HEAT TRANSFER LABORATORY
LAB MANUAL

LIST OF EXPERIMENTS:

1. To find out the overall thermal conductance and plot the temperature distribution in case of a composite wall
2. To determine the thermal conductivity of a liquid.
3. To find out the temp. Distribution along the length of a Pin Fin under free convection
4. To find out the temp. Distribution along the length of a Pin Fin under forced convection
5. To find out the Heat Transfer Coefficient of vertical cylinder in natural convection.
6. To find out the Stefan Boltzmann constant.
7. To calculate the overall heat transfer coefficient for parallel flow heat exchanger.
8. To calculate the overall heat transfer coefficient for counter current flow heat exchanger.
9. To find the heat transfer co-efficient for Drop-wise condensation.
10. To find the heat transfer co-efficient for Film-wise condensation process.

EXPERIMENT-1

OBJECTIVE: Study of conduction heat transfer in composite wall.

AIM:

1. To determine total thermal resistance and thermal conductivity of composite wall.
2. To calculate thermal conductivity of one material in composite wall.
3. To plot the temperature profile along the composite wall.

INTRODUCTION:

When a temperature gradient exists in a body, there is an energy transfer from the high temperature region to the low temperature region. Energy is transferred by conduction and heat transfer rate per unit area is proportional to the normal temperature gradient:

$$\frac{q}{A} \alpha \frac{\Delta T}{\Delta X}$$

When the proportionality constant is inserted,

$$q = -kA\frac{\Delta T}{\Delta X}$$

Where q is the heat transfer rate and T/ X is the temperature gradient in the direction of heat flow. The positive constant k is called thermal conductivity of the material.

THEORY:

A direct application of Fourier's law is the plane wall. Fourier's equation:

$$q = -\frac{kA}{\Delta X}\left(T_2 - T_1\right)$$

Where the thermal conductivity is considered constant. The wall thickness is X, and T_1 and T_2 are surface temperatures. If more than one material is present, as in the multiplayer Wall, the analysis would proceed as follows:

The temperature gradients in the three materials (A, B, C), the heat flow may be written

$$q = -k_A A\frac{\Delta T_A}{\Delta X_A} = -k_B A\frac{\Delta T_B}{\Delta X_B} = -k_C A\frac{\Delta T_C}{\Delta X_C}$$

DESCRIPTION:

The Apparatus consists of a heater sandwiched between two asbestos sheets. Three slabs of different material are provided on both sides of heater, which forms a composite structure. A small press- frame is provided to ensure the perfect contact between the slabs. A Variac is provided for varying the input to the heater and measurement of input power is carried out by a Digital Voltmeter & Digital Ammeter. Temperatures Sensors are embedded between inter faces of the slab, to read the temperature at the surface. The experiment can be conducted at various values of power input and calculations can be made accordingly.

UTILITIES REQUIRED:

1. Electricity Supply: Single Phase, 220 VAC, 50 Hz, 5-15Amp socket with earth connection.
2. Bench Area Required: 1m x 1m.

EXPERIMENTAL PROCEDURE:

STARTING PROCEDURE:

1. Ensure that Mains ON/OFF switch given on the panel is at OFF position &dimmer-stat is at zero position.
2. Connect electric supply to the set up.
3. Switch ON the Mains ON / OFF switch.
4. Set the heater input by the dimmer-stat, voltmeter in the range 40 to 100 V.
5. After 1 hour. Note down the reading of voltmeter, ampere meter and temperature sensors in the observation table after every 10 minutes interval till observing change inconsecutive readings of temperatures (± 0.2 ^oC).

CLOSING PROCEDURE:

1. After experiment is over set the dimmer stat to zero position.
2. Switch OFF the Mains ON/OFF switches.
3. Switch OFF electric supply to the set up.

OBSERVATION & CALCULATIONS:

DATA:

$d = 0.25$ m

X_1 = 0.020 m = 20mm

X_2 = 0.020m = 20 mm

X_3 = 0.012m = 12mm

K_1=125w/m°C

K_2=1.4w/m°C

K_3=----w/m°C

OBSERVATION TABLE:

Sl. No	V Volts	A Amps	T_1 ºC	T_2 ºC	T_3 ºC	T_4 ºC	T_5 ºC	T_6 ºC	T_7 ºC	T_8 ºC

CALCULATIONS:

To plot the temperature profile,

Distance	0	10	20	45
Avg. Temp				

At distance 0, average temp $= \frac{(T_1 + T_2)}{2}$

At distance 10, average temp $= \frac{(T_3 + T_4)}{2}$

At distance 20, average temp $= \frac{(T_5 + T_6)}{2}$

At distance 45, average temp $= \frac{(T_7 + T_8)}{2}$

Heat supplied by the heater, $W = 0.86 \times V \times I$, watts

Amount of Heat Transfer, Q = W, watts

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

Overall Temp. Difference $\Delta T = \frac{(T_1 - T_7) + (T_2 - T_8)}{2}$, ^oC

Total thermal resistance of composite wall $R_t = \frac{\Delta T}{q}$, ^oC m^2/W

Total thickness of wall $\Delta X = X_1 + X_2 + X_3$, m

Thermal Conductivity of composite wall $K_{eff} = \frac{q \times \Delta X}{\Delta T}$, W/m ^oC

Thermal Conductivity of press wood $K_3 = \frac{X_3}{\left[\frac{\Delta T}{q} - \left(\frac{X_1}{k_1} + \frac{X_2}{k_2}\right)\right]}$, W/m ^oC

NOMENCLATURE:

A	=	Area of heat transfer, m^2
d	=	Diameter, m
I	=	Ammeter reading, amp
K eff	=	Thermal conductivity of composite wall, W/m ^oC
k1	=	Thermal conductivity of cast iron, W/m ^oC
. k2	=	Thermal conductivity of Press wood, W/m ^oC
k3	=	Thermal conductivity of Bakelite, W/m ^oC
Q	=	Amount of heat transfer, W
q	=	Heat flux, W/m^2
Rt	=	Total thermal resistance of composite wall, ^oC m^2/W
ΔT	=	Overall temperature difference, ^oC
T_1 & T_2	=	Interface temperature of 1ST slab and heater, ^oC
T_3 & T_4	=	Interface temperature of 1st and2nd slab, ^oC
T_5 & T_6	=	Interface temperature of 2nd and 3rd slab, ^oC
T_7 & T_8	=	Top surface temperature of press wood, ^oC
V	=	Voltmeter reading, volts
W	=	Heat supplied by the heater, W

ΔX = Total thickness of wall, m

X1 = MS Slab thickness, m

X2 = Bakelite slab thickness, m

X3 = Press wood thickness, m

PRECAUTION

1. Use the stabilize A.C. Single phase supply only. The voltage should not very more than $\pm$ volts
2. Keep Dimmer stat to zero before start and increase the voltage slowly.
3. Keep all the assembly undisturbed.
4. Remove air gap between plates by moving hand press gently.
5. Operate selector switch of temperature indicator gently.

There is a possibility of getting abrupt result if the supply voltage fluctuating or if the satisfactory steady state condition is not reached.

EXPERIMENT-2

OBJECTIVE:

Study of heat transfer through liquid

AIM:

To determine the thermal conductivity of a liquid

INTRODUCTION:

When temperature gradient exists in a body, there is an energy transfer from the high temperature region to the low temperature region. Energy is transferred by conduction and heat transfer rate per unit area is proportional to the normal temperature gradient:

$$\frac{q}{A} \approx \frac{\partial T}{\partial X}$$

When the proportionality constant is inserted,

$$\mathrm{q} = -\mathrm{KA}\,\frac{\partial \mathrm{T}}{\partial \mathrm{X}}$$

Where q is the heat transfer rate and $\partial \mathbf{T} / \partial \mathbf{X}$ is the temperature gradient in the direction of heat flow. The positive constant **k** is called is thermal conductivity of the material.

