ANNAI MATHAMMAL SHEELA ENGINEERING COLLEGE

DEPARTMENT OF MECHANICAL ENGINEERING

Sub Code & Name: ME6502 HEAT & MASS TRANSFER

2 MARKS WITH QUESTION AND ANSWER

UNIT-1 CONDUCTION

PART-A

1. Define Heat transfer?

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

2. What are the modes of heat transfer?

1. Conduction
2. Convection
3. Radiation

3. What is conduction?

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

In conduction, energy exchange takes place by the kinematics motion or direct impact of molecules .Pure conduction is found only in solids.

4. Define convection.

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

5. Define Radiation.

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

6. State Fourier's Law of conduction.

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

$Q \alpha - A \frac{dT}{dx}$ $Q = -KA \frac{dT}{dx}$ where A – are in m^2

$\frac{dT}{dx}$ - Temperature gradient in K/m K – Thermal conductivity W/mK.

7. Define Thermal Conductivity.

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

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

Heat transfer $Q = \frac{\Delta T_{overall}}{R}$ Where $\Delta T = T_1 - T_2$

$R = \frac{L}{KA}$ - Thermal resistance of slab

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

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

Heat transfer $Q = \frac{\Delta T_{overall}}{R}$ Where, $\Delta T = T_1 - T_2$

$R = \frac{1}{2\pi LK} \text{ in } \left[\frac{r_2}{r_1}\right]$ Thermal resistance of slab

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

10. State Newton's law of cooling or convection law.

Heat transfer by convection is given by Newton's law of cooling

$Q = hA (T_s - T_\infty)$

Where

A – Area exposed to heat transfer in m^2, h - heat transfer coefficient in W/m^2K

T_s – Temperature of the surface in K, T_∞ - Temperature of the fluid in K.

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

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = \frac{1}{\infty}\ \frac{\partial T}{\partial t} \qquad \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} + \frac{q}{K} = \frac{1}{\alpha}\ \frac{\partial T}{\partial t}$$

12. Define overall heat transfer co-efficient.

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

Heat transfer $Q = UA\,\Delta T$.

13. Write down the equation for heat transfer through composite pipes or cylinder.

Heat transfer $Q = \frac{\Delta T_{overall}}{R}$, Where , $\Delta T = T_a - T_b$,

$$R = \frac{1}{2\pi L}\ \frac{1}{h_a r_1} + \frac{In\left[\frac{r_2}{r_1}\right]}{K_1} + \frac{In\left[\frac{r_1}{r_2}\right]L_2}{K_2} + \frac{1}{h_b r_3}.$$

14. What is critical radius of insulation (or) critical thickness?

Critical radius = r_c Critical thickness = $r_c - r_1$

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

15. Define fins (or) extended surfaces.

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

16. State the applications of fins.

The main applications of fins are

1. Cooling of electronic components
2. Cooling of motor cycle engines.
3. Cooling of transformers 4. Cooling of small capacity compressors

17. Define Fin efficiency.

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

$$\eta_{fin} = \frac{Q_{fin}}{Q_{\max}}$$

18. Define Fin effectiveness.

Fin effectiveness is the ratio of heat transfer with fin to that without fin

$$\text{Fin effectiveness} = \frac{Q_{with\ fin}}{Q_{without\ fin}}$$

19. What is meant by steady state heat conduction?

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

20. What is meant by transient heat conduction or unsteady state conduction?

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

21. What is Periodic heat flow?

In Periodic heat flow, the temperature varies on a regular basis

Example;

1. Cylinder of an IC engine.
2. Surface of earth during a period of 24 hours

22. What is non Periodic heat flow?

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

Example:

1. Heating of an ingot in furnace.
2. Cooling of bars.

23. What is meant by Newtonian heating or cooling process?

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

24. What is meant by Lumped heat analysis?

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

25. What is meant by semi-infinite solids?

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

26. What are the factors affecting the thermal conductivity?

1. Moisture
2. Density of material
3. Pressure
4. Temperature
5. Structural of material

27. Explain the significance of thermal diffusivity.

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

28. What are Heisler charts?

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

PART -B

1. A wall is constructed of several layers. The first layer consists of masonry brick 20 cm. thick of thermal conductivity 0.66 W/mK, the second layer consists of 3 cm thick mortar of thermal conductivity 0.6 W/mK, the third layer consists of 8 cm thick lime stone of thermal conductivity 0.58 W/mK and the outer layer consists of 1.2 cm thick plaster of thermal conductivity 0.6 W/mK. The heat transfer coefficient on the interior and exterior of the wall are 5.6 W/m^{2}K and 11 W/m^{2}K respectively. Interior room temperature is 22°C and outside air temperature is -5°C. Calculate

- **a) Overall heat transfer coefficient**
- **b) Overall thermal resistance**
- **c) The rate of heat transfer**
- **d) The temperature at the junction between the mortar and the limestone.**

2. A furnace wall made up of 7.5 cm of fire plate and 0.65 cm of mild steel plate. Inside surface exposed to hot gas at 650°C and outside air temperature 27°C. The convective heat transfer co-efficient for inner side is 60 W/m^{2}K. The convective heat transfer co-efficient for outer side is 8W/m^{2}K. Calculate the heat lost per square meter area of the furnace wall and also find outside surface temperature.

3. A steel tube (K = 43.26 W/mK) of 5.08 cm inner diameter and 7.62 cm outer diameter is covered with 2.5 cm layer of insulation (K = 0.208 W/mK) the inside surface of the tube receivers heat from a hot gas at the temperature of 316°C with heat transfer co-efficient of 28 W/m^{2}K. While the outer surface exposed to the ambient air at 30°C with heat transfer co-efficient of 17 W/m^{2}K. Calculate heat loss for 3

m length of the tube.

4. **Derive an expression of Critical Radius of Insulation for a Cylinder.**

5. **A wire of 6 mm diameter with 2 mm thick insulation (K = 0.11 W/mK). If the convective heat transfer co-efficient between the insulating surface and air is 25 W/m^2L, find the critical thickness of insulation. And also find the percentage of change in the heat transfer rate if the critical radius is used.**

6. **An aluminum alloy fin of 7 mm thick and 50 mm long protrudes from a wall, which is maintained at 120°C. The ambient air temperature is 22°C. The heat transfer coefficient and conductivity of the fin material are 140 W/m^2K and 55 W/mK respectively. Determine**
1. Temperature at the end of the fin.
2. Temperature at the middle of the fin.
3. Total heat dissipated by the fin.

7. **A copper plate 2 mm thick is heated up to 400°C and quenched into water at 30°C. Find the time required for the plate to reach the temperature of 50°C. Heat transfer co-efficient is 100 W/m^2K. Density of copper is 8800 kg/m^3. Specific heat of copper = 0.36 kJ/kg K.**
Plate dimensions = 30 × 30 cm.
[Oct. 97 M.U. April '97 Bharathiyar University]

8. **A steel ball (specific heat = 0.46 kJ/kgK. and thermal conductivity = 35 W/mK) having 5 cm diameter and initially at a uniform temperature of 450°C is suddenly placed in a control environment in which the temperature is maintained at 100°C. Calculate the time required for the balls to attained a temperature of 150°C. Take h = 10W/m^2K.**
[M.U. April-2000, 2001, 2002, Bharathiyar Uni. April 98] Bharathiyar Uni. April 98]

9. Alloy steel ball of 2 mm diameter heated to 800°C is quenched in a bath at 100°C. The material properties of the ball are K = 205 kJ/m hr K, ρ = 7860 kg/m^3, C_ρ = 0.45 kJ/kg K, h = 150 KJ/ hr m^2 K. Determine (i) Temperature of ball after 10 second and (ii) Time for ball to cool to 400°C.

