UNIVERSAL INSTITUTE OF ENGINEERING & TECHNOLOGY
LALRU , MOHALI -140501

MECHANICAL ENGINEERING DEPARTMENT

Lab Manual

Course Name	:	Heat Transfer
Course Code	:	
Class	:	B. Tech
Branch	:	ME
Year	:	2019 – 2020

SYLLABUS

HEAT & MASS TRANSFER LABORATORY

COURSE OBJECTIVES:

1. To provide students with the necessary skills to conduct experiments on conduction and convection of heat; collect data, perform analysis and interpret results to draw valid conclusions through standard test procedures

2. To determine thermal properties and performance of radiation heat transfer, heat exchanger, vapour compression refrigerator and air conditioner

COURSE CONTENT

PART – A

1. Determination of Thermal Conductivity of Metal Rod.
2. Determination of Thermal Conductivity of Liquid
3. Determination of Thermal Conductivity of Insulating Material
4. Determination of Overall Heat Transfer Coefficient of a Composite wall.
5. Determination of Effectiveness on a Metallic fin.
6. Determination of Heat Transfer Coefficient in a free Convection on a vertical tube.
7. Determination of Heat Transfer Coefficient in a Forced Convention Flow through a Pipe.

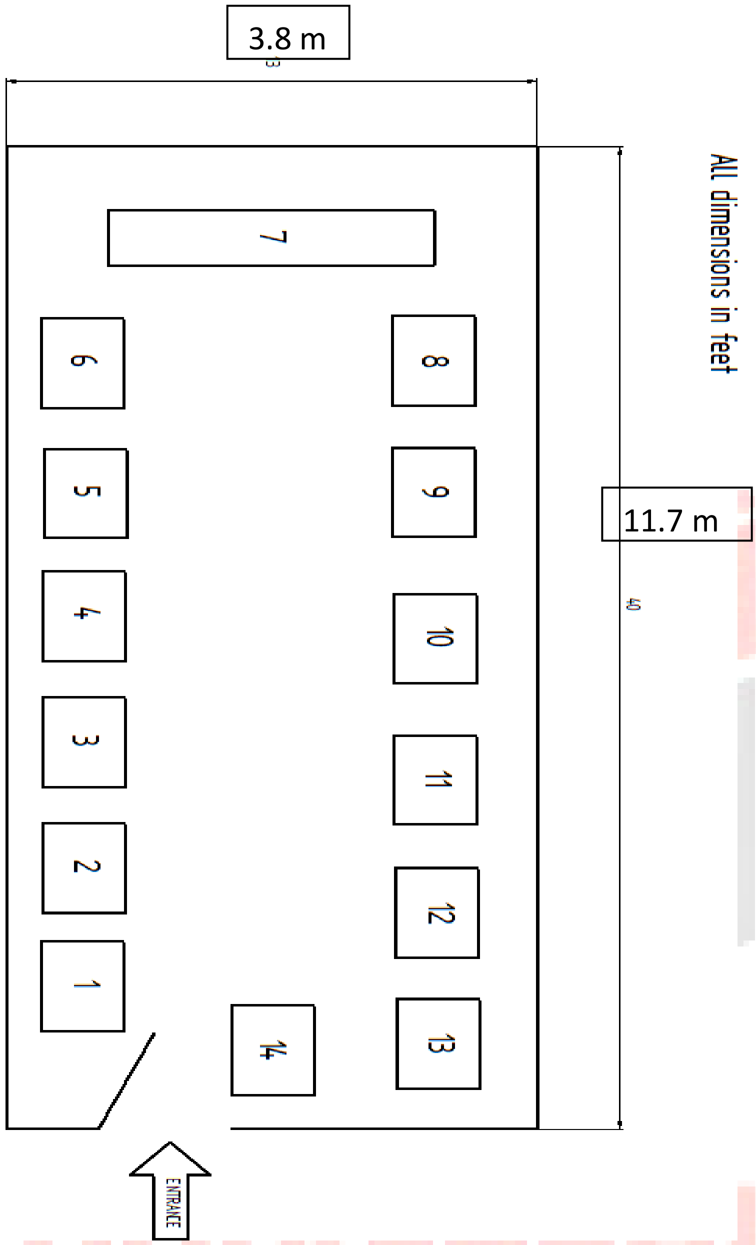
PART – B

8. Determination of Critical Heat Flux.
9. Determination of Emissivity of a Surface.
10. Determination of Stefan Boltzman Constant.
11. Determination of LMDT and Effectiveness in a Parallel Flow and Counter Flow Heat Exchangers.
12. Performance Test on Vapour Compression Refrigeration.
13. Performance Test on a Air – Conditioner

Heat and Mass Transfer Laboratory Manual

Contents:

Laboratory Layout



1. Critical heat flux apparatus
2. Stefan-Boltzmann unit
3. Thermal conductivity of metal rod
4. Emissivity measurement unit
5. Thermal conductivity of liquid
6. Parallel and counter flow heat exchanger
7. Air conditioning test rig
8. Natural convection heat transfer
9. Heat transfer from Pin-Fin unit
10. Forced convection heat transfer
11. Thermal conductivity of composite wall
12. Thermal conductivity of insulating powder
13. Refrigeration test rig
14. Thermal conductivity of insulating material

EXPERIMENT NO.1

THERMAL CONDUCTIVITY OF METAL ROD

AIM:

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

INTRODUCTION:

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

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

Where „Q" is the heat transfer in (watts), „A" is the area of heat transfer (m^2), $\Delta T/\Delta X$ is the temperature gradient in the direction of heat flow ($^0C/m$). Where the proportionality constant is a property of a material and is known as thermal conductivity.

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

The positive constant „k" is called the co-efficient of thermal conductivity of material. The negative sign indicates that heat transfer takes place in the direction of decreasing temperature. Co-efficient of thermal conductivity has the units of W/m^0C. Note that heat flow rate is involved and the numerical value of the co-efficient of thermal conductivity indicates how fast heat will flow in a given material.

Thermal conductivity co-efficient is a physical property of the material. Although it is fairly constant in narrow temperature range, it varies over a wide temperature range. Metals, which are good conductors of heat, have high values of co-efficient of thermal conductivity; for example 385 W/m^0C for copper. Insulating material have low values of co-efficient of thermal conductivity for example 0.048 W/m^0C for fibre insulating board. In any conduction heat transfer problem, it is essential to have the knowledge of co-efficient of thermal conductivity of the material involved in the heat transfer process. This setup has been designed to measure the temperature gradient along the length of the aluminium rod and to determine it"s co-efficient of thermal conductivity.

APPARATUS:

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

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

OPERATIONAL PROCEDURE:

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

g. Read inlet and outlet water temperatures (T7 and T8) of the cooling water jacket.

h. Measure the cooling water flow rate in the rotometer.

i. Using the measured temperatures and water flow rate, the temperature gradient along the length of the aluminium rod and co-efficient of thermal conductivity of aluminium are calculated using the procedure given below.

j. Repeat the experiment for different heat input and mass flow rate of water.

WORKING PRINCIPLE:

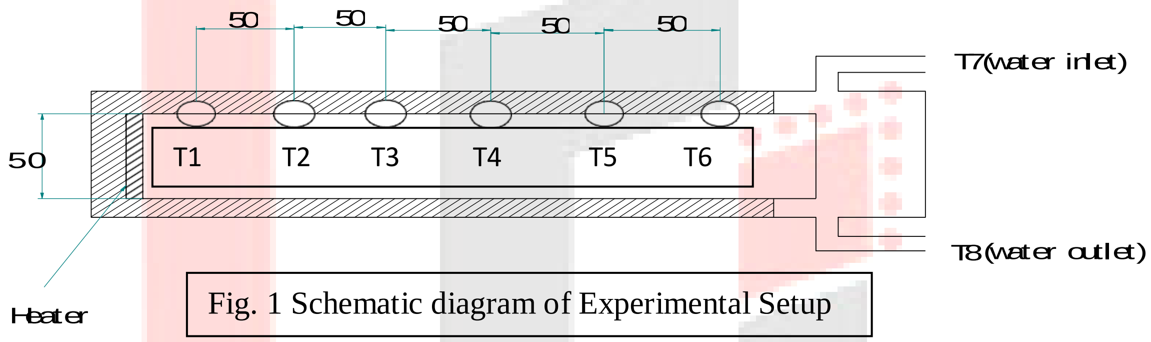


Fig. 1 Schematic diagram of Experimental Setup

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

$$Q_i = Q_0 + Q_l \text{.................}(1)$$

Where

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

Q_0 = Output heat flow rate from the aluminum rod

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

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

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

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

$$Q_i = Q_0 = mCp\ \Delta Tw \text{..........................}(2)$$

ΔTw = Rise in temperature of the cooling water = $(T_7 - T_8)$ in ^{0}C m = water flow rate in kg/s in the cooling water jacket from rotometer.

