LABORATORY MANUAL

CHEMICAL ENGINEERING LAB I

(CHE F312)

Cycle – Heat Transfer

First Semester 2021-2022

DEPARTMENT OF CHEMICAL ENGINEERING

BIRLA INSTITUTE OF TECHNOLOGY & SCIENCE, PILANI, DUBAI CAMPUS, DIAC, DUBAI

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EXPERIMENT – 1

HEAT TRANSFER THROUGH COMPOSITE WALLS

1. Objective:

- To study the conduction heat transfer in composite wall.

2. Aim:

- To determine total thermal resistance and thermal conductivity of composite wall.
- To determine thermal conductivity of one material (Press wood)
- To plot temperature gradient along composite wall structure.

3. Theory:

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:

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

When the proportionality constant is inserted,

$$Q = -kA\frac{\partial T}{\partial X}$$

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

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

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

when the thermal conductivity is considered constant. The wall thickness is ΔX, 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:

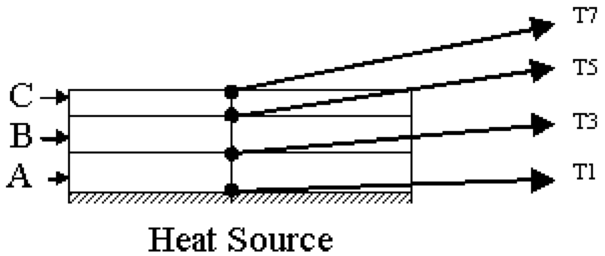


Figure 1.1

The temperature gradients in the three materials, the heat flow may be written

$$Q = -k_A A\frac{T_3 - T_1}{\Delta X_A} = -k_B A\frac{T_5 - T_3}{\Delta X_B} = -k_C A\frac{T_7 - T_5}{\Delta X_C}$$

The heat flow must be same through all sections. Solving these three equations simultaneously, the heat flow is written as

$$Q = \frac{T_1 - T_7}{\Delta X_A / K_A A + \Delta X_B / k_B A + \Delta X_C / k_C A}$$

4. Experimental Setup:

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 interfaces 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.

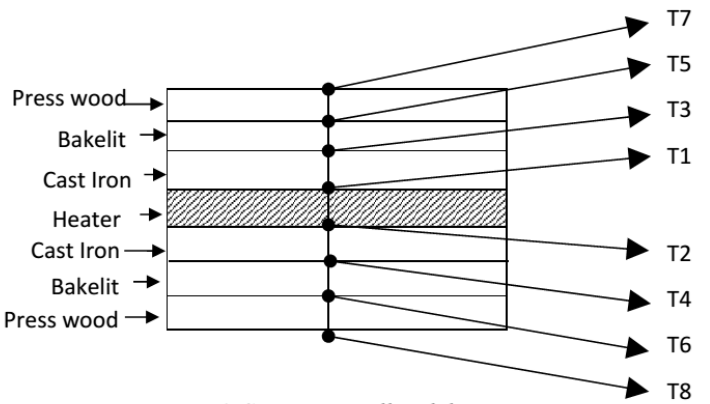


Figure 2 Composite wall with heater

5. Experimental Procedure:

1. Start the supply of heater by varying the dimmerstat.
2. Adjust the power input at the desired value.
3. Start taking readings of all the temperature sensors after one hour at each five-minute interval until observing three consecutive readings are approximately the same.
4. Note down final steady state readings in the observation table.

6. Utilities required:

Electricity Supply: 1 Phase, 220 V AC, 2 Amp

Figure 1.3 Heat transfer through composite wall Apparatus

7. Specifications:

Slab Sizes:

Cast Iron	:	Diameter = 250 mm, Thickness = 19 mm.
Bakelite	:	Diameter = 250 mm, Thickness = 17 mm.
Press Wood	:	Diameter = 250 mm, Thickness = 12 mm.
Heater	:	Nichrome heater (200 W) wounded on mica and insulated with mica and asbestos is provided.
Control Panel	:	The control panel consists of Digital voltmeter, Digital Ammeter, Digital temperature indicator with multi channel switch, Variac to control the heat input to the heater.
Temp sensors	:	RTD PT-100 type (8 nos.)

8. Formulae:

1. Heat input,

$$W = V * I \text{ ; Watt} \qquad Q = \frac{W}{2} \text{ ; Watt}$$

2. Heat Flux,

$$q = \frac{Q}{A} \text{ ; Watt / m}^2 \qquad A = \frac{\pi * D^2}{4} \text{ m}^2$$

3. Total thermal resistance,

$$R_t = \frac{\Delta T}{q} \quad \text{m}^2\text{-}^o\text{C / Watt}$$

$\Delta T = T_1 - T_7$ (For Upper side)

$\Delta T = T_2 - T_8$ (For Lower side)

4. Thermal conductivity of composite wall,

$$K_{eff} = \frac{\Delta X}{R_t} \quad \text{Watt / m-}^o\text{C}$$

$$\Delta X = X_1 + X_2 + X_3$$

5. Thermal conductivity of one material (Press Wood)

$$K_3 = \frac{X_3}{\left[\frac{\Delta T}{q}\right] - \left[\frac{X_1}{K_1} + \frac{X_2}{K_2}\right]}$$

9. Observation and Calculations:

Data:

Slab Sizes:

Cast Iron	:	D = 250 mm, X_1 = 19 mm
Bakelite	:	D = 250 mm, X_2 = 17 mm
Press Wood	:	D = 250 mm, X_3 = 12 mm
K_1	=	52 Watt / m-^{o}C
K_2	=	1.4 Watt / m-^{o}C

Observation Table:

Sr. No.	V	I	Temperature sensor readings							
			T_1 °C	T_2 °C	T_3 °C	T_4 °C	T_5 °C	T_6 °C	T_7 °C	T_8 °C
			At x=0		At x=19 mm		At x=36 mm		At x=48 mm	
1										
2										
3										

10. Calculation Table:

i. To Calculate Thermal Conductivity of Composite Slab:

Sr. No.	W	Q	q	R_t^U	K_{eff}^U	R_t^L	K_{eff}^L
1							
2							
3							

ii. To calculate Thermal conductivity of one material (Press wood):

Sr. No.	ΔT^U	ΔT^L	K_3^U	K_3^L
1				
2				
3				

iii. To plot temperature profile:

Distance, S	Upper Side, T^U	Lower Side, T^L	Temperature Difference^U	Temperature Difference^L
0	T_1	T_2		
0.019	T_3	T_4	(T_1-T_3)	(T_2-T_4)
0.036	T_5	T_6	(T_3-T_5)	(T_4-T_6)
0.048	T_7	T_8	(T_5-T_7)	(T_6-T_8)

11. Inferences & Conclusions: Compare and interpret results

12. Nomenclature:

A	=	Area of the plate, m^2.
D	=	Diameter of the plate, m.
I	=	Ammeter reading, amp.
K_{eff}	=	Thermal conductivity of composite wall.
K_1	=	Thermal conductivity of Cast Iron plate.
K_2	=	Thermal conductivity of Bakelite Plate.
K_3	=	Thermal conductivity of Press Wood Plate.
Q	=	Heat supplied by the heater in one direction.
q	=	Heat Flux.
R_t	=	Slab resistivity.
Superscript U	=	For Slab, Upper side of the heater.
Superscript L	=	For Slab, Lower side of the heater.
T_1 & T_2	=	Interface temperature of cast Iron and heater.
T_3 & T_4	=	Interface temperature of cast Iron and bakelite
T_5 & T_6	=	Interface temperature of bakelite and press wood
T_7 & T_8	=	Top surface temperature of press wood
V	=	Voltmeter reading, volt.
W	=	Total Heat supplied by the heater, Watt.
X_1	=	Cast Iron plate thickness.
X_2	=	Bakelite plate thickness.
X_3	=	Press wood plate thickness.

