SIR C.R.REDDY COLLEGE OF ENGINEERING

ELURU-534 007

HEAT AND MASS TRANSFER LAB MANUAL

DEPARTMENT OF MECHANICAL ENGINEERING

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HEAT AND MASS TRANSFER LAB

LIST OF EXPERIMENTS

1.HEAT TRANSFER IN NATURAL CONVECTION –VERTICAL CYLINDER

Aim:
To determine surface heat transfer co-efficient for heated vertical cylinder in natural convection.

Apparatus:
Equipment consists of vertical cylinder, heater, panel consisting of voltmeter, ammeter, temperature indicators (digital type),dimmer and thermocouple selector switch.

Description:
The apparatus consists of a vertical tube enclosed in a rectangular duct open at both top and bottom. The duct is of sufficient dimensions so as not to interfere with the connection process, while at the same time preventing external disturbances effecting the data. One side of the duct is made of transparent glass to facilitate visual observation. An electrical heating element embedded in the copper tube acts as heat source. The surface temperatures of the tube are measured at different heights using thermo couples. The surface of the tube is polished to minimize radiation losses. A volt meter and an ammeter enable the determination of power dissipated by the heater and hence heat input to the system. Different thermo couples can be selected using thermo couple selector.

Procedure:
1. Connect the three-pin plug of the heater to main switch on the mains.
2. Rotate the dimmer to clock wise direction to give initial heat input to the heater.
3. Allow the unit to stabilize.
4. Note down the voltage and current from respective meters.
5. Note down the temperature by operating thermo couple selector switch to positions 1, 2, 3, 4, 5, 6, 7 and 8.
6. Repeat the experiment for different heat inputs and tabulate the readings for calculation.

Precautions:
1. Input wattage to heater should be constant in one complete set of readings.
2. Temperature should be noted when the unit is in steady state condition.
3. There should not be any fluctuations in digital meters.

Specifications:
1. Diameter of the cylinder (D) = 45 mm
2. Length of the cylinder (L) = 450 mm

Calculations:

1. Heat input Q = VI watts

2.Mean surface temperature of cylinder

$$T_S = \frac{T_1 + T_2 + T_3 + \ldots + T_7}{7} \; {}^0C$$

3. Film temperature $T_f = \dfrac{T_s + T_8}{2} \; {}^0C$

4. Change in temperature $\Delta T = T_s - T_8 \; {}^0C$

5. Surface area $A = \Pi DL \; m^2$

6. Experimental surface heat transfer coefficient of the vertical cylinder

   $H_{exp} = Q$

   Theoritical heat transfer coefficient :

   7. Fluid properties of air at film temperature are obtained from data book.: μ, Cp, Pr, k, β etc.

      a. Grashoff number based on length= $Gr = g \beta L^3 \Delta T / \nu 2$

S. No	Heat input			Surface Temperature in ^0C		Ambient Temp. in ^0C $T_\infty = T_8$	Temp. difference ΔT in ^0C $T_s - T_8$	Film Temp. T_f in ^0C $\frac{T_s + T_8}{2}$
	Voltage V in Volts	Current I in Amps	Q in Watts	T_1 T_2 T_3 T_4 T_5 T_6 T_7	Average fin temp. T_s			

Non – dimensional			Surface heat Transfer coefficient h in Watts/m^2 ^{0}C	
Grash off number	Prandtl number	Nusse number	Theoretical	Experimental

VIVA QUESTIONS

1. What is convection?
2. Classify convection.
3. What is forced convection & natural convection?
4. Explain difference between forced convection and natural convection?
5. On which properties does convection heat transfer strongly depend?
6. Define convection heat transfer coefficient with dimensions.
7. Define Nussult number.
8. Develop velocity boundary layer for flow over a flat plate?
9. The Prandtl number will be lowest for------
10. What is significance of Nussult's number in convection?
11. The hydro dynamic and thermal boundary layers are identical at Prandtl number equal to-----
12. The temperature gradient in the fluid flow over a heated plate will be------
13. The ratio of heat transfer by convection to that by conduction is called-----
14. Define buoyancy force and discuss significance of the buoyancy force in Natural convection?
15. Define volume expansion coefficient and discuss significance in Natural convection?
16. Define Grashoff number and discuss significance of Grashoff number?
17. The free convection heat transfer is significantly affected by----
18. The dimension less parameter $\frac{\left(\beta g \rho^3 l^3 \Delta t\right)}{\mu^3}$ is called as----
19. The convective heat transfer coefficient from a hot cylindrical surface exposed to still air varies in accordance with------
20. For Laminar conditions, the thickness of thermal boundary layer increases with the distance from the leading edge in proportion to------

2.HEAT TRANSFER IN NATURAL CONVECTION – PINFIN

Aim: To determine the heat transfer coefficient, fin efficiency and temperature distribution along the length of a pinfin in natural convection.

Apparatus: PINFIN Apparatus.

Description of apparatus:
The apparatus consists of a pinfin of a placed inside an open duct (one side open) the other end of the duct is connected to the suction side of the blower. The delivery side of the blower is taken up through a gate value and an orificemeter to the atmosphere. The air flow rate can be carried by the gate value and can be measured on the 'U' tube manometer connected to the orifice meter. A heater is connected to the pin fin and, thermo couples are connected equidistance all along the length of the pin fine, sixth thermo couple is left in the duct. The panel of the apparatus consists of voltmeter, ammeter, digital type temperature indicator, dimmerstat to control power input to heater, thermo couple selector switch, U-tube manometer and a schematic diagram.

Procedure:
1. Connect the three pin plug top to 230 V, 50 Hz, 15 Amp power socket.
2. Keep the thermo couple selector switch in "ZERO" position.
3. Turn the dimmer knob clockwise and set the power input to the heater to any desired value by looking at the voltmeter and ammeter.
4. Allow the unit to stabilize.
5. Turn the thermocouple selector switch clock wise by step (1, 2, 3, …., 6).
6. Note down the temperatures indicated by the temperature indicator on each step.
7. Repeat the experiment for different power input to the heater.
8. After the experiment for different power input to the heater position, keep the thermo couple selector in 'ZERO' position and disconnect the plug.

Precautions:
1. Power input should be stable.
2. Keep the Blower in "OFF" position.

Graph:
A graph is drawn taking thermo couple location (x) on x-axis and experimental temperature on y-axis. Similarly another graph is drawn taking calculated temperature on y-axis on the same sheet.

Observations:
1. Diameter of the Fin = D = 12 mm = 0.012 m.
2. Length of the Fin = l = 240 mm = 0.024 m.
3. Thermal conductivity of brass (Fin material) K_f

= Watts/ m^0C

= Watts/ m^0C

Calculation:

1. Heat transfer coefficient : (h)

   i) Average surface temperature of fin $= T_S = \frac{T_1 + T_2 + T_3 + T_4 + T_5}{5}$ in ^0C

   ii) Ambinet temperature of the duct = $T_C = T_6$ in ^0C

   iii) Film temperature $= T_f = \frac{T_5 + T_\infty}{2}$ ^0C

   iv) Fluid properties are evaluated from data book at film temperature such as K, P, v, pr etc.

   v) Temperature difference $\Delta T = T_S - T_\infty$

   vi) Grass off number $= \frac{q\Delta TD^3}{\upsilon^2}$ where 'g' is acceleration due to gravity.

   vii) Nusselt number is given by

   $N_U = 0.53(Gr\,Pr)^{1/4}$ for $10^4 < Gr\,Pr < 10^9$

   $N_U = 0.13(Gr\,Pr)^{1/4}$ for $Gr\,Pr > 10^9$

   viii) $N_U = \frac{hD}{k} = 0.85(Gr\,Pr)0.188$ for $10^2 < Gr\,Pr < 10^4$ where k is thermal conductivity air at film temperature.