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

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

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

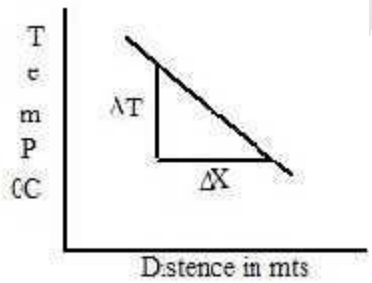


Fig.2: Plot of temperature v/s distance

Thus, the temperature gradient $\Delta t/\Delta x$ at the center of the aluminium rod in ^{0}C/m can be determined from the slope of the curve (by drawing a tangent).

Determination of co-efficient of thermal conductivity:

The heat conduction equation is given by

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

Where,

Q = Heat flow rate through the aluminium rod in watts

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

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

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

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

$k = m\,Cp\,\Delta Tw / [A\,(\Delta t/\Delta x)]$

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

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

TABULAR COLUMN:

Sl no	Heat input			Thermocouple reading in ^{0}C						Cooling water Temperature		Mass flow rate of water		Heat carried away by water	Temperature gradient	Thermal conductivity
	V	A	Q	T1	T2	T3	T4	T5	T6	T7	T8	Lpm	Kg/s	Q_w	dt/dx	K (W/m k)

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

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

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

EXPERIMENT NO.2

THERMAL CONDUCTIVITY OF LIQUID

AIM:

To determine the thermal conductivity of given liquid.

INTRODUCTION:

Heat is transferred or propagated by three different processes, viz., Conduction, Convection and Radiation. The fact that heat can be conducted through a body is very well known. For example when a metal rod is heated at one end, the heat gradually spreads along the rod and the other end becomes hot after some time. The power of transmitting heat in this manner is proposed by all substances solids, liquids, gases , to vary degree and the process is called Conduction.

Conduction is a process of heat transfer through solids or liquids. For a given temperature difference between surfaces , rate of heat transfer (Q watts) depends upon the coefficient of thermal conductivity of a substance (K , W/m^{o}C) , area of the heat transfer (A,m^2) and temperature difference (Δt,^{0}C) between the surfaces and thickness of the material (ΔX , m) according to the equation,

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

Substances such as metals conduct more heat and have a high value of thermal conductivity, as high as 200 W/m^{0}C. Insulating materials conduct less heat and have lower values of thermal conductivity say about 0.1 to 1 W/m^{0}C. In circumstances where the heat loss from the system has to be minimized, such as power transmission lines, furnaces etc,. it is essential to cover them with proper materials. This setup has been designed to study heat transfer through liquids.

In determination of conductivity of liquids , the problem is to eliminate Convection which will transmit more heat than conduction. By insulating on all sides and circulating cooling water on one side this effect can be minimized.

SPECIFICATION AND DESCRIPTION:

The setup consists of the following items.

a) *Aluminum Cylinder*:

The aluminium cylinder is of size 100 mm in diameter and 100 mm in length. The thermocouples are placed to measure the oil temperature at intervals of 25 mm. The outer surface is properly insulated to avoid heat loss.

b) *Heaters*:

Provided to heat the liquid. There are two heaters, one is at the bottom of the cylinder and other is at the outer surface of the cylinder.

* Capacity

Band Heater	:	150 watts
Flat Heater	:	150 watts

c) *Cooling arrangement*:

The top surface of the cylinder is cooled by water cooling as shown in the figure. The water is continuously circulated through the water jacket with the fixed rate of flow.

d) *Thermocouples*: K-type to measure temperature

1,2,3,4 : At a interval of 25mm , to measure liquid temperature at different points.

6 : Water outlet temperature to the cooling jacket.

5 : Water inlet temperature to the cooling jacket.

e) Channel selectors and digital temperature indicators.

f) Heat control or Regulator : To vary input power of the heater.

g) Control Panel : To switch on/off the console and the heater.

h) Digital Voltmeter and Digital Ammeter to measure voltage and amperage.

OPERATIONAL PROCEDURE :

1. Switch - ON the Mains and the Console.
2. Switch - ON the Heater.
3. Set the heat control or regulator.
4. Allow water to flow through the cooling jacket. Wait for some time till the temperature stabilizes with time, i.e, steady state is reached.
5. Read the temperatures T1 to T6 using channel selector and digital temperature indicator.
6. Note down the Voltmeter and Ammeter Readings.

7. Using the temperatures, measure rate of heat transfer and the coefficient of the thermal conductivity using given procedure.

WORKING PRINCIPLE:

The heat balancing equation for one dimensional flow is given by, (neglecting the losses in stable condition)

Heat lost from oil = Heat gained by water

i.e, $Q_L = Q_W$

$Q_W = m \times C_P \times (T6 - T5)$ in Watts

Where,

m = Mass flow rate in kg/s.

C_P = Specific heat of water in J/Kg C

$Q_L = K A (dT/dX)$ in Watts

Where,

K = Thermal conductivity of Liquid in W/m C

A = Area of the cylinder in m^2

dT/dX = Temperature slope

From Eqn.1 $Q_W = Q_L$

$m \times C_P \times (T6 - T5) = K A (dT/dX)$

OBSERVATIONS:

Diameter of cylinder containing liquid: 100 mm

Height of the cylinder: 100 mm

Distance between the thermocouples: 25 mm

Tabular Column

SL. NO	V	I	Q	Mass Flow Rate		Thermocouple Reading , Oil temperature				Water inlet temperature	Water outlet temperature	Q_w	Q_L	K
				LPM	Kg/s	T1	T2	T3	T4	(T5)	(T6)			W/m°C

CALCULATIONS:

1. Heat gained by water:

Q_W = m x C_P x (T6 – T5)

where , m = Mass flow rate in Kg/s.
C_P = Specific heat of water
= 4187 J/KgK
T6 = Water outlet temperature
T5 = Water inlet temperature

2. Heat Conducted through liquid

Q_L = K A (dT/dX)

Where, K = Thermal conductivity of Liquid in W/m^2C
A = Area of the cylinder in m^2
dT/dX = Temperature slope

On Equating

K = (Q/A)(dT/dX) W/m C

EXPERIMENT NO.3

THERMAL CONDUCTIVITY OF INSULATING MATERIAL

AIM:

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

INTRODUCTION:

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

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

Rate of heat transfer through a material is given by,

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

Where,

Q = Rate of heat transfer in Watt

K = Co-efficient of thermal conductivity in W/m^0C

A = Area of heat transfer in m^2

ΔT = Temperature between the walls in^0C

ΔX = Thickness of the material in m

Insulators have low thermal conductivities say, about $0.1W/m^0C$ to $1W/m^0C$ whereas metals which are good thermal conductors have co-efficient of thermal conductivity as high as $200W/m^0C$

This setup has been designed to study conduction heat transfer through insulating powder and to determine it‟s co-efficient of thermal conductivity.

