SRM VALLIAMMAI ENGINEERING COLLEGE

(An Autonomous Institution)

SRM Nagar, Kattankulathur-603 203.

DEPARTMENT OF MECHANICAL ENGINEERING

1909611 – HEAT TRANSFER LABORATORY

MANUAL

REGULATION: 2019

ACADEMIC YEAR: 2024 - 2025

Name : ………………………………………

Reg. No. : ………………………………………

Branch : ………………………………………

Year & Sem. : ……………………………………....

SAFETY REGULATIONS

Users of Thermal Engineering Lab must comply with the following safety instructions.

1. Wear always pants and safety shoes when you operate any engine. Sandals are not allowed at all.

2. There should be no over-crowding.

3. Make sure that you stay away from hot exhaust lines and moving parts of engines

4. Before operating any machine, you must be aware of the following

a. Location of fire extinguishers and the outside exits.

b. How the engine operates. Read instruction or manual before operating it.

c. How to turn off the engine in case of damages.

5. When you hear or see a danger alarm from the engine that you using, stop the engine immediately.

6. Make sure that there is no fuel or oil spill on the floor.

7. Consult the instructor for safety precautions to be followed.

8. Do not run inside the lab and concentrate on the present task.

9. When moving heavy equipments or gas cylinders, use carts

10 Always use the right tools for the given task.

11. Handle the tools and equipments with extreme care and return the tools to their proper places (Tool Cabinets).

12 For cleaning tools or equipments, use only the proper cleaner. Never use fuels such as gasoline or diesel for cleaning.

13. Handle fuels with extreme caution.

  a. Use the designated area for this purpose.

  b. Use the proper containers (safety cans) to carry fuels.

  c. Make sure there is no electric spark present.

  d. Do not leave fuels in open containers.

14. Make sure that all gas cylinders are chained and well supported.

15. Before operating engine, make sure that there is no fuel or gas leakage

1909611	**HEAT TRANSFER LABORATORY**	**L T P C** 0 0 4 2

LIST OF EXPERIMENTS (60 PERIODS)

OBJECTIVES:

The main learning objective of this course is to prepare the students:

1. To study the heat transfer phenomena to predict the relevant coefficient using implementation
2. To expose the mechanisms of free and forced convection
3. To demonstrate the phase change heat transfer and calculate the performance of heat exchanging devices
4. To explain diffusion and convective mass transfer
5. To study the performance of refrigeration cycle / components

HEAT TRANSFER LAB **45**

1. Thermal conductivity measurement using guarded plate apparatus.
2. Thermal conductivity measurement of pipe insulation using lagged pipe apparatus.
3. Determination of heat transfer coefficient under natural convection from a vertical cylinder.
4. Determination of heat transfer coefficient under forced convection from a tube.
5. Determination of Thermal conductivity of composite wall.
6. Determination of Thermal conductivity of insulating powder.
7. Heat transfer from pin-fin apparatus (forced convection modes)
8. Determination of Stefan – Boltzmann constant.
9. Determination of emissivity of a grey surface.
10. Effectiveness of Parallel / counter flow heat exchanger.

REFRIGERATION AND AIR CONDITIONING LAB **12**

11. Determination of COP of a refrigeration system
12. Experiments on Psychometric processes
13. Performance test on a reciprocating air compressor
14. Performance test in a fluidized Bed Cooling Tower

COMPUTERIZED HEAT TRANSFER LAB **03**

15. Experimental analysis of Thermal conductivity for various cross section of Iron Rod using LAB VIEW software.

TOTAL: 60 PERIODS

1909611 – HEAT TRANSFER LABORATORY

(For a batch of 30 students)

SL.No.	LIST OF EQUIPMENTS	QUANTITY
1	Guarded plate apparatus	1 No.
2	Lagged pipe apparatus	1 No.
3	Natural convection-vertical cylinder apparatus	1 No.
4	Forced convection inside tube apparatus	1 No.
5	Composite wall apparatus	1 No.
6	Thermal conductivity of insulating powder apparatus	1 No.
7	Pin-fin apparatus	1 No.
8	Stefan-Boltzmann apparatus	1 No.
9	Emissivity measurement apparatus	1 No.
10	Parallel/counter flow heat exchanger apparatus	1 No.
11	Single/two stage reciprocating air compressor	1 No.
12	Fluidized bed cooling tower apparatus	1 No.
13	Refrigeration test rig	1 No.
14	Air-conditioning test rig	1 No.
15	Thermal Conduction System	1 No.

COURSE OUTCOMES:

Upon the completion of this course the students will be able to,

1. Conduct tests on heat conduction apparatus and evaluate thermal conductivity of materials.
2. Identify the correlation to find the heat transfer rate in free and forced convection.
3. Analyze the performance of parallel/counter flow heat exchanger apparatus and reciprocating air compressor.
4. Integrate the concepts of radiative heat transfer apparatus and evaluate Stefan Boltzmann constant and emissivity.
5. Conduct tests to evaluate the performance of refrigeration and air conditioning test rigs.

CO	**PO**												**PSO**			
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**	**4**
1	**3**	**3**		**3**		**2**	**2**	**1**					**3**	**3**		
2	**3**	**3**		**3**		**2**	**2**	**1**					**3**	**3**		
3	**3**	**3**		**3**		**2**	**2**	**1**					**3**	**3**		
4	**3**	**3**		**3**		**2**	**2**	**1**					**3**	**3**		
5	**3**	**3**		**3**		**2**	**2**	**1**					**3**	**3**		

1909611 – HEAT TRANSFER LABORATORY

CYCLE OF EXPERIMENTS

CYCLE - I

HEAT TRANSFER **45**

1. Thermal conductivity measurement using guarded plate apparatus.
2. Thermal conductivity measurement of pipe insulation using lagged pipe apparatus.
3. Determination of heat transfer coefficient under natural convection from a vertical cylinder.
4. Determination of heat transfer coefficient under forced convection from a tube.
5. Determination of Thermal conductivity of composite wall.
6. Determination of Thermal conductivity of insulating powder.
7. Heat transfer from pin-fin apparatus (forced convection modes)
8. Determination of Stefan – Boltzmann constant.

CYCLE - II

9. Determination of emissivity of a grey surface.
10. Effectiveness of Parallel / counter flow heat exchanger.

REFRIGERATION AND AIR CONDITIONING LAB **12**

11. Determination of COP of a refrigeration system.
12. Experiments on Psychometric processes.
13. Performance test on a reciprocating air compressor.
14. Performance test in a fluidized Bed Cooling Tower.

COMPUTERIZED HEAT TRANSFER LAB **03**

15. Experimental analysis of Thermal conductivity for various cross section of Iron Rod using LAB VIEW software.

ADDITIONAL EXPERIMENTS

1. Find the overall heat transfer co-efficient and effectiveness on Alto-800 radiator.
2. Find the overall heat transfer co-efficient and effectiveness on spiral tube heat exchanger.

EXP. NO.:
DATE:

THERMAL CONDUCTIVITY MEASUREMENT USING GUARDED PLATE APPARATUS.

Aim:

To find the thermal conductivity of the specimen by two slabs guarded hot plate method.

Specification:

1). Central Heater - suitable capacity, with 100 mm dia. sandwiched between two copper plates.
2). Ring Guard Heater - of suitable capacity, with 37mm width sandwiched between two copper plates.
3). Cooling chamber with water circulation arrangement.
4). Specimens 6 to 20 mm thick and 180 dia.
5). Glass wool bag insulation around the set-up.
6). A Control Panel comprising of -
   a) Voltmeter - 100/200 v
   b) Ammeter - 0 - 2 A
   c) Dimmerstats for central & guard heater 0-240 V 2 A - one
   d) Digital Temperature indicator 0-2000c with 0.10C least count using chromel - alumel thermocouples, provided with cold junction compensation

Procedure:

1. Connect the power supply to the unit**.** Turn the regulator knob clockwise and the power to the main heater to any desired value.
2. Adjust the regulator for guard heater so that the main heater temperature is less than or equal to the guard heater temperature.
3. Allow water through the cold plate at a steady rate. Note the temperatures at different locations when the unit reaches steady state. The steady state is defined as; **the temperature gradient across the plate remains same at different time intervals.**
4. For different power inputs in **Ascending order only** the experiment may by repeated and readings are tabulated as below.
5. The guard heater enables the heat flow in uni- direction.
   Thermocouples 1 & 2 are connected to the heater.

   Thermocouples 3 & 4 are connected to the interface of specimen and cold plate.

Thermocouples 5 & 6 are connected to the Guard heater.

Thermocouples 7 & 8 are for measuring the inlet and outlet water temperature.

Calculation:

1. Power Input

$$Q = \frac{(V \, X \, A)}{2} \text{ watts (since the heat flows on either side of the heater)}$$

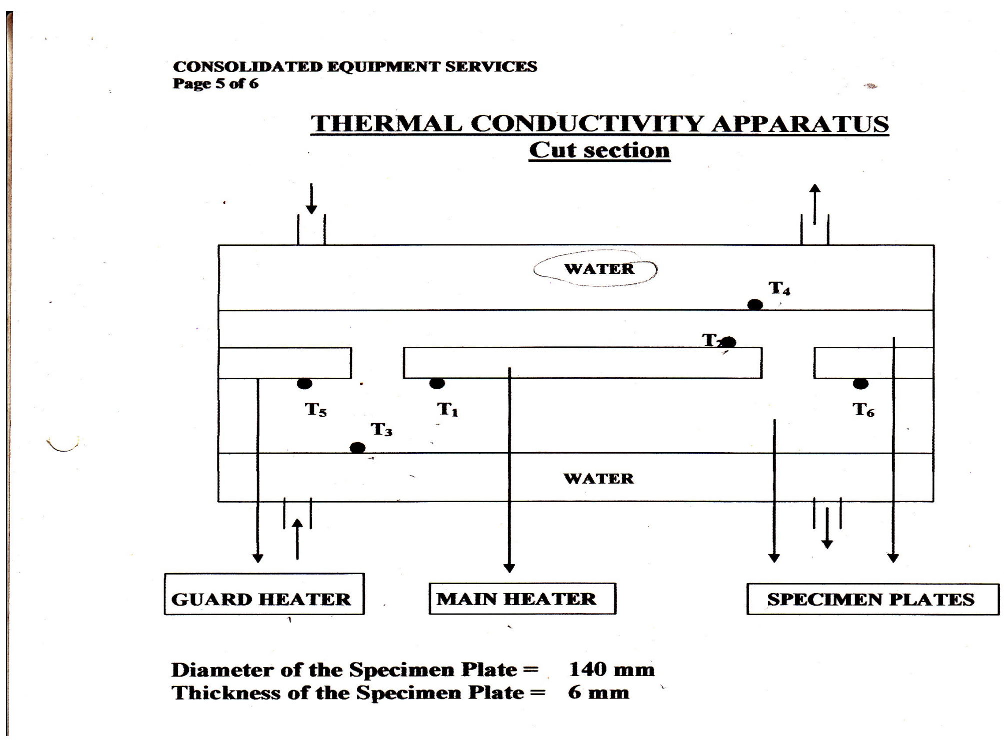
Where K = Thermal conductivity of the specimen.

2. $dT = \frac{T_1+T_2+T_3+T_4}{4} - \frac{T_5+T_6}{2}$
3. $Q = K\,A\frac{dT}{dX}$

Where D - Diameter of the Specimen Plate = 140 mm

X - Thickness of the Specimen Plate = 6 mm

A - The effective heat transfer area = 0.0143 m.



Tabulation:

Sl. No.	**Volts V**	**Amps A**	**T_1** °C	**T_2** °C	**T_3** °C	**T_4** °C	**T_5** °C	**T_6** °C	**T_7** °C	**T_8** °C

Result:

Thermal conductivity of the given specimen =

VIVA QUESTIONS & ANSWERS

1. Fourier's Law is based on assumption that ________

Ans: Heat transfer in steady state

2. Heat conducted through unit area and unit thick face per unit time when temperature difference between opposite faces is unity is called _________

Ans: Thermal conductivity

3. Give the 3 basic expressions governing the 3 modes of heat transfer.

1) Fourier Law of conduction $Q = -KA\frac{dT}{dx}$ dT

where A – Area in m^2

$\frac{dT}{dx} - \textit{temperature gradient in } K/m$

K – Therma conductivity W/mK

2. Newton's Law of cooling

$Q = hA(T_s - T_\infty)$, Where H – heat transfer co – eff in W/m^2K, A – Surface Area in m^2

T_s – Surface Temperature in K

T_∞ - Fluid Temperature in K

3. Stefan – Boltzman Law

$E_b = \sigma T^4$, Where σ - Stefan Boltzman constant = 5.669×10^{-8} $w/m^2 k^4$, T – Temperature in K

4. Given two examples of heat transfer with internal heat generation.

1. Chemical Reaction, 2. Nuclear Reaction & 3. Combustion Reaction.

5. State Fourier's Law of conduction.

The rate of heat conduction is proportional to the area measured – normal to the direction of heat flow and to the temperature gradient in that direction.

$$Q = -KA\frac{dT}{dx}$$

where A – are in m2 dT dx - Temperature gradient in K/m K – Thermal conductivity W/mK.

6. What is conduction?

Heat conduction is a mechanism of heat transfer from a region of high temperature to a region of low temperature within a medium (Solid, Liquid and Gases) or different medium in direct physical contact.

7. Write down the three dimensional heat conduction equation in Cartesian co ordinate system?.

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} + \frac{q^{\cdot}}{k} = \frac{1}{\propto}\frac{\partial T}{\partial x}$$

Where $q^{\cdot}$ – Heat generator – W/m^2 & α – Thermal Diffusivity – m^2 /s

8. What is mean by steady state heat conduction?

If the temperature of a body does not vary with time, it is said to be in a steady state and that type of conduction is known as steady state heat conduction.

9. What is periodic heat flow?

In periodic heat flow temperature varies on a regular basis.

Ex.: Cylinder of an IC Engine

10. What is non periodic heat flow?

In non periodic heat flow, the temperature at any point within the system varies non linearly with time.

Ex.: Cooling of bars.

EXP.NO:

DATE:

THERMAL CONDUCTIVITY MEASUREMENT OF PIPE INSULATION USING LAGGED PIPE APPARATUS.

Aim:
To determine the thermal conductivity of the given insulating material by using Lagged pipe apparatus.

Apparatus Required:
1. Ammeter. 2. Voltmeter. 3. Thermocouple and 4. Temperature Indicator.

Specifications:
1. Heater diameter (d_1) = 20 mm.
2. Heater with asbestos diameter (d_2) = 40 mm.
3. Asbestos & Saw dust diameter (d_3) = 80 mm.
4. Length = 500 mm.

Procedure:
1. Switch on the unit and check if all channels of temperature indicator showing proper temperature.
2. Switch on the heater using the regulator and keep the power input at some particular value.
3. Allow the unit to stabilize for about 20 to 30 minutes.
4. Now note down the ammeter, voltmeter reading which gives the heat input.
5. Temperatures 1,2 and 3 are the temperatures of heater rod, 4,5 and 6 are the temperatures on the asbestos layer. 7 and 8 are temperatures on the saw dust lagging. The average temperature of each cylinder is taken for calculation.
6. The temperatures are measured by thermocouple (Fe/Ko) with multipoint digital temperature indicator.
7. The experiment may be repeated for different heat inputs.

Formulae Used:

1. **Heat Transfer rate, (Q) = (V X A) watts**

2. **Thermal Conductivity of Asbestos.**

$$Q = \frac{K_1 2\,\pi\, L\,(\Delta T)}{\ln\left(\frac{r_2}{r_1}\right)}$$

Where ΔT - Temperature across the lagging.

K_1 - Thermal conductivity of asbestos lagging material.

L - Length of the cylinder.

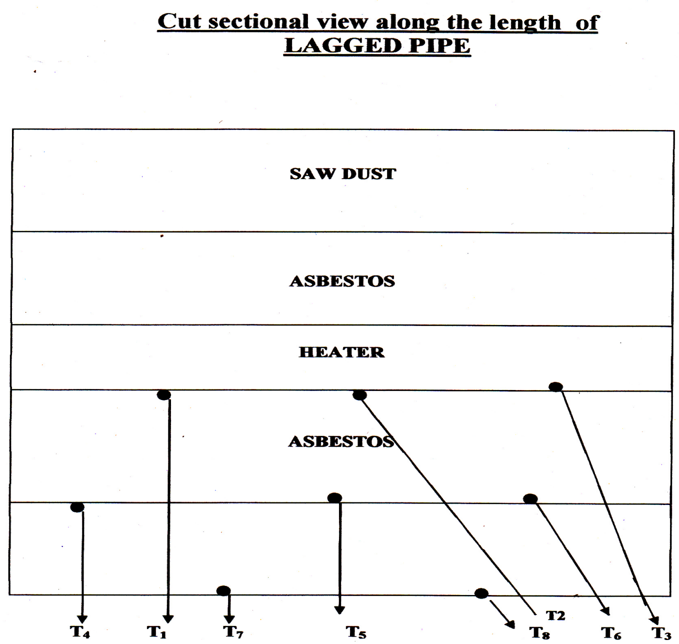
3. Thermal Conductivity of Sawdust

$$Q = \frac{K_2 2\,\pi\, L\,(\Delta T)}{ln\,(\frac{r_2}{r_1})}$$

Where ΔT - Temperature across the lagging.