   $\therefore$ Heat transfer coefficient $= \frac{N_U K}{D}$

2. Efficient of fin : n

$$n_{fin} = \frac{\text{Actual heat transfered by fin}}{\text{Heat which would have been transferred in entire fin is at base temperature}}$$

$$= \frac{\tanh(ML)}{ML}$$

Where $M = \sqrt{\frac{hp}{K_f A}}$

P is perimeter of the fin = TID in M

A is cross sectional area of the fin $\pi/4\ D^2$ in M^2

K_{fin} is thermal conductivity of fin material (Brass)

3. Temperature distribution :

   i) $T_S = T + \frac{(T_1 - T_\infty)\cos h\,(ML)}{\cos h\,M(L - X_1)}$ $X_1 = 15$ mm

   T_2, T_3, T_4, T_5 are calculated by choosing appropriate value of x

   $T = T_\infty + \frac{(T_S - T_\infty)\cos h\,M(L - x)}{\cos h\,(ML)}$

S. No	Heat input			Fin surface Temperature in ^0C		Ambient Temp. in ^0C $T_\infty = T_6$	Temp. difference ΔT in ^0C $T_{fav} - T_\infty$	Film Temp. T_f in ^0C $\frac{T_{fav} + T_\infty}{2}$
	Voltage V in Volts	Current I in Amps	Q in Watts	T_1 T_2 T_3 T_4 T_5	Average fin temp. T_{fav}			

Non – dimensional			Heat Tranfer coefficient h in Watts/m^2 ^0C	$M = \sqrt{\frac{hp}{K_f A}}$	Fin efficiency η_f percentage
Grash off number	Prandtl number	Nusse number			

VIVA QUESTIONS

1. What is convection?
2. Classify convection.
3. What is forced convection & natural convection?
4. Explain difference between forced convection and natural convection?
5. Force convection in a liquid bath is caused by----
6. Explain Newton’s law of cooling?
7. Give the relation between ‘Fluid velocity’ and ‘Heat transfer’?
8. On which properties does convection heat transfer strongly depend?
9. Define convection heat transfer coefficient with dimensions.
10. Define Nussult number.
11. Develop velocity boundary layer for flow over a flat plate?
12. Explain Prandtl number.
13. Fluid properties are evaluated at what temperature?
14. The Prandtl number will be lowest for------
15. What is significance of Nussult’s number in convection?
16. The hydro dynamic and thermal boundary layers are identical at Prandtl number equal to-----
17. The temperature gradient in the fluid flow over a heated plate will be------
18. The ratio of heat transfer by convection to that by conduction is called-----
19. Define buoyancy force and discuss significance of the buoyancy force in Natural convection?
20. Define volume expansion coefficient and discuss significance in Natural convection?
21. Define Grashoff number and discuss significance of Grashoff number?
22. What is significance of Rayleigh’s number?
23. The free convection heat transfer is significantly affected by----
24. The dimension less parameter $\frac{(\beta g \rho^3 l^3 \Delta t)}{\mu^3}$ is called as----
25. What is significance of Stanton number?

26. The convective heat transfer coefficient from a hot cylindrical surface exposed to still air varies in accordance with------
27. For Laminar conditions, the thickness of thermal boundary layer increases with the distance from the leading edge in proportion to------
28. What is the material used in pin fin experiment?

3.HEAT TRANSFER IN FORCED CONVECTION - PINFIN

Aim: To determine the heat transfer coefficient, efficiency and temperature distribution of a pin fin in forced convection.

Apparatus:
The apparatus consists of pin fin in an open duct, blower, gate value an orifice meter, a U manometer a heater along with thermocouples, Voltmeter and ammeters.

Procedure:
With air circulation: (Blower "ON") forced convection

1. Connect the three pin plug top to a 230 V, 50 Hz, 15 A power socket, the indicator lamp "ON".
2. Keep the thermo couple selector switch in "ZERO" position.
3. Turn the dimmer knob clockwise and set the power input to the heater to any desired value by looking at the voltmeter P ammeter.
4. Switch "ON" the blower.
5. Set the air flow rate at any desired value looking at the difference in 'U' tube manometer levels.
6. Allow the unit to stabilize.
7. Turn the thermo couple selector switch clockwise step by step (1, 2, 3, 4, 5)
8. Note down the temperature indicated by the temperature indicator on each step.
9. Repeat the experiment by varying air flow rate and keeping the power input to heater constant.
10. Tabulate all the readings and calculate for different conditions.
11. After experiment is over put "OFF" the blower, turn the dimmer knob anti-clockwise you hear a click, keep the thermocouple selector in zero position, disconnect the power supply.

Observations :

Diameter of the fin D_f = 12 mm
Length of the fin L = 15 cm.
Thermal conductivity of brass (KL) = 100.4 watts/m ^{0}k
Diameter fo the orifice d_0 = 20 mm
Diameter of the pipe d_p = 42 mm
Coefficient of discharge of orifice C_d = 0.61
Density of air ρ_a = 1.17 kg/m^3
Width of the duct W = 15 cm.
Breadth of the duct B = 10 cm.

Calculation :

1. Calculation of velocity of air in duct:

   (a) Velocity of orifice $V_0 = C_d\sqrt{\frac{2gho(\rho_m - \rho_a)}{\rho_a}\,\frac{1}{1-\beta}}$

   where $\beta = \frac{\text{dia. of orifice}}{\text{dia of pipe}} = \frac{28}{42}$

   $g = 9.81$, $C_d = 0.61$, $\rho_a = 1.17\ kg/m^3$, $\rho_m = 1000\ kg/m^3$

   (b) Velocity of air in the duct $= \frac{V_0 \times \text{C.S.Area. of orifice}}{\text{C.Sarea of duct}}$

   $$V_a = \frac{V_0 \times \frac{\pi}{4} do^2}{w \times B}\ m/s$$

2. Reynolds number of air flow:

   $R_e = \frac{D_f V_a P_a}{\mu_a}$ $\mu_a = 1.8 \times 10^{-5}$ kg m/s.

   Prandti number $= \frac{\mu C_P}{K}$ at room temperature
   $= 0.7$

   Nusselt number $= \frac{hD_f}{K_a}$

3. Heat transfer coefficient relations:

   $N_u = 0.989\ Re^{0.33}\ Pr^{1/3}$ for $1 < Re < 4$
   $= 0.911\ Re^{0.385}\ Pr^{1/3}$ for $4 < Re < 40$
   $= 0.683\ Re^{0.466}\ Pr^{1/3}$ for $40 < Re < 4000$
   $= 0.193\ Re^{0.6187}\ Pr^{1/3}$ for $4000 < Re < 40{,}000$
   $= 0.0266\ Re^{0.805}\ Pr^{1/3}$ for $40{,}000 < Re$

   Find heat transfer coefficient.

4. $M = \sqrt{\frac{h\,p}{K_b A}}$

   where h found previously
   p is the perimeter of the fin πD_f
   K_b thermo conductivity of brass.
   A_C sectional area of fin.

   Efficiency of Fin = $n_{fin} = \frac{\tan h\,(ML)}{(ML)}$

S.No	Heat input			Orifice drop		Fin surface temps in ^{0}C	Ambient Temp. in ^{0}C $T_\infty = T_6$	Velocity of air in the duct Va m/s
	Voltage V in Volts	Current I in Amps	Q in Watts	mm of water	m of air	T_1 T_2 T_3 T_4 T_5		

Mass of rate of air ma kg/sec	Non dimensional numbers			Heat Tranfer coefficient h in Watts/m^2 ^{0}C	$M = \sqrt{\frac{hp}{K_f A}}$	Fin efficiency η_f percentage	Heat transfer rate Q Watts
	Reynolds number Re	Prandtl number Pr	Nusselt number Nu				

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6. Explain Newton’s law of cooling?
7. Give the relation between ‘Fluid velocity’ and ‘Heat transfer’?
8. On which properties does convection heat transfer strongly depend?
9. Define convection heat transfer coefficient with dimensions.
10. Define Nussult number.
11. Develop velocity boundary layer for flow over a flat plate?
12. What is drag force?
13. Define friction coefficient (or) drag coefficient?
14. Explain Reynolds number?
15. What is critical Reynolds number?
16. Explain Prandtl number.
17. Fluid properties are evaluated at what temperature?
18. For forced convection, Nussult number is a function of---------
19. The Prandtl number will be lowest for------
20. What is significance of Nussult’s number in convection?
21. The hydro dynamic and thermal boundary layers are identical at Prandtl number equal to-----
22. The temperature gradient in the fluid flow over a heated plate will be------
23. The ratio of heat transfer by convection to that by conduction is called-----
24. What is significance of Stanton number?
25. The convective heat transfer coefficient from a hot cylindrical surface exposed to still air varies in accordance with------
26. For Laminar conditions, the thickness of thermal boundary layer increases with the distance from the leading edge in proportion to------
27. Which dimensionless number has a significant role in forced convection?