SPECIFICATION AND DESCRIPTION

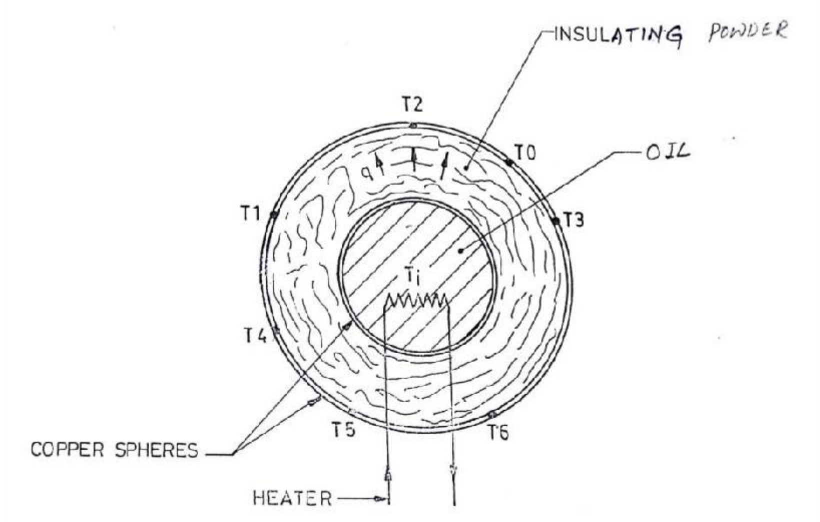


Figure shows the schematic of the experimental setup for thermal conductivity of insulating material. The system consists of the following:

a) Insulating sphere:
   It consists of two concentric spheres. The inner and outer sphere have 250mm and 300 mm diameters respectively. The space between the spheres is filled with insulating powder. The inner sphere is filled with oil and a heater is provided in it to heat the oil to the required high temperature. The arrangement is such that the heat transfer from the inner sphere to the outer sphere can be studied.
b) Oil heater:
   Capacity: 500W
c) Digital voltmeter and ammeter to measure power input.
d) Digital temperature indicator to measure temperature.
   Temperature points:
   T1, T2, T3 – temperatures on the upper hemisphere in ^{0}C
   T4, T5, T6 – temperatures on the lower hemisphere in^{0}C
   T7 – temperature of the oil in the sphere in ^{0}C
e) Thermostat to set and control heater voltage at a particular temperature.
f) Electrical supply: 1Ph, 230V, 16A with ground.

OPERATIONAL PROCEDURE :

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

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

WORKING PRICIPLE:

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

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

K = Thermal conductivity of the powder in W/m^0C

Q = Total heat transfer rate in Watt

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

r_i = Radius of the inner sphere = 125mm

r_o = Radius of outer sphere = 150mm

ΔT = Ti – To in ^0C

Ti = Inside oil temperature in ^0C

To = (T1+T2+T3+T4+T5+T6)/6 in ^0C

OBSERVATIONS:

r_i = Radius of the inner sphere = 125mm

r_o = Radius of outer sphere = 150mm

TABULAR COLUMN

Sl NO	Heat input			Temperature on Sphere						Average Sphere Temperature	Oil Temperature	Shape Factor R	Themal Conductivity K in W /m C
	V	I	Q	T1	T2	T3	T4	T5	T6	T_0	$T7 = T_i$		

EXPERIMENT NO.4

HEAT TRANSFER THROUGH COMPOSITE WALL

AIM:

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

INTRODUCTION:

Conduction is a process of heat transfer through solids. For a given temperature difference between the surfaces, the rate of heat transfer (Q, watts) depends upon the coefficient of thermal conductivity of the substance (k, W/m K), area of heat transfer (A, m^2) and the temperature difference (**ΔT**, ^{0}**C**)between the surfaces and thickness of the material (Δ X, m) according to the equation,

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

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

APPARATUS:

The setup consists of the following important items:

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

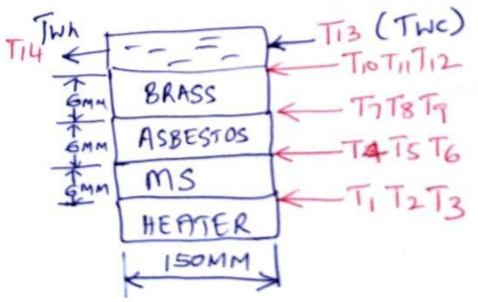
c) Thermostat: to set and control heater temperature range.

d) Control panel: to switch on/off the console and the heater.

PROCEDURE

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

WORKING PRINCIPLE:



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

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

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

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

Tabular column:

Heat input			Temperature of composite wall															
V	I	Q	Bottom of MS plate				Top of MS plate				Top of Asbestos plate				Top of brass plate			
			T1	T2	T3	Tmb	T4	T6	T7	Tmt	T7	T8	T9	Tat	T10	T11	T12	Tbt

Mass flow rate of water in Kg/s	Water inlet temperature	Water outlet temperature	Heat carried away by water in W	Overall heat transfer co-efficient	
	T13	T14	Q_w	U_{exp}	U_{th}

That is, Qi = m Cp ΔTw

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

Cp = specific heat of water 4.2 kJ/kg K

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

Qi = m Cp **Δ** Tw = Kms A **(**ΔTms /Lms) = Kas A **(Δ** Tas /Las) = K_b A **(Δ** T_b /L_b)

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

L = length of the heat flow.

U_{th} = 1/[Lms/Kms + Las/Kas + L_b/K_b] …….W/m°C

Calculations:

Q_0 = m Cp **Δ** Tw = W

A = (Π/4)*D^2 = m^2

Kms = (Q/A) * L_{ms}/(T_{mb}-T_{mt}) = W/m°C

$Kas = (Q/A) * L_{as}/(T_{mt}-T_{at}) =$ W/m°C

$K_b = (Q/A) * L_b/(T_{at}-T_{bt}) =$ W/m°C

Overall heat transfer coefficient,

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

U= …. W/m°C

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

EXPERIMENT NO.5

HEAT TRANSFER COEFFICIENT IN NATURAL CONVECTION

AIM:

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

INTRODUCTION:

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

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

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

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

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

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

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

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

Q=h A Δ T, where **Q**=heat transfer rate in watts

A=surface area of heat flow in m^2

ΔT=over all temperature difference between the wall and fluid

h= convection heat transfer co-efficient in watts

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

Apparatus:

1. A metallic tube of diameter (d) 45 mm and length (L) 450mm with a electrical heater coil along the axis of the tube.

2. Seven thermocouple are fixed on the tube surface.

3.Control panel instrumentation consists of multichannel digital display

a)Temperature indicator to measure surface temperature T1 to T7 of the tube and ambient temperature T8.

b) Digital ammeter and voltmeter to measure power input to the heater.

c) Regulator to control the power input to the heater.

5. Front transparent acrylic enclosure for safety of the tube when not in use.

OPERATIONAL PROCEDURE:

1. Keep the tube in vertical position.

2. Switch ON the mains and the control.

3. Set the regulator to set the heat input.

4. Wait for sufficient time to allow temperature to reach steady values.

5. Note down temperatures T1 to T8 using channel selector and digital temperature indicator.

6. Note down the Ammeter and Voltmeter readings.

7. Tabulate the heat input and transfer co-efficient using the procedure.

8. Calculate the convection heat transfer co-efficient using the procedure given below.

9. Repeat the experiment by changing the heat input.

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

Calculations:

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

Therefore, **Q= h As (Ts-T∞)**

Where,

Q = (Ammeter reading) x (Voltmeter reading), in watts

D D= Diameter of tube= 45 mm

L= length of the tube = 450 mm

As=Tube surface area = π D L = m^2

Ts= (T1+T2+T3+T4+T5+T6+T7)/7 = °C

T∞= T_8 = Ambient air temperature=T8= °C

Therefore,

Heat transfer co-efficient, h_{expt}= Q/As (Ts-T∞) = W/m^2K

Determination of Theoretical heat transfer co-efficient:

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

Note down the properties of air t from data hand book

Tm = (Ts+ T∞)/2 = °C

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

ν= m^2/s

k= W/mK

Pr=

β = 1/(Tm +273) = K^{-1}

ΔT = (Ts-T∞) = °C

g= 9.81 m/s^2

Gr (Groshoff No.) = $(g\ \beta\ L^3 \Delta T)/\ \nu^2$ =

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

Nu = hL/k,

h_{th} = W/m^{2}K

RESULTS

h_{exp}= W/m^{2}K

h_{th} = W/m^{2}K

EXPERIMENT NO.6

HEAT TRANSFER COEFFICIENT IN FORCED CONVENTION

AIM:

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

INTRODUCTION:

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

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

$Q=h\ A\ \Delta T$

Where, Q=heat transfer rate, watt

A=surface area of heat flow, m^2

ΔT=overall temperature difference between the wall and fluid in ^0C

h= convective heat transfer coefficient ($W/m^{20}C$).

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

Mode	„h" $W/m^2\ ^0C$
Free convection	5-25
Forced convection: air , water	10-500, 100-15000
Boiling water	2500-25000
Condensation and water vapor	5000-100000

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

APPARATUS:

The important components of the set up are:

a. Heat exchanger tube-the tube is thermally insulated outside to prevent heat transfer losses to the atmosphere.
b. Heater, wattage :500 watts (approx.)
c. Regulator to control the power input to the heater
d. Volt and Ampere Meters to measure power input to the heater
e. ThermocouplesT1 and T7 to measure air temperature at the inlet and outlet of the duct. T2 - T6 to measure test specimen temperatures.
f. Channel selector
g. Digital temperature indicator
h. Blower: to blow air through the heat exchanger.
i. Orifice meter with manometer to air flow rate from the blower.
j. Control panel to house the whole instrumentation.