10. A large steel plate 5 cm thick is initially at a uniform temperature of 400°C. It is suddenly exposed on both sides to a surrounding at 60°C with convective heat transfer co-efficient of 285 W/m^{2}K. Calculate the centre line temperature and the temperature inside the plate 1.25 cm from themed plane after 3 minutes. Take K for steel = 42.5 W/mK, α for steel = 0.043 m^2/hr.

11. Derive general heat conduction equation in Cartesian coordinates?

12. Derive general heat conduction equation in cylindrical coordinates?

UNIT-2 CONVECTION

PART-A

1. **Define convection.**

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

2. Define Reynolds number (Re) & Prandtl number (Pr).

Reynolds number is defined as the ratio of inertia force to viscous force.

$$Re = \frac{\text{Inertia force}}{\text{Viscous force}}$$

Prandtl number is the ratio of the momentum diffusivity of the thermal diffusivity.

$$Pr = \frac{\text{Momentum diffusivity}}{\text{Thermal diffusivity}}$$

3. **Define Nusselt number (Nu).**

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

Nusselt number (Nu) = $\frac{Q_{conv}}{Q_{cond}}$.

4. Define Grash of number (Gr) & Stanton number (St).

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

$$Gr = \frac{\text{Inertia force} \times \text{Buyoyancy force}}{(\text{Viscous force})^2}$$

Stanton number is the ratio of nusselt number to the product of Reynolds number and prandtl number.

$$St = \frac{Nu}{Re \times Pr}$$

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

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

6. What is meant by laminar flow and turbulent flow?

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

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

7. **What is meant by free or natural convection & forced convection?**

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

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

8. **Define boundary layer thickness.**

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

9. **What is the form of equation used to calculate heat transfer for flow through cylindrical pipes?**

$Nu = 0.023 (Re)^{0.8} (Pr)^{n}$

n = 0.4 for heating of fluids, n = 0.3 for cooling of fluids

10. **What is meant by Newtonian and non – Newtonian fluids?**

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

11. What is dimensional analysis?

Dimensional analysis is a mathematical method which makes use of the study of the dimensions for solving several engineering problems. This method can be applied to all types of fluid resistance, heat flow problems in fluid mechanics and thermodynamics.

12. State Buckingham's *Π* theorem.

Buckingham's *Π* theorem states as follows: "If there are n variables in a dimensionally homogeneous equation and if these contain M fundamental dimensions, then the variables are arranged into (n-m) dimensionless terms. These dimensional terms are called *Π* terms.

13. What are all the limitations of dimensional analysis?

1. The complete information is not provided by dimensional analysis .It only indicates that there is some relationship between the parameters.
2. No information is given about the internal mechanism of physical phenomenon.
3. Dimensional analysis does not give any clue regarding the selection of variables.

14. What is hydro dynamics boundary layer?

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

15. What is thermal boundary layer?

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

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

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

17. Define displacement thickness.

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

18. Define momentum thickness.

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

19. Define energy thickness.

The energy thickness can be defined as the distance, measured perpendicular to the boundary of

the solid body ,by which the boundary should be displaced to compensate for the reduction in kinetic energy of the flowing fluid on account of boundary layer formation

PART-B

1. **Air at 20°C, at a pressure of 1 bar is flowing over a flat plate at a velocity of 3 m/s. if the plate maintained at 60°C, calculate the heat transfer per unit width of the plate. Assuming the length of the plate along the flow of air is 2m.**

2. Air at 20°C at atmospheric pressure flows over a flat plate at a velocity of 3 m/s. if the plate is 1 m wide and 80°C, calculate the following at x = 300 mm.

1. Hydrodynamic boundary layer thickness,
2. Thermal boundary layer thickness,
3. Local friction coefficient,
4. Average friction coefficient,
5. Local heat transfer coefficient
6. Average heat transfer coefficient,
7. Heat transfer.

