

**SHREEYASH PRATISHTHAN'S
SHREEYASH TECHNICAL CAMPUS**

**SHREEYASH COLLEGE OF ENGINEERING &
TECHNOLOGY, AURANGABAD**



DEPARTMENT OF MECHANICAL ENGINEERING

Heat Transfer Laboratory Manual

V Semester B. Tech Mechanical Engineering

Year : _____

Name: _____

Roll No: _____ **Class** _____

Course _____

DEPARTMENT OF MECHANICAL ENGINEERING

MISSION OF THE DEPARTMENT

To impart systematic teaching methodologies for the quality education in addition to co-curricular & extra-curricular activities. To enhance the practical knowledge of the students through industry – institute interaction. To inculcate sensitivity towards society and respect towards nation

QUALITY POLICY

- To impart to the students, fundamental knowledge in the theory and practice of the core areas of Mechanical Engineering, making them fit to pursue higher education or computing as a career.
- To enable the students to apply their knowledge in the identification, design, development, production, and maintenance of mechanical systems, for real life problems.
- To enable our students to engage in continuous professional development and to remain current in their field of work.
- To familiarize with the basic manufacturing processes and to study the various tools and equipment used, hands-on training is given in different sections. Essentially student should know the labor involved, machinery or equipment necessary, time required to fabricate and also should be able to estimate the cost of the product or job work.

SYLLABUS
Mechanical Engineering Lab-III

Subject Code	: BTMCL 507	No. of Credits	: 3
No. of Contact Hours /	: 04	Total Marks	: 100
lab	HT+ TOM-II+ MD-I		

Practical Scheme:

Practical: 6 hrs/batch

Examination Scheme:
 Continuous Assessment: 60 Mark
 External Exam: 40 Marks

PART – A (Heat Transfer)
List of Practical's/Experiments/Assignments (Any Three from Group)

1. Determination of thermal conductivity of a metal rod.
2. Determination of thermal conductivity of insulating powder.
3. Determination of conductivity of a composite slab.
4. Temperature is distribution on a fin surface.
5. Determination of film heat transfer coefficient for natural convection.
6. Determination of film heat transfer coefficient for forced convection.
7. Determination of heat transfer coefficient for cylinder in cross flow in forced convection.
8. Performance of Double pipe Heat Exchanger/Shell and Tube Heat Exchanger.
9. Determination of emissivity of a metal surface.
10. Determination of Stefan Boltzman's constant.
11. Determination of critical heat flux.
12. Calibration of measuring instruments pressure gauge, thermocouple, flow-meter etc.

HEAT TRANSFER LABORATORY

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EXPERIMENT NO.1**THERMAL CONDUCTIVITY OF METAL ROD****AIM:**

To determine the thermal conductivity of metal rod (Aluminum).

INTRODUCTION:

Conduction is a process of heat transfer through solids, liquids and gases. When the temperature gradient exists in a body, experience has shown that there is a transfer of heat from high temperature region to the low temperature region. The heat transfer rate per unit is proportional to the temperature gradient in the direction of heat flow:

$$Q/A \propto (\Delta T/\Delta X)$$

Where „Q“ is the heat transfer in (watts), „A“ is the area of heat transfer (m²), $\Delta T/\Delta X$ is the temperature gradient in the direction of heat flow (°C/m). Where the proportionality constant is a property of a material and is known as thermal conductivity.

$$Q/A = -k (\Delta T/\Delta X)$$

The positive constant „k“ is called the co-efficient of thermal conductivity of material. The negative sign indicates that heat transfer takes place in the direction of decreasing temperature. Co-efficient of thermal conductivity has the units of W/m⁰C. Note that heat flow rate is involved and the numerical value of the co-efficient of thermal conductivity indicates how fast heat will flow in a given material.

Thermal conductivity co-efficient is a physical property of the material. Although it is fairly constant in narrow temperature range, it varies over a wide temperature range. Metals, which are good conductors of heat, have high values of co-efficient of thermal conductivity; for example 385 W/m⁰C for copper. Insulating material have low values of co-efficient of thermal conductivity for example 0.048 W/m⁰C for fibre insulating board. In any conduction heat transfer problem, it is essential to have the knowledge of co-efficient of thermal conductivity of the material involved in the heat transfer process. This setup has been designed to measure the temperature gradient along the length of the aluminum rod and to determine it's co-efficient of thermal conductivity.

APPARATUS:

Fig.1 shows the schematic representation of experimental setup. It consists of an aluminium rod, one end of which is heated by an electric heater and other end projects inside the cooling water jacket. The middle portion of the rod is thermally insulated from the surroundings using asbestos rope. The temperature of the rod is measured at four different locations along its length. Following are the important features of the experimental setup.

- a. Aluminium rod length : 500 mm (effective)
Diameter : 40 mm
No. of thermocouples mounted along the length : 6 (at the intervals of 50 mm)
- b. Band heater
- c. Thermal insulation covering the aluminum rod to reduce those losses to the surroundings.
- d. Cooling water jacket with water supply connections and thermocouples at both inlet and outlet.
- e. Heat controller or regulator to vary the input power to the heater
- f. Rotameter to measure water flow rate in the cooling water jacket.
- g. Thermocouples to measure the temperature at 1, 2, 3, 4, 5 & 6 along the length of the aluminum rod and 7 & 8 to measure temperature at inlet and outlet of water jacket.
- h. Digital temperature indicator and channel selector.

OPERATIONAL PROCEDURE:

- a. Switch on the mains and the console.
- b. Open the valve at the inlet of the cooling water jacket and maintain constant water flow rate in the rotameter.
- c. Switch on the heater.
- d. Set the heat controller or regulator which adjusts power input to heater.
- e. Wait till the temperatures T1 to T6 are constant with time that is steady state is reached.
- f. Read the temperatures T1 to T6 on the metal rod using the channel selector and digital temperature indicator.

- g. Read inlet and outlet water temperatures (T7 and T8) of the cooling water jacket.
- h. Measure the cooling water flow rate in the rotometer.
- i. Using the measured temperatures and water flow rate, the temperature gradient along the length of the aluminium rod and co-efficient of thermal conductivity of aluminium are calculated using the procedure given below.
- j. Repeat the experiment for different heat input and mass flow rate of water.

