H.T.LAB MANUAL

Laboratory manual for the HEAT TRANSFER

Laboratory for Sixth semester Mechanical (17MEL67)

Department of Mechanical Engineering

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PARTICULARS OF EXERCISES

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EXPT NO : 1

THERMAL CONDUCTIVITY OF METAL BAR

AIM: To determine the thermal conductivity of a good conductor material.

THEORY: From Fourier's Law of heat conduction

$Q = kA\frac{dT}{dx}$ Watt

K = Thermal conductivity of the material in W/m-^oK

Thermal conductivity is a property of the material and can be defined as the amount of heat conducted across a unit area per unit time when the temperature gradient is unity.

A = cross sectional area of the metal rod in m^2

dT/dx = temperature gradient in $^oC/m$

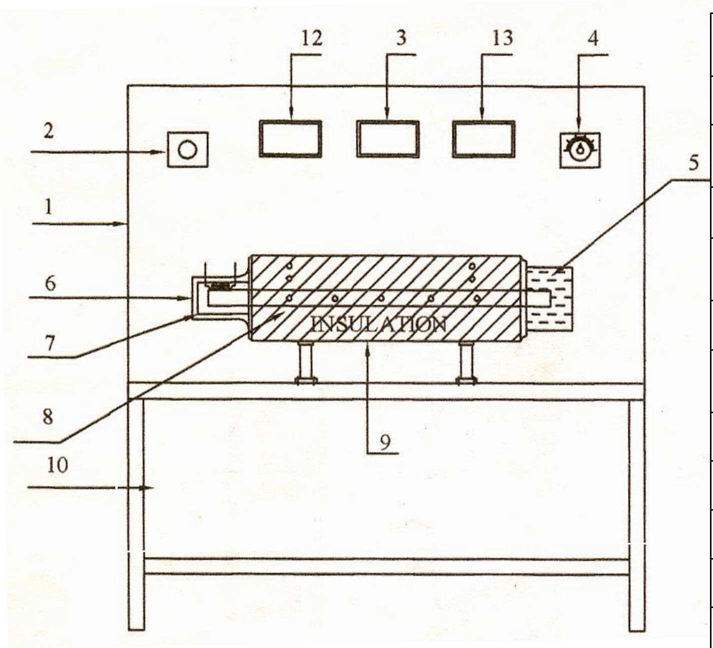
DESCRIPTION OF THE APPARATUS

The apparatus consists of a metal bar, one end of which is heated by an electric heating coil while the other end projects inside the cooling water jacket. The middle portion of the rod is surrounded by an insulating material like asbestos to minimize lateral heat transfer from the rod and thus ensure a more nearly constant temperature gradient throughout the length of the rod. The temperature of the bar is measured at five different locations while the radial temperature distribution is measured by separate thermocouples at two different sections in the insulating shell. The heater is provided with a dimmer for controlling the heat input. Water can be circulated through the jacket and its flow rate and temperature rise can be noted down.

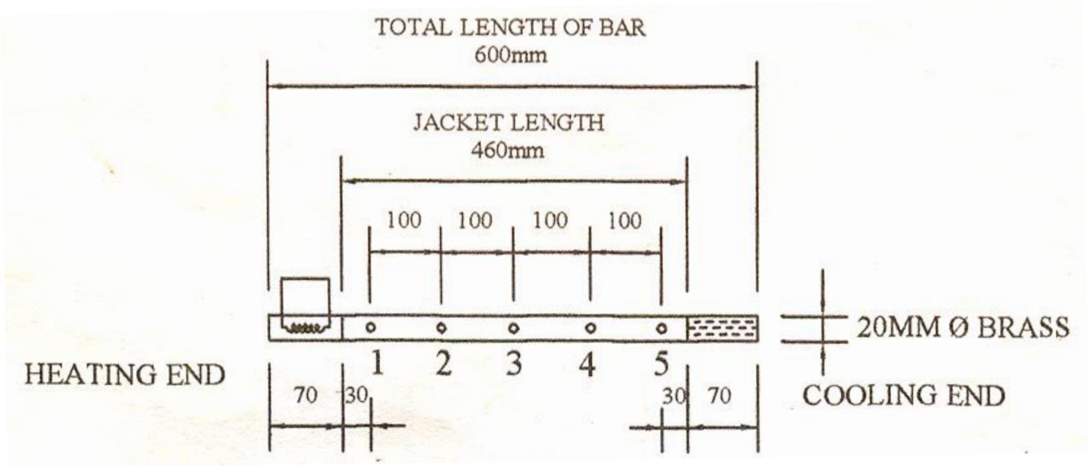
PROCEDURE

1. Connect the equipment to the power supply.
2. Give heat input to the heater by slowly rotating the dimmer and adjust the voltage.
3. Start the cooling water supply through the jacket and adjust.
4. Allow sufficient time to reach study state conditions.
5. Note down the temperature from 1 to 9 and also the mass flow rate of water.
6. Repeat the experiment for other heat inputs.

APPARATUS



SL. NO	DESCRIPTION	QTY
1	PANNEL BOARD	1 NO
2	DIMMERS FOR HEATER CONTROLLER	1 NO
3	DIGITAL TEMP INDICATOR	1 NO
4	THERMOCOUPLE SELECTOR SWITCH	1 NO
5	WATER COOLING JACKET	1 NO
6	ASBESTOS PIPE FOR HEATER COVERING	1 NO
7	BRASS BUSH	1 NO
8	20MM 0 BRASS ROD	1 NO
9	M.S SHELL 3MM THICK	1 NO
10	M.S SHELL 3MM THICK	1 NO
11	25MM SQ. TUBE FRAME	1 NO
12	TC THERMOCOUPLES	11NOS
13	DIGITAL VOLTMETER	1 NO
14	DIGITAL AMMETER J	1 NO



SPECIFICATIONS:-

1. Length of the Metal Bar : 460 mm
2. Diameter of the Metal Bar : 20 mm
3. No. of thermocouples mounted on the bar : 5
4. No. of thermocouples mounted in the insulating shell : 4

   Cooling water jacket diameter : 100 mm
5. Temperature Indicator (Digital type) : 0 - 199.9 °C
6. Dimmer for control of Heater Coil : 1KW

SI. No.	Voltage	Current	Metal Bar Thermocouple Reading					Insulating Shell Temperature ^{0}c				Cooling Water Temp. in ^{0}c		Mass Flow Rate
	V	A	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	cc/min
01														
02														
03														

SPECIMEN CALCULATIONS

1. Draw the variation of temperature along the length of the bar from the graph.

$\frac{dT}{dx} = \cdots$ … … … … … … … … .. ^{0} C / m

2. Area of the metal rod A $= \frac{\pi d^2}{4}$ =…………… m^2

3. Mass flow rate of cooling water m_w = ………… cc / min

C_{pw} = Specific heat of water = 4187 j/kg ^{o} k

4. Heat flowing out of the bar = Heat carried away by the cooling water dt

$$kA\frac{dT}{dx} = m_w C_{pw}(T_{out} - T_{in})$$

EXPT NO: 2

HEAT TRANSFER THROUGH COMPOSITE WALL

AIM: 1) To determine the overall conductance of the composite wall and compare it with the theoretical value computed from the values of thermal conductivity of the materials and the dimensions of the component walls.

2) To plot the actual temperature distribution across the composite wall and compare it with the theoretical temperature distribution.

THEORY: Derive the expression for overall conductance of a composite wall of layers of three different materials and the equations for determining the interface temperatures.

APPARATUS: The apparatus consists of three slabs of different materials of same thickness clamped on both sides using bolts and nuts. On one side of the composite wall a heater is fitted. End losses from the composite wall are minimized by providing thick insulation all rounds to ensure unidirectional heat flow.

Thermocouples are fitted at the interface of the plates at different points as to obtain average temperature for each surface. Heat conducted through the composite wall is taken away by circulating water on the out side of the wall whose rate of flow and an increase in temperature can be recorded.

EXPERIMENTAL PROCEDURE:

The heat input to the heater is fixed for any desired temperature of the plates. After a steady state is reached, average temperature of the slabs at the inter faces are noted and water flow quantity and the rise in temperature of water are recorded. By varying the heat input to the system through a variac different set of readings can obtained.

CALCULATION PROCEDURE:

Under steady state conditions, heat output through water = $Q = m_w (T_{w0} – T_{w1})$

Where m_w = Mass flow rate of water.

T_{w1} & T_{w0} are Temperature of water at in let and outlet respectively. This is also equal to

$$\frac{K_1 A (T_1 - T_2)}{L_1} = \frac{K_2 A (T_2 - T_3)}{L_2} = \frac{K_3 A (T_3 - T_4)}{L_3} =$$

Where T_1, T_2, T_3 and T_4 are the average temperature of the slab at the various surface a above in the fig.

Assuming standard values for K_1, K_2,K_3 the overall conductance of the composite wall.

$$C = \frac{1}{\frac{1}{A}\left(\frac{L_1}{K_1}+\frac{L_2}{K_2}+\frac{L_3}{K_3}\right)} = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$\text{But } C = \frac{1}{L/AK} = \frac{Q}{T_1 - T_4}$$

This can be compared with the values given by the expression (1).

Temperature distribution across the length of the composite slab is recorded and plotted.

The experiment is repeated for different heat inputs.

