)	T_4 (°C)

OBSERVATION OF DISC TEMPERATURE (T_5):

SL.NO	TIME (t) (Sec)	TEMPERATURE (T_5) (^oC)

FORMULA USED :

Ref: Heat and Mass Transfer Data book by Kothandaraman & Subramanian, New Age Publishers.

The radiation energy falling on the disc 'D' from the hemispherical Enclosure 'E' is

Emissive power (E) = $\sigma A_D T_S^4$

Where.

A_D = Area of the disc 'D' in m^2

T_S = Average surface temp of Enclosure = $\frac{T_2+T_3+T_4}{3}$ in K

The radiant energy of the disc D, emitting into the enclosure E_D is

$$E_D = \sigma A_D T_D^4 = \sigma A_D (T_{avg}^4 - T_d^4)$$

Where,

T_D = Temperature of disc T_5 in K

The net energy transferred to the disc

$$m C_p \frac{dT}{dt} = \sigma A_D (T_D^4 - T_s^4)$$

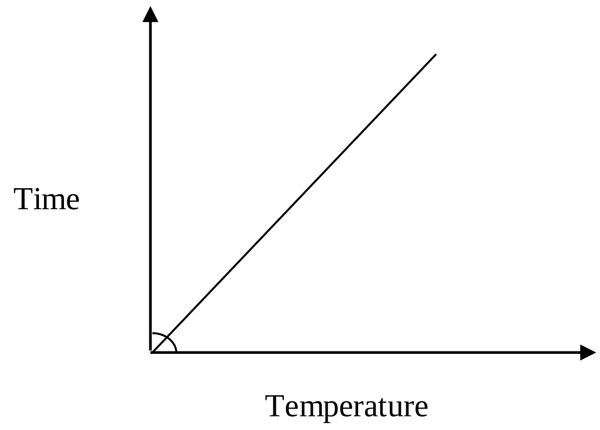
Where,

m – Mass rate of test disc in kg

C_p - Specific heat of test disc in kJ/kg K

$$\text{Stefan Boltzmann's Constant } (\sigma) = \frac{m C_p (dT/dt)}{A_D (T_D^4 - T_s^4)} \quad W/m^2K^4$$

MODEL GRAPH :



RESULT:

Thus the Stefan Boltzmann's constant is determined as (σ) ……………………

VIVA –VOCE Questions

1) State Stephan Boltzmann law & its constant value?

   The emissive power of a black body is proportional to fourth power of its absolute temperature & its constant's value is 5.67×10^{-8} W/m^2 K^4

2) What is the effect on internal energy of an object during radiation?

   In radiation, internal energy of an object decreases.

3) Define Emissive Power.

   It is defined as the total amount of radiation emitted by the body per unit time and unit area.

4) Define Monochromatic emissive Power.

   The energy emitted by the surface at a given length per unit time per unit area in all dimensions is known as monochromatic emissive power.

5) Define Radiation.

   The heat transfer from one body to another without any transmitting medium is known as radiation

6) Define Emissivity.

   It is defined as the ability of the surface of a body to radiate the heat.

7) What is meant by Gray body?

   If a body absorbs a definite percentage of incident radiation irrespective of their wavelength, the body is known as Gray body.

10. DETERMINATION OF THERMAL CONDUCTIVITY (INSULATING POWDER)

AIM :