4.HEAT TRANSFER IN FORCED CONVECTION TUBE – VARIABLE FLOW

Aim: To find the heat transfer coefficient in forced convection of air in a tube compare with predicted heat transfer coefficient.

Apparatus:
Tabular test section, Air heater, Flow straightener, Temperature indicators.

Description of apparatus:
The apparatus consists of a blower for supply of air. Air from blower passes through a flow straightner and an air heater and then to the test section. Air flow is measured by an orifice meter placed near the test section. Heating of air is done by band heater placed around the tube, the voltage to the heater being controlled by a dimmerstat. Temperature of the air at the in let to and outlet from the test section are measured using thermo couples located in the air steam. Test section wall surface temperatures are measured using thermocouples embedded in the walls at different axial distance from the entrance. The test section is enclosed in a water jacket where the circulating water removes heat from air. Water jacket is insulated to minimize heat lose by radiation and convection to the surroundings. A by-pass line on the air systems enables tests to be conducted at different Reynolds numbers. The next flux is varied systematically by controlling the by pass value so that the manometer head across the orifice varies uniformly.

Procedure:
1. Connect the three-pin plug to the mains. Switch on the mains.
2. Give the initial heat input to the heater. Switch on the blower when by pass value fully open. Wait for few minutes.
3. Adjust the water flow rate such that it causes a temperature rise of at least 3 - 4^0C.
4. Allow the system to stabilize.
5. Heater input, water flow rate and orifice drop are recorded.
6. Note down the temperatures by rotating the thermo couple selector switch.
7. Repeat the experiment at different heat inputs and tabulate the corresponding readings.

Precautions:
1. Airflow rate should be kept constant.
2. Blower is started when the value is fully open.
3. Heat input should be constant.

Calculations:

1. Mass flow rate of air through pipe (m_a)

$$m_a = \frac{c_d a \rho_a \sqrt{2gh_a}}{\sqrt{1-\beta^4}} \text{ kg/sec}$$

where c_d is the coefficient of discharge = 0.62 'a' is the cross sectional area of orifice in m^2 ρ_a is the density of air at room temperature.

$$\rho_a = \frac{\rho_{at} \times 273}{273 + t} \qquad \rho_{at} \text{ is density at } 0^0C = 1.296 \text{ kg/m}^3$$

g is acceleration due to gravity.

h_a is height of air column in 'm' of water

$$h_a = \frac{h_m(\rho_m - \rho_a)}{\rho_a} \text{ m of water.}$$

h_m is height of water column

ρ_m, ρ_a are densities of water, air in kg/m^3

$$\beta = \frac{\text{Diameter of orifice}}{\text{Diameter of pipe}} = \frac{D_O}{D_P} = \frac{20\text{mm}}{40\text{mm}}$$

2. Average velocity of air (V_a)

$$V_a = \frac{m_a}{\rho_a A_1} \text{ m/sec}$$

where A_1 is cross sectional area of pipe = $\frac{\pi}{4} D_P{}^2$

3. Heat balance in the process:

(a) Heat lost by air : Q_a

$$Q_a = MaC_{pa}(T_{ai} - T_{ao}) \text{ Watts}$$

where C_{pa} is the specific heat of air = 1.005 Kj/kg^{0}C

T_{ai} is the inlet air temperature

T_{ao} is the outlet air temperature

m_a in kg/sec

(b) Heat gained by water (Q_w)

$$Q_w = m_w C_{pw} (T_{wo} - T_{wi})$$

m_w is the mass flow rate of water in kg/sec

C_{pw} is the specific heat of water

T_{wo} is the water outlet temperature

T_{wi} is the water inlet temperature.

4. Heat transfer coefficient:

i. Surface area of the pipe = A = $\pi D_p L$

Where D_p is the diameter of pipe in m

L is the length of pipe in m.

ii. Bulk temperature of air = $T_i = \frac{T_{ai} - T_{ao}}{2}$

Where T_{ai} is air inlet temperature
T_{ao} is air outlet temperature

iii. Average surface temperature $T_o = \frac{T_2 + T_3 + T_4 + T_5 + T_6}{5}$

(a) Based on heat lost by air $h_a = \frac{Q_a}{A(T_i - T_o)}$

(b) Based on heat gained by water $h_a = \frac{Q_w}{A(T_i - T_o)}$

(c) Theoretical heat transfer coefficient:
Properties of air at 40^0C are (From data book)
$\upsilon = 16.96 \times 10^{-6} m^2/sec.$ pr = 0.699

Reynolds number $R_e = \frac{V_a D_p}{\upsilon}$

Prandtl number : N_U
Laminau flow $R_e < 2100$

$$N_U = 3.66 + \frac{0.085 N_{6Z}}{1 + 0.04(N_{6Z})2/3}\left(\frac{\mu_b}{\mu_w}\right)^{0.14} \qquad N_{6Z} < 100$$

$$= 1.86(N_{6Z})^{1/3}\left(\frac{\mu_a}{\mu_w}\right)^{0.14} \qquad N_{6Z} < 0$$

where $N_{6Z} = R_e pr\left(\frac{D_p}{L}\right)$

μ_b/μ_w can be taken as 1 for rough calculations
as temperature air (bulk) and at wall are almost equal

Transition region : 2100 < Re < 10,000

$$N_U = 0.116(Re^{2/3} - 125)Pr^{1/3}\left(1 + \left(\frac{D}{2}\right)^{2/3}\right)\left(\frac{\mu_b}{\mu_w}\right)^{0.14}$$

Turbulent region Re > 10,000

$$N_U = 0.036 Re^{0.8} Pr^{1/3}\left(\frac{D}{2}\right)^{0.055}$$

Theoretical heat transfer coefficient $h_m = \frac{N_U K_a}{D_P}$

S.No	Heat input			Orifice drop		Water flow rate (m_w)		Air temperature in ^0C			Tube surface temperature in ^0C	
	Voltage V in volts	Current I in Amps	Wattage Q in Watts	Hw in m of water	H a in m of air	Ml/min	Kg/sec	Inlet T_{ai}	Outlet T_{ao}	Bulk temp. T_i	T_2 T_3 T_4 T_5 T_6	$T_0 = \frac{T_2 + T_3 + T_4 + T_5}{5}$
Full opening												
Half opening												
Quarter opening												

Water temp. in ^0C		Mass flow rate of air m_a in		Average velocity of air (V_a) in	Heat balance in KW			Heat transfer coefficient in $KW/m^2\ ^0C$		
Inlet T_{wi}	Outlet T_{wo}	Kg/sec	Kg/sec	m/s	Heat lost by air Q_a	Heat gained by water Q_w	Nusselt number	Based on heat lost by air	Based on heat gained by water	Theoretical heat transfer coefficient
Full opening										
Half opening										
Quarter opening										

VIVA QUESTIONS

1. What is convection?
2. Classify convection.
3. What is forced convection & natural convection?
4. Explain difference between forced convection and natural convection?
5. Force convection in a liquid bath is caused by----
6. Explain Newton’s law of cooling?
7. Give the relation between ‘Fluid velocity’ and ‘Heat transfer’?
8. On which properties does convection heat transfer strongly depend?
9. Define convection heat transfer coefficient with dimensions.
10. Define Nussult number.
11. Develop velocity boundary layer for flow over a flat plate?
12. What is drag force?
13. Define friction coefficient (or) drag coefficient?
14. Explain Reynolds number?
15. What is critical Reynolds number?