DATA SHEET

SPECIFICATIONS:

Diameter of each plate D = 130 mm or 0.13 m

Thickness L1 = L2 = L3 = 4mm or 0.004 m

Material of plate 1 = M .S

Material of plate 2 = Asbestos

Material of plate 3 = copper

TABULATION:

Sl. No	**Temp. of hot plate**				**Temp. of cold plate**				**Time for circulation of 1000cc of cold water**	**Temp. of circulating water at inlet t_{wi}**	**Temp of water at outlet $t_{w0}(t_7)$**	**Power input V X T**
	t_1	**t_2**	**t_3**	**$t_h = \frac{t_1+t_2+t_3}{3}$**	**t_4**	**t_5**	**t_6**	**$t_c = \frac{t_4+t_5+t_6}{3}$**				

SPECIMEN CALCULATION:

TRAIL NO:-

1) Mass flow rate of water $m_w = \frac{500}{1000 \times t} = \frac{0.5}{t} =$ ……………………….kg/sec

2) Energy carried away by water $q = M\ C_P \times (T_{W0} - T_{Wi})$

3) Average temperature of the heater surface $T_h =$ ……………………… ºC

4) Average temperature of the cooling plate surface = $T_c =$ …………………ºC

5) Overall thermal conductance (expt) $C_{expt} = \frac{q}{T_h - T_c} =$ …………………….W/K

6) Overall thermal conductance $\frac{1}{C} = ... W/K$

7) Overall Conductance (theoretical) $= C_{th} = \frac{L_1}{K_1 A_1} + \frac{L_2}{K_2 A_2} + \frac{L_3}{K_3 A_3}$

Thickness of each plate = $L_1 = L_2 = L_3 = 0.004$ m.

Area of each plate=A=$\frac{\pi D^2}{4} = \frac{\pi}{4} \times (0.13)^2 = ...m^2$

$$C_{th} = \frac{0.004}{A} \times \left[\frac{1}{K_1} + \frac{1}{K_2} + \frac{1}{K_3} \right] = ... W/K$$

8) Average temperature of interface of M.S. and asbestos = T_2= ºC

9) Average temperature of interface of asbestos and copper = T_3= ºC

EXPT NO: 3

HEAT TRANSFER THROUGH A PIN FIN WITH NATURAL CONVECTION OF HEAT TO THE SURROUNDINGS.

AIM: i) To determine the heat transfer coefficient for natural convection of heat transfer from the surface of a fin.

ii) To determine the temperature distribution along the length of the fin and compare it with the theoretical temperature distribution.

iii) To find the effectiveness of the fin.

EXPERIMENTAL SETUP:

A brass fin of circular cross section is fitted across a long rectangular duct. One end of the fin projects out side the duct and is heated by an electrical heater. The input to the heater can be varied by means of a variac. Voltmeter and ammeter are provided to measure the input. Thermocouples are embedded along the length of the fin at regular intervals.

PROCEDURE:

1) See general instructions.
2) After an initial reading of all the thermocouples, switch on the heater and adjust the input to the desired value by variac. Note down the ammeter and voltmeter readings.
3) Note down the readings of all the thermocouples every half an hour until the steady state is reached.
4) The experiment is repeated for different inputs.

DATA SHEET

Length of the fin L = 150mm.

Diameter of the fin D = 10mm

Material of the fin = Brass.

TABULATION:

Trail No	Voltmeter Reading V (volts)	Ammeter reading I (amps)	Thermocouple readings (^{0}C)				
			T_1	T_2	T_3	T_4	$T_5 = T_a$
1							
2							
3							

SPECIMEN CALCULATION

TRIAL NO:

1) Average surface temperature $T_s = \frac{T_1 + T_2 + T_3\ T_4}{4} =$ ^oC

2) Ambient temperature $T_a = T_5 =$ ^0C

3) Power input =Rate of heat transfer through the fin to the surrounding Q = V I= Watts

4) Surface area of the fin A = ∏DL = m^2

5) Average surface heat transfer coefficient $\bar{h} = \frac{VI}{\Pi DL\,(T_s - T_a)} =$ $W / m^2 K$.

(Assume end of the fin is insulated) Evaluation of heat transfer coefficient of fluid properties.

6) Mean fluid temperature $T_f = \frac{T_s + T_a}{2} =$ ^oC

7) Properties of air at mean fluid temperature $T_f =$ ^0C

(From HTDHB)

i) Kinematic viscosity = γ = m^2 / s
ii) Density of air = ρ = k_g / m^3
iii) Thermal conductivity of air = K_f = w/m K
iv) Dynamic viscosity μ = kg / m s
v) Specific heat C_P = J / kg K
vi) Prandtl number P_r =
vii) Coefficient of volume expression $\beta = \frac{1}{T_f + 273} =$ K^{-1}

Where $\Delta T = T_s - T_a$ and L = D = Dia of the fin.

8) Grashoff number $G_r = \frac{\beta g \Delta T L^3}{\gamma^2} =$

9) $G_r \times P_r$ =

10) Nusselt no. $N_u = C \times (G_r \times P_r)^m$

(Read the value of C & m from the HTDHB corresponding to the value of $G_r \times P_r$)

11) Heat transfer coefficient = $h = \frac{N_u \times K_f}{L} =$

12) $m = \sqrt{\frac{hp}{KA}} = \sqrt{\frac{h \times \Pi D}{K \times \frac{\Pi D^2}{4}}} = \sqrt{\frac{4h}{KD}}$ = Where K = thermal conductivity of brass.

13) Temperature distribution is given by $\frac{T - T_a}{T_b - T_a} = \frac{\cosh m(L - x)}{\cosh mL}$

Where L= Length of the tube, T_b = Temperature at the base of the fin = T_1+2 = ^oC.

14) Heat transfer through the fin = q_{fin} = mKA (T_s – T_a) tanh mL= Watts.

15) Effectiveness of the fin = $\frac{\tanh mL}{mL}$ =

TABULATION OF RESULTS

Temperature along the fin	**T_1 (^oC)**	**T_2 (^oC)**	**T_3 (^oC)**	**T_4 (^oC)**
Theoretical (Calculated from fluid properties)				
Experimental (Measured)				

Average surface heat transfer coefficient $\bar{h}$ =

Heat transfer coefficient calculated from fluid properties h_{cal} =

Rate of energy input q = V I = Watts

Rate of heat transfer through the fin q_{fin} = Watts

Graphs:

i) Theoretical temperature distribution = T vs x

ii) Experimental temperature distribution = T vs x

EXPT NO: 4

HEAT TRANSFER BY NATURAL CONVECTION OVER A VERTICAL TUBE

AIM : To determine the values of theoretical and average heat transfer coefficient for natural convection and plot a graph of local heat transfer coefficient versus distance along the tube.

THEORY:- when hot surface is kept in atmosphere heat is transferred to the surrounding fluid by natural convection. The fluid layer in contact with the hot body gets heated and rises up due to decrease in its density and the colder fluid rushes in to occupy the place of the heated fluid. Thus the convection current is set up. The movement of the fluid is entirely due to the density difference of the fluid which in turn is due to the difference in temperature.

DESCRIPTION OF THE APPARATUS:- The apparatus consists of a copper tube fitted in a rectangular duct in a vertical fashion. The duct is open at the top and bottom and forms an enclosure and serves the purpose of undistributed surroundings. One side of the duct is made up of a Perspex sheet for visualization. An electrical heating element is kept inside vertical tube which is used to the tube surface. The heat is lost from the tube to the surrounding air by natural convection. The surface temperature of the vertical tube is measured by seven thermocouples. The heat input to the heater is measured by the voltmeter and ammeter readings and is varied by dimmer stat.

PROCEDURE :

1) Switch on the supply and adjust the power input to obtain the required heat input.
2) Wait till steady state is reached by observing the temperature readings T1 to T7 from time to time.
3) Note down the readings of the thermocouples 1 to 7 and the ambient temperature T8.
4) Repeat the experiment for different values of energy input.

DATA SHEET

SPECIFICATION:

Diameter of the tube D = 42mm or 0.042m

Length of the tube L = 500mm or 0.5m

Number of thermocouple junctions = 7

Spacing between thermocouple locations = 70mm or 0.07m

Type of thermocouple = Iron constantan.

TABULATION OF READINGS:-

Trail	Volt meter reading	Ammeter reading	Thermocouple readings (^{0} C)

No	V (volts)	I (amps)	T_1	T_2	T_3	T_4	T_5	T_6	T_7	$T_8 = T_a$
1										
2										
3										

SPECIMAN CALCULATION:-

1) Ambient temperature $T_a = T_8 =$ ^oC

2) Power input = Rate of heat transfer from the vertical tube Q = V I = Watts.