K_2 - Thermal conductivity Sawdust.

L - Length of the cylinder.



d_1 - heater diameter = 20 mm

d_2 - heater with asbestos diameter = 40 mm

d_3 - asbestos & saw dust diameter = 80 mm

Length = 500 mm

TABLE:

Sl. No.	Volts	Current	Heater Temperature				Asbestos Temperature				Sawdust Temperature		
			T_1 °C	T_2 °C	T_3 °C	Avg. temp. °C	T_4 °C	T_5 °C	T_6 °C	Avg. Temp. °C	T_7 °C	T_8 °C	Avg. Temp. °C

Result:

1. Thermal conductivity of the given Asbestos material =
2. Thermal conductivity of the given Saw dust material =

VIVA QUESTIONS & ANSWERS

1. Define Thermal Conductivity.

Thermal conductivity is defined as the ability of a substance to conduct heat.

2. Define fins (or) extended surfaces.

It is possible to increase the heat transfer rate by increasing the surface of heat transfer. The surfaces used for increasing heat transfer are called extended surfaces or sometimes known as fins.

3. What is heat generation in solids? Give examples.

The rate of energy generation per unit volume is known as internal heat generation. Ex.: Electric coils, 2. Resistance heater and 3. Nuclear reactor.

4. Define Heat transfer?

Heat transfer can be defined as the transmission of energy from one region to another region to temperature difference.

5. What are the modes of heat transfer?

1. Conduction 2. Convection 3. Radiation

6. What is meant by newtonian heating or cooling process.

The process in which the internal resistance is assumed as negligible in comparison with its surface resistance is known as Newtonian heating or cooling process.

7. What is meant by lumped heat analysis??

In a Newtonian heating or cooling process the temperature throughout the solid is considered to be uniform at a given time. Such an analysis is called Lumped heat capacity analysis.

8. What are the factors affecting the thermal conductivity?

Moisture, Density of material, Pressure, Temperature and Structure of material.

9. Explain the significance of thermal diffusivity

The physical significance of thermal diffusivity is that it tells us how fast heat is propagated or it diffuses through a material during changes of temperature with time.

10. Explain the significance of Fourier number.

It signifies the degree of penetration of heating or cooling effect of a solid.

EXP. NO:
DATE :

DETERMINATION OF HEAT TRANSFER COEFFICIENT UNDER NATURAL CONVECTION FROM A VERTICAL CYLINDER.

Aim:

To determine the actual heat transfer coefficient and theoretical heat transfer coefficient by natural convection method

Apparatus Required:

1. Ammeter. 2. Voltmeter. 3. Thermocouple, 4. Heater and 5. Temperature Indicator.

Specifications:

1. Length of the rod (L) = 0.50 m.
2. Diameter of the rod (D) = 40 mm.
3. Area of the rod A = πDL m^2

Procedure:

1. Connect the three pin plug to the 230 V, 50 Hz, 15 ams main supply and switch on the unit.
2. Turn the regulator knob clockwise, set the heat input by fixing the voltmeter and ammeter readings.
3. Keep the temperature indicator switch in the first position.
4. Allow the unit to attain the steady state condition.
5. When the steady state condition is reached note down the temperature indicated by the temperature indicator.
6. In the temperature indicator T_2, T_3, T_4, & T_5 represents the temperature of the heater at different points. T_1 represent the inlet temperature of the air and T_6 represents the outlet temperature of the air. These values are noted in the table.
7. Calculate the theoretical het transfer coefficient ($h_{theoretical}$) and actual heat transfer coefficient (h_{actual}) by using the given formulas.
8. Repeat the experiment from step 2 to step 7 by varying the heat input to the system.

Calculations:

A. Theoretical Heat Transfer Coefficient:

1. Grashoff Number.

$$Gr = \frac{g\beta l^3 \Delta T}{\gamma^2}$$

where

g - acceleration due to gravity, 9.81 m/s^2

β - Coefficient of Expansion, $\beta = \dfrac{1}{(T_f + 273)}$

$$T_f = \frac{T_w + T_a}{2}$$

where T_w - Surface temperature in °C

T_a - Air temperature in °C

$\Delta T = (T_w - T_a)$

γ - Kinematic viscosity at men film temperature (T_f) from HMT data book.

P_r - Prandtl Number.

2. **Use the following free convection correlations for vertical cylinders**

$N_u = \dfrac{h_{theo} \; X \; L}{K}$ $= 0.53 * (G_r P_r)^{1/4}$ for $G_r P_r < 10^5$

$N_u = \dfrac{h_{theo} \; X \; L}{K}$ $= 0.56 * (G_r P_r)^{1/4}$ for $10^5 < G_r P_r < 10^8$

$N_u = \dfrac{h_{theo} \; X \; L}{K}$ $= 0.13 * (G_r P_r)^{1/3}$ for $10^8 < G_r P_r < 10^5$

Where Nu - Nusselt Number.

h - Theoretical Heat transfer coefficient in W/m^{2}K

K - Thermal conductivity of air in W/m K

3. Theoretical Heat Transfer coefficient.

$$h_{theo} = \frac{N_u \; X \; K}{L}$$

B. Actual Heat Transfer Coefficient:

1. Heat Input:

$Q = V \; X \; A = h_{act} \; x \; A \; x \; \Delta T$ in watts

Where Q - Heat Transfer rate in watts

h_{act} - Actual Heat Transfer coefficient in W/m^{2}K

A - Surface area of the Heater = πDL.

$\Delta T = (T_w - T_s)$, $T_w = \frac{T_2 + T_3 + T_4 + T_5}{4}$,

$T_a = \frac{T_1 + T_6}{2}$

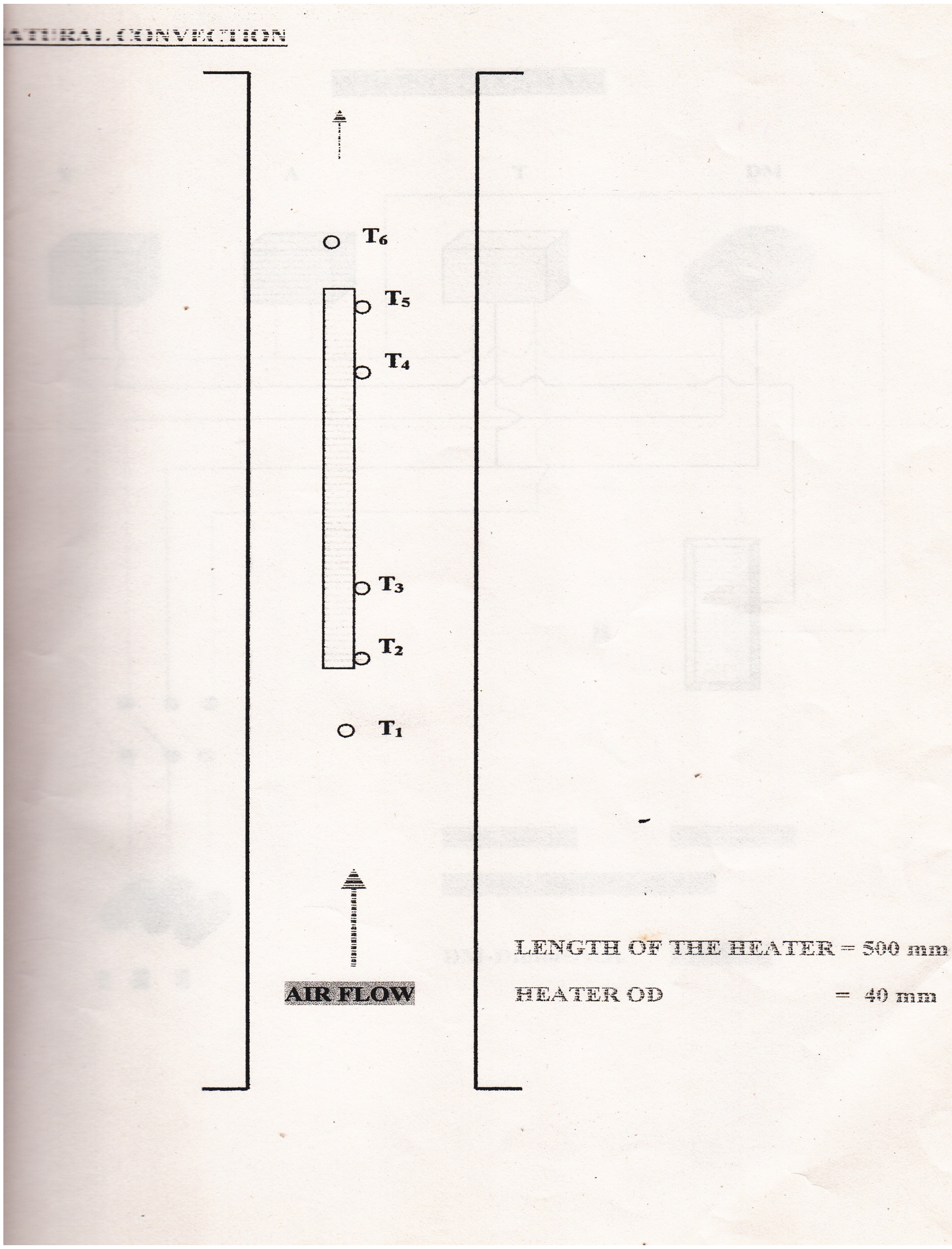


Table:

Sl. No.	Voltmeter Reading	Ammeter reading	Temperature along the heated cylinder					
	V in volts	A in amps	T_1 °C	T_2 °C	T_3 °C	T_4 °C	T_5 °C	T_6 °C

Result:

The theoretical and actual heat transfer coefficient have been calculated by using natural convection method.

1. Theoretical heat transfer coefficient = _____________.
2. Actual heat transfer coefficient = ____________.

VIVA QUESTIONS AND ANSWERS

1. Name the law which governs convection heat transfer

Ans: Newton's law of cooling

2. Define overall heat transfer co-efficient.

The overall heat transfer by combined modes is usually expressed in terms of an overall conductance or overall heat transfer co-efficient 'U'. TΔHeat transfer Q = UA

3. Define convection.

Convection is a process of heat transfer that will occur between a solid surface and a fluid medium when they are at different temperatures.

4. Define Reynolds number (Re)

It is defined as the ratio of inertia force to viscous force. (R_e = Inertia force / Viscous force)

5. Define Prandtl number (Pr).

Prandtl number is the ratio of the momentum diffusivity of the thermal diffusivity. (P_r = Momentum diffusivity / Thermal diffusivity)

6. What is meant by Newtonian and non – Newtonian fluids?

The fluids which obey the Newton's Law of viscosity are called Newtonian fluids and those which do not obey are called non – Newtonian fluids.

7. Define Nusselt Number (Nu).

It is defined as heat flow by convection process under an unit temperature gradient to the heat flow rate by conduction under an unit temperature gradient through a stationary thickness (L) of metre.

8. State Newton's law of Convection.

Heat transfer from the moving fluid to solid surface is given by the equation $Q = hA(T_w - T_\alpha)$

Where h – Local heat transfer coefficient in W/m^2 K, A – Surface area in m^2, T_w – Wall temp. in K and T_α – Temp. of fluid in K.

9. Define Momentum thickness?

It is defined as the distance through which the total loss of momentum per second be equal to if it were passing a stationary plate.

10. Define Energy thickness.

The energy thickness can be defined as the distance measured perpendicular to the boundary of the solid body, by which the boundary should be displaced to compensate for the reduction in KE of the flowing fluid on account of boundary layer formation.

EXP. NO.:
DATE:

DETERMINATION OF HEAT TRANSFER COEFFICIENT UNDER FORCED CONVECTION FROM A TUBE.

Aim:

To determine the actual heat transfer coefficient and theoretical heat transfer coefficient by Forced convection method.

Apparatus Required:

1. Ammeter. 2. Voltmeter. 3. Thermocouple, 4. Temperature Indicator, 5. Blower and 6. Manimeter.

Specification:

Diameter of the pipe (d_1) = 40 mm

Diameter of orifice (d_2) = 20 mm

Length of test section (L) = 500 mm

Precautions:

1. Keep the dimmer stat at zero position before starting.
2. Increase the voltage and current slowly and do not exceed 100 V & 2 Amps
3. Keep the assembly run disturbed during resting.
4. Do not stop blower in between testing period.

Procedure:

1. Connect the three pin plug to the 230 V, 50 Hz, 15 ams main supply and switch on the unit.
2. Turn the regulator knob clockwise, set the heat input by fixing the voltmeter and ammeter readings.
3. Switch on the blower. Adjust the position of the valve to any desired flow rate of air.
4. Keep the temperature indicator switch in the first position and Allow the unit to attain the steady state condition.
5. When the steady state condition is reached note down the temperature indicated by the temperature indicator.
6. In the temperature indicator T_2, T_3, T_4, & T_5 represents the temperature of the heater at different points. T_1 represent the inlet temperature of the air and T_6 represents the outlet temperature of the air. These values are noted in the table.

7. Note Manometer reading h_1 and h_2.
8. Calculate the theoretical het transfer coefficient ($h_{theoretical}$) and actual heat transfer coefficient (h_{actual}) by using the given formulas.
9. Repeat the experiment from step 2 to step 7 by varying the heat input to the system.

Formulas:

A. Theoretical Heat Transfer Coefficient:

1. Head of air.

$$h_0 = (h_1 - h_2)\left(\frac{\rho_w}{\rho_a} - 1\right), \quad \text{in m}$$

where

h_1 & h_2 = Manometer readings in m

ρ_w - Density of water, 1000 Kg/m^3

ρ_a - Density of air, 1.16 Kg/m^3

2. Volume Flow of air.

$$Q_v = \frac{C_d\, a_1 a_2 \sqrt{2gh_0}}{\sqrt{{a_1}^2 - {a_2}^2}} \quad \text{in m}^3\text{/sec}$$

where C_d - Coefficient of discharge (0.6).

a_1 - Area of the pipe in m^2

a_2 - Area of the orifice in m^2

3. Velocity of air.

$$V = \frac{Q_v}{A} \quad \text{in m/s}$$

4. Reynolds Number.

$$R_e = \frac{V d_1}{\gamma}$$

where γ - Kinematic viscosity at $T_f = \frac{T_S + T_a}{2}$ (from HMT data book.) in m^2/sec.

5. Nusselt Number.

$$N_u = 0.023 * \left({R_e}^{0.8}\right)\left({P_r}^{0.4}\right)$$

where P_r - Prandtl Number at $T_f = \frac{T_w + T_a}{2}$ (from HMT data book.) in m^2/sec.

6. Theoretical Heat Transfer coefficient.

$$N_u = \frac{h_{theo} \times L}{K}$$

B. <u>Actual Heat Transfer Coefficient:</u>

1. Heat Input:

$Q = V \text{ X } A = h_{act} \text{ x } A \text{ x } \Delta T$ in watts

where $Q = V \text{ x } A$ (Heat Transfer rate) in watts

h_{act} - Actual Heat Transfer coefficient in W/m^2K

A - Surface area of the Heater = πDL.