16. Explain Prandtl number.
17. Fluid properties are evaluated at what temperature?
18. For forced convection, Nussult number is a function of---------
19. The Prandtl number will be lowest for------
20. What is significance of Nussult's number in convection?
21. The hydro dynamic and thermal boundary layers are identical at Prandtl number equal to-----
22. The temperature gradient in the fluid flow over a heated plate will be------
23. The ratio of heat transfer by convection to that by conduction is called-----
24. What is significance of Stanton number?
25. The convective heat transfer coefficient from a hot cylindrical surface exposed to still air varies in accordance with------
26. For Laminar conditions, the thickness of thermal boundary layer increases with the distance from the leading edge in proportion to------
27. Which dimensionless number has a significant role in forced convection?

5.HEAT TRANSFER IN FORCED CONVECTION - TUBE

Aim: To find the heat transfer coefficient in forced convection of air in a tube compare with predicted heat transfer coefficient.

Apparatus:
Tabular test section, Air heater, Flow straightener, Temperature indicators.

Description of apparatus:
The apparatus consists of a blower for supply of air. Air from blower passes through a flow straightner and an air heater and then to the test section. Air flow is measured by an orifice meter placed near the test section. Heating of air is done by band heater placed around the tube, the voltage to the heater being controlled by a dimmerstat. Temperature of the air at the in let to and outlet from the test section are measured using thermo couples located in the air steam. Test section wall surface temperatures are measured using thermocouples embedded in the walls at different axial distance from the entrance. The test section is enclosed in a water jacket where the circulating water removes heat from air. Water jacket is insulated to minimize heat lose by radiation and convection to the surroundings. A by-pass line on the air systems enables tests to be conducted at different Reynolds numbers. The next flux is varied systematically by controlling the by pass value so that the manometer head across the orifice varies uniformly.

Procedure:
1. Connect the three-pin plug to the mains. Switch on the mains.
2. Give the initial heat input to the heater. Switch on the blower when by pass value fully open. Wait for few minutes.
3. Adjust the water flow rate such that it causes a temperature rise of at least 3 - 4^0C.
4. Allow the system to stabilize.
5. Heater input, water flow rate and orifice drop are recorded.
6. Note down the temperatures by rotating the thermo couple selector switch.
7. Repeat the experiment at different heat inputs and tabulate the corresponding readings.

Precautions:
1. Airflow rate should be kept constant.
2. Blower is started when the value is fully open.
3. Heat input should be constant.

Calculations:

1. Mass flow rate of air through pipe (m_a)

$$m_a = \frac{c_d a \rho_a \sqrt{2gh_a}}{\sqrt{1-\beta^4}} \ kg/sec$$

where c_d is the coefficient of discharge = 0.62 'a' is the cross sectional area of orifice in m^2 ρ_a is the density of air at room temperature.

$$\rho_a = \frac{\rho_{at} \times 273}{273 + t}$$ ρ_{at} is density at 0^0C = 1.296 kg/m^3

g is acceleration due to gravity.

h_a is height of air column in 'm' of water

$$h_a = \frac{h_m(\rho_m - \rho_a)}{\rho_a} \text{ m of water.}$$

h_m is height of water column

ρ_m, ρ_a are densities of water, air in kg/m^3

$$\beta = \frac{\text{Diameter of orifice}}{\text{Diameter of pipe}} = \frac{D_O}{D_P} = \frac{20mm}{40mm}$$

2. Average velocity of air (V_a)

$$V_a = \frac{m_a}{\rho_a A_1} \text{ m/sec}$$

where A_1 is cross sectional area of pipe = $\frac{\pi}{4} D_P{}^2$

3. Heat balance in the process:

(a) Heat lost by air : Q_a

$$Q_a = MaC_{pa}(T_{ai} - T_{ao}) \text{ Watts}$$

where C_{pa} is the specific heat of air = 1.005 Kj/kg^{0}C
T_{ai} is the inlet air temperature
T_{ao} is the outlet air temperature
m_a in kg/sec

(b) Heat gained by water (Q_w)

$$Q_w = m_w C_{pw} (T_{wo} - T_{wi})$$

m_w is the mass flow rate of water in kg/sec
C_{pw} is the specific heat of water
T_{wo} is the water outlet temperature
T_{wi} is the water inlet temperature.

4. Heat transfer coefficient:

i. Surface area of the pipe = A = $\pi D_p L$
Where D_p is the diameter of pipe in m
L is the length of pipe in m.

ii. Bulk temperature of air = $T_i = \frac{T_{ai} - T_{ao}}{2}$
Where T_{ai} is air inlet temperature

T_{ao} is air outlet temperature

i. Average surface temperature $T_o = \frac{T_2 + T_3 + T_4 + T_5 + T_6}{5}$

(a) Based on heat lost by air $h_a = \frac{Q_a}{A(T_i - T_o)}$

(d) Based on heat gained by water $h_a = \frac{Q_w}{A(T_i - T_o)}$

(e) Theoretical heat transfer coefficient:
Properties of air at 40^0C are (From data book)
$\upsilon = 16.96 \times 10^{-6} m^2/sec.$ pr = 0.699

Reynolds number $R_e = \frac{V_a D_p}{\upsilon}$

Prandtl number : N_U
Laminau flow $R_e < 2100$

$$N_U = 3.66 + \frac{0.085 N_{6Z}}{1 + 0.04(N_{6Z})2/3}\left(\frac{\mu_b}{\mu_w}\right)^{0.14} \qquad N_{6Z} < 100$$

$$= 1.86(N_{6Z})^{1/3}\left(\frac{\mu_a}{\mu_w}\right)^{0.14} \qquad N_{6Z} < 0$$

where $N_{6Z} = R_e pr\left(\frac{D_p}{L}\right)$

μ_b/μ_w can be taken as 1 for rough calculations
as temperature air (bulk) and at wall are almost equal

Transition region : 2100 < Re < 10,000

$$N_U = 0.116(Re^{2/3} - 125)Pr^{1/3}\left(1 + \left(\frac{D}{2}\right)^{2/3}\right)\left(\frac{\mu_b}{\mu_w}\right)^{0.14}$$

Turbulent region Re > 10,000

$$N_U = 0.036 Re^{0.8} Pr^{1/3}\left(\frac{D}{2}\right)^{0.055}$$

Theoretical heat transfer coefficient $h_m = \frac{N_U K_a}{D_P}$

S.No	Heat input			Orifice drop		Water flow rate (m_w)		Air temperature in ^0C			Tube surface temperature in ^0C	
	Voltage V in volts	Current I in Amps	Wattage Q in Watts	Hw in m of water	Ha in m of air	Ml/min	Kg/sec	Inlet T_{ai}	Outlet T_{ao}	Bulk temp. T_i	T_2 T_3 T_4 T_5 T_6	$T_0 = \frac{T_2 + T_3 + T_4 + T}{5}$

Water temp. in ^0C		Mass flow rate of air m_a in		Average velocity of air (V_a) in	Heat balance in KW			Heat transfer coefficient in $KW/m^2\ ^0C$		
Inlet T_{wi}	Outlet T_{wo}	Kg/sec	Kg/sec	m/s	Heat lost by air Q_a	Heat gained by water Q_w	Nusselt number	Based on heat lost by air	Based on heat gained by water	Theoretical heat transfer coefficient

VIVA QUESTIONS

1. What is convection?
2. Classify convection.
3. What is forced convection & natural convection?
4. Explain difference between forced convection and natural convection?
5. Force convection in a liquid bath is caused by----
6. Explain Newton's law of cooling?
7. Give the relation between 'Fluid velocity' and 'Heat transfer'?
8. On which properties does convection heat transfer strongly depend?
9. Define convection heat transfer coefficient with dimensions.
10. Define Nussult number.
11. Develop velocity boundary layer for flow over a flat plate?
12. What is drag force?
13. Define friction coefficient (or) drag coefficient?
14. Explain Reynolds number?
15. What is critical Reynolds number?
16. Explain Prandtl number.
17. Fluid properties are evaluated at what temperature?
18. For forced convection, Nussult number is a function of---------
19. The Prandtl number will be lowest for------

20. What is significance of Nussult's number in convection?
21. The hydro dynamic and thermal boundary layers are identical at Prandtl number equal to-----
22. The temperature gradient in the fluid flow over a heated plate will be------
23. The ratio of heat transfer by convection to that by conduction is called-----
24. What is significance of Stanton number?
25. The convective heat transfer coefficient from a hot cylindrical surface exposed to still air varies in accordance with------
26. For Laminar conditions, the thickness of thermal boundary layer increases with the distance from the leading edge in proportion to------
27. Which dimensionless number has a significant role in forced convection?