3) Average heat transfer coefficient $\bar{h} = \frac{V\,I}{A\,\Delta T} = \frac{V\,I}{\Pi D L\,(T_S - T_a)} =$ $W/m^2\,K$

Computing local and average heat transfer co-efficient from fluid properties and Empirical relations:

4) Mean film temperature $T_f = \frac{T_s + T_a}{2} =$ $^0\,C$

5) Fluid properties from the H.T. data hand book at $T_f =$ ^oC

$\rho =$ Kg / m^3

$\mu =$ Kg / ms

$C_P =$ J / KgK

$K_f =$ W / mK

$\beta = \frac{1}{T_f + 273} =$ K^{-1}

$\gamma =$ m^2 / s

$P_r =$

6) $\Delta T = T_S - T_a$

7) Grashoff number = $Gr = \frac{\beta\, g\, \Delta T\, L_c^3}{\nu^2} =$

Where L_C = Vertical length of the tube in m = x

8) $Gr \times Pr =$

9) Corresponding to $Gr \times Pr =$ from HTDHB

$Nu_x =$

10) Local heat transfer coefficient h_{Lx} at $x = x_1$ $= Nu_x \times \frac{K_f}{x_1} =$

11) Average Nusselt No over the length $x_1 = Nu_{x-x1} = \frac{4}{3} \times Nu_{x-x1} =$

12) Average heat transfer coefficient over the length x_1 = $h_{x=x_1} = \frac{4}{3} \times Nu_{x=x_1} =$

TABULATION OF RESULTS:-

Distance from leading edge X (mm)	4	11	18	25	32	39	46	50
Local nusselt no.								
Average nusselt no.								
Local heat transfer coefficient h_x(w/m^{2}k)								
Average heat transfer coefficient h_x(w/m^{2}k)								

Graphs

h_x v/s X

$\bar{h}$ v/s X

EXPT NO: 5

HEAT TRANSFER THROUGH A PIN FIN WITH FORCED CONVECTION OF HEAT TO THE SURROUNDIGS.

AIM: 1) To determine the heat transfer coefficient for forced convection heat transfer from the surface of pin fin.

2) To determine the temperature distribution along the length of the fin and compare it with the theoretical temperature distribution

3) To find the effectiveness of the fin

EXPERIMENTAL SET UP: A brass fin of circular cross section is fitted across a long rectangular duct. One end of the fin projects outside the duct and is heated by an electrical heater. The input to the heater can be varied by means of a variac. The input can be measured by a voltmeter and an ammeter. Thermocouples are embedded at regular intervals along the length of the fin. An air blower is fitted at the end of the duct to draw air across the fin perpendicular to its axis. A control valve is fitted on the delivery side of the blower to vary the air flow rate. A calibrated orifice is also fitted in the delivery pipe to measure the air flow rate. A water manometer is provided to measure the pressure difference across the orifice.

PROCEDURE:

1) See general instructions
2) After an initial reading of all the thermocouples switch on the heater and adjust the input to the desired value by the variac. Note down the ammeter and voltmeter readings.
3) Switch on the blower and adjust the control valve for a desired discharge.
4) When the steady state is reached note down the following readings.
   The readings of the thermocouples 1,2,3,4 and 5.
   The manometer reading in mm of water.

DATA SHEET

SPECIFICATIONS:

Length of the fin L = 150 mm or 0.15 m

Diameter of the fin D = 10 mm or 0.01 m

Area of the duct A_d = (150 x 100) mm^2 or 0.015 m^2

Diameter of the orifice d_0 = 20mm or 0.02 m

Coefficient of discharge C_d = 0.6

Room pressure P_a = 700 mm of H_g

TABULATION OF READINGS

Trail NO	Voltmeter Reading V(volts)	Ammeter reading I (amps)	Manometer reading h_w mm of water	Thermocouple readings (^{0} C)				
				T_1	T_2	T_3	T_4	$T_5 = T_a$
1								
2								
3								
4								

SPECIMEN CALCULATION
Trail no:-

1. Temperature at the base of the fin = $T_b = (T_1 + 2)$ = ^{0} C

2. Room pressure = P_a = 700mm of H_g or $\frac{700 \times 1.01325}{760}$ =…………………..bar

3. Room temperature = $T_a = (T_5 + 273)$ = K.

4. Density of air at R.T.P. = $\rho_a = \frac{p_a \times 10^5}{R\,T_a}$ =………………………… kg/m^3

   [R= 287.25J/kg-K].

5. Air head causing flow of air through the orifice

   $h_a = \frac{\rho_a \times h_w}{\rho_a \times 1000} = \frac{1000 \times h_w}{\rho_a \times 1000}$ =…………..m of water

6. Volume flow rate of air through the orifice Q

   $Q = C_d \times A_0 \times \sqrt{2gh_a} = C_d \times \frac{\Pi\, d_0^2}{4} \times \sqrt{2gh_a}$ =…………………m^3/sec

7. Velocity of air flow through the duct $V = \frac{Q}{\text{Area of duct}}$ = ……………. m/s

8. Average temperature of the fin surface $T_s = \frac{T_1 + T_2 + T_3 + T_4}{4}$ = ………………^0C

9. Mean film temperature of the fluid $T_f = \frac{T_s + T_a}{2}$ =………………………..^0C

10. Properties of air at mean film temperature T_f =
(From HTDHB)

i) ρ = kg/m^3
ii) μ = kg/ms
iii) γ = m^2/s
iv) C_P = J / kg K
v) K_f = w / m K
vi) P_r =

11. Reynolds number $R_e = \frac{VD}{\gamma}$ =

12. Corresponding to this Renold's Number read the values of C, m and n in the equation

$N_u = C \times R_e^m \times P_r^n$

$N_u = \frac{hD}{K_f}$ =

13. Heat transfer coefficient $h = \frac{N_u \times K_f}{D}$ =

14. $m = \sqrt{\frac{hP}{KA}} = \sqrt{\frac{4h}{KD}}$ =………………………m^{-1}
(K= thermal conductivity of brass)

15. $Q_{fin} = mKA \times (T_s - T_a) \times \tanh mL$= …………………watts

16. Effectiveness of the fin = $\frac{\tanh mL}{mL}$ =

17. Energy input to the fin = heat transfer through the fin Q = V I watts

18. Average value of heat transfer coefficient $\bar{h} = \frac{VI}{\Pi DL (T_s - T_a)}$ = w/ m^2 k

19. Temperature distribution (theoretical) given by

$$\frac{T_x - T_a}{T_b - T_a} = \frac{\text{Cosh } m (L - X)}{\text{Cosh } mL}$$

T_1 =
T_2 =
T_3 =
T_4 =

TABULATION OF RESULTS

Distance from the base of the fin	X_1=	X_2=	X_3 =	X_4=
Temperature along the fin	T_1 (^{0}C)	T_2 (^{0}C)	T_3 (^{0}C)	T_4 (^{0}C)

Theoretical (Calculated using fluid properties)				
Experimental (measured) (Thermocouple readings)				

HEAT TRANSFER COEFFICIENT

From fluid properties h =

From experiment $\bar{h}$ =

EXPT NO: 6

DETERMINATION OF THE EMISSIVITY OF A TEST SURFACE

OBJECT: To determine the emissivity of the test surface and plotting a graph of emissivity versus temperature.

THEORY: All surfaces irrespective of their temperature emit as well as absorb radiant energy. The rate of emission is a function of the surface properties and temperature. Unless a surface is exposed to vacuum, other modes of heat transfer will exist, apart from radiant heat transfer.

It is possible to evaluate the emissivity of a surface by a comparison method, even in the presence of convection. Let surface R be a reference surface whose emissivity is known and S be the surface under test whose emissivity has to be determined. Let the two surfaces have the same shape and be located in such away that the flow geometry around them is identical. Heat loss from each surface will have a radiative component and a connective component. Thus we can write.

$Q_R = Q_{R_{rad}} + Q_{R_{conv}}$ for the reference surface.

$Q_R = Q_{R_{rad}} + Q_{R_{CONV}}$ For the test surface

Let ™$_R$ and ™$_S$ be the emissivity of there reference and the test surfaces respectively, T_R and T_S their temperatures in Kelvin and h_R and h_S their surface heat transfer co-efficient. Let T_a be the temperature of air surrounding both the surfaces.

Then $Q_R = A_P$ ™$_R$ $\sigma (T_R^4 - T_a^4) + A_P h_R (T_R - T_a)$

Then $Q_S = A_P$ ™$_S$ $\sigma (T_S^4 - T_a^4) + A_P h_S (T_S - T_a)$

In the experiment T_{RS} and T_a can be measured. If Q_R and Q_S are so adjusted that T_R and T_S are almost equal (And if the surface R is a Black surface, i.e. ™$_R$ = 1), we can assume $h_R = h_S$.

Then $Q_R - Q_S = A_P \sigma (T_R^4 - T_a^4)$ (™$_R$ - ™$_S$) = (1 - ™$_S$) $A_P \sigma (T_R^4 - T_a^4)$

$$\text{Therefore} \quad \varepsilon_S = 1 - \frac{Q_R - Q_S}{A_P \, x (T_R^4 - T_a^4)}$$

EXPERIMENTAL SET UP: The experimental set up consists of two geometrically similar circular sand witch heater plates mounted in a horizontal position. The plates are located symmetrically within the glass enclosure. One plate has its surface coated with lampblack. This is the reference surface. The other plate is the specimen plate.

The heater coils with in the plates are wound to provide a nearly uniform temperature of the surfaces. Each coil is connected to the mains through a dimmer start. The power in put is measured by means of an ammeter and a voltmeter. The temperatures of the two plates are measured by a number of Iron-constantan thermocouples. One thermocouple is kept in the enclosure to measure the ambient temperature. The thermocouples are connected to a digital voltmeter through a selector switch.

