EXPERIMENT NO-1

THERMAL CONDUCTIVITY OF METAL ROD

AIM:
To determine the Thermal Conductivity of a given metal rod.

INTRODUCTION:

Heat conduction is the transfer of energy between neighboring molecules in a substance due to a temperature gradient. In metals also the free electrons transfer energy. In solids which do not transmit radiation, heat conduction is the only process for energy transfer. In gases and liquids heat conduction is super imposed by an energy transport due to convection and radiation.

According to Fourier’s conduction law “the rate of heat transfers directly proportional to the temperature difference and area, but is inversely proportional to the thickness of the layer.

\[ Q_{\text{Cond}} \propto A \frac{dT}{dx} \quad \Rightarrow \quad Q_{\text{Cond}} = -KA \frac{dT}{dx} \]

The proportionality constant \( k \) is the thermal conductivity of the material. It can be defined as the “rate of heat transfer through unit thickness of the material per unit area per unit temperature difference”. The thermal conductivity \( K \) is a scalar as long as the material is isotropic, which means that the ability of the material to conduct heat depends on the position of the material. Thermal conductivity of a material depends on the chemical composition of the substances of which it is composed, the phase (i.e. gas, liquid or solid) in which it’s crystalline structure if a solid, the temperature & pressure to which it is subjected and whether or not it is homogeneous material.

Thermal energy in solids may be conducted in two modes. They are:
- LATTICE VIBRATION:
- TRANSPORT BY FREE ELECTRONS.

In good electrical conductors a rather large number of free electrons move about in a lattice structure of the material. Just as these electrons may transport may transport electric charge, they may also carry thermal energy from a high temperature region to low temperature region. In fact, these electrons are frequently referred as the electron gas. Energy may also be transmitted as vibration energy in the lattice structure of the material. In general, however, this latter mode of energy transfer is not as large as the electron transport and it is for this reason that good electrical conductors are almost always good heat conductors, for eg: ALUMINIUM, COPPER & SILVER.

With the increase in temperature, however the increased lattice vibrations come in the way of electron transport by free electrons and for most of the pure metals the thermal conductivity decreases with the increase in the temperature.

The modes of heat transfer are:
(a) Conduction
(b) Convection
(c) Radiation.
(a) **Conduction**: If the flow of heat is a result of transfer of internal energy from one molecule to another, the process is called conduction. Through solids, this is the only possible mode of heat transmission.

(b) **Convection**: In liquids and gases, however, the molecules are no longer confined to a certain point but constantly change their positions even if the substance is at rest. The heat energy is transported along with the motion of these molecules from one region to another. This process is called convection.

(c) **Radiation**: All solid bodies as well as liquids and gases have a tendency of radiating thermal energy in the form of electromagnetic waves and of absorbing similar energy emerging from the neighboring bodies. This type of heat transport is known as thermal radiation.

### Thermal conductivity of selected substances at 20°C and 100 k Pa

<table>
<thead>
<tr>
<th>Substance</th>
<th>K in W/Km</th>
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<tr>
<td>Silver</td>
<td>427</td>
<td>Water</td>
<td>0.598</td>
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<td>Copper</td>
<td>399</td>
<td>Hydrocarbons</td>
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<td>0.5...1.3</td>
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<td>R 123</td>
<td>0.0090</td>
<td>Krypton</td>
<td>0.0093</td>
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</table>

### PRECAUTIONS:

1. Do not give heater input without the supply of water.
2. Input should be given very slowly.
3. Run the water in the jacket for about 5 min after the experiment.
4. Do not run the equipment if the voltage is below 180V.
5. Check all the electrical connections before running.
6. Before starting and after finishing the experiment the heater controller should be in off position.
7. Do not attempt to alter the equipment as this may cause damage to the whole system.

### PROCEDURE:

1. Give necessary electrical and water connections to the instrument.
2. Switch on the MCB and console ON to activate the control panel.
3. Give input to the heater by slowly rotating the heater regulator.
4. Start the cooling water supply through the water jacket (make sure not to exceed 3 LPM)
5. Note the temperature at different points, when steady state is reached.
6. Repeat the experiment for different heater input.
7. After the experiment is over, switch off the electrical connections, allow the water to flow for some time in the water jacket and then stop it.
EXPERIMENTAL SETUP

Fig: Metal rod with thermocouple placement and water flow.

Fig: Thermal Conductivity of Metal Rod Experimental Setup
PRE-VIVA QUESTIONS:

1. What are the basic heat transfer mechanisms
2. What is the driving force to transfer following
   (i) Heat transfer (ii) Mass transfer (iii) Fluid transfer (iv) Electrical energy transfer
3. What are the applications of heat transfer?
4. Differentiate between heat transfer and thermodynamics?
5. Define the conduction heat transfer modes?
6. What are the assumptions of Fourier conduction law?
7. What is thermal conductivity?
8. Mention the thermal conductivity of following materials
   (i) Diamond (ii) Gold (ii) Copper (iii) Aluminum (iv) Brick (v) Mica (vi) Bakelite
9. Define thermal diffusivity

READING TABLE:

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<th>Sl. No.</th>
<th>V Volts</th>
<th>I A</th>
<th>R Lpm</th>
<th>T₁ °C</th>
<th>T₂ °C</th>
<th>T₃ °C</th>
<th>T₄ °C</th>
<th>T₅ °C</th>
<th>T₆ °C</th>
<th>Q W</th>
<th>K W/mK</th>
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SPECIFICATIONS:

- Type of Material = Aluminium
- Diameter of the metal rod = 50mm
- Test length of the metal rod = 200mm
- Distance between two consecutive thermocouples = 50mm
- Distance between First end and first thermocouple, last thermocouple and last end
  = 25mm
- Thermocouple type-K type (Cr-Al)
- Maximum voltage and current range=150 V

CALCULATIONS:

1. CROSS – SECTIONAL AREA OF METAL ROD:

   \[ A = \frac{\pi \times D^2}{4} \text{ m}^2 \]
Where,

\[ D = \text{diameter of the metal rod} = 0.05 \text{m}. \]

2. **MASS FLOWRATE OF WATER, } m_w \]

\[ m_w = \frac{R}{60} \text{ kg/s} \]

Where,

- \( R \) = Rota meter reading in LPM.

3. **HEAT INPUT TO THE SYSTEM, } Q_1 \]

Heat input to the system = Heat carried away by water

\[ Q_1 = Q_w \]

\[ Q_w = m_w \times C_{pw} \times \Delta T_w \quad \text{Watts.} \]

Where,

- \( m_w \) = mass flow rate of water, kg/sec.
- \( C_{pw} \) = Specific heat of water = 4180 J/kg °C.
- \( T_1 \) to \( T_4 \) = Temperatures on metal rod at different locations, °C
- \( T_5 \) and \( T_6 \) = Inlet and outlet temperatures of cooling water, °C
- \( \Delta T_w \) = Temperature difference of water inlet and outlet from the water jacket.
  \[ = (T_6 - T_5) \ °C \]

4. **THERMAL CONDUCTIVITY OF THE METAL ROD, } K \]

\[ K = \frac{Q_1}{A \times \frac{dT}{dX}} \text{ W/m°C} \]

Where,

- \( A \) = cross – sectional area of the rod, m²
- \( dT/dX \) = slope calculated from graph. (Shown in the diagram), °C/m

**MODEL GRAPHS:**
Where ‘X’ = test length with thermocouple points as shown below

**RESULT:** Thermal conductivity of given material is: ______________________W/m °C.

**VERIFICATION:** The experiment conducted and verified with the standard value of thermal conductivity of metal rod (say, $K_{\text{Aluminium}} = 209$ W/m °C).

**CONCLUSION:** The experiment value of thermal conductivity of metal rod is less than the standard value because (i) the thermal conductivity of a material may depend on temperature and also the temperature of the material does change with time (ii) Also, it depends on the composition of the metal rod used in experimentation.

**POST VIVA QUESTIONS:**

1. For which material thermal conductivity is highest?
2. Why negative sign in Fourier’s Law?
3. What are the units of thermal conductivity?
4. How is thermal conductivity measured practically?
5. What is the material for which thermal conductivity is to be found in thermal conductivity of solids experiment?
EXPERIMENT NO-2  

HEAT TRANSFER THROUGH COMPOSITE WALL

AIM:
- To determine the overall heat transfer coefficient through a composite wall
- To compare with theoretical value of overall heat transfer coefficient.

INTRODUCTION:

In engineering applications, we deal with many problems. Heat Transfer through composite walls is one of them. It is the transport of energy between two or more bodies of different thermal conductivity arranged in series or parallel. For example, a fastener joining two mediums also acts as one of the layers between these mediums. Hence, the thermal conductivity of the fastener is also very much necessary in determining the overall heat transfer through the medium. An attempt has been made to show the concept of heat transfers through composite walls.

PROCEDURE:
Symmetrically arrange the plates and ensure perfect contact between the plates.
1. Switch ON mains and the CONSOLE.
2. Set the heater regulator to the known value.
3. Wait for sufficient time to allow temperature to reach steady values.
4. Note down the Temperatures 1 to 7 using the channel selector and digital temperature indicator.
5. Note down the ammeter and voltmeter readings.
6. Calculate the overall conductance using the procedure given below.
7. Repeat the experiment for different heat input.

PRECAUTIONS:
1. Check all the electrical connections.
2. Do not run the equipment if the voltage is below 180V.
3. Do not attempt to alter the equipment as this may cause damage to the whole system.

**PRE VIVA QUESTIONS:**
1. Define heat transfer coefficient.
2. Define Thermal Conductance.
3. Define Composite wall.
4. What do you mean by thermal conductivity, give typical values of thermal Conductivities of metals, solid non metals, liquids & gases

**EXPERIMENTAL SETUP**

Fig: Heat Transfer through Composite Wall Experimental Set-up
Fig: Heat Transfer through Composite Wall Experimental Set-up

### TABULAR COLUMN

<table>
<thead>
<tr>
<th>Sl No</th>
<th>Flow meter reading in LPM</th>
<th>Temperature in °C</th>
<th>Heat conducted Q&lt;sub&gt;cond&lt;/sub&gt; in W</th>
<th>Overall heat transfer coefficient U&lt;sub&gt;expt&lt;/sub&gt; W/m&lt;sup&gt;2&lt;/sup&gt;°C</th>
<th>Overall heat transfer coefficient U&lt;sub&gt;theor&lt;/sub&gt; W/m&lt;sup&gt;2&lt;/sup&gt;°C</th>
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### SPECIFICATIONS:

- Capacity of the Heater: 400 Watts
- Diameters of the each rod, d: 50 mm
- Length of the Aluminium rod, L<sub>1</sub>: 12mm
- Length of the Mild steel rod, L<sub>2</sub>: 25mm
- Length of the Bakelite rod, L<sub>3</sub>: 20mm
- Water flow meter: 0.2 to 2 LPM
- Thermostat range: 0-350 °C
- Thermal conductivity of metal rods:
  - Aluminium = K<sub>1</sub> = 205 W/m-K
  - Mild steel K<sub>2</sub> = 25 W/m-K
  - Bakelite K<sub>3</sub> = 0.08 W/m-K
CALCULATIONS:
1. HEAT CONDUCTED OR HEAT CARRIED BY WATER
   \[ Q_{\text{Cond}} = m_w \times C_p \times (T_6 - T_5) \text{ W} \]
   Where,
   - \( m_w \) = mass flow rate of water or flow meter reading in liter/sec = \( \frac{m_w}{60} \) kg/sec
   - \( C_p \) = specific heat of water 4180 J/kg-K
   - \( T_5 \& T_6 \) = Water inlet & outlet Temperature in °C

2. EXPERIMENTAL OVERALL HEAT TRANSFER COEFFICIENT
   \[ U_{\text{expt}} = \frac{Q_{\text{Cond}}}{A \times (T_1 - T_4)} \text{ W/m}^2\text{K} \]
   Where,
   - \( A \) = Cross sectional area of the rods = \( \frac{\pi \times d^2}{4} \), m²
   - \( T_1 \& T_2 \) = Surface temperature of the metals °C

3. THEORETICAL OVERALL HEAT TRANSFER COEFFICIENT
   \[ U_{\text{Theo}} = \frac{1}{\left( \frac{L_1}{K_1} \right) \times \left( \frac{L_2}{K_2} \right) \times \left( \frac{L_3}{K_3} \right)} \text{ W/m}^2\text{K} \]
   Where,
   - \( L_1, L_2, L_3 \) = length of the Aluminium, Mild steel and Bakelite rod respectively.
   - \( K_1, K_2, K_3 \) = thermal conductivity of the Aluminium, Mild steel and Bakelite rod respectively.

4. TEMPERATURE AT THE SURFACE
   \[ Q_{\text{Cond}} = \frac{K_1 \times A(T_1 - T_2)}{L_1} = \frac{K_2 \times A(T_2 - T_3)}{L_2} = \frac{K_3 \times A(T_3 - T_4)}{L_3} \text{ W} \]

RESULTS:
- The experimental overall heat transfer coefficient of composite wall is ____ W/m² K.
- The theoretical overall heat transfer coefficient of composite wall is ____ W/m² K.