6.HEAT TRANSFER THROUGH COMPOSITE WALL

Aim: To determine the overall heat transfer coefficient and to compare with that from theoretical heat transfer coefficient of the composite wall.

Apparatus:

Composite wall apparatus, stop clock, measuring jar.

Description:

The apparatus consists of slabs of different materials of some thickness. The three different materials are mild steel, asbestos and copper. The three slabs are clamped 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 heat flow across the slabs and insulated at ends. Thermo couples are embedded at different places or sections and three at different places at the same section to find out the average temperature. On the outside of the wall cooling water jacket is provided which takes away heat conducted through slabs. The mass rate of flow and increase of temperature of water can be found out.

Procedure:

1. Connect the three pin plug of the apparatus to the mains and switch on the mains.
2. Rotate the diameter to give initial input to the heater.
3. Adjust the water flow rate in the cooling chamber (below 20 ml/min)
4. Allow the unit to reach steady state condition. (Three is no change in temperature at any section).
5. Note down the voltage and current form digital voltmeter and ammeter respectively. Also the temperature at different points using thermo couple selector switch.
6. Repeat the experiment by giving different heater inputs.

Precautions:

1. The wattage given to the heater should not exceed the capacity of the heater.
2. Note down the temperature only after steady state is reached.
3. The readings on digital meters should remain constant for a certain amount of time.

Details of composite wall:

1. Diameter of the composite wall (D) = 100 mm.
2. Thickness of each wall $L_1 = L_2 = L_3$ = 6 mm.
3. Thermal conductivity of mild steel = Watts/m^{0}C.
4. Thermal conductivity of asbestos sheet = Watts/m^{0}C.
5. Thermal conductivity of copper = Watts/m^{0}C.

Calculation:

1. Mass flow rate of water : (m_w)
   Water flow rate V = ml/min.
   Density of water ρ = 1000 kg/m^3
   Mass flow rate m_w = kg/hr

2. Heat gained by water : (Q_w)
   $Q_w = m_w C_{pw} (Tw_2 - Tw_2)$ Watts
   Where C_{pw} → specific heat of water = 4.18 Kj/kg^{0}C
   Tw_2 → water outlet temperature in ^{0}C
   Tw_1 → water inlet temperature in ^{0}C

3. Average temperature at the hot end of the composite wall T_{h1}

$$T_{h1} = \frac{T_1 + T_2 + T_3}{3} \text{ in } ^0C$$

4. Average temperature at the cold end of the composite wall T_{h2}

$$T_{h2} = \frac{T_{10} + T_{11} + T_{12}}{3} \text{ in } ^0C$$

5. Overall heat transfer coefficient

$$U_{exp} = \frac{Q_{w2}}{A(T_{h1} - T_{h2})} \text{ KW/m}^2\ ^0C$$

   where A is heat transfer area $= \frac{\pi}{4} D^2$ in m^2

6. Theoretical heat transfer conductance (U_{Th})

$$U_{Th} = \frac{1}{\frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{L_3}{K_3}} \text{ KW/m}^2\ ^0C$$

S.No	Heat input		Temperatures in ^{0}C					Mass flow rate of water		Overall heat transfer coefficient in KW/m^2 ^{0}C	
	Voltage V in Volts	Current I in Amps	T_1 T_2 T_3 T_4 ….T_{12}	T_h	T_{h2}	Water temp		ml/min	m_w kg/sec	Experimental U_{exp}	Theoretical U_{th}
						T_{w1} (T_{13})	T_{w2} (T_{14})				

VIVA QUESTIONS

1. Define thermal conductivity?
2. For which material thermal conductivity is highest?
3. Why negative sign in Fourier's Law?
4. What are the units of thermal conductivity?
5. What is the first law of thermodynamics?
6. What is the second law of thermodynamics?
7. How is thermal conductivity measured practically?
8. Why are diamonds sinks used in cooling electronic components?
9. What is the physical mechanism of conduction in solids, liquids and gases?
10. What do you mean by "ρc_p"?
11. What is the physical significance of thermal diffusivity?
12. Is heat transfer a scalar or vector quantity?
13. What do you mean by steady heat transfer and how does it differ from transient heat transfer?
14. What is lumped system? How does heat transfer in a lumped system differ from steady heat transfer?
15. How are ordinary and partial differential equations used in heat transfer analysis?
16. What is a boundary condition? Explain.

7.TEST OF EMISSIVITY MEASUREMENT APPARATUS

Aim:
To measure the emissivity of the test plate surface

Apparatus:
Emissivity apparatus

Theory:
An ideal black surface is one which absorbs all the radiation falling on it. Its reflectivity and transmissivity is zero. The radiation emitted per unit time per unit area from the surface of the body is called emissive power. It is denoted by $\in$

The emissivity of a surface to the emissive part of a black surface at the same temperature. For a black body absorptivity is 1 and by kirchoff's law its emissivity is 1. Emissivity depends on the surface temperature and the nature of the surface.

Procedure:
1. Connect the three-pin plug to main.
2. Keep the heater selector switch in position (1) & rotate the main water dimmer clockwise & adjust the power input to any desired value by looking at voltmeter & ammeter starting from lower power input.
3. Keep the heater selector switch I position (2) & rotate the guarded heater dimmer clockwise & adjust the power input to required value by looking at panel board. Keep the voltage guarded heater slightly lower than the main heater.
4. Allow the heater unit to stabilize the corresponding power inputs.
5. When the temperature of the thermocouple (3), (5) are equal note down the temperature of various thermocouples located by rotating thermo-couple selector.
6. Repeat the experiment for different power inputs to the main heater & corresponding input to the guarded heater.
7. Tabulate the readings & calculate thermal conductivity of materials.
8. After experiment to over turn both the dimmer knobs in anti-clockwise direction till you heat a check burning back the voltmeter & ammeter & thermo-couple selector switch to zero position disconnect three-pin plug from mains.

Precautions:
1. The voltage of guarded heater should not be less than that of mains heater in order to restart the main heater.
2. Readings must be taken only after steady state is reached i.e. temperature of thermocouple (3) + (5) are equal.

Model calculations:

1. Average black body temperature:

$$T_b = \frac{T_1 + T_2 + T_3}{3}$$

2. Average heat transfer temperature

$$T_s = \frac{T_4 + T_5 + T_6}{3}$$

3. Power input to black body:

$$P_b = \in_b A_b \left[T_b^4 - T_\alpha^4\right]$$

$\in_b$ = emissivity of black body

A_b = Area of black surface

4. Power input to test sec/sc $P_s = \in_s A_s \left[T_s^4 + T_\alpha^4\right]$

Here $\in_s = \frac{T_b^4 + T_\alpha^4}{T_s^4 + T_\alpha^4}$

Voltage in Volts	Current in Amps	Power in Watts	Black surface temperature			Voltage in Volts	Current in Amps	Power in Watts	Test surface temperature			Chamber temperature $T_\alpha = T_7$	Emissivity $\in_s$
			T_1	T_2	T_3				T_4	T_5	T_6		

VIVA QUESTIONS

1. Explain Radiation.
2. Heat energy transfers in radiation in which form?
3. What is a Block body?
4. Explain Stefan – Boltzman's law? What is value of the Stefan – Boltzman contant?
5. Explain spectral blackbody emissive power?
6. Discuss Planck's distribution law.
7. Define emissivity.
8. Explain obsorptivity, reflectivity and transmissivity.
9. Define irradiation.
10. Explain Kirchoff's law.
11. Radiation between two surfaces mainly depends on-----

12. Define Shape factor (or) view factor (or) configure factor (or) angle factor
13. Explain Radiosity?
14. Explain Radiation Heat transfer between two surfaces?
15. What is network representation and what is its algebra?
16. Define Radiation shields?
17. Thermal radiation occur in the portion of electro magnetic spectrum between the wavelengths -----
18. For infinite parallel plates with emissivities ε_1 and ε_2 shape factor for radiation from surface 1 to surface 2 is ------

8.DETERMINATION OF STEFEN-BOLTZMAN'S CONSTANT

Aim: To determine the Stefen-Boltzman constant of radiation heat transfer.