3. **Air at 30°C flows over a flat plate at a velocity of 2 m/s. The plate is 2 m long and 1.5 m wide. Calculate the following:**

1. **Boundary layer thickness at the trailing edge of the plate,**
2. **Total drag force,**
3. **Total mass flow rate through the boundary layer between x = 40 cm and x = 85 cm.**

4. **Air at 290°C flows over a flat plate at a velocity of 6 m/s. The plate is 1m long and 0.5 m wide. The pressure of the air is 6 kN/^{2}. If the plate is maintained at a temperature of 70°C, estimate the rate of heat removed from the plate.**

5. Air at 40°C flows over a flat plate, 0.8 m long at a velocity of 50 m/s. The plate surface is maintained at 300°C. Determine the heat transferred from the entire plate length to air taking into consideration both laminar and turbulent portion of the boundary layer. Also calculate the percentage error if the boundary layer is assumed to be turbulent nature from the very leading edge of the plate.

6. 250 Kg/hr of air are cooled from 100°C to 30°C by flowing through a 3.5 cm inner diameter pipe coil bent in to a helix of 0.6 m diameter. Calculate the value of air side heat transfer coefficient if the properties of air at 65°C are

K = 0.0298 W/mK

μ = 0.003 Kg/hr – m

Pr = 0.7

ρ = 1.044 Kg/m^3

7. **In a long annulus (3.125 cm ID and 5 cm OD) the air is heated by maintaining the temperature of the outer surface of inner tube at 50°C. The air enters at 16°C and leaves at 32°C. Its flow rate is 30 m/s. Estimate the heat transfer coefficient between air and the inner tube.**

8. **Engine oil flows through a 50 mm diameter tube at an average temperature of 147°C. The flow velocity is 80 cm/s. Calculate the average heat transfer coefficient if the tube wall is maintained at a temperature of 200°C and it is 2 m long.**

9. **A large vertical plate 4 m height is maintained at 606°C and exposed to atmospheric air at 106°C. Calculate the heat transfer is the plate is 10 m wide.**

10. A thin 100 cm long and 10 cm wide horizontal plate is maintained at a uniform temperature of 150°C in a large tank full of water at 75°C. Estimate the rate of heat to be supplied to the plate to maintain constant plate temperature as heat is dissipated from either side of plate.

11 Explain the thermal & velocity boundary layer for flow over a horizontal flat plate.

UNIT-3 PHASE CHANGE HEAT TRANSFER AND HEAT EXCHANGERS

PART-A

1. What is meant by Boiling and condensation?

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

2. Give the applications of boiling and condensation.

Boiling and condensation process finds wide applications as mentioned below.

1. Thermal and nuclear power plant.
2. Refrigerating systems
3. Process of heating and cooling
4. Air conditioning systems

3. **What is meant by pool boiling?**

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

4. What is meant by Film wise and Drop wise condensation?

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

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

5. Give the merits of drop wise condensation?

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

6. What is heat exchanger?

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

7. What are the types of heat exchangers?

The types of heat exchangers are as follows

1. Direct contact heat exchangers
2. Indirect contact heat exchangers
3. Surface heat exchangers
4. Parallel flow heat exchangers
5. Counter flow heat exchangers
6. Cross flow heat exchangers
7. Shell and tube heat exchangers
8. Compact heat exchangers.

8. What is meant by direct heat exchanger (or) open heat exchanger?

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

9. What is meant by indirect contact heat exchanger?

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

10. What is meant by Regenerators?

In this type of heat exchangers, hot and cold fluids flow alternately through the same space. Examples: IC engines, gas turbines.

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

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

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

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

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

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

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

14. What is meant by compact heat exchangers?

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

15. What is meant by LMTD?

We know that the temperature difference between the hot and cold fluids in the heat exchanger varies from point in addition various modes of heat transfer are involved. Therefore based on concept of appropriate mean temperature difference, also called logarithmic mean temperature difference, also called logarithmic mean temperature difference, the total heat transfer rate in the heat exchanger is expressed as

$Q = U\ A\ (\Delta T)m$ Where U – Overall heat transfer coefficient W/m^2K A – Area m^2

$(\Delta T)_m$ – Logarithmic mean temperature difference.