$\Delta T = (T_W - T_S)$

$$T_w = \frac{T_2 + T_3 + T_4 + T_5}{4}$$

where T_w - Wall temperature in °C

$$T_a = \frac{T_1 + T_6}{2}$$

where T_a - Air temperature in °C

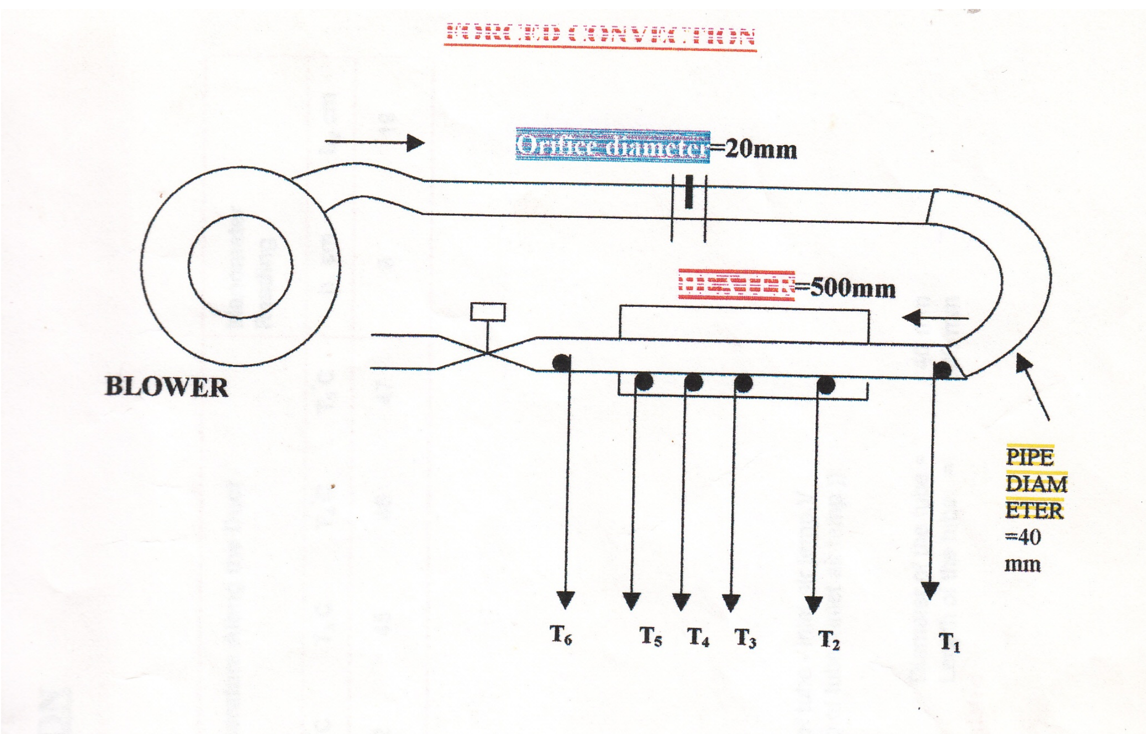


Table:

Sl. No.	Voltage	Current	Inlet	Temperature along	Inlet	Manometer

			temperature of air	the duct				temperature of air	Readings	
	V in volts	A in amps	T_1 in °C	T_2 °C	T_3 °C	T_4 °C	T_5 °C	T_6 °C	h_1 cm	h_2 cm

Result :

The theoretical and actual heat transfer coefficient have been calculated by using Forced convection method.

1. Theoretical heat transfer coefficient = ____________.
2. Actual heat transfer coefficient = ____________.

VIVA QUESTIONS AND ANSWERS

1. What is meant by laminar flow?

Laminar flow: Laminar flow is sometimes called stream line flow. In this type of flow, the fluid moves in layers and each fluid particle follows a smooth continuous path. The fluid particles in each layer remain in an orderly sequence without mixing with each other.

2. What is meant by turbulent flow?

Turbulent flow: In addition to the laminar type of flow, a distinct irregular flow is frequency observed in nature. This type of flow is called turbulent flow. The path of any individual particle is zig – zag and irregular. Fig. shows the instantaneous velocity in laminar and turbulent flow.

3. What is meant by free or natural convection?

If the fluid motion is produced due to change in density resulting from temperature gradients, the mode of heat transfer is said to be free or natural convection.

4. What is meant by forced convection?

If the fluid motion is artificially created by means of an external force like a blower or fan, that type of heat transfer is known as forced convection.

5. Define boundary layer thickness.

The thickness of the boundary layer has been defined as the distance from the surface at which the local velocity or temperature reaches 99% of the external velocity or temperature.

6. What are Heisler charts?

In Heisler chart, the solutions for temperature distributions and heat flows in plane walls, long cylinders and spheres with finite internal and surface resistance are presented. Heisler charts are nothing but a analytical solutions in the form of graphs

7. What is hydro dynamics boundary layer?

In hydrodynamics boundary layer, velocity of the fluid is less than 99% of free stream velocity.

8. In which mode of heat transfer, the convection heat transfer coefficient usually higher, natural or forced convection? Why?.

Convection heat transfer coefficient is higher in forced convection than in natural convection, because it mainly depends upon the factors such as fluid density, velocity and viscosity.

9. Define bulk temperature.

Bulk temp. is nothing but a average temperature of the fluid at any cross section of flow.

10. State Buckingham π theorm.

If there are n variables in a dimensionally homogeneous equation and if these contain m fundamental dimensions, then the variables are arranged into (n – m) dimensionless terms. These dimensionless terms are called π terms.

EXP. NO.:
DATE:

DETERMINATION OF THERMAL CONDUCTIVITY OF COMPOSITE WALL.

Aim:

To determine Thermal conductivity of the given composite wall.

Apparatus required:

1. Ammeter (0 - 5 Amps), 2. Voltmeter (0 - 200 V), 3. Heater, 4. Thermocouple and Temperature Indicator (0 - 1200)°C and 5. Composite Wall set up.

Specifications:

1. Heater -- Nichrome (300 Watt)
2. Diameter of the plate (d) ---
3. Total thickness of the composite slab (dx) ---

Procedure:

1. Connect the three pin plug to a 230V, 50Hz, 15A power and switch on the unit.
2. Keep the thermocouple selector switch in first position.
3. Turn the regulator knob to clockwise and set the power to the heater to any desired value by looking at the voltmeter and ammeter.
4. Allow the unit to stabilize.
5. Take the readings of all thermocouples at an interval of 10 minutes until fairly steady state temperatures are achieved and the rate of rise is negligible.
6. Varying the power input to the heater and repeat the above steps.
7. After all the experiment is over, put off the blower switch, turn the energy Regulator knob anti clockwise, put OFF the main switch and disconnect the power supply.

Formula used:

1. Heat Input (Q):

$$Q = V * I \quad in\ Watts$$

2. Heat Flux (q):

$$q = \frac{Q}{A} \quad in\ \frac{W}{m^2}$$

where $A = \pi/4 * d^2$ (Area of the composite plate)

3. According to Fourier law of heat conduction

$$Q = -K * A * \frac{dT}{dx} \quad in\ Watts$$

from the above, for Composite wall,

$$K = \frac{Q * dx}{A * dT} \quad in\ \frac{W}{m\ K}$$

where K - Thermal conductivity of composite wall.

dx - Total thickness of the composite slab = 37 mm

$dT = (T_a - T_d)\ in\ K$

where T_a - Average temperature of starting side $T_a = \frac{T_1 + T_2}{2}$

T_d - Average temperature of ending side $T_d = \frac{T_7 + T_8}{2}$

Table:

Sl. No.	Voltmeter reading (Volts)	Ammeter reading (Amps)	Heater Plate Temperature (°C)		MS Plate Temperature (°C)		Fibre Plate Temperature (°C)		Wooden Plate Temperature (°C)	
			T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8

Result :

Thermal conductivity of the given Composite wall ___________________.

VIVA QUESTIONS AND ANSWERS

1. What is thermal boundary layer?

In thermal boundary layer, temperature of the fluid is less than 99% of free stream temperature.

2. What are the dimensional parameters used in forced convection?

1. Reynolds number (Re) 2. Nusselt Number (Nu) 3. Prandtl number (Pr)

3. Indicate the concept of significance of boundary layer.

In the boundary layer concept the flow field over a body is divided into two regions: A thin region near the body called the boundary layer where the velocity and the temperature• gradients are large. The region outside the boundary layer where the velocity and the temperature gradients are very• nearly equal to their free stream values.

4. Define displacement thickness.

The displacement thickness is the distance, measured perpendicular to the boundary, by which the free stream is displaced on account of formation of boundary layer.

5. Write down equation for conduction of heat through hollow sphere.

Heat Transfer $Q = \Delta T_{overall}/R$

Where $\Delta T - T_1 - T_2$ & $R = \frac{r_2 - r_1}{4\pi k(r_1 r_2)}$

6. Write down the steady state, two dimensional conduction equation without heat generation.

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = 0$$

7. Write down the general equation for one dimensional steady state heat transfer in slab or plane wall without heat generation.

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = \frac{1}{\propto}\frac{\partial T}{\partial t}$$

8. Write down the general equation for one dimensional steady state heat transfer in slab with heat generation.

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} + \frac{q^{\cdot}}{k} = \frac{1}{\propto}\frac{\partial T}{\partial t}$$

9. Write down the equation for heat transfer through a composite plane wall.

Heat transfer $Q = \frac{\Delta T_{overall}}{R}$ & $R = \frac{1}{h_a A} + \frac{L_1}{K_1 A} + \frac{L_2}{K_2 A} + \frac{L_3}{K_3 A} + \frac{1}{h_b A}$

10. **Write down the equation for heat transfer through a composite pipes or cylinder.**

Heat transfer $Q = \frac{\Delta T_{overall}}{R}$ & $R = \frac{1}{2\pi L}\frac{1}{h_a}\frac{1}{r_1} + \frac{\ln\left(\frac{r_2}{r_1}\right)}{K_1} + \frac{\ln\left(\frac{r_3}{r_2}\right)}{K_2} + \frac{1}{h_b r_3}$

EXP. NO.:
DATE:

DETERMINATION OF THERMAL CONDUCTIVITY OF INSULATING POWDER

Aim:

To determine Thermal conductivity of the given Insulating powder.

Apparatus required:

1. Ammeter (0 - 5 Amps), 2. Voltmeter (0 - 200 V), 3. Heater, 4. Thermocouple and Temperature Indicator (0 - 1200)°C and 5. Insulating powder apparatus set up.

Specifications:

1. Heater (200 Watt)
2. Thermocouple - Chromel Alumel Thermocouples (8 Nos.)
3. Insulating Powder - Magnesium oxide.
4. Radius of the Inner Copper Sphere - r_i = 50 mm.
5. Radius of the Outer Copper Sphere - r_o = 100 mm.

Procedure:

1. Connect the three pin plug to a 230V, 50Hz, 15A power and switch on the unit.
2. Keep the thermocouple selector switch in first position.
3. Turn the regulator knob to clockwise and set the power to the heater to any desired value by looking at the voltmeter and ammeter. Adjust input equal to 40 Watts maxi. by Voltmeter and ammeter.
4. Allow the unit to stabilize.
5. Take the readings of all thermocouples at an interval of 10 minutes until fairly steady state temperatures are achieved and the rate of rise is negligible.
6. Varying the power input to the heater and repeat the above steps.
7. After all the experiment is over, put off the blower switch, turn the energy Regulator knob anti clockwise, put OFF the main switch and disconnect the power supply.

Formula used:

1. Heat Input (Q):

$$Q = V * I \quad in\ Watts$$

2. According to Fourier law of heat conduction through hollow sphere

$$Q = -K * A * \frac{dT}{dr}$$

from the above, for given sphere

$$K = \frac{Q\,[r_0 - r_i]}{4\pi r_0 r_i\,[T_i - T_0]} \quad in\ \frac{W}{m\,K}$$

where K - Thermal conductivity of the Insulating powder.

T_i - Average temperature of Inner Sphere, $T_i = \frac{[T_1 + T_2 + T_3 + T_4]}{4}$

T_o - Average temperature of Outer Sphere, $T_o = \frac{[T_5 + T_6 + T_7 + T_8]}{4}$

Table:

Sl. No.	Voltmeter reading (Volts)	Ammeter reading (Amps)	Temperature of Inner Sphere (°C)				Temperature of Outer Sphere (°C)			
			T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8

Result :

Thermal conductivity of the given Insulating Powder ____________________.

VIVA QUESTIONS AND ANSWERS

1. What is meant by semi-infinite solids?

In semi-infinite solids, at any instant of time ,there is always a point where the effect of heating or cooling at one of its boundaries is not felt at all .At this point the temperature remains unchanged .In semi infinite solids, the biot number values is ∞.

2. Write down the equation for conduction of heat through a slab or plane wall.

Heat transfer $Q = \frac{\Delta T_{overall}}{R}$ Where $\Delta T = T_1 - T_2$, $R = \frac{L}{KA}$ - Thermal resistance of slab

L = Thickness of slab, K = Thermal conductivity of slab, A = Area

3. Write down the equation for conduction of heat through a hollow cylinder.

Heat transfer $Q = \frac{\Delta T_{overall}}{R}$ Where, $\Delta T = T_1 - T_2$, $R = \frac{1}{2\pi LK}$ in $\left[\frac{r_2}{r_1}\right]$ thermal resistance of slab

L – Length of cylinder, K – Thermal conductivity, r_2 – Outer radius , r_1 – inner radius.

4. Write down the three dimensional heat conduction equation in cylindrical coordinate system.

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{1}{r^2}\frac{\partial^2 T}{\partial \emptyset^2} + \frac{\partial^2 T}{\partial z^2} + \frac{q^{\cdot}}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial \theta}$$

5. What is meant by Transient heat conduction or unsteady state conduction?

If the temperature of the body varies with time, it is said to be in a transient state and that type of conduction is known as transient heat conduction or unsteady state heat conduction.

6. List down the three types of boundary conditions.

1. Prescribed temperature, 2. Prescribed heat flux and 3. Convection boundary conditions.

7. What is critical radius of insulation or critical thickness.

Addition of insulating material on a surface does not reduce the amount of heat transfer rate always. In fact under certain circumstances it actually increases the heat loss upto certain thickness of insulation. The radius of insulation for which the heat transfer is maximum is called critical radius of insulation and corresponding thickness is called critical thickness.

8. What is meant by infinite solid?

A solid which extends itself infinitely in all directions of space is known as infinite solid. In infinite solids, the biot number value is in between 0.1 and 100.

9. Define Biot Number?

It is defined as the ratio of internal conductive resistance to the surface convective resistance.

10. What is the significance of Biot number.

Biot number is used to find lumped heat analysis, semi infinite solids and infinite solids.

If Bi <0.1 – Lumped heat analysis.

Bi = α – Semi infinite solids

0.1<Bi>100 infinite solids

EXP. NO.:
DATE:

HEAT TRANSFER FROM PIN-FIN APPARATUS

Aim:

To determine the FIN efficiency of the PIN-FIN apparatus for forced convection.

Apparatus required:

1. Ammeter, 2. Voltmeter, 3. Heater, 4. Blower, 5. Fin Specimen, 6. Thermocouple and Temperature Indicator.

Specifications:

Duct width (B)	= 150 mm
Duct height (W)	= 100 mm
Orifice Diameter (d_o)	= 20 mm
Orifice coefficient (C_d)	= 0.6
Fin length (L)	= 14.5 cm
Fin diameter (d_f) (Characteristic length)	= 12 mm

Procedure:

1. Connect the three pin plug to a 230V, 50Hz, 15A power and switch on the unit.
2. Keep the thermocouple selector switch in first position.
3. Turn the regulator knob to clockwise and set the power to the heater to any desired value by looking at the voltmeter and ammeter.
4. Allow the unit to stabilize.
5. Switch on the blower.
6. Set the airflow rate to any desired value looking at the difference in U tube manometer limb levels.
7. Note down the temperatures indicated by temperature indicator.
8. Repeat the experiment by varying the airflow rate and keeping the power input to the heater constant.
9. Varying the power input to the heater and keeping the airflow rate constant.
10. Tabulate the readings and calculate for different conditions.
11. After all the experiment is over, put off the blower switch, turn the energy Regulator knob anticlockwise, put OFF the main switch and disconnect the power supply.