(The digital voltmeter is calibrated to read the temperatures directly)

PROCEDURE

1) See general instruction.
2) After an initial reading of all the thermocouples, switch on the heaters.
3) First give the power in put the black surface. Adjust it to some desired value.
4) Then give the power input to the black surface and adjust the value to the slightly less then the input to the black surface.
5) When steady state is reached, measure the temperatures given by the three thermocouples connected to the black surface and take their average value.
6) Similarly measure the temperatures given by the three thermocouples connected to the test surface and take their average. Ideally both the average temperatures should be equal. If they are not equal, adjust the power input to the test plate and wait for the steady state to be attained and then note down the temperatures.
7) Note down the ambient temperature.
8) Repeat the steps 3 to 7 for different power inputs.

DATA SHEET

SPECIFICATION:

Diameter of the test surface D = m

Number of Thermocouples = 7

1, 2, 3 - Black surface.

4, 5, 6 - Gray or test surface.

7 - Ambient or enclosure.

TABULATION OF READINGS:-

Trail no	Block surface temp			Test surface temp			Ambient Temp	Input to black surface		Input to test surface	
	T_1	T_2	T_3	T_4	T_5	T_6	$T_7 = T_a$	V_B	I_B	V_S	I_S
1											
2											
3											

SPECIMEN CALCULATION:-

TRAIL NO:-

1) Area of the test surface A= $\frac{\Pi D^2}{4}$ = m^2

2) Power input to the black surface $Q_B = V_B I_B =$ ……………… watts.

3) Power input to the test surface $Q_S = V_S I_S =$…………………. watts

4) Average temperature of black surface $T_B = \frac{T_1 + T_2 + T_3}{3} + 273 =$ K

5) Average temperature of test surface $T_S = \frac{T_4 + T_5 + T_6}{3} + 273 =$ K

6) Ambient temperature $T_a = T_7 + 273 =$ K

1) Stefan Boltzman constant $\sigma = 5.67 \times 10^{-8}$ W/m^2 K^4

2) Emissivity of test surface = $\in = 1 - \frac{Q_B - Q_S}{A\,\sigma\,(T_S^4 - T_a^4)}$ =

EXPT NO: 7

DETERMINATION OF STEFAN BOLTZMANN CONSTANT

OBJECT: To determine the value of Stefan Boltzmann constant for radiation heat transfer.

PRINCIPLE: The energy exchange between a small black body located at the centre of a hemispherical surface is given by $q_{1-2} = \sigma A (T_1^4 – T_2^4)$ or $\sigma = \frac{q_{1-2}}{A(T_1^4 - T_2^4)}$

Where A is the surface area of the small body.

The method consists of maintaining the hemispherical surface to a desired constant high temperature by supplying preheated water at a temperature close to boiling point on the outside of the hemispherical dome. A small copper disc coated with lamp black is introduced at the center of the hemisphere and the rate of temperature rise of the disc is determined. Then by equating the rate of radiation energy exchange between the hemispherical surface and the disc to the rate of energy absorption by the disc, the Stefan Boltzmann constant is evaluated.

APPARATUS: The fig shows the cross sectional view of the apparatus.

PROCEDURE:

a) Fill the water in the upper tank.
b) Switch on the immersion heater and heat it up to 90^o C.
c) Remove the disc `D' before pouring the water into the lower tank.
d) Switch off the heater and open the valve and allow the water into the second tank.
e) Allow it to reach steady state.
f) Note down the thermocouple temperatures T_1, T_2, T_3, T_4 & T_5.
g) Insert the disc and immediately note the temperature T_6 at every five seconds interval from zero seconds.
h) Draw the graph of temperature v/s time and find $\frac{dT}{dt}$
i) Calculate ` σ ' using the equation : $\sigma = \frac{m.s.(dT / dt)}{A_o (T^4 - Ts^4)}$

DATA SHEET

Mass of the disc, m = 5 g or 5×1^{-3} kg.

Material of the disc copper.

Specific heat of the material C_P = 385 J/kg K.

Diameter of the disc d = 20 mm or 20×10^{-3} m.

TABULATION OF READINGS

TRIAL NO.	THERMOCOUPLE READINGS (^{O}C)				
	T_1	T_2	T_3	T_4	T_5
1					
2					
3					

VARIATION OF TEMPERATURE V/S TIME OF THE SPECIMEN

TRIAL 1		TRIAL 2		TRIAL 3	
TEMP (^{O}C)	TIME SEC	TEMP (^{O}C)	TIME SEC	TEMP (^{O}C)	TIME SEC
	0		0	0	

STEFAN BOLTZMANN CONSTANT

Area of the disc = $A_1 = \frac{\Pi d^2}{4} =$ m^2.

Mass of the disc, m = 5×10^{-3} kg.

Specific heat of the disc material (Copper) C_P = 385 J/Kg K.

Temperature of the hemispherical surface = $T_e = \frac{T_1 + T_2 + T_3 + T_4 + T_5}{5}$ = ^{o}C or K.

Average temperature of the disc t_s = ^{o}C.

or $T_s = t_s + 273 =$ K.

Rate of temperature rise of the disc = $\frac{dT}{dt}$ = (From graph)

Rate of energy absorption by the disc = $m \times C_P \times \frac{dT}{dt}$ =   w.

Rate of radiation energy exchange between the disc and the enclosure

$= \sigma \times A_1 x F_{12} \times (T_e^4 - T_s^4)$ w.

Where σ is the Stefan Boltzmann constant, $F_{12} = 1$ for a small body in a large enclosure.

Equating Rate of radiation energy exchange to rate of energy absorption by the disc, we

Get $\sigma \times A_1 x F_{12} \times (T_e^4 - T_s^4) = m \times C_P \times \frac{dT}{dt} =$

$$\therefore \text{ Stefan Boltzmann constant } \sigma = \frac{m \times C_P \times \frac{dT}{dt}}{A_1 \times (T_e^4 - T_s^4)} =$$

Graph : Temp v/s Time

EXPT NO : 8

HEAT EXCHANGER

OBJECT: To determine the Logarithmic Mean temperature difference and the overall heat transfer coefficient of a tube in tube heat exchanger for both parallel flow and counter flow.

THEORY : 1) What is a heat exchanger ?

2) Classification of heat exchangers.
3) Derivation of the equation for LMTD.
4) Determination of heat exchanger effectiveness
5) What is fouling factor?

DESCRIPTION OF THE EXPERIMENTAL SET UP :

The apparatus consists of a concentric tube in tube heat exchanger. The hot fluid that is hot water is obtained from an electric geyser and it flows through the inner tube. The cold fluid which is cold water can be admitted from any one of the ends, enabling the heat exchanger to be run as a parallel flow or a counter flow heat exchanger. This can be done by operating the different valves provided. Temperatures of the fluids can be measured by the thermometers. Flow rates of hot and cold fluids can be measured by collecting the water in a measuring jar and noting down the time by a stop watch. The outer tube is provided with adequate asbestos rope insulation to minimize the heat loss to the surroundings.

PROCEDURE :

1) The thermometers are kept in the various thermometer pockets provided.
2) The flow of water is started on the hot water side.
3) The geyser is switched on.
4) The flow rate of hot water is adjusted to desired value from 2 to 5 liters/min.
5) The flow rate of cold water is adjusted to the about 4 to 5 liters/min.
6) Keeping the flow rates constant, temperature of cold and hot fluids at inlet and exit are noted after the steady state has been reached.
7) The procedure is repeated for different flow rates and for parallel and counter flow.

Data sheet

Length of heat exchanger L = 1.3 m

Inner dia of inner tube d_I = 16.7 mm

Outer dia of inner tube d_o = 21.4 mm

Inner dia of outer tube D_i = 37 mm

Outer dia of outer tube D_o = 40 mm

Tabulation of readings

Trial No:	Type of flow	Hot water			Cold water		
		Time for collecting 1000cc of water t_h sec	Inlet temp T_{hi} ^{0}C	Outlet temp T_{ci} ^{0}C	Time for collecting 1000cc of water t_c sec	Inlet temp T_{ci} ^{0}C	Outlet temp T_{co} ^{0}C
1	**Parallel flow**						
2	**Parallel flow**						
3	**Counter flow**						
4	**Counter flow**						

SPECIMEN CALCULATION

PARALLEL FLOW: TRIAL NO:

ΔT_1 = Temperature difference at section 11 = $(T_{hi} - T_{ci})$

ΔT_2 = Temperature difference at section 22 = $(T_{ho} - T_{co})$

$$\textbf{L.M.T.D.} = \frac{\Delta T_1 - \Delta T_2}{1n \dfrac{\Delta T_1}{\Delta T_2}}$$

To find U_o = Overall heat transfer coefficient referred to outer surface area.

Mass flow rate of hot fluid $m_h = \dfrac{1000}{t_h \times 1000} = \dfrac{1}{t_h}$ Kg / sec.

Heat lost by hot fluid $q_n = m_n \times C_P \times (T_{hi} - T_{co}) =$ J / sec.

(C_P = 4.187 KJ / Kg ^{o}C or 4187 J / Kg ^{o}C)

$mc = 1 / t_c =$ Kg / sec.

Heat gained by cold fluid $q_c = mc \times C_{Pc} \times (T_{co} - T_{ci}) =$ J / sec.

Average heat transfer = $\dfrac{q_h + q_c}{2}$ = J / sec.