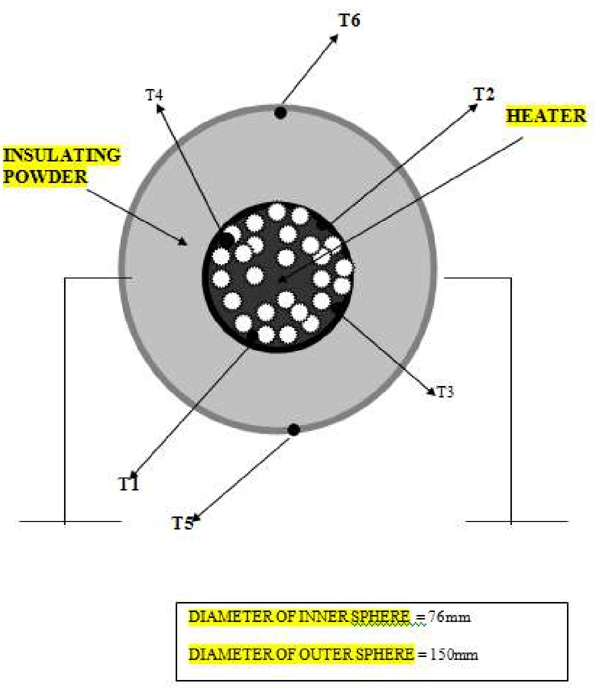
To determine the thermal conductivity of the given Insulating powder.

SPECIFICATIONS:

Radius of inner sphere	:	37.5 mm
Radius of outer sphere	:	75 mm
Insulating Powder	:	Magnesium oxide Powder

DIAGRAM:

Thermal Conductivity of Insulating Powder



PROCEDURE:

- The apparatus consisting of concentric spheres made of copper. The inner Sphere is a heater, and in between the spheres insulating powder is (Magnesium oxide) filled and sealed.
- There are two thermocouples fixed to the heater T_1 & T_2 and two thermocouples fixed on the inner wall of the outer sphere T_3 & T_4. A multiunit digital temperature indicator is provided to measure temperature at different locations.
- The whole unit mounted on a laminated work bench with panel. An ammeter & voltmeter is provided to measure the input power and a dimmerstat is provided to vary the input power.
- The Heater is switched on. The input voltage can be adjusted to a suitable level, which in turn will vary the input heat.
- The heater supplies heat to the inner pipe, which in turn passes through the insulating powder to the outer pipe.
- The Thermocouple readings are noted frequently till consecutive readings are same indicating steady has been reached.
- After establishing the steady state, the input voltage is reduced and the power supply is switched off.

OBSERVATIONS:

SL. NO	Heat input (Q)			Heater Temperature		Insulating Powder Temperature				Themal Conductivity (K) W/m K
	V volts	I Amperes	Q=V*I Watts	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	T_6 (°C)	

FORMULA USED :

$$Q = \frac{(T_i - T_o)}{(r_2 - r_1) / (4 \pi K r_1 r_2)} \text{ Watts}$$

Where,

Q = Heat input in watts

K = Thermal Conductivity of the material in W/m K

r_0 = Radius of the Outer sphere in m

r_i = Radius of the Inner sphere in m

T_0 = Insulating powder Temperature $(T_3+T_4+T_5+T_6) / 4$

T_1 = Heater Temperature $(T_1+T_2) / 2$

(K) = ________________________________ W/m K

RESULT:

Thus, the thermal Conductivity of the insulting powder is (K) _________________ W/m K

VIVA –VOCE Questions

1) What is steady-state condition?

   Steady state implies that temperature at each point of system remains constant in due course of time.

2) What is heat conduction?

   Conduction is the transfer of heat from one part of a substance to another part or to another substance in physical contact with it.

3) What is thermal conductivity?

   Thermal conductivity is the rate of heat transfer through a unit thickness of material per unit area per unit temperature difference.

4) What are the factors affecting the thermal conductivity?

   a.Moisture b. Density of material c. Pressure d. Temperature e. Structure of material

5) Define heat flux.

   The quantity of heat transfer per unit time per unit area of the internal surface as Heat flux.

6) Define temperature gradient.

   The greatest temp variation is in direction normal to the iso thermal surface is known as temperature gradient.

ADDITIONAL EXPERIMENT

1. DETERMINATION OF THERMAL CONDUCTIVITY (LAGGED PIPE)

AIM

To determine the thermal conductivity of the given Lagged pipe.