THEORY:

For thermal conductivity of liquids using Fourier's law, the heat flow through the liquid from hot fluid to cold fluid is the heat transfer through conductive fluid medium. Fourier's equation:

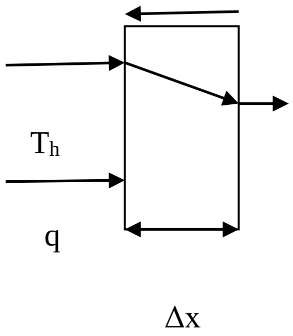
$$\mathrm{q} = \frac{-\mathrm{KA}}{\Delta \mathrm{X}}(\mathrm{T}_1 - \mathrm{T}_2)$$

Fourier's law for the case of liquid

At steady state, the average face temperatures are recorded (T_h and T_c) along with the rate of heat transfer (Q). Knowing, the heat transfer area (A_h) and the thickness of the sample (ΔX) across which the heat transfer takes place, the thermal conductivity of the sample can be

Calculated using Fourier's Law of heat conduction.

$$Q = kA_h \,\Delta T/\Delta X = kA_h (T_h - T_c) / \Delta X$$



Heat transfer area = A_h (area ⊥ to direction of heat flow)

DESCRIPTION:

The apparatus is based on well-established "Guarded Hot Plate" method. It is a steady state absolute method suitable for materials, which can be fixed between two parallel plates and can also be extended to liquids that fill the gap between the plates.

The essential components of the set-up are the hot plate, the cold plate, and heater to heat the hot plate, cold water supply for the cold plate, RTD PT-100 Sensors and the liquid specimen holder.

In the set-up, a unidirectional heat flow takes place across the liquid whose two faces are maintained at different temperatures by the hot plate on one end and by the cold plate at the other end.

A heater heats hot plate and voltage to the heater is varied with the help of variac to conduct the experiment on different voltages as well as different heat inputs. Temperatures are measured by RTD PT-100 sensors attached at three different places on the hot plate as well as on the cold plate. These sensors are provided on the inner surface facing the liquid sample. An average of these sensor readings are used as T_h and T_c at steady state condition.

Heat is supplied by an electric heater for which, we have to record the voltmeter reading (V) and ammeter reading (A) after attaining the steady state condition. The temperature of the cold surface is maintained by circulating cold water at high velocity. The gap between hot plate and cold plate forms the liquid cell, in which liquid sample is filled.

The depth of the liquid in the direction of flow must be small to ensure the absence of convection currents and a liquid sample of high viscosity and density shall further ensure the absence of convection and the heat transfer can be safely assumed to take place by conduction alone.

UTILITIES REQUIRED:

Water supply 5 lit/min (approx.)
Drain.

Electricity Supply: 1 Phase, 220 V AC, 2 Amperes.
Table for set-up support (optional)

EXPERIMENTAL PROCEDURE:

1. Fill the liquid cell with the sample liquid (glycerol) through the inlet port, keeping the apparatus tilted towards upper side so that there is complete removal of air through the outlet port. Liquid filling should be continued till there is complete removal of air and also liquid glycerol comes out of the outlet port. Close the outlet port followed by inlet port.
2. Allow cold water to flow through the cold-water inlet.
3. Start the electric heater to heat hot plate. Adjust the voltage of hot plate heater in the range of 10 to 50 volts.
4. Adjust the cold-water flow rate such that there is no appreciable change the outlet temperature of cold water (there should be minimum change).
5. Go on recording the thermocouple readings on hot side as well as on cold side, and once steady state is achieved (may be after 30-60 min); (steady state is reached when there no appreciable change in the thermocouple readings, ± 0.1,°C), record the three thermocouple readings (Th1, Th2, Th3 i.e. T_1, T_2, T_3 on Temperature Indicator) on the hot side and three thermocouple readings (T_{c1}, T_{c2}, T_{c3} i.e. T_4, T_5, T_6 on Temperature Indicator) on the cold side along with the voltmeter (V) and ammeter (A) readings.
6. Stop the electric supply to the heater, and continue with the supply of cold water till there is decrease in temperature of hot plate (may be for another 30-40 min).
7. Open the liquid outlet valve slightly in the downward tilt position and drain the sample liquid in a receiver, keeping liquid inlet port open.

SPECIFICATION:

1. Hot Plate

Material = brass

Diameter = 180 mm

2. Cold Plate

Material = Aluminum

Diameter = 180 mm

3. Sample Liquid depth = 18 mm

4. Temp. Sensors = RTD PT-100 type.

Type = RTD PT-100 type

Quantity = 6 Nos.

No. 1 to No. 3 mounted on hot plate.
No. 4 to No. 6 mounted on cold plate.

5. Digital Temperature indicator

Range = 0°C to 199.9°C

Least Count = 0.1^{o}C

6. Variac = 2 Amp, 230VAC

7. Digital Voltmeter = 0 to 250 Volts

8. Digital Ammeter = 0 to 2.5 Amp.

9. Main Heater = Nichrome heater 300 Watt approximate, ring heater mica held between plates 300 watt, top heater held between plates 300 watt, separate dimmer for heaters, volt and current meter, multi-channel digital temp indicator

FORMULAE

1. Heat input,

$$Q = V*I \text{ watt}$$

2. Thermal conductivity of liquid,

$$K = Q \frac{\Delta X}{A(T_h - T_c)}, \text{ Watt/m°C}$$

OBSERVATIONS & CALCULATIONS:

DATA:

Effective diameter of plate = 0.165 m

Effective area of heat transfer, A = 0.02139 m^2

OBSERVATIONS TABLE:

Sl. No.	V	I	W	T_{h1}	T_{h2}	T_{h3}	T_{C1}	T_{C2}	T_{C3}	Cold water flow rate

Record the following at steady state:

Sample liquid:

Heat input,	Q	=	-------------- watt
Hot face average temperature,	T_h	=	$(T_{h1} + T_{h2} + T_{h3}) / 3$
Cold face temperature,	T_c	=	$(T_{c1} + T_{c2} + T_{c3}) / 3$
Temperature difference,	ΔT	=	$(T_h - T_c)$
Thermal conductivity,	K	=	------------- W/m °C

NOMENCLATURE:

Q = Heat supplied by heater, watt.

A = Heat transfer area, m^2

T_h = Hot face average temperature, °C

T_c = Cold face average temperature, °C

ΔT = Temperature difference, °C

K = Thermal conductivity of liquid, w/m, °C

ΔX = Thickness of liquid, mm = 18 mm

PRECAUTIONS & MAINTENANCE INSTRUCTIONS:

1. Use the stabilize A.C. Single Phase supply only.
2. Never switch on mains power supply before ensuring that all the ON/OFF switches given on the panel are at OFF position.
3. Voltage to heater starts and increases slowly.
4. Keep all the assembly undisturbed.
5. Never run the apparatus if power supply is less than 180 volts and above than 240 volts.
6. Operate selector switch of temperature indicator gently.
7. Always keep the apparatus free from dust.
8. Testing liquid should be fully filled.

There is a possibility of getting abrupt result if the supply voltage is fluctuating or if the satisfactory steady state condition is not reached**.**

TROUBLESHOOTING:

1. If electric panel is not showing the input on the mains light. Check the fuse and also check the main supply.
2. If D.T.I displays "1" on the screen checks the computer sockets if loose tight it.
3. If temperature of any sensor is not displays in D.T.I check the connection and rectify that.
4. Voltmeter showing the voltage given to heater but ampere meter does not. Tight the heater socket & switch if ok it means heater burned and replace that.

REFERENCES:

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3. Perry, R.H., Green, D.(editors), **"Perry's Chemical Engineers' Handbook"**, 6th ed., McGraw Hill, NY, 1985.
4. McCabe, W.L., Smith, J.C., Harriott, P., **"Unit Operations of Chemical Engineering"**, 4th ed. McGraw Hill, NY, 1985.
5. Coulson, J.M., Richardson, J.F., **"Coulson & Richardson's Chemical Engineering Vol. - 1"**, 5th ed., Asian Books ltd., ND, 1996.

EXPERIMENT-3 & 4

AIM:

To study the temperature distribution along the length of a pin under free convection heat transfer.

INTRODUCTION:

Extended surfaces or fins are used to increase the heat transfer rate from a surface to a fluid wherever it is not possible to increase the value of the surface heat transfer coefficient or the temperature difference between the surface and the fluid. The use of this is very common and they are fabricated in a variety of shapes (Fig.1) circumferential fins around the cylinder of a motor cycle engine and fins attached to condenser tubes of a refrigerator are few familiar examples.