VERIFICATION: The experimental value of overall heat transfer coefficient of the given composite wall is compared and verified with calculated theoretical value.

CONCLUSION: The overall heat transfer coefficient of a composite wall depends on the heat flux, the temperature difference and experimentally found thermal conductivity. For a composite material, the experimentally found thermal conductivity of each material is found to be higher than given value. Therefore, the experimental overall heat transfer coefficient is greater than the theoretical overall heat transfer coefficient.

POST VIVA QUESTIONS:
1. When overall heat transfer coefficient will be used?
2. What is the effect of temperature on thermal conductivity of non-metallic Solids?
3. What is Periodic heat flow?
4. Define thermal contact resistance
5. Define critical thickness of insulation. What is its significance?
EXPERIMENT NO-3

HEAT TRANSFER THROUGH PIN – FIN

AIM:
- To find out the temperature distribution along the given fin for constant base temperature under natural and force flow conditions.
- To find out effectiveness of the fin under both conditions.

INTRODUCTION:

A spine or pin-fin is an extended surface of cylindrical or conical shape used for increasing the heat transfer rates from the surfaces, whenever it is not possible to increase the rate for heat transfer either by increasing heat transfer co-efficient or by increasing the temperature difference between the surface and surrounding fluids.

The purpose of fins is to improve heat dissipation from a surface to surroundings. Fins are widely used in engineering heat transfer equipment’s. Electrical apparatus like transformers and motors in which the generated heat should be efficiently transferred, are provided with fins on the outside surface. The fins are commonly used on engine heads of scooter, motorcycles, as well as small capacity compressors. The pin type fins are also used on the condenser of a domestic refrigerator.

The fins are designed and manufactured in many shapes and forms. These are mainly of following types.

(i) Straight fin: It is an extended surface attached to a plane wall. It may be of uniform cross sectional area, or its cross sectional area may vary along its length to form a triangular, parabolic or trapezoidal shape.

Fig: Straight fins

(ii) Annular fin: This is a fin circumferentially attached to a cylinder and its cross section varies with radius from centre line of cylinder.
(iii) **Pin Fin or spine:** These fins are of circular cross section whose diameter is much smaller than its length. The pin fins may also be of uniform or non-uniform cross section.

**PRECAUTIONS:**

1. Check all the electrical connections.
2. Do not run the equipment if the voltage is below 180V.
3. Do not obstruct flow of air while experiment is going on.
4. Do not turn the heater regulator to the maximum as soon as the equipment is started.
5. Do not attempt to alter the equipment as this may cause damage to the whole system.

**PROCEDURE:**

1. Switch on the MCB and then console on switch to activate the control panel.
2. Switch on the heater and regulate the power input using the heater regulator.
3. Switch on the blower unit and adjust the flow of air using gate valve of blower to a desired difference in manometer (for forced flow only otherwise skip to step 4).
4. Wait for reasonable time to allow temperatures to reach steady state.
5. Measure the voltage, current and temperatures from \( T_1 \) to \( T_6 \) at known time interval.
6. Calculate the effectiveness & efficiency of the fin using the procedure given.
7. Repeat the experiment for different values of power input to the heater and blower air flow rates.

**PRE VIVA QUESTIONS:**

1. Define fin. Mention its function
2. List out the types of fins
3. What are three conditions of fin?
4. Define effectiveness and efficiency of fin
5. What is convection?
6. Classify convection.
7. What is forced convection & natural convection?
8. Explain difference between forced convection and natural convection?
EXPERIMENTAL SETUP

Fig: Pin – Fin Experimental set-up
**TABULAR COLUMN:**

**Free convection**

<table>
<thead>
<tr>
<th>Sl no</th>
<th>Temperature in °C</th>
<th>Heat transfer coefficient h W/m²°C</th>
<th>Effectiveness ε</th>
<th>Efficiency η</th>
<th>Calculated Temp in °C</th>
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**Forced convection**

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<th>Velocity of air in V m/sec</th>
<th>Heat transfer coefficient h W/m²°C</th>
<th>Effectiveness ε</th>
<th>Efficiency η</th>
<th>Calculated Temp in °C</th>
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**SPECIFICATIONS:**

- Diameter of the Fin: 12mm
- Length of the Fin: 110mm
- Duct size: 100mm x100mm
- Thermocouples: 3 for fin and 1 for room temperature
- Fin Material: Copper (Thermal conductivity K<sub>Cu</sub>=380W/mK)

**CALCULATIONS:**

**NATURAL CONVECTION:**

1. Convective heat transfer coefficient, h

   
   - \( N_U = 1.1(Gr.Pr)^{1/6} \) when \( 10^{-1} < (Gr.Pr) < 10^4 \)
\[ N_u = 0.53 (Gr \cdot Pr)^{0.25} \] when \( 10^4 < (Gr \cdot Pr) < 10^9 \)

\[ N_u = 0.13 (Gr \cdot Pr)^{0.33} \] when \( 10^9 < (Gr \cdot Pr) < 10^{12} \)

Prandtl Number,

\[ Pr = \frac{\mu \times C_p}{K_{\text{air}}} \]

Grashoff Number,

\[ Gr = \frac{l^3 \times \rho^2 \times \beta \times g \times (T_m - T_a)}{\mu^2} \]

Coefficient of thermal expansion,

\[ \beta = \frac{1}{(273 + T_f)} \] 1/K

Where,

- \( T_m = \) mean effective temperature on the fin surface, \((T_2 + T_3 + T_4)/3\)°C.
- \( T_a = T_1 = \) ambient temperature of the chamber, °C.
- \( \mu = \) Absolute Viscosity, Ns/m².
- \( C_p = \) Specific Heat of the given fluid, J/kg°C.
- \( K_{\text{air}} = \) Thermal Conductivity of the fluid (air), W/m°C.
- \( h = \) Convective heat transfer coefficient, W/m²°C
- \( L = \) Characteristic length of the given specimen, m.
- \( \rho = \) Density of the fluid, kg/m³.
- \( g = \) Acceleration due to gravity, m/s².

All the properties of air (K, \( \mu \), \( \rho \), Pr) should be taken at \( T_f = (T_m + T_a)/2 \) from the data handbook.

\[ \text{Nu} = \text{Nusselt Number}, \quad N_u = \frac{h \times l}{K_{\text{air}}} \text{ or } \frac{h \times d}{K_{\text{air}}} \]

\[ h = \frac{K_{\text{air}} \times N_u}{D_c}, \text{ W/m}^2\text{°C} \]

Where,

- \( \text{Nu} = \) Nusselt Number calculated
- \( D_c = \) diameter of the fin = 0.020 m

**2. Effectiveness of the fin, \( \varepsilon \)**

\[ \varepsilon = \sqrt{\frac{K_{\text{fin}} \times P}{h \times A} \times \tanh(ML)} \]

\[ m = \frac{h \times p}{K_f \times A_c} \]

Where,

- \( A_c = \) is the Cross-section area of the fin, m²
\[ A_c = \frac{\pi \times D_c^2}{4}, m^2 \]

- \( P = \text{Perimeter of the fin} = \pi D_c \text{ m} \)
- \( K_f = \text{Thermal Conductivity of fin material (Copper) = 380 W/mK} \)
- \( h = \text{Heat transfer co-efficient of fin, W/m°C} \)

3. Efficiency of the fin

\[ \eta_{fin} = \frac{\tanh(mL)}{mL} \]

4. Temperature distribution

\[ \frac{T_X - T_2}{T_2 - T_a} = \frac{\cosh m(L - X)}{\cosh (mL)} \]

Where,
- \( T_X = \) is the temperature along the fin at a distance \( X \) measured from the base, °C
- \( T_2 = \) is the fin base temperature, °C
- \( T_a = \) is surrounding air temperature, °C
- \( X = \) is the distance of the unknown temperature point, m
- \( L = \) is the length of the fin = 0.170m

**FORCED CONVECTION:**

1. Convective heat transfer coefficient, \( h \)

\[ N_u = 0.913(Re)^{0.618} \times Pr^{0.333} \]

\[ Re = \frac{\rho \times D_H \times V}{\mu} \]

Where,
- \( D_H = \) Hydraulic diameter=4A/P
- \( A = \) Cross-sectional area of duct=Lxb
- \( P = \) Perimeter of the duct=2(L+b)
- \( V = \) Velocity of air, m/s

\[ h = \frac{K_{air} \times N_u}{D_c}, W/m^2°C \]

2. Effectiveness of the fin, \( \varepsilon \)

\[ \varepsilon = \sqrt{\frac{K_{fin} \times P}{h \times A} \times \tanh(Ml)} \]

\[ m = \frac{h \times p}{K_f \times A_c} \]

3. Efficiency of the fin

\[ \eta_{fin} = \frac{\tanh(mL)}{mL} \]
4. Temperature distribution

\[
\frac{T_X - T_2}{T_2 - T_a} = \frac{\cosh m(L - X)}{\cosh (mL)}
\]

Rate of Heat Transfer from the Fin, \( Q \)

\[
Q = \sqrt{h \times p \times K_f \times A_c \times (T_m - T_a) \times \tanh (mL), \text{Watts}}
\]

RESULTS:

Free convection

- Heat transfer coefficient of Pin fin for natural convection, \( h = \) ________ W/m°C
- Efficiency of pin fin for natural convection, \( \eta = \) __________
- Effectiveness of pin fin for natural convection, \( \varepsilon = \) __________

Forced convection

- Heat transfer coefficient of Pin fin for forced convection, \( h = \) ________ W/m°C
- Efficiency of pin fin for forced convection, \( \eta = \) __________
- Effectiveness of pin fin for forced convection, \( \varepsilon = \) __________

VERIFICATION: Heat transfer coefficient, Efficiency, Effectiveness of copper pin fin material for natural and forced convection is calculated and compared.

CONCLUSION: The above found performance parameter of copper pin fin for forced convection is greater than that of free convection because of providing an external source like fans, blowers etc., thereby significant amounts of heat energy can be transported very efficiently.

POST VIVA QUESTIONS:
1. Explain the method of heat transfer in extend surface.
2. What is the purpose of thermocouples?
3. What is the application of fins?
4. Give practical examples where fins are used.
5. What are fin parameters?
6. On what factors fins are designed
EXPERIMENT –4

HEAT TRANSFER THROUGH NATURAL CONVECTION

AIM:

To determine the natural heat transfer coefficient ‘h’ from the surface of the tube in both vertical and horizontal position.

INTRODUCTION:

There are certain situations in which the fluid motion is produced due to change in density resulting from temperature gradients. The mechanism of heat transfer in these situations is called free or natural convection. Free convection is the principal mode of heat transfer from pipes, transmission lines, refrigerating coils, hot radiators etc.

The movement of fluid in free convection is due to the fact that the fluid particles in the immediate vicinity of the hot object become warmer than the surrounding fluid resulting in a local change of density. The colder fluid creating convection currents would replace the warmer fluid. These currents originate when a body force (gravitational, centrifugal, electrostatic etc) acts on a fluid in which there are density gradients. The force, which induces these convection currents, is called a buoyancy force that is due to the presence of a density gradient within the fluid and a body force. Grashoff’s number a dimensionless quantity plays a very important role in natural convection.

Heat transfer theory seeks to predict the energy transfer that takes place between material bodies as a result of temperature difference. This energy transfer is defined as heat. The three modes by which heat can be transferred from one place to another are conduction, convection and radiation. It is well known that a hot plate of metal will cool faster when
placed in front of a fan than when placed in still air. With the fan, we say that the heat is convected away, and we call the process convection heat transfer. Convection involves the transfer of heat by motion and mixing of a fluid.

Forced convection happens when the fluid is kept in motion by an external means, such as a turbine or a fan. Some examples of forced convection are stirring a mixture of ice and water, blowing on the surface of coffee in a cup, orienting a car radiator to face airflow, etc. Convection is called natural convection when motion and mixing of fluid is caused by density variation resulting from temperature differences within the fluid. The density of fluid near the hot surface is less than that of the colder fluid away from the heated surface, and gravity creates a buoyant force which lifts the heated fluid upward.

In the case of conduction through a solid of area $A$ and thickness $L$, heat flow is given by

$$\frac{Q}{t} = \frac{kA\Delta T}{L} \quad (1)$$

Where $\Delta T$ is the temperature difference across the thickness $L$ and $k$ is the thermal conductivity of the object.

In the case of convection, the heat flow is proportional only to the surface area $A$ of the object,

$$\frac{Q}{t} = hA\Delta T \quad (2)$$

Where $h$ is the convective heat transfer coefficient (units Wm$^{-2}$ K$^{-1}$) which depends on the shape and orientation of the object. $\Delta T$ is the temperature difference between the surface of the object and the surrounding fluid.

Convection is an enhanced form of conduction, since the movement of the fluid helps carry heat transferred by conduction, so one would expect some relation between $h$ and $k$. If the temperature of the cylinder is not much above that of the surrounding air, the moving fluid can be approximated as a stationary layer having some characteristic thickness $L$. Comparing equations (1) and (2), one immediately has the relation $h = k/L$. In fact, as the temperature of the cylinder increases, fluid motion increases and becomes turbulent, whereupon the fluid becomes more efficient at carrying heat, and $h$ can turn out to be $10^2$ – $10^4$ times $k/L$. The proportionality between $h$ and $k/L$ is called the Nusselt number $Nu$,

$$Nu = \frac{h}{k/L} = \frac{hL}{k}$$
Where \( k \) is thermal conductivity of air and \( L \) is the characteristic length. Note that \( Nu \) is a dimensionless quantity.