OPERATIONAL PROCEDURE:

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

WORKING PRINCIPLE:

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

Where,

Q=heat transfer rate, W

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

P=power input to the heater

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

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

L= length of the tube 0.5 m

D = diameter of the tube 40 mm

d = orifice diameter 20 mm

ΔT=average temperature between the tube and the air ^0C

h=convective heat transfer coefficient (W/m^2K)

C_d=

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

TABLE OF MEASUREMENTS:

Sl.No.	Heat Input			Manometer readings		Head of water hw	Temperatures of tube, °C					Air Temperature		Water Temperature		Convective heat transfer coefficient	
	V	I	Q	h1	h2	h1~h2	T_2	T_3	T_4	T_5	T_6	Inlet T1	Outlet T2	Inlet T1	Outlet T2	h_{th}	h_{ex}

Calculations:

Determination of experimental heat transfer co-efficient calculations

$T_s = [T_2+T_3+T_4+T_5+T_6]/5 =$ °C

$T_\infty = [T_1+T_7] / 2 =$ °C

$\Delta T = (T_s - T_\infty) =$ °C

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

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

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

$T_m = (T_s + T_\infty)/2 =$ °C

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

Kinematic viscosity of air, $\nu =$ m^2/s

Thermal conductivity of air, k W/m k

Pr =

Calculation of velocity of air (V):

$A_1 = \Pi/4*D^2=$ m^2, $A_2 = \Pi/4*d^2=$ m^2

$\rho_a = P/RT =$ kg/m^3

$\rho_w h_w = \rho_a h_a$, $h_a =$ m

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

$V = Q_a/ A_1 =$ m/s

$Re = (VD)/\nu =$

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

Choose the equation from data book based on Reynods number.

$hD/k = Nu$,

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

EXPERIMENT NO.7

EFFECTIVENESS ON A PIN FIN

AIM:

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

INTRODUCTION:

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

APPARATUS:

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

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

OPERATIONAL PROCEDURE:

1) Switch on the mains and console

2) Switch on the heater and adjust the power input.

3) Wait till steady state is reached and note down all the temperature indication by the temperature indicator.

4) After conducting experiment in natural convection mode, start the blower and adjust the flow as required for forced convection.

5) Increase the power supplied to the heater as to maintain the same temperature before starting the blower.

6) Wait till steady state condition is reached and note down the temperature as well as velocity of flow.

7) Repeat the procedure for different heat inputs.

Tabular Column:

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

Calculations:

1) Surface Temperature, Ts= (T1+T2+T3+T4+T5)/5
2) Atmospheric temperature, $T\infty$ = T6=
3) $T_{mean} = (T\infty + Ts)/2$

   At mean temperature note down the values of thermo physical properties of air from heat transfer data hand book thermo physical properties of air are (ν) kinematic viscosity, (K_{air}) thermal conductivity of air and Prandtl No.
4) Reynolds no(Red) =(v∗d)/(γ) ,where „v" is velocity of air flowing over the fin

   Based on the Reynolds no choose the value of constants C and m from the heat transfer data hand book
5) $h = K_{air} [C.\ Red^{m} (Pr)^{0.33}]/d$
6) $Q = \sqrt{(hPKA)}\ (Ts - T\infty)\ \tanh(mL)$
7) Efficiency, η= tanh(mL)/(mL)
8) Effectiveness, ε=

tanh(mL)/[√(hA/PK)] where, Ts=Surface

temperature of fin

$T\infty$=surrounding temperature (^{0}C)

L=length of fin = m

d=diameter of the fin =   m

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

A= $\pi d^2/4$ m^2

K=thermal conductivity of Al

= W/m°C

Result:

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

Efficiency of the fin (η) is %.

Effectiveness of the fin (ε) is

EXPERIMENT NO.8

CRITICAL HEAT FLUX

AIM:

To study boiling heat transfer phenomenon across the given wire and determine critical heat flux.

INTRODUCTION:

When heat is added to a liquid from a submerged solid surface which is at temperature higher than the saturation temperature of the liquid, it is for a part of the liquid to change phase. This change of phase is called boiling. Boiling is of various types, the types depending on the temperature difference between the surface and liquid. The different types are indicated by fig(1) in which typical experimental boiling curve obtaining in a saturated pool of liquid is drawn.

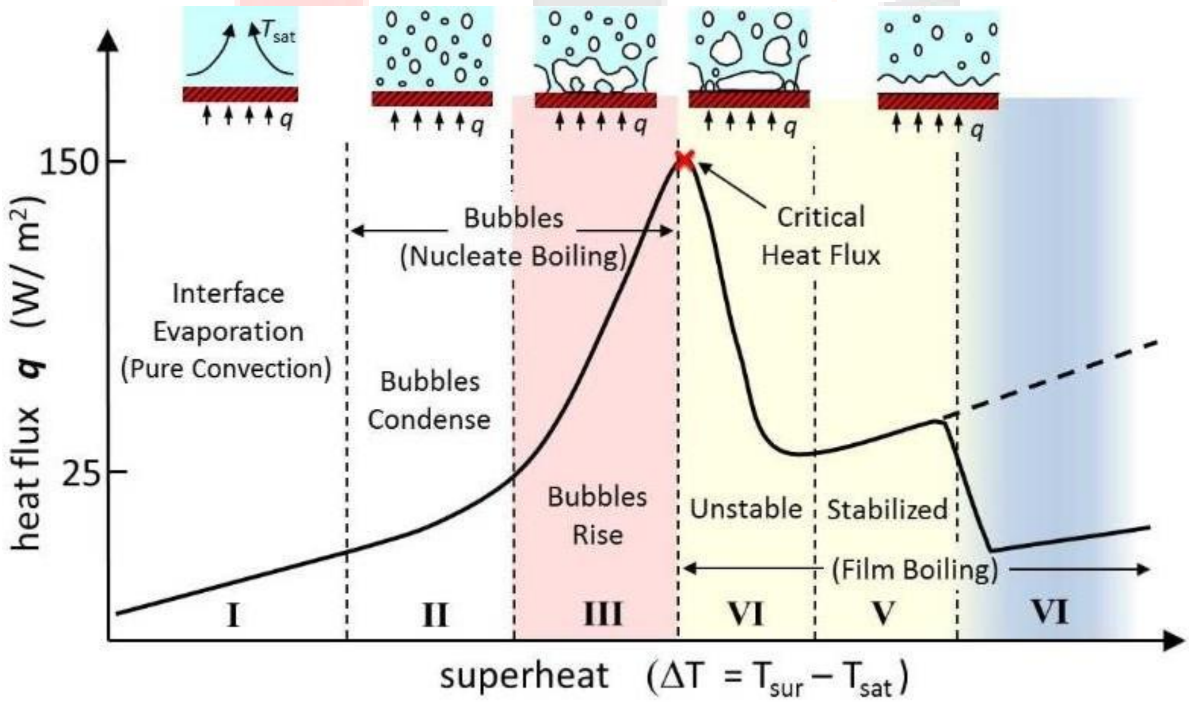


Fig1: Boiling curve

The heat supplied to the surface is plotted against (Tw-Ts), the difference between the temperature of the surface and the saturation temperature of the liquid. It is seen that boiling curve can be divided into three regions; 1. Natural convection region, 2. Nuclear boiling region,3) Film boiling region. The region of natural convection occurs at low temperature differences. Heat transferred from the heat surface to the liquid in the vicinity causes the liquid to super heated. This super heated liquid rises to the free liquid surfaces by natural convection, where is produced by the evaporation.

As the temperature difference (Tw-Ts) is increased, nucleate boiling starts. In this region, it is observed that, bubbles start to from at certain location on the heated surface. Region 2 consists of a two parts. In the first part 2a, the bubbles are formed are very few in number of locations where they are formed increase. Some of the bubbles now rise all the way to the free surface.

With increasing temperature difference, a stage is finally reached when rate of formation of bubbles is so high, that they start to collapse, and blanked the surface with a vapour film. This is the beginning of the region 3, viz., film boiling, in the first part of this region, 3a the vapour film is unstable. So that film boiling may be occurred a portion of the heated surface area, nucleate boiling may be occurring on the remaining area. In the second part 3b, a stable film covers the entire surface. The temperature difference in this region is of the order of 1000^0C and consequently radiative heat transfer the across the vapor film is also significant.