Formula used:

1. **Surface temperature**

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

2. **Ambient temperature** $T_a = T_8$ °C

3. **Mean film temperature** $T_f = \frac{T_w + T_a}{2}$

4. **Volume of air flowing through the duct**

$$Q = \frac{C_d a_1 a_2 \sqrt{2 g h_a}}{\sqrt{{a_1}^2 - {a_2}^2}}$$

Where C_d = Co-efficient of orifice = 0.6
g = Gravitational constant = 9.81 m/sec^2
h_a = heat of air = $(\rho_w / \rho_a) * h$
a_1 = area of the pipe
a_2 = area of the orifice
h= manometer differential head

5. **Velocity of air in the duct**

$$V = \frac{Q}{W * B}$$

Where W = Width of the duct in m

B = Breadth of the duct in m

6. **Reynold's number of airflow**

$$R_e = \frac{V * d_f}{\gamma}$$

Where V = Velocity of air in the duct in m/sec

d_f = Diameter of the fin in m

γ = Kinematic Viscosity of air at T_f in (from HMT data book)

7. **Nusselt Number**

1. $N_u = 0.989 * \left({R_e}^{0.333}\right) * \left({P_r}^{0.333}\right), for\ 1 < R_e < 4$

2. $N_u = 0.911 * \left({R_e}^{0.385}\right) * \left({P_r}^{0.333}\right), for\ 4 < R_e < 40$

3. $N_u = 0.683 * \left({R_e}^{0.466}\right) * \left({P_r}^{0.333}\right), for\ 40 < R_e < 4000$

4. $N_u = 0.913 * \left({R_e}^{0.618}\right) * \left({P_r}^{0.333}\right), for\ 4000 < R_e < 40000$

5. $N_u = 0.0266 * \left({R_e}^{0.805}\right) * \left({P_r}^{0.333}\right), for\ R_e > 40000$

where P_r - Prandtl Number at T_f in (from HMT data book)

8. **Heat transfer co-efficient**

$$h = \frac{N_u\ K}{d_f}\ ,$$ where K - Thermal conductivity for T_f

9. **Fin efficiency**

$$ή_{fin} = \frac{\tanh\ (mL)}{mL}\ X\ 100\ \%$$

where

$$m = \sqrt{\frac{hP}{KA}}\ ,$$

P = Perimeter = $\pi\ d_f$

A - Surface area of the fin = $\pi\ d_f L$ & L - Length of the fin in m

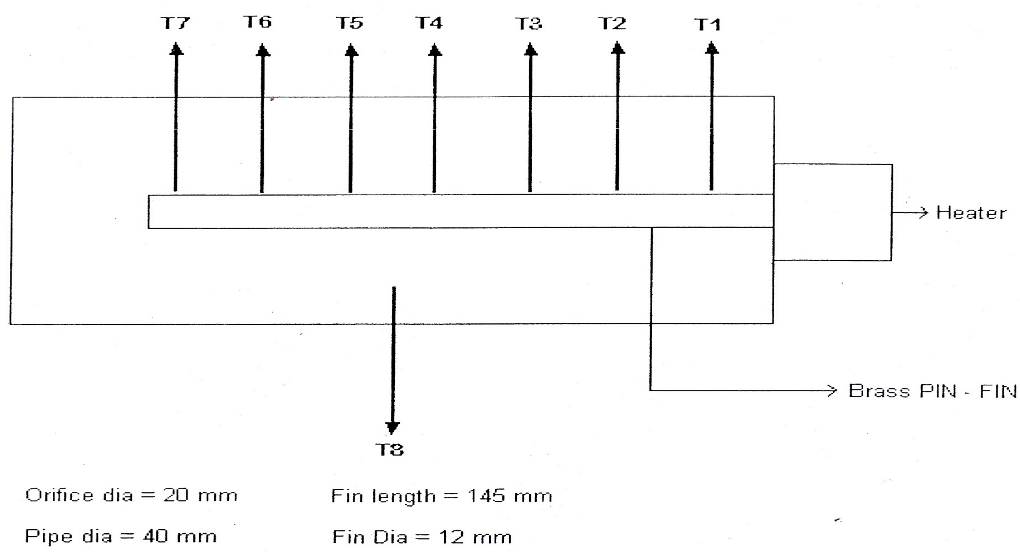


Figure 5. PIN – FIN apparatus

Table:

Sl. No.	Valve Position	Volts	Current	Pin - Fin Surface Temperature							Amb. Temp.	Manometer Reading	
		V volts	A amps	T_1 °C	T_2 °C	T_3 °C	T_4 °C	T_5 °C	T_6 °C	T_7 °C	T_8 °C	h_1 cm	h_2 cm
	1/4												
	1/2												
	3/4												
	Full open												

Result :

The fin efficiency has been calculated by using Pin fin apparatus (using Forced convection method)

1. Fin efficiency _____________.

VIVA QUESTIONS AND ANSWERS

1. Define Fin efficiency.

The efficiency of a fin is defined as the ratio of actual heat transferred to the maximum possible heat transferred by the fin.

2. Define fin effectiveness.

It is the ratio of heat transfer with fin to that of without fin.

Fin effectiveness = $(Q_{\text{with fin}}/Q_{\text{without fin}})$

3. Define kinematic viscosity.

It is defined as the ratio of dynamic viscosity to mass density.

4. Define Grashof number (Gr)

It is defined as the ratio of product of inertia force and buoyancy force to the square of viscous force.

5. Define Stanton Number.

It is the ratio of Nusselt number to the product of Reynolds number and **Prandtl** number.

6. What is the unit of thermal conductivity and heat transfer coefficient?

Thermal conductivity – W/mK and Heat transfer coefficient – W/m^2K

7. What is dimensional analysis?

Dimensional analysis is a mathematical method which can be applied to all types of fluid resistances, heat flow problems in fluid mechanics and thermodynamics.

8. State the applications of fins.

The main applications of fins are 1. Cooling of electronic components 2. Cooling of motor cycle engines. 3. Cooling of transformers 4. Cooling of small capacity compressors.

9. List the various promoters used for maintaining drop wise condensation.

Oleic acid, Benzyl, Certain fats and waxes are effective promoters used for maintaining dropwise condensation.

10. What is burnout point? Why is it called so?

A point at which the flow is maximum is known as burnout point. Once we cross this point, large temperature difference is required to get the same heat flux and most material may burn at this temperature.

EXP. NO.:
DATE:

DETERMINATION OF STEFAN – BOLTZMANN CONSTANT.

Aim:

To find out the Stefan - Boltzman constant using concentric hemisphere.

Apparatus required:

1.Voltmeter, 2. Ammeter, 3. Thermocouple, 4. Heater and 5. Temperature Indicator.

Specification:

1. Mass of the disc m = 0.005 Kg
2. Diameter of the disc d = 20 mm
3. Material of the disc - Copper
4. Weight of the disc = 0.008
5. Specific heat C_p = 0.381 KJ/Kg K

PROCEDURE:

1. Allow water to flow through the hemisphere. Remove the disc from the bottom of the hemisphere.

2. Switch on the heater and allow the hemisphere to reach a steady temperature.

3. Note down the temperatures T_1, T2 and T_3. The average of these temperatures is the hemisphere temperature (T_h).

4. Refit the disc at the bottom of the hemisphere and start the stop clock. The raise in temperature T_4 with respect to time is noted.

5. Also note down the disc temperature at T_4 when steady state is reached (T_d). A is the area of the disc receiving the heat radiation.

Formulas:

1. **Average temperature of the hemisphere**

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

2. **Steady state temperature of the disc (T_d).**

3. **Area of the disc**

$$A = \left(\frac{\pi}{4}\right) * d^2$$

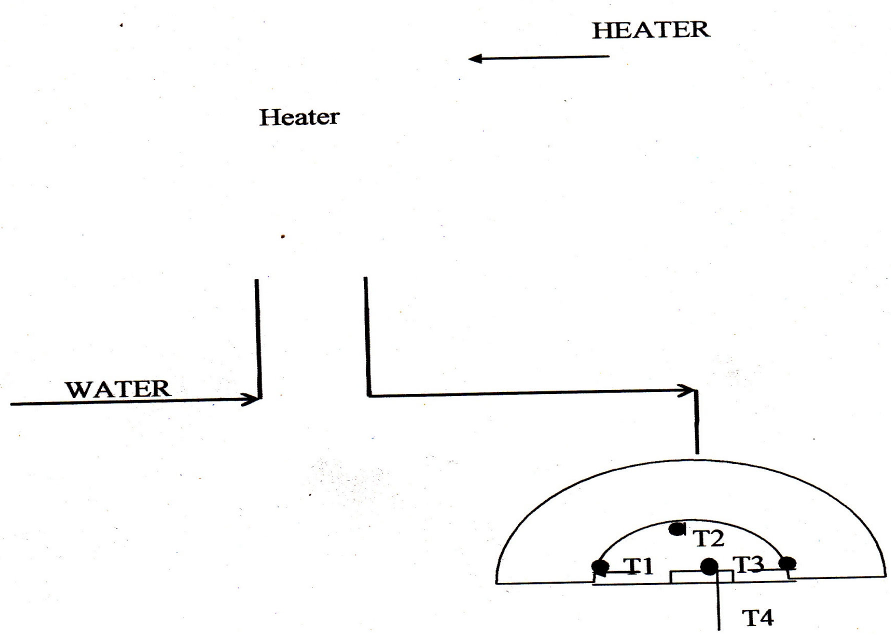
4. Stefan - Boltzman constant

$$\sigma = \frac{Q}{[\varepsilon_b * (T_h{}^4 - T_d{}^4) * A]}$$

Where Q = mass of the disc * Cp of the disc* (dT/dt)

dT/dt = 0.1/30

STEFAN-BOLTZMAN APPARATUS



DISC DIAMETER	**=**	**20 mm**
DISC MATERIAL	**=**	**COPPER**
DISC WEIGHT	**=**	**0.008 Kg.**

Table:

Sl. No.	T_1	T_2	T_3	Average temp. of the hemisphere	Time measurement		Steady state temp. of the disc
	°C	°C	°C	T_h in °C	T_4 in °C	In sec	T_d in °C

Result:

The Stefan - Boltzman Constant is ___________________________.

VIVA QUESTIONS AND ANSWERS

1. A perfect black body is one which __________

Ans: Absorb heat radiation of all wave lengths falling on it.

2. The valve of the wave length for maximum emissive power is given by ________

Ans: Wein's Law

3. Thermal diffusivity of a substance is given by _________ Ans: $\frac{K}{\rho C_P}$

4. The unit for Stefan – Boltzman constant is ___________ Ans: Watt/m^2/k^4

5. Two plates spaced 150mm apart are maintained at 1000°C and 70°c. The heat transfer will take place mainly by _________ Ans: Radiation.

6. The amount of radiation mainly depends on __________

Ans: Nature of body, temperature of body and type of surface of body

7. What is meant by radiation shape factor?

The space factor is defined as the fraction of the radiative energy that is diffused from one surface element and strikes the other surface directly with no intervening reflections. It is represented by Fiji. Other names for the radiation shape factor are view factor, angle factor, and configuration factor.

8. Define a black body

Black body is on ideal surface having the following properties.

1) A black body absorbs all incident radiation regardless of wave length and direction.
2) For a prescribed temperature and wave length, no surface can emit more energy than black body.

9. Write down the Stefan Boltzman law with its Unit

The total energy emitted by a black body at a particular temperature is given by

Eb = σT^4 Where σ – Stefan Boltzman constant – 5.669 x 10^{-8} w/m^2k^4

10. Define emissive power [E]

The emissive power is defined as the total amount of radiation emitted by a body per unit time and unit area. It is expressed in W/m^2

10. Define monochromatic emissive power [Eb]

The energy emitted by the surface at a given length per unit time per unit area in all directions is known as monochromatic emissive power.

EXP. NO.:
DATE:

DETERMINATION OF EMISSIVITY OF A GREY SURFACE

AIM

To measure the Emissivity of the test plate surface.

Apparatus required:

1.Voltmeter, 2. Ammeter, 3. Thermocouple, 4. Heater, 5. Test Plate, 6. Black Body and 7. Temperature Indicator.

Specification:

1. Diameter of the test plate = 0.150 m
2. Diameter of the Black plate = 0.150 m

PROCEDURE:

1. Connect the three pin plug to the 230V, 50 Hz, 15 Amps main supply and switch on the unit.
2. Keep the thermocouple selector switch in first position.
3. Keep the toggle switch in position 1. By operating the energy regulator I power will be fed to back plate.
4. Now keep the toggle switch in position 23 and operate regulator 2 and feed power to the test surface.
5. Allow the unit to stabilize.
6. Ascertain the power inputs to the black and test surfaces are set at equal values.
7. Turn the thermocouple selector switch clockwise step by step and note down the temperatures indicated by the temperature indicator from channel 1 to 7
8. Tabulate the readings and calculate.
9. After the experiment is over turn both the energy regulators 1 & 2.
10. For various power inputs repeat the experiment.

Formulas:

1. Temperature of black body in absolute unit $T_b = (T_b + 273)$ in K.
2. Temperature of the polished body in absolute unit $T_p = (T_p + 273)$ in K.
3. Temperature of the chamber in absolute unit $T_c = (T_c + 273)$ in k.

4. Emissivity of the test plate**.**

$$\epsilon_p = \frac{[\varepsilon_b(T_b{}^4 - T_c{}^4)]}{(T_p{}^4 - T_c{}^4)}$$

where ε_b is emissivity of black body is 1.

5. Power Input (Q).

$$Q = \varepsilon_p \sigma A(T_p{}^4 - T_c{}^4) = \varepsilon_p \sigma A(T_b{}^4 - T_c{}^4)$$

(Since Power input is same for both heaters and area of radiating surface (A) is also same)

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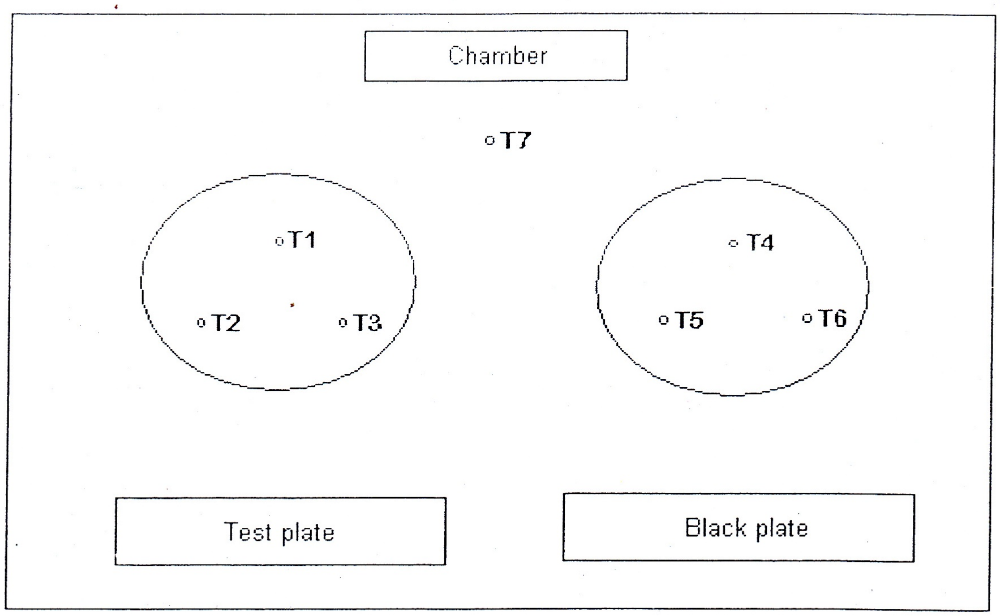


Figure 7. Emmisivity apparatus

Table:

Voltage	Current	Black body temperature			Average Temperature	Polished body temperature			Average Temperature	Chamber Temperature	Emissivity
V volts	A Amps	T_5 ºC	T_6 ºC	T_7 ºC	T_b ºC	T_1 ºC	T_2 ºC	T_3 ºC	T_p ºC	T_4 ºC	ε_ρ

Result:

The emissivity of the polished surface area, ε_ρ =

VIVA QUESTIONS AND ANSWERS

1. What is meant by absorptivity, reflectivity and transmissivity?

Absorptivity is defined as the ratio between radiation absorbed and incident radiation. Reflectivity is defined as the ratio of radiation reflected to the incident radiation.

2. What is gray body?

If a body absorbs a definite percentage of incident radiation irrespective of their wave length, the body is known as gray body. The emissive power of a gray body is always less than that of the black body.

3. Define Radiation.

The heat transfer from one body to another without any transmitting medium is known as radiation .It is an electromagnetic wave phenomenon.

4. Define intensity of radiation (Ib).

It is defined as the rate of energy leaving a space in a given direction per unit solid angle per unit area of the emitting surface normal to the mean direction in space. In =

5. State Lambert's cosine law.

It states that the total emissive power Eb from a radiating plane surface in any direction proportional to the cosine of the angle of emission $E_b \propto \cos\theta$

6. What is meant by transmissivity (τ).

Transmissivity is defined as the ratio of radiation transmitted to the incident radiation.

7. State Stefan – Boltzmann law.

The emissive power of a black body is proportional to the fourth power of absolute temperature.

$$E_b = \sigma T^4$$

8. Define emissivity.

It is defined as the ability of the surface of a body to radiate heat. It is also defined as the ratio of emissive power of any body to the emissive power of a black body of equal temperature.

$$\text{Emissivity} = (E/E_b)$$

9. Define irradiation (G).

It is defined as the total radiation incident upon a surface per unit time per unit area. It is expressed in W/m^2

10. What is radiosity (J).

It is used to indicate the total radiation leaving a surface per unit time per unit area. It is expressed in W/m^2

EXP. NO.:
DATE:

EFFECTIVENESS OF PARALLEL / COUNTER FLOW HEAT EXCHANGER

AIM:

To find the overall heat transfer co-efficient and effectiveness in parallel flow and counter flow heat exchanger.