13. Precautions and Maintenance Instructions:

1. Never switch on main power supply before ensuring that all the ON/OFF switch given on the panel is at OFF position.
2. Use the stabilize A.C. Single Phase supply only.
3. If electric panel is not showing the input on the mains light. Check the fuse and also check the main supply.
4. If temperature of any sensor is not displays in D.T.I check the connection and rectify that.
5. Always keep the apparatus free from dust.

EXPERIMENT - 2

UNSTEADY STATE HEAT TRANSFER

1. Objective:

- To study unsteady state heat transfer using the lumped capacitance method for finite geometric shape.

2. Aim:

- To determine internal thermal resistance of the body by calculating Biot number for the solid cylinders.
- Draw a graph between time, *t (s)* verses $\ln\left[\frac{T - T_\infty}{T_i - T_\infty}\right]$ and from the slope calculate *Bi* and *h* and compare with average values.

3. Theory:

In many situations where steady state is not prevalent, analysis becomes much more difficult. It is in these situations where unsteady (transient) heat flow causes temperature and other variables to change with time. However, in some unsteady situations, for which a certain criterion is met, the use of the lumped capacitance theory greatly simplifies the analysis (also known as *lumped-heat-capacity* method). The criterion is based on the assumption that temperature gradients within a solid are negligible compared to the temperature gradients between the solid and the surrounding fluid. Whether this assumption is valid or not depends on the value of Biot number (B_i).

To understand the lumped heat capacity theory we consider a hot metal block that is submerged in water. The basic concept of this theory is that the temperature within the solid block is assumed to be spatially uniform at any instant throughout the unsteady heating process. This implies that the temperature gradient within the solid is negligible compared to the gradient across the solid-fluid interface.

Heat transfer process that is dependent on time is termed as transient heat transfer or unsteady state heat transfer. Such processes are analyzed by solving general heat conduction equation using simplified assumptions, such as considering only one directional heat transfer:

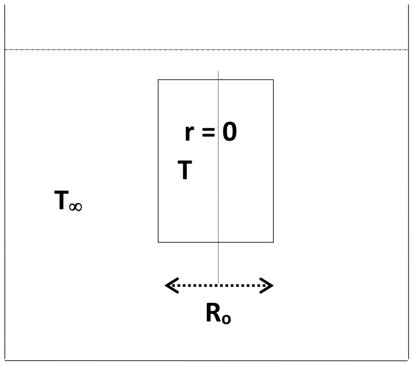
$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t}$$

Assuming a system with negligible internal resistance, i.e., a system that has infinite thermal conductivity (Ideal Case). This assumption is justified when external thermal resistance between the surface of the system and surrounding medium is very large as compared to the internal thermal resistance, e.g., consider a metallic surface at temperature T_i (at $t = 0$) being suddenly placed in a bath of water where temperature is maintained at T_∞ ($t > 0$), then the energy balance for the metallic body over a small time interval, *dt*, is:

$$\rho V C_P \, dT/dt = h A (T_\infty - T) \quad \text{------ (1)}$$

Equation (1) can be written as:

$$\frac{\mathbf{dT}}{\mathbf{T_\infty - T}} = \frac{\mathbf{d(T_\infty - T)}}{\mathbf{(T_\infty - T)}} = \frac{\mathbf{hA}}{\mathbf{\rho C_P V}}\mathbf{dt} \qquad \text{------ (2)}$$



$T_\infty > T_i$ At t = 0, T = T_i ; r ≥ 0

Figure 2.1

Integration yields:

$$\ln (T_\infty - T) = -\frac{\mathbf{hA}}{\mathbf{\rho C_P V}}\mathbf{t} + C \qquad \text{------ (3)}$$

Boundary Condition 1: at t = 0, T = T_i

thus, C = ln (T_∞ - T_i)

From Equation (3), we have

$$\ln\left[\frac{T - T_\infty}{T_i - T_\infty}\right] = -\frac{hA}{\rho C_P V} t($$

$$\frac{\mathbf{T - T_\infty}}{\mathbf{T_i - T_\infty}} = e^{-(h A/\rho \, C_P \, V)\, t} \qquad (4)$$

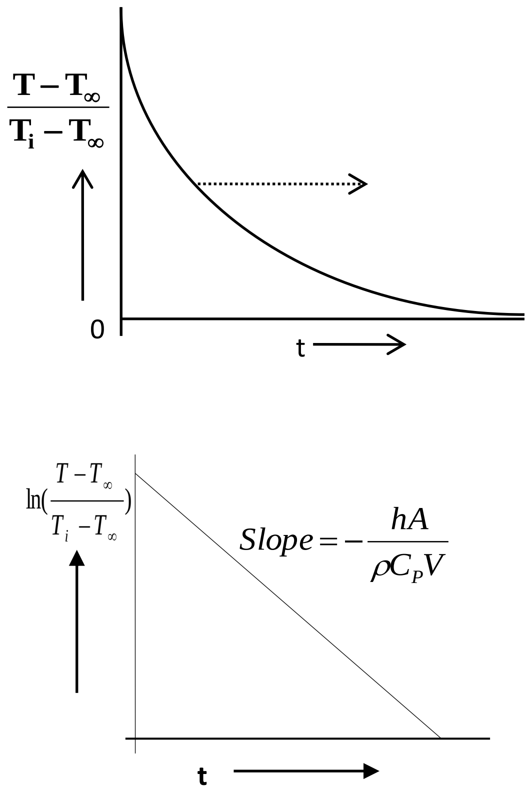


Figure 2.2

Thermal capacitance of the system is given by:

$C_t = C_P \rho V$

Thermal resistance is given by:

$R_t = 1 / (h A)$

Defining the following dimensionless numbers as:

Biot number, $B_i = \frac{\mathbf{h(V/A)}}{\mathbf{k}}$ (for a cylinder)

Fourier number, $F_o = \dfrac{\alpha t}{(V/A)^2}$ (for a cylinder)

In terms of these two dimensional groups,

Equation (4) can be written as:

$$\frac{T - T_\infty}{T_i - T_\infty} = e^{-B_i F_o} \qquad (5)$$

(When B_i <0.1, the body has negligible internal thermal resistance)

Instantaneous heat flow rate to solid cylinder is given by:

$Q_i = \rho\, C_P\, V\, (dT/dt)$

$$Q_i = h*A\,(T_\infty - T_i)\, e^{-hAt/\rho C_P v} = hA\,(T_\infty - T_i)\, e^{-B_i Fo} \qquad (6)$$

and total heat gained during time t_f is

$$Q = \int_0^{t_f} Q_i * dt = C_P\, \rho\, V\, (T_\infty - T_i)\, [1 - e^{-h.A.t_f/\rho * C_P * v}]$$

$$Q = C_P\, \rho\, V\, (T_\infty - T_i)\, [1 - e^{-B_i Fo}] \qquad (7)$$

For $B_i > 0.1$,

Graphical solution of energy equation (in cylindrical coordinate)

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} = \frac{1}{\alpha}\frac{\partial T}{\partial t}$$

Boundary condition: $\dfrac{\partial T}{\partial r} = 0$ at r = 0

$$-k\left(\frac{\partial T}{\partial r}\right)_{r=R_o} = h\,[(T)_{r=Ro} - T_\infty] \text{ when } t > 0$$

Initial condition: T = T_i at t = 0 when r > 0

4. Description:

The set up consists of a water bath with stirrer and heater. The Digital Temperature Controller (DTC) controls temperature of the bath. Two solid cylinders of different materials (Brass and SS) are provided with the set up. One cylinder at a time can be used for experimentation. Digital temperature Indicator is used to measure the temperature of the test cylinder.

5. Experimental Procedure:

1. Fill the water bath with water up to the desired level.
2. Set the desired bath temperature with the help of DTC (T_∞).
3. Start the stirrer and the heater.
4. Wait till desired bath temperature has been achieved.
5. Dip the Test cylinder into the hot water bath and start collecting the data of time vs. temperature.
6. Continue till steady state has been achieved (i.e., variation in temperature with time is negligible)
7. Repeat the above steps for another bath temperature.
8. Stop the electric supply to heater and motor.