WORKING PRINCIPLE:

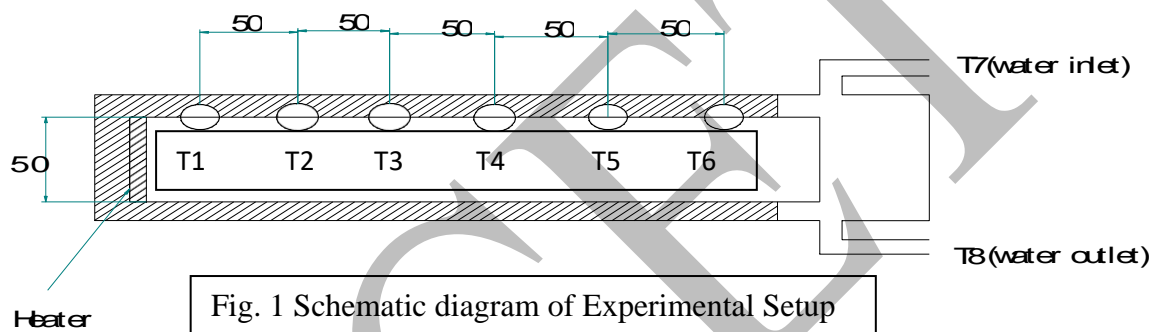


Fig. 1 Schematic diagram of Experimental Setup

Fig. 1 shows the schematic of the heat transfer process. The heat balance equation is given by:

$$Q_i = Q_0 + Q_1 \dots \dots \dots (1)$$

Where

Q_i = Input heat flow rate from the heater to the aluminum rod

Q_0 = Output heat flow rate from the aluminum rod

= Heat flow rate absorbed by water in the cooling water jacket

Q_1 = Heat loss from the rod to the surroundings through thermal insulation, assumed to be zero.

We can assume the $Q_1=0$, because of good thermal insulation.

Therefore, we get the heat flow rate through the rod as:

$$Q_i = Q_0 = mC_p \Delta T_w \dots \dots \dots (2)$$

$$\Delta T_w = \text{Rise in temperature of the cooling water} = (T_7 - T_8) \text{ in } ^\circ\text{C}$$

m = water flow rate in kg/s in the cooling water jacket from rotometer.

C_p = specific heat of water, 4.2 kJ/kg K.

Determination of temperature gradient ($\Delta t/\Delta x$) along the length of aluminum rod:

From the measured temperatures $T_1, T_2, T_3, T_4, T_5,$ and T_6 , surface temperature distributions along the length of the aluminium rod can be determined by plotting a graph of distance along the rod on the x axis and temperature on the y axis as shown in the Fig.2

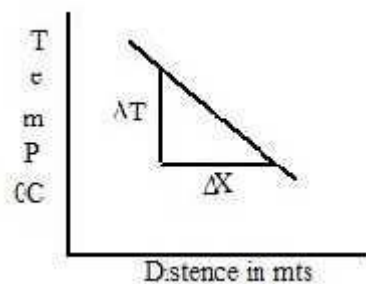


Fig.2: Plot of temperature v/s distance

Thus, the temperature gradient $\Delta t/\Delta x$ at the center of the aluminium rod in $^{\circ}\text{C}/\text{m}$ can be determined from the slope of the curve (by drawing a tangent).

Determination of co-efficient of thermal conductivity:

The heat conduction equation is given by

$$Q = -kA(\Delta t/\Delta x) \dots\dots\dots(3)$$

Where,

Q = Heat flow rate through the aluminium rod in watts

K = Co-efficient of thermal conductivity of aluminium, W/mK

$A = \pi d^2/4$ = Area of heat transfer in m^2

D =Diameter of the aluminium rod = 40 mm = 0.04 m

From eqs (2) & (3), we get

$$k = m C_p \Delta T w / [A (\Delta t/\Delta x)]$$

The co-efficient of thermal conductivity (k) can be obtained by substituting the measured values of $m, \Delta T w, \Delta T/\Delta X, A$ and C_p .

The above analysis assumes that the heat loss from the aluminum rod is negligible due to thermal insulation.

TABULAR COLUMN:

Sl no	Heat input			Thermocouple reading in °C						Cooling water Temperature		Mass flow rate of water		Heat carried away by water	Temperatur e gradient	Thermal conductivity
	V	A	Q	T 1	T 2	T 3	T 4	T 5	T 6	T7	T8	Lp m	Kg/ s	Q _w	dt/dx	K (W/m k)

The typical value of the co-efficient of thermal conductivity of aluminium is 200-360 W/m K. The difference between the actual and measured values of „k“ is due to the heat losses through the thermal insulation and may be acceptable as in any heat transfer experiment.

The experiment can be repeated for different water flow rate and heat input. The values of „k“ obtained are tabulated.

Result: Thermal conductivity of aluminum rod is W/m °C.

EXPERIMENT NO.2**THERMAL CONDUCTIVITY OF INSULATING MATERIAL****AIM:**

To determine the co-efficient of thermal conductivity of insulating powder.

INTRODUCTION:

Materials that offer high resistance to the flow of heat are called as heat insulators. Heat insulators find extensive application in the systems where heat losses are to be minimized such as heat transmission lines in power plants, furnaces etc.

In many heat transfer equipment, heat loss to the surroundings is to be minimized to the maximum economy. In such cases, they are lagged by materials of lower thermal conductivity, which are referred to as insulators. Powders have the advantage of taking any shape between any two conforming surfaces. In addition, its thermal conductivity will be much lower than that of the solid from which it was made. This is because of the large air space between the particles, which have very low values of thermal conductivity. Thermal conductivity of such material is a complicated function of geometry of the particles, thermal conductivity of the particles, the nature of heat transfer between the air particles which depends of the magnitude of the air space and temperature etc. Thus, it is very difficult to estimate the thermal conductivity in most practical cases. The set up provided is one such apparatus to find thermal conductivity.

Rate of heat transfer through a material is given by,

$$Q = K A (\Delta T / \Delta X)$$

Where,

Q = Rate of heat transfer in Watt

K = Co-efficient of thermal conductivity in W/m⁰C

A = Area of heat transfer in m²

ΔT = Temperature between the walls in⁰C

ΔX = Thickness of the material in m

Insulators have low thermal conductivities say, about 0.1W/m⁰C to 1W/m⁰C whereas metals which are good thermal conductors have co-efficient of thermal conductivity as high as 200W/m⁰C This setup has been designed to study conduction heat transfer through insulating powder and to determine its co-efficient of thermal conductivity.

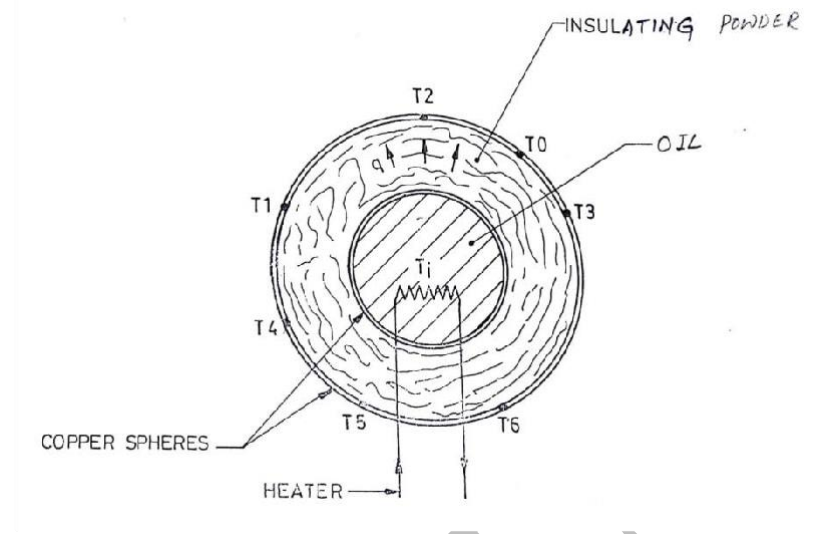
SPECIFICATION AND DESCRIPTION

Figure shows the schematic of the experimental setup for thermal conductivity of insulating material. The system consists of the following:

- a) **Insulating sphere:**
It consists of two concentric spheres. The inner and outer sphere have 250mm and 300 mm diameters respectively. The space between the spheres is filled with insulating powder. The inner sphere is filled with oil and a heater is provided in it to heat the oil to the required high temperature. The arrangement is such that the heat transfer from the inner sphere to the outer sphere can be studied.
 - b) **Oil heater:**
Capacity: 500W
 - c) Digital voltmeter and ammeter to measure power input.
 - d) Digital temperature indicator to measure temperature.
- Temperature points:**
- T1, T2, T3 – temperatures on the upper hemisphere in $^{\circ}\text{C}$
 T4, T5, T6 – temperatures on the lower hemisphere in $^{\circ}\text{C}$
 T7 – temperature of the oil in the sphere in $^{\circ}\text{C}$
- e) Thermostat to set and control heater voltage at a particular temperature.
 - f) Electrical supply: 1Ph, 230V, 16A with ground.

OPERATIONAL PROCEDURE :

1. Switch on the MCB, mains and console.
2. Switch on the heater.
3. Switch on the thermostat and set for a particular temperature.
4. Wait for some time till the oil temperature stabilizes.
5. After some time the surface temperatures will come to study state.
6. Note down the ammeter readings, voltmeter readings and the temperatures at all points.

7. Using the measured temperature, calculate the co-efficient of thermal conductivity of the insulating powder using the procedure given.

WORKING PRICIPLE:

Figure shows the schematic of the heat transfer process through the insulating sphere. The co-efficient of the thermal conductivity of the insulating sphere is given by,

$$K = Q/R\Delta T$$

K = Thermal conductivity of the powder in W/m⁰C

Q = Total heat transfer rate in Watt

R = Shape factor = $4\pi r_o r_i / (r_o - r_i)$

r_i = Radius of the inner sphere = 125mm

r_o = Radius of outer sphere = 150mm

ΔT = T_i – T_o in ⁰C

T_i = Inside oil temperature in ⁰C

T_o = (T₁+T₂+T₃+T₄+T₅+T₆)/6 in ⁰C

OBSERVATIONS:

r_i = Radius of the inner sphere = 125mm

r_o = Radius of outer sphere = 150mm

TABULAR COLUMN

Sl NO	Heat input			Temperature on Sphere						Average Sphere Temperature	Oil Temperature	Shape Factor R	Thermal Conductivity K in W /m C
	V	I	Q	T1	T2	T3	T4	T5	T6				

EXPERIMENT NO.3**HEAT TRANSFER THROUGH COMPOSITE WALL****AIM:**

To determine the also overall heat transfer coefficient for heat transfer through composite material consisting of Mild Steel, asbestos and brass.

INTRODUCTION:

Conduction is a process of heat transfer through solids. For a given temperature difference between the surfaces, the rate of heat transfer (Q , watts) depends upon the coefficient of thermal conductivity of the substance (k , W/m K), area of heat transfer (A , m²) and the temperature difference (ΔT , °C) between the surfaces and thickness of the material (ΔX , m) according to the equation,

$$Q = -kA (\Delta T / \Delta X)$$

Substances such as metals conduct more heat and have high values of co-efficient of thermal conductivity, as high as about 200 watts/m °C, insulating materials conduct less heat and have low values of co-efficient of thermal conductivity, say about 0.1 to 1 watts/m °C. In circumstances where heat loss from the system has to be minimized, such as in power plant transmission lines, furnaces, etc. It is essential to cover heat carrying systems with proper materials. This set-up has been designed to study heat through composite materials

APPARATUS:

The setup consists of the following important items:

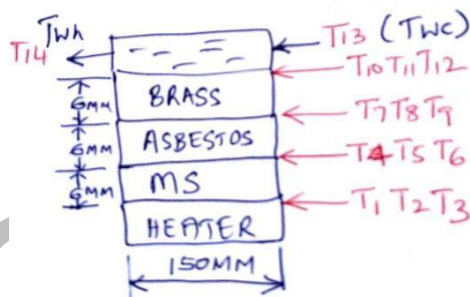
- a) Composite walls: It consists of a band heater at one end with mild steel, asbestos and brass plates composited to form heat flow path. The plates are covered with insulation to prevent heat loss.
- b) Band heater: provided to heat one end of the composite wall
Capacity: 400 watts, diameters of mild steel, asbestos and brass plates: 150 mm
Thickness of each plate: 6 mm
- c) Rotometer: provided to measure water flow rate
- d) Thermocouples: k – type to measure temperature
- a) Channel selector and digital temperature display
- b) Heat control or regulator: to vary input power to the heater.

- c) Thermostat: to set and control heater temperature range.
- d) Control panel: to switch on/off the console and the heater.

PROCEDURE

- a) Switch on the mains and the console
- b) Switch on the heater
- c) Set the temperature setting(thermostat) to the safe value
- d) Set the heat control/regulator and adjust the water flow rate
- e) Wait till the temperatures stabilize with time, that is, steady state is reached.
- f) Read the temperatures measured, rate of heat transfer and co-efficient through composite walls are calculated.
- g) Measure water flow rate from the Rotometer.
- h) Using the temperatures measured, rate of heat transfer and co-efficient through composite walls are calculated using procedure given below.

WORKING PRINCIPLE:



The heat balance equation for dimensional flow is given by (neglecting losses in stable condition).

$$Q = Q_i = Q_{ms} = Q_{as} = Q_b$$

Where Q_{ms} , Q_{as} , Q_b are the same heat flowing across mild steel, asbestos and brass respectively.

Q_i is the overall heat flow across composite material. Considering individual material, the heat transmitted across each of the material is equal to the heat carried away by cooling water jacket measured on Rota meter.

Tabular column:

Heat input			Temperature of composite wall															
V	I	Q	Bottom of MS plate				Top of MS plate				Top of Asbestos plate				Top of brass plate			
			T1	T2	T3	T _{mb}	T4	T6	T7	T _{mt}	T7	T8	T9	T _{at}	T10	T11	T12	T _{bt}

Mass flow rate of water in Kg/s	Water inlet temperature	Water outlet temperature	Heat carried away by water in W	Overall heat transfer coefficient	
	T13	T14	Q _w	U _{exp}	U _{th}

That is, $Q_i = m C_p \Delta T_w$

Here m = water flow rate in kg/sec = flow rate in LPM * (1/60)

C_p = specific heat of water 4.2 kJ/kg K

ΔT_w = Rise in temperature of cooling water (T14-T13).