**PRECAUTIONS:**
1. Check all the electrical connections.
2. Do not run the equipment if the voltage is below 180V.
3. Make sure that heater regulator is at the minimum position before switching on the console.
4. Do not attempt to alter the equipment as this may cause damage to the whole system.

**PROCEDURE:**
1. Keep the tube in the vertical position.
2. Switch on MCB and then CONSOLE ON switch.
3. Switch on the heater and set the voltage (say 40V) using heater regulator and the digital voltmeter.
4. Wait for sufficient time to allow temperature to reach steady values.
5. Note down the Temperatures 1 to 4 using the channel selector and digital temperature indicator.
6. Note down the ammeter and voltmeter readings.
7. Calculate the convection heat transfer co-efficient using the procedure given below.
8. Repeat the experiment for different heat inputs and also for horizontal position with different heat inputs.

**NOTE:**
1. The experiment should be carried out in the absence of wind flow through the window as well as in the absence of fan for better results.
2. For better result, the horizontal and vertical experiments should be conducted after the tube is cooled down to almost room temperature.
3. For comparison of results in horizontal and vertical position the temperatures should be considered for equal interval of time, in both cases.

**PRE VIVA QUESTIONS:**
1. What is Natural convection?
2. State the Newton’s law of cooling.
3. Define convection heat transfer coefficient with dimensions
4. Define local heat transfer coefficient and average heat transfer coefficient
5. Define Grashoff, Nusselt and Prandtl numbers
EXPERIMENTAL SET UP:

Fig. Experimental setup for natural convection with horizontal position.

Fig: Natural convection through horizontal & vertical experimental set up.
TABULAR COLUMN

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Position</th>
<th>Heat Input Q In W</th>
<th>Temperatures°C</th>
<th>( h_{\text{expt}} ) in W/m²°C</th>
<th>( h_{\text{theo}} ) in W/m²°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>V</td>
<td>I</td>
<td>Q</td>
<td>T₁</td>
</tr>
<tr>
<td>1</td>
<td>Vertical</td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td>Vertical</td>
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<td>3</td>
<td>Vertical</td>
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<tr>
<td>1</td>
<td>Horizontal</td>
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<tr>
<td>2</td>
<td>Horizontal</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>3</td>
<td>Horizontal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Where: \( V \) = Voltage, volts and \( I \) = Current, amps

SPECIFICATION:
- Material = Stainless Steel
- Inner Diameter of the tube (d) = 35mm
- Outer Diameter of the tube (d) = 38mm
- Length of the tube (L) = 500mm

CALCULATIONS:

1. PRACTICAL

\[
h = \frac{Q}{A(T_m - T_a)} \text{ W/m}^2\text{°C}
\]

Where,
- \( Q \) = heat given to the heater = \( V \times I \) watts.
- \( A \) = Area of the tube surface = \( \pi \times d \times L \), m²
- \( d \) = Diameter of the pipe = 0.038m
- \( L \) = length of the pipe = 0.5m
- \( T_m \) = mean surface temperature of specimen = \( (T_2 + T_3 + T_4)/3 \), °C
- \( T_a \) = \( (T_1 + T_5) \) = Ambient air temperature, °C

2. THEORETICAL

i. VERTICAL POSITION: for \( 10^4 < \text{Gr.Pr} < 10^9 \)

\[
h_v = \frac{0.59 \times (\text{Gr. Pr})^{0.25} \times K}{L} \text{ W/m}^2\text{°C}
\]

ii. HORIZONTAL POSITION: for \( 10^4 < \text{Gr.Pr} < 10^9 \)
\[ h_h = \frac{0.48 \times (Gr \cdot Pr)^{0.25} \times K}{L}, \text{W/m}^2\text{C} \]

Prandtl Number,
\[ Pr = \frac{\mu \times C_p}{K} \]

Grashoff Number,
\[ Gr = \frac{L^3 \times \rho^2 \times \beta \times g \times (T_m-T_a)}{\mu^2} \]

Coefficient of thermal expansion,
\[ \beta = \frac{1}{(273+T_f)} \frac{1}{\text{K}} \]

All the properties of air should be taken at \( T_f = \frac{(T_m+T_a)}{2} \) from the data handbook.

Here, \( L \) is the characteristic length and is given as:
- \( L = L = 0.5 \text{m} \), for vertical position.
- \( L = d = 0.038 \text{m} \), for horizontal position.

Where,
- \( \mu \) = Absolute Viscosity, Ns/m².
- \( C_p \) = Specific Heat of the given fluid, J/kg°C.
- \( K \) = Thermal Conductivity of the fluid, W/m°C.
- \( h \) = Convective heat transfer coefficient, W/m²°C
- \( L \) = Characteristic length of the given specimen, m.
- \( \rho \) = Density of the fluid, kg/m³.
- \( g \) = Acceleration due to gravity, m/s².

**RESULT:**

<table>
<thead>
<tr>
<th>Position of stainless steel rod</th>
<th>( h_{\text{theo}} ) (W/m²°C)</th>
<th>( h_{\text{exp}} ) (W/m²°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical</td>
<td></td>
<td></td>
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<tr>
<td>Horizontal</td>
<td></td>
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</tr>
</tbody>
</table>

**VERIFICATION:** The experimental natural convective heat transfer coefficient for given position is calculated and verified with the theoretical natural convective heat transfer coefficient.

**CONCLUSION:** For both position, the theoretical natural convective heat transfer coefficient is greater than experimental natural convective heat transfer coefficient.
The experimental natural convective heat transfer coefficient for horizontal position is greater than vertical position since the movement of the air helps carry heat transferred by conduction in the horizontal position.

**POST VIVA QUESTIONS:**

1. List out the parameters affecting on natural convection heat transfer
2. Give the relation between ‘Fluid velocity’ and ‘Heat transfer’?
3. On which properties does convection heat transfer strongly depend?
4. What is Nusselt Number?
5. What is a boundary layer?
6. What is the significance of Grashoff, Nusselt and Prandtl Numbers?
7. What will happen to electrical iron if its surface is kept to open air at infinite amount of time?
EXPERIMENT-5

HEAT TRANSFER THROUGH FORCED CONVECTION

AIM:
To determine convective heat transfer coefficient in forced convection.

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

**FORCED CONVECTION:** If the motion of fluid is induced by some external means such as a pump or blower, then the heat transfer process is known as “Forced Convection”. In forced convection heat transfer rate is high due to rapid movements of the fluid particles. Heat transfer by forced convection generally makes use of a fan, blower, or pump to provide high velocity fluid (gas or liquid). The high-velocity fluid results in a decreased thermal resistance across the boundary layer from the fluid to the heated surface. This, in turn, increases the amount of heat that is carried away by the fluid.

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

\[ Q = h \times A \times \Delta T \]

Where,
- \( Q \) = Heat transfer rate, watts
- \( A \) = Surface area of heat flow, \( m^2 \)
- \( \Delta T \) = Overall temperature difference between the wall and fluid, \( ^\circ C \)
- \( h \) = Convection heat transfer co-efficient, \( W/m^2 \, ^\circ C \)

PROCEDURE:

1. Switch on the MCB and then console on switch to activate the control panel.
2. Switch on the blower unit first and adjust the flow of air using wheel valve of blower to a desired difference in manometer.
3. Switch on the heater and set the voltage (say 80V) using the heater regulator and digital voltmeter.
4. Wait for reasonable time to allow temperatures to reach steady state.
5. Measure the voltage, current and temperatures from \( T_1 \) to \( T_6 \) at known time interval.
6. Calculate the convective heat transfer co-efficient using the procedure given.
7. Repeat the experiment for different values of power input to the heater and blower air flow rates.

**PRECAUTIONS:**
1. Check all the electrical connections.
2. Do not run the equipment if the voltage is below 180V.
3. Do not obstruct flow of air while experiment is going on.
4. Make sure that heater regulator is at the minimum position before switching on the console.
5. Do not attempt to alter the equipment as this may cause damage to the whole system.

**PRE VIVA QUESTIONS:**
1. Define forced convection heat transfer. Give examples
2. What are the parameters affecting on forced convection heat transfer?
3. Define Reynolds number. What is its significance?
4. What is the critical Re when fluid flows over flat plates and through pipes.
5. Define Stanton number and Raleigh Numbers.
6. Define thermal boundary layer and hydro dynamic boundary layers
7. What do you mean by leading edge and trailing edge?

**TABULAR COLUMN:**

<table>
<thead>
<tr>
<th>SL No.</th>
<th>Manometer Reading, m of water</th>
<th>Heat Input, Watts</th>
<th>Air temperature, °C</th>
<th>Surface Temperature of the metal, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H&lt;sub&gt;1&lt;/sub&gt;</td>
<td>H&lt;sub&gt;2&lt;/sub&gt;</td>
<td>V</td>
<td>I</td>
</tr>
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<td>1.</td>
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<tr>
<td>4.</td>
<td></td>
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</tr>
</tbody>
</table>

Where: V = Voltage, volts and I = Current, amps

**SPECIFICATION:**
Diameter of rod = 0.036m
Length of rod = 0.5m
Coefficient of discharge = 0.62
Diameter of orifice = 15mm
CALCULATIONS:

PRACTICAL

\[ h = \frac{Q}{A(T_i - T_o)} \, W/m^2^\circ C \]

Where,

- Q = heat given to the heater = V x I Watts.
- A = Surface Area of the tube surface = \( \pi d L \) m²
- d = Diameter of the test tube = 0.036 m
- L = Length of the test tube = 0.5 m
- Ti = mean temperature on surface of the tube = \((T_1+T_2+T_3)/3\), °C
- To = Average temperature of the air = \((T_4+T_5)/2\), °C

**THEORETICAL**

\[
h = \frac{0.023(Re^{0.8} \times Pr^{0.4}) \times K}{D}
\]

Reynolds Number,
\[
Re = \frac{\rho \times D \times V}{\mu}
\]

Prandtl Number,
\[
Pr = \frac{\mu \times C_p}{K}
\]

Where,
- D = inner diameter of the tube = 0.036 m.
- \(\rho\) = Density of air, kg/m³
- \(\mu\) = Absolute viscosity of the fluid, Ns/m²
- K = Thermal conductivity of the given fluid, W/m °C
- \(C_p\) = Specific heat of the fluid, J/kg °C
- V = Velocity of air, m/s

\[
V = \frac{\text{Discharge of air through pipe, } (Q) \text{ m}^3/\text{s}}{\text{flow area, } (A)}
\]

Flow area is calculated as follows A:
\[
A = \frac{\pi \times D^2}{4}
\]

Discharge of air through pipe, Q
\[
Q = 0.62 \times a \times \sqrt{2gH_a} \text{ m}^3/\text{s}
\]

\[
a = \frac{\pi \times d^2}{4} \text{ m}^2
\]

Where,
- a = Orifice area, m²
- d = Orifice Diameter, = 15 mm
- $H_a = \text{height of air in manometer, m}$
  
  \[ H_a = \frac{H_w \times \rho_w}{\rho_a}, m \]

- $H_w = \text{height of water in manometer, m}$

- $\rho_w = \text{density of water} = 1000 \text{ kg/m}^3$

- $\rho_a = \text{density of air} = 1.293 \text{ kg/m}^3$

All the properties of air ($\rho, \mu, K_{air}, Cp, Pr$) should be taken at $(T_i + T_o)/2$ from the data hand book.

RESULT:
- The experimental forced convective heat transfer coefficient is $h_{\text{expt}} = ____ W/m^2\circ C$
- The theoretical forced convective heat transfer coefficient is $h_{\text{theo}} = ____ W/m^2\circ C$

VERIFICATION: The experimental forced convective heat transfer coefficient is calculated and verified with the theoretical forced convective heat transfer coefficient.

CONCLUSION: The experimental forced convective heat transfer coefficient is greater than theoretical forced convective heat transfer coefficient because the forced convection heat transfer rate is high due to rapid movements of the fluid particles and the high-velocity fluid results in a decreased thermal resistance across the boundary layer from the fluid to the heated surface.

POST VIVA QUESTIONS:
1. How is natural convection different from forced convection?
2. What is Orifice - meter?
3. What is the function of blower?
4. What is Newton’s law of cooling?
5. Force convection in a liquid bath is caused by__________
6. On which properties does convection heat transfer strongly depend?
7. For forced convection, Nussult number is a function of__________
8. The Prandtl number will be lowest for__________
9. What is significance of Nussult’s number in convection?
10. What is significance of Stanton number?
11. Which dimensionless number has a significant role in forced convection?
12. If the reynold number is very high what will be the value of heat transfer coefficient and why?
14. What is Mach no? How does it influence the heat flow.
AIM:

The experiment is conducted to determine the emissivity of the non–black surface and compare with the black body.