16. What is meant by Fouling factor?

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

17. What is meant by effectiveness?

The heat exchanger effectiveness is defined as the ratio of actual heat transfer to the maximum possible heat transfer.

$$\text{Effectiveness } \varepsilon = \frac{\text{Actual heat transfer}}{\text{Maximum possible heat transfer}} = \frac{Q}{Q_{max}}$$

PART-B

1. **Water is boiled at the rate of 24 kg/h in a polished copper pan, 300 mm in diameter, at atmospheric pressure. Assuming nucleate boiling conditions calculate the temperature of the bottom surface of the pan.**

2. A nickel wire carrying electric current of 1.5 mm diameter and 50 cm long, is submerged in a water bath which is open to atmospheric pressure. Calculate the voltage at the burn out point, if at this point the wire carries a current of 200A.

3. **Water is boiling on a horizontal tube whose wall temperature is maintained ct 15°C above the saturation temperature of water. Calculate the nucleate boiling heat transfer coefficient. Assume the water to be at a pressure of 20 atm. And also find the change in value of heat transfer coefficient when**

   1. **The temperature difference is increased to 30°C at a pressure of 10 atm.**
   2. **The pressure is raised to 20 atm at Δ T = 15°C**

4. **A vertical flat plate in the form of fin is 500m in height and is exposed to steam at atmospheric pressure. If surface of the plate is maintained at 60°C. calculate the following.**

1. The film thickness at the trailing edge

2. Overall heat transfer coefficient

3. Heat transfer rate

4. The condensate mass flow rate.

Assume laminar flow conditions and unit width of the plate.

5. A condenser is to design to condense 600 kg/h of dry saturated steam at a pressure of 0.12 bar. A square array of 400 tubes, each of 8 mm diameters is to be used. The tube surface is maintained at 30°C. Calculate the heat transfer coefficient and the length of each tube.

6. Steam at 0.080 bar is arranged to condense over a 50 cm square vertical plate. The surface temperature is maintained at 20°C. Calculate the following.

- **a. Film thickness at a distance of 25 cm from the top of the plate.**
- **b. Local heat transfer coefficient at a distance of 25 cm from the top of the plate.**
- **c. Average heat transfer coefficient.**
- **d. Total heat transfer**
- **e. Total steam condensation rate.**
- **f. What would be the heat transfer coefficient if the plate is inclined at 30°C with horizontal plane?**

7. With a neat and labeled sketch explain the various regimes in boiling heat transfer.

8. Compare LMTD and NTU method of heat exchanger analysis.

9. Discuss briefly the pool boiling regimes of water atmospheric pressure.

10. Classify the heat exchanger, draw the temperature distribution in a condenser and evaporator and derive the expressions for effectiveness of parallel flow heat exchanger by NTU method.

UNIT-4 RADIATION

PART - A

1. Define emissive power [E] and monochromatic emissive power. [$E_{b\lambda}$]

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

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

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

Absorptivity is defined as the ratio between radiation absorbed and incident radiation.

Reflectivity is defined as the ratio of radiation reflected to the incident radiation.

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

3. What are black body and gray body?

Black body is an ideal surface having the following properties.

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

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

4. State Planck's distribution law.

The relationship between the monochromatic emissive power of a black body and wave length of a radiation at a particular temperature is given by the following expression, by Planck.

$$E_{b\lambda} = \frac{C_1 \lambda^{-5}}{e^{\left(\frac{C_2}{\lambda T}\right)} - 1}$$

Where $E_{b\lambda}$ = Monochromatic emissive power W/m^2

λ = Wave length – m
$c_1 = 0.374 \times 10^{-15}$ W m^2
$c_2 = 14.4 \times 10^{-3}$ mK

5. State Wien's displacement law.

The Wien's law gives the relationship between temperature and wave length corresponding to the maximum spectral emissive power of the black body at that temperature.