Apparatus required:

4. Heat Exchanger apparatus, 2. Temperature Indicator, 3. Thermocouple, 4. Stop watch and 5. Water Heater.

Specifications:

1. Length of the heat exchanger = 1800 mm
2. Inner copper tube:

   Inner diameter = 12 mm & Outer diameter (D_o) = 15 mm

5. Outer GI tube ID Inner diameter= 40 mm

Procedure:

For Parallel flow arrangement

1. Connect water supply at the back of the unit. The inlet water flows through Geyser and inner pipe of the heat exchanger and flows out. Also the inlet water flows through the annuals gap of the heat exchanger and flows out.
2. For Parallel flow open valve V2, V4 and V5.
3. Control the hot water flow approximately 2 lit./min. and cold water flow approximately 5 lit./min.
4. Switch ON the geyser. Allow the temperature to reach steady state.
5. Note temperature T_1 and T_2 (hot water inlet and outlet temperature respectively).
6. Under Parallel flow condition T_3 is the cold water inlet temperature and T_4 is the cold water outlet temperature.
7. Note the temperature T_3 and T_4.
8. Note the time for 1 litre flow of hot and cold water. Calculate mass flow rate Kg/sec.

9. Change the water flow rates and repeat the experiment.

For counter flow arrangement:

1. Connect water supply at the back of the unit. The inlet water flows through Geyser and inner pipe of the heat exchanger and flows out. Also the inlet water flows through the annuals gap of the heat exchanger and flows out.
2. For counter flow open valve V3, V1 and V5.
3. Control the hot water flow approximately 2 lit./min. and cold water flow approximately 5 lit./min.
4. Switch ON the geyser. Allow the temperature to reach steady state.
5. Note temperature T_1 and T_2 (hot water inlet and outlet temperature respectively).
6. Under counter flow condition T_4 is the cold water inlet temperature and T_3 is the cold water outlet temperature.
7. Note the temperature T_3 and T_4.
   6. Note the time for 1 litre flow of hot and cold water. Calculate mass flow rate Kg/sec.
   7. Change the water flow rates and repeat the experiment.

Formulas:

A. For Parallel flow.

1. Logarithmic Mean Temperature Difference (LMTD)

$$LMTD = \frac{\Delta T_i - \Delta T_0}{ln\frac{\Delta T_i}{\Delta T_0}}$$

where $\Delta T_i = T_1 - T_3$

$\Delta T_0 = T_2 - T_4$

T_1 – Hot water Inlet temperature in K

T_3 – Cold water Inlet temperature in K

T_2 – Hot water Outlet temperature in K

T_4 – Coldwater outlet temperature in K

2. Heat transfer (Q)

$$Q = m_h * C_{ph} * [T_1 - T_2] \quad \text{in Watts}$$

where m_h – Mass of hot water in Kg.

C_{ph} – Specific heat capacity of hot water = 4.186 KJ/Kg K.

A – Outer area of the copper tube = Πd$_o$ L

8. Overall heat transfer coefficient (U).

$$U = \frac{Q}{A * (LMTD)}, W/m^2 K$$

9. Effectiveness of heat transfer

$$\epsilon = \frac{[T_1 - T_2]}{[T_1 - T_3]}$$

B. For counter flow.

1. Logarithmic Mean Temperature Difference (LMTD)

$$LMTD = \frac{\Delta T_i - \Delta T_0}{ln\frac{\Delta T_i}{\Delta T_0}}$$

where $\Delta T_i = T_1 - T_3$

$\Delta T_0 = T_2 - T_4$

T_1 – Hot water Inlet temperature in K

T_3 – Cold water outlet temperature in K

T_2 – Hot water Outlet temperature in K

T_4 – Coldwater inlet temperature in K

2. Heat transfer (Q)

$$Q = m_h * C_{ph} * [T_1 - T_2] \quad \text{in Watts}$$

where m_h – Mass of hot water in Kg.

C_{ph} – Specific heat capacity of hot water = 4.186 KJ/Kg K.

A – Outer area of the copper tube = Πd$_o$ L

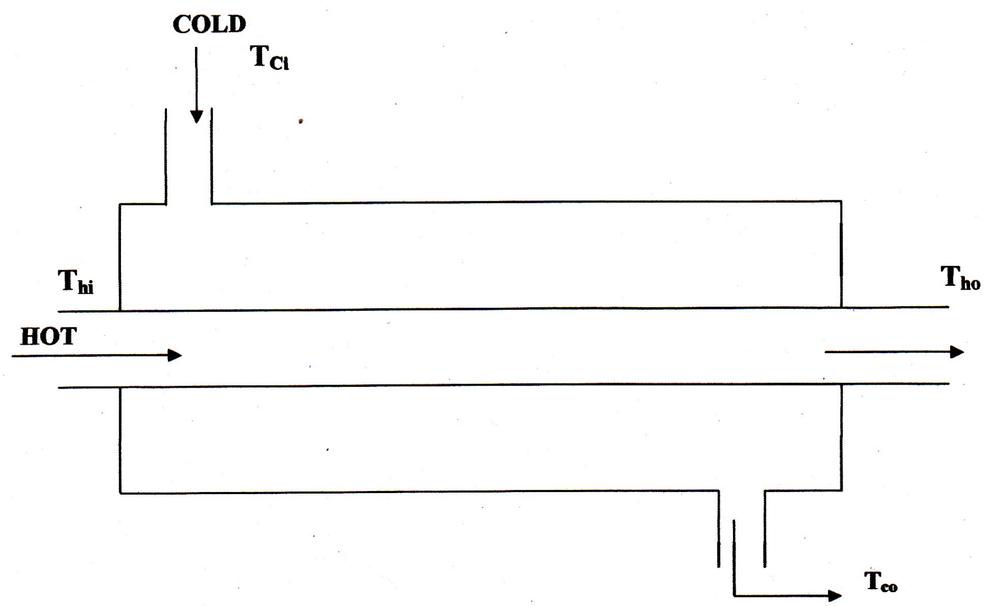
10. Overall heat transfer coefficient (U).

$$U = \frac{Q}{A * (LMTD)}, W/m^2 K$$

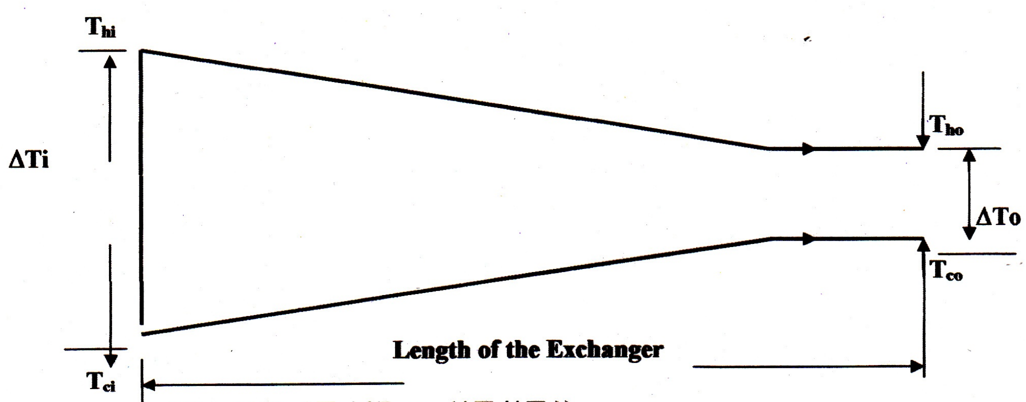
11. Effectiveness of heat transfer

$$\epsilon = \frac{[T_3 - T_4]}{[T_1 - T_4]}$$

PARALLEL FLOW HEAT EXCHANGER

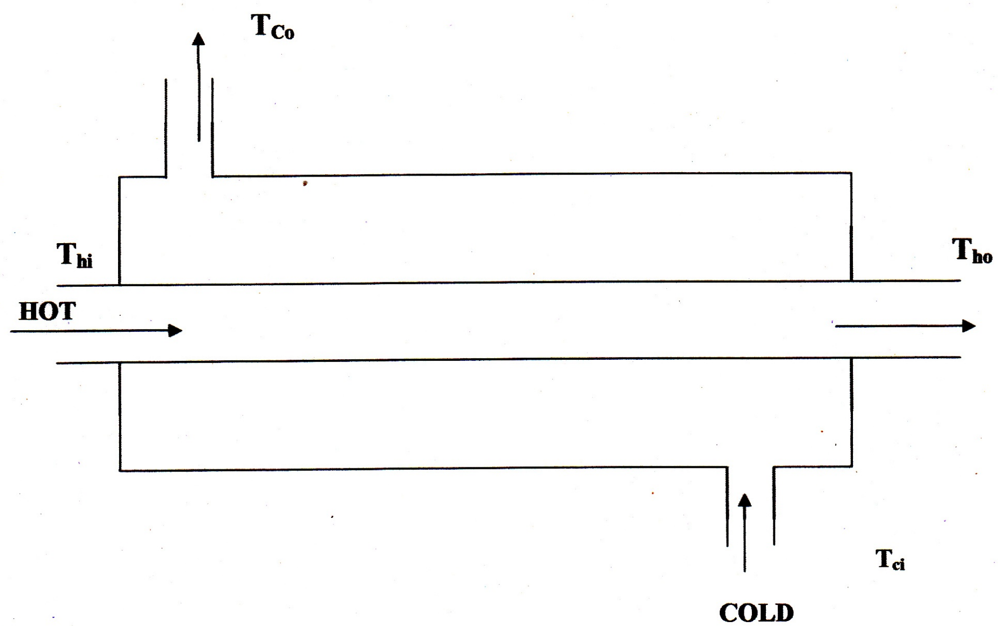


PARALLEL FLOW

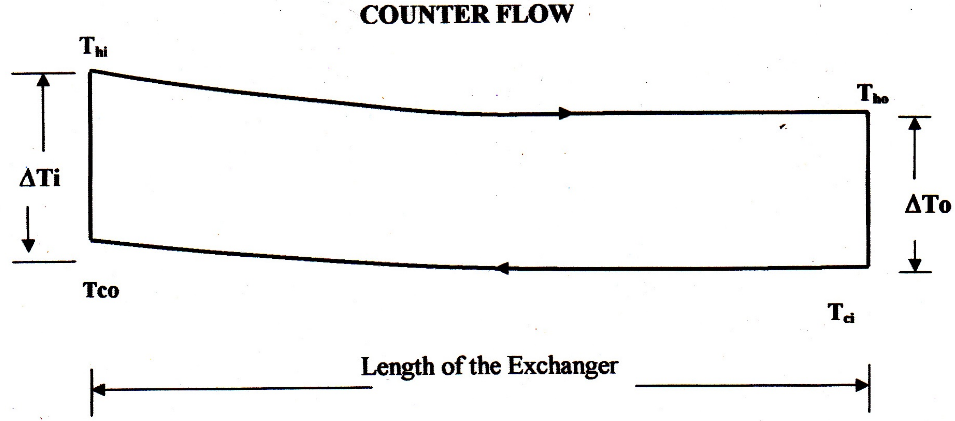


$$\Delta T_m = (\Delta T_i - \Delta To) / (Log_e (\Delta T_i / \Delta T_o))$$

COUNTER FLOW HEAT EXCHANGER



COUNTER FLOW



$$\Delta T_m = (\Delta T_i - \Delta To)/(Log_e\ (\Delta T_i/\Delta T_o))$$

Table:

For parallel flow:

Sl. NO.	Hot water temperatures		Cold water temperatures (°C)		Time taken for 1 lit. of hot flow	Time taken for 1 lit. of cold water flow
	Inlet T_{hi}	Outlet T_{ho}	Inlet T_{ci}	Outlet T_{co}	sec	sec
	T_1	T_2	T_3	T_4		

For counter flow:

Sl. NO.	Hot water temperatures (°C)		Cold water temperatures (°C)		Time taken for 1 lit. of hot water flow	Time taken for 1 lit. of cold water flow
	Inlet T_{hi}	Outlet T_{ho}	Inlet T_{ci}	Outlet T_{co}	sec	sec
	T_1	T_2	T_4	T_3		

Result:

Thus the overall heat transfer coefficient and effectiveness of Parallel flow and counter flow heat exchanger have been calculated.

For Parallel flow

1. Overall heat transfer coefficient_______________.
2. Effectiveness___________________.

For Counter flow

1. Overall heat transfer coefficient_______________.
2. Effectiveness___________________.

VIVA QUESTIONS AND ANSWERS

1. What is meant by Boiling and condensation?

The change of phase from liquid to vapour state is known as boiling. The change of phase from vapour to liquid state is known as condensation.

2. Give the applications of boiling and condensation.

Boiling and condensation process finds wide applications as mentioned below. 1. Thermal and nuclear power plant. 2. Refrigerating systems 3. Process of heating and cooling 4. Air conditioning systems

3. What is meant by pool boiling?

If heat is added to a liquid from a submerged solid surface, the boiling process referred to as pool boiling. In this case the liquid above the hot surface is essentially stagnant and its motion near the surface is due to free convection and mixing induced by bubble growth and detachment.

4. What is meant by Film wise condensation?

The liquid condensate wets the solid surface, spreads out and forms a continuous film over the entire surface is known as film wise condensation.

5. What is meant by Drop wise condensation?

In drop wise condensation the vapour condenses into small liquid droplets of various sizes which fall down the surface in a random fashion.

6. Give the merits of drop wise condensation?

In drop wise condensation, a large portion of the area of the plate is directly exposed to vapour. The heat transfer rate in drop wise condensation is 10 times higher than in film condensation.

7. What is heat exchanger?

A heat exchanger is defined as an equipment which transfers the heat from a hot fluid to a cold fluid.

8. What are the types of heat exchangers?

The types of heat exchangers are as follows 1. Direct contact heat exchangers 2. Indirect contact heat exchangers 3. Surface heat exchangers 4. Parallel flow heat exchangers 5. Counter flow heat exchangers 6. Cross flow heat exchangers 7. Shell and tube heat exchangers 8. Compact heat exchangers.

9. What is meant by Direct heat exchanger (or) open heat exchanger?

In direct contact heat exchanger, the heat exchange takes place by direct mixing of hot and cold fluids.

10. What is meant by Indirect contact heat exchanger?

In this type of heat exchangers, the transfer of heat between two fluids could be carried out by transmission through a wall which separates the two fluids.

EXP. NO.:
DATE:

DETERMINATION OF COP OF A REFRIGERATION SYSTEM

Aim:

To determine the coefficient of performance (COP) of a vapour compression refrigeration system.

Apparatus required:

1. Vapour compression refrigeration test rig.
2. Stop watch.
3. Thermometer.

Procedure:

1. Put on the main switch, condenser fan and temperature indicator.
2. Fill water in the evaporator vessel 3/4th level. Note the level of water using a measuring scale.
3. Note the initial temperature of water T_5
4. Note the starting time and switch on the compressor.
5. Allow the unit to stabilize.
6. Note the time for 10 revolution of compressor energy meter reading.
7. When the temperature T_3 and T_4 are almost equal note the following.
   The closing time, Temperature of water T_5, Pressure gauge readings P_1, P_2, P_3 and P_4 at different state points, Temperature at different state points T_1, T_2, T_3 and T_4 using the selector switch provided on the temperature indictor.
8. The experiment may be repeated for a different water level. (Water needs to be changed)

Formula:

A. Coefficient of Performance by Experimental method:

1. Refrigerating Effect (Q)

$$Q = m * C_p * \left(\frac{dt}{dT}\right), \quad in\ KW$$

where m - Mass of water in the evaporator vessel

$$m = \rho_w \left(\frac{\pi}{4} * d^2\right) * h, \quad in\ Kg$$

ρ_w - Density of water (1000 Kg/ m^3)

d - Diameter of the vessel = 295 mm

$$Rate\ of\ fall\ in\ temperature\ of\ water\ = \frac{[T_{5\ initial} - T_{5\ final}]}{Duration\ of\ experiment\ in\ sec} = \frac{dt}{dT}\ in\ \frac{°C}{sec}$$

C_p of water = 4.182 KJ/Kg K.