INTRODUCTION:

Radiation is one of the modes of heat transfer, which does not require any material medium for its propagation. All bodies can emit radiation & have also the capacity to absorb all or a part of the radiation coming from the surrounding towards it. The mechanism is assumed to be electromagnetic in nature and is a result of temperature difference. Thermodynamic considerations show that an ideal radiator or black body will emit energy at a rate proportional to the fourth power of the absolute temperature of the body. Other types of surfaces such as glossy painted surface or a polished metal plate do not radiate as much energy as the black body, however the total radiation emitted by these bodies still generally follow the fourth power proportionality. To take account of the gray nature of such surfaces, the factor called emissivity (ε), which relates the radiation of the gray surface to that of an ideal black surface, is used. The emissivity of the surface is the ratio of the emissive power of the surface to the emissive power of the black surface at the same temperature. Emissivity is the property of the surface and depends upon the nature of the surface and temperature.

LAWS OF RADIATIONS:

Planck Radiation Law
The primary law governing blackbody radiation is the Planck Radiation Law, which governs the intensity of radiation emitted by unit surface area into a fixed direction (solid angle) from the blackbody as a function of wavelength for a fixed temperature. The Planck Law can be expressed through the following equation.
Stefan-Boltzmann Law: The thermal energy radiated by a black body per second per unit area is proportional to the fourth power of the absolute temperature.

\[ P = \frac{\sigma T^4}{A} \text{ } \text{J/m}^2\text{s} \quad \text{(Stefan-Boltzmann Law)} \]

\[ \sigma = 5.6703 \times 10^{-8} \text{ watt/m}^2\text{K}^4 \]

Kirchhoff's law: For a body of any arbitrary material, emitting and absorbing thermal electromagnetic radiation at every wavelength in thermodynamic equilibrium, the ratio of its emissive power to its dimensionless coefficient of absorption is equal to a universal function only of radiative wavelength and temperature.

Planck also noted that the perfect black bodies of Kirchhoff do not occur in physical reality. They are theoretical fictions. Kirchhoff's perfect black bodies absorb all the radiation that falls on them, right in an infinitely thin surface layer, with no reflection and no scattering. They emit radiation in perfect accord with Lambert's cosine law.

Wien's law: Wien’s law states that the dominant wavelength at which a blackbody emits electro-magnetic radiation is inversely proportional to the Kelvin temperature of the object

\[ \lambda_{\text{max}} = \frac{0.0029Km}{T} \]

\( \lambda_{\text{max}} \) = wavelength of maximum emission of the object in m

T = temperature of the object in K

Emissivity: The emissivity of a material is the relative ability of its surface to emit energy by radiation. It is the ratio of energy radiated by a particular material to energy radiated by a black body at the same temperature. A true black body would have an \( \epsilon = 1 \) while any real object would have \( \epsilon < 1 \).

Table: Total emissivity’s of selected materials
PROCEDURE:
Give necessary electrical connections and switch on the MCB and switch on the console on to activate the control panel.
1. Switch On the heater of the Grey body and set the voltage (say 45V) using the heater regulator and digital voltmeter.
2. Switch On the heater of the Black body and set the voltage or current (say higher than gray body) using the heater regulator and digital voltmeter.
3. Wait to attain the steady state.
4. Note down the temperatures at different points and also the voltmeter and ammeter readings.
5. Tabulate the readings and calculate the surface emissivity of the non-black surface.

PRECAUTIONS:
1. Check all the electrical connections
2. Do not run the equipment if the voltage is below 180V.
3. Make sure that heater regulator is at the minimum position before switching on the console.
4. After finishing the experiment open the acrylic door to remove the heat from the chamber.
5. Do not attempt to alter the equipment as this may cause damage to the whole system.

PRE VIVA QUESTIONS:
1. Explain Radiation.
2. Heat energy transfers in radiation in which form?
3. What is a Block body?
4. Explain Stefan – Boltzmann’s law? What is value of the Stefan – Boltzmann constant?
5. Explain spectral blackbody emissive power?
6. Discuss Planck’s distribution law.
7. Define emissivity.
8. Explain absorptivity, reflectivity and transmissivity.
10. Explain Kirchhoff’s law.
11. Radiation between two surfaces mainly depends on-----
12. Define Shape factor (or) view factor (or) configure factor (or) angle factor
13. Explain Radiation Heat transfers between two surfaces?
### TABULAR COLUMN:

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Heater input</th>
<th>Temperature, °C</th>
<th>Emissivity (ε)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Black body</td>
<td>Grey body</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Voltage, ‘V’ volts</td>
<td>Current ‘I’ amps</td>
<td>Temperature, °C</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
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<td>3</td>
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</tr>
</tbody>
</table>

\[
T_B = \frac{T_1 + T_2}{2} \quad T_G = \frac{T_3 + T_4}{2} \quad T_A = \frac{T_5}{2}
\]

### EXPERIMENTAL SET UP:

**Fig:** Line diagram of surface emissivity
CALCULATIONS:

HEAT INPUT TO THE BLACK BODY, $Q_B$

$$ Q_B = V \times I \quad \text{Watts.} $$

HEAT INPUT TO THE GREY BODY, $Q_G$

$$ Q_G = V \times I \quad \text{Watts.} $$

EMMISSIVITY OF THE GREY BODY, $\varepsilon_G$

$$ \varepsilon_G = \frac{Q_G(T_B^4 - T_A^4)}{Q_B(T_G^4 - T_A^4)} $$

Where,

- $Q_G = \text{Heat input to the grey body.}$
- $Q_B = \text{Heat input to the black body.}$
- $A = \text{Area of plates} = (\pi d^2/4) \text{ m}^2$
- Diameter of plates = $d = 0.2\text{m}$
- $T_B = \text{Temperature of black body in K}$
- $T_G = \text{Temperature of grey body in K}$
\( T_A = \) Ambient temperature in K

**RESULT:** The Emissivity of the grey body is \( \varepsilon_G = \) ______________.

**VERIFICATION:** Real materials emit energy at a fraction called the emissivity of black-body. By definition, a black body in thermal equilibrium has an emissivity of \( \varepsilon = 1.0 \). A source with lower emissivity independent of frequency often is referred to as a gray body. Therefore, the emissivity of non-black (grey body) surface is compared and verified with that of black body.

**CONCLUSION:** The emissivity of the given non-black surface is less than that of the black body (\( \varepsilon = 1.0 \)), because emissivity depends on the property of the surface, the nature of the surface and temperature.

**POST VIVA QUESTIONS:**

1. Explain the mechanism of radiation heat transfer
2. What are the characteristics of radiation heat transfer?
3. Define monochromatic emissivity, total emissivity, normal total emissivity
4. Define intensity of radiation
5. What do you mean by greenhouse effect?
6. What is radiation shield? What is its effect on heat transfer?
7. What is the range of values for the emissivity of a surface?
EXPERIMENT – 7

STEFAN BOLTZMAN’S APPARATUS

AIM:
To determine Stefan Boltzmann Constant for radiation heat transfer

APPARATUS: Stefan Boltzmann Apparatus, stop watch

THEORY:
Stefan-Boltzmann Law: The thermal energy radiated by a black body per second per unit area is proportional to the fourth power of the absolute temperature.

$$\frac{P}{A} = \sigma T^4 \text{ J/m}^2\text{s} \quad \text{Stefan-Boltzmann Law}$$

$$\sigma = 5.6703 \times 10^{-8} \text{ W/m}^2\text{K}^4$$

Thermal radiation: That electromagnetic radiation emitted by a body as a result of its temperature. Thermal radiation is restricted to a limited range of the electromagnetic spectrum.

A blackbody is a perfect radiator.
Three characteristics:
- It absorbs all incident radiation
- It radiates more energy than any real surface at the same temperature
- The emitted radiation is independent of direction

Radiation from real surfaces:
- Emit and absorb less than blackbodies
- Reflect radiation
- Emit and absorb differently depending on angle and wavelength
- Do not obey the simple laws

Absorptivity \( \alpha \): Fraction of incident radiation absorbed
Reflectivity \( \rho \): Fraction of incident radiation reflected
Transmittivity \( \tau \): Fraction of incident radiation transmitted

Thus \( \alpha + \rho + \tau = 1 \)
DESCRIPTION OF THE APPARATUS:

The apparatus consists of

1. **Copper** hemispherical enclosure with insulation.
2. **SS jacket** to hold the hot water.
3. **Overhead water heater** with quick release mechanism and the thermostat to generate and dump the hot water.
4. **Heater regulator** to supply the regulated power input to the heater.
5. **Thermocouples** at suitable position to measure the surface temperatures of the absorber body.
6. **Digital Temperature Indicator** with channel selector to measure the temperatures.
7. Control panel to house all the instrumentation.
8. With this the whole arrangement is mounted on an aesthetically designed self-sustained MS powder coated frame with a separate control panel.

PROCEDURE:

1. Fill water slowly into the overhead water heater.
2. Switch on the supply mains and console.
3. Switch on the heater and regulate the power input using the heater regulator. (say 60 – 85 °C)
4. After water attains the maximum temperature, open the valve of the heater and dump to the enclosure jacket.
5. Wait for about few seconds to allow hemispherical enclosure to attain uniform temperature – the chamber will soon reach the equilibrium. Note the enclosure temperature.
6. Insert the Test specimen with the sleeve into its position and record the temperature at different instants of time using the stop watch.
7. Plot the variation of specimen temperature with time and get the slope of temperature versus time variation at the time t = 0 sec
8. Calculate the Stefan Boltzmann’s constant using the equations provided.
9. Repeat the experiment 3 to 4 times and calculate the average value to obtain the better results.

PRECAUTIONS:

1. Check all the electrical connections.
2. Do not run the equipment if the voltage is below 180V.
3. Do not switch on the heater without water in the overhead tank.
4. Do not turn the heater regulator to the maximum as soon as the equipment is started.
5. Do not attempt to alter the equipment as this may cause damage to the whole system.
PRE VIVA QUESTIONS:
1. Define black body, grey body, white body and diathermanous body
2. Define emissive power
3. What is Stephan Boltzmann law & its constant value?
4. What is the effect on internal energy of an object during radiation?

EXPERIMENTAL SET UP:
OBSERVATIONS:
Enclosure Temperature, $T_e = T_1 + T_2/2$, Initial Temperature of the specimen, $T_i =$

<table>
<thead>
<tr>
<th>Time, t(sec)</th>
<th>Specimen Temperature, $T_s$ °C</th>
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<tbody>
<tr>
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<td>90</td>
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<td>100</td>
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CALCULATIONS:
Stefan Boltman’s Constant is Calculated Using the Relation:

$$\sigma = \frac{m \times C_p \left(\frac{dT_s}{dt}\right)\,t = 0}{A_D \left(T_e^4 - T_s^4\right)}$$

Where,

- $m =$ mass of the test specimen = 0.0047Kg
- $C_p =$ Specific heat of the specimen = 410 J/Kg °C
- $T_e =$ Enclosure temperature, °K
- $T_s =$ Initial temperature of the specimen, °K
- $\left(\frac{dT_s}{dt}\right) =$ calculated from graph.
- $A_D =$ Surface area of the test specimen, $A_D = \pi d^2/4$, $m^2$
- $D =$ Diameter of test specimen, $d=0.015$ m.

MODEL GRAPH: Plot specimen temperature ($T_s$) v/s time (t)
RESULT: Stefan Boltzmann’s value is \( \sigma = \frac{W}{m^2 K^4} \)

VERIFICATION: Stefan Boltzmann’s value is calculated and verified with Stefan Boltzmann’s constant as 5.67e-8 \( \frac{W}{m^2 K^4} \)

CONCLUSION: Thus, Stefan–Boltzmann’s law is proved which states that the total intensity radiated over all wavelengths increases as the temperature increases of a black body which is proportional to the fourth power of the thermodynamic temperature.

POST VIVA QUESTIONS

1. Thermal radiation occur in the portion of electromagnetic spectrum between the Wavelengths ________
2. For infinite parallel plates with emissivities 1 and 2 shape factor for radiation from surface 1 to surface 2 is ________
4. What is the emissive power of a body if absolute temperature is zero?
5. What is the example of body very near to black body in nature?
6. What is shape factor with respect to radiation?
EXPERIMENT – 8

PARALLEL & COUNTER FLOW HEAT EXCHANGER

AIM:

To determine LMTD & Effectiveness of the heat exchanger under parallel and counter Flow arrangement.

INTRODUCTION:

Heat exchangers are devices in which heat is transferred from one fluid to another. The fluids may be in direct contact with each other or separated by a solid wall. Heat Exchangers can be classified based on its principle of operation and the direction of flow. The temperatures of the fluids change in the direction of flow and consequently there occurs a change in the thermal head causing the flow of heat. The classic example of a heat exchanger is found in an internal combustion engine in which a circulating fluid known as engine coolant flows through radiator coils and air flows past the coils, which cools the coolant and heats the incoming air.

The temperatures profiles at the two fluids in parallel and counter flow are curved and have logarithmic variations. LMTD is less than the arithmetic mean temperature difference. So, it is always safer for the designer to use LMTD so as to provide larger heating surface for a certain amount of heat transfer.