Area of heat transfer surface $A = \pi\, d_o \times L$ = m^2

Overall heat transfer coefficient $U = \dfrac{q \text{ in J/sec}}{A \times L.M.T.D.}$ = $W / m^2 K$

Effectiveness $= \dfrac{\dot{m}_h\, Cp_h\, (T_{hi} - T_{ho})}{(\dot{m}\, C)_{min}\, (T_{hi} - T_{ci})}$ =

Calculation of U_o from fluid properties $\dfrac{1}{U_O} = \dfrac{r_o}{r_i} \times \dfrac{1}{h_i} + \dfrac{r_o \ln \frac{r_o}{r_i}}{K} + \dfrac{1}{h_o}$

To find h_i

$T_{bh} = \dfrac{T_{hi} + T_{ho}}{2}$ = ^oC

Read properties of water at T_{bh}

ρ =

C_p =

K_f =

P_r =

γ =

$A_i = \dfrac{\Pi\, d_i^2}{4}$ = m^2

$V_h = \dfrac{m_h}{\rho_h\, A_i}$ = m/sec

$R_e = \dfrac{V_h\, d_i}{\lambda}$ =

$N_u = C \times R_e^m \times P_r^n$ =

$N_u = \dfrac{h_i \times d_i}{K_f}$ =

h_i =

To find h_o

$m_c = \rho_c\, A_c \times V_c$ = Kg / sec

$A_c = \dfrac{\Pi}{4}\, (D_i^2 - d_o^2)$ = m^2

$T_{bc} = \dfrac{T_{ci} + T_{co}}{2}$ = ^oC

Read properties of water at T_{bc}

ρ = ………………….

C_p =…………………..

K_f =…………………….

P_r =…………………….

γ = ………………….

$V_c = \frac{m_c}{\rho_c\, A_c}$ = m / sec.

$R_e = \frac{V_c\, d_c}{\gamma}$ =

$(d_c = Di - d_o)$

$N_u = C \times R_e^m \times P_r$ =

$N_u = \frac{h_o\, d_c}{K_f}$ =

h_o =

$$\frac{1}{U_0} = \frac{r_0}{r_i} \text{ x } \frac{1}{h_i} + \frac{r_0 \ln \frac{r_0}{r_i}}{K} + \frac{1}{h_0} =$$

U_0 = ………………………….

COUNTER FLOW : TRAIL NO :

ΔT_1 = Temperature difference at section 11 = $(T_{hi} - T_{co})$ = ^oC

ΔT_2 = Temperature difference at section 22 = $(T_{ho} - T_{ci})$ = ^oC

$$\text{L.M.T.D} = \frac{\Delta T_1 - \Delta T_2}{\ln \frac{\Delta T_1}{\Delta T_2}}$$

To find U_o = Overall heat transfer coefficient referred to outer surface area.

Mass flow rate of hot fluid $m_h = \frac{1000}{t_h \times 1000} = \frac{1}{t_h}$ Kg / sec.

Heat lost by hot fluid $q_n = m_n \times C_P \times (T_{hi} - T_{co})$ = J / sec.

(C_P = 4.187 KJ / Kg ^oC or 4187 J / Kg ^oC)

mc = 1 / t_c = Kg / sec.

Heat gained by cold fluid $q_c = mc \times C_{Pc} \times (T_{co} - T_{ci})$ = J / sec.

Average heat transfer = $\frac{q_h + q_c}{2}$ = J / sec.

Area of heat transfer surface $A = \pi\, d_o \times L \;=$ m^2

Overall heat transfer coefficient $U = \dfrac{q \text{ in J/sec}}{A \times L.M.T.D.} =$ $W / m^2 K$

Effectiveness $\varepsilon = \dfrac{\dot{m}_h\, Cp_h\, (T_{hi} - T_{ho})}{(\dot{m}\, C)_{min}\, (T_{hi} - T_{ci})} =$

Calculation of U_o from fluid properties $\dfrac{1}{U_O} = \dfrac{r_o}{r_i} \times \dfrac{1}{h_i} + \dfrac{r_o \ln \frac{r_o}{r_i}}{K} + \dfrac{1}{h_o}$

To find h_i

$T_{bh} = \dfrac{T_{hi} + T_{ho}}{2} =$ ^oC

Read properties of water at T_{bh}

ρ =………………….

C_p =………………….

K_f =…………………

P_r =………………….

γ =…………………..

$A_i = \dfrac{\Pi\, d_i^2}{4} =$ m^2

$V_h = \dfrac{m_h}{\rho_h\, A_i} =$ m/sec

$R_e = \dfrac{V_h\, d_i}{\lambda} =$

$N_u = C \times R^m_e \times P_r^n =$

$N_u = \dfrac{h_i \times d_i}{K_f} =$

$h_i =$

To find h_o

$m_c = \rho_c\, A_c \text{ x } V_c =$ Kg / sec

$A_c = \dfrac{\Pi}{4}\, (D^2_i - d^2_o) =$ m^2

$T_{bc} = \dfrac{T_{ci} + T_{co}}{2} =$ ^oC

Read properties of water at T_{bc}

ρ =

C_p =

K_f =

P_r =

γ =

$$V_c = \frac{m_c}{\rho_c\ A_c} = \qquad \text{m / sec.}$$

$$R_e = \frac{V_c\ d_c}{\gamma} =$$

($d_c = Di - d_o$)

$$N_u = C \times R_e^m \times P_r =$$

$$N_u = \frac{h_o\ d_c}{K_f} =$$

h_o =

$$\frac{1}{U_0} = \frac{r_0}{r_i} \text{ x } \frac{1}{h_i} + \frac{r_0 \ln \frac{r_0}{r_i}}{K} + \frac{1}{h_0} =$$

U_0 =

EXPT NO : 9

BOILING & CONDENSATION

AIM: To Find the Heat Transfer Coefficient of Condensation Apparatus.

INTRODUCTION:

CONDENSATION: Fluid in a gaseous or vapour phase changes to a liquid state with the liberation of heat from the vapour.

When a vapour is in contact with a surface whose temperature t_s is lower than the saturation t_{sat} corresponding to the vapour pressure, the condensation sets in and the vapour changes to liquid phase. The condensation of vapour liberates latent heat and there is heat flow to the cooled surface and that may get eventually result in more vapour to condense on the exposed surface or upon the previously formed condensate.

SPECIFICATIONS:

1) Condenser: One copper coil for condensation dimensions-dia = 10mm,
   Length = 1000mm, material is copper
2) Main unit: M.S. fabricated construction comprising of test section and generator.
   Test section is provided with glass cylinder for visualization of the process. It also houses rotameter and necessary piping and valves to connect condenser in operation.
3) Steam generator: Suitable for above experiment with electric heater and safety buzzer
4) Instrumentation:
   i) Multi channel digital temperature indicator with cold junction cold compensation with thermocouples.
   ii) Rotameter to measure flow rate of water flowing through condenser Range –60 to 600LPM
   iii) Pressure gauge.

5) Control panel: Separate control panel to house temperature indicator, necessary switches, steam generator safety circuit etc.

PROCEDURE:

1. Fill up the water in steam generator.
2. After filling the water close to the top cover of the steam generator. Start water flow through on the condenser and note down the flow rate in rotameter. Ensure that during measurement, water is flowing only through the condenser under test.
3. Switch on the heater.
4. Slowly steam generation will start in the steam generator of the unit and the steam rises to the test section, gets condensed and falls down in the cylinder.
5. If the water flow rate is low then steam pressure in the chamber will rise and pressure gauge will read the pressure. If the water flow rate is changed then the condensation will accuor at more or less atmospheric pressure.
6. Observations like temperature, water flow, pressure are noted down in the observation table at the end of each set.

TABULATION OF READINGS:-

Trail No	Water flow rate Steam pressure		Temperature ^{0}C			
	LPH	kg/cm^2	T_1	T_2	T_3	T_4
1						
2						
3						

PRECAUTIONS:

1. Do not start heater supply unless water is filled in the steam generator. If water is insufficient in the steam generator, you will get buzzer sound from control panel.
2. Operate gently the selector switch of temperature indicator as will as control valves.

SPECIMEN CALCULATION

Normally steam will not be pressurized. But if pressure gauge reads some pressure then properties of steam should be taken at that pressure or other wise atmospheric pressure will be taken. We will first calculate that heat transfer coefficient inside the condenser under test. For this properties of water are taken at bulk mean temperature i.e;

$\frac{T_{wi} + T_{W0}}{2}$ = T_{bm}. Bulk mean temp. See the properties.

Where T_{wi} = Water inlet temp to the condenser and

T_{wo} = water outlet temp from the condenser.

.

READ PROPERTIES OF WATER AT T_{BM}

Density of water ρ_w = …………………….kg/m^3

Kinematic viscosity γ = …………………...m^2/s

Thermal conductivity K =…………………W/m-k

Prondle number P_r =……………..

Now Reynolds number:

$$R_e = \frac{4\,m_w}{\Pi\, D_1 \mu} =$$

Where D_1 is inner dia of condenser =10mm

m_w is mass flow rate

This value of R_e > 2100 then flow is turbulent and below this value is laminar. Normally flow will be turbulent of the pipe.

Now Nusselt number:

$$N_u = 0.023\,(R_e)^{0.8} \times (P_r)^{0.4}$$

And $h_i = \frac{N_u\, K}{L}$ = ………………………. W/m^{2}k

Where h_i is inside heat transfer coefficient.