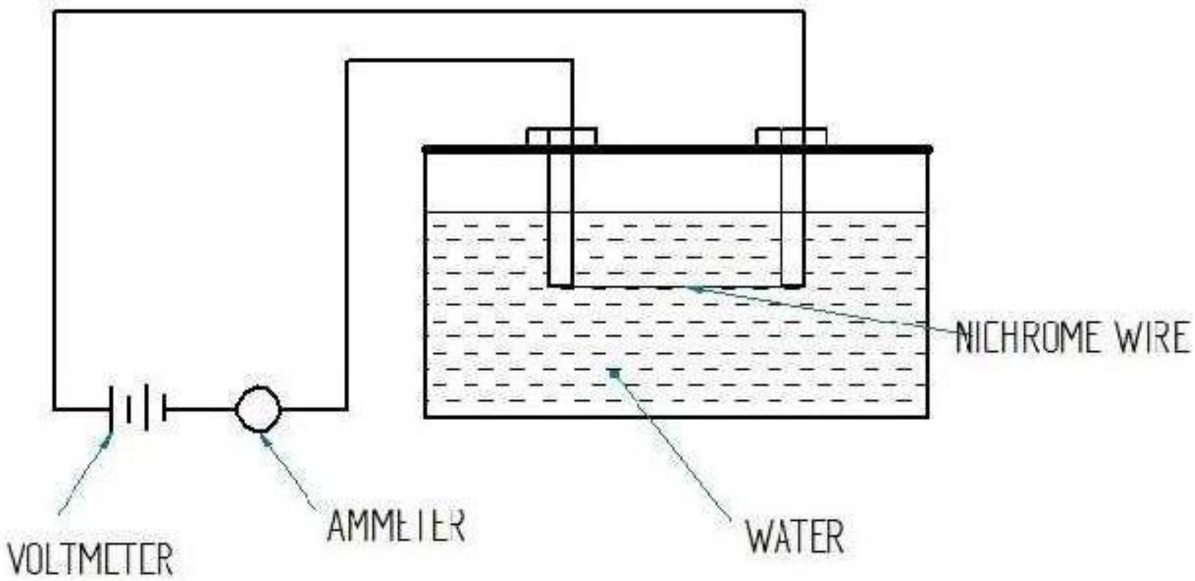
It is observed from fig(1) that the heat flux do not increase in the regular manner with the temperature difference. In region 1, the heat flux is proportional to (Tw-Ts) where in is slightly greater than unity. When transition from natural convection to nucleate boiling occurs, the heat flux start increase more rapidly with temperature difference, the value of an increasing to about 3.at the end of the region 2,the boiling curve reached a peak(point a). Beyond this, in region 3a inspite of increasing the temperature difference, the heat flux decreases because of thermal resistance to heat flow increases with the formation of vapour film. The heat flux passes through a minimum (point b) at the end of the region 3a,. it starts increasing again with (Tw-Ts) only when stable film boiling and radiation becomes increasingly important.

The discussion so far has been concerned with the various types of boiling which occur in saturated pool boiling. If the liquid is below the saturation temperature we say that sub cooled pool boiling is taking place. Also in many practical situation eg,. Steam generator; one is interested in boiling in a liquid flowing through tubes. This is called forced convection boiling. It is obvious that forced convection boiling may also be saturated or sub – cooled of the nucleate of film type.

It is of interest to note how the temperature of the heating surfaces changes as the heat flux is steadily increased from zero. Up to the point A, natural convection boiling and then nucleate boiling occur and the temperature of the heating surface is obtained by reading the value of (Tw-Ts) from the boiling curve and adding to it the value of A.the temperature of the surface will shoot up to the value corresponding to the point C. it is apperent from the fig1 that the surface temperature corresponding to the point C is high. For most surfaces, it is enough to cause the metal to melt. Thus in most practical situations, it is undesirable to exceed the value of heat flux corresponding to point A. this value is therefore of considerable engineering significance and called the critical or peak heat flux. The pool-boiling curve as described above is known as Nucleate Pool Boiling Curve.

APPARATUS:

The apparatus consists of a container housing the test heater and heater coil for initial heating of the water. This heater coil is directly connected to the mains and the test heater is connected also to the main through dimmer stat and an ammeter is connected in series while a voltmeter across it to read the current and voltage. A micro controlled based peak detector has been provided to measure the maximum current during the process. The heater wire can be viewed through a poly carbonate glass window.



Specification:

- Heater for initial heating – heater coil -1.5 kW
- Test heater (R-1) nichrome wire = mm (to be measured according to wire used
- Length of wire = mm,

EXPERIMENT:

The experimental set up is designed to study the pool boiling phenomenon up to critical heat flux point. The pool boiling over the heater wire can be visualized in the different regions up to the critical heat flux point at which the wire melts. The heat flux from the wire is slowly increased by gradually increasing the applied convection to the nucleate boiling can be seen. The formation of bubbles and their growth in size and number cam be visualized followed by vigorous bubble formation and their immediate carrying over to surface.

PROCEDURE:

1. Take the sufficient quantity of distilled water in the container.
2. See that both heaters are completely submerged.
3. Connect the test wire across the studs.
4. Switch on the auxiliary heater and maintain the bulk temperature of the water in the container
5. Switch on test heater W2.
6. Very gradually increases the voltage across it by slowly changing the variac from one position to the other and stop a while at each position to observe the boiling phenomenon on wire.
7. Record the voltage and current at various intermediate stages. This can be used to find the resistance of wire, at varying temperature. Note down the resistance at room temperature can be calculated.
8. Go to increasing the voltage till wire breaks and carefully note the voltage and current at this point.
9. Repeat this experiment by altering the bulk temperature of water.

Precautions:

1. Keep the variac to zero voltage position before starting the experiment take sufficient amount of distilled water in the container so that both the heaters are immersed completely.
2. Connect the test heater wire across the studs.
    1. Do not touch the water or terminal points after putting the switch is in ON position.
    2. Very gradually operate the variac in steps and allow sufficient time between.
    3. After attaining the critical heat flux condition, decrease slowly the voltage and bring it to zero.

Observations:

- Diameter of test heater wire, d =   mm
- Length of the test heater wire, L =   mm

Note: The ammeter and voltmeter readings are to be noted down for each bulk temperature.

Tabular Column:

Voltage, V	Current, I	Heat Input Q = VxI	$q = Q/\pi dL$ (W/m^2)	Critical Heat Flux, q_c (W/m^2)

EXPERIMENT NO.9

EMISSIVITY OF SURFACE

AIM:

To determine the emissivity of the radiating surface

INTRODUCTION:

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

$$Q = \sigma A T^4$$

Where, „Q‟ is the heat transfer rate in watts, "σ" is called Stefan Boltzman‟s Constant having the value of $5.669x10^4$ W/m^2K^4,‟A‟ is the surface area (m^2)

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

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

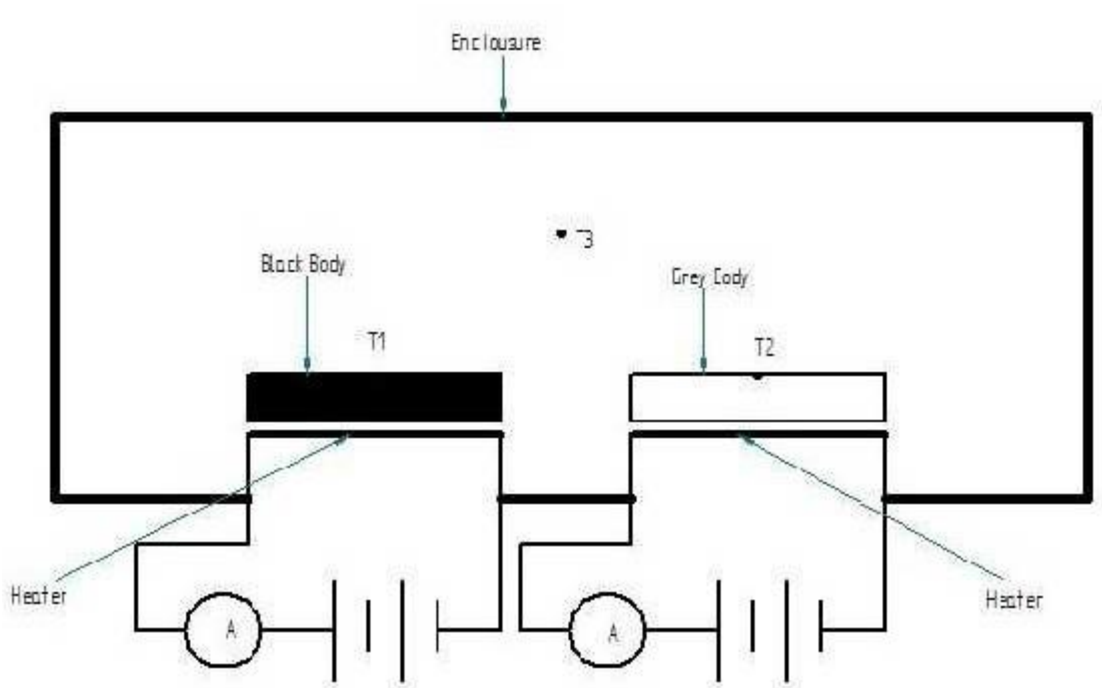


Fig:1 Scheme diagram for emissivity apparatus

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

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

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

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

Channel selector and digital temperature display.