![Parallel flow](image1)

![Counter flow](image2)
PROCEDURE:

1. Switch ON mains and the CONSOLE.
2. Start the flow on the hot water side.
3. Start the flow through annulus also.
4. Set the exchanger for parallel or counter flow using the change over mechanism.
5. Switch ON the heater of the geyser.
6. Set the flow rate of the hot water (say 1.5 to 4 LPM) using the rotameter of the hot water.
7. Set the flow rate of the cold water (say 3 to 8 LPM) using the rotameter of the cold water.
8. Wait for sufficient time to allow temperature to reach steady values.
9. Note down the Temperatures 1 to 4 using the channel selector and digital temperature indicator.
10. Note down the flow rates of the water and tabulate.
11. Now, change the direction of flow for the same flow rates and repeat the steps 9 to 11.
12. Repeat the experiment for different flow rates of water.

PRECAUTIONS:

1. Check all the electrical connections.
2. Do not run the equipment if the voltage is below 180V.
3. Do not attempt to alter the equipment as this may cause damage to the whole system.

PRE VIVA QUESTIONS

1. Define heat exchanger
2. Classify heat exchangers
3. What do you mean by compact heat exchanger?
4. Difference between parallel and counter flow heat exchanger.
5. Define LMTD and AMTD
6. What is NTU? What are its significances?
EXPERIMENTAL SETUP:

EXPERIMENTAL SETUP OF HEAT EXCHANGER
### TABULAR COLUMN:

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Flow Direction</th>
<th>Air flow rate, Manometer Reading in m</th>
<th>Water Flow rate, m&lt;sub&gt;W&lt;/sub&gt;, LPM</th>
<th>Temperatures °C</th>
<th>LMTD In °C</th>
<th>U in W/m&lt;sup&gt;2&lt;/sup&gt; °C</th>
<th>ε</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td></td>
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</tr>
<tr>
<td>2</td>
<td>Counter</td>
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</tr>
</tbody>
</table>

**NOTE:**
- T<sub>1</sub> = Hot water inlet temperature.
- T<sub>2</sub> = Hot water outlet temperature.
- T<sub>3</sub> = Cold Water Inlet Temperature (In Case of Parallel Flow)
  Cold Water Outlet Temperature (In Case of Counter Flow)
- T<sub>4</sub> = Cold Water Outlet Temperature (In Case of Parallel Flow)
  Cold Water Inlet Temperature (In Case of Counter Flow)

### CALCULATIONS:

1. **Heat Transfer Rate, Q**

\[
Q = \frac{Q_H + Q_C}{2} \text{ Watts}
\]

Where,
- Q<sub>H</sub> = Heat transfer rate from hot water and is given by:
  \[Q_H = m_a \times C_{P_a} \times (T_1 - T_2) \text{ W}\]
- m<sub>a</sub> = mass flow rate of hot air in, kg/sec.
  \[m_a = 0.62 \times \rho_a \times A_o \times \sqrt{2gH_a}, \text{ kg/s}\]

\[H_a = \left(\frac{\rho_w - \rho_a}{\rho_a}\right) \times H_w, \text{ m of air}\]

\[A_o = \frac{\pi d_o^2}{4}, \text{ m}^2\]
- d<sub>o</sub> = Diameter of Orifice = 20 mm
- ρ<sub>a</sub> = Density of hot air is 1.2 kg/m<sup>3</sup>
- ρ<sub>W</sub> = Density of water is 1000 kg/m<sup>3</sup>
- H<sub>a</sub> = Head of air in m
- H<sub>w</sub> = Head of water in manometer (H<sub>1</sub> – H<sub>2</sub>) m
- C<sub>Pa</sub> = Specific heat of hot air is 1005 J/kg K
- Q<sub>C</sub> = heat transfer rate from cold water and is given by:
  \[Q_C = m_w \times C_{p_w} \times (T_3 - T_4) \text{ W}\]
- m<sub>w</sub> = mass flow rate of cold water = m<sub>w</sub>/60, kg/sec.
2. LMTD: Logarithmic Mean Temperature Difference:

\[ T_{LMTD} = \frac{\Delta T_i - \Delta T_o}{\ln \left( \frac{\Delta T_i}{\Delta T_o} \right)}, ^\circ C \]

Where,

- \( \Delta T_i = (T_{Hi} - T_{Ci}) \) for parallel flow, \(^\circ C\)
- \( \Delta T_i = (T_{Hi} - T_{Co}) \) for counter flow, \(^\circ C\)
- \( \Delta T_o = (T_{Ho} - T_{Co}) \) for parallel flow, \(^\circ C\)
- \( \Delta T_o = (T_{Ho} - T_{Ci}) \) for counter flow, \(^\circ C\)

NOTE: The suffix
- \( H = \) Hot air
- \( C = \) Cold Water
- \( i = \) Inlet
- \( o = \) Outlet

3. Overall Heat Transfer Co-Efficient:

\[ U = \frac{Q}{A \times T_{LMTD}}, W/m^2 ^\circ C \]

Where,

- \( Q = \) heat transfer rate, W.
- \( A = \) surface area of pipe = \( \pi \times D_i \times L \) m\(^2\)
- \( D_i = \) Inner diameter of the water pipe = 0.06 m.
- \( L = \) Length of the water pipe = 6.4 m.
- \( \Delta T_{LMTD} = \) Logarithmic mean temperature difference °C.

4. Effectiveness of Heat Exchanger, \( \varepsilon \)

i. EXPERIMENTAL:

\[ \varepsilon_{Exp} = \frac{T_{Co} - T_{Ci}}{T_{Hi} - T_{Ci}} \]  
\[ \text{if } C_{Max} > C_{Min} \]

\[ \varepsilon_{Exp} = \frac{T_{Hi} - T_{Ho}}{T_{Hi} - T_{Ci}} \]  
\[ \text{if } C_{Max} < C_{Min} \]

Or,

\[ \varepsilon = \frac{Q_{act}}{Q_{Max}} \]

\[ Q_{Max} = C_{min} (T_{Hi} - T_{ci}), W \]

ii. THEORETICAL:

\[ \varepsilon_{Th} = \frac{1 - e^{-NTU(1+C)}}{(1 + C)}, \text{ for parallel flow} \]

\[ \varepsilon_{Th} = \frac{1 - e^{-NTU(1-C)}}{1 - Ce^{-NTU(1-C)}}, \text{ for Counter flow} \]

Where,

- \( C_{MAX} = m_H \times C_{PH} \)
- \( C_{MIN} = m_C \times C_{PC} \)
- \( C = C_{MIN} / C_{MAX} \)
NTU = Number of Transfer units is given by,

\[ NTU = \frac{U \times A}{C_M} \]

- \( C_M \) = minimum of \( C_{MIN} \& C_{MAX} \)

5. PERCENTAGE OF ERROR (% error)

\[ % \ Error = \left( \frac{\varepsilon_{Th} - \varepsilon_{Exp}}{\varepsilon_{Th}} \right) \times 100 \]

RESULT:
- LMTD and Effectiveness of Parallel flow heat exchanger are __________
- LMTD and Effectiveness of Counter flow heat exchanger are __________

VERIFICATION: The effectiveness and overall coefficient of heat exchanger for both parallel and counter flow is calculated by conducting experiment on heat exchanger and is verified by calculating the % of error using theoretical and experimental effectiveness during parallel and counter flow of heat exchanger.

CONCLUSION: The effectiveness and overall coefficient of heat exchanger is greater for the counter flow type when compare to parallel flow type of heat exchanger because (i) more uniform temperature difference between the two fluids minimizes the thermal stresses throughout the heat exchanger, (ii) the outlet temperature of the cold fluid can approach the highest temperature of the hot fluid and (iii) the more uniform temperature difference produces a more uniform rate of heat transfer throughout the heat exchanger.

POST VIVA QUESTIONS:

1. What are the applications of heat exchanger?
2. What is fouling and fouling factor?
3. Draw the temperature v/s length of heat exchanger graph for parallel flow and counter flow arrangements
4. Define effectiveness of heat exchanger
5. Define capacity rate and capacity ratio
6. Why effectiveness of counter flow heat exchanger is more than that of parallel flow heat exchanger
7. What is Relative direction of motion of fluids?
8. What is the maximum possible value of effectiveness for parallel flow heat exchangers?
9. Write the thermal profile for parallel and counter flow heat exchangers?
10. What is the temperature difference adapted in calculations if LMTD is zero?
11. Define effectiveness and NTU for heat exchangers.
12. What is the difference between regenerator and recuperator?
13. Write down the thermal profile for evaporator and condenser systems.
EXPERIMENT – 9

CONDENSATION APPARATUS

AIM:
- To determine overall heat transfer coefficient ($U_0$)
- To determine steam side film coefficient ($h_S$)
- To determine cold fluid heat transfer coefficient ($h_i$)

INTRODUCTION:

Condensation is the process of change of state free vapour to liquid. Condensation occurs on a surface when the vapour saturation temperature is higher than the temperature of surface. The temperature of the condensate so formed will be less than the saturation temperature of the vapour and becomes sub-cooled. More vapour starts condensing on the exposed surface or on the previous condensate, since the temperature of the previous condensate is lower. The phenomenon of condensation heat transfer is more complex, which involves change of phase and additional characteristics / variables that control the condensation process.

There are two basic types of condensation - Film Condensation and Drop wise Condensation.

i. **Film Condensation:** When the condensate tends to “wet” the surface, then it is called “film condensation”. In this process, the liquid condensate distributes itself as a continuous thin film on the cooled surface. This happens when the surface tension between the liquid and the solid material is sufficiently small for example, condensation of steam on a clean metallic surface, when the surface is clean and grease / oil free.

   In film condensation, heat transfer from the vapour to the cooling surface takes place through the condensate film formed on the surface. As the new condensate formed joins the film existing on the surface, the film thickness increases. The heat is transferred from the vapour to the condensate by convection and further from condensate to the surface by conduction. This combined mode of heat transfer by conduction and convection reduce the rate of heat transfer in film condensation process. Hence, the rate of heat transfer is lower in film condensation (as compared to drop wise condensation).

ii. **Drop-wise Condensation:** When the condensate does not wet the surface, it forms the droplets on the surface, it is known as “drop-wise condensation”. When the surface tension is large, the condensate coalesces into a multitude of droplets of
different sizes. With time, each droplet grows as more vapour condenses on its exposed surface. The formation of each droplet is initiated at a point of surface imperfection (pit, scratch, etc.) and such sites are called “nucleation sites”. At some time, the tangential pull of gravity, or shear force exerted by the vapour stream, dislodges the droplet and carries it downstream.

The moving droplet devours the smaller droplets in its path, thereby creating a clean trail ready for the generation of new droplets of smaller sizes. This surface renewal process occurs periodically as the droplets accumulate and grow in size. Since the condensation rate is the highest in the absence of condensate on the surface, the periodic cleaning performed by the large drops renews finite size regions of the surface for the restart of the condensation. This surface renewal process is the main reason why drop wise condensation is a highly effective heat transfer mechanism. The heat transfer coefficient is roughly ten times greater than the corresponding condensation in the form of thin film.

In the design of condensers, whose function is to cool a vapour stream and to convert it into liquid, there is a great advantage to promote the breakup of the condensate into droplets. This can be achieved by:

- Coating the solid surface with an organic substance like wax, oil, oleic acid, etc.
- Injecting non-wetting chemicals into the vapour, which get deposited on the surface of the condenser.
- Coating the surface with a polymer of low surface energy like Teflon, Silicon, etc. or with a noble metal like gold, silver, etc.

![Fig: Film Condensation](image-url)
Drop wise Condensation

The mechanism of drop wise condensation is complex because of its intermittent time dependent character, effect of surface tension (due to drop size and shape) and the uncertainty associated with the location of nucleation sites and the time when the largest droplet will start its downstream movement. Hence, a unifying theory of dropwise condensation has not been developed.

DESCRIPTION OF THE APPARATUS: The apparatus consists of
1. Heat exchanger tube made of copper which is placed inside the GLASS CHAMBER of dimension \( \varnothing 100 \times 200 \text{mm} \).
2. Steam Generator with necessary fittings and accessories to generate and supply the steam.
3. Rota meter to directly measure the flow rate of the water into the condensate tube.
4. Centrifugal Mono-block Pump with control valves and bypass to regulate the flow of water through the condenser tube.
5. Thermocouples at suitable position to measure the temperatures of body and the air.
6. Digital Temperature Indicator with channel selector to measure the temperatures.
7. Control panel to house all the instrumentation.
8. With this the whole arrangement is mounted on an aesthetically
9. Designed self-sustained MS powder coated frame with a separate control panel.

PROCEDURE:
1. Fill water slowly into the water tank and steam generator.
2. Switch on the supply mains and console.
3. Switch on the heater of steam generator to generate the steam.
4. Once the steam is generated follow the steps below.
5. Open the inlet valve and allow the cold fluid to flow through the condenser.
6. Adjust the flow rate of cold fluid to minimum.
7. Open the steam inlet valve and keep steam pressure constant (say 0.2kg/cm²) throughout the experiment.
8. After cold fluid temperature becomes steady state, note down the inlet temperature, outlet temperature and flow rate of cold fluid and also note down the volume of condensate collected at the given time interval(say 1min).
9. Keeping steam pressure constant take 4 – 5 readings for different cold fluid flow rate from minimum to maximum.