6. Specifications:

Constant Temperature Water Bath	:	Material: SS Capacity-8 lit. (approx)
Stirrer for Bath	:	SS Impeller with shaft coupled to a FHP motor.
Heater	:	Nichrome wire 800 W.
Test Cylinder	:	Material: S.S./Brass.
Control Panel comprises of		
Digital Temperature Controller (For Water Bath)	:	0-200 ^oC,
Digital Temperature Indicator	:	0-200 ^oC,
Temperature Sensors	:	RTD PT-100 type

Figure 2.3 Unsteady State Heat Transfer Apparatus

7. Formulae:

$$\alpha = \frac{k}{\rho C_P} \qquad V = \pi * R_o^2 * L \qquad A = 2 * \pi * R_o * L$$

$$F_o = \frac{\alpha t}{(V / A)^2} \qquad T_e = \frac{T - T_\infty}{T_i - T_\infty} \qquad B_i = \frac{\ln(T_e)}{(-F_o)}$$

$$h = \frac{2 * K * B_i}{R_o} \qquad Q_i = h * A * (T_\infty - T_i) * e^{(-B_i * F_o)}$$

8. Observations & Calculations:

Data:

R_o = 0.019 m   L = 0.140 m

For brass:				For SS:			
ρ	=	8522	kg/ m^3	ρ	=	7817	kg/ m^3
C_P	=	385	J/kg K	C_P	=	461	J/kg K
k	=	110.7	W/m K	k	=	16.3	W/m K

Observations:

Test Piece = ________________________ (Brass / SS)

T_i = ____________ °C

T_∞ = ____________ °C

Sr. No.	Time (t) sec	Temperature (T) °C
1.		
2.		
3.		
4.		
5.		

CALCULATIONS:

Compute the data in the following form.

Sr. No.	Time (t) sec	T_e	F_o	B_i	h	Q_i

If $B_i < 0.1$, the body has negligible internal thermal resistance. If it is not, then use Heisler Chart to estimate B_i number. Superimpose the plot $(T_\infty - T) / (T_\infty - T_i)$ Vs. F_o on the Heisler Chart and determine the matching B_i. From B_i calculate the heat transfer coefficient.

From the graph of *ln Te* and *t*, find the slope and use this slope to find out the average heat transfer coefficient and Biot number for the test cylinder.

9. Inferences & Conclusions:
Compare and interpret results.

10. Nomenclature:

A	=	Surface area of metallic body.
B_i	=	Biot number
C_P	=	Specific heat of material, J/(kg K)
F_o	=	Fourier number
h	=	Heat transfer Co-efficient.
k	=	Thermal conductivity of Material, W/m-K
L	=	length of cylinder, m
Q_i	=	Heat flow rate to cylinder.
R_o	=	Radius of cylinder, m
R_t	=	Thermal Resistance.
T_∞	=	Bath temperature.
T	=	Temperature of Test Piece at any time, t
T_i	=	Initial Temperature of Test Piece.
V	=	Volume of metallic body.
ρ	=	Density of material, kg/ m^3

11. Precautions & Maintenance Instructions:

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. Keep all the assembly undisturbed.
4. Don’t switch ON the heater before filling the water into the bath.

EXPERIMENT - 3

SHELL & TUBE HEAT EXCHANGER

1. Objective:

- To study heat transfer in 1, 2 Shell and Tube Heat Exchanger.

2. Aim:

- Determine overall heat transfer coefficient for shell & tube heat exchanger.
- Draw a graph between flow rate v/s effectiveness, heat transfer coefficient.

3. Introduction:

Heat Exchanger is a device 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 according to following three categories:

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

4. Theory:

A transfer type of heat exchanger is one in 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. Single-Single Pass.
2. 1 - 2 Parallel-Counter Flow Exchanger
3. 2 - 2 Pass.

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 surrounding it. The heat transfer takes place across the walls of the inner tube.

The heat lost by the hot fluid can be calculated

q_h = Heat Transfer rate from the hot water.

$$\mathbf{q_h = m_h C_{Ph}\left(T_{hi} - T_{ho}\right)} \quad \text{kJ/s}$$

Heat taken by the cold fluid can also be calculated

$\mathbf{q_c}$ = Heat Transfer rate to the cold water.

$$\mathbf{q_c = m_c C_{Pc}\left(T_{co} - T_{ci}\right)} \quad \text{kJ/s}$$

$$q = \frac{q_c + q_h}{2} \qquad\qquad U_o = \frac{q}{A_o \, \Delta T_m}$$

where, ΔT_m, logarithmic mean temperature difference, can be calculated as per the following formula:

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

Note that in a special case of Counter Flow Exchanger 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. However, it is obvious that since ΔT is constant throughout the exchanger, hence:

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

5. Description:

The apparatus consists of Shell and Tube heat exchanger. The hot fluid is hot water, which is attained from an insulating water bath using a magnetic drive pump and it flow through the inner tube while the cold water flowing through the annulus. For flow measurement rotameters are provided at inlet of cold water and outlet of hot water line. The hot water bath is of recycled type with Digital Temperature Controller from 0 to 100 °C.

6. Utilities required:

Water supply 20 L/min (approx. at constant head condition, 1 bar)
Drain Required.
Electricity Supply: 1 Phase, 220 V AC, and 4 kW.
Space required: 1.1m x 0.415m x 1.2m.

7. Experimental Procedure:

Starting Procedure:

1. Clean the apparatus and make water bath free from dust.
2. Close all the drain valves provided.
3. Fill water bath ¾ with clean water and ensure that no foreign particles are present in it.
4. Connect cold water supply to the inlet of cold water rotameter line.
5. Connect outlet of cold water from shell to drain.
6. Ensure that all On/Off Switches given on the Panel are at OFF position.
7. Now switch on the main power supply (220 V ac, 50 Hz).
8. Switch on heater by operating rotary switch given on the panel.
9. Set temperature of the water bath with the help of digital temperature controller.
10. Open flow control valve and by-pass valve for hot water supply.
11. Switch on magnetic pump for hot water supply.
12. Adjust hot water flow rate with the help of flow control valve and rotameter.
13. Record the temperatures of hot and cold water inlet & outlet when steady state is achieved.

Closing Procedure:

1. When experiment is over, switch off heater first.
2. Switch of magnetic pump for hot water supply.
3. Switch off power supply to panel.
4. Stop cold water supply with the help of Flow Control Valve.
5. Stop Hot water supply with the help of Flow Control Valve.
6. Drain cold and hot water from the shell with the help of given drain valves.
7. Drain water bath with the help of drain valve.

8. Specification:

1. Shell: Material = S.S., Inner dia. = 208 mm, Length = 500 mm,
   25% cut baffles at 100 mm distance 4 Nos.
2. Tube: Material = S.S., OD = 16 mm, Length of tubes = 500 mm, No. of tubes = 24
3. Temperature Controller = Digital 0 - 200^{o}C
4. Temperature Sensors = RTD PT-100 type (4 nos.)
5. Temperature Indicator = Digital 0 to 200^{o}C with multi-channel switch.
6. Electric Heater = 230 V AC 2 kW (2 Nos.)
7. Flow measurement = Rotameter (2 No.)
8. Water Bath = Material: SS insulated with ceramic wool and powder coated MS outer Shell, fitted with heating elements.
9. Pump = FHP magnetic drive pump (max. operating T 85^{o}C).