$Q_i = m C_p \Delta T_w = K_{ms} A (\Delta T_{ms} / L_{ms}) = K_{as} A (\Delta T_{as} / L_{as}) = K_b A (\Delta T_b / L_b)$

ΔT = Temperature difference, k = thermal conductivity, A = area of the heat flow.

L = length of the heat flow.

$U_{th} = 1/[L_{ms}/K_{ms} + L_{as}/K_{as} + L_b/K_b] \dots\dots W/m^{\circ}C$

Calculations:

$$Q_0 = m C_p \Delta T_w = \quad W$$

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

$$K_{ms} = (Q/A) * L_{ms}/(T_{mb}-T_{mt}) = \quad W/m^{\circ}C$$

$$K_{as} = (Q/A) * L_{as}/(T_{mt}-T_{at}) = \quad W/m^{\circ}C$$

$$K_b = (Q/A) * L_b/(T_{at}-T_{bt}) = \quad W/m^{\circ}C$$

Overall heat transfer coefficient,

$$U_{ex} = 1/[L_{ms}/K_{ms} + L_{as}/K_{as} + L_b/K_b]$$

$$U = \dots \quad W/m^{\circ}C$$

Result: Overall heat transfer coefficient of the given composite wall is
W/m[°]C.

SYNCEER

EXPERIMENT NO.4**HEAT TRANSFER COEFFICIENT IN NATURAL CONVECTION****AIM:**

To determine the heat transfer co-efficient in natural convection for vertical tube

INTRODUCTION:

Heat transfer can be defined as the transmission of energy from one region to another as a result of temperature difference between them. There are three different modes of heat transfer; namely conduction, convection and radiation

Conduction: The property which allows passage for heat energy, even though their parts are not in motion relative to one another.

Convection: is the transfer of heat within the fluid by mixing one portion of fluid with another.

Heat Radiation: The property of emit or to absorb different kind of ratio of electromagnetic waves.

Out of these type of heat transfer the convective heat transfer which of concern, divides into two categories viz.,

Natural Convection: If the motion of fluid caused only due to difference in density resulting from temperature gradients without the use of pump or fan, then the mechanism of heat transfer is known as “natural or free convection”.

Forced convection: If the motion of fluid is induced by some external means such as a pump or blower.

The Newton's law of cooling in convective heat transfer is given by

$Q = h A \Delta T$, where Q = heat transfer rate in watts

A = surface area of heat flow in m^2

ΔT = over all temperature difference between the wall and fluid

h = convection heat transfer co-efficient in watts

This setup has been designed to study heat transfer by natural or free convection

Apparatus:

1. A metallic tube of diameter (d) 45 mm and length (L) 450mm with a electrical heater coil along the axis of the tube.
2. Seven thermocouple are fixed on the tube surface.
3. Control panel instrumentation consists of multichannel digital display
 - a) Temperature indicator to measure surface temperature T1 to T7 of the tube and ambient temperature T8.
 - b) Digital ammeter and voltmeter to measure power input to the heater.
 - c) Regulator to control the power input to the heater.
5. Front transparent acrylic enclosure for safety of the tube when not in use.

OPERATIONAL PROCEDURE:

1. Keep the tube in vertical position.
2. Switch ON the mains and the control.
3. Set the regulator to set the heat input.
4. Wait for sufficient time to allow temperature to reach steady values.
5. Note down temperatures T1 to T8 using channel selector and digital temperature indicator.
6. Note down the Ammeter and Voltmeter readings.
7. Tabulate the heat input and transfer co-efficient using the procedure.
8. Calculate the convection heat transfer co-efficient using the procedure given below.
9. Repeat the experiment by changing the heat input.

Sl.NO	Heat Input			Temperature along the tube							Average tube Temperature	Ambient Temperature	Convective heat transfer coefficient	
	V	I	Q	T1	T2	T3	T4	T5	T6	T7			T _{av}	T8

Calculations:

Determination of experimental heat transfer co-efficient: For steady state condition, heat given to heater = Heat lost from the tube surface by natural convection.

$$\text{Therefore, } Q = h A_s (T_s - T_\infty)$$

Where,

$$Q = (\text{Ammeter reading}) \times (\text{Voltmeter reading}), \text{ in watts}$$

$$D = \text{Diameter of tube} = 45 \text{ mm}$$

$$L = \text{length of the tube} = 450 \text{ mm}$$

$$A_s = \text{Tube surface area} = \pi D L = \quad \text{m}^2$$

$$T_s = (T_1 + T_2 + T_3 + T_4 + T_5 + T_6 + T_7) / 7 = \quad \text{°C}$$

$$T_\infty = T_8 = \text{Ambient air temperature} = T_8 = \quad \text{°C}$$

Therefore,

$$\text{Heat transfer co-efficient, } h_{\text{expt}} = Q / A_s (T_s - T_\infty) = \quad \text{W/m}^2\text{K}$$

Determination of Theoretical heat transfer co-efficient:

The theoretical value of the natural heat transfer co-efficient is calculated given by:

Note down the properties of air at from data hand book

$$T_m = (T_s + T_\infty) / 2 = \quad \text{°C}$$

At mean temperature properties of air should be noted down from the HMT data hand book.

$$\nu = \quad \text{m}^2/\text{s}$$

$$k = \quad \text{W/mK}$$

$$\text{Pr} =$$

$$\beta = 1 / (T_m + 273) = \quad \text{K}^{-1}$$

$$\Delta T = (T_s - T_\infty) = \quad \text{°C}$$

$$g = 9.81 \text{ m/s}^2$$

$$\text{Gr (Grashoff No.)} = (g \beta L^3 \Delta T) / \nu^2 =$$

Nu = choose the equation from data book based on Gr.Pr

$$Nu = \frac{hL}{k},$$

$$h_{th} = \quad \quad \quad W/m^2K$$

RESULTS

$$h_{exp} = \quad \quad \quad W/m^2K$$

$$h_{th} = \quad \quad \quad W/m^2K$$

SYNOPSIS

EXPERIMENT NO.5**HEAT TRANSFER COEFFICIENT IN FORCED CONVECTION****AIM:**

To determine the heat transfer co-efficient in forced convection for hot air flowing through horizontal tube

INTRODUCTION:

It is well know that a hot plate of metal will cool faster in from a fan than when exposed to still air. We say that the heat is convected away and we call the process as convective heat transfer. The velocity at which air blows over the hot plate obviously influences the heat transfer rate.

The Newton's law of cooling in convective heat transfer is given by

$$Q=h A \Delta T$$

Where, Q=heat transfer rate, watt

A=surface area of heat flow, m²

ΔT =overall temperature difference between the wall and fluid in °C

h= convective heat transfer coefficient (W/m²°C).