Apparatus: Stafen_Boltzman apparatus consists of main switch, thermo couple selector switch, Digital temperature indicator, Schematic diagram showing test chamber with placement of thermocouples, water heating chamber with kettle element fitted and a test chamber, thermo meter and a stop watch.

Description of Apparatus: The apparatus is centered on a flanged copper hemisphere fixed on a flat non-conducting plates the outer surface of the hemisphere is enclosed in a metallic water jacket used to heat the hemisphere to a suitable temperature. On the hemispherical surface iron-constant thermo couples are attached at various places. The disc is mounted on an isolated bakelite sleeve which is fitted in a hole drilled in the center of the base plate. An iron-constantan thermo couple is used to measure the temperature of the disc.

Procedure:

1. Drain water if any from the test chamber by opening the drain value and close it.
2. Fill water into the water heating chamber upto 3/4 the capacity of the chamber.
3. Remove thermo couple T_4 from its position (From the bottom of the test chamber)
4. Keep the thermo couple selector switch at 'ZERO' position.
5. Plug the kettle heater plug into the main switch socket.
6. Connect the main three pin plug to 230 V, 50 Hz, 5 Amp power supply.
7. Put 'ON' the main switch and wait till the water in the heating chamber reaches 60^0C temperature by inserting stick thermo meter form top.
8. Put 'OFF' the main switch.
9. Allow the hot water to flow into the test chamber by opening the tap provided underneath the heating chamber till the hot water oozes out of the breather hole provided on the top of the test chamber.
10. Close the tap and allow the unit to stabilize for some time.
11. Take down the temperatures of the thermocouples T_1, T_2, T_3 recorded on the temperature indicator by turning the thermocouple selector switch clock wise in steps marked 1, 2, 3.
12. Inset the test thermocouple T_4 into its position through the bottom hole of the test chamber and simultaneously start a stop clock provided. Record the temperatures of T_4 at an interval of five seconds & 10 seconds by keeping the selector switch at position 4.
13. Tabulate the readings and calculate.
14. Drain the test chamber water fully.
15. Refill the boiler to 3/4 of its capacity.
16. Switch on main switch.
17. Switch repeat experiment for different temperatures 70^0, 80^0C etc.

Graph:

A graph is drawn on temperature of the disc (T_4) Vs time (t) in seconds. From graph slope of the line = dT/dt

Model calculations:

Mass of the test disc M = 1.2 gms.

Specific heat of disc material (C_P) copper = Watts/kg ^{0}C

Diameter of the disc D = 20 mm.

Temperature of the enclosure $T_E = \frac{T_1 + T_2 + T_3}{3}$ in ^{0}K.

From graph 1 slope of the line $= \frac{dT}{dt}$ ^{0}C/sec.

Rate of heat absorbed by the disc $Q = mC_P \frac{dT}{dt}$ Watts

Stefen Bolazman constant $\sigma = \frac{Q}{A(\in_E T_E^4 - \in_S T_S^4)}$

Where T_S is the temperature of the disc material when it sis inserted i.e. T_4 at 0 seconds.

A is the areas of the heat transfer $= \frac{\pi}{4} D^2$

D is diameter of the disc, $\in_E = \in_S = \in = 0.22$

S.No	Temperature of water in the Boiler in ^{0}C	Temperature of the enclosure in ^{0}C T_1 T_2 T_3 $\frac{T_1 + T_2 + T_3}{3}$	T_E in K	T_S in K	From graph slope of the line $\frac{dT}{dt}$	Heat absorbed the disc Q Watts	Stefen Boltzman constant σ

VIVA QUESTIONS

1. Explain Radiation.
2. Heat energy transfers in radiation in which form?
3. What is a Block body?
4. Explain Stefan – Boltzman's law? What is value of the Stefan – Boltzman contant?
5. Explain spectral blackbody emissive power?
6. Discuss Planck's distribution law.
7. Define emissivity.
8. Explain obsorptivity, reflectivity and transmissivity.
9. Define irradiation.
10. Explain Kirchoff's law.
11. Radiation between two surfaces mainly depends on-----
12. Define Shape factor (or) view factor (or) configure factor (or) angle factor
13. Explain Radiosity?
14. Explain Radiation Heat transfer between two surfaces?
15. What is network representation and what is its algebra?
16. Define Radiation shields?
17. Thermal radiation occur in the portion of electro magnetic spectrum between the wavelengths -----
18. For infinite parallel plates with emissivities ε_1 and ε_2 shape factor for radiation from surface 1 to surface 2 is ------

9.TEST ON HEAT EXCHANGER

Aim: To study and compare temperature distribution, heat transfer rate, overall heat transfer coefficient in PARALLEL flow and COUNTER flow.

Apparatus:
Stop clock, measuring flask, thermometers etc. and heat exchanger equipment.

Specifications:

Length of the heat exchanger = 1200 mm
Inner tube Inner diameter = 9.5 mm
Outer diameter = 32 mm
Capacity of Geyser = 3 liters; wattage = 3 Kw

Description of Apparatus:
The apparatus consists of a concentric tube heat exchanger. The hot fluid i.e. hot water is obtained from an electric geyser and it flow through inner tube. The cold fluid i.e. cold water can be admitted at any one of the ends enabling the heat exchangers to run as a parallel flow apparatus or a counter flow apparatus. This can be done by operating the different values provided. Temperatures of the fluids can be measures using. Flow rate can be measured using stop clock and measuring flask. The outer tube is provided with adequate asbestos rope insulation to minimize the heat loss to the surrounding.

Procedure:

1. Start the flow on hot water side.
2. Start the flow on cold water side.
3. Put on the electric geyser.
4. Adjust the flow rate on cold water side slightly higher than flow rate on hot water side.
5. Adjust the flow rate same bill the steady state condition is reached.
6. Note the temperatures and measure the flow rate.
7. The experiment is repeated for parallel as well as counter flow head exchanges.

Calculation: C_P of water = 4.18 kj/kgk = 4180 j/kgk

Parallel flow:

1. Heat transfer from (LOST) hot water $Q_h = m_h C_{Ph} (T_{hi} - T_{ho})$ watts
2. Heat transfer to (GAINED BY) cold water $Q_C = m_C C_{PC} (T_{ho} - T_{hi})$ watts
   m_h – mass of hot water kg/sec
   m_C – mass of cold water kg/sec
3. Log mean temperature difference LMTD $= \dfrac{(T_{hi} - T_{Ci}) - (T_{ho} - T_{Co})}{\text{in}\left[\dfrac{T_{hi} - T_{Ci}}{T_{ho} - T_{Co}}\right]}$

4. Overall heat transfer coefficient $U = \frac{Qavg}{A_3(LMTD)} m^2\ {}^0C.$

   Where $Qavg = \frac{Q_h + Q_C}{2}$

   Surface area of inner tube = $A_S = \pi D_0 L$

   D_0 = To outer diameter of inner tube.

   L = Length of the tube.

5. Effectiveness of heat exchanger : $C_c > C_h$

$$E = \frac{C_C(T_{CO} - T_{Ci})}{C_{min}[T_{hi} - T_{Ci}]}$$

$$= \frac{\text{Actual heat transfer rate}}{\text{Maximum possible heat transfer rate}}$$

$C_c = m_c C_{pc}$ $C_{min} = m_h C_{ph}$

Counter flow:

1. $Q_h = m_h C_{ph} (T_{hi} - T_{ho})$ watts
2. $Q_c = m_c C_{pc} (T_{ci} - T_{co})$ watts
3. Log mean temperature difference $= \frac{(T_{hi} - T_{Co}) - (T_{ho} - T_{Ci})}{in\left[\frac{T_{hi} - T_{Co}}{T_{ho} - T_{Ci}}\right]}$
4. Overall heat transfer coefficient $U = \frac{Q_{au}}{A_S LMTD}$
5. Effectiveness $E = \frac{M_C C_{PC}(T_{CO} - T_{Ci})}{m_h C_h (T_{hi} - T_{Ci})}$

Precautions:

1. Keep water flow rate same.
2. Temperature should be noted when steady state condition is reached.
3. Check the value for direction of flow of water in each case i.e., Parallel / Counter flow.