Figure 3.1 Shell and Tube Heat Exchanger

9. Formulae:

1. Average Heat Transfer

$$q_{av} = \frac{q_h + q_c}{2}$$

Where, $\mathbf{q_h = m_h C_{Ph}(T_{hi} - T_{ho})}$ and $\mathbf{q_c = m_c C_{Pc}(T_{co} - T_{ci})}$

2. Heat Transfer Area,

$$\boldsymbol{A_o = N * \pi * d_o * L}$$

3. LMTD

$$\boldsymbol{\Delta T_m = \frac{\Delta T_i - \Delta T_o}{\ln(\Delta T_i / \Delta T_o)}}$$

$\boldsymbol{\Delta T_i = T_{hi} - T_{co}}$ and $\boldsymbol{\Delta T_o = T_{ho} - T_{ci}}$

4. Overall Heat Transfer Co-efficient

$$U_o = \frac{q_{av}}{A_o \, \Delta T_m}$$

5. Effectiveness of the heat exchanger

$$\varepsilon = q_{av} / q_{max} = q_{av} / (m \cdot C_p)_{min} (T_{hi} - T_{ci})$$

9. Observation & Calculation:

Data:

N = ________ number of tubes

d_o = __________ mm = __________ m outer diameter of the tube

L = __________ mm = __________ m length of the tube

C_{ph} = ____________ kJ /kg ºC (at average T of hot stream, T_h)

C_{pc} = ____________ kJ /kg ºC (at average T of cold stream, T_c)

Observation Table:

Sr. No.	Hot water side			Cold water side		
	Flow rate W_h, LPH	**T_{hi} (ºC)**	**T_{ho} (ºC)**	**Flow rate W_c, LPH**	**T_{ci}(ºC)**	**T_{co} (ºC)**
1						
2						
3						
4						

Calculations:

For Run No. 1:

Average Temperature of Hot water, $\boldsymbol{T_h = \frac{T_{hi} + T_{ho}}{2}}$

Average Temperature of Cold water, $\boldsymbol{T_c = \frac{T_{ci} + T_{co}}{2}}$

Density of Cold water at temperature T_c, (ρ_c) = ____________________ kg/m^3

Density of Hot water at temperature T_h, (ρ_h) = ____________________ kg/m^3

Mass Flow Rate of Hot Water, $m_h = \frac{W_h * \rho_h}{1000 * 3600}$ kg/s

Mass Flow Rate of Cold Water, $m_c = \frac{W_c * \rho_c}{1000 * 3600}$ kg/s

Calculate U_o and ε using formula 1 to 5 given in formula section (Section 9)
Repeat the calculation similarly for all runs.

Calculation Table:

Sr. No.	q_h, kJ/s	q_c, kJ/s	q_{av}, kJ/s	ΔT_m	Uo, kJ/(m^2 s °C)	ε

Draw a graph between flow rate of cold water and overall heat transfer coefficient **U** & effectiveness, **ε.**

11. Inferences & Conclusions: Compare and interpret results.

12. Nomenclature:

A_o	=	Area of Heat Transfer, m^2
Cp_c and Cp_h	=	Specific heat of cold and hot fluid, respectively, kJ/kg °C
L	=	length of the tube, m
ΔT_m	=	Logarithm Mean Temperature Difference.
m_c and m_h	=	Cold and hot water flow rate, respectively, kg/s
N	=	Number of tubes.
q_{av}	=	Average heat transfer, kJ/s
q_c and q_h	=	Heat gained by cold water and Heat lost by hot water, kJ/s
T_{ci} and T_{hi}	=	Cold and Hot water inlet temp, respectively, °C
T_{co} and T_{ho}	=	Cold and Hot water outlet temp, respectively, °C
T_c and T_h	=	Mean Temperature of cold and hot water, respectively, °C
U_o	=	Overall heat transfer coefficient, kJ / m^2 s °C
ρ_c	=	Density of Cold fluid, kg/m^3
ρ_h	=	Density of Hot fluid, kg/m^3

13. Precautions & Maintenance Instructions:

1. Never switch on main power supply before ensuring that all the on/off switches given on the Panel are at off position.
2. Never Switch on Heaters before filling water bath ¾ with clean water. It may damage heaters.
3. Never fully close the Delivery and By-pass line Valves simultaneously.
4. Always keep apparatus free from dust.
5. To prevent clogging of moving parts, run Pump at least once in a fortnight.

EXPERIMENT - 4

HEAT TRANSFER FROM A PIN FIN

1. Objective:

- To study the conduction of heat transfer from a pin fin.

2. Aim:

- To study the temperature distribution along the length of a pin fin under free and forced convection heat transfer.
- Draw a graph between flow rate and heat transfer coefficient & efficiency for different voltage settings.

3. 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. Circumferential fins around the cylinder of a motorcycle engine and fins attached to condenser tubes of a refrigerator are few familiar examples.

4. Theory:

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

Fin efficiency = $\varepsilon = \tanh(mL)/mL$

The temperature profile within a pin fin is given by:

$$[T-T_f] / [T_b - T_f] = [\cosh m (L-x) + H \sinh m (L-x)] / [\cosh mL + H \sinh mL]$$

Where,

T_f is the free stream temperature of air

T_b is the temperature of fin at its base

T is the temperature within the fin at any x

L and D are the length and diameter of the fin

m is the fin parameter defined as:

Fin parameter, $m = \sqrt{[h C / (k_b A)]}$

$\beta = 1/[T_{mf} + 273.15]$, 1/K

Velocity of air = $V' = Q$ / cross-sectional area of duct

Velocity of air at T_{mf} may be calculated from:

$V = V' [T_{mf} + 273.15] / [T_f + 273.15]$

5. Description:

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. RTD PT-100 type temperature sensors measure temperatures at five points along the length of the fin. An orifice meter, fitted on the delivery side of the blower, measures the flow rate of air.

Firgure 4.1 Heat Transfer from Pin Fin Apparatus

6. Utilities Required:

Electricity Supply: 1 Phase, 220 V AC, 5 Amp.

7. Experimental Procedure:

Natural Convection:

1. Start heating the fin by switching on the heater element and adjust the voltage by Dimmerstat. (Increase slowly from 0 onwards)
2. Start recording temperatures at each five minute interval until observing three consecutive readings are same.
3. Record the final steady state readings of Temperature Sensor No.1 to 6.
4. Repeat the same experiment for different heat input by varying voltage by Dimmerstat.

Forced Convections:

1. Start heating the fin by switching on the heater and adjust voltage by dimmerstat.
2. Start the blower and adjust the flow of air with the help of fly valve provided on the outlet pipe.
3. Start recording temperatures at each five minute interval until observing three consecutive readings are same.
4. Record the pressure difference across the orifice by the manometer.
5. Repeat the experiment for different air flow rate and different heat input.

8. Specification:

Duct size	=	150 mm x 100 mm x 1000 mm
Diameter of the fin	=	12.7 mm, Length of the fin: 150 mm
Diameter of the Orifice	=	26 mm
Diameter of the delivery pipe (Int.)	=	52 mm
Temperature Indicator	=	0-200^{o}C, RTD PT-100 type
RTD PT-100 type Sensors	=	6 Nos.

Temperature Sensor No.6 reads ambient temperature in the inside of the duct.
Centrifugal blower with Single-phase motor
Dimmerstat for heat input control 230 V, 2 Amps.
Heater suitable for mounting at the fin end outside the duct
Voltmeter 0- 250 V.
Ammeter 0- 2 A

9. Formulae:

9.1 Free Convection:

Mean temperature of the fin, T_m $$T_m = \frac{T_1+T_2+T_3+T_4+T_5}{5}$$

Temperature of the fluid, T_f $$T_f = T_6$$

Grashof No. $$G_r = \frac{g * \beta * D^3 * \Delta T}{\nu^2}$$

$$\beta = \frac{1}{T_{mf}+273.15} \qquad T_{mf} = \frac{T_m+T_f}{2}$$

Nusselt No. $$N_u = 0.53*\left(G_r * P_r\right)^{1/4}$$

Free convective heat transfer coefficient

$$h = \frac{N_u * k_{air}}{D}$$

Fin parameter, $$m = \sqrt{\frac{h*C}{k_b*A}}$$

Where, $$C = \pi * D \qquad A = \frac{\pi * D^2}{4}$$

Fin efficiency, $$\varepsilon = \frac{\tanh(m*L)}{m*L}$$

Fin Parameter, $$H = \frac{h}{k_b*m}$$

Theoretical temperature profile within the fin

$$\frac{T - T_f}{T_b - T_f} = \frac{[Cosh(m(L-x)) + H * Sinh(m(L-x))]}{[Cosh(mL) + H * Sinh(mL)]}$$