The convective heat transfer coefficient depends upon the viscosity of the fluid in addition to its dependence on the thermal properties of the fluid (thermal conductivity, specific heat, density, etc). If a heated plate is exposed to ambient room air without all external source of motion, movement of air would be experienced as a result of the density gradient heat near plate. We call this natural or free convection. If the convection is experienced the case of the fan blowing air over a plate, we call this forced convection. The approximate ranges of convection heat transfer coefficient are given in table below

Mode	„h“ W/m ² °C
Free convection	5-25
Forced convection: air , water	10-500, 100-15000
Boiling water	2500-25000
Condensation and water vapor	5000-100000

This setup has been designed to study forced convection heat transfer.

APPARATUS:

The important components of the set up are:

- a. Heat exchanger tube-the tube is thermally insulated outside to prevent heat transfer losses to the atmosphere.
- b. Heater, wattage :500 watts (approx.)
- c. Regulator to control the power input to the heater
- d. Volt and Ampere Meters to measure power input to the heater
- e. Thermocouples T1 and T7 to measure air temperature at the inlet and outlet of the duct. T2 - T6 to measure test specimen temperatures.
- f. Channel selector
- g. Digital temperature indicator
- h. Blower: to blow air through the heat exchanger.
- i. Orifice meter with manometer to air flow rate from the blower.
- j. Control panel to house the whole instrumentation.

OPERATIONAL PROCEDURE:

1. Switch on the mains and the console
2. Start the blower first
3. Control blower flow rate to a suitable value
4. Measure the pressure drop across the orifice meter and calculate air mass flow rate.
5. Switch on the heater and adjust the power input to the heater to a suitable value using the regulator.

WORKING PRINCIPLE:

The air flows through the heat exchanger because of the blower action. In steady state, power input to the heater is equal to the heat transferred to the air. This is used as the base for calculation of heat transfer coefficient.

Where,

Q = heat transfer rate, W

Q_a = Volume flow rate of air m^3/s

P = power input to the heater

A_1 =cross sectional area of the main pipe, $(\pi D^2)/4 \text{ m}^2$

A_2 =cross sectional area of orifice $(\pi d^2)/4$

L = length of the tube 0.5 m

D = diameter of the tube 40 mm

d = orifice diameter 20 mm

ΔT =average temperature between the tube and the air $^{\circ}\text{C}$

h =convective heat transfer coefficient $(\text{W}/\text{m}^2\text{K})$

C_d =

Volume flow rate of air, $Q_a = (C_d A_1 A_2 \sqrt{2g h_a}) / (A_1^2 - A_2^2)^{1/2} \text{ m}^3/\text{s}$

TABLE OF MEASUREMENTS:

Sl.No	Heat Input			Manometer readings		Head of water hw	Temperatures of tube, $^{\circ}\text{C}$					Air Temperature		Water Temperature		Convective heat transfer coefficient		
	V	I	Q	h1	h2	h1~h2	T ₂	T ₃	T ₄	T ₅	T ₆	Inlet T1	Outlet T2	Inlet T1	Outlet T2	h_{th}	h_{ex}	

Calculations:

Determination of experimental heat transfer co-efficient calculations

$$T_s = [T_2 + T_3 + T_4 + T_5 + T_6] / 5 = \quad ^{\circ}\text{C}$$

$$T_{\infty} = [T_1 + T_7] / 2 = \quad ^{\circ}\text{C}$$

$$\Delta T = (T_s - T_{\infty}) = \quad ^{\circ}\text{C}$$

$$Q = h A (T_s - T_{\infty})$$

$$h_{exp} = Q / (A (T_s - T_{\infty})) = \quad \text{W}/\text{m}^2\text{K}$$

Determination of Theoretical **heat transfer co-efficient** calculations

$$T_m = (T_s + T_{\infty}) / 2 = \quad ^{\circ}\text{C}$$

Following properties of air from heat transfer data hand book at mean temperature are noted down

$$\text{Kinematic viscosity of air, } \nu = \quad \text{m}^2/\text{s}$$

Thermal conductivity of air, k W/m k

Pr =

Calculation of velocity of air (V):

$$A_1 = \Pi/4 * D^2 = \quad \text{m}^2, \quad A_2 = \Pi/4 * d^2 = \quad \text{m}^2$$

$$\rho_a = P/RT = \quad \text{kg/m}^3$$

$$\rho_w h_w = \rho_a h_a, \quad h_a = \quad \text{m}$$

$$Q_a = [C_d A_1 A_2 \sqrt{2gh_a}] / (A_1^2 - A_2^2)^{1/2} = \quad \text{m}^3/\text{s}$$

$$V = Q_a / A_1 = \quad \text{m/s}$$

$$Re = (VD)/\nu =$$

If Reynolds No. value is more than 2300, flow is Turbulent otherwise flow is Laminar. Usually for forced convection heat transfer experiment the value of Reynolds No. is more than 2300, hence flow is turbulent.

Choose the equation from data book based on Reynolds number.

$$hD/k = Nu,$$

$$h_{th} = (Nu \times k)/D = \quad \text{W/m}^2\text{K}$$

EXPERIMENT NO.6**EFFECTIVENESS ON A PIN FIN****AIM:**

Determine the rate of heat transfer, effectiveness and efficiency of the pin-fin.

INTRODUCTION:

Fins are widely used to enhance the heat transfer (usually convective, but it could also be radiative) from a surface. This is particularly true when the surface is in contact with a gas. Fins are used on air cooled engines, electronic cooling forms, as well as for a number of other applications. Since the heat transfer coefficient tends to be low in gas convection, area is added in the form of fins to the surface to decrease the convective thermal resistance.

APPARATUS:

A metallic fin of circular cross section of length 'L' is fitted in the rectangular duct. The base of the fin is fixed to a heater plate for heating the fin. Thermocouples are provided on the surface of the fin. The duct is provided with a fan to contact the air flow with the help of regulator.

A multi-channel temperature indicator has been provided to monitor different temperature points. Measure the velocity of air flow over fin. Power input to the heater is given by regulating the ammeter and voltmeter.

OPERATIONAL PROCEDURE:

- 1) Switch on the mains and console
- 2) Switch on the heater and adjust the power input.
- 3) Wait till steady state is reached and note down all the temperature indication by the temperature indicator.
- 4) After conducting experiment in natural convection mode, start the blower and adjust the flow as required for forced convection.

- 5) Increase the power supplied to the heater as to maintain the same temperature before starting the blower.
- 6) Wait till steady state condition is reached and note down the temperature as well as velocity of flow.
- 7) Repeat the procedure for different heat inputs.

Tabular Column:

Sl.No	Heat Input			Test specimen temperature					Chamber temperature	Velocity of air, V in (m/s)
	V	I	Q	T1 (°C)	T2 (°C)	T3 (°C)	T4 (°C)	T5 (°C)	T6	

Calculations:

1) Surface Temperature, $T_s = (T_1 + T_2 + T_3 + T_4 + T_5) / 5$

2) Atmospheric temperature, $T_\infty = T_6 =$

3) $T_{\text{mean}} = (T_\infty + T_s) / 2$

At mean temperature note down the values of thermo physical properties of air from heat transfer data hand book thermo physical properties of air are (ν) kinematic viscosity, (K_{air}) thermal conductivity of air and Prandtl No.