SPECIFICATIONS:

d_1 - Heater diameter = 20mm

d_2 - Heater with asbestos diameter = 40 mm

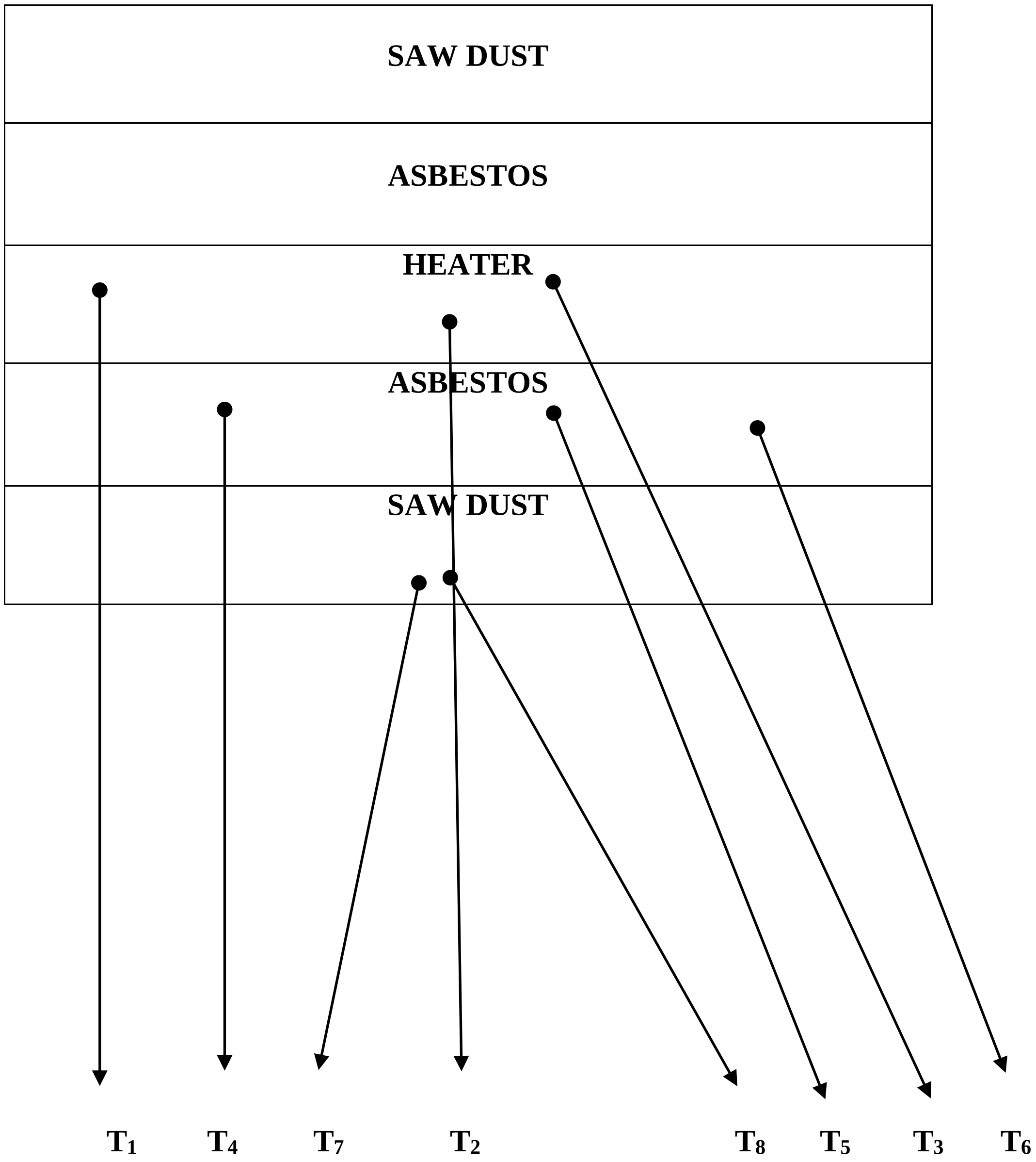
d_3- asbestos & saw dust diameter = 80mm

Length = 500 mm

APPARATUS REQUIRED:

1. Experimental setup
2. Stabilized power supply
3. Stop clock

DIAGRAM:



PROCEDURE:

- Switch on the heater and set the voltage using the regulator.
- The electrical heater transforms heat from the coil to the steel pipe filled with asbestos and it further transforms to the outer pipe filled with saw dust through conduction.
- Wait for reasonable time for allow temperature at various points to reach steady state.
- Measure the voltage current and temperature from t_1 to t_6 at equal intervals until the system reaches steady state.