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

<u>**OPERATIONAL PROCEDURE:**</u>

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

d. Observe the temperature of the black body and test surface in close time intervals and adjust power input to the test plate heater such that both black body and test surface temperature are same. This procedure requires trial and error method and one has to wait sufficiently long to reach the steady state.

e. After attaining steady state, record input powers to heaters and temperatures of the black body, test plate and the enclosure. Using the above measurements calculate the emissivity of the test surface using the procedure given below.

WORKING PRINCIPLE:

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

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

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

V_1=voltage across heater to black surface (volts)

I_1=current to the black surface (amps)

V_2=voltage across heater to test plate (volts)

I_2=current to the test plate heater (amps)

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

d= diameter of the test plate m

T_1=temperature of the black plate ,K

T_2=temperature of the test plate , K

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

ε =emissivity of the test plate

σ = Stefan boltman‟s constants

=5.67×10^{-8} $W/m^2 K^4$

The constant in the denominator (0.86) takes into account various factors such as radiation shape factor, effect of conduction and free convention losses and other factors (such as non-uniformities in enclosures temperatures), which cause deviation from the typical radiation heat transfer, experiment. The above analysis requires that the temperature of black surface and test plate are same (T1=T2).

Tabular Column:

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

Sample calculation:

A = 0.7854*d^{2} = m^2

$$\varepsilon = 1 - \frac{0.86[Qb - Qg]}{\sigma \times A[T_1^4 - T_3^4]}$$

Result:

Emissivity of the surface is

EXPERIMENT NO.10

STEFAN BOLTZMAN CONSTANT

AIM:

To determine the Stefan boltzman‟s constant.

INTRODUCTION:

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

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

Q=rate of the heat transfer , watts

σ=Stefan boltzman‟s constant=5.669×10^{-8} watts/m^2K^4

A=surface area , m^2.

The above equation is only applicable for black bodies (for ex, a piece of metal covered with carbon black approximates this behaviour) and is valid only for thermal radiation. Other types of bodies (like a glossy painted surface or a polished metal plate) do not radiate as much as energy as the black body but still the radiation emitted follows T^4 proportionality.

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

APPARATUS:

The setup consists of the following important parts,

a. Copper hemispherical enclosure.
b. Non-conducting base plate made of asbestos.
c. Thermocouples, iron – constantan type to measures temperature on the copper hemisphere T_1 and T_2 on the disc and T3 on specimen and T4 of hot water
d. Disc mounted in insulated bakelite sleeve, made of aluminium.
   Disc dia(D): mm, mass (m) = grams,
   Specific heat = kJ/kgK.

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

WORKING PRINCIPLE:

The enclosure is maintained at the higher temperature using heater. The disk or the test piece is inserted in to its place along with variation in its temperature (T3) with time is recorded.

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

$$Q_e = \sigma\, A_D T_e^{\,4} \ldots\ldots\ldots (1)$$

Where,

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

A_D=area of the disc,m^2

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

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

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

Where, (dT/dt),is the rate of increase in temperature (^{0}C/sec) at the instant when the disc is inserted in to the setup. The stefan boltzman constant is obtained using the relationship,

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

OPERATIONAL PROCEDURE:

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

e. Allow the heated water enters into the hemispherical enclosure to attain uniform high temperature –the enclosure will soon reach thermal equilibrium.

f. Measure the enclosure temperature with the thermocouple (T_1 and T_2) using channel selector and digital temperature indicator.

g. Insert disk (D) with sleeve into its position and record temperature of the disc (T_3) at different instant of time using stop watch.

h. Plot the variation of disc temperature (T_3) with time sec as shown in fig(2) and get the slope of temperature versus time variation (^{0}C/sec) at the time t=0 sec.

i. Using eq(3) calculate the Stefan boltzman‟s constants.

j. Repeat the experiments 3 to 4 and calculate the average value to obtain the better value of the Stefan boltzman‟s constant.

Tabular Column:

Sl.No.	Time „t‟ (s)	Specimen Temperature „T_3‟ (°C)

Calculations:

1. Temperature of the enclosure = T_{sphere} ^{0}C
2. Mass of the test disc (m)= gm
3. Specific heat of the disc material Cp= J/kg ^{0}C
4. Obtain (dT_3/dt) using the plot of the T_3 vs t and determine the slope.

5. Calculate Stefan boltzman‟s constant using the relationship.

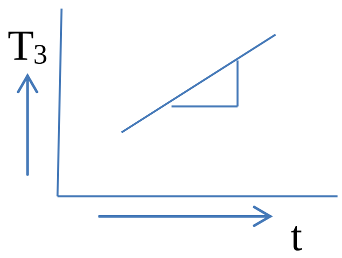


Fig 2: Plot of temperature T_3 v/s t

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

Sample calculations:

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

$dT_2 / dt =$ $^0C/s$ by plotting graph and taking slope.

T_s = Average temperature of hemispherical cup T1+T2/2 = K

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

Result: stefan boltzman constant $\sigma =$ W/m^2K^4

EXPERIMENT NO.11

EFFECTIVENESS OF HEAT EXCHANGERS

AIM:

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

INTRODUCTION:

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

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

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

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

OPERATIONAL PROCEDURE:

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

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

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

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

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

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

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

Tabular Column:

Sl. No.	Mass flow rate of water, Kg/s		Mode of operation	T_{hi} (^{0}C)	T_{ho} (^{0}C)	T_{ci} (^{0}C)	T_{co} (^{0}C)	effectiveness
	Hot water (m_h)	Cold water m_c						
			Parallel flow					
			Counter flow					

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

Qh = mh x Cph ($T_{h,i}$- $T_{h,o}$) Ch = mh x Cph if Ch< Cc ε= [($T_{h,i}$- $T_{h,o}$)/ (T_{hi}- $T_{c,i}$)]

Qc = mc x Cpc ($T_{c,0}$- $T_{c,i}$) Cc = mc x Cpc if Cc< Ch ε= [($T_{c,o}$- $T_{c,i}$)/ (T_{hi}- $T_{c,i}$)]

Cpc = 4200kJ/kgK hw = head of water in mts

Theoretical effectiveness calculations:

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

Q= (Qh+ Qc)/2
Q=UA ΔTM where,
Q=heat transfer rate, watts
U=overall heat transfer co efficient
A=surface area of heat transfer ,m^2
D=diameter of the inner tube, m
L=effective length of heat exchanger, m
ΔTM_{lm}=logarithmic mean temperature