2. Work done by the compressor

$$W = \frac{[\,3600 * 10]}{[\,t * E]}, in\ KW$$

where t - time taken for 10 revolution of energy meter constant in sec

E - Energy meter constant = 750 rev/KW. hr

3. **COP of the Refrigeration system**

$$COP = \frac{Refrigerating\ Effect}{Work\ done}$$

<u>B. Calculation of COP using p - h chart:</u>

1. Convert all the pressure gauge readings in bar.

   Note:

   [14.5 psi = 1 Kg

   Absolute pressure = Gauge pressure in Kg + 1.03 bar]

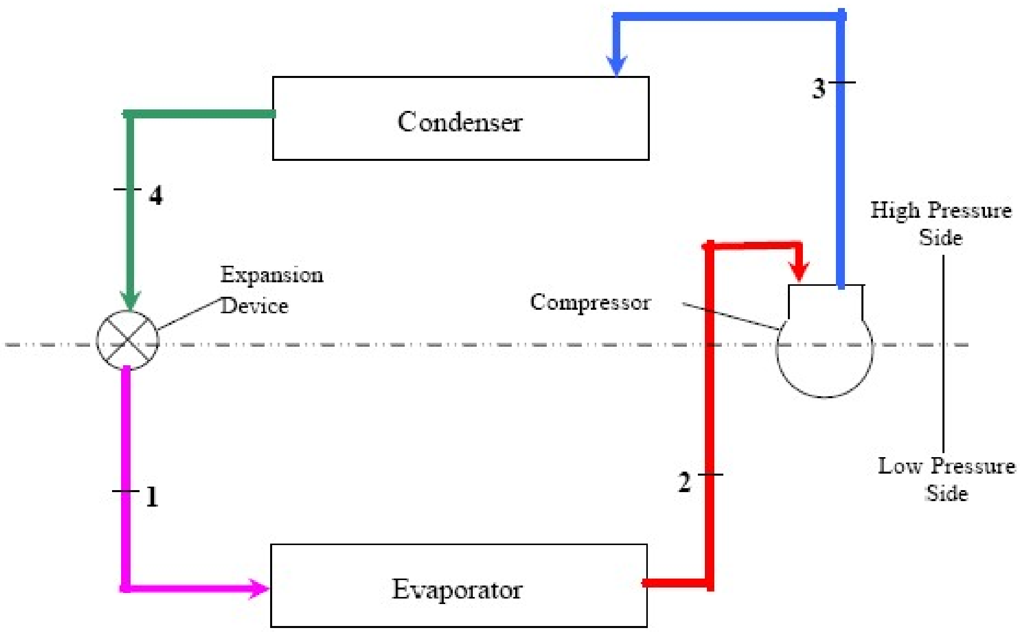
2. Plot the different state points on the p - h chart using absolute pressure and temperature readings. Note the Enthalpy at each point. P_1, T_1 corresponds to point 1 and gives H_1. Similarly P_2, T_2, P_3, T_3 and P_4, T_4 corresponds to 2,3 and 4 respectively and gives H_2, H_3 and H_4 respectively.

3. State 4 - 1 represents adiabatic compression and state 3 - 4represents the isobaric evaporation.

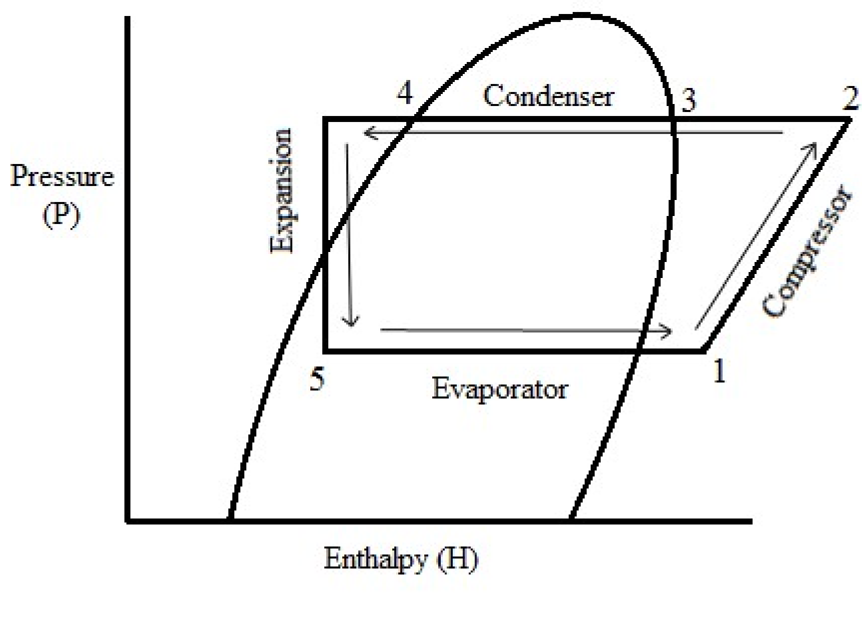
4. Coefficient of Performance.

$$COP = \frac{Isobaric\ Evaporation}{Adiabatic\ Compression} = \frac{[H_4 - H_3]}{[H_1 - H_4]}$$

C. Efficiency of cycle = [$(COP)_{exp}$ / $(COP)_{the}$] * 100 %



REFRIGERATION CYCLE



P – h diagram

Table

Sl.No.	**Time at which readings are taken (sec)**	**Time taken for 10 revolution of energy meter disc (sec)**	**Temperature (°C)**				**Pressure (psi)**			
			T_1	**T_2**	**T_3**	**T_4**	**P_1**	**P_2**	**P_3**	**P_4**

Initial Temp. of water $T_{5\ initial}$ = ; Final Temp. of water $T_{5\ final}$ =

Note:

1. P_1 & T_1 - Compressor delivery Pressure and Temperature.
2. P_2 & T_2 - Condenser Outlet Pressure and Temperature.
3. P_3 & T_4 - Pressure and Temperature after Expansion
4. P_4 & T_4 - Compressor Suction Pressure and Temperature.

RESULT:

Thus the coefficient of performance of vapour compression refrigeration system was found.

$(COP)_{Exp}$ = -----

$(COP)_{The}$ = ------

Efficiency of cycle = ------

VIVA QUESTIONS AND ANSWERS

1. Define tons of refrigeration.

A tone of refrigeration is defined as the quantity of heat to be removed from one tone of water (1000 Kg) at 0°C to convert that into ice at 0°C in 24 hours. In actual practice 1 tonne of refrigeration = 210 KJ/min = 3.5 KW.

2. Define COP of refrigerators.

Coefficient of performance is defined as the ratio of heat absorbed by the evaporator or refrigeration effect to the compressor work.

3. Name four important properties of a good refrigerant.

Low boiling point, Low specific volume, High critical temperature and pressure and Low specific heat of liquid.

4. Name any four commonly used refrigerants.

Ammonia, Carbon dioxide, Sulphur dioxide and Froen 12.

5. What is the functioning of throttling valve in vapour compression refrigeration system.

The function of throttle valve is to allow the liquid refrigerant under high pressure and temperature to pass at controlled rate after reducing its pressure and temperature.

6. What are the types of refrigeration systems?

1. Vapour compression refrigeration systems and 2. Vapour absorption refrigeration systems.

7. List out the important components of vapour compression refrigeration systems.

1. Evaporator, 2. Compressor, 3. Condenser and 4. Expansion valve.

8. What are the expansion devices used in vapour compression plant? When they are used?

1. Throttling valve and 2. Capillary tubes. Capillary tubes are used only for small plants in which length and size are fixed and also evaporator pressure is fixed.

Throttling valves are used in larger plants because these regulate the flow of the refrigerant according to the load on the evaporator.

9. What are the effect of superheat and subcooling on the vapour compression cycle?

Superheating increases the refrigeration effect and COP may be increased or decreased. But subcooling always increase the COP of the refrigeration and also decrease the mass flow rate of refrigerant.

10. What are the advantages and disadvantages of air refrigeration system?

Advantages:

1. The refrigerant used namely air is cheap and easily available.
2. There is no danger of fire or toxic effects due to leakages.

Disadvantages:

1. The quantity of refrigerant used per tone of refrigeration is high as compared to other systems.
2. The COP of the system is very low and therefore running cost is high.

EXP. NO.:
DATE:

AIR CONDITION TEST RIG. (EXPERIMENTS ON PSYCHOMETRIC PROCESSES.)

Aim :

To determine the coefficient of performance (COP) of a vapour compression air-conditioning system by experimentally and using p-h chart.

Apparatus required:

1. Air Condition test rig, 2. Stop Watch, 3. Anemometer and 4. Thermometers

Procedure:

1. Switch on the mains. Switch on the condenser fan and blower.
2. Keep the manually operated valves in proper position.
3. Switch on the compressor and allow the unit to stabilize by adjusting the airflow through the duct.
4. Note down the following;
   a) Pressure of super heated vapour at the exit of the compressor (Delivery) P_1
   b) Pressure at entry to throttle valve P_2
   c) Pressure after throttling P_3
   d) Pressure of super heated vapour at suction to the compressor P_4
   e) Note the corresponding temperatures T_1, T_2, T_3 and T_4 at respective state points.

Formulas:

A. Coefficient of Performance by Experimental method:

1. Mass flow rate of air.

$$m = \rho * A * V$$

where ρ - Density of air = 1.16 Kg/m^3

A - Area of the Orifice= 0.005 m^2 (Dia. of orifice = 0.08 m)

V - Velocity of air flow in m/sec (Measured by Anemometer)

2. Use Psychrometric chart to calculate the enthalpy drop.

a. By using inlet T_{d1} and T_{wb1}, note down enthalpy H_1 from Psychrometric chart.

b. By using Outlet T_{d2} and T_{wb2}, note down enthalpy H_2 from Psychrometric chart.

3. Refrigerating effect

$$Q = m * (H_1 - H_2)$$

4. Work done by the compressor (or) Power to the compressor.

$$W = \frac{[3600 * 10]}{[t * E]}, in\,KW$$

where t - time taken for 10 revolution of energy meter constant in sec

E - Energy meter constant = 1200 rev/KW. hr

5. COP of the Refrigeration system

$$COP = \frac{Refrigerating\ Effect}{Work\ done}$$

B. Calculation of COP using p - h chart:

1. Convert all the pressure gauge readings in bar.

Note:

[14.5 psi = 1 Kg

Absolute pressure = Gauge pressure in Kg + 1.03 bar]

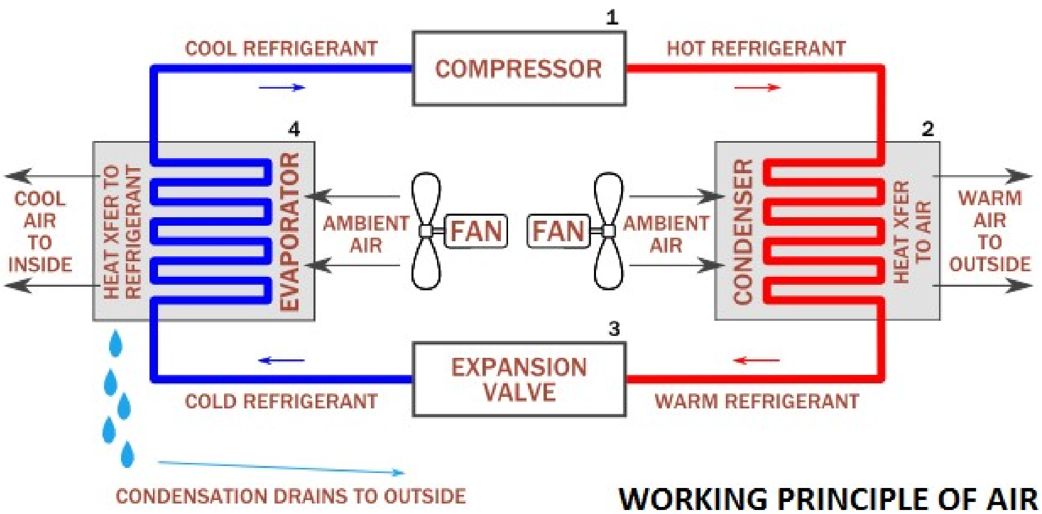
2. Plot the different state points on the p - h chart (R22) using absolute pressure and temperature readings. Note the Enthalpy at each point. P_1, T_1 corresponds to point 1 and gives H_1. Similarly P_2, T_2, P_3, T_3 and P_4, T_4 corresponds to 2,3 and 4 respectively and gives H_2, H_3 and H_4 respectively.

3. State 4 - 1 represents adiabatic compression and state 3 - 4represents the isobaric evaporation.

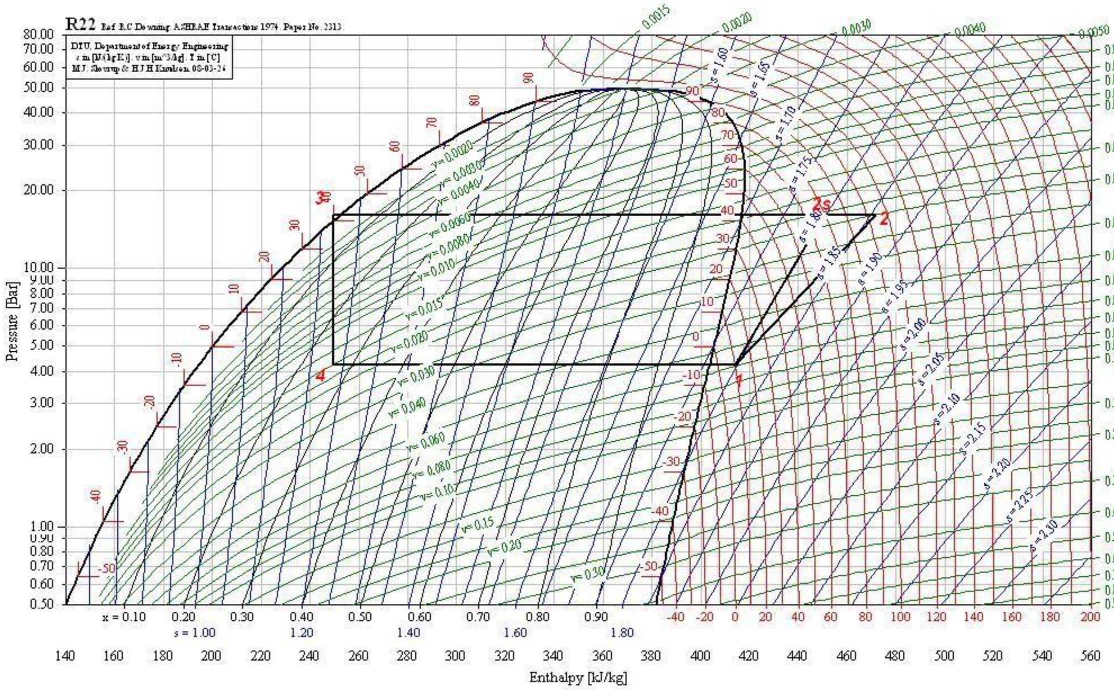
4. Coefficient of Performance.

$$COP = \frac{Isobaric\ Evaporation}{Adiabatic\ Compression} = \frac{[H_4 - H_3]}{[H_1 - H_4]}$$

C. Efficiency of cycle = [(COP)$_{exp}$ / (COP)$_{the}$] * 100 %



WORKING PRINCIPLE OF AIR CONDITIONER


R22 Ref. R.C Downing. ASHRAE Transactions 1974. Paper No. 2313.
Pressure [Bar]
Enthalpy [kJ/kg]
1
2
2s
3
4

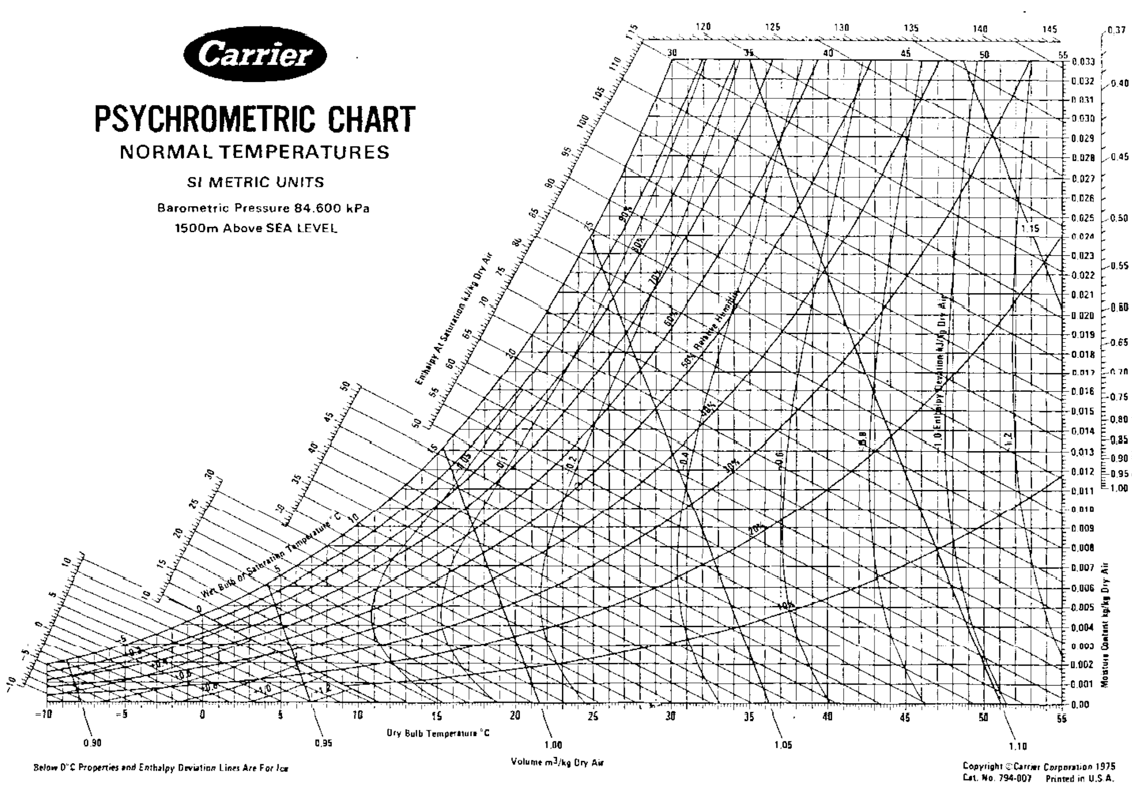

Carrier
PSYCHROMETRIC CHART
NORMAL TEMPERATURES
SI METRIC UNITS
Barometric Pressure 84.600 kPa
1500m Above SEA LEVEL
Enthalpy At Saturation kJ/kg Dry Air
Wet Bulb of Saturation Temperature °C
Dry Bulb Temperature °C
Volume m3/kg Dry Air
Moisture Content kg/kg Dry Air
Sensible Heat Factor
Below 0°C Properties and Enthalpy Deviation Lines Are For Ice
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Table:

1. **Time taken for 10 revolution of energy meter of compressor_______________.**
2. **Anemometer reading_____________________.**

Sl. No.	Temperature (°C)				Pressure (psi)				Inlet Readings (°C)		Outlet Read (°C)	
	T_1	T_2	T_3	T_4	P_1	P_2	P_3	P_4	WBT	DBT	WBT	DBT

Result:

1. Coefficient of performance (COP) of a vapour compression air-conditioning system by experimentally =______________.
2. Coefficient of performance (COP) of a vapour compression air-conditioning system using p-h chart =_______________.