FAMILIAR EXAMPLES:

It is obvious that a fin surface sticks out from primary heat transfer surface. The temperature difference with surrounding fluid will steadily diminish as one moves out along the fin. The design of the fins therefore requires knowledge of the temperature distribution in the fin. The main object of this experiment set up is to study the temperature distribution in a simple pin fin.

Fin effectiveness= ε=tanh mL/mL

The temperature profile within a pin fin is given by:

$\theta/\theta_o = [T-T_f] / [T_b-T_f]$= (Cosh m(L-x) + HSinh m (L-x)] / [Cosh mL+HSinh mL]

where Tf is the free stream tem. Of air; Tb is the temp. of fin at its base; T is the temp. Within in the fin at any x; L is the length of the fin and D is the fin diameter. M is the fin parameter defined as:

fin parameter m= $\sqrt{}$ [hC/(k_b A)]

k_b=thermal conductivity of brass fin = 95 kcal/h-m-ºC

Where C= perimeter = π*D

A=cross-sectional area of fin= (Π/4) D^2

APPARATUS:

A brass fin of circular cross section is fitted across a long rectangular duct. The other end of the duct is connected to the suction side of a blower and the air flows past the fin perpendicular to its axis. One end of the fin projects outside the duct and is heat by a heater. Temperature at five points along the length of the fin is measured by RTD PT-100 type temperature sensors connected along the length of the fin. The air flow rate is measured by an orifice meter fitted on the delivery side of the blower.

SPECIFICATIONS: -

1. Dust size: -1800mm*100mm*100mm
2. Diameter of the fin: 12.7mm
3. Length of the fin: 150mm
4. Diameter of the pipe: 52mm
5. Diameter of the orifice: 26mm
6. Coefficient of discharge C_d: 0.64
7. Centrifugal blower: 1 phase motor
8. Temp. Indicator: 0-199.9°C, RTD PT-100 type
9. Thermal Conductivity of fin material (Brass):95 Kcal/hr-m-°c
10. Temp. Sensors No.6 reads ambient temp. in the inside of the Duct.
11. Dimmerstat for heat input control 230V, 2 Amps.
12. Voltmeter 0-250V
13. Ammeter 0-2A

NATURAL CONVECTION:

PROCEDURE:

1. Start heating the fin by switching on the heater element and adjust the voltage on dimmer stat to say 60 volts (increase slowly from 0 onwards)
2. Note down the Temp. sensors readings No. 1 to 5
3. When steady state is reached, record the final readings of Temperature Sensor No.1 to 5 and also the ambient temperature reading, Temperature Sensor No.6
4. Repeat the same experiment with voltage =100 volts and 120 volts.

FORCED CONVECTIONS:

PROCEDURE

1. Start heating the fin by switching on the heater and adjust dimmerstat voltage equal to 100 volts.
2. Start the blower and adjust the difference of level in the manometer H=cm with the help of valve.
3. Note down the Temperature Sensor readings (1) to (5) at a time interval of 5 minutes.
4. When the steady state is reached, record the final readings (1) to (5) and also record the ambient temperature readings by (6)
5. Repeat the same experiment with H=cm etc.

OBSERVATIONS:

Experiment	Power Input, W=V* I	FIN TEMPERATURE, ^{O}C					Ambient Temp.	Manometer Reading, ΔH, m of Water
		T1	T2	T3	T4	T5	T6	
		x=3 cm	x=6 cm	x=9 cm	x=12 cm	x=15 cm		
Forced Convection								
Free Convection								

CALCULATION:

FREE CONVECTION

EXPERIMENTALLY

$$T_m = \frac{T_1 + T_2 + T_3 + T_4 + T_5}{5}, \ ^{o}C$$

$$\Delta T = T_m - T_f \text{ , °C} \qquad (T_f = T_6)$$

$$Q = V \times I \text{ , W}$$

$$A_s = \pi d L \text{ , m}^2$$

$$h_{Exp} = \frac{Q}{A_s \times \Delta T} \text{ , W/m}^2\ {}^oC$$

THEORETICALLY

$$T_m = \frac{T_1 + T_2 + T_3 + T_4 + T_5}{5} \text{ , °C}$$

$$\Delta T = T_m - T_f \text{ , °C} \qquad (T_f = T_6)$$

$$T_{mf} = \frac{T_m + T_f}{2} \text{ , °C}$$

$$\beta = \frac{1}{(T_{mf} + 273.15)} \text{ , 1/K}$$

$$G_r = \frac{g \beta D^3 \Delta T}{v^2}$$

$$N_u = 0.53 \times (G_r \times P_r)^{1/4}$$

$$h_{Theo} = \frac{N_u \times k_{air}}{D} \text{ , W/m}^{2o}C$$

$$m = \sqrt{\frac{hC}{k_b A}} \text{ , m}$$

$$C = \pi D \text{ , m}^2$$

$$A = \frac{\pi}{4} D^2 \text{ , m}^2$$

$$\varepsilon = \frac{\tanh mL}{mL}$$

$$H = \frac{h}{K_b m} \text{ , m}$$

$$\frac{\theta}{\theta_o} = \frac{T - T_f}{T_b - T_f} = [\cosh, m(L-x) + H \sinh m(L-x)] / [\cosh ml + H \sinh mL]$$

Taking base temperature, Tb=T_1

FORCED CONVECTION:

EXPERIMENTALLY

$$T_m = \frac{T_1 + T_2 + T_3 + T_4 + T_5}{5} = \frac{43 + 39.7 + 39.3 + 38.5 + 38.2}{5} = 39.74 \text{ , °C}$$

$$\Delta T = T_m - T_f = 39.74 - 33 = 6.74 \text{ , °C} \quad (T_f = T_6)$$

$$Q = V \times I = 49.9 \times 0.25 = 12.47 \text{ , W}$$

$$A_s = \pi dL = \pi \times 0.0127 \times 0.15 = 5.98 \times 10^{-3} \text{ , m}^2$$

$$h_{Exp} = \frac{Q}{A_s \times \Delta T} = \frac{12.47}{5.98 \times 10^{-3} \times 6.74} = 309.3 \text{ , W/m}^2\text{ °C}$$

THEORETICALLY

$$T_m = \frac{T_1 + T_2 + T_3 + T_4 + T_5}{5} = \frac{43 + 39.7 + 39.3 + 38.5 + 38.2}{5} = 39.74 \text{ , °C}$$

$$T_{mf} = \frac{T_m + T_f}{2} = \frac{39.74 + 33}{2} = 36.37 \text{ , °C}$$

$$a_p = \frac{\pi}{4} d_p^{\ 2} = \frac{\pi}{4} \times 0.052^2 = 2.123 \times 10^{-3} \text{ , m}^2$$

$$a_o = \frac{\pi}{4} d_o^{\ 2} = \frac{\pi}{4} \times 0.026^2 = 5.309 \times 10^{-4} \text{ , m}^2$$

$$\Delta H = \frac{h_1 - h_2}{100}\left(\frac{\rho_w}{\rho_a} - 1\right) = \frac{19.2 - 8.7}{100}\left(\frac{1000}{1.21} - 1\right) = 86.67 \text{ , m}$$

$$Q_a = \frac{c_o a_p a_o \sqrt{2g\Delta H}}{\sqrt{a_p^{\ 2} - a_o^{\ 2}}} = \frac{0.64 \times 2.12 \times 10^{-3} \times 5.30 \times 10^{-4} \times \sqrt{2 \times 9.81 \times 86.67}}{\sqrt{\left(2.12 \times 10^{-3}\right)^2 - \left(5.30 \times 10^{-4}\right)^2}} = 0.0144$$