4) Reynolds no (Re_d) = $(\nu * d) / (\gamma)$, where „ ν “ is velocity of air flowing over the fin
Based on the Reynolds no choose the value of constants C and m from the heat transfer data hand book

5) $h = K_{\text{air}} [C \cdot Re_d^m (Pr)^{0.33}] / d$

6) $Q = \sqrt{(hPKA)} (T_s - T_\infty) \tanh(mL)$

7) Efficiency, $\eta = \tanh(mL) / (mL)$

8) Effectiveness, $\epsilon = \tanh(mL) / [\sqrt{(hA/PK)}]$

where, T_s = Surface temperature of fin

T_∞ = surrounding temperature ($^{\circ}\text{C}$)

L = length of fin = m

d =diameter of the fin = m

$m = \sqrt{\left(\frac{hP}{KA}\right)}$, P =perimeter of fin= πd m

$A = \pi d^2/4$ m²

K =thermal conductivity of Al

= W/m°C

Result:

The rate of heat transfer of PIN-FIN apparatus is W.

Efficiency of the fin (η) is %.

Effectiveness of the fin (ϵ) is

EXPERIMENT NO.7
EMISSIVITY OF SURFACE

AIM:

To determine the emissivity of the radiating surface

INTRODUCTION:

Radiation is one of the modes of heat transfer, which does not require any material medium for its propagation. The mechanism is assumed to be electromagnetic in nature is the result of temperature difference. Thermodynamic considerations show that an ideal radiator or black and will emit energy at a rate proportional to the fourth power of the absolute temperature of the body. When two bodies will exchange heat by radiation, the net heat exchange is given by,

$$Q = \sigma AT^4$$

Where, „Q“ is the heat transfer rate in watts, “σ” is called Stefan Boltzman“s Constant having the value of $5.669 \times 10^{-8} \text{ W/m}^2\text{K}^4$,”A“ is the surface area (m^2)

All the bodies emit and absorb the thermal radiation to and from surroundings. The rate of thermal radiation depends upon the temperature of body. Thermal radiations are electromagnetic waves and they do not require any medium for propagation. When thermal radiation strikes a body, part of it is reflected, part of it is absorbed and part of it is transmitted through body. The fraction of incident energy, reflected by the surface is called reflectivity (ρ). The fraction of incident energy, absorbed by the surface is called absorptivity (α) and the fraction of incident energy transmitted through body is called transmissivity (τ). The surface which absorbs all the incident radiation is called a black surface. For a black surface, $\rho + \alpha + \tau = 1$. The radiant flux, emitted from the surface is called emissive power (E). The emissivity of a surface is ratio of emissive power of a surface to that of black surface at the same temperature. Thus, $\varepsilon = E / E_b$

fig(1) shows the schematic of the test setup. It consists of the following:

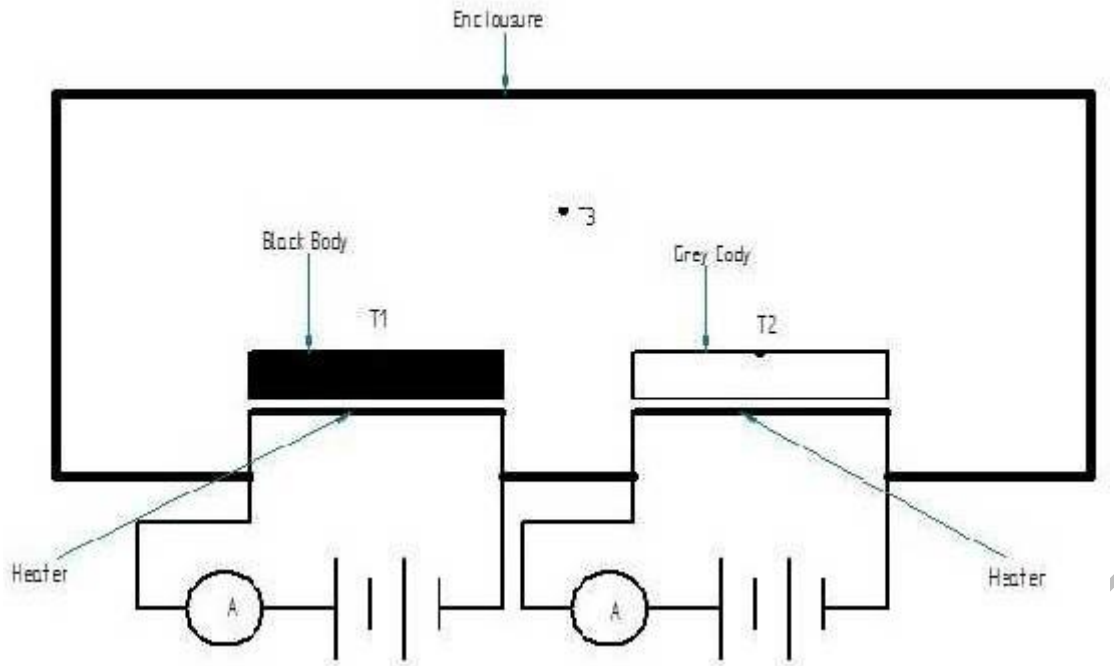


Fig:1 Scheme diagram for emissivity apparatus

Black Body made of circular steel plate with the surface black anodized. Grey body or test steel plate made of circular steel plate of same size as the black body with polished surface.

Heaters are provided to heat the black body and grey body to identical temperature.

Voltmeter and ammeter provided to measure the input power to the heaters.

Thermocouples to measure surface temperature of the black body (T_1), test plate (T_2).

Channel selector and digital temperature display.

Heat control or regulator to vary input power to the heaters. Controls panel to switch on/off the console and the heater.

OPERATIONAL PROCEDURE:

- a. Switch on the mains and console
- b. Switch on the heater to the black body and adjust the power input to the heater to a suitable value using regulator.
- c. Switch on the heater to the test plate and keep the power input to a value less than that input to the black body.

- d. Observe the temperature of the black body and test surface in close time intervals and adjust power input to the test plate heater such that both black body and test surface temperature are same. This procedure requires trial and error method and one has to wait sufficiently long to reach the steady state.
- e. After attaining steady state, record input powers to heaters and temperatures of the black body, test plate and the enclosure. Using the above measurements calculate the emissivity of the test surface using the procedure given below.