VIVA QUESTIONS AND ANSWERS

1. What is meant by Recuperater (or) surface heat exchangers?

This is the most common type of heat exchangers in which the hot and cold fluid do not come into direct contact with each other but are separated by a tube wall or a surface.

2. What is meant by parallel flow and counter flow heat exchanger?

In this type of heat exchanger, hot and cold fluids move in the same direction. In this type of heat exchanger hot and cold fluids move in parallel but opposite directions.

3. What is meant by shell and tube heat exchanger?

In this type of heat exchanger, one of the fluids move through a bundle of tubes enclosed by a shell. The other fluid is forced through the shell and it moves over the outside surface of the tubes.

4. What is meant by compact heat exchangers?

There are many special purpose heat exchangers called compact heat exchangers. They are generally employed when convective heat transfer coefficient associated with one of the fluids is much smaller than that associated with the other fluid.

5. What is meant by Fouling factor?

We know the surfaces of a heat exchangers do not remain clean after it has been in use for some time. The surfaces become fouled with scaling or deposits. The effect of these deposits the value of overall heat transfer coefficient. This effect is taken care of by introducing an additional thermal resistance called the fouling resistance.

6. What is dew point temperature.

It is the temperature at which the water vapour present in air begins to condense when the air is cooled. For saturated air, the dry bulb, Wet bulb and Dew point temperature are all same.

7. Define Specific Humidity.

It is defined as the mass of water vapour present in one Kg of dry air . It is the ratio of the mass of water vapour to mass of dry air in a given volume of the moisture.

8. Define Relative humidity.

Relative Humidity is the ratio of the mass of water vapour (m_v) in a certain volume of moist air at a given temperature to the mass of water vapour (m_{vs}) in the same volume of saturated air at the same temperature.

9. What is sensible heating and sensible cooling?

Air is heated at constant specific humidity in which there is no addition of moisture during heating. Air is cooled at constant specific humidity in which there is no removal of moisture during cooling.

10. How are air conditioning systems are classified?

I. Based on construction of components,

1. Unitary system, 2. Central system, 3. Package system and 4. Spilit units

II. based on fluid flow methods,

1. Direct expansion systems, 2. Chilled water system and 3. Chilled water air washer system.

EXP. NO.:
DATE:

PERFORMANCE TEST ON A RECIPROCATING AIR COMPRESSOR

Aim:

To conduct performance test on Reciprocating air compressor to determine the volumetric efficiency, overall efficiency and also draw performance characteristics curves.

Apparatus required:

1. Two stage air compressor, 2. Energy meter, 3. 'U' tube manometer, 4. Stop watch and 5. Tachometer

Specification :

1. Compressor: 2- stage, Single acting
2. Bore of LP cylinder D_1= 63mm
3. Bore of HP cylinder D_2= 79mm
4. Stroke length of HP cylinder L_1 = 80 mm
5. Stroke length of LP cylinder L_2 = 80 mm
6. Diameter of orifice meter, d = 12 mm
7. Torque of arm length = 300 mm
8. Energy meter Constant = 180 rev/KW hr.
9. Orifice diameter (d) = 12 mm
10. Motor: 3Φ induction motor with swinging field, 5 HP, 1440 rpm

Procedure:

1. The outlet valve of the reservoir is closed.
2. The manometer is checked for equal water level in limps.
3. The compressor is then started and the pressure inside the reservoir is allowed to build up.
4. The outlet valve is opened slowly and adjusted so that the pressure is maintained constantly (2 Kgf/cm^2) to take values.
5. At constant pressure the following readings are noted down.
    a. Pressure gauge reading.
    b. Speed of motor and compressor.
    c. Time taken for 5 revolution of energy meter reading.
    d. Compressor air inlet and outlet temperature.
6. The same procedure is repeated for various reservoir pressures (4,6,8, 10 & 12 Kgf/cm^2)

Formulas:

1. **Actual discharge of air (V_a):**

$$V_a = C_d * a * \sqrt{2 * g * h_a}, \quad \text{in } m^3$$

where C_d - Coefficient of discharge = 0.6

a - area of the Orifice in m^2

h_a - Head of air column in m

$$h_a = \frac{\rho_w * (h_1 - h_2)}{\rho_a}$$

where ρ_w - Density of water (1000 Kg/ m^3)

ρ_a - Density of air (1.16 Kg/ m^3)

(h_1 - h_2) - Manometer level difference in m

2. **Theoretical discharge of air** (V_{the})

$$V_{the} = \frac{L * A * N}{60}, in\ m^3$$

where L - Stroke length in m

A - Piston area = $(\pi/4) * D^2$

N - Speed of the compressor in rpm

3. **Volumetric Efficiency ($ή_v$):**

$$ή_{vol} = \frac{V_a}{V_{the}} * 100, \quad in\ \%$$

4. **Shaft Power (Output power):**

$$P_o = 9.81 * P_a * V_a * \rho_a, \quad in\ KW$$

5. **Input Power:**

$$P_i = \frac{[3600 * n]}{[E * t]} * 1000, \quad in\ KW$$

where n - No. of revolutions of Energy meter.

E - Energy meter constant (180 rev/KW hr)

t - time taken for n number of revolutions of Energy meter.

6. **Overall Efficiency ($ή_o$):**

$$ή_o = \frac{Output\ power}{Input\ power} * 100, \quad in\ \%$$

7. **Polytropic work done:**

$$W_{poly} = \frac{\frac{nR}{n-1}}{T_o - T_i}, \quad in\, J/Kg$$

where n - Polytropic index

$$n = \frac{1}{1 - \frac{\ln\left(\frac{T_o}{T_i}\right)}{\ln\left(\frac{P_o}{P_i}\right)}}$$

T_i - Inlet Temp. of air in °C

T_o - Outlet Temp. of air in °C

P_i - Inlet Pressure. of air in Kg/cm^2 (P_{atm})

P_o - Outlet Pressure of air in Kg/cm^2

8. Isothermal Work done:

$$W_{iso} = R * T_i * \ln\left(\frac{P_o}{P_i}\right), \quad in\, J/Kg$$

9. Isothermal Efficiency:

$$ή_{iso} = \frac{W_{iso}}{W_{Poly}} * 100, \quad in\, \%$$

Graphs:

The following performance graphs are to be plotted.

Gauge Pressure V_s $ή_{vol}$

Gauge Pressure V_s $ή_{iso}$

Gauge Pressure V_s $ή_{over}$

Gauge Pressure V_s Input Power

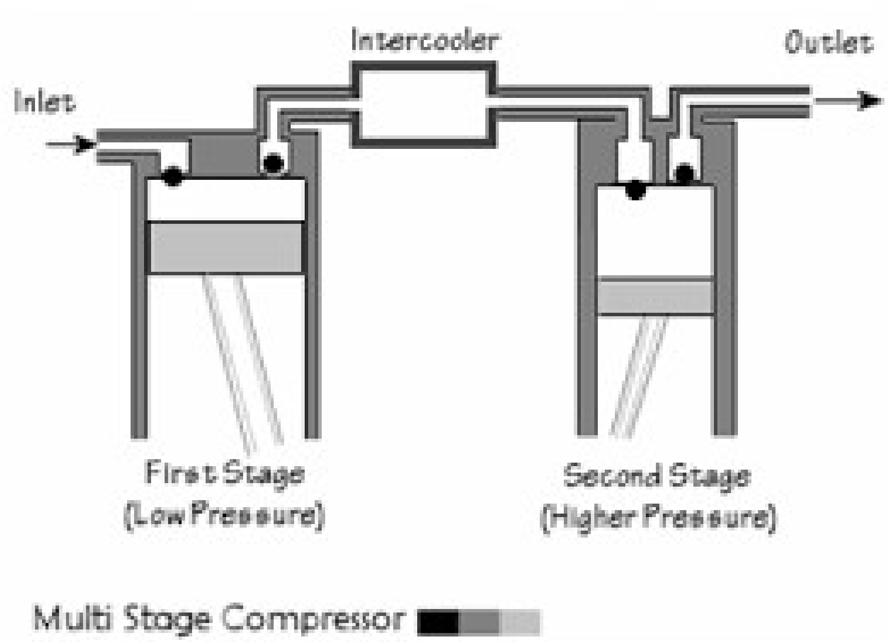

Table:

Sl no.	Pressure (Kg/cm^2)	Manometer reading(cm)		Time for 5 rev. of meter (sec)	Speed of compressor (rpm)	Temperature(^oC)	
		h_1 (cm)	h_2 (cm)			T_1	T_2

Sl.No.	Pressure ,P (Kg/cm^2)	Volumetric efficiency, η_{vol} (%)	Isothermal efficiency, η_{iso} (%)	Overall efficiency, η_o(%)

Result :

Thus the volumetric, isothermal and overall efficiency of the two stage reciprocating air compressor were found at various pressures and performance graphs were plotted.

VIVA QUESTIONS AND ANSWERS

1. What is mass transfer?

The process of transfer of mass as a result of the species concentration difference in a mixture is known as mass transfer.

2. List out the applications of compressed air.

Compressed air is mostly used in Pneumatic brakes, Pneumatic drills, Pneumatic jacks, pneumatic lifts, spray painting, shop cleaning, injecting fuel in diesel engines, super charging of internal combustion engines, refrigeration and air conditioning.

3. What are the modes of mass transfer?

There are basically two modes of mass transfer, 1. Diffusion mass transfer 2. Convective mass transfer

4. What is molecular diffusion?

The transport of water on a microscopic level as a result of diffusion from a region of higher concentration to a region of lower concentration in a mixture of liquids or gases is known as molecular diffusion.

5. What is Eddy diffusion?

When one of the diffusion fluids is in turbulent motion, eddy diffusion takes place.

6. Classify the various types of air compressors.

a). According to the design and principles of operation

1. Reciprocating compressor and 2. Rotary compressors.

b). According to the acton

1. Single acting compressors and Double acting compressors.

c). According to no. of stages

1. ingle stage compressors and 2. Multistage compressors.

d). According to the pressure limits

1. Low Pressure, 2. Medium Pressure and 3. High pressure.

7. Define the term Isothermal compression efficiency.

It is defined as the ratio between isothermal work to the actual work of the compressor.

8. Define Volumetric efficiency of the compressor?

It is defined as the ratio of volume of free air sucked into the compressor per cycle to the stroke volume of the cylinder.

9. Define FAD or Free Air Delivered.

The free air delivered is the actual volume delivered at the stated pressure with reduced intake pressure and temperature and expressed in m^3/min.

10. What do you mean by perfect inter cooling.

When the temperature of the air leaving the intercooler is equal to the original atmospheric air temperature, then inter cooling is known as perfect inter cooling.

EXP. NO.:
DATE:

PERFORMANCE TEST IN A FLUIDIZED BED COOLING TOWER

Aim

To conduct performance test on Fluidized Bed Cooling Tower to calculate efficiency of the cooling tower.

Apparatus Required

FBCT with essential measuring instruments like Thermometer (both Wet & Dry bulb), U Tube Manometer, Orifice meter and Blower for air supply.

Specifications

1. Pipe Diameter (d_1) --- 40 mm
2. Orifice Diameter (d_2) --- 24 mm

Procedure

1. Connect the water and power supply to the equipment.
2. Adjust the flow rate of water and air (Minimum water and Maximum air flow) just enough for fluidizing the medium.
3. Note the Manometer reading.
4. Note the inlet and outlet temperature of water, condition of air at inlet and outlet by noting readings on the wet bulb and dry bulb thermometers.
5. Repeat the experiment for various flow rates.

Description

The FBCT equipment consists of a 600 mm long Perspex column, 65 mm internal diameter, equipped with air and water flow systems. Ambient air is supplied by centrifugal blower. Air flow rate is measured with an orifice plate of 24 mm diameter connected to a pipe diameter of 40 mm. The water is sprayed at the top of the column. The water flow rate is measured using a water meter provided.

Hot water derived from a heater unit is sprayed on top of the column and collected at the bottom in a vessel. Air from a blower unit flows in a counter current direction to the water. Air inlet and outlet conditions are measured using wet and dry bulb thermometer provided. Water inlet and outlet temperatures are measured using a digital temperature indicator with thermocouple sensors fitted at the respective locations. The flow rates could be altered using the speed controller of the blower. A mist eliminator is provided at the outlet air section.

Formulas

1. **Overall efficiency of the tower**

$$\eta_{over} = \frac{[T_1 - T_2]}{[T_1 - T_{WBT}]}$$

2. **Humidification Efficiency**

$$Humidification\ Efficiency = \frac{[W_2 - W_1]}{[W_3 - W_1]}$$

where W_1 - Specific Humidity of air at inlet condition from Psychrometric chart

W_2 - Specific Humidity of air at outlet condition from Psychrometric chart

W_3 - The maxi possible limit to which air can be humidified up to saturation condition corresponding to spray water temperature of T_1 °C

3. **Mass flow rate of air (m_a)**

$$m_a = 0.6 * \frac{[a_1 * a_2 * \sqrt{2 * g * H}]}{\sqrt{a_1{}^2 - a_2{}^2}} * \rho_a$$ in m/s

where

$$H = \left(\frac{\rho_w}{\rho_a}\right) * (h_1 \sim h_2) \quad in\, m$$

where

ρ_w - Density of water (1000 Kg/m^3)

ρ_a - Density of air (1.16 Kg/m^3)

($h_1 \sim h_2$) - Manometer level difference in m

4. **Heat gained by the air (Q_{air})**

$$Q_{air} = m_a * (h_{inlet} - h_{outlet})$$ in KW

where m_a - Mass flow rate of air in Kg/sec

From Psychrometric chart,

h_{inlet} - Sp. Enthalpy of air at inlet for inlet WBT (T_3) & DBT (T_4) of air in KJ/Kg

h_{outlet} - Sp. Enthalpy of air at outlet for outlet WBT (T_5) & DBT (T_6) of air in KJ/Kg

5. **Heat lost by the water (Q_{water})**

$$Q_{water} = m_w * C_{pw} * (T_1 - T_2) \quad in\, KW$$

where

$$m_w = \frac{1}{t} \quad in\, Kg/sec$$

m_w - Mass flow rate of water

C_{pw} - Specific heat of water (4.178 KJ/Kg K)

T_1 - Temperature of water at inlet in °C

T_2 - Temperature of water at outlet in °C

6. Efficiency of the Fluidized bed cooling tower (η_{tower})

$$\eta_{tower} = \frac{Q_{air}}{Q_{water}} * 100 \quad in\,\%$$

Table:

Sl. No.	Inlet Water Temp	Outlet Water Temp	Inlet condition of Air		Outlet condition of air		Time for 1 Lit. water collection	Manometer Reading	
	T_1	T_2	T_3 WBT	T_4 DBT	T_5 WBT	T_6 DBT	t	h_1	h_2
	°C	°C	°C	°C	°C	°C	Sec	cm	cm

Result

The performance test on Fluidized Bed Cooling Tower (FBCT) is conducted and the efficiency of the tower is ____________________.