Test On Heat Exchanger

S. No	Type of flow	Hot water				Cold water			
		ml/sec	Kg/sec	Inlet temp. in ^0C T	Outlet temp. in ^0C T	ml/sec	Kg/sec	Inlet temp. in ^0C T	Outlet temp. in ^0C T
1	2	3	4	5	6	7	8	9	10
1	Parallel Flow								
2	Counter Flow								

Heat lost hot water Q_n	Heat gained by cold water Q_C	Average heat transfer $Q_{au} = \frac{Q_h + Q_C}{2}$	LMTD	Overall heat transfer Co-eff.	Effectiveness ∈
11	12	13	14	15	16

VIVA QUESTIONS

1. Classify convection.
2. What is forced convection & natural convection?
3. Explain difference between forced convection and natural convection?
4. Force convection in a liquid bath is caused by----
5. Explain Newton's law of cooling?
6. Give the relation between 'Fluid velocity' and 'Heat transfer'?
7. On which properties does convection heat transfer strongly depend?
8. Define convection heat transfer coefficient with dimensions.
9. Define Nussult number.
10. Develop velocity boundary layer for flow over a flat plate?
11. What is drag force?
12. Define friction coefficient (or) drag coefficient?
13. Explain Reynolds number?
14. What is critical Reynolds number?
15. Explain Prandtl number.
16. Fluid properties are evaluated at what temperature?
17. For forced convection, Nussult number is a function of---------
18. The Prandtl number will be lowest for------
19. What is significance of Nussult's number in convection?
20. The hydro dynamic and thermal boundary layers are identical at Prandtl number equal to-----
21. The temperature gradient in the fluid flow over a heated plate will be------
22. The ratio of heat transfer by convection to that by conduction is called-----
23. Define buoyancy force and discuss significance of the buoyancy force in Natural convection?

24. Define volume expansion coefficient and discuss significance in Natural convection?
25. Define Grashoff number and discuss significance of Grashoff number?
26. What is significance of Rayleigh's number?
27. The free convection heat transfer is significantly affected by----
28. The dimension less parameter $\frac{(\beta g \rho^3 l^3 \Delta t)}{\mu^3}$ is called as----
29. What is significance of Stanton number?
30. The convective heat transfer coefficient from a hot cylindrical surface exposed to still air varies in accordance with------
31. For Laminar conditions, the thickness of thermal boundary layer increases with the distance from the leading edge in proportion to------
32. Which dimensionless number has a significant role in forced convection?
33. Explain about a heat exchanger.
34. Classify heat exchangers.
35. Which type of heat transfer takes place in heat exchangers?
36. What is fouling?
37. Classify fouling?
38. What is the relation between fouling and overall heat transfer coefficient?
39. Define heat capacity ratio?
40. Explain different methods to design heat exchangers?
41. Define LMTD
42. Explain LMTD for parallel flow
43. Explain LMTD counter flow
44. What is correction factor?
45. What is effectiveness?
46. Explain effectiveness in parallel and counter flow?
47. Expand NTU
48. The normal automobile radiator is a heat exchanger of which type?
49. The Condenser in a thermal power plant is an exchanger of which type?
50. The effectiveness of heat exchanger is given by-------

10.CRITICAL HEAT FLUX APPARATUS

Aim:

Determination of critical heat flux values at different bulk temperatures and to observe the boiling phenomenon

Introduction:

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

The experimental setup is designed to study the pool boiling phenomenon up to critical heat flux point. The pool boiling over the heater wire can be visualized in the different regions up to the critical heat flux point at which the wire melts. The heat flux from the wire is slowly increased by gradually increasing the applied voltage across the test wire and the change over from natural convection to nucleate boiling can be seen. The formation of bubbles and their growth in size and number can be visualized followed by vigorous bubble formation and their immediate carrying over to surface and ending this in the breaking of wire indicating the occurrence of critical heat flux point. This is repeated for various temperatures of the water in the container up to saturation temperature.

Specifications:

1. Glass container – diameter : 200 mm, height 100 mm
2. Heater for initial heating (Nichrome wire) (R_1) – 1 KW
3. Test heater (Nichrome wire, size: ϕ 12 mm) (R_2)
4. Length of the test heater (R_2) – 100 mm

Procedure:

1. Take sufficient amount of distilled water in the container.
2. See that both heaters are completely immersed.
3. Connect heater R_1 and heater R_2 across the studs and make the necessary electrical connections.
4. Switch ON the heater R_1.
5. Keep it on till we get the required bulk temperature of water in the container say 50^0C, 60^0C, 70^0C up to the saturation temperature.
6. Switch OFF the heater R_1.
7. Switch ON the test heater R_2.
8. Gradually increase the voltage across it by slowly changing the variac position and stop a while at each position to observe the boiling phenomenon on the wire.
9. Increase the voltage till the wire breaks carefully note the voltage and current at this point.
10. Repeat this experiment by altering the bulk temperature of water.

Precautions:

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

Observations:

1. Daimeter of test heater wire d = mm.
2. Length of the test heater L= mm
3. Surface area A = d x L= mm^2

S.No	Bulk temperature of water $(T^0)C$	Ammeter reading (I) amps	Voltage reading (V) Volts	Critical heat flux $\frac{Q}{A}$

Results:

The critical heat flux at various bulk temperatures of water can be calculated by the following procedure:

Heat Input = V x I Watts

Critical Heat Flux = $\frac{V \times I}{A} w/m^2$

Peak heat flux in saturated pool boiling :

$$\frac{Q}{A} = \frac{\pi}{24} \times \lambda \times \rho \times V \left(\frac{\sigma \times g \times (\rho_l - \rho_v)}{\rho_v{}^2} \right)^{0.25} \left(\frac{\rho_l + \rho_v}{\rho_l} \right)^{0.5}$$

λ = Latent heat

$\frac{Q}{A}$ = Heat flux

σ = Liquid –vapour surface tension

ρ_l = Density of Liquid

ρ_v = Density of vapour

The properties are evaluated at the liquid saturation temperature. It can can be observed that the critical heat flux value goes on decreasing as the bulk temperature approaches the saturation temperature.

VIVA QUESTIONS

1. What is pool boiling?
2. Define flow boiling?
3. Define sub cooled boiling?
4. Define saturated boiling?
5. Explain different regimes of pool boiling?
6. Explain Neucleate boiling?
7. Define film boiling?
8. Explain what is critical heat flux?
9. Explain how bubbles are formed in boiling?
10. Explain Leiden frost point?
11. What is Condensation?
12. Classify Condensation processes?
13. What is the condition for condensation?
14. Define film condensation?
15. Define drop wise condensation?
16. Explain flow regimes in film condensation?

11.THERMAL CONDUCTIVITY OF SOLIDS

Aim: To determine thermal conductivity of solid by the guarded plate method.

Apparatus:
Main heater, guarded heater, specimen, cold water circulation, panel consists of voltmeter, ammeter, temperature (digital type) indicators, dimmer and selector switch for main and guarded heaters, thermo couple selector.

Description:
Electrically heater, thermal guards are placed adjacent to the exposed surface of heat source 'H', specimen and heat pads. The guards are independently maintained at the temperature at the adjacent surfaces. So that ideally no heat leakage occurs from the source used in the computation of thermal conductivity of specimen is equal to and not less than that actual passing through.

The heat source is an electric plate heater. The input which is measured using a voltmeter an ammeter. Thermal couples are located on either side of the specimen. The whole assembly is enclosed in insulated layer of mineral wool to prevent radiation and convection losses upto the extent. Cooling water sources are provided at the end to minimize the heat loss. Panel consists of ammeter, voltmeter, temperature indicators all are of digital type, two dimmer controls, temperature indicators all are of digital type, two dimmer controls main and guarded heaters selector and thermo couple selector switches.