WORKING PRINCIPLE:

Fig. (1) shows the schematic of the apparatus used to determine the emissivity of the test surface. The experimental setup is designed in such a way that under steady state conditions, the heat dissipation by the conduction and convection, although small, are same or both plates: the difference in power input to the heaters of black surface and test plate which are at the same temperature is due to the difference in the radiation characteristics because of different emissivity by the relationship,

Where W_1 =heat input to the black surface = $V_1 I_1$ watts

W_2 =heat input to the test plate = $V_2 I_2$ watts

V_1 =voltage across heater to black surface (volts)

I_1 =current to the black surface (amps)

V_2 =voltage across heater to test plate (volts)

I_2 =current to the test plate heater (amps)

A =area of the test plate [$\pi(d^2)/4$] m^2

d = diameter of the test plate m

T_1 =temperature of the black plate ,K

T_2 =temperature of the test plate , K

ϵ_b =emissivity of the black plate (assumed equal to 1)

ϵ =emissivity of the test plate

σ = Stefan boltzman's constants

= $5.67 \times 10^{-8} \text{ W/m}^2 \text{ K}^4$

The constant in the denominator (0.86) takes into account various factors such as radiation shape factor, effect of conduction and free convection losses and other factors (such as non-uniformities in enclosures temperatures), which cause deviation from the typical radiation heat transfer, experiment. The above analysis requires that the temperature of black surface and test plate are same ($T_1=T_2$).

Tabular Column:

Sl. No.	Heat input to heaters						T1=T2 (°C)	T3 (°C)
	Vb (V)	Ib (A)	Qb= Vb x Ib (W)	Vg (V)	Ig (A)	Qg= Vg x Ig (W)		
1	47	0.46	21.62	34	0.31	10.54	100	54.5

Sample calculation:

$$A = 0.7854 \cdot d^2 = \quad \text{m}^2$$

$$\epsilon = 1 - \frac{0.86[Q_b - Q_g]}{\sigma \times A [T_1^4 - T_3^4]}$$

Result:

Emissivity of the surface is

EXPERIMENT NO.08**STEFAN BOLTZMAN CONSTANT****AIM:**

To determine the Stefan boltzman's constant.

INTRODUCTION:

The most commonly used relationship in the radiation heat transfer is the Stefan boltzman's law, which relates the heat transfer rate to the temperature of the hot and cold surfaces,

$$Q = \sigma A (T_h^4 - T_c^4)$$

Q=rate of the heat transfer , watts

σ =Stefan boltzman's constant= 5.669×10^{-8} watts/m²K⁴

A=surface area , m².

The above equation is only applicable for black bodies (for ex, a piece of metal covered with carbon black approximates this behaviour) and is valid only for thermal radiation. Other types of bodies (like a glossy painted surface or a polished metal plate) do not radiate as much as energy as the black body but still the radiation emitted follows T⁴ proportionality.

This setup has been designed to determine the values of the Stefan boltzman's constant.

APPARATUS:

The setup consists of the following important parts,

- Copper hemispherical enclosure.
- Non-conducting base plate made of asbestos.
- Thermocouples, iron – constantan type to measures temperature on the copper hemisphere T₁ and T₂ on the disc and T₃ on specimen and T₄ of hot water
- Disc mounted in insulated bakelite sleeve, made of aluminium.

Disc dia(D): mm, mass (m) = grams,

Specific heat = kJ/kgK.

- e. Channel selector and temperature display.
- f. Heater coil to heat the enclosure.

WORKING PRINCIPLE:

The enclosure is maintained at the higher temperature using heater. The disk or the test piece is inserted in to its place along with variation in its temperature (T_3) with time is recorded.

The radiation energy falling on the disc (D) from the enclosure is given by

$$Q_e = \sigma A_D T_e^4 \dots\dots\dots (1)$$

Where,

Q_e = rate of radiation emitted on the enclosure falling on the disc(watts)

A_D = area of the disc, m^2

T_e^4 = average temperature of the enclosure recorded by thermocouples (K)

The emissivity of the enclosure and the disc are assumed unity because of black surface characteristics. The radiation energy emitted by the disc to the enclosure is given by,

$$mC_p(dT/dt)_{t=0} = \sigma A_D(T_s^4 - T_D^4) \dots\dots\dots (2)$$

Where, (dT/dt) , is the rate of increase in temperature ($^{\circ}C/sec$) at the instant when the disc is inserted in to the setup. The stefan boltzman constant is obtained using the relationship,

$$\sigma = \frac{mC_p(dT/dt)_{t=0}}{A_D(T_s^4 - T_D^4)} \dots\dots\dots (3)$$

OPERATIONAL PROCEDURE:

- a. Switch on the mains and the console.
- b. Remove the disc (D) or test piece.
- c. Switch – on the heater.
- d. Allow the water to reach some prescribed temperature.

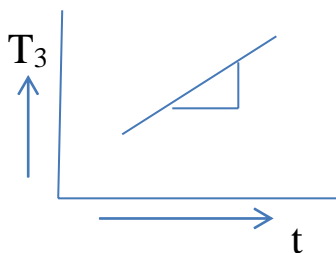
- e. Allow the heated water enters into the hemispherical enclosure to attain uniform high temperature –the enclosure will soon reach thermal equilibrium.
- f. Measure the enclosure temperature with the thermocouple (T_1 and T_2) using channel selector and digital temperature indicator.
- g. Insert disk (D) with sleeve into its position and record temperature of the disc (T_3) at different instant of time using stop watch.
- h. Plot the variation of disc temperature (T_3) with time sec as shown in fig(2) and get the slope of temperature versus time variation ($^{\circ}\text{C}/\text{sec}$) at the time $t=0$ sec.
- i. Using eq(3) calculate the Stefan boltzman"s constants.
- j. Repeat the experiments 3 to 4 and calculate the average value to obtain the better value of the Stefan boltzman"s constant.

Tabular Column:

Sl.No.	Time „t“ (s)	Specimen Temperature „T ₃ “ (°C)

Calculations:

1. Temperature of the enclosure = T_{sphere} $^{\circ}\text{C}$
2. Mass of the test disc (m)= gm
3. Specific heat of the disc material C_p = J/kg $^{\circ}\text{C}$
4. Obtain (dT_3/dt) using the plot of the T_3 vs t and determine the slope.
5. Calculate Stefan boltzman"s constant using the relationship.

**Fig 2:** Plot of temperature T_3 v/s t

$$\sigma = \frac{mC_p(dT_2/dt)}{A_D(T_s^4 - T_{d=t=0}^4)} \quad \text{W/m}^2\text{K}^4$$

Sample calculations:

$$A_D = (\pi/4) * D^2 = \quad \text{m}^2$$

$$dT_2 / dt = \quad \text{°C/s by plotting graph and taking slope.}$$

$$T_s = \text{Average temperature of hemispherical cup } T_1 + T_2 / 2 = \quad \text{K}$$

$$T_{3 t=0} = \quad \text{K}$$

$$\text{Result: Stefan boltzman constant } \sigma = \quad \text{W/m}^2\text{K}^4$$

SYSCET

EXPERIMENT NO.09**EFFECTIVENESS OF HEAT EXCHANGERS****AIM:**

To determine effectiveness of parallel flow and counter flow heat exchanger.

INTRODUCTION:

Heat exchanger is a device in which heat is transfer from a hot to a cold fluid across a separating wall. This is an important component of any thermal system; such as condenser in a thermal power plant, evaporate and condensers in refrigerator, radiator of a motorcar etc. The heat transfer process is dominated by convection in fluid – solid boundaries and conduction through the separating wall. The size and weight are the important aspects in the design of the heat exchangers. The important performances parameter is the overall heat transfer co-efficient which determines the heat transfer rate in the equipment.