10. Repeat the experiment at another constant steam pressure say, (0.3 kg/cm²).

PRECAUTIONS:

1. Check all the electrical connections.
2. Do not run the equipment if the voltage is below 180V.
3. Do not give continuous steam without running the cold water.
4. Run the water in the condensate tube for about 5 min after the experiment.
5. Do not run the equipment if the voltage is below 180V.
6. Check all the electrical connections before running.
7. Before starting and after finishing the experiment the steam valve should be in shut position.
8. Do not attempt to alter the equipment as this may cause damage to the whole system.

NOTE: While doing experiment follow the precautions below

1. Initially, close the valve on the top of the condenser unit
2. Start the steam and then open the valve at the top of the condenser unit and close it as soon as the steam is filled.
3. Also make sure to open the water connection of the condenser unit to which the steam is released and close the steam valve of other unit.

PRE VIVA QUESTIONS:

1. Define condensation
2. List out the types of condensation
3. Define film condensation and drop wise condensation
4. What is film coefficient?

TABULAR COLUMN:

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Steam pressure. (P) kg/cm²</th>
<th>Cold fluid temperature°C</th>
<th>Flow rate of cold fluid (W) LPM</th>
<th>Volume of condensate collected at given time interval, (Vc) kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁</td>
<td>T₂</td>
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</table>
CALCULATIONS:

1. **Mass Flow Rate of Cold Fluid**

   \[ m_w = \frac{W}{60}, \text{kg/s} \]

   Where, \( W \) = Cold fluid flow rate, LPM

2. **Heat Carried Away By Cold Fluid**

   \[ Q_C = m_w \times C_{PW} \times \Delta T_W \text{ Watt.} \]
Where,

- \(m_w\) = mass flow rate of cold fluid, kg/s.
- \(C_{Pw}\) = Specific heat of cold fluid, kJ/kg \(\cdot\) °K.
- \(\Delta T_w\) = Cold fluid temperate difference, \((T_2 - T_1)\) °K

3. **Mass Flow Rate of Condensate Fluid**

\[
M_c = \frac{V_c kg}{s}
\]

Where,

- \(M_c\) = mass flow rate of condensate, kg/s.
- \(V_c\) = volume of condensate collected, kg
- \(t\) = Time interval, sec.

4. **Heat Lost By The Steam**

\[
Q_s = \frac{M_c \times h_{fg}}{1000}, \text{Watts}
\]

Where,

- \(M_c\) = mass flow rate of condensate, kg/s.
- \(h_{fg}\) = latent enthalpy obtained from steam table for given pressure, kJ/kg.

5. **Overall Heat Transfer Co-Efficient**

\[
U_o = \frac{Q_s}{A \times \Delta T_{LMTD}}, \frac{W}{m^2\cdot\circ C}
\]

Where,

- \(Q_s\) = Heat Lost By the Steam, Watt.
- \(A\) = Area occupied by the inner tubes, m².
  \[A = D_o \times L \times n, m^2\]
- \(D_o\) = outer diameter of inner tube, 40 mm
- \(L\) = Length of the tube, 0.16 m
- \(n\) = Number of tubes.
- \(\Delta T_{LMTD}\) = Logarithmic mean temperature difference.

\[
T_{LMTD} = \frac{(T_S - T_1) - (T_S - T_2)}{ln \left(\frac{(T_S - T_1)}{(T_S - T_2)}\right)}, \circ C
\]

Where, \(T_S\) = Temperature obtained from steam tables at given pressure.
6. **Cold Fluid Heat Transfer Co - Efficient:**

Find: \( C_p, \mu, \rho \) and \( k \). @ \( T_{avg} = \frac{T_1+T_2}{2} \) From hand book.

\[
h_i = \frac{0.023 \times Re^{0.8} \times Pr^{0.4} \times k}{D_i}, \text{W/m}^2\text{°C}
\]

Where,

- \( Re = \) Reynolds number.

\[
Re = \frac{\rho \times V \times D_i}{\mu}
\]

- \( D_i = \) inner dia of the inner tube = 36mm.

- \( V = \) Velocity of the cold fluid,

\[
V = \frac{M_w}{\rho \times A_T}, \text{m/s}
\]

\[
A_T = \frac{\pi \times D_i^2}{2}, \text{m}^2
\]

- \( \rho = \) density of the fluid, kg/m³.

- \( \mu = \) viscosity of fluid, Ns/m²

- \( C_p = \) specific heat of the fluid, kJ/kg-°C

- \( k = \) Thermal conductive of the fluid, W/m-°C

- \( Pr = \) Prandlt Number.

\[
Pr = \frac{\mu \times C_p}{k}
\]

7. **Steam Side Heat Transfer Co - Efficient**

\[
h_s = 0.943 \left[\frac{k^3 \times \rho^2 \times g \times h_{fg} \times T_{avg}}{\mu \times L \times \Delta T}\right]^{0.25}
\]

Where,

- \( \Delta T = (T_S - T_W) \) °C.

- \( L = \) Length of the condenser = 0.18 m.

- \( T_W = \frac{T_S + T_{C,avg}}{2} \)

- \( T_{C,avg} = \frac{T_1 + T_2}{2} \)
TABULATE THE READING:

<table>
<thead>
<tr>
<th>Steam Side Heat Transfer Co – Efficient, $h_s$ W/m²°C</th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
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<td>Cold Fluid Side Heat Transfer Co-Efficient, $h_i$ W/m² °C</td>
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<tr>
<td>Reynolds Number, Re</td>
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<tr>
<td>$\frac{1}{V^{0.8}}$</td>
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<tr>
<td>Velocity of The Cold Fluid, ‘V’ m/s</td>
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<tr>
<td>$\frac{1}{U_o}$</td>
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<tr>
<td>Overall Heat Transfer Co-Efficient $U_o$ W/m² - °C.</td>
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<td>Logarithm Temp. Mean Difference ΔT&lt;sub&gt;LMTD&lt;/sub&gt;°C.</td>
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<td>Heat Lost By Steam $Q_s$, Watt</td>
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<tr>
<td>Heat Carried Away By Cold Fluid, $Q_c$, Watt</td>
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</table>
8. MODEL GRAPH (WILSON’S GRAPH):

- Draw the graph of \( \frac{1}{V^{0.8}} \) v/s \( \frac{1}{U_0} \)
- Draw for different steam pressures.

VERIFICATION:
Found the overall heat transfer coefficient, steam side film coefficient, cold fluid heat transfer coefficient and is verified by drawing Wilson’s plot and hence calculated the value of theoretical \( h_i \) from the graph.

CONCLUSION: The two types of condensation process is studied and found the overall heat transfer coefficient, steam side film coefficient and cold fluid heat transfer coefficient.

POST VIVA QUESTIONS:
1. What is the surface conditions required for drop-wise condensation?
2. What is the significance of Nusselt theory?
3. Define overall heat transfer coefficient
4. Define steam side film coefficient
5. Define cold fluid heat transfer coefficient
6. What is Physical state of heat exchanging fluid?
EXPERIMENT-10

VAPOUR COMPRESSION REFRIGERATION

AIM:

To demonstrate the working of vapour compression refrigeration system and calculate its capacity and performance.

INTRODUCTION:

Refrigeration is a process by which the temperature of a given space is reduced below that of the atmosphere or surroundings. Refrigeration can be realized by several methods, for example, Ice refrigeration, dry ice Refrigeration, evaporative refrigeration, air Refrigeration, vapour compression Refrigeration etc. The modern Refrigeration uses the vapour compression method. In this method, a closed system the (refrigerant) experiences a thermodynamic cycle; by virtue of doing network on the system in such a cycle, it is possible to extract heat from a low temperature source (the Refrigeration space) and rejects heat to a higher temperature sink (the atmosphere or cooling water).

Fig: 1 Vapour compression Refrigeration

Fig. (1) Shows the schematic of the vapour compression machine. The thermodynamic cycle in temperature- entropy (T-S) and enthalpy entropy (H-S) diagrams are shown in fig.(2). The cycle consists of the following processes
1. Process (1) – (2): Isentropic compression (in ideal cycle) of vapour refrigerant from lower pressure to higher pressure, temperature increases. (But in actual practice, the process is not isentropic because of losses and inefficiency).

2. Process (2) – (3): Condensation of high pressure of saturated/super-heated vapour to liquid at high pressure.


In the ideal cycle the refrigerant enters the throttling valve/capillary as a liquid at (3) and leaves (4) at constant enthalpy as liquid – vapour mixture. The refrigerant enters the evaporator and extracts heat from the refrigerated space at constant temperature ($T_1$) and lower pressure in the vaporization process (4-1). The refrigerant may leave the evaporator as a two phase mixture or as a saturated vapour or as a slightly superheated vapour as shown in fig.(2). Ideally, the refrigerant is compressed to the condenser pressure in the isentropic process (1-2). Heat is rejected from the condenser to the atmosphere or cooling water in the process (2-3).

The “co-efficient of performance” (COP) is defined as the ratio of the refrigeration obtained to the net work done on the system in the cycle:
\[ COP = \frac{Q_1}{W} \]

The actual co-efficient of performance must take into account the effect of irreversibility in the individual processes as well as heat losses to or heat gain from the surroundings through the walls of interconnecting piping.

The capacity of the refrigerator is the rate at which heat can be extracted from the cold body, or in other words, is the rate at which refrigeration is produced. It is expressed in “tons of refrigeration”. A ton of refrigeration is defined as the quantity of heat removed to form 1 ton of ice in 24 hr., when the initial temperature of water is 0°C.

One tons of refrigeration = refrigeration effect in 24hrs.

\[ 1 \, TOR = \frac{m_{ice} \times h_{ice}}{24 \times 60} \, \text{kJ/min} \]

\[ h_{ice} = \text{latent heat of ice} = 336 \, \text{kJ/kg} \]

\[ 1 \, TOR = \frac{1000 \times 336}{24 \times 60} \, \text{kJ/min} \]

1 TOR = 210 kJ/min or 3.5 kW

The horse power input per ton of refrigeration in terms of co-efficient of performance of the refrigerator is given by.

\[ \text{HP/Ton} = 4.715/\text{COP} \]

**DESCRIPTION OF THE APPARATUS:**

The Refrigeration system consists of:

1. **REFRIGERANT:** R-134 A is used as a medium to undergo vapour compression cycle
2. **COMPRESSOR:** Reciprocating type, capacity 1/3 HP, Kirloskar make, used to compress refrigerant vapour at low pressure from the evaporator to a higher pressure at the condenser inlet
3. **CONDENSER:** Is a heat exchanger equipment to condense refrigerant vapor at higher temperature to a liquid
4. **COOLING FAN:** Provided to blow atmospheric air on the condenser to assist cooling of refrigerant in the condenser
5. **THROTTLE VALVE**: Provided to facilitate expansion of high pressure liquid refrigerant to a low pressure liquid-vapor mixture at constant enthalpy

6. **CAPILLARY TUBE**: Performs the same function as the throttle valve. It is a fixed length small bore transparent tubing installed between condenser and evaporator – used to demonstrate the working of the throttle valve. During the refrigeration experiment, either the throttle valve or the capillary tube will be used. Switching can be realized by suitable connecting / valve system.

7. **EVAPORATOR**: Is a chamber where cooling takes place because of evaporation of liquid – vapor refrigerant at low temperature and pressure. It consists of a metallic bowl having grooves below the surface through which the refrigerant flows while evaporation

8. **DIGITAL PRESSURE INDICATORS**: Provided to measure of the refrigerant at compressor inlet and compressor outlet

9. **TEMPERATURE INDICATORS WITH CHANNEL SELECTOR**: Provided to measure temperatures of the refrigerant at
   - Compressor inlet/evaporate outlet
   - Compressor outlet / condenser inlet
   - Condenser outlet /throttling or capillary inlet.
   - Throttling or capillary exit / evaporate inlet
   - inside freezer

10. **DIGITAL POWER METER**: Provided to measure power input to the compressor.

**PROCEDURE:**

1. Switch – ON the mains and the console
2. Keep either the throttle valve or the capillary tube open both devices have the same expansion (or throttling) effect.
3. Switch –ON the motor which drives the compression and the fan (which cools the condenser)
4. The refrigerant passes through the vapour compression cycle as mentioned earlier resulting in cooling in evaporator chamber or freezer
5. Wait for about 5 minutes and note the temperatures $T_1$ to $T_5$ and pressures $P_1$ and $P_2$
6. The temperature $T_5$ in the freezer denotes the refrigeration process
7. Note the power input (P) to the compressor
8. Using the measured temperatures, pressures and power input to the compressor, the co-efficient of performance and the capacity of the refrigerator can be determined.
PRECAUTIONS:
1. Check all the electrical connections.
2. Do not run the equipment if the voltage is below 180V.
3. Do not switch ON the compressor frequently.
4. Do not attempt to alter the equipment as this may cause damage to the whole system.