, m^3/s

$$V' = \frac{Q_a}{A} = \frac{0.0144}{1.26 \times 10^{-4}} = 114.23 \text{, m/s}$$

$$A = \frac{\pi}{4} D^2 = \frac{\pi}{4} \times 0.0127^2 = 1.26 \times 10^{-4} \text{ , m}^2$$

$$V_1 = V' \left\lfloor T_{mf} + 273.15 \right\rfloor / \left\lfloor T_f + 273.15 \right\rfloor = 115.48 \text{ , m/s}$$

$$R_e = \frac{DV_1\rho_a}{\mu} = 94.69 \times 10^3$$

$$N_u = 0.615\left(94.69 \times 10^3\right)^{0.466} = 128.18$$

$$h_{Theo} = \frac{N_u K_{air}}{D} = \frac{128.18 \times 0.02699}{D} = 272.4$$, W/m^{2o}C

$$m = \sqrt{\frac{hC}{K_b A}}$$, m

$$C = \pi D$$, m

$$\varepsilon = \frac{\tanh mL}{mL}$$

$$H = \frac{h}{K_b m}$$, m

$$\frac{\theta}{\theta_o} = \frac{T - T_f}{T_b - T_f} = \left[\cosh, m(L - x) + H \sinh m(L - x)\right] / \left[\cosh ml + H \sinh mL\right]$$

Taking base temperature, Tb=T_1

NOMENCLATURE:

a_p	=	Area of pipe, m^2
a_o	=	Area of orifice, m^2
A	=	Cross sectional area of fin, m^2
A_S	=	Surface heat transfer area, m^2
C	=	Perimeter, m
C_o	=	Orifice coefficient
D	=	Fin diameter, m
d_o	=	Orifice diameter, m
d_p	=	Diameter of pipe, m
g	=	Acceleration due to gravity, m/s^2
Gr	=	Grashoff’s number

h_1, h_2	=	Manometer reading, cm
H	=	Parameter, m
IH	=	Head loss, m
h_{Exp}	=	Experimental heat transfer coefficient, W/m^{2o}C
h_{Theo}	=	Theoretical heat transfer coefficient, W/m^2 ^{o}C
I	=	Ammeter reading, amps
K_b	=	Thermal conductivity of brass fin, W/m ^{o}C
K_{air}	=	Thermal conductivity of air, W/m ^{o}C
L	=	Fin length, m
m	=	Fin parameter, m
N_u	=	Nusselt number
Pr	=	Prandtl number
Q	=	Amount of heat transfer, W
Q_a	=	Volumetric flow rate of air through the duct, m^3/s
T	=	Fin surface temperature, ^{o}C
T_{mf}	=	Fluid mean temp, ^{o}C
T_m	=	Fin mean temperature, ^{o}C
T_f	=	Fin temperature at any point, ^{o}C
T_b	=	Fin base temperature, ^{o}C
V	=	Voltmeter reading, volts
V’	=	Velocity of air, m/s
V_1	=	Velocity of air at Tmf, m/s
x	=	Distance of the sensor at base of the fin, m

ε = Fin effectiveness

ρ_a = Density of air, kg/m3

μ = Dynamic viscosity of air, kg/m s

ν = Kinematic viscosity of air, m^2/s

ρ_w = Density of water, kg/m^3

$\frac{\theta}{\theta_o}$ = Theoretical temperature profile within the fin

PRECAUTIONS & MAINTENANCE INSTRUCTIONS:

1. Never run the apparatus if power supply is less than 180 volts and above than 230volts.
2. Never switch on mains power supply before ensuring that all the ON/OFF switches given on the panel are at OFF position.
3. Operator selector switches OFF temperature indicator gently.
4. Always keep the apparatus free from dust.

TROUBLE SHOOTING:

1. If electric panel is not showing the input on the mains light. Check the main supply.

REFERENCES:

1. Holman, J.P., “Heat Transfer”, 9th ed., McGraw Hill, ND, 2008, Page 39-46.
2. D.S Kumar, “Heat & Mass Transfer”, 7th ed, S.K Kataria & Sons, ND, 2008, Page 233-239, 253-256, 260-262.

EXPERIMENT-5

AIM: To find out the Heat Transfer Coefficient of vertical cylinder in natural convection.

APPARATUS:

Apparatus for Measuring Heat Transfer Coefficient through natural convection

APPARATUS DESCRPTION

The setup is designed and fabricated to study natural convection phenomenon from a vertical cylinder in term, of average heat transfer coefficient.

The apparatus consists of brass tube fitted in rectangular duct in vertical fashion. The duct is open at top and bottom and forms and encloses which serves the purpose of undisturbed surrounding. One side of it is made of glass/acrylic for visualization. A heating element is kept in a vertical tube which heats tube surface. The heat is lost from tube to surroundings by natural convection. The temperature is measured by seven temperature sensors. The heat input to the heater is measured by digital ammeter and digital voltmeter and can be varied by dimmer stat.

THEORY

The fluid motion is produced by due to change in density resulting from temperature gradients. The mechanism of heat transfer in these situations is called free or natural convection. Convection of the principle mode heat transfer from pipes, transmission lines, refrigerating coils, hot radiators and many other practical situations in everyday life.

The movement of fluid in free convection is due to the fact that the fluid particle in immediate vicinity of the hot object becomes warmer than surrounding fluid resulting in a local change of density. The warmer fluid would be replaced by colder fluid creating what are called convection currents. These currents originate when a body force (gravitational, centrifugal, electrostatic etc) at on a fluid in which there are density gradients. The force which induces these convection currents is called *buoyancy force* which is due to presence of density gradients within the fluid and the body force.

PROCEDURE

1. Switch on the supply and adjust the dimmer stat to obtain the required heat input.
2. Connect the computer with USB cable to operate via software.

3. Start the heating of the test section with the help of dimmer stat and adjust desired heat input with help of digital volt meter and digital ammeter. (Don't exceed 90 volts).
4. Log the data of all the temperature sensors until the steady is reached. (Wait at least 25 minutes for first set of reading and then 10 minutes for consecutive readings).
5. Put the value of heat input in the software.
6. Repeat the experiment for different heat input.

DATA:

Diameter (D) : 38 mm

Length (L) : 500 mm

UTILITIES REQUIRED:

- Electricity supply: 1 phase, 220 volts AC, 2 amperes.
- Table for set-up support.

OBSERVATION TABLE:

Voltage V	Ampere I	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8

CALCULATION:

Heat transfer coefficient is given by

$$h = \frac{q}{A_s\left(T_s - T_a\right)} Kcal/hr - m^2 - ^\circ C$$

q = VI (Kcal/hr)

$A_s = \pi DL\ m^2$

$$T_S = \frac{T_1 + T_2 + T_3 + T_4 + T_5 + T_6 + T_7}{7}$$

T_a= Ambient temperature in duct in ℃ (T_8).

NOMENCLATURE

V	=Voltage
I	= Ampere
T_1, T_2…….T_7	=Temperature of tube surface at different locations.
Ta	=Ambient temperature in duct, ˚C = T_8
h	=Heat transfer coefficient.
q	=Heat transfer rate.
As	=Surface area of tube.
D	=Diameter of tube.
L	=Length of tube.
Ts	=average of temperature of tube surface.