One of the important classifications of the heat exchangers is based on the direction of the flow of hot and cold fluids. In the parallel flow heat exchangers, both hot and cold fluids flow in the same direction, whereas in the counter flow type, fluid flow in opposite direction.

This equipment has been designed to determine the overall heat transfer coefficient in parallel and counter flow heat exchangers.

The outer tube is well insulated to prevent the heat loss to the atmosphere valve system to control water flow rate and direction of flow in the annular area (in copper tube) for parallel and counter flow. Inner diameter of copper tube is 22 mm and outer diameter is 25.5 mm, inner diameter of ss tube is 36 mm and outer diameter is 39 mm. length of the tubes id 1100 mm.

OPERATIONAL PROCEDURE:

- a) Allow water to circulate in the inner copper tube by opening flow controller valve, monitor the flow rate.

- b) Operate the valve system to make water flow either in parallel or counter flow direction.

Use drain valve to remove water, if any condensed in outer shell.

d) Switch ON the temperature indicator and allow for the temperature becomes Steady. Switch ON the channel selector to the required thermocouple and observe Temperature variations with time.

e) After steady state is reached, note the temperatures T1 – cold water inlet, T2 – cold water outlet, T3 – hot water inlet, T4 - hot water outlet.

f) After the experiments is completed, switch OFF the heater, stop water circulation and drain the water collected in the pipe.

g) calculate the heat transfer coefficient using the procedure given below.

Tabular Column:

Sl. No	Mass flow rate of water, Kg/s		Mode of operation	T _{hi} (°C)	T _{ho} (°C)	T _{ci} (°C)	T _{co} (°C)	effectiveness
	Hot water (m _h)	Cold water (m _c)						
			Parallel flow					
			Counter flow					

Calculations for experimental value of effectiveness of parallel flow and counter flow heat exchanger

$$Q_h = m_h \times C_{ph} (T_{h,i} - T_{h,o}) \quad C_h = m_h \times C_{ph} \quad \text{if } C_h < C_c \quad \epsilon = [(T_{h,i} - T_{h,o}) / (T_{h,i} - T_{c,i})]$$

$$Q_c = m_c \times C_{pc} (T_{c,o} - T_{c,i}) \quad C_c = m_c \times C_{pc} \quad \text{if } C_c < C_h \quad \epsilon = [(T_{c,o} - T_{c,i}) / (T_{h,i} - T_{c,i})]$$

$$C_{pc} = 4200 \text{ kJ/kgK} \quad h_w = \text{head of water in mts}$$

Theoretical effectiveness calculations:

Heat transfer in the double pipe arrangement, see fig is given by relationships

$$Q = (Q_h + Q_c)/2$$

$$Q = UA \Delta T_m \text{ where,}$$

Q=heat transfer rate, watts

U=overall heat transfer co efficient

A=surface area of heat transfer ,m²

D=diameter of the inner tube, m

L=effective length of heat exchanger, m

ΔT_{lm} =logarithmic mean temperature

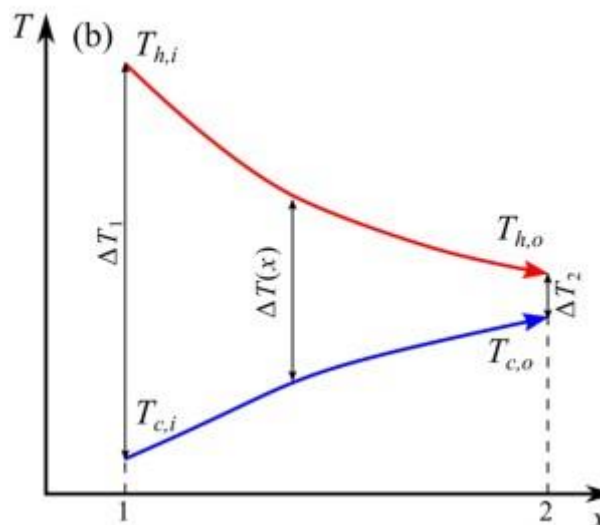


Fig: Temperature V/S Length diagram of Parallel flow heat exchanger

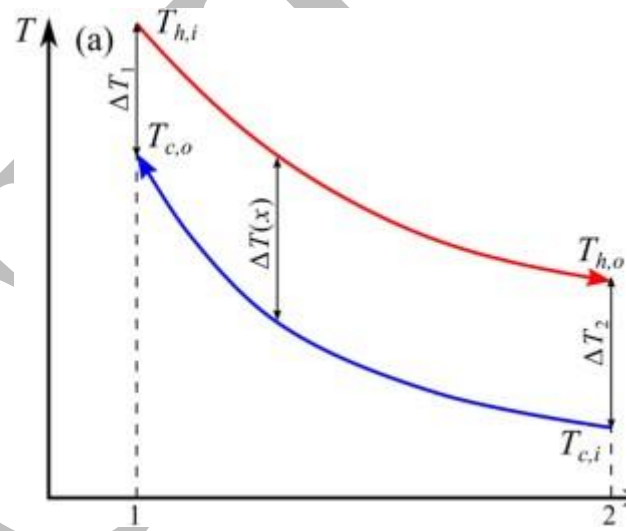


Fig: Temperature V/S Length diagram of Counter flow heat exchanger

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)}$$

$$\Delta T_1 = (T_{h,i} - T_{c,i}), \Delta T_2 = (T_{h,o} - T_{c,o}), \text{ for Parallel flow heat exchanger}$$

$$\Delta T_1 = (T_{h,i} - T_{c,o}), \Delta T_2 = (T_{h,o} - T_{c,i}), \text{ for Counter flow heat exchanger}$$

$T_{h,i}$ = Inlet temperature of hot water in °C

$T_{h,o}$ = Outlet temperature of hot water in °C

$T_{c,i}$ = Inlet temperature of cold water in °C

$T_{c,o}$ = Outlet temperature of cold water in °C

$U = q / (A \times \Delta T_{lm})$, $Ch = m_h \times C_{ph}$, $Cc = m_c \times C_{pc}$, Compare the values of Ch and Cc which ever value is minimum that value is considered as C_{min} other value is C_{max}

$$NTU = [U \times A] / C_{min}; C = C_{min} / C_{max}$$

Theoretical effectiveness for **Parallel flow** heat exchanger

$$\epsilon_{th} = [1 - e^{-NTU(1+C)}] / (1+C)$$

Theoretical effectiveness for **Counter flow** heat exchanger

$$\epsilon_{th} = [1 - e^{-NTU(1-C)}] / [1 - C e^{-NTU(1-C)}]$$

Results:

Experimental effectiveness for **Parallel flow** heat exchanger

Experimental effectiveness for **Counter flow** heat exchanger

Theoretical effectiveness for **Parallel flow** heat exchanger

Theoretical effectiveness for **Counter flow** heat exchanger

SYNOPSIS

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