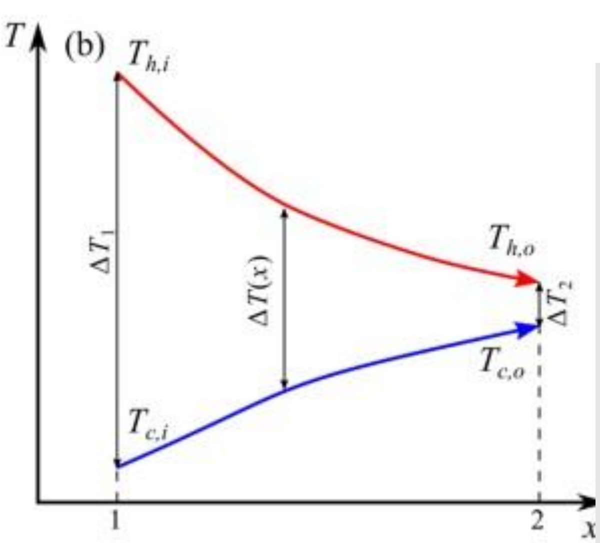


Fig: Temperature V/S Length diagram of Parallel flow heat exchanger

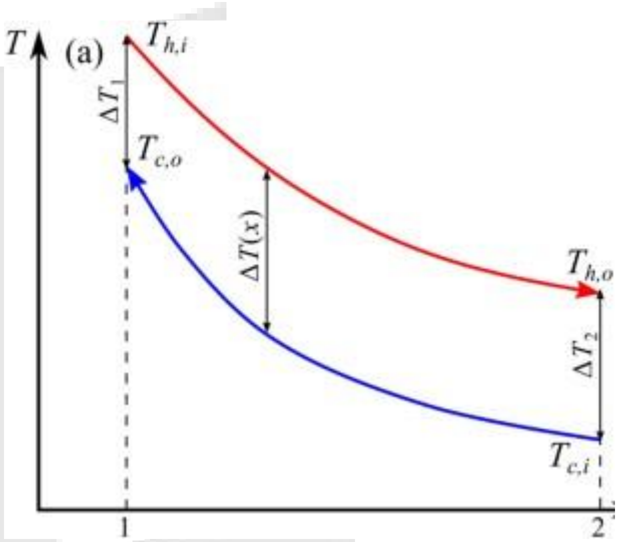


Fig: Temperature V/S Length diagram of Counter flow heat exchanger

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

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

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

$T_{h,i}$= Inlet temperature of hot water in ^{0}C
$T_{c,i}$= Inlet temperature of cold water in ^{0}C
$T_{h,o}$= Outlet temperature of hot water in ^{0}C
$T_{c,o}$= Outlet temperature of cold water in ^{0}C

U = q/ (A x ΔT_{lm}), Ch = mh x Cph , Cc = mc x Cpc, Compare the values of Ch and Cc which ever value is minimum that value is considered as Cmin other value is Cmax

NTU =[U x A] / Cmin; C = Cmin/ Cmax

Theoretical effectiveness for **Parallel flow** heat exchanger

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

Theoretical effective ness for **Counter flow** heat exchanger

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

Results:

Experimental effectiveness for **Parallel flow** heat exchanger

Experimental effectiveness for **Counter flow** heat exchanger

Theoretical effectiveness for **Parallel flow** heat exchanger

Theoretical effectiveness for **Counter flow** heat exchanger

EXPERIMENT NO.12

VAPOUR COMPRESSION REFRIGERATION

AIM:

To find the COP of vapour compression refrigeration system.

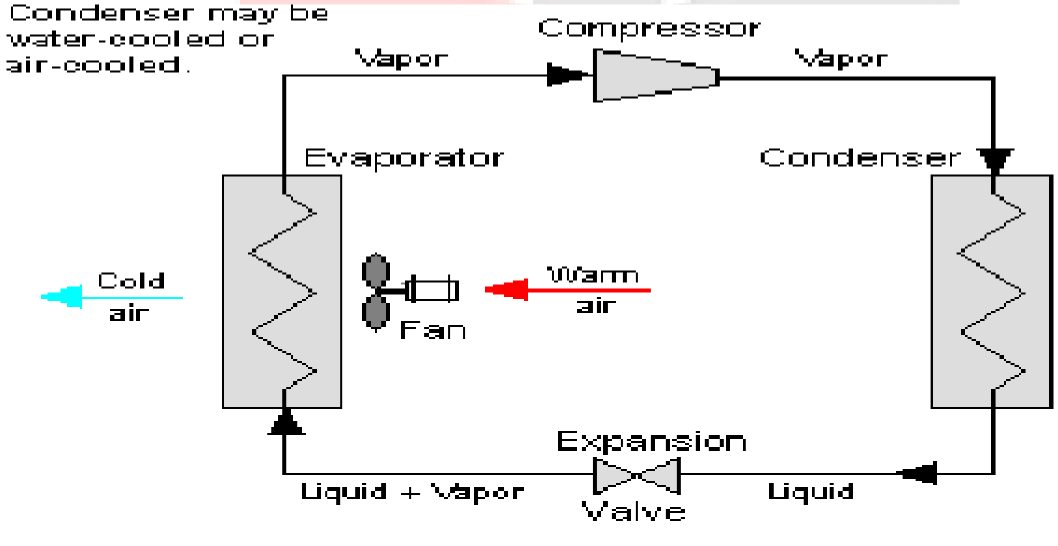
INTRODUCTION:

Refrigeration is the process of providing and maintaining temperature of system below that of surrounding atmosphere. The vapour refrigerant entering the compressor to a high pressure and temperature is in isentropic manner.

The high pressure and high vapour first drop to T_{sat} and subsequently the vapour refrigerator condenses to liquid state. The liquid refrigerant is collected in the liquid storage tank and later it is expanded to low pressure & temperature by passing it through the throttle valve.

The low temperature liquid then enters the evaporator where it absorbs heat from the space to be cooled mainly the refrigerator & become vapour.

COP= Refrigerator effect/work done= (ha-hc)/(hb-ha)



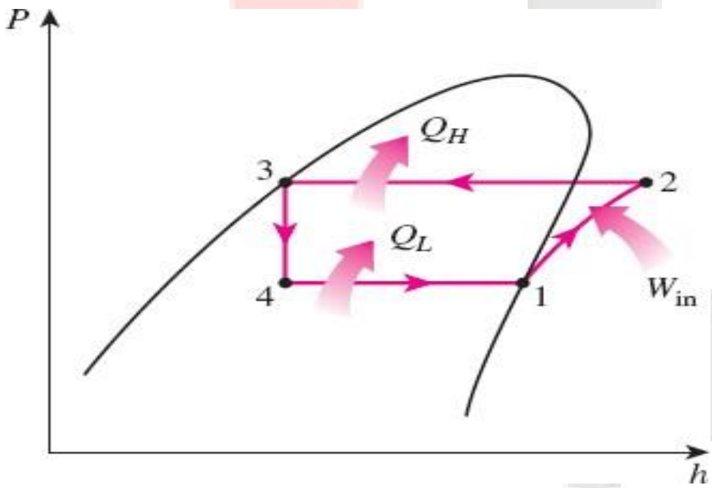
VAPOR COMPRESSION REFRIGERATION

PROCEDURE:

1. Switch on the mains, console and compressor.
2. Keep known quantity of water inside the evaporator and note down the intial time
3. Wait for temperature to reach steady state.
4. Once the steady state is reached, note down temperature T1,T2,T3,T4.
5. Note down the pressure P1 & P2.
6. Finally calculate COP and relative COP

TABULAR COLUMN:

Sl. No.	Pressure		Temperature (^{0}C)			
	Condenser, P1	Evaporator, P2	T1	T2	T3	T4



CALCULATIONS:

Theoretical COP of VCR:

COP_{th} = Net Refrigerating effect/ work done on compressor

$COP_{th} = [(h_1-h_4)/(h_2-h_1)]$

The enthalpies h_1, h2, and h_4 note down from Pressure enthalpy diagram of refrigerant shown in figure

EXPERIMENTT NO.13

AIR CONDITIONING TEST RIG

AIM:

To determine the air conditioning effect and Coefficient of performance.

INTRODUCTION:

The science of air conditioning deals with maintaining a desirable internal air conditions irrespective of external atmospheric conditions. The factors involved in any air conditioning installation are:

a. Temperature
b. Humidity
c. Air movement and circulation
d. Air filtering, cleaning and purification

The simultaneous control of these factors within the required limits is essential for human comfort or for any industrial application of the air conditioning system.

In any air conditioning system, temperature and humidity are controlled by thermodynamic processes. Depending on the season, the air conditioning processes involve cooling, heating, humidification and dehumidification of air. Other aspects such as air movements, circulation, purification etc. obtained by installing suitable fans, blowers, ducting and filters.