PRE VIVA QUESTIONS:
1. Define refrigeration
2. Define TOR
3. List out the applications of refrigeration
4. Define COP, relative COP
5. What are the properties of a good refrigerant
6. Classify refrigeration systems
7. List out various types of refrigerants

TABULAR COLUMN:

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<thead>
<tr>
<th>Sl. No</th>
<th>Type of valve</th>
<th>Mass flow rate of water</th>
<th>$t$ in sec</th>
<th>Temperature, °C</th>
<th>Pressure, Bar</th>
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<td>Thermo-Static Expansion valve</td>
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<tr>
<th>Type of valve</th>
<th>Cooling effect $Q_c$ in W</th>
<th>Work input $W$ in W</th>
<th>COP$_{act}$</th>
<th>COP$_{th}$</th>
<th>COP$_{relative}$</th>
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<td>Thermo-Static Expansion valve</td>
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</table>
EXPERIMENTAL SET-UP

CALCULATIONS:

1. Cooling Effect = heat rejected by water

   \[ Q_c = m \cdot C_p \cdot (T_{wi} - T_{wo}) \] in W

Where,

\[ m = \text{mass flow rate of water} = \frac{j}{\text{time taken for 1 liter of water flow in sec}}, \text{kg/sec} \]
\[ C_p = \text{specific heat of water} = 4180 \text{ J/kg.}^\circ C \]
\[ T_{wi} = \text{Temperature of water at inlet (}^\circ C) \]
\[ T_{wo} = \text{Temperature of water at outlet (}^\circ C) \]
\[ T_1 = \text{Temperature at compressor inlet (}^\circ C) \]
\[ T_2 = \text{Temperature at compressor outlet (}^\circ C) \]
\[ T_3 = \text{Temperature at condenser outlet (}^\circ C) \]
\[ T_4 = \text{Temperature at evaporator inlet (}^\circ C) \]
\[ T_5 = \text{Temperature inside freezer} \]
\[ P_1 = \text{Pressure upstream of the compressor, kg/cm}^2 \]
\[ P_2 = \text{Pressure downstream of the compressor, kg/cm}^2 \]

2. **Work input to the compressor,** \( W = \text{Power supplied} \)

\[ W = \frac{3600 \times n}{k \times t}, W \]

Where,
\[ n = \text{no of revolutions of energy meter disc} = 5 \text{ rev} \]
\[ K = \text{energy meter constant} = 750 \text{ rev/kW-hr} \]
\[ t = \text{Time taken for ‘} n \text{’ revolutions in sec} \]

3. **Co – Efficient of Performance (COP)_{act}**

\[ COP_{act} = \frac{Q_c}{W} \]

4. **Co – Efficient of Performance (COP)_{th}**

\[ COP_{th} = \frac{H_1 - H_4}{H_2 - H_1} \]

Where,
\[ H_1 = \text{Enthalpy of the refrigerant at exit of the evaporator, kJ/kg.} \]
\[ H_2 = \text{Enthalpy of the refrigerant at exit of the compressor, kJ/kg.} \]
\[ H_3 = \text{Enthalpy of the refrigerant at exit of the condenser, kJ/kg.} \]
\[ H_4 = \text{Enthalpy of the refrigerant at exit of the throttle valve/capillary tube, kJ/kg.} \]

The values of enthalpies of the refrigerant at different states are obtained from pressure-enthalpy chart provided.

**Note:**
\[ H_1 \text{ is obtained for Temperature} \ T_1 \text{ and Pressure} \ P_1 \]
\[ H_2 \text{ is obtained for Temperature} \ T_2 \text{ and Pressure} \ P_2 \]
\[ H_3 \text{ is obtained for Pressure} \ P_2 \]
\( H_4 = H_3 \)

5. **Relative Co–Efficient of Performance \( \text{COP}_{\text{relative}} \)**

\[
\text{COP}_{\text{relative}} = \frac{\text{COP}_{\text{act}}}{\text{COP}_{\text{th}}}
\]

6. **HP Per TON of Refrigerent, HP/TON**

\[
\frac{\text{HP}}{\text{TON}} = \frac{4.715}{\text{COP}_{\text{act}}}
\]

7. **TONS of Refrigerent, TON**

\[
\text{TON} = \frac{m_a \times Q_c}{210}
\]

**RESULT:**

1. The Co-efficient of Performance of given refrigerant is ________.
2. Tons of Refrigerant = ________tons
3. Relative COP = ____________.

**VERIFICATION:** The coefficient of performance, Tons of refrigeration and Relative COP for a given refrigerant (R-134 A) is calculated and is verified using the standard values of same refrigerant.

**CONCLUSION:** The vapour compression refrigeration process is experimented in a refrigerator with refrigerant as R-134A whose standard COP value (= 3.315) is compared with the experimental value of COP. This may vary with the standard value because of change in initial saturation temperature of condenser and evaporation and superheat and sub cooling temperature of the refrigerant.

**POST VIVA QUESTIONS:**

1. What are the advantages of vapour compression refrigeration
2. Define wet compression, dry compression, super heating and sub cooling
3. Draw vapour compression refrigeration on P-H chart
4. What is the chemical name of R-12, R22 and R-134a
5. Define DBT, WBT, WBD, SH, AH, RH, Specific weight, DPT, Saturation ratio, adiabatic temperature, enthalpy of saturated air
6. Show following processes on psychometric chart Sensible heating, sensible cooling, cooling with dehumidification, humidification, heating with humidification
Fig: Tetrafluoroethane (CH$_2$FCF$_3$) (R134a)
EXPERIMENT – 11

TRANSIENT HEAT CONDUCTION APPARATUS

AIM:

To determine heat transfer coefficient and instantaneous heat transfer rate for transient heat conduction and draw the graph of temperature variation with time.

INTRODUCTION:

The heat transfer depends on time or temperature varies with time is considered as unsteady state or transient heat transfer. In various practical situations transient heat transfer takes place. In heat transfer analysis, temperature inside the body is assumed to be uniform and temperature varies with time only. Such analysis is called lumped system analysis. In most cases the temperature within the body will change from point to point as well as with time. In such cases lumped system is not applicable. Temperature charts or Heisler charts are used to determine the temperature at any point at any time. Transient problems are analyzed by using dimensionless numbers like Biot number and Fourier number.

Biot number: It is defined as internal conduction resistance to surface convective resistance.

\[ B_i = \frac{hL_c}{k} \]

Where,

- \( L_c \) = Characteristic length = \( \frac{\text{Volume of the body (V)}}{\text{Surface area (A)}} \) in m
- \( h \) = Convective heat transfer coefficient of the given fluid in W/m\(^2\)-K
- \( k \) = thermal conductivity of the given specimen in W/m-K

1. Biot number provides the measure of temperature drop in the solid relative to the temperature difference between the surface and the fluid.
2. The Biot number is required to determine the validity of the lumped heat capacity. The lumped system analysis can only be applied when \( Bi \leq 0.1 \)

Fourier number: It is defined as the ratio of the rate of heat conduction to the rate of thermal energy storage in the solid.

\[ F_o = \frac{at}{L_c^2} \]

Where,
\( \alpha = \) thermal diffusivity of the material in m\(^2\)/s
\( t = \) time interval in sec

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

When a body is subjected to heating or cooling, irrespective of the material it requires certain time to attain steady state. Hence the other way of expressing is that the unsteady process will occur till it attains the steady process. In unsteady process the temperature will change with respect to time.

Unsteady state heating or cooling can be categorized as:

**PERIODIC HEAT FLOW:** where the temperature within the system undergoes periodic changes which may be regular or irregular.

**NON–PERIODIC HEAT FLOW:** where the temperature at any point within the system changes non–linearly with respect to time.

Unsteady state heat flow is very common in all heating or cooling problems at the beginning of the system. Hardening by quenching, cooling of IC engine cylinders, and heating of boiler tubes are common examples of unsteady state heat flow.

**DESCRIPTION OF APPARATUS:**

1. The apparatus consists of a specially designed Stainless Steel Tank with heater arrangement.
2. An ALUMINIUM sphere is provided to study the experiment with the stand to place in the heater tank.
3. Heater regulator with Thermostat to supply the regulated power input to the heater and to set the temperature.
4. Thermocouples at suitable position to measure the temperatures.
5. Digital Temperature Indicator with channel selector to measure the temperatures.
6. The whole arrangement is mounted on an aesthetically designed sturdy frame made of MS tubes and NOVAPAN Board with all the provisions for holding the tanks and accessories.

**PROCEDURE:**

1. Take the fluid (water or oil) in the tank.
2. Heat the fluid to the required temperature say 70°C in case of water and more than 100°C in case of oil.
3. Note down the initial temperature of sphere and hot fluid.
4. Immerse the sphere in hot fluid bath for heating.
5. Note down the core and outer surface temperature of the sphere at every 10 seconds till it attains fluid temperature.
6. Take out the sphere from hot fluid and cool it in atmospheric air.
7. Note down the temperature at every 10 second till it reaches atmospheric condition.
8. Repeat the experiment for different temperatures of fluid.

PRECAUTIONS
1. Clean the tank regularly after every use.
2. Do not run the equipment if the voltage is below 180V.
3. Check all the electrical connections before running.
4. Do not attempt to alter the equipment as this may cause damage to the whole system.

PRE VIVA QUESTIONS;
1. What is steady state and unsteady state heat transfers? Give examples
2. Define Biot number and Fourier number
3. Define the transient heat conduction

EXPERIMENTAL SET-UP
EXPERIMENTAL SETUP OF TRANSIENT HEAT CONDUCTION

OBSERVATIONS

- Initial Temperature of the fluid, $T_{\infty} = \underline{\quad}^\circ C$
- Initial Temperature of the sphere, $T_o = T_3 = \underline{\quad}^\circ C$

Note:
- $T_2$ in case of water or oil, $T_1$ in case of air.
- Take $T_4$ with respect to time for Heating process and
- Take $T_3$ with respect to time for cooling process.

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<th>Fourier Number $Fo$</th>
<th>Temperatures $^\circ C$</th>
<th>$T_c = T_4$</th>
<th>$T_o = T_3$</th>
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CALCULATIONS:

1. **Determination of Heat Transfer Co-efficient, $h$**

   \[ h = \frac{N_u \times k}{D}, \text{W/m}^2\text{K} \]

   i. $N_u = $ Nusselt Number is given by

   \[ N_u = 2 + 0.43 (GrPr)^{0.25} \text{For: } 1 < GrPr < 10^5 \]
\[ N_u = 2 + 0.50 \left( GrPr \right)^{0.25} \text{For: } 3 \times 10^5 < GrPr < 8 \times 10^5 \]

ii. \( Pr = \text{Prandtl Number} = \frac{C_p \times \mu}{k} \)

iii. \( Gr = \text{Grashoff Number} \) & is given by

\[
Gr = \frac{D^3 \times \rho^2 \times \beta \times g \times (T_0 - T_\infty)}{\mu^2}
\]

- \( D = \text{Diameter of sphere} = 0.075 \text{ m} \)
- \( k = \text{Thermal conductivity of fluid, W/mK} \)
- \( k_{\text{wat}} = \text{Water or oil in case of heating} \)
- \( k_{\text{air}} = \text{Air in case of cooling} \)
- \( \rho = \text{Density of fluid, kg/m}^3 \)
- \( \beta = \text{Volumetric thermal expansion coefficient} = 1/(T_r+273) \text{ 1/K} \)
- \( T_r = \text{Mean film temperature} = (T_o+T_\infty)/2 \text{ 0°C} \)
- \( \Delta T = \text{Temperature difference between sphere and fluid} = (T_o-T_\infty) \text{ 0°C} \)
- \( \mu = \text{Absolute viscosity of fluid, N-s/m}^2 \)

**NOTE:**
Properties of fluid such as \( \rho, \mu, K, P_r \) are obtained from HMT data book at \( T_f \)

2. **Determination of Instantaneous Heat Flow, \( Q \)**

\[
Q_i = -hA(T_i - T_\infty)e^{-B_iF_o}, \text{ Watts}
\]

\[
B_i = \text{Biot Number} = \frac{h \times r}{K_s}
\]

\[
F_o = \text{Fourier Number} = \frac{\alpha \times t}{r^2}
\]

Where,

- \( h = \text{heat transfer co-efficient, W/m}^2\text{K} \)
- \( A = \text{Surface area of the sphere} = 4\pi r^2. \)
- \( \alpha = \text{Thermal diffusivity of sphere material} = 84.18 \times 10^{-6} \text{ m}^2/\text{s} \)
- \( t = \text{Time at the given instant, sec} \)
- \( r = \text{Radius of the sphere, m (or, Lc is the characteristic length= V/As of solid)} \)
- \( T_i = \text{Temperature of the sphere at given time instant, 0°C,} \)
- \( T_\infty = \text{Initial temperature of hot fluid or cold fluid} \)
- \( k_s = \text{Thermal conductivity of sphere} = 205 \text{ W/m°C} \)

3. **Determination of Theoretical Temperatures, \( T \)**

\[
\frac{(T - T_\infty)}{(T_i - T_\infty)} = e^{-B_iF_o}
\]

- \( T = \text{Temperature of the sphere in the given time, 0°C} \)
F_o= is obtained at different time instants

MODEL GRAPHS:

- Experimental temperature v/s time,
- Theoretical temperature v/s time

RESULTS: The heat transfer coefficient for transient heat conduction heat transfer,

\[ h = \text{______________ W/ m}^2\text{°C}. \]

VERIFICATION: The heat transfer coefficient for transient heat conduction heat transfer in the Aluminium sphere is calculated by using Biot and Fourier number and is verified with that of standard value of the same Aluminium sphere

CONCLUSION: Transient heat conduction is one in which the heat flow and the temperature distribution at any point of the system vary continuously with time and it is also known as unsteady state heat transfer. Thus, Lumped parameter analysis is used to find the heat transfer coefficient for transient heat conduction heat transfer which means that the temperature of the solid changes with both position and time. But in many engineering problems, the variation of temperature with position is neglected during the transient heat conduction. Hence, the temperature is a function of time only.