- Calculate the thermal conductivity of asbestos and sawdust.

OBSERVATIONS:

SL. No.	Heat input (Q)			Heater Temperature			Asbestos Temperature			Saw dust temp		Thermal conductivity
	V Volts	I amperes	Q = V*I Watts	T_1 (^{0}C)	T_2 (^{0}C)	T_3 (^{0}C)	T_4 (^{0}C)	T_5 (^{0}C)	T_6 (^{0}C)	T_7 (^{0}C)	T_8 (^{0}C)	(K) W/mk

FORMULA USED

Heat Flow from the heater to outer surface asbestos lagging

$$Q = \frac{2 \pi L K_1 (T_b - T_a)}{\text{In} [(r_2) / (r_1)]} \quad \text{Watts}$$

Where,

Q = Heat input in watts

K_1 = Thermal Conductivity of the asbestos in W/m K

R_2 = Radius of the asbestos pipe in m

R_1 = Radius of the heater Pipe in m

T_b = Heater Temperature $(T_1 + T_2 + T_3) / 3$

T_a = Asbestos Temperature $(T_4 + T_5 + T_6) / 3$

K_1 = ______________________________ W/m K

Heat flow from the heater to outer surface a Sawdust

$$Q = \frac{2 \pi L K_2 (T_b - Ta)}{\text{In} [(r_3) / (r_2)]} \quad \text{Watts}$$

Where,

Q ` = Heat input in watts

K_2 = Thermal Conductivity of the Sawdust in W/m K

R_2 = Radius of the asbestos pipe in m

R_3 = Radius of the heater Pipe in m

T_b = Asbestos Temperature $(T_4 + T_5 + T_6) / 3$

T_a = Saw dust Temperature $(T_7 + T_8) / 2$

K_2 = ______________________________ W/m K

RESULT

Thus the thermal Conductivity of the asbestos is (K_1) _________ W/m k

Thermal Conductivity of the Sawdust is (K_2) _________________ W/m K

VIVA –VOCE Questions

1) What is steady-state condition?
   Steady state implies that temperature at each point of system remains constant in due course of time.
2) What is heat conduction?
   Conduction is the transfer of heat from one part of a substance to another part or to another substance in physical contact with it.
3) What is thermal conductivity?
   Thermal conductivity is the rate of heat transfer through a unit thickness of material per unit area per unit temperature difference
4) Name the material having highest & least thermal conductivity?
   Diamond & Freon-12.

5) Write down the equation for conduction of heat through a hollow cylinder.
   Heat conduction is a mechanism of heat transfer from a region of high temperature to a region of low temperature within a medium [solid, liquid or gases] or different medium in direct physical contact

6) State Fourier's law of conduction
   The rate of heat conduction is proportional to the area measured normal to the direction of heat flow and tothe temperature gradient in that direction
   Q = -kA dT /dxWhere, A- Area in m^2. dT / dx,- Temperature gradient, K/m,
   K-Thermal conductivity, W/mK

7) Define Thermal conductivity
   Thermal conductivity is defined as the ability of a substance to conduct heat

8) Write down the equation for conduction of heat through a slab or plane wall.
   Heat transfer, Q = Toverall / R; Where, _ T = T_1- T_2;
   R = L / kAThermal resistance of slab, L- Thickness of slab; K-Thermal conductivity of slab;
   A- Area
   Heat transfer, Q = _ Toverall / R, Where _ T = T_1- T_2; R = 1 / 2_Lk in [r2 / r1] –
   Thermalresistance of slab,
   L – Length of cylinder; k – Thermal conductivity; r_2 – Outer radius, r1–Inner radius.