Dry air: Mechanical mixture of oxygen, nitrogen, carbon dioxide etc.
Moist air: Mixture of dry air and water vapour
Saturated air: It is a mixture of dry air and water vapour when the air has diffused the maximum amount of water vapour into it.
Degree of saturation: It is the ratio of actual mass of water vapour in a unit mass of dry air to the mass of water vapour in the same mass of dry air when it is saturated at the same temperature and pressure.
Humidity: It is the mass of water vapour present in 1 kg of dry air expressed in gm per kg of dry air.
Absolute Humidity: It is the mass of water vapour present in 1 m^3 of dry air, expressed in gm per cubic meter of dry air.
Relative Humidity: It is the ratio of actual mass of water vapour in a given volume of moist air to the mass of water vapour in the same volume of saturated air at the same temperature and pressure.
Dry bulb temperature: It is the temperature of air recorded by a thermometer when it is not affected by the moisture present in the air.
Wet bulb temperature: It is the temperature of air recorded by a thermometer when its bulb is surrounded by a wet cloth exposed to the air.

Psychometer: It is an instrument containing dry bulb thermometer and wet bulb thermometer. The difference in the readings of these two thermometers gives the relative humidity of the air surrounding the psychometer.

<u>APPARATUS</u>:

The test rig consists of a cooling coil which is part of the vapour compression refrigeration system working on refrigerant. In the downstream of the cooling coil, heaters are provided to heat air. The system is provided with fans, air duct and valve system to circulate air over the cooling coil and heaters and to operate the system in both closed and open cycles. The system is instrumented with thermometers and wind velocity indicators to determine the state of air-moisture mixture during the operation of the air conditioning system. Following are the important components.

1. Cooling coil of the vapour compression refrigeration system consisting of compressor, condenser, throttle/capillary tube, digital pressure and temperature indicators with selector switch and power meter. The system works on refrigerant.
2. Suction fan
3. Duct system with a window (close/open).
4. Wind anemometer to measure air velocity in the duct.
5. Temperature indicators to measure air temperature upstream of the cooling coil and downstream of air.
6. Digital pressure indicator at both upstream and downstream of compressor.
7. Digital power meter for compressor and heater.
8. Pressure switches to limit pressures upstream and downstream of compressor.

<u>OPERATIONAL PROCEDURE:</u>

i. Open Cycle – Cooling:

a. Switch „ON‟ the Mains and the Console.
b. Open the window and the set the valve to work the air conditioning system in the open cycle operation.
c. Switch „ON‟ the thermostat, keep at maximum.
d. Switch „ON‟ all the MCB‟s
e. Switch „ON‟ the compressor of the refrigeration unit, the cooling coil temperature begins to fall.
f. Switch „ON‟ the suction fans.
g. Switch „ON‟ the pre-heater.
h. Observe temperatures at the inlet and outlet of the air conditioning unit till the fairly steady state is reached.
i. Note the following:

T1= Temperature of refrigerant after evaporator or inlet to compressor (°C)

T2 = Temperature of refrigerant after compression (°C)

T3 = Temperature of refrigerant after condensation (°C)

T4 = Temperature of refrigerant after throttle/capillary tube (°C)

T5 = Air inlet temperature, before cooling coil (°C)

T6 = Air outlet temperature, after cooling coil and post heater (°C)

HP=Pressure, High Pressure Side (kg/cm^2)

LP=Pressure, Low Pressure Side (kg/cm^2)

V= Air velocity from wind anemometer (m/s)

P_c = Power input to the compressor (Watts)

Ph = Power input to the heater (Watts)

ii. Closed Cycle – Cooling:

Repeat the above procedure with the following:

a. Window closed
b. Valve different position to facilitate the circulation of air inside the duct system
c. Additional fan switched „OFF".

iii. Humidification-open cycle operation:

Repeat the above procedure with the following:

a. Open the window, position the valve accordingly.
b. Switch „ON" both the fans.
c. Switch „ON" both pre-heater and post-heater.
d. Switch „ON" the steam generator.

iv. Simulation of winter air conditioning – open cycle operation:

Repeat the above procedure with the following:

a. Open the window, position the valve accordingly.
b. Switch „ON" both the fans.
c. Switch „ON" post-heater only (Switch „OFF" pre-heater and steam generator).

WORKING PRINCIPLE:

a. Definitions of some psychometric processes:

Sensible cooling: It is a process where air is cooled without changing the specific humidity.

Sensible heating: It is a process where air is heated without changing the specific humidity.

Humidification: It is a process where moisture is added to the air without changing the dry bulb temperature.

De-humidification: It is a process where moisture is removed from the air without changing the dry bulb temperature.

b. Cooling – Open and closed cycles:

In this process, air passes over the pre-heater and becomes hot. Hot air is cooled to a lower temperature while passing over the cooling coil of the refrigeration system. Air is cooled without adding or subtracting the water vapour to the dry air.

The heat rejected by the air (per kg of air) during cooling can be obtained from the psychometric chart by the enthalpy (H) difference between the air inlet and outlet.

Heat rejected = $(H_5 – H_6)$ kJ/kg

It may be noted that the specific humidity remains constant ($W_i = W_o$), the dry bulb temperature reduces from T_5 to T_6 and the relative humidity increases from Φ_i to Φ_o.

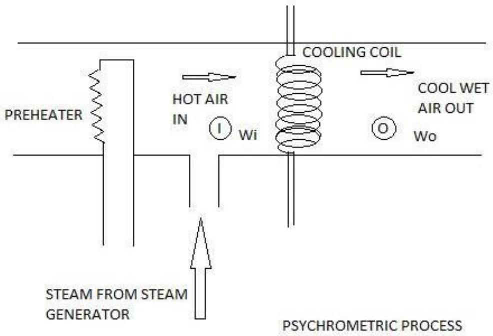
c. Simulation of Winter Air heating Process:
In this process, cold air from the cooling coil is again heated to the required temperature by the post heater. This simulates the air heating process encountered during winter.

d. Using this air conditioning system, study of the following thermodynamic processes can also be made:

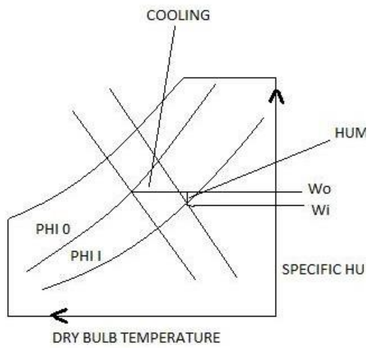
i. Heating and Humidification and

ii. Sensible heating.

These processes can be represented on a psychometric chart.



PSYCHROMETRIC PROCESS



PSYCHROMETRIC CHART

FIG. SCHEMATIC OF COOLING AND HUMIDIFICATION PROCESS

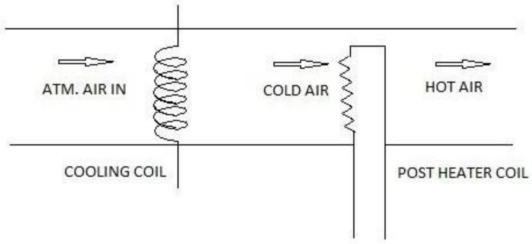


FIG. SCHEMATIC OF COOLING AND HUMIDIFICATION PROCESS

Calculations:

1. **COOLING – OPEN CYCLE:**

a. Refrigeration Cycle:

Temperatures	Pressures
T1 =	HP= bar
T2 = °C	LP= bar
T3 = °C	
T4 = °C	

b. Air Conditioner:

Temperatures

T5 = °C

T6 = °C

Air Velocity= m/s

Power to compressor= kW

c. Calculation of co-efficient of performance and Ton of refrigeration:

From the pressure-enthalpy diagram for refrigerant, we get

H_1= KJ/kg

H_2= KJ/kg

H_3= KJ/kg

H_4= KJ/kg

Co-efficient of Performance (COP) = $\frac{H1-H4}{H2-H1}$ = =

HP per Ton of Refrigeration =

Power input to compressor = kW =

Ton of refrigeration =

2. COOLING – CLOSED CYCLE:

a. Refrigeration Cycle:

Temperatures Pressures

T1 = °C HP= bar

T2 = °C LP= bar

T3 = °C

T4 = °C

b. Air Conditioner:

Temperatures

T5 = °C

T6 = °C

Air Velocity= m/s

Power to compressor= kW

c. Calculation of co-efficient of performance and Ton of refrigeration:

From the pressure-enthalpy diagram for refrigerant, we get

H_1= KJ/kg

H_2= KJ/kg

H_3= KJ/kg

H_4= KJ/kg

Co-efficient of Performance (COP) = $\frac{H1-H4}{H2-H1}$ = – =

HP per Ton of Refrigeration =

Power input to compressor =

Ton of refrigeration =