VIVA QUESTIONS AND ANSWERS

1. What is free convective mass transfer?

If the fluid motion is produced due to change in density resulting from concentration gradients, the mode of mass transfer is said to be free or natural convective mass transfer.

2. Define forced convective mass transfer?

If the fluid motion is artificially created by means of an external force like a blower or fan, that type of mass transfer is known as forced convective mass transfer.

3. Give two examples for convective mass transfer?

1. Evaporation of alcohol and 2. Evaporation of water from an ocean when air is blows over it.

4. Define Mass concentration.

It is defined as the mass of a component per unit volume of the mixture. It is expressed in Kg/m^3

5. Define Molar concentration.

It is defined as number of molecules of a component per unit volume of the mixture. It is expressed in $Kg – mole / m^3$

6. Define mass fraction.

The mass fraction is defined as the ratio of mass concentration of species to the total mass density of the mixture.

7. Define mole fraction.

The mole fraction is defined as the ratio of mole concentration of a species to the total molar concentration.

8. List out applications of cooling tower.

Steam power plants, Nuclear Power plants and air conditioning units.

9. Explain adiabatic humidification of air.

The air is passed through an insulated chamber. This insulating chamber has sprays in which water is maintained at a temperature higher than the dew point temperature of entering air but lower than its dry bulb temperature. So, both cooling and humidification are done without supplying or rejecting heat from the water supply. At the same time, the same water is circulated again and again.

10. Give the examples of mass transfer.

Some examples of mass transfer. 1. Humidification of air in cooling tower 2. Evaporation of petrol in the carburetor of an IC engine. 3. The transfer of water vapour into dry air.

EXP. NO.:
DATE:

Experimental analysis of Thermal conductivity for various cross section iron rod using LAB VIEW software

Aim:

To determine the thermal conductivity of the iron rod for various cross section area.

Abstract

The objective of this experiment is, To evaluate the thermal conductivity of mild steel experimentally using “Thermal Conduction system – model 9051”.

Experimental results were compared with the theoretical results. There was difference in theoretical and experimental results.

Introduction

Conduction, convection and radiation are basic modes of heat transfer. When a temperature difference exists in a stationary medium, which may be in solid, heat transfer occurs due to conduction across the medium.

By conduction heat spontaneously flows from a body at a higher temperature to a body at a lower temperature. In the absence of external driving fluxes, temperature difference disappear over time and the body approaches thermal equilibrium.

Convection is the major mode of heat transfer in the fluids. In our experiments we had both convection and conduction heat transfer.

Technical Specification

- ✓ Mild Steel bar (variable area) bottom side 25 mm top side 50 mm – 1 no
- ✓ Heater Capacity (250 W) – 1 no
- ✓ Dimer-stat (230 V, 2A) – 1 no
- ✓ Temperature sensor (k-type) – 10 no’s for mild steel bar
- ✓ Temperature Sensor (RTD type) – 2 no’s for water inlet & outlet
- ✓ Masibus Scanner (16 Channel) with Modbus communication – 1 set
- ✓ Digital Voltmeter (0-300 V AC) – 1 no
- ✓ Digital Ammeter (0-5 A AC) – 1 no
- ✓ Lab view based customized software provided

Experimental Procedure

The following experimental procedure should be followed while conducting this experiment:

- ✓ Establish constant and steady cooling water flow
- ✓ Switch ON the main supply and give the input to heater trough dimmer-stat
- ✓ Set the Voltmeter and Ammeter reading
- ✓ Take the reading every 10 min gap to take Voltmeter, Ammeter, Temperature reading 1-12 no's, Water flow rate.
- ✓ After experiment finish please decrease the Dimmer-Stat and Switch OFF the main supply.

Observations and calculation

Observation:

- ✓ Diameter of mild steel in bottom side = 25 mm
- ✓ Diameter of mild steel in top side = 50 mm
- ✓ Length of mild steel = 300 mm
- ✓ Inlet water temperature = …….. °C
- ✓ Outlet water temperature = ………..°C
- ✓ Voltmeter reading = ………. V
- ✓ Ammeter reading = ………..A
- ✓ Volume of flow rate in cooling water, V' = ……… ml/sec

Formula used:

- ✓ Thermal Conductivity of mild steel bar

  $K = Qd/(A \times (T_{hot} - T_{cold}))$ W/mK.

  Where,

  K – Thermal Conductivity of mild steel bar w/mK

  Q – Heat Supplied by system W

  d – Distance, A - Area of the surface,

  T_{hot} - Water outlet Temperature,

  T_{cold} – Water inlet Temperature

- ✓ Heat Supplied

  $Q = mC_p\Delta T$

  Where,

  Q – Heat Supplied, m –Mass of the system

  C_p – Specific heat capacity, ΔT – Change in temperature

- ✓ Cross sectional area, $A = (\pi r_1 + \pi r_2) \times \sqrt{((r_1 - r_2)^2 + h^2)} + \pi (r_1^2 + r_2^2)$

  Where, $r_1 = 0.0254$ m

  $r_2 = 0.0127$ m

  $h = 0.3$ m

Result

Thermal Conductivity of mild steel bar measured successfully with a value of ………………

VIVA QUESTIONS AND ANSWERS

Thermal Conductance

The inverse of thermal resistance is known as thermal conductance, K, and is equal is to the amount of heat flow conducted through a solid of area A and thickness, per degree temperature differences

Thermal Resistance

Thermal resistance is the temperature difference between two surfaces of thickness L per amount of heat conducted through the surface of area A. then the heat flow.

Infinite solids

A solid which extends itself infinitely in all directions of space is known as infinite solid. A Biot Number value is in between 0.1 and 100.

Fourier Number

It is defined as the ratio of characteristics body dimension to temperature wave penetration depth in time.

Factors affecting the Thermal Conductivity

Pressure, Temperature, Humidity, Structure of material, and Density of material.

Heat Flux

The quantity of heat transferred per unit time per unit area of isothermal surface is defined as the heat flux determined by the relation.

Multiple Choice Question for Competitive Exams and Gate Exam

Heat Transfer

1. Unit of thermal conductivity in M.K.S. units is
(a) kcal/kg m2 °C
(b) kcal-m/hr m2 °C
(c) kcal/hr m2 °C
(d) kcal-m/hr °C
(e) kcal-m/m2 °C.

Ans: b

2. Unit of thermal conductivity in S.I. units is
(a) J/m2 sec
(b) J/m °K sec
(c) W/m °K
(d) (a) and (c) above
(e) (b) and (c) above.

Ans: e

3. Thermal conductivity of solid metals with rise in temperature normally
(a) increases
(b) decreases
(c) remains constant
(d) may increase or decrease depending on temperature
(e) unpredictable.

Ans: b

4. Thermal conductivity of non-metallic amorphous solids with decrease in temperature
(a) increases
(b) decreases
(c) remains constant
(d) may increase or decrease depending on temperature
(e) unpredictable.

Ans: b

5. Heat transfer takes place as per -
(a) zeroth law of thermodynamics
(b) first law of thermodynamic
(c) second law of the thermodynamics
(d) Kirchhoff law (e) Stefan's law.

Ans: c

6. When heat is transferred from one particle of hot body to another by actual motion of the heated particles, it is referred to as heat transfer by

(a) conduction
(b) convection
(c) radiation
(d) conduction and convection
(e) convection and radiation.

Ans: a

7. When heat is transferred form hot body to cold body, in a straight line, without affecting the intervening medium, it is referred as heat transfer by
(a) conduction
(b) convection
(c) radiation
(d) conduction and convection
(e) convection and radiation.
Ans: c

8. Sensible heat is the heat required to
(a) change vapour into liquid
(b) change liquid into vapour
(c) increase the temperature of a liquid of vapour
(d) convert water into steam and superheat it
(e) convert saturated steam into dry steam.
Ans: c

9. The insulation ability of an insulator with the presence of moisture would
(a) increase
(b) decrease
(c) remain unaffected
(d) may increase/decrease depending on temperature and thickness of insulation
(e) none of the above.
Ans: b

10. When heat is Transferred by molecular collision, it is referred to as heat transfer by
(a) conduction
(b) convection
(c) radiation
(d) scattering
(e) convection and radiation.
Ans: b

11. Heat transfer in liquid and gases takes place by
(a) conduction
(b) convection
(c) radiation
(d) conduction and convection
(e) convection and radiation.
Ans: b

12. Which of the following is the case of heat transfer by radiation
(a) blast furnace
(b) heating of building
(c) cooling of parts in furnace
(d) heat received by a person from fireplace
(e) all of the above.
Ans: d

13. Heat is closely related with
(a) liquids
(b) energy
(c) temperature
(d) entropy
(e) enthalpy.
Ans: c

14. Pick up tne wrong case. Heat flowing from one side to other depends directly on
(a) face area
(b) time
(c) thickness
(d) temperature difference
(e) thermal conductivity.
Ans: c

15. Metals are good conductors of heat because
(a) their atoms collide frequently
(b) thier atoms-are relatively far apart
(c) they contain free electrons
(d) they have high density
(e) all of the above.
Ans: a

16. Which of the following is a case of steady state heat transfer
(a) I.C. engine
(b) air preheaters
(c) heating of building in winter
(d) all of the above
(e) none of the above.
Ans: e

17. Total heat is the heat required to
(a) change vapour into liquid
(b) change liquid into vapour
(c) increase the temperature of a liquid or vapour
(d) convert water into steam and superheat it
(e) convert saturated steam into dry steam.

Ans: d

18. Cork is a good insulator because it has
(a) free electrons
(b) atoms colliding frequency
(c) low density
(d) porous body
(e) all of the above.
Ans: d

19. Thermal conductivity of water in general with rise in temperature
(a) increases
(b) decreases
(c) remains constant
(d) may increase or decrease depending on temperature
(e) none of the above.
Ans: d

20. Thermal conductivity of water at 20°C is of the order of
(a) 0.1
(b) 0.23
(c) 0.42
(d) 0.51
(e) 0.64.
Ans: d

21. Temperature of steam at around 540°C canbe measured by
(a) thermometer
(b) radiatiouv pyrometer
(c) thermistor
(d) thermocouple
(e) thermopile.
Ans: d

22. Thermal conductivity of air at room temperature in kcal/m hr °C is of the order of
(a) 0.002
(b) 0.02
(c) 0.01
(d) 0.1
(e) 0.5.
Ans: b

23. The time constant of a thermocouple is
(a) the time taken to attain the final temperature to be measured
(b) the time taken to attain 50% of the value of initial temperature difference
(c) the time taken to attain 63.2% of the value of initial temperature difference
(d) determined by the time taken to reach 100°C from 0°C

(e) none of the above.
Ans: c

24. Thermal conductivity of air with rise in temperature
(a) increases
(b) decreases
(c) remains constant
(d) may increase or decrease depending on temperature
(e) none of the above.
Ans: a

25. Heat flows from one body to other when they have
(a) different heat contents
(b) different specific heat
(c) different atomic structure
(d) different temperatures
(e) none of the above.
Ans: d

26. The concept of overall coefficient of heat transfer is used in heat transfer problems of
(a) conduction
(b) convection
(c) radiation
(d) all the three combined
(e) conduction and comte_ction.
Ans: e

27. In heat transfer, conductance equals conductivity (kcal/hr/sqm/°C/cm) divided by
(a) hr (time)
(b) sqm (area)
(c) °C (temperature)
(d) cm (thickness)
(e) kcal (heat).
Ans: d

28. The amount of heat flow through a body by conduction is
(a) directly proportional to the surface area of the body
(b) directly proportional to the temperature difference on the two faces of the body
(c) dependent upon the material of the body
(d) inversely proportional to the thickness of the body
(e) all of the above.
Ans: e

29. Which of the following has least value of conductivity
(a) glass
(b) water

(c) plastic
(d) rubber
(e) air.
Ans: e

30. Which of the following is expected to have highest thermal conductivity
(a) steam
(b) solid ice
(c) melting ice
(d) water
(e) boiling water.
Ans: b

31. Thermal conductivity of glass-wool varies from sample to sample because of variation in
(a) composition
(b) density
(c) porosity
(d) structure
(e) all of the above.
Ans: e

32. Thermal conductivity of a material may be defined as the
(a) quantity of heat flowing in one second through one cm cube of material when opposite faces ^re maintained at a temperature difference of 1°C
(b) quantity of heat flowing in one second through a slab of the material of area one cm square, thickness 1 cm when its faces differ in temperature by 1°C
(c) heat conducted in unit time across unit area through unit thickness when a temperature difference of unity is maintained between opposite faces
(d) all of the above
(e) none of the above.
Ans: d

33. Which of the following has maximum value of thermal conductivity
(a) aluminium
(b) steel
(c) brass
(d) copper
(e) lead.
Ans: a

34. Moisture would find its way into insulation by vapour pressure unless it is prevented by
(a) high thickness of insulation
(b) high vapour pressure
(c) less thermal conductivity insulator
(d) a vapour seal

(e) all of the above.
Ans: d

35. Heat is transferred by all three modes of transfer, viz, conduction, convection and radiation in
(a) electric heater
(b) steam condenser
(c) melting of ice
(d) refrigerator condenser coils
(e) boiler.
Ans: e

36. According to Prevost theory of heat exchange
(a) it is impossible to transfer heat from low temperature source to t high temperature source
(b) heat transfer by radiation requires no medium
(c) all bodies above absolute zero emit radiation
(d) heat transfer in most of the cases takes place by combination of conduction, convection and radiation
(e) rate of heat transfer depends on thermal conductivity and temperature difference.
Ans: c

37. The ratio of heat flow Q1/Q2 from two walls of same thickness having their thermal conductivities as ATj - 2K2 will be
(a) I
(b) 0.5
(c) 2
(d) 0.25
(e) 4.0
Ans: c

38. Heat transfer by radiation mainly depends upon
(a) its temperature
(b) nature of the body
(c) kind and extent of its surface
(d) all of the above
(e) none of the above.
Ans: d

39. Thermal diffusivity is
(a) a dimensionless parameter
(b) function of temperature
(c) used as mathematical model
(d) a physical property of the material
(e) useful in case of heat transfer by radiation.
Ans: d

40. Thermal diffusivity of a substance is .
(a) proportional of thermal conductivity
(b) inversely proportional to k
(c) proportional to (kf
(d) inversely proportional to k2
(e) none of the above.
Ans: a

41. Unit of thermal diffusivity is
(a) m2/hr
(b) m2/hr°C
(c) kcal/m2 hr
(d) kcal/m.hr°C
(e) kcal/m2 hr°C.
Ans: a

42. Thermal conductivity of wood depends on
(a) moisture
(b) density
(c) temperature
(d) all of the above
(e) none of the above.
Ans: d

43. In convection heat transfer from hot flue gases to water tube, even though flow may be turbulent, a laminar flow region (boundary layer of film) exists close to the tube. The heat transfer through this film takes place by
(a) convection
(b) radiation
(c) conduction
(d) both convection and conduction
(e) none of the above.
Ans: c

44. Film coefficient is defined as Inside diameter of tube
(a) Equivalent thickness of film
(b) Thermal conductivity Equivalent thickness of film Specific heat x Viscosity
(c) Thermal conductivity Molecular diffusivity of momentum Thermal diffusivity
(d) Film coefficient x Inside diameter Thermal conductivity
(e) none of the above.
Ans: b

45. Heat conducted through unit area and unit thick face per unit time when temperature difference between opposite faces is unity,is called
(a) thermal resistance
(b) thermal coefficient
(c) temperature gradient

(d) thermal conductivity
(e) heat-transfer.
Ans: d

46. The rate of energy emission from unit surface area through unit solid angle, along a normal to the surface, is known as
(a) emissivity
(b) transmissive
(c) reflectivity
(d) intensity of radiation
(e) absorptivity.
Ans: d

47. Emissivity of a white polished body in comparison to a black body is
(a) higher
(b) lower
(c) same
(d) depends upon the shape of body
(e) none of the above.
Ans: b

48. A grey body is one whose absorptivity
(a) varies with temperature
(b) varies with wavelength of the incident ray
(c) is equal to its emissivity
(d) does not vary with temperature and. wavelength of the incident ray
(e) none of the above.
Ans: c

49. Two balls of same material and finish have their diameters in the ratio of 2 : 1 and both are heated to same temperature and allowed to cool by radiation. Rate of cooling by big ball as compared to smaller one will be in the ratio of
(a) 1 :1
(b) 2: 1
(c) 1 : 2
(d) 4 : 1
(e) 1 : 4.
Ans: c

50. A non-dimensional number generally associated with natural convection heat transfer is
(a) Grashoff number
(b) Nusselt number
(c) Weber number
(d) Prandtl number
(e) Reynold number.
Ans: a