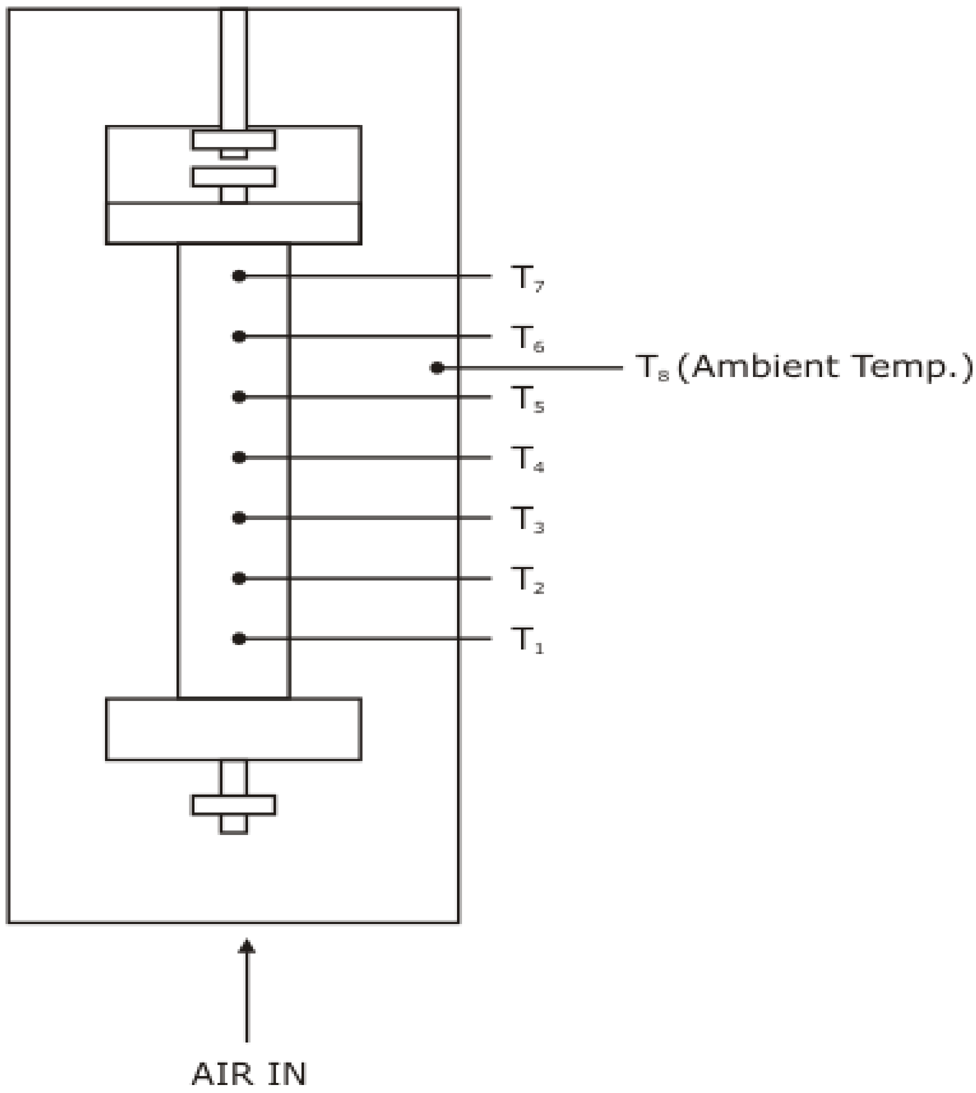
PRECAUTIONS

1. Keep the dimmer stat at zero poison before giving the supply.
2. Increase the dimmer stat slowly.
3. Increase the voltage gradually.
4. Don’t stop supply between the testing periods.
5. Operate channel switch of temperature indicator gently.
6. Don’t exceed 90 volts.

REFERENCE

1. A Text Book of Heat and Mass Transfer by DR. D.S. Kumar.

2. A Text Book of Heat and Mass Transfer by R. Yadav.
3. A Text Book of Fundamentals of Engineering Heat and Mass Transfer by R.C. Sachdeva



EXPERIMENT-6

OBJECTIVE:

Study of Radiation heat transfer by black body and study the effect of hemisphere temperature on it.

AIM:

To find out the Stefan Boltzmann constant.

INTRODUCTION:

All substances at all temperature emit thermal radiation. Thermal radiation is an electromagnetic wave and does not require any material medium for propagation. All bodies can emit radiation and have also the capacity to absorb all of a part of the radiation coming from the surrounding towards it.

THEORY:

The most commonly used law of thermal radiation is the Stefan Boltzmann law which states that thermal radiation heat flux or emissive power of a black surface is proportional to the fourth power of absolute temperature of the surface and is given by

$$\frac{Q}{A} = E_B = \sigma T^4 \ W/m^2k^4$$

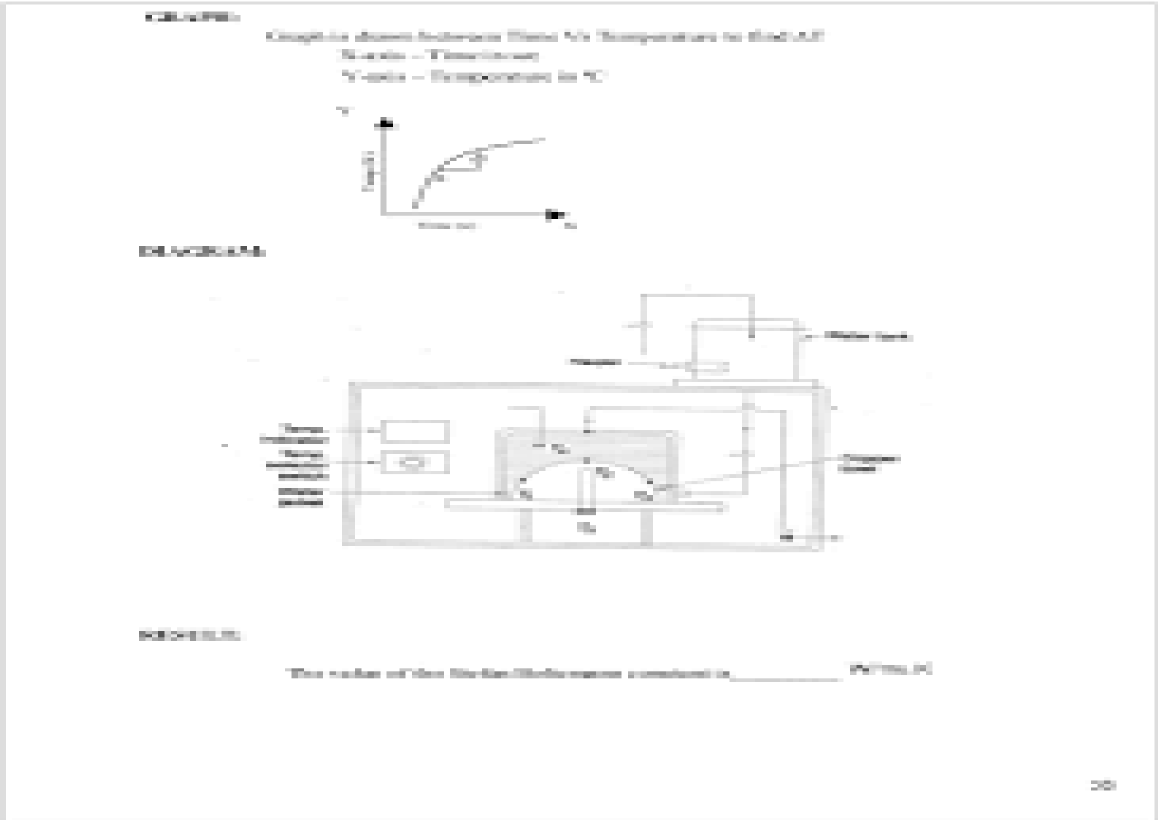
The constant of proportionality is called the Stefan Boltzmann constant and has the value of 5.67 x 10^{-8} $W/m^2 K^4$. The Stefan Boltzmann law can be derived by integrating the Planck's law over the entire spectrum of wavelength from 0 to ∞. The objective of this experimental set up is to measure the value of this constant fairly closely, by an easy arrangement.

DESCRIPTION:

The apparatus consists of a hemisphere fixed to a Bakelite Plate, the outer surface of which forms the jacket to heat it. Hot water to heat the hemisphere is obtained from a hot water tank, which is fixed above the hemisphere. The copper test disc is introduced at the center of hemisphere. The temperatures of hemispheres and test disc are measured with the help of temperature sensors.

UTILITIES REQUIRED:

1. Electricity Supply: Single Phase, 220 VAC, 50Hz, 5-15Amp socket with earth Connection.
2. Water supply: Initial fill.
3. Drain Required.
4. Bench Area Required: 1m x 1m.



EXPERIMENTAL PROCEDURE:

Starting Procedure:

1. Close all the valves.
2. Fill heater tank 3/4th with water by removing the lid of the tank and put the lid back to its position after doing so.
3. Ensure that switches given on the panel are at OFF position.
4. Connect electric supply to the set up.

5. Switch ON the Mains ON / OFF switch.
6. Set the desired water temperature in the DTC by operating the increment or decrement and set button of DTC.
7. Switch ON the heater and wait till desired temperature achieves.
8. Remove the disc from the bottom of test chamber by removing the support provided to hold it.
9. Switch OFF the heater.
10. Fill test chamber with hot water of heater tank by opening the valve provided at top of the chamber, till observing the overflow of water through chamber outlet and then close the valve.
11. Note the reading of water temperature (T_1) and initial temperature of the disc (T_{2i}).
12. Insert the disc to the bottom of the chamber and note the reading of temperature T_2 after 5-10 sec interval.