(Taking base temperature, $T_b = T_1$)

9.2 Forced convection:

Mean temperature of the fin, T_m $$T_m = \frac{T_1 + T_2 + T_3 + T_4 + T_5}{5}$$

Temperature of the fluid, T_f $$T_f = T_6 \qquad T_{mf} = \frac{T_m + T_f}{2}$$

Volumetric flow rate of air,

$$Q = \frac{C_d * a_o * a_p * \sqrt{(2 * g * \Delta H)}}{\sqrt{(a_p^2 - a_o^2)}} \quad , \quad \Delta H = \Delta h * \left(\frac{\rho_w}{\rho_a} - 1 \right)$$

Velocity of air, $V = \frac{Q}{a_p}$ (at ambient fluid temperature)

Velocity of air at mean fluid temperature (T_{mf}),

$$V_1 = V * \left[\frac{T_{mf} + 273.15}{T_f + 273.15} \right] \quad , \quad R_e = \frac{V_1 * \rho_a * D}{\mu}$$

Using the correlation for force convection:

Nusselt No. $$N_u = 0.615 * (R_e)^{0.466}$$

Heat transfer coefficient, $$h = \frac{N_u * k_{air}}{D}$$

Fin parameter, $$m = \sqrt{\frac{h * C}{k_b * A}}$$

Fin efficiency, $$\varepsilon = \frac{\tanh(m * L)}{m * L}$$

Theoretical temperature profile within the fin

$$\frac{T - T_f}{T_b - T_f} = \frac{[Cosh(m(L-x)) + H * Sinh(m(L-x))]}{[Cosh(mL) + H * Sinh(mL)]}$$

(Taking base temperature, $T_b = T_1$)

10. Observations & Calculations:

Data

Fin dia., D	=	12.7×10^{-3} m
Fin length, L	=	150×10^{-3} m
Dia of the orifice, d_o	=	26 mm = 0.026 m
Dia of the pipe of the orifice, d_p	=	52 mm = 0.052 m
Area of the orifice, a_o	=	0.0005309 m^2
Area of the pipe of the orifice, a_p	=	0.00212372 m^2
Orifice coefficient of discharge C_d	=	0.64

μ= 0.00002, k_{air}= 0.02896, k_b = 95

Free Convection

Sr. No.	V	I	T_1, ºC	T_2, ºC	T_3, ºC	T_4, ºC	T_5, ºC	T_6, ºC

Forced Convection

Sr. No.	V	I	T_1, ºC	T_2, ºC	T_3, ºC	T_4, ºC	T_5, ºC	T_6, ºC	Δh, cm

Calculation Table:

Sr. No	N_u	h	m	η in %

11. Inferences & Conclusions: Compare and interpret results.

12. Nomenclature:

A	=	X-sectional area of fin.
a_o	=	Area of the orifice, m^2
a_p	=	Area of the pipe of the orifice, m^2
C	=	Perimeter of Fin, m.
Cp	=	Specific heat of air, kcal/kg-^oC
Cd	=	Co-efficient of discharge for orifice.
D	=	Fin diameter
d_o	=	Diameter of the orifice, m
d_p	=	Diameter of the pipe, mm.
Gr	=	Grashof number
g	=	Acc. due to gravity.
H	=	Fin Parameter.
ΔH	=	Manometer reading, m
h	=	heat transfer coefficient.
k_b	=	Thermal conductivity of brass fin, Watt / m ^oC
k_{air}	=	Thermal conductivity of air, Watt / m ^oC
L	=	Length of the fin, m.
m	=	Fin parameter
Nu	=	Nusselt number
Pr	=	Prandtl number
Q	=	Volumetric flow rate of air through the duct m^3
T	=	Temperature of the fin at distance x.
T_b	=	Base Temperature.
T_m	=	Fin mean temperature.
T_{mf}	=	Mean temp of fluid and fin surface.
T_f	=	Temperature of fluid.
V	=	velocity of air at T_{mf}
x	=	Distance of the sensor at base of the fin.
ε	=	Fin efficiency.
ρ_a	=	Density of air, kg/m^3
ρ_w	=	Density of water, kg/m^3
μ	=	Dynamic viscosity of air, kg/ m-h
ν	=	Kinematic viscosity of air, m^2 /h.
β	=	Co-efficient of thermal expansion of fluid.

13. Precautions & Maintenance Instructions:

1. Never switch on mains power supply before ensuring that all the ON/OFF switches given on the panel are at OFF position.
2. Operate selector switch of temperature indicator gently.
3. Always keep the apparatus free from dust.

EXPERIMENT - 5

DOUBLE PIPE HEAT EXCHANGER

1. Objective:

- To study the heat transfer phenomena in parallel / counter flow arrangements in a double pipe heat exchanger.

2. Aim:

- To calculate overall heat transfer coefficient for both type of heat exchanger.
- Draw a graph between flow rate (x-axis) against heat transfer co-efficient.

3. 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.

4. Theory:

A transfer type of heat exchanger is the one in 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.

The simplest type of heat exchanger consists of two concentric pipes of different diameters, as shown in *Figure 3,* called the double-pipe heat exchanger. One fluid in a double-pipe heat exchanger flows through the smaller pipe while the other fluid flows through the annular space between the two pipes. The heat transfer takes place across the walls of the inner tube.

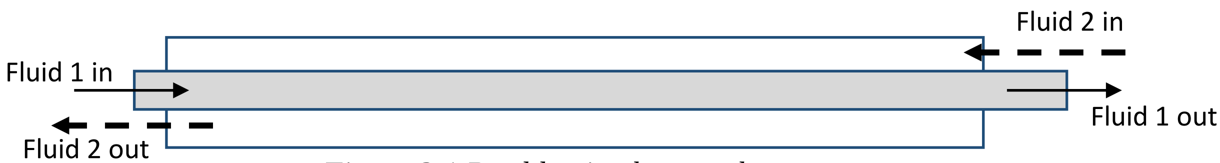


Figure 3.1 Double pipe heat exchanger

Two types of flow arrangement are possible in a double-pipe heat exchanger: parallel flow and counter flow.

5. Description:

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

For flow measurement rotameters are provided at inlet of cold water and outlet of hot water line.

The hot water flows always in one direction and the flow rate of which is controlled by means of valves and rotameter. The direction of cold water flow can be adjusted by operating the valves provided, parallel or counter to hot water flow as required.

RTD PT-100 type sensors measure the temperature of inlet and outlet of Hot and Cold water. Description of temperature sensors are as follows:

T1	=	Temperature of hot water inlet, T_{hi}
T2	=	Temperature of hot water outlet, T_{ho}
T3	=	Temperature of cold water inlet, T_{ci}
T4	=	Temperature of cold water outlet for parallel flow, T_{co}
T5	=	Temperature of cold water outlet for counter flow, T_{co}

6. **Utilities Required**:

Electricity Supply: Single Phase, 220 VAC, 50 Hz, 3 kW.

Continuous Water Supply at 10 LPM and 1 Bar.

Drain Required.

Floor Area Required: 2 m x 1 m.

7. **Experimental Procedure:**

Starting Procedure:

1. Clean the apparatus and make Water Bath free from Dust.
2. Close all the drain valves provided.
3. Fill Water Bath ¾ with Clean Water and ensure that no foreign particles are present in it.
4. Connect Cold water supply to the inlet of Cold water Rotameter Line.
5. Set the flow of cold water to any one of the flow arrangements (parallel or counter) by adjusting the valves provided.
6. Connect Outlet of Cold water to Drain.
7. Ensure that all On/Off Switches given on the Panel are at OFF position.
8. Now switch on the Main Power Supply (220 V AC, 50 Hz).
9. Switch on Heater by operating Rotary Switch given on the Panel.
10. Set Temperature of the Water Bath with the help of Digital Temperature Controller.
11. Open Flow Control Valve and Bypass Valve for Hot Water Supply.
12. Switch on Magnetic Pump for Hot Water supply.
13. Adjust Hot water and Cold water flow rate with the help of Control Valve and rotameter.