Procedure:
1. Connect the three pin plug to the mains.
2. Keep the heater selector switch in position 1 and rotate the main heater dimmer clockwise and adjust the power input to any desired value by looking at voltmeter and ammeter starting form lower power input.
3. Keep the heater selector switch in position 2 and rotate the guarded heater dimmer clockwise and adjust the power input to the required value by looking at panel board. Keep the voltage of guarded heater slightly lower than main heater (2V).
4. Allow the unit to stabilize at corresponding power inputs.
5. When the temperatures of thermocouples 3 and 5 are equal, note down the temperature at various thermo couple locations by rotating thermo couple selector.
6. Repeat the experiment for different power inputs to the main heater and corresponding inputs to the guarded heater.
7. Tabulate all reading and calculate thermal conductivity of material.
8. After experiment is over turn both the dimmer knobs anti clockwise direction till you hear a click, bring back the voltmeter, ammeter and thermo couple selector switch to 'ZERO' position, disconnect the three pin plug from the mains.

Precautions:

1. The voltage of guarded heater should be less than that of the main heater (2 V) in order to restrict the heat transfer side ways.
2. Readings must be taken only after steady state is reached i.e. temperature of thermo couples 3 and 5 are equal.

S. No	Main heater		Guarded heater		Temperature across two specimens ^{0}C									K W/m^0 K
	Volts	Amps	Volts	Amps	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	

VIVA QUESTIONS

1. Define thermal conductivity.
2. For which material thermal conductivity is highest?
3. Why negative sign in Fourier's Law?
4. What are the units of thermal conductivity?
5. What is the first law of thermodynamics?
6. What is the second law of thermodynamics?
7. How is thermal conductivity measured practically?
8. Why are diamonds sinks used in cooling electronic components?
9. What is the physical mechanism of conduction in solids, liquids and gases?
10. What do you mean by "ρc_p"?
11. What is the physical significance of thermal diffusivity?
12. Is heat transfer a scalar or vector quantity?
13. What do you mean by steady heat transfer and how does it differ from transient heat transfer?
14. What is lumped system? How does heat transfer in a lumped system differ from steady heat transfer?
15. From heat transfer point of view, what is the difference between isotopic and un isotopic materials?
16. What is heat generation in a solid?
17. How are ordinary and partial differential equations used in heat transfer analysis?
18. What is a boundary condition? Explain.
19. What is the material for which thermal conductivity is to be found in thermal conductivity of solids experiment?

12.VAPOR COMPRESSION REFRIGERATION SYSTEM

INTRODUCTION:

The vapor compression system is the most important system from the view point of commercial of domestic utility. It is the most practical form of refrigeration. In this system the working fluid is vapor. It readily evaporates, condenses (or) changes alternating between the vapor and liquid phases without leaving the refrigerant plant during evaporation. It absorbs heat from the cold body. This heat is used as its latent heat for converting it from the liquid to vapor. The condensing (or) cooling (or) liquefying it rejects heat to external body thus creating a cooling effect in the working fluid this system thus acts as a latent heat pump. Since to pump its latent heat from the cold body (or) bring of rejects it can delivers it to the external hot body (or) cooling medium. The principle upon which the vapor compression system works apply to all the gases for which tables of thermodynamic properties are available.

Simple vapor compression cycle:
In a simple vapor compression system fundamental process are computed in one cycle. There are.

1. Compression
2. Condensation
3. Expansion
4. Vaporization

The vapors at low temperature and pressure enters the "Compressor" where it is compressed isentropically of subsequently its lamp of pressure increase considerably this vapor after leaving the compressor enters the "condenser" where it is considered into high pressure liquid of it is collected in a "receives tank" from it is throttled down to a lower pressure of has a low temperature. After finding its way through expansion value it finially panes on to "evaporator" where is extracts heat from the surroundings (or) circulating fluid being refrigerated & vaporizes to low pressure vapor actual vapor compression cycle.

The actual vapor compression cycle differs from the theoretical cycle in several ways because of the following reasons:

1. Frequently the liquid refrigerant is sub cooled before it is allowed to enter the expansion value, of usually the gas leaving the evaporator a few degree before it enters the compressor. This super heating may occur as a result of the type of expansion control used (or) through a pick up of heat in the suction line between the evaporator and compressor.
2. Compression, although usually assumed to be isentropic may actually prove to be neither isentropic (nor) poly-tropic.
3. Both the compression suction of discharge valves are actuated by pressure difference & this process requires the actual suction pressure inside the compressor to be slightly below that of the evaporator and the discharge pressure to be above of condenser.
4. Although isentropic compressor assumes no heat transfer between the refrigerant of the cylinder walls, actually the cylinder walls are hotter than the

in coming gases from the evaporator of cooler than the than the compressed gases discharged to the condenser.

5. Pressure drop in loop suction & liquid line piping and any vertical difference in head created by locating the evaporator & condenser at different elevations.

The various process of a actual vapor compression cycle on T-S diagram are discussed as follows:

Process 1-2-3 : This process represents passage of refrigerant through the evaporator, with 1-2 indicating gain of latent heat of vaporization & 2-3 the gain of super heat before entrance to compressor both of these process approach very closely to the construct pressure conditions.

Process 3-4-5-6-7-8: This path entrance to the discharge of the compressor path 3-4 represents the throttling action that occurs during passage through the suction values, and path 7-8 represents the throttling during passage through exhaust values both of thus electrons drop it temperature.

Compression of the refrigerant occurs along 5-6, which is actually neither isentropic nor poly-tropic. The heat transfer indicated by path 4-5 & 6-7 occurs essentially at constant pressure process.

Process 8-9-10-11: This process represents the passage of refrigerant through the condenser with 8-9 indicating removal of super heat, 9-10 the removal of latent heat & 10-11 represents removal of liquid (or) sub-cooling.

Process 11-1: This process represents passage of the refrigerant through the expansion value both theoretically of practically an irreversible adiabatic path.

Model calculation:

P_1 = Pressure at inlet of condenser

P_2 = Pressure at exit of condenser

P_3 = Pressure after expansion

P_4 = Pressure at return to compressor

T_1 = Temperature after compression

T_2 = Temperature after condensation

T_3 = Temperature after expansion

T_4 = Temperature at section to compressor

H_1 (T_4, P_4) = enthalpy at the suction of compressor (kj/kg)

H_2 (T_1, P_1) = enthalpy at delivery of compressor

H_3 (T_2, P_2) and H_4 (T_3, P_3) = enthalpy at throttling.

The above enthalpies corresponding to pressure P_1, P_2, P_3 & P_4 and corresponding temperature is calculated from the pressure v/s enthalpy chart provided.

1. Co-efficient of performance $= \dfrac{H_1 - H_3}{H_2 - H_1}$
2. Weight of refrigeration $= W = \dfrac{50}{H_1 - H_3}$

1 ton of refrigeration = 210 kj/min

3. Theoretical power = W × (H_2 – H_1) (compressed work)
4. Quantity of heat rejected to condenser = W (H_2 – H_3) kj/min

S.No	Time (min)	Temperature				Pressure				Time taken for 5 rev	Power input
		T_1	T_2	T_3	T_4	P_1	P_2	P_3	P_4		

VIVA QUESTIONS

1. Define TON of refrigeration.
2. What are the important properties of refrigerants?
3. What are the common refrigerants used in vapor compression refrigeration?
4. Draw the P – H diagram for vapor compression refrigeration cycle.
5. Draw the T – S diagram for vapor compression refrigeration cycle.
6. What do you mean by dry compression?
7. What do you mean by wet compression?
8. What is the importance of capillary tube in vapor compression cycle?
9. Which type of compressor is used for domestic refrigerator?
10. What do you mean by hermitically sealed compressor?
11. What are the disadvantages of wet compression?
12. Define dryness factor.
13. What are the refrigerants, which cause Ozone layer depletion?
14. What is the chemical that is responsible for Ozone layer depletion?
15. What do you mean by global warming?
16. What are the Eco-friendly refrigerants?
17. What are the harmful effects of Ozone layer depletion?
18. What are the harmful effects of global warming?