Closing Procedure:

1. After experiment is over switch OFF the Mains ON/OFF switch.
2. Switch OFF electric supply to the set up.
3. Drain the water from chamber and heater tank by the drain valve provided.

SPECIFICATION:

Hemispherical enclosure dia. =200 mm

Jacket Diameter =250 mm

Suitable sized Water jacket for hemisphere.

Base plate, Bakelite diameter=250 mm

No. Of Temp. Sensor mounted on B=1

No. of Temp. Sensor mounted on D=1

Temp. Indicator digital=0-199.9°C RTD PT-100 type

Immersion water heater of suitable capacity and tank for hot water.1.5Kw

The surface of B and A forming the enclosure are black by using lamp black to make their absorptive to be approximately unity. The copper surface of the disc D is also blacked.

OBSERVATION & CALCULATION:

DATA:

D =0.02 m

m = 0.0051 kg

s = 4186 J/kg-^oC

OBSERVATION:

T_1= -----------^oC

T_{2i}= -----------^oC

t, sec	T_2, ^oC
0	
5	
10	

CALCULATIONS:

$A_D = \frac{\pi D^2}{4}$, **m^2 = ------------------ m^2**

$T_E = T_1 + 275.15$ K = ----------------- K

$T_D = T_2 + 275.15$ K = ----------------K

t, sec	$T_D = T_2 + 275.15$ K
0	
5	
10	

Plot the graph of T vs t and obtain the slope dT/dt.

$\sigma = \frac{ms[\frac{dT}{dt}]}{A_D(T_E^4 - T_D^4)}$, Watt/m^{2}K^4

NOMENCLATURE:

A_D = Area of disc, m^2

D = Diameter of disc, m

m = Mass of disc, kg

s= Specific heat of the disc material, kJ/kg ^{o}C

T= Temperature of disc at time t, K

T_1=Temperature of enclosure, ^{o}C

T_2 =Temperature of disc at time t, ^{o}C

T_{2i} =Initial temperature of the disc, ^{o}C

T_E=Temperature of enclosure, K

T_D =Initial temperature of the disc, K

t = Time, sec

σ=Stefan Boltzmann constant, Watt/m^{2}k^4

PRECAUTIONS & MAINTENANCE INSTRUCTIONS:

1. Never run the apparatus if power supply is less than 180 volts and above than 230 volts.
2. Never switch ON mains power supply before ensuring that all the ON/OFF switches given on the panel are at OFF position.

3. Operator selector switches off temperature indicator gently.
4. Always keep the apparatus free from dust.

TROUBLESHOOTING:

1. If electric panel is not showing the input on the mains light, check the main Supply.

REFERENCES:

1. Holman, J. P., “Heat Transfer”, 9th ed., McGraw Hill, ND, 2008, Page 372.
2. Y. A. Cengel, “Heat & Mass Transfer”, McGraw Hill, ND, 2008, Page 28, 667-671.

EXPERIMENT-7 & 8

OBJECTIVE: To study the heat transfer phenomena in parallel / counter flow arrangements.

AIM: To calculate overall heat transfer coefficient for both type of heat exchanger.

INTRODUCTION:

Heat Exchangers are devices in which heat is transferred from one fluid to another. The necessity for doing this arises in a multitude of industrial applications. Common examples of heat exchangers are the radiator of a car, the condenser at the back of a domestic refrigerator and the steam boiler of a thermal power plant.

Heat Exchangers are classified in three categories:

1) Transfer Type.
2) Storage Type.
3) Direct Contact Type.

THEORY:

A transfer type of heat exchanger is one on which both fluids pass simultaneously through the device and heat is transferred through separating walls. In practice most of the heat exchangers used are transfer type ones.

The transfer type exchangers are further classified according to flow arrangement as -

1. **Parallel flow** in which fluids flow in the same direction.
2. **Counter flow** in which they flow in opposite direction and
3. **Cross flow** in which they flow at right angles to each other.

A simple example of transfer type of heat exchanger can be in the form of a tube type arrangement in which one of the fluids is flowing through the inner tube and the other through the annulus surroundings it. The heat transfer takes place across the walls of the inner tube.

DESCRIPTION:

The apparatus consists of a tube in tube type concentric tube heat exchanger. The hot fluid is hot water which is obtained from an insulated water bath using a magnetic drive pump and it flows through the inner tube while the cold fluid is cold water flowing through the annulus.

The hot water flows always in one direction and the flow rate of which is controlled by means of a valve. The cold water can be admitted at one of the end enabling the heat exchanger to run as a parallel flow apparatus or a counter flow apparatus. This is done by valve operations.
RTDPT-100 type sensors measure the temperature. For flow measurement Rotameters are provided at the inlet of hot and cold water supply. The readings are recorded when steady state is reached.

UTILITIESREQUIRED:

Water supply 10 lit/min
(approx.) Drain.
Electricity Supply: 1 Phase, 220 V AC, 3 kW.
Floor area 2 m x 0.6m

EXPERIMENTAL PROCEDURE:

1) Put water in bath and switch on the heaters.

2) Adjust the required temperature of hot water using DTC.

3) Adjust the valve. Allow hot water to recycle in bath by switching on the magnetic pump.
4) Start the flow through annulus and run the exchanger either as parallel flow or counter

flow unit.

5) Adjust the flow rate on cold water side by rotameter provided.

6) Adjust the flow rate on hot water side by rotameter provided.
7) Keeping the flow rates same, wait till the steady state conditions are reached.

8) Record the temperatures on hot water and cold water side and the flow rates.

SPECIFICATIONS:

Inner Tube : Material = SS, ID = 9.5 mm, OD = 12.7 mm

Outer tube : Material = SS, ID = 28 mm, OD =
33.8mm Length of the heat Exchanger: L = 1.13m

Temperature Controller : Digital, Range:0-200^{o}C

Temperature Indicator : Digital Range: 0-200^{o}C & least count 0.1^{o}C with Multi-channel switch.

Temperature Sensors : RTD–PT-100 type. (5
Nos) Flow measurement : Rotameter (2No.)

Water Bath : Material: SS insulated with ceramic wool and powder coated MS outer Shell fitted with heating elements.

Pump : FHP magnetic drive pump (Max operating temp.85
^{o}C).

Heater : Nichrome wire, capacity 4kW

FORMULAE:

1. Rate of heat transfer from hot water**,**

$$Q_h = M_h C_{ph} (T_{hi} - T_{ho}), \text{ Watt}$$

2. Rate of heat transfer to cold water,

$$Q_C = M_c C_{pc} (T_{co} - T_{ci}), \text{Watt}$$

3. Average heat transfer,

$$Q = \frac{(Q_h + Q_c)}{2}, \text{Watt}$$

4. LMTD,

$$\Delta T_m = \frac{\Delta T_2 - \Delta T_1}{ln\frac{\Delta T_2}{\Delta T_1}}, °C$$

where: $\Delta T_1 = T_{hi} - T_{ci}$ (for parallel flow)

$= T_{hi} - T_{co}$ (for counter flow)

and $\Delta T_2 = T_{ho} - T_{co}$ (for parallel flow)

$= T_{ho} - T_{ci}$ (for counter flow)

- Note that in a special case of Counter Flow Exchanger exists when the heat capacity rates C_c & C_h are equal, then $T_{hi} - T_{co} = T_{ho} - T_{ci}$ thereby making $\Delta T_i = \Delta T_o$. In this case LMTD is of the form 0/0 and so undefined. But it is obvious that since ΔT is constant throughout the exchanger, hence

$$\Delta T_m = \Delta T_i = \Delta T_o$$

(acc. to ref. Fundamental of Engineering Heat & Mass Transfer by R.C. Sachdeva, Pg. 499)

Overall heat transfer coefficient,

$$U_i = \frac{Q}{A_i \Delta T_m}, \text{Watt/m}^2 °C \ \& \ U_o = \frac{Q}{A_o \Delta T_m}, \text{Watt/m}^2 °C$$

OBSERVATION & CALCULATION:

DATA:

Inside heat transfer area, $A_i = 7.088 * 10^{-5}\ m^2$

Outside heat transfer area, $A_0 = 61.575*10^{-5}\ m^2$

OBSERVTION TABLE:

FOR PARALLEL FLOW:

Sl. No.	Hot water side			Cold water side		
	Flow rate	Thi °C	Tho °C	Flow rate	Tci °C	Tco°C
1						
2						

FOR COUNTER FLOW:

Sl. No.	Hot water side			Cold water side		
	Flow rate	Thi °C	Tho °C	Flow rate	Tci °C	Tco°C
1						
2						

CALCULATIONS:

CASE I: Counter Flow

Mass flow rate of hot water:

Average temperature =------------°C

M_H = -----Kg/hr

ρ_H = -------Kg/m^3

C_{pH}=-------J/Kg°K

Mass flow rate of cold water

Average temperature =------------°C

M_C = -----Kg/hr

P_C = -------Kg/m^3

C_{pC}=-------J/Kg°K

Heat flow Rate

$Q_h = M_h \times C_{ph} \times \Delta T$=--------W

$Q_c = M_c \times C_{pc} \times \Delta T$=--------W

Effectiveness of HE, $\varepsilon = \frac{Q_{actual}}{Q_{max}} \times 100\ \%$

$Q_{actual} = \frac{Q_C + Q_H}{2}$ = -----------KW

$Q_{max} = M_h C_{ph} (Th_i - Tc_i)$ =-------KW

LMTD for counter flow = $\frac{(T_{hi} - T_{co}) - (T_{ho} - T_{ci})}{\ln[\frac{T_{hi} - T_{co}}{T_{ho} - T_{ci}}]}$

$U_o = \frac{Q}{A_o \times LMTD}$ =------------W/m^2°C

$U_i = \frac{Q}{A_i \times LMTD}$=------------- W/m^2°C

CASE II: Parallel Flow

Mass flow rate of hot water:

Average temperature =------------°C

M_H = -----Kg/hr

ρ_H = -------Kg/m^3

C_{pH}=-------J/Kg°K

Mass flow rate of cold water

Average temperature =------------°C

M_C = -----Kg/hr

P_C = -------Kg/m^3

C_{pC}=-------J/Kg°K

Heat flow Rate

$Q_h = M_h \times C_{ph} \times \Delta T$=--------W

$Q_c = M_c \times C_{pc} \times \Delta T$=--------W

Effectiveness of HE, $\varepsilon = \frac{Q_{actual}}{Q_{max}} \times 100\ \%$

$Q_{actual} = \frac{Q_C + Q_H}{2}$ = -----------KW

$Q_{max} = M_h C_{ph} (Th_i - Tc_i)$ =-------KW

LMTD for parallel flow = $\frac{(T_{hi} - T_{ci}) - (T_{ho} - T_{co})}{\ln[\frac{T_{hi} - T_{ci}}{T_{ho} - T_{co}}]}$

$U_o = \frac{Q}{A_o \times LMTD}$ =------------W/m^2°C

$U_i = \frac{Q}{A_i \times LMTD}$=------------- W/m^2°C

NOMENCLATURE:

Q_h = heat loss by the hot water, W

M_h = mass flow rate of the hot water

C_{ph} = specific heat of hot fluid at mean temperature

T_{ho} = outlet temperature of the hot water

T_{hi} = inlet temperature of the hot water

Q_c = heat gained by the cold water

M_c = mass flow rate of the cold water

C_{pc} = specific heat of cold fluid at mean temperature

T_{co} = outlet temperature of the cold water

T_{ci} = inlet temperature of the cold water

Q = average heat transfers from the system

U = overall heat transfer coefficient

U_i = Inside overall heat transfer coefficient

A_i = πr_i X-sectional area of inner pipe

U_o = outside overall heat transfer coefficient

$A_o = \pi r_i$ X-sectional area of outer pipe

PRECAUTIONS AND MAINTENANCEINSTRUCTION:

1. Never switch on mains power supply before ensuring that all the ON/OFF switches given on the panel are at OFF position.
2. Keep all the assembly undisturbed.
3. Never run the apparatus if power supply is less than 180 volts and above than 230volts.
4. Operate selector switch of temperature indicator gently.
5. Always keep the apparatus free from dust.
6. Don't switch ON the heater before filling the water into the bath.

TROUBLESHOOTING:

1. If electric panel is not showing the input on the mains light. Check the fuse and also check the main supply.
2. If D.T.I displays "1" on the screen check the computer socket if loose tight it.
3. If temperature of any sensor is not displays in D.T.I check the connection and rectify that.

REFERENCES:

1. Holman, J.P., **"Heat Transfer"**, 8^{th} ed., McGraw Hill, NY, 1976.
2. Kern, D.Q., **"Process Heat Transfer"**, 1^{st} ed., McGraw Hill, NY, 1965.
3. McCabe, W.L., Smith, J.C., Harriott, P., **"Unit Operations of Chemical engineering"**, 4^{th} ed. McGraw Hill, NY, 1985.

4. Coulson, J.M., Richardson, J.F., **“Coulson & Richardson’s Chemical Engineering Vol. -1”**, 5th ed., Asian Books ltd., ND, 1996.

EXPERIMENT-9 & 10

OBJECTIVE: To study of heat transfer in the process of condensation.

AIM: To find the heat transfer co-efficient for Drop-wise condensation and Film-wise condensation process.

INTRODUCTION:

In all applications, the steam must be condensed as it transfers heat to a cooling medium, e.g. cold water in the condenser of a generating station, hot water in a heating calorimeter, sugar refinery, etc. During condensation very high heat fluxes are possible &provided the heat can be quickly transferred from the condensing surface to the cooling medium, heat exchangers using steam can be compact & effective.

THEORY:

Steam may condense on to a surface in two distinct modes, known as “Film wise” & “Drop wise”. For the same temperature difference between the steam & the surface, drop wise condensation is much more effective than film wise & for this reason the former is desirable although in practical plants, it rarely occurs for prolonged periods.

FILMWISE CONDENSATION:

Unless specially treated, most materials are wettable & as condensation occur a film condensate spreads over the surface. The thickness of the film depends upon a numbers of factors, e.g. the rate of condensation, the viscosity of the condensate and whether the surface is vertical or horizontal, etc. Fresh vapor condenses on to the outside of the film & heat is transferred by conduction through the film to the metal surface beneath. As the film thickness it flows downward &drips from the low points leaving the film intact & at an equilibrium thickness.

The film of liquid is a barrier to the transfer of heat and its resistance accounts for most of the difference between the effectiveness of film wise and drops wise condensation.

DROPWISE CONDENSATION:

By specially treating the condensing surface the contact angle can be changed and the surface becomes ‘non-wettable’. As the steam condenses, a large number of generally spherical beads cover the surface. As condensation proceeds, the beads become larger, coalesce, and then strike downwards over the surface. The moving bead gathers all the static beads along its downward in its trail. The 'bare' surface offers very little resistance to the transfer of heat and very high heat fluxes are therefore possible. Unfortunately, due to the nature of the material used in the construction of condensing heat exchangers, film wise condensation is normal. (Although many bare metal surfaces are 'non- wettable' this is not true of the oxide film which quickly covers the bare material)

DESCRIPTION:

The equipment consists of a metallic container in which steam generation takes place. The lower portion houses suitable electric heater for steam generation. A special arrangement is provided for the container for filling the water. The glass cylinder houses two water cooled copper condensers, one of which is chromium plated to promote drop wise condensation and the other is in its natural state to give film wise condensation. A connection for pressure gauge is provided. Separate connections of two condensers for passing water are provided. One Rota meter with appropriate piping can be used for measuring water flow rate in one of the condensers under test. A digital temperature indicator provided has multipoint connections, which measures temperatures of steam, two condensers, water inlet & outlet temperature of condenser water flows.

UTILITIES REQUIRED:

Water supply 5 lit/min (approx.)

Electricity Supply: 1 Phase, 220 V AC, and 2.0 kW.

Table for set-up support (optional)

EXPERIMENTAL PROCEDURE:

1. Fill water in steam generator through funnel by opening the valve.
2. Fill water in the steam generator up to half mark. (Visible in transparent glass window).
3. Start water flow through one of the condensers, which is to be tested and note down water flow rate in rotameter. Ensure that during measurement, water is flowing only through the condenser under test and second valve is closed.