14. Record the temperatures of Hot and Cold water Inlet & Outlet when steady state is achieved.
15. Repeat the procedure for another flow arrangement.

Closing Procedure:

1. When experiment is over, Switch off heater first.
2. Switch off Magnetic Pump for Hot Water supply.
3. Switch off Power Supply to Panel.
4. Stop cold water supply with the help of Flow Control Valve.
5. Stop Hot water supply with the help of Flow Control Valve.
6. Drain Water Bath with the help of Drain valve.

8. Specification:

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 = 1.6 m
Temperature Sensors	:	RTD–PT-100 type. (5 Nos.)
Flow measurement	:	Rotameter (2 Nos.)
Water Bath	:	Material: SS insulated with ceramic wool.
Pump	:	FHP magnetic drive pump (Max operating temperature 85°C).

Control Panel comprises:

Digital Temperature Controller	:	Digital, Range: 0-199.9°C
Digital Temperature Indicator	:	Digital Range: 0-199.9°C with Multi channel switch.

With Standard make On/Off switch, Mains Indicator etc.
The whole set-up is well designed and arranged on a powder-coated structure.

Figure 5.1 Double Pipe Heat Exchanger

Formulae:

1. Rate of heat transfer from hot water,

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

$$M_h = \frac{F_h * \rho_h}{3600*1000}, \text{ kg/s}$$

2. Rate of heat transfer to cold water,

$$Q_c = M_c C_{pc}\left(T_{co} - T_{ci}\right), \text{ W}$$

$$M_C = \frac{F_C * \rho_C}{3600*1000}, \text{ kg/s}$$

3. Average Heat Transfer,

$$Q = \frac{Q_h + Q_c}{2}, \text{ W}$$

4. LMTD, $$\Delta T_m = \frac{\Delta T_2 - \Delta T_1}{\ln \frac{\Delta T_2}{\Delta T_1}}, \ {}^{o}\text{C}$$

$\Delta T_1 = T_{hi} - T_{ci}$ (For parallel flow) $\Delta T_2 = T_{ho} - T_{co}$ (For parallel flow)

$\Delta T_1 = T_{hi} - T_{co}$ (For counter flow) $\Delta T_2 = T_{ho} - T_{ci}$ (For counter flow)

Note that in a special case of Counter Flow Exchanger when the heat capacity rates C_c & C_h are equal, then $T_{hi} - T_{co} = T_{ho} - T_{ci}$ thereby making $\Delta T_1 = \Delta T_2$.

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 $\Delta T_m = \Delta T_1 = \Delta T_2$

5. Overall heat transfer coefficient,

$$U_i = \frac{Q}{A_i \Delta T_m}, \text{ W/m}^2\,{}^{\circ}\text{C}$$

$$U_o = \frac{Q}{A_o \Delta T_m}, \text{ W/m}^2\,{}^{\circ}\text{C}$$

$$A_i = \pi * d_i * L$$

$$A_o = \pi * d_o * L$$

10. Observation & Calculation:

Data: Pipe dimensions

d_i = 0.0095 m
d_o = 0.0127 m
L = 1.6 m

Observation Table:

Parallel Flow

Sr. No.	Hot water side			Cold water side		
	F_h (LPH)	**T_{hi} (°C)**	**T_{ho} (°C)**	**F_C (LPH)**	**T_{ci} (°C)**	**T_{co} (°C)**
1						
2						

Counter flow

Sr. No.	Hot water side			Cold water side		
	F_h (LPH)	**T_{hi} (°C)**	**T_{ho} (°C)**	**F_C (LPH)**	**T_{ci} (°C)**	**T_{co} (°C)**
1						
2						

Calculations:

Properties of Hot water at average temperature $\left(\frac{T_{hi}+T_{ho}}{2}\right)$:

ρ_h = ________________ kg/m^3
C_{ph} = ________________ J/kg°C

Properties of Cold water at average temperature $\left(\frac{T_{ci}+T_{co}}{2}\right)$:

ρ_h = ________________ kg/m^3
C_{ph} = ________________ J/kg°C

Calculate Overall Heat Transfer Co-efficient using formulae given in formulae section.

11. Inferences & Conclusions: Compare and interpret results.

12. Nomenclature:

ρ_C	=	Density of cold water at mean temp, kg/m^3.
ρ_h	=	Density of hot water at mean temp, kg/m^3.
A_i	=	Inside heat transfer area, m^2.
A_o	=	Outside heat transfer area, m^2.
C_{pc} and C_{ph}	=	Specific heat of cold and hot fluid, respectively, kJ/kg °C.
d_i and d_o	=	Inner and outer diameter of the tubes, respectively, m.
F_h and F_c	=	Flow rate of hot and cold water, respectively, LPH.
M_c and M_h	=	Cold and hot water mass flow rate, respectively, kg/s
Q	=	Average of heat transfer rate, W.
Q_c and Q_h	=	Heat gained by cold water and Heat lost by hot water, kJ/s.
T_{ci} and T_{hi}	=	Cold and Hot water inlet temp, respectively, °C.
T_{co} and T_{ho}	=	Cold and Hot water outlet temp, respectively, °C.
ΔT_m	=	Log mean temperature difference, ^{o}C.
U_i and U_o	=	Inside and outside overall heat transfer coefficient, respectively, W/m^2 °C.

13. Precautions & Maintenance Instructions:

1. Never switch on mains power supply before ensuring that all the ON/OFF switches given on the panel are at OFF position.
2. Don’t switch on heater before filling water into the bath.
3. Always keep the apparatus free from dust.

EXPERIMENT - 6

EMISSIVITY MEASUREMENT APPARATUS

1. OBJECTIVE:

Study of Radiation heat transfer by black body and test plate.

2. AIM:

- To find out the emissivity of a test plate.
- Draw a graph between voltage verses emissivity.

3. INTRODUCTION:

Radiation is the energy emitted by matter in the form of *electromagnetic waves* (or photons) as a result of the changes in the electronic configurations of the atoms or molecules. Unlike conduction and convection, the transfer of heat by radiation does not require the presence of an intervening medium.

Thermal radiation, which is the form of radiation emitted by bodies because of their temperature. It differs from other forms of electromagnetic radiation such as x-rays, gamma rays, microwaves, radio waves, and television waves that are not related to temperature.

All bodies at a temperature above absolute zero emit thermal radiation. All bodies can emit radiation and have also the capacity to absorb a part of the radiation coming from the surrounding towards it.

4. THEORY:

An ideal black surface is one which absorbs all the incident radiation with reflectivity and transmissivity equal to zero. The radiant energy per unit time per unit area from the surface of the body is called the emissive power and is usually denoted by ε. The emissivity of the surface (E') is the ratio of the emissive power of the surface to the emissive power of a black surface at the same temperature. If emissive power is noted by E, then

$$E' = E/E_b$$

For black body absorptivity = 1 and by the knowledge of Kirchhoff's Law of Emissivity, emissivity of the black body becomes unity. Emissivity being a property of the surface depends on the nature of the surface and temperature.

5. DESCRIPTION:

The experimental set up consists of two circular copper plates identical in size and is provided with heating coils. The plates are mounted on bracket and are kept in an enclosure so as to provide undisturbed natural convection surroundings. The heat input to the heater is varied by separate Dimmerstat and is measured by using an ammeter and a voltmeter with the help of selector switches. The temperature of the plates is measured by Pt-100 sensors. A Pt-100 sensor is also kept in the enclosure to read the ambient temperature of enclosure.

Plate 1 is blackened by a thick layer of lampblack to form the idealized black surface whereas the plate 2 is the test plate whose emissivity is to be determined. The heater inputs to the two plates are dissipated from the plates by conduction, convection and radiation. The experimental set up is designed in such a way that under steady state conditions the heat dissipation by conduction and convection is same for both the cases. When the surface temperatures are same, the difference in the heater input readings is because of the difference in radiation characteristics due to their different emissivity.