Now, calculate heat transfer coefficient on the outer surface of the condenser, for this properties of water are taken at bulk mean temperature of condenser

i..e, $T_{bm} = \dfrac{T_s + T_w}{2}$

Where T_s = Temperature of steam in ^0C

T_w = Temperature of condenser wall ^0C

READ PROPERTIES AT T_{BM} (CONDENSER)

Density of water ρ_w = ...kg/m^3

Thermal conductivity K =………………w/m-k

Viscosity of condensate μ =…………………N-s /m^2

Heat of evaporation λ = …………………….KJ/kg

$$h_0 = 0.943 \left[\frac{\lambda \rho g K^3}{(T_s - T_w) L} \right]^{0.25}$$

Length of condenser L = 1000mm

From these values overall heat transter coefficient U can be calculated as

$$\frac{1}{U} = \frac{1}{h_i} + \frac{D_i}{D_0} + \frac{1}{h_0} = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

EXPT NO : 10

DETERMINATION OF THERMAL CONDUCTIVITY OF AN INSULATING MATERIAL BY THE GUARDED HOT PLATE METHOD.

AIM : To find the thermal conductivity of an insulating material.

PRINCIPLE : The apparatus is designed on the guarded hot plate principle. The fig. shows the cross section of the apparatus. It consists of the central heater assembly. The central plate is surrounded by a guard ring which is separately heated. Two specimen are heated on the either side of the assembly to ensure that all the heat comes out through the specimen only. The specimen is held between the hot plate and cold plate both above and below the heater assembly. The primary and guard heaters are made up of mica sheets which is wound with closely spaced Nichrome wire and packed with upper and lower mica sheets. These heaters together form a flat piece which with upper and lower copper pads and rings form the heater plate assembly. The guard ring heater is used to ensure that heat transfer through the specimen is unidirectional and to eliminate the distortion caused by edge losses. Thermocouple 1 to 6 are embedded as shown in the fig. to measure the temperatures. Knowing the power input to the central heater the temperature difference across the specimen ,the dimensions of the specimen, K thermal conductivity of the specimen can be calculated.

TEST PROCEDURE

3) See general instructions no.4
4) After an initial reading of all the thermocouples switch on the heaters.
5) Keep the transformer to zero voltage position and then gradually increase it to the desired value taking care that the power input does not exceed 200W.
6) Adjust the power input to the guard heater through the separate auto transformer provided for the purpose, so that the temperatures of the central heater plate are almost same. This will ensure that the heat transfer is predominantly one dimensional.
7) Note down the readings of all the thermocouples at every 30 minutes till the temperatures shows steady values.
8) When the temperatures are steady tabulate the values finally.

DATA SHEET

SPECIFICATIONS :

Diameter of central heating plate = 100 mm

Thickness of central heating plate = 50 mm

Inside diameter of heating ring = 175 mm

Outside diameter of the heating ring = 225 mm

Diameter of specimen D = 225 mm

Thickness of specimen L = 35 mm

TABULATION OF READINGS :

Trial No.	Duration of Time		Cooling Plate		Guard Plate		Central Heater Plate		Central Heater Input		Guard Heater Input	
	Hrs	Min	Top (T_1)	Bottom (T_2)	Top (T_1)	Bottom (T_2)	Top (T_1)	Bottom (T_2)	V_1	I_1	V_2	I_2
1												
2												
3												
4												

SPECIMEN CALCULATION :

TRIAL NO

Energy input Q = VI = Watts. {Rate of heat transfer through the specimen from the Central heater in both the directions }

Thickness of the Specimen L = m

Area of the specimen A = $\frac{\Pi D^2}{4}$ = m^2.

Average temperature of cold plate $T_c = \frac{T_1 + T_2}{2}$ = ^oC.

Then $\frac{Q}{2} = \frac{KA \times (T_h - T_c)}{L}$ =

Or K = Thermal conductivity of the specimen

$$= \frac{Q \times L}{2 \times A \times (T_h - T_c)} =$$ W / m K

EXPT NO: 11

DETERMINATION OF THERMAL CONDUCTIVITY OF LIQUIDS BY THE GUARD RING HEATER METHOD

AIM : To determine the thermal conductivity of liquids and to plot the temperature gradient through the liquid.

PRINCIPLE : As liquids are generally poor conductors of heat, to determine the value of thermal conductivity of liquids and ensure one dimensional steady state heat transfer accurately, the principle of guard ring heater method is employed. The figure shows diagrammatically the construction of the apparatus. It consists of a central vessel in which the liquid whose thermal conductivity is to be determined is stored. The heater is placed at the of vessel to transfer heat in a downward direction through the liquid in order to prevent convection currents being set up. A cooling plate at the bottom of the vessel transfers heat to circulating water. The energy carried away by the circulating water can be calculated by measuring the rate of flow of water and the rise in temperature of water. Thermocouples are placed at regular intervals in the liquid to measure the temperature gradient in the liquid. Knowing the temperature gradient and the rate of heat transfer through the liquid, the thermal conductivity of the liquid determined. Provision is made for running the liquid under test and replacing by any other liquids on which tests have to be conducted.

PROCEDURE

1) Fill the vessel with the specimen liquid whose thermal conductivity is to be determined.
2) Read general instructions.
3) After an initial reading of all the thermocouples switch on the heaters. Adjust the dimmer stats of the two heaters to appropriate voltages. The input to the guard heater will be approximately 50% of the input central heater. Note down the voltmeter and ammeter readings.
4) Regulate the flow rate of the circulating water to around 250 to 300cc/min.
5) Note down the readings of all the thermocouples every 30 minutes till steady state is reached.
6) When the temperature are steady tabulate the values finally.
7) Measure the flow rate of water using a measuring jar and stop watch.
8) Measure the inlet and outlet temperature of water.
9) Repeat the experiment for different values of input.

10) Repeat the experiment for specimens of different liquids.

DATA SHEET

SPECIFICATIONS :

Diameter of vessel D = 100mm

Total depth of liquid L = 100mm

Thermocouple location from the heater plate.

X1 = 25 mm

X2 = 50 mm

X3 = 75 mm

TABULATION OF READINGS.

Trail No	Central heater input		Guard heater Input		Thermocouple readings (^{0} C)								Inlet temp Of water T_{wi} (^{0}C)	Outlet temp Of water T_{w0}(^{0}C)	Time for collection of 500ccof water t (sec)
	V_1 volts	I_1 Amps	V_2 volts	I_2 Amps	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8			

SPECIMEN CALCULATION :

TRAIL NO :

1) Rate of heat transfer through the liquid = Rate of at which energy is carried away by circulating water q. $q = \dot{m} C_p = (T_{W1} - T_{wo}) =$ Watts

2) Mass flow rate of water $m = \frac{500}{1000 \times t} = \frac{0.5}{t} =$ kg/sec

3) Area of the plate $A = \frac{\Pi D^2}{4} = \frac{\Pi \times 0.1^2}{4} =$ m^2

4) Average temperature of the liquid at $X_1 = T_1 = \frac{T_2 + T_3}{2} =$ ^{0} C

at $X_2 = T_2 = \frac{T_4 + T_5}{2} =$ ^{0} C

at $X_3 = T_3 = \frac{T_6 + T_7}{2} =$ ^{0} C

5) $\frac{dT}{dX}$ From the graph = ^{0} C/m

6) Thermal conductivity $K = \frac{q/A}{dT/dX}$ W/mK

TABULATION OF RESULTS

Trail No	Mass flow rate of water $\dot{m}$ (kg/s)	Heat carried away by water q (J/s)	$\frac{q}{A}$ (w/m^2)	$\frac{dT}{dX}$ (^{0}C/m)	K W/mK	Average value of thermal conductivity K
1						
2						
3						
4						

EXPT NO : 12

TRIAL ON A VAPOUR COMPRESSION REFRIGERATOR

AIM: To conduct a trial on a vapour compression refrigerator and determine its co-efficient of performance.

THEORY : i) What is refrigeration ?

ii) Methods of refrigeration.

iii) Definitions of a) Refrigerator b) Heat Pump c) C.O.P. of Refrigerators d) C.O.P. of Heat Pump e) One Tonne of Refrigeration f) Refrigerant.

iv) Show that $C.O.P._{Heat\ Pump} = 1 + C.O.P._{Refigerator}$.

v) Principle of working of V – C refrigerator.

vi) Principle of working of vapour absorption refrigerator.

vii) Comparison of V-C and V-A systems.

viii) Sketch T-S and P-h diagram of V-C refrigeration cycle.

ix) Requirement of a good refrigerant.

x) Some common refrigerants and their important properties.

xi) Applications of refrigeration.

EXPERIMENTAL SET UP : With a neat sketch, briefly describe the set up.

PROCEDURE :

i) Thermometers are kept in the various thermometer pockets provided.

ii) Power supply to the system is switched on.

iii) When the thermometer record steady values the following readings are noted down

a) Reading of pressure gauges and the various thermometers.

b) Energy meter reading at the beginning

iv) The power supply is switched off.

DATA SHEET

REFRIGERANT USED : FREON 12

BAROMETER READING : 700 MM OF Hg

TABULATION OF READINGS

Sl. No.	Particulars	Symbol	Units	
1	Duration of trial	t	S	
2	Pressure at inlet to compressor	P_{g1}	Psi	
3	Pressure at exit of throttle valve	P_{g2}	kgf / cm^2	
4	Pressure at inlet to throttle valve	P_{g3}	kgf / cm^2	
5	Pressure at exit of throttle valve	P_{g4}	Psi	
6	Temperature at inlet to compressor	T_1	^oC	
7	Temperature at exit of compressor	T_2	^oC	
8	Temperature at inlet to throttle valve	T_3	^oC	
9	Temperature at exit of throttle valve	T_4	^oC	
10	Energy meter reading at the beginning of the trial.	E_1	Kw- hr	
11	Energy meter reading at the end of the trial.	E_2	Kw- hr	
12	Time for 5 readings of energy meter disc.	T_e	S	

SPECIMEN CALCULATION

Barometer reading 700 mm of Hg.