4. When the temperature of steam reaches the set point, start the steam supply to condenser under test. Steam gets condensed on the tubes, and falls down in the cylinder.
5. Depending upon type of condenser under test Drop wise or Film wise can be visualized.
6. 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 matched, then condensation will occur at more or less atmospheric pressure or up to 1 kg pressure.
7. Observations like temperatures, water flow rates, and pressure are noted down in the observations table at the end of each set.

Repeat above steps to test second condenser.

8. SPECIFICATION:

Condensers = One chromium plated for drop wise condensation & one natural finish for Film wise condensation otherwise identical in construction.

Dimensions = 19 mm outer dia. 160 mm length, Fabricated from copper with reverse flow in

Concentric tubes. Fitted with Temperature sensor for surface temperature measurement

Main Unit= M.S. Fabricated construction comprising test section & steam generation section.

Test section provided with glass cylinder for visualization of the process.

Heating Elements = Suitable water heater.

Instrumentation = 1) Temperature Indicator: Digital 0-199.9°C & least count 0.1°C with

Multi-channel switch.

2) Temperature Sensors: RTD PT-100 Type.

3) Rotameter: for measuring water flow rate.

4) Pressure Gauge: Dial type 0 - 2 Kg/cm2

FORMULAE:

Heat losses from steam, $Q_s = M_s * \lambda$, Watt

Heat taken by cold water, Qw= Mw *Cp*(T5– T4), Watt

Average hear transfer, $Q = \frac{(Qs+Qw)}{2}$, Watt

Inside heat transfer co-efficient, hi $= \frac{Q}{(Ai*\Delta Tm)}$, Watt/$m^2$ -^{O}C

Outside heat transfer co-efficient, ho= $\frac{Q}{Ao*\Delta Tm}$, Watt/m^2-^{O}C

$$\Delta Tm = \frac{\Delta T2 - \Delta T1}{ln(\frac{\Delta T2}{\Delta T1})}$$

$\Delta T_2 = T_3 - T_2$ (For Plain Condenser)

$\Delta T_1 = T_3 - T_1$ (For Plated Condenser)

Experimental overall heat transfer co-efficient,

$$\frac{1}{U_{EX}} = \frac{1}{h_1} + \left[\frac{D_i}{D_o} x \frac{1}{h_o}\right]$$

Reynolds Number,

$$Re_d = \frac{4m_w}{\pi D_i \rho_1 v_1}$$

Nusselt Number,

$Nu_1 = 0.023(R_{ed})^{0.8}(P_r)$

Inside heat transfer co-efficient,

$h_i = \frac{Nu_1 K}{L} W/m^2 {}^oc$

Outside heat transfer coefficient,

$h_o = 0.943\left[\frac{\lambda \rho_2^2 g k_2^3}{(T_s - T_w)\mu L}\right]^{0.25}$,Watt/m^2-^{O}C

Theoretical overall heat transfer coefficient,

$\frac{1}{U_{TH}} = \frac{1}{h_i} + \left[\frac{D_i}{D_o}\ x \frac{1}{h_o}\right]$

OBSERVATIONS & CALCULATIONS:

DATA:

O.D of heat transfer surface, D_o= 19mm

I.D. of heat transfer surface, Di =16mm

Length of heat transfer surface, L = 160mm

Inside heat transfer area, Ai = 0.000201 m^2

Outside heat transfer area, Ao= 0.000284 m^2

Latent heat of steam, $\lambda = 2257.2 \times 10^3$ J/kg

OBSERVATION TABLE:

Condenser under Test:

Sl. No.	Water Flow Rate (LPH)	Steam Condensed (ml)	Time (min)	Temperature				
				T1	T2	T3	T4	T5

TEMPERATURE:

T1- Surface Temperature of Plated Condenser

T2- Surface Temperature of Plain Condenser

T3- Temperature of steam in column

T4- Water inlet temperature (common for both condensers)

T5- Water outlet temperature (common for both condensers)

CALCULATION:

Properties of water at bulk mean temperature of water i.e. (Twi +Two)/2 Where Twi and Two are water inlet & outlet temperatures.

Following properties are required:

CP = Specific heat of water (4.186 kJ/kg- K)

$\rho 1$ = Density of water kg/m^3

$\rho 1$ = Density of water kg/m^3

$\rho 2$ = Density of water kg/m^3

$\nu 1$ = Kinematics Viscosity at 40 ^{0}C (0.657 m^2/sec)

$\nu 2$ = Kinematics Viscosity at 100 ^{0}C (0.2932 m^2/sec)

μ = Viscosity of water at 100 ℃ (1.154)

μ = Viscosity of water at 35 ℃ (1.215)

k1 = Thermal conductivity at 40 ℃ (540W /m -K)

k2 =Thermal conductivity at 100 ℃ (586W /m -K)

Now calculate,

Reynolds's number,

$$Re_d = \frac{4m_w}{\pi D_i \rho_1 v_1}$$

and, Prandtl Number,

$P_r = \frac{\mu C_p}{K}$

Nusselt Number,

Nu = 0.023 $(R_{ed})^{0.8}$ $(Pr)^{0.4}$

$h_1 = \frac{Nu_1 K}{L} W/m^2\text{-}^o c$

Now calculate heat transfer coefficient on outer surface of the condenser (h_o). For this properties of water are taken at bulk mean temperature of condensate i.e

$\frac{T_s+T_w}{2}$ °C $=T_2$ °C

Properties needed are:

ρ_2 =Density of water Kgm/m^3

K_2 = Thermal Conductivity Kcal/ hr - m°C (W/ m °C)

μ = Viscosity of condensate Kgf - sec/m^2. (Kg/m sec)

λ =Heat of evaporation J/Kg. (2257.2 x 10^3 J/kg)

$$h_o = 0.943\left[\frac{\lambda\rho_2^2 g k_2^3}{(T_s-T_w)\mu L}\right]^{0.25}$$

From these values overall Heat Transfer coefficient (U) can be calculated.

$$\frac{1}{U} = \frac{1}{h_i} + \left[\frac{D_i}{D_o}\ x\ \frac{1}{h_o}\right] \qquad \text{Kcal/hr-m}^2\text{-}^o\text{C}$$

And,

Calculate the experimental overall heat transfer co-efficient and compare with theoretical overall heat transfer coefficient. Same procedure can be repeated for other condenser. Except for some exceptional cases overall heat transfer co-efficient for Drop-wise Condensation will be higher than that of film wise condensation. Results may vary from theory in some degree due to unavoidable heat losses.

NOMENCLATURE:

D_{id} = Inner dia. of condenser.

D_{od} = outer dia. of condenser

h_i = Inside Heat Transfer Co-efficient.

h_o= outside Heat Transfer Co-efficient.

T_S = Temperature of steam °C.

T_W = Temperature of condenser wall °C.

ΔT_m = Log mean temperature difference

Ms = Rate of steam condensation, Kg/s

Mw = Cold water flow rate, Kg/s

Cp = Specific heat of water.

G = Acceleration due to gravity

L = Length of condenser

ρ = Density of water kg/m^3

ν = Kinematics Viscosity m^2/sec.

k = Thermal conductivity, W/m-^{O}C

P_r= Prandtl number.

PRECAUTIONS & MAINTENANCE INS

1. Use the stabilized A.C. Single Phase supply only.
2. Never switch on mains power supply before ensuring that all the ON/OFF switches given on the panel are at OFF position.
3. Voltage to heater starts and increases slowly.
4. Keep all the assembly undisturbed.
5. Never run the apparatus if power supply is less than 180 volts and above than 240 volts.
6. Operate selector switch of temperature indicator gently.
7. Do not start heater supply unless water is filled in the test unit.
8. Always keep the apparatus free from dust. There is a possibility of getting abrupt result if the supply voltage is fluctuating or if the satisfactory steady state condition is not reached.

TROUBLE SHOOTING:

1. If electric panel is not showing the input on the mains light. Check the fuse and also check the Main supply.

2. If D.T.I displays “1” on the screen check the computer socket if loose tight it.
3. If temperature of any sensor is not displays in D.T.I check the connection and rectify that.

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