6. UTILITIES REQUIRED:

Electricity Supply: 1 Phase, 220 V AC, 4 Amps

7. EXPERIMENTAL PROCEDURE:

1. Gradually increase the input to the heater to black plate and adjust it to some value and adjust heater input to test plate slightly less than the black plate.
2. Check the temperature of the two plates with small time intervals and adjust the input of test plate only, by the Dimmerstat so that the two plates will be maintained at the same temperature.
3. This will require some trial and error and may take more than one hour or so to obtain the steady state condition.
4. After attaining the steady state conditions record the temperatures and Voltmeter and Ammeter reading for both the plates.
5. The same procedure is repeated for various surface temperatures in increasing order.

8. SPECIFICATION:

1.	Test plate diameter	=	160 mm
2.	Black plate diameter	=	160 mm
3.	Dimmerstat for both plates	=	0-2 A, 0-220V.
4.	Voltmeter	=	0-250V,
5.	Ammeter	=	0-2.5 A
6.	RTD Temperature sensor	=	7 Nos.

7. Heater for test plate and black plate: Nichrome strip wound on mica sheet and sand-witched between two mica sheets (200 W)

9. FORMULAE:

1. $$E_b - E = \frac{(W_b - W_t)}{A * \sigma * (T_s^4 - T_a^4)}$$

2. $$A = \frac{\pi * d^2}{4}$$

3. $$T_s = \left[\frac{T_1 + T_2 + T_3}{3} + 273.15\right] \quad or \quad \left[\frac{T_4 + T_5 + T_6}{3} + 273.15\right]$$

4. $T_a = T_7 + 273.15$

5. $W_b = V_b * I_b$

6. $W_t = V_t * I_t$

10. OBSERVATIONS & CALCULATIONS:

DATA:

σ = 5.699×10^{-8} W/m² K⁴

d = 160 mm

A = _________________ m^2

E_b = _________________

OBSERVATION TABLE:

Sr. No.	V_t	I_t	V_b	I_b	T1	T2	T3	T4	T5	T6	T7

CALCULATION TABLE:

Sr. No.	Wt	Wb	T_s	T_a	E

11. Inferences & Conclusion:

12. NOMENCLATURE:

A = Surface Area of disc, m^2
d = diameter of the disk, mm
E = Emissivity of test plate
E_b = Emissivity of black body.
I_b = Ampere of the black plate heater.
I_t = Ampere of the test plate heater.
T_a = Temperature of air in the duct.
T_s = Surface temperature of Discs, K
V_b = Voltage of black plate heater.
V_t = Voltage of test plate heater.
W_b = wattage supplied to black plate.
W_t = Wattage supplied to test plate
σ = Stefan Boltzman Constant, $W/m^2 K^4$

13. PRECAUTIONS & MAINTENANCE INSTRUCTIONS:

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. Never run the apparatus if power supply is less than 180 volts and above than 240 volts.
4. Operate selector switch of temperature indicator gently.
5. Always keep the apparatus free from dust.

14. 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 temperature of any sensor is not displays in D.T.I check the connection and rectify that.

EXPERIMENT - 7

Dropwise and Filmwise Condensation

1. Objective:

- To study the Dropwise and Filmwise condensation phenomena.

2. Aim:

- To determine the inside and outside heat transfer coefficient of Filmwise and Dropwise condensers.
- To compare overall heat transfer coefficient of dropwise and filmwise condenser.

3. Theory:

Condensation Heat Transfer**:**

The process of condensation is the reverse of boiling. Whenever a saturated vapor comes in contact with a surface at a lower temperature, condensation occurs. There are two modes of condensation: a) filmwise, in which the condensate wets the surface forming a continuous film, which covers the entire surface, and b) dropwise, in which the vapor condenses into small liquid droplets of various sizes, which fall down the surface in a random fashion.

Unless specially treated, most materials are wettable & as condensation occur a film condensate spreads over the surface. In this type of condensation, the film covering the entire surface grows in thickness as it moves down the surface by gravity. Fresh vapor condenses on to the outside of the film & heat is transferred by conduction through the film to the metal surface beneath. There exists a thermal gradient in the film and so it acts as a resistance to heat transfer.

By specially treating the condensing surface, the contact angle can be changed and the surface becomes ‘non-wettable’. By modifying the surface properties using additives and surface coatings, it is possible to achieve dropwise condensation. It is generally difficult to maintain this type of condensation for long time. Condensation that starts as dropwise generally converted into filmwise condensation after some time. Hence, in all practical applications filmwise condensation is assumed. In order to minimize the thermal resistance of the condensing film, length of the surface is kept small.

In dropwise condensation a large portion of the area of the plate is directly exposed to the vapor, making heat transfer rates much larger (5 to10 times) than those in filmwise condensation.

4. Experimental Setup

Filmwise and Dropwise Condensers enclosed in a Borosilicate Glass Tube with flow control valves, Steam generator with heating elements, Digital Temperature Indicator with selector switch, Rotameter.

Figure 1.1 Dropwise and Filmwise condensation apparatus

- **Steam Generator:** Made of Stainless Steel, insulated with ceramic wool provided with Level indicator. equipped with 2 kW heater and Pressure Gauge, Manual Release Valve, Feed Line and Steam Line.
- **Heating Elements:** Heater, 1.5 kW
- **Dropwise Condenser:**
  MOC: Copper with chrome plating
  Dimensions: ID (d_i) = 16 mm
  OD (d_o) = 19 mm
  Length (L) = 170 mm
- **Filmwise Condenser:**
  MOC: Copper with Natural finish
  Dimensions: ID (d_i) = 16 mm
  OD (d_o) = 19 mm
  Length (L) = 170 mm
- **Digital Temperature Controller:** 0-199.9 °C, RTD PT-100 type
- **Temperature Sensors:** RTD PT-100 Type
- **Temperature Indicator** with Selector Switch: A digital temperature indicator provided with multipoint connections, which measures temperatures of steam, two condensers, inlet & outlet temperature of condenser water flows.

  T_1 = Surface Temperature of Chrome Plated Condenser, °C.
  T_2 = Surface Temperature of Plain Copper Condenser, °C.
  T_3 = Temperature of steam in column, °C.
  T_4 = Water inlet temperature, °C.
  T_5 = Water outlet temperature, °C

- **Rota meter:** For measuring water flow rate, Range = ______________________
- **Pressure Gauge:** Dial type, range 0 - 2 kg/cm^2. (1 kg/cm^2 = ______________atm)
- Standard make on/off switch, Mains Indicator & fuse.
- The whole unit is assembled rigidly on a base plate.

5. Experimental Procedure

Starting Procedure:

1. Ensure that ON/OFF switches given on the panel are at OFF position.
2. Close all the drain valves.
3. Open the funnel valve and air vent valve provided at the top of steam generator.
4. Fill water in the steam generator up to 3/4th of its capacity by observing the level of water in the level indicator.
5. Close the funnel valve and air vent valve.
6. Switch On the main supply.
7. Set the temperature of required steam with the help of DTC, say 100 °C.
8. Switch ON the heater and wait until steam temperature reaches to required value.
9. Ensure that wet steam vent valve and needle valve provided at front are closed.
10. Allow steam to pass through the pipe and slowly open wet steam vent valve to release wet steam from the pipe.
11. Close the vent valve.
12. Connect cooling water supply.
13. Open the valve to allow cooling water to flow through desired condenser (Ensure that during experiment, water is flowing only through the condenser under test and second valve is closed).
14. Set the flow rate of cooling water by Rota meter.
15. Open the needle valve slowly to allow steam to enter in the test section and start the stopwatch to measure mass of steam condensed.
16. Observe that the Steam is condensed on the tubes, and falls down in the glass cylinder (Depending upon type of condenser under test Dropwise or Filmwise condensation can be visualized.)
17. After steady state, record the temperature, flow rate of cooling water, pressure.
18. Close the needle valve.
19. Stop the Stopwatch and open the drain valve of the glass chamber to measure the condensate for particular time.

Closing Procedure:

1. When experiment is over, switch OFF the heater.
2. Partially open air vent valve at steam generator to release the steam.
3. Stop cooling water supply to the condenser.
4. Switch OFF main supply.
5. Drain the apparatus completely after getting cool.