Atmospheric pressure $P_a = \frac{1.01325 \times 700}{760} =$ bar.

1) Absolute pressure of refrigerant entering the compressor $P_1 = P_a + P_{g1} \times 0.069$

=……………….. bar.

2) Absolute pressure of refrigerant leaving the compressor $P_2 = P_a + P_{g2} \times 0.981 =$

=………………….bar.

3) Absolute pressure of refrigerant entering the throttle valve $P_3 = P_a + P_{g3} \times 0.981$

=…………….bar.

4) Absolute pressure of refrigerant leaving the throttle valve = $P_4 = P_a + P_{g4} \times 0.069$

= bar

Read the enthalpies of the refrigerants from the pressure enthalpy chart for Freon – 12.

5) Enthalpy of refrigerant entering the compressor at P_1 and T_1 h_1 = KJ/kg.

6) Enthalpy of refrigerant leaving the compressor at P_2 and T_2, h_2 = KJ/kg.

7) Enthalpy of refrigerant entering the throttle valve at P_3, h_3 = KJ/kg.

8) Enthalpy of refrigerant leaving the throttle valve and entering the evaporator at P_4 and T_4, h_4 = KJ/kg.

9) Theoretical coefficient of performance, $COP_{th} = \frac{\text{Energy extracted in the evaporator}}{\text{Work input to the Compressor}}$

$$= \frac{h_1 - h_4}{h_2 - h_1} =$$

10) Energy rejected in the condenser $= h_2 - h_3 =$ kJ/kg.

11) Mass flow rate of refrigerant, $\dot{m} = \frac{\text{Capasity of the unit in Tonnes} \times 3.52}{h_1 - h_4} =$

= kg/s.

12) Theoretical work input to compressor $= \dot{m}\ (h_2 - h_1) =$ kw.

13) Actual work input the unit $= \frac{(E_2 - E_1)}{t} \times 3600 =$ kw.

Alternately

14) Power input $= \frac{\eta_e \times 3600}{1500 \times t_e} =$

1. AIM :

The Air - Conditioning test rig enables

a. To study a vapor compression refrigeration system and determine its coefficient of performance,

b. To study the concept of air conditioning,

c. To understand humidification process and

d. To understand dehumidification process.

2. TOOLS USED: -

(a) Stop watch- To measure the Energy meter readings.

(b) Anemometer - To measure the velocity of air flowing out from duct.

DESCRIPTION OF AIR CONDITIONING TEST RIG :

The test rig essentially consists of a vapor compression refrigeration system, an air conditioning chamber, 2 heaters, one fan / blower, a boiler etc.

The vapour compression Air Conditioning system consists of a compressor, (supposed to be heart of the system) an air cooled condenser, an expansion device (a thermostatic expansion valve and also a capillary is provided of which one can be used at a time by adjusting a hand shut-off valve and the solenoid valve), a Rotameter (to measure the flow rate of liquid refrigerant i.e. R-22), a filter drier and an evaporator. A fan / blower is arranged across the evaporator coil and the coil / fan assembly is incorporated inside a metallic chamber of given cross section and dimensions to cool the flowing air. The system is provided with thermocouples T-i to T_5 to measure the temperatures of the refrigerant at inlet of compressor (suction), inlet to condenser (discharge), outlet to condenser, inlet to evaporator and conditioned air. Four pressure gauges Pi to P_4 are fitted at inlet to compressor (suction) or evaporator outlet, condenser inlet, condenser outlet and evaporator inlet respectively. Dry and wet bulb thermometers are provided at two points on the air conditioning chamber to measure the air conditions. Provision is also made to measure the circulating air flow rate using an orifice and a water manometer and discharge velocity by anemometer. Two heaters are provided to monitor the air condition. A boiler is also provided to supply steam. The test rig is fully instrumented and fool proofing is provided in handling the equipment.

The air conditioning test rig works as a standard vapor compression cycle. A brief account on the standard vapor compression cycle follows :

Pressure Point Details :

Pt Suction Pressure (Evaporator Outlet) P_2 Delivery Pressure (Condenser Inlet) P_3 Delivery Pressure (Condenser Outlet) P_4 Suction Pressure (Evaporator Inlet)

Temperature Point Details :

Tt Inlet to Compressor (Suction). T_2 Inlet to Condenser (Discharge) T3 Outlet of Condenser T_4 Inlet to Evaporator T_5 Conditioned Air

3. THEORY

a. STANDARD VAPOUR - COMPRESSION CYCLE

b. THE SVCC CONSISTS OF THE FOLLOWING PROCESSES:

1 - 2 Reversible adiabatic compression from saturated vapor to a super heated condition (electrical input)

2 - 3 Reversible heat rejection at constant pressure (de superheating and condensation of the refrigeration).

3 - 4 Irreversible isenthalpic expansion from saturated liquid to a low pressure vapor. 4 - 1 Reversible heat addition at constant pressure

The actual cycle differs slightly from the SVCC due to some practical consideration.

R22 (Freons) are commonly used as refrigerants due to their inherent properties.

The coefficient of performance of any refrigeration cycle is defined as the ratio between net refrigeration (output) and compressor work (input).

C.O.P. = Net refrigeration Compression work hi - h_4

(dimension less)

h_2- hi

The C.O.P. value is an indication of how well the system is operating.

The actual vapour compression refrigeration cycle will be slightly different compared to the SVCC. However, the formula remains the same.

C. AIR CONDITIONING PROCESS

The air conditioning process in the system can be represented by combination ,of humidification and dehumidification on a psychrometric chart. One psychrometric is also provided for reference.

i

Mark points 1 and 2 using dry and wet bulb temperatures at each point. Determine specific enthalpy (Kj/Kg of dry air) (on constant enthalpy lines).

Heater can be used to alter the condition of air

Energy transfer (cooling) = hi - h_2 (Kj/Kg of dry air)

Net cooling = m_A x <h_n - h_2) KW

m_A - Mass flow rate of conditioned air in Kg / S

m_A = Anemometer reading (m / s) x Area of duct (m^2) x Density of air (Kg / m^3) **4.**

OPERATING PROCEDURE I INSTRUCTION: -

a. COOLING AND DEHUMIDIFICATION PROCESS

- ❖ Switch ON the mains through stabilizer.
- ❖ Switch ON the condenser cooling fan, evaporator cooling fan and extra cooling fan.
- ❖ Make sure the water level in the wet bulb thermometers is appropriate.
- ❖ Now select the operating system i.e. capillary or thermostatic expansion through
- ❖ solenoid valve and open the corresponding valves(refer valve operating chart)$_v$
- ❖ Switch ON the compressor mains by rotating thermostat (in clockwise direction) fully.
- ♦> Allow the air to flow through the air conditioning chamber and allow it to stabilize.
- ♦> After stabilization, record all the corresponding readings, given under heading of table of readings.

b. COOLING AND HUMIDIFICATION

- ♦> Switch ON the mains through stabilizer.
- ❖ Switch ON the condenser cooling fan, evaporator cooling fan and extra cooling fan.

❖ Make sure the water level in the wet bulb thermometers is appropriate.

♦> A boiler is provided exclusively for generating steam.

Fill the boiler with water up to 3/4th level and close all the valves (Water filling valve, steam allowing valve to the system)

❖ Switch ON the heater provided for the boiler.

❖ Allow 20 - 25 minutes for formation of steam.

❖ Now select the operating system. I.e, capillary or thermostatic expansion through solenoid valve and open the corresponding valves (Ref. Valve operating chart).

❖ Switch ON the compressor mains by rotating thermostat (in clockwise direction) fully.

❖ Allow the air to flow through the air conditioning chamber and allow it to stabilize. ♦> Allow the

steam to the system.

♦> After stabilization record the corresponding readings given under heading of table of readings.

c. HEATING AND HUMIDIFICATION PROCESS

> Switch ON the mains through stabilizer.

> Make sure the water level in the wet bulb thermometers is appropriate. ,

> Fill the boiler with water upto 3/4th level and close all the valves (Water filling valve and steam allowing valve to the system).

> Switch ON the heater provided for the boiler.

> Allow 20 - 25 minutes for formation of steam .

r- Switch ON the evaporator cooling fan and allow the air to pass through the duct.

r- Switch ON the heater 2 provided inside the top of the duct and allow the system to stabilize.

Allow the steam to the chamber.

/- Allow some time for stabilization.

After stabilization note down the corresponding readings given under heading of table of readings.