$$\lambda_{mas} T = c_3$$

Where $c_3 = 2.9 \times 10^{-3}$ [Radiation constant]

$$\Rightarrow \quad \lambda_{mas} T = 2.9 \times 10^{-3} \text{ mK}$$

6. State Stefan – Boltzmann law. [April 2002, M.U.]

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

$$E_b \propto T^4$$
$$E_b = \sigma T^4$$

Where E_b = Emissive power, w/m^2
σ = Stefan. Boltzmann constant
= 5.67×10^{-8} W/m^2 K^4
T = Temperature, K

7. Define Emissivity.

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

Emissivity $\varepsilon = \frac{E}{E_b}$

8. State Kirchoff's law of radiation.

This law states that the ratio of total emissive power to the absorbtivity is constant for all surfaces which are in thermal equilibrium with the surroundings. This can be written as

$$\frac{E_1}{\alpha_1} = \frac{E_2}{\alpha_2} = \frac{E_3}{\alpha_3}$$

It also states that the emissivity of the body is always equal to its absorptivity when the body remains in thermal equilibrium with its surroundings.

$\alpha_1 = E_1$; $\alpha_2 = E_2$ and so on.

9. Define intensity of radiation (I_b).

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

$$I_n = \frac{E_b}{\pi}$$

10. State Lambert's cosine law.

It states that the total emissive power E_b from a radiating plane surface in any direction proportional to the cosine of the angle of emission

$$E_b \quad \infty \quad \cos\theta$$

11. What is the purpose of radiation shield?

Radiation shields constructed from low emissivity (high reflective) materials. It is used to reduce the net radiation transfer between two surfaces.

12. Define irradiation (G) and radiosity (J)

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

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

13. What is meant by shape factor?

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

14. What are the assumptions made to calculate radiation exchange between the surfaces?

1. All surfaces are considered to be either black of gray.
2. Radiation and reflection process are assumed to be diffuse.
3. The absorptivity of a surface is taken equal to the emissivity and independent of temperature of the source of the incident radiation.

15. What is meant by shape factor and mention its physical significance.

The shape factor is defined as "The fraction of the radioactive energy that is diffused from one surface element and strikes the other surface directly with no intervening reflection ".it is represented by Fij. Other names for radiation shape factor are view factor, angle factor and configuration factor .The shape factor is used in the analysis of radioactive heat exchange between two surfaces.

16. Discuss the radiation characteristics of carbon dioxide and water vapour.

The CO2 and H2 O both absorb and emit radiation over certain wave length regions called absorption bands.

The radiation in these gases is a volume phenomenon.

The emissivity of CO2 and the emissivity of H 2O at a particular temperature increase with partial pressure and mean beam length.

PART-B

1. A black body at 3000 K emits radiation. Calculate the following:

- **i) Monochromatic emissive power at 7 μm wave length.**
- **ii) Wave length at which emission is maximum.**
- **iii) Maximum emissive power.**
- **iv) Total emissive power,**
- **v) Calculate the total emissive of the furnace if it is assumed as a real surface having emissivity equal to 0.85.**

2. **Assuming sun to be black body emitting radiation at 6000 K at a mean distance of 12 × 10^{10} m from the earth. The diameter of the sun is 1.5 × 10^{9} m and that of the earth is 13.2 × 10^{6} m. Calculation the following.**

1. Total energy emitted by the sun.
2. The emission received per m^2 just outside the earth's atmosphere.
3. The total energy received by the earth if no radiation is blocked by the earth's atmosphere.
4. The energy received by a 2 × 2 m solar collector whose normal is inclined at 45° to the sun. The energy loss through the atmosphere is 50% and the diffuse radiation is 20% of direct radiation.

3. Two black square plates of size 2 by 2 m are placed parallel to each other at a distance of 0.5 m. One plate is maintained at a temperature of 1000°C and the other at 500°C. Find the heat exchange between the plates.

4. Two parallel plates of size 3 m × 2 m are placed parallel to each other at a distance of 1 m. One plate is maintained at a temperature of 550°C and the other at 250°C and the emissivities are 0.35 and 0.55

respectively. The plates are located in a large room whose walls are at 35°C. If the plates located exchange heat with each other and with the room, calculate.1. Heat lost by the plates. 2. Heat received by the room.