Precautions:

6. Never switch on mains power supply before ensuring that all the ON/OFF switch given on the panel is at OFF position.

7. Do not start heater supply unless water is filled in the steam generator unit.
8. Operate gently the selector switch of temperature indicator to read various temperatures.
9. Increase the temperature gradually of the heater during initial set-up experimentation.
10. Never use the heater at full wattage for longer period of time.

6. Observations:

(a) Dropwise Condensation:

Parameter	**Value**	**units**
m_w = Cooling water flow rate	40	lph
T_1 = Surface Temperature of Chrome Plated Condense	45.6	C
T_3 = Temperature of steam in column	76.96	C
T_4 = Water inlet temperature	37	C
T_5 = Water outlet temperature	38.9	C
Condensate flow rate (V mL collected in t min)	V/t = 6.8	ml/ min

(b) Filmwise Condensation:

Parameter	**Value**	**Units**
m_w = Cooling water flow rate	40	lph
T_2 = Surface Temperature of Plain Copper Condenser	39.4	C
T_3 = Temperature of steam in column	74	C
T_4 = Water inlet temperature	33.1	C
T_5 = Water outlet temperature	34.2	C
Condensate flow rate (V mL collected in t min)	V/t = 6	ml/ min

7. Calculations:

Calculations: For each type of condensation carry out following calculations to estimate inside, outside and overall heat transfer coefficient.

Density of condensate at T_3, ρ_s = _____________ kg/m^3

Convert the volumetric flow rate to mass flow rate of steam condensate, m_s, *kg/s*

Latent heat of steam at T_3, λs = ________________ kJ/kg

Heat losses from steam, $Q_s = m_s * \lambda_s$ = ________________ kW = ______________W

Heat taken by cold water, which is circulating inside the condenser tube

$Qw = m_w C_p (T_5 - T_4)$ = ___________ W

Average hear transfer, Q = (Qs + Qw) / 2 = ___________ W

7.1 Inside convection heat transfer coefficient

First calculate the heat transfer coefficient inside the condenser under test.
For this, properties of water are taken at bulk mean temperature of water, $T_b = (T_4 + T_5) / 2$
Determine following properties at T_b:

- Density of water, ρ, kg/m^3
- Dynamic Viscosity, μ, kg/(m·s)
- Thermal Conductivity, k, W/(m·°C)
- Prandtl Number, Pr

Calculate Velocity, v = volumetric flow rate / cross-section area =
$= (m_w / \rho) (4 / \pi * d_i^2)$
= _________________ m/s

Calculate Reynolds Number, $Re_d = (\rho \, v \, d_i) / \mu$

If this value of **$Re_d > 2500$** then flow is **turbulent**. Normally flow will be turbulent in the tube.
For Turbulent flow:

- Nusselt Number $Nu_d = 0.023 (Re_d)^{0.8} (Pr)^n$ (Dittus –Boelter equation[1])
  - where *n = 0.3 for cooling and n = 0.4 for heating*, in our case n = ________
    [*What are the other restrictions to use this equation?*]

For laminar flow

- Nusselt Number, $Nu_d = 1.86 (Re_d \, Pr)^{1/3}$
  (Sieder and Tate equation[2], neglecting the viscosity correction term)

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[1] *Heat Transfer,* J. P. Holman, 10th edition, McGraw-Hill, 2010, section 6.2, page no. 280
[2] *Heat Transfer*, J. P. Holman, 10th edition, McGraw-Hill, 2010, section 6.2, page no. 283

Inside heat transfer coefficient (h_i) = $(Nu_d\ k) / d_i$ = ____________________

Estimate h_i from experimental data

$h_i = Q / (A_i\ \Delta T_m)$

where, ΔT_m = *LMTD = formula ?* = ________________ = _______________ ℃

A_i = = ________________ *m2*

h_i = ____________ $W/(m^2 \cdot ℃)$

How much this value differs from the other calculations? Why?

7.2 Outside convection heat transfer coefficient

Calculate heat transfer coefficient on outer surface of the condenser ho:

For **Filmwise condenser**, the properties of water are taken at bulk mean temperature of condensate, $T_b = (T_2 + T_3) / 2$

- Density of water, ρ_L, kg/m^3
- Dynamic Viscosity, μ_L, kg/(m·s)
- Thermal Conductivity, k_L, W/(m·°C)

For filmwise condensation, h_{o_film} can be estimated by following equation[3]:

$$h_{o\_film} = 0.926\, k_L \left[\frac{g\, \rho_L^2}{\mu_L\, \Gamma_v}\right]^{\frac{1}{3}}$$

This equation will apply up to a Reynolds number of 30; above this value waves on the condensate film become important. The Reynolds number for the condensate film is given by

$$Re_c = \frac{4\, \Gamma_v}{\mu_L}$$

Where, $\Gamma_v = vertical\ tube\ loading, condensate\ rate\ per\ unit\ tube\ perimeter, \frac{kg}{m\,s}$

$$\Gamma_v = \frac{W_c}{N_t\, \pi\, d_o}$$

Where W_c = condensate flow rate, kg/s, N_t = number of tubes

[3] *Chemical Engineering Design*, Towler and Sinnott, 2nd edition, 2013, page no. 1114

Above a Reynolds number of around 2000, the condensate film becomes turbulent. The presence of waves will increase the heat-transfer coefficient, so the use of the above equation for a Reynolds number more than 30 will give conservative (safe) estimates.
The dropwise h_{o_drop} average heat transfer coefficient is 5 to 10 times that for filmwise condensation.

$$h_{o\_drop} = \underline{??} * h_{o\_film}$$

In addition, the resistance of the layer of stream condensate in both type of condensation is small in comparison with the resistance inside condenser tube and increase in overall coefficient is relatively small when dropwise condensation is achieved. For normal design, therefore filmwise condensation is assumed.

Estimate h_o from experimental data:

$h_o = Q / (A_o \, \Delta T_m)$

where, ΔT_m = *LMTD = formula ?* = ________________ = _______________ ℃

A_o = = ________________ *m2*

h_o = ____________ $W/(m^2\ ℃)$

How much this value differs from the filmwise condensation? Why?

7.3 Overall heat transfer coefficient:

From the values of inside and outside heat transfer coefficients, the overall heat transfer coefficient (U_i) can be calculated:

$$\frac{1}{U_i} = \frac{1}{h_i} + \frac{d_i}{d_o}\frac{1}{h_o}$$

U_i = ____________________ $W/(m^2 \cdot ℃)$

8. Results:

Type of condenser	h_i	h_o	U_i
Units →			
Filmwise, empirical equation			
Filmwise, experimental data			
Dropwise			

9. Inference:

Compare and interpret results.

10. Nomenclature:

A_i	=	Inside heat transfer surface area, m^2
A_o	=	Outside heat transfer surface area. m^2
d_i	=	Inner dia. of condenser, m
d_o	=	Outer dia. of condenser, m
hi	=	Inside Heat Transfer Coefficient, W/(m·°C)
h_o	=	Outside Heat Transfer Coefficient, W/(m·°C)
m_s	=	Rate of steam condensation, kg/s
m_W	=	Flow rate of cooling water, LPH
Qs	=	Heat loss from steam, W
Qw	=	Heat taken by cooling water, W
Q	=	Average Heat Transfer, W
T_S	=	Temperature of steam, °C.
T_W	=	Temperature of condenser wall, °C.
T1	=	Surface Temperature of Gold Plated Condenser, °C.
T2	=	Surface Temperature of Plain Copper Condenser, °C.
T3	=	Temperature of steam in column, °C.
T4	=	Water inlet temperature, °C.
T5	=	Water outlet temperature, °C.
ΔT_m	=	Log mean temperature difference, °C
t	=	Time to collect V mL of condensate, s
U	=	Overall heat transfer coefficient, W/(m^2·°C)
V	=	Volume of steam condensed, mL
ρ_S	=	Density of water at T_3, kg/m^3
ρ_W	=	Density of water, kg/m^3