5.TECHNICAL SPECIFICATONS:

a) Hermetically Sealed Compressor

Capacity

b) Air Cooled Condenser

Capacity

c) Condenser Cooling Fan

Capacity

d) Rotameter (Refrigerant R 22)

e) Hand Shut Off Valves

f) Filter Drier

g) Energy meters

h) Pressure / Compound Gauges

i) Line Voltage Corrector

Capacity

j) Measuring Instruments
a) Digital Voltmeter
b) Digital Ammeter

c) Digital Temp. Indicator

k) Finned Heater I) Anemometer m) Stop Watch 1.0 Ton

1.0 Ton

1/10 HP : 0.4 to 4 LPM : 3/8" & 1/4"

: DM - 50 (3/8") : 10 to 20 Amps : 1/4" x 2 ½" Dial

4 KVA

0-300 VAC 0- 10 Amps AC - 30 to 199.9° C

5000 Watt each

For velocity measurement in m / Racer

6. TABLE OF READINGS A. Cooling & Dehumidification Capillary / Thermostatic Expansion

TABLE: 1

SI. No.	Pressure in Psi				Temp, in Deg. c					Avg. Air velocity in m/s	Ref. Flow Rate in LPM	V (Volts)	I (Amp)	E/M Reading Con Fan in sec/rev	E/M Readir Evp. F
	PI	P2	P3	P4	T1	T2	T3	T4	T5						
01	56.2	242	247.5	60	18	75	38	6	20	3.565	0.8	226	4.79	38.75	18.78

w TABLE:2

SI. No.	Dry Bulb Temp. Inlet	Wet Bulb Temp. Inlet	Dry Bulb Temp. Outlet	Wet Bulb Temp. Outlet
01	25.5	23	20.5	19

The above readings are for Capillary Expansion. Similarly same set of readings can be taken for Thermostatic Expansion Valve also. *

B. Cooling & Humidification

TABLE: 1

I SI. ; NO. yw	Pressure in Psi				Temp, in Deg. c					Avg. Air velocity in m/s	Ref. Flow Rate in LPM	V (Volts)	I (Amp)	E/M Reading Con Fan in sec/rev	E/M Readi Evp. F
	PI	P2	P3	P4	T1	T2	T3	T4	T5						
1	3 5=1	IS5"					34	-2			o . Q	2		I 5". i £	2 - 0 -

TABLE:2

SI. No.	Dry Bulb Temp. Inlet	Wet Bulb Temp. Inlet	Dry Bulb Temp. Outlet	Wet Bulb Temp. Outlet
	a- 5	i 1	4-3	*1*

C. Heating & Humidification T A B L E : 2

SI. **No.**	Dry Bulb Temp. Inlet	Wet Bulb Temp. Inlet	Dry Bulb Temp. Outlet	Wet Bulb Temp. Outlet

7. FORMULA

a. Volume Flow Rate of Refrigerants

$$V = \frac{\text{Rotameter reading in LPM}}{1000x60} m^3 / sec$$

$$\text{b. C.O P. (Co-efficient of Performance)} = \frac{hh - h_4 \text{ (Enthalpy rise on the evaporator)}}{h_2 - hi \text{ (Compressor work input)}}$$

c. Mref (Mass flow rate of refrigerant) = p $_{re}$f x V $_{re}$f

d. dh = h 1 - h_2

e Refrigeration Effects = M x dh

8. SAMPLE CALCULATION

A. COOLING AND DEHUMIDIFICATION FOR CAPILLARY EXPANSION

Pt = 56.5 Psi

= 56 5 x 6895 x 10"^{6} = 0.389 Mpa (Gauge)

= 0.389 + 0 1 =

0.489 Mpa

(Absolute)

P_2 = 242 Psi

= 242 x 6895 x 10~^{5} = 1 668 Mpa (Gauge) = 1.668 + 0.1 = 1 768 Mpa (Absolute)

P_3 = 247.5 Psi

= 247.5 x 6895 x 10"^{6} = 1.706 Mpa (Gauge)

= 1.706 + 0.1

= 1.806 Mpa (Absolute)

P_4 = 60 Psi

= 60 x 6895 x 10"^{6} = 0.4137 Mpa (Gauge)

= 0.4137 + 0.1

= 0.5137 Mpa (Absolute)

Volume Flow Rate of Refrigerant

Rotameter reading

V = --------------------------- m^3 / sec
1000 x 6 0

0.8

1000 x60 = 1.33 x 10"^{5} m^3 / sec

State points (P_{1f} Ti), (P_2, T_2), (P_3, T_3), (P_4, T_4), on Enthalpy Chart of R - 22

hi = 425 KJ/Kg

h_2 = 460 KJ/Kg

h_3 = h_4 = 250 KJ/Kg

hi-h_4 425-250 175

C.O.P =------------------- = ------------------------- = ------------ = 5

'h_2-h! 460-425 35

Density of liquid refrigerant from chart of R - 22

At T_3 = 38° C

p_{ref} = 1137.3 Kg/m^3

Mass Flow Rate of Refrigerant **Mref = pref X** V**ref**

= 1137.3 x 1.33 x 10~^{5} = 0.0151 Kg/sec Air Conditioning Process **INLET CONDITION**

Ambient dbti = 25.5° C wbti = 23° C **OUTLET CONDITION**

(* dbt_2 = 20.5° C

wbt_2 = 19° C Sensible Cooling = dbti - dbt_2

= 25.5° C- 20.5 = 5° C

State points locate on psychrometric chart using dbti Vs wbti and dbt_2 Vs wbt_2 and corresponding humidity ratio and enthalpy values are read.

Wi = 17 g / Kg of dry air

W_2 = 13.5 gl Kg of dry air

i

h-i = 69 KJ / Kg of dry air

h_2 = 54 KJ/Kg of dry air

Dehumidification = Wi - W_2

= 17-13.5 = 3.5 g
I Kg of dry air

dh = hi -

h_2 = 69-54

= 15 KJ I Kg of dry air

Properties of air (density) at 25.5° C (288.5 K) At 288.5K = 1.1774 Kg/m^3.

Average Air Velocity (From Anemometer)

	1	2	3	Average
Bottom	4.4	3.0	3.8	3.73
Top	3.9	2.4	3.9	3.4

1

$$\text{Average Velocity } V = \frac{3.73 + 3.4}{2} = \mathbf{3.565\ m/sec}$$

Area of Rectangular Duct L = 49 cm

W= 13 cm A = 0.49 x 0.13 **= 0.0637 m^2**

Mass Flow Rate of Air = 3.565x0.0637 x 1.1774

= 0.267 Kg / sec

.. Refrigeration Effect = M x dh

= 0.267 x 15 **= 4.01 KW**

1.0 ton of Refrigeration = 3.5 KW

$$\text{Tonnage} = \frac{4.01}{3.5}$$

= 1.145 TR

B. COOLING AND DEHUMIDIFICATION BY USING THERMOSTATIC EXPANSION

Pt = 64 Psi

= 64 x 6895 x 10"^{6} =

0.441 Mpa (Gauge)

= 0.441 + 0.1 =

0.541 Mpa

(Absolute)

P_2 = 260 Psi

$= 260 \times 6895 \times 10^{-6} =$

1.793 Mpa (Gauge)

= 1.793 + 0.1 =

1.893 Mpa

(Absolute)

P_3 = 255 Psi

$= 255 \times 6895 \times 10^{-6} =$

1.758 Mpa (Gauge)

= 1.758 + 0.1 =

1.858 Mpa

(Absolute)

P_4 = 72 Psi

$= 72 \times 6895 \times 10^{-6} =$

0.496 Mpa (Gauge)

= 0.496 + 0.1 =

0.596 Mpa

(Absolute)

Volume Flow Rate of Refrigerant

$$V = \frac{\text{Rotameter reading}}{1000 \times 60} \ m^3/sec$$

1

1000x60 $= 1.6 \times 10^{-5}\ m^3 / sec$

State points (Pi, Ti), (P_2, T_2), (P_3, T_3), (P_4, T_4), on Enthalpy Chart of R - 22

h_1 =410 KJ/Kg h_2 =

450 KJ/Kg h_3 = h_4 =

250 KJ/Kg

$$\text{CO.P.} = \frac{hi-h_4}{h_2-h_1} = \frac{410-250}{450-410} = \frac{160}{40} = 4$$

Density of liquid refrigerant from chart of R - 22 at T_3 = 43 C p_{ref} = 1115.15 Kg/m^3

Mass Flow Rate of Refrigerant

$M_{re}f$ = pref X $V_{re}f$

= 1115.15 x 1.6 x 10"[5]

= 0.0178 Kg/sec Air

Conditioning Process

INLET CONDITION

Ambient dbt-i = 26° C

wbti = 23° C OUT

LET CONDITION

dbt_2 = 21° C

wbt_2 = 19°C

Sensible Cooling = dbti - dbt_2 = 26-

21 = 5° C

State points locate on psychrometric chart using db^ Vs wbti and dbt_2 Vs wbt_2 and corresponding humidity ratio and enthalpy values are read.

W_1 = 17 g / Kg of dry air

W_2 = 13 g / Kg of dry air

hi = 66 KJ / Kg of dry air

h_2 = 51 KJ/Kg of dry air

Dehumidification = Wi - W_2

= 17-13

(=4 g I Kg of dry air

dh = hi - h_2 = 66-51

= 15 KJ/Kg of dry air

Properties of air (density at 26° C) 299 K . At 299K = 1.1774 Kg/m^3.

Average Air Velocity (From Anemometer) 1 2 3 Average

Bottom	4.4	3.0	3.8	3.73
Top	3.9	2.4	3.9	3.4

Average Velocity V = $\frac{3.73 + 3.4}{2}$ **= 3.565**

Area of Rectangular Duct L = 49 cm