POST VIVA QUESTIONS:

1. What is the significance of Biot and Fourier Number?
2. What do you mean by characteristic length? Get the characteristic length of rectangular slab, cylinder and sphere
3. What are the applications of Heisler charts?
4. Give few examples for heat transient heat conduction through semi-infinite solids
EXPERIMENT -12

AIR CONDITIONING TEST RIG

AIM:

- To demonstrate the working of air conditioning system.
- To demonstrate cooling, heating and humidification processes.

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: Temperature, Humidity, Air movement and circulation and 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 session, the air conditioning processes involve cooling, heating, humidification and dehumidification of air. Other aspects such as air movements, circulations, purification, etc. are obtained by installing suitable fans, blowers, ducting and filters. This equipment is designed to demonstrate different air conditioning processes such as cooling, heating, humidification, etc. required for different season of the year.

IMPORTANT DEFINITIONS:

1. **Dry Air:** Mechanical mixture of oxygen, nitrogen, carbon dioxide, etc.

2. **Moist Air:** Mixture of dry air and water vapour.

3. **Saturated Air:** Is such a mixture of dry air and water vapour when the air has diffused the maximum amount of water vapour into it.

4. **Degree of Saturation:** 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.

5. **Humidity:** Is the mass of water vapour present in 1 Kg of dry air expressed in gm per Kg of dry air.
6. **Absolute humidity:** Is the mass of water vapour present in 1 m³ of dry air, gm per cubic meter of dry air

7. **Relative Humidity:** Is the ratio of actual mass of water vapour in volume of moist air to the mass of water vapour in the same volume of saturated air at the same temperature and pressure.

8. **Dry bulb temperature:** Is the temperature of air recorded by a thermometer when it is not affected by the moisture present in the air.

9. **Wet Bulb Temperature:** Is the temperature of the air recorded by a thermometer when its bulb is surrounded by a wet cloth exposed to the Air

10. **Psychrometer:** 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 Psychrometer.

**DESCRIPTION OF THE APPARATUS:**

It consists of a cooling coil which is a part of the vapour compression refrigeration system working on Freon – 22. In the upstream and downstream of the cooling coil, heaters are provided to heat air either at the upstream or the downstream of the cooling coil. A steam generator is provided to increase humidity of air. The system is provided to increase humidity of air. The system is provided with fans, air duct and valve system to circulate air over the cooling coil and heater and to operate the system in both closed and open cycle. The system is instrumented with thermometers, digital humidity indicators, pressure indictors 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:*

Cooling coil of the vapour compression refrigeration system consisting of Compressor, condenser, throttle / capillary tube, pressure and temperature Indicators with selector switch and power meter. The system works on Freon-22

1. **Air Heaters - 2 set (3 Nos. of 500 W each)**

2. **Steam generator which consists of immersion type heating coil**

3. **Suction fan (2 Nos.)**

4. **Valve system to change the system to perform in both closed and open**

5. **Duct system with a window (close / open)**
6. Wind Anemometer to measure air velocity in the duct
7. Wet Bulb & Dry Bulb Temperatures (2 Nos.) placed before and after evaporator / cooling coil.
8. Temperature indicator with selector switch to measure air temperature upstream of cooling coil and downstream of post heater.
9. Energy meters (2 Nos.) for compressor and downstream of compressor
10. Pressure gauges – at both upstream and downstream of compressor
11. Pressure switches to limit pressures upstream and downstream of compressor
12. Thermostat to limit negative temperatures in the cooling coil

**WORKING PRINCIPLE:** Definition of some psychometric processes:

- **Sensible cooling:** Is a process where air is cooled without changing specific humidity
- **Sensible heating:** Is a process where air is heated without changing specific humidity
- **Humidification:** Is a process where moisture is added to the air without changing the dry bulb temperature
- **De-humidification:** Is a process where moisture is removed from the air without changing the dry bulb temperature

*Fig: Sensible heating & Sensible cooling:*
Fig. (1) Shows the schematic of the psychometric process and its representation in the psychometric chart. The heat rejected by air (per Kg of air) during cooling can be obtained from the psychometric chart by the enthalpy ($\Delta h$) difference between the air inlet and outlet

\[
\text{Heat rejected} = (h_1 - h_2) \text{ KJ/Kg}
\]

It may be noted that the specific humidity remains constant ($\omega_i = \omega_o$), the dry bulb temperature reduces from $T_1$ to $T_2$ and the relative humidity increases from $\phi_i$ to $\phi_o$.

**Cooling and humidification:** Fig (2) shows the psychometric process and its representation in the psychometric chart. In this process, steam (or moisture) is added to the airstream before cooling by the cooling coil. In this process, the dry bulb temperature decreases from $T_1$ to $T_2$, specific humidity increases from $\omega_i$ to $\omega_o$, and the relative humidity increases from $\phi_i$ to $\phi_o$. The net amount of heat rejected (per Kg) by air during this process is given by

\[
\text{Heat rejected} = (h_1 - h_2) \text{ KJ/Kg}
\]

![Diagram of cooling and humidification system](image)

**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 as shown in fig (3). This simulates the air heating process encountered during winter.
PROCEDURE: The following are the operational procedures for different cycles:

A: OPEN CYCLE – COOLING:
1. Switch –ON the mains and the console
2. Open the window and set the valve to work the Air Conditioning system in the open cycle operation
3. Switch –ON the thermostat, keep at maximum
4. Switch –ON all the switches
5. Switch –ON the compressor of the refrigeration unit. The cooling coil temperature begins to fall.
6. Switch –ON the suction fans
7. Switch –ON pre-heater
8. Observe temperatures (T₅ and T₆) at the inlet and outlet of the Air Conditioning unit till fairly steady state is reached
9. Note the following:
   - T₁ = Temperature of refrigeration after Evaporator or inlet to compressor (°C)
   - T₂ = Temperature of refrigeration after Compressor (°C)
   - T₃ = Temperature of refrigeration after Condensation (°C)
   - T₄ = Temperature of refrigeration 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 =high Pressure r side PSI
   - LP = low pressure side PSI
   - V=Air velocity from wind Anemometer
   - Pₑ = Power input to the compressor
   - Pₕ = Power input to the heater
   - Wet and Dry Bulb Temperatures before and after cooling coil and find relative humidity from chart
     - φᵢ =Relative humidity of air at inlet (%)
     - φₒ =relative humidity of air at outlet (%)

B: CLOSED CYCLE – COOLING:
Repeat the above procedure (as mentioned in A) with the following changes:
1. Window closed.
2. Valve in Close cycle position to facilitate circulation of air inside the Duct system
3. Additional fan Switched –OFF.
4. Note all parameters as mentioned in A (9)

**C: HUMIDIFICATION – OPEN CYCLE OPERATION**

Repeat the above procedure (as mentioned in A) with the following:
1. Open the window, position the valve accordingly.
2. Switch– ON both fans
3. Switch – ON both pre –heater and post heater.
4. Switch –ON steam generator
5. Note all parameters as mentioned in A (9)

**D: SIMULATION OF WINTER AIR CONDITIONING – OPEN CYCLE OPERATION**

Repeat the above procedure (as mentioned in A) with the following:
1. Open the Window, position the valve accordingly.
2. Switch– ON both fans
3. Switch –ON post heater only (switch – OFF Pre-heater and steam generator)
4. Note all parameters as mentioned in A (9)

**PRECAUTIONS:**

1. Check all the electrical connections.
2. Do not run the equipment if the voltage is below 180V from each line.
3. Minimum time gap of 20min is required to restart the compressor.
4. Do not switch ON the compressor frequently.
5. Do not attempt to alter the equipment as this may cause damage to the whole system.

**PRE VIVA QUESTIONS:**

1. What is air conditioning
2. Define psychometry.
3. Show following processes on psychometric chart Sensible heating, sensible cooling, cooling with dehumidification, humidification, heating with humidification
4. Classify air conditioning systems
5. What do you mean by comfortable air conditioning?
TABULAR COLUMN:

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Type of process</th>
<th>TEMPERATURE, °C</th>
<th>t in sec</th>
<th>Pressure, Bar</th>
<th>V in m/sec</th>
<th>humidity</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>T₁</td>
<td>T₂</td>
<td>T₃</td>
<td>T₄</td>
<td>T₅</td>
</tr>
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<td>Open cycle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Closed cycle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note:
- T₁ to T₄ indicates Refrigeration Cycle.
- T₅ & T₆ indicate Air conditioner.

EXPERIMENTAL SET-UP:
CALCULATIONS: - REFRIGERATION CYCLE

1. POWER INPUT TO THE COMPRESSOR, \( P_c \)

\[
P_c = \frac{n \times 3600 \times \eta_m}{K \times t_c \times 736}, hp
\]

Where,
- \( n \) = No. of revolutions of energy meter (Say 5)
- \( K \) = Energy meter constant = 750 revs/kW-hr
- \( t_c \) = time for 5 rev. of energy meter for compressor in seconds
- \( t_h \) = time for 5 rev. of energy meter for heater in seconds
- \( \eta_m \) = efficiency of belt transmission = 80%
- 736 = conversion factor to hp

2. POWER INPUT TO THE HEATER, \( P_h \)

\[
P_h = \frac{n \times 3600 \times \eta_m}{K \times t_h \times 736}, hp
\]

3. Theoretical Co – Efficient of Performance:

\[
P_h = \frac{n \times 3600 \times \eta_m}{K \times t_h \times 736}, hp
\]

Where,
- \( h_1 \) = Enthalpy of the refrigerant at exit of the evaporator, kJ/kg.
- \( h_2 \) = Enthalpy of the refrigerant at exit of the compressor, kJ/kg.
- \( h_3 \) = Enthalpy of the refrigerant at exit of the condenser, kJ/kg.
- \( h_4 \) = Enthalpy of the refrigerant at exit of the throttle valve/capillary tube, kJ/kg.

The values of enthalpies of the refrigerant at different states are obtained from pressure-enthalpy chart provided.

Note;
- \( h_1 \) is obtained for Temperature \( T_1 \) and Pressure \( P_1 \)
- \( h_2 \) is obtained for Temperature \( T_2 \) and Pressure \( P_2 \)
- \( h_3 \) is obtained for Pressure \( P_2 \)
- \( h_4 = h_3 \)

4. Actual Co – Efficient of Performance:
**Mass flow rate of air** \( m_a = \rho AV \) kg/sec

Where,
- \( \rho \) = Density of air = 1.2 kg/m\(^3\)
- \( A \) = Area of the duct = 0.41x0.44 = 0.1804 m\(^2\)
- \( V \) = velocity of air from anemometer m/sec

**Cooling Effect/heating effect**, \( Q_c = m_a C_p (T_5-T_6) \) in W

\[ = m_a (h_5-h_6) \] in W

Where,
- \( C_p \) = specific heat of air = 1005 J/kgK
- \( T_5 \) = Air inlet Temperature, before cooling coil (ºC)
- \( T_6 \) = Air outlet Temperature, after cooling coil and post heater (ºC)
- \( h_5 \) = Enthalpy of air at the inlet to the cooling coil, kJ/kg of dry air.
- \( H_6 \) = Enthalpy of air at the outlet of the cooling coil, kJ/kg of dry air.

\[ COP_{act} = \frac{Q_c}{P_c} \]

5. **Relative Co-efficient of Performance:**

\[ COP_{relative} = \frac{COP_{act}}{COP_{th}} \]

6. **HP PER TON OF REFRIGERENT, HP /TON**

\[ \frac{HP}{TON} = \frac{4.715}{COP} \]

7. **TONS OF REFRIGERENT, TON**

\[ TON = \frac{m_a \times Q_c}{210} \]

RESULT:

1. The Co-efficient of Performance of given refrigerant is ____________.
2. Heat rejected by air = ____________

**VERIFICATION:** The Co-efficient of Performance of given refrigerant (Freon-22) is calculated and is verified by using the standard value of the same refrigerant. Heat rejected by air to the atmosphere is the air which is made to circulate in condenser part (say by the condenser fan) in the air conditioner which passes around the condenser coils. This air is one which makes the Freon-22 refrigerant to condense by taking away the heat from the refrigerant, so that it is ready to expand for next cycle. Therefore, this ensures the constant temperature inside the room by operating the room air-conditioner.
CONCLUSION: By finding the COP of the given refrigerant (Feron-22) and heat rejected by the air, we can know the efficiency of air-conditioner and the temperature inside the room to be constant after every cycle of evaporation and condensation of refrigerant.

POST VIVA QUESTIONS:

1. What are the applications of air conditioning
2. Define DBT, WBT, WBD, SH, AH, RH, Specific weight, DPT, Saturation ratio, adiabatic temperature, enthalpy of saturated air

Chlorodifluoromethane(CHClF₂) (Freon 22)