5. **A gas mixture contains 20% CO_2 and 10% H_2o by volume. The total pressure is 2 atm. The temperature of the gas is 927°C. The mean beam length is 0.3 m. Calculate the emissivity of the mixture.**

6. **Two black square plates of size 2 by 2 m are placed parallel to each other at a distance of 0.5 m. One plate is maintained at a temperature of 1000°C and the other at 500°C. Find the heat exchange between the plates.**

7. State and prove the laws: (i) Kirchoff's law of radiation (ii) Stefan – Boltzmann law.

8. Derive heat transfer and logarithmic mean temperature difference (LMTD) for counter floe Heat exchanger.

9. Define effectiveness of a heat exchanger. Derive expression for the effectiveness of a double pipe parallel flow heat exchanger. State assumption mode.

10. Explain briefly the following:

- **(i) Thermal radiation**
- **(ii) Specular and diffuse reflection**
- **(iii) Reciprocity rule and summation rule**

11. Derive the radiation exchange between

- **(i) Large parallel gray surface and**
- **(ii) Small gray bodies**

UNIT-5 MASS TRANSFER

PART-A

1. What is mass transfer?

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

2. Give the examples of mass transfer.

Some examples of mass transfer.

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

3. What are the modes of mass transfer?

There are basically two modes of mass transfer,

1. Diffusion mass transfer
2. Convective mass transfer

4. What is molecular diffusion?

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

5. What is Eddy diffusion?

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

6. What is convective mass transfer?

Convective mass transfer is a process of mass transfer that will occur between surface and a fluid medium when they are at different concentration.

7. State Fick's law of diffusion.

The diffusion rate is given by the Fick's law, which states that molar flux of an element per unit area is directly proportional to concentration gradient.

$$\frac{m_a}{A} = -D_{ab}\frac{dC_a}{dx}$$

where,

$\frac{ma}{A}$ – Molar flux, $\frac{\text{kg -mole}}{\text{s-m}^2}$

D_{ab} Diffusion coefficient of species a and b, m^2/s

$\frac{dC_a}{dx}$ – concentration gradient, kg/m^3

8. What is free convective mass transfer?

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

Example: Evaporation of alcohol.

9. Define forced convective mass transfer.

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

Example: The evaluation if water from an ocean when air blows over it.

10. Define Schmidt Number.

It is defined as the ratio of the molecular diffusivity of momentum to the molecular diffusivity of mass.

$$Sc = \frac{\text{Molecular diffusivity of momentum}}{\text{Molecular diffusivity of mass}}$$

11. Define Scherwood Number.

It is defined as the ratio of concentration gradients at the boundary.

$$Sc = \frac{h_m x}{D_{ab}}$$

hm – Mass transfer coefficient, m/s

D_{ab} – Diffusion coefficient, m^2/s

x – Length, m

PART-B

1. **Hydrogen gases at 3 bar and 1 bar are separated by a plastic membrane having thickness 0.25 mm. the binary diffusion coefficient of hydrogen in the plastic is 9.1 × 10^{-3} m^2/s. The solubility of hydrogen in the membrane is 2.1 × 10^{-3} $\frac{kg-mole}{m^3\ bar}$ a uniform temperature condition of 20° is assumed.**

Calculate the following

1. **Molar concentration of hydrogen on both sides**
2. **Molar flux of hydrogen**
3. **Mass flux of hydrogen**

2. Oxygen at 25°C and pressure of 2 bar is flowing through a rubber pipe of inside diameter 25 mm and wall thickness 2.5 mm. The diffusivity of O2 through rubber is 0.21 × 10^{-9} m^2/s and the solubility of O2 in rubber is 3.12 × 10^{-3} $\frac{kg-mole}{m^3-bar}$. Find the loss of O_2 by diffusion per meter length of pipe.

3. **An open pan 210 mm in diameter and 75 mm deep contains water at 25°C and is exposed to dry atmospheric air. Calculate the diffusion coefficient of water in air. Take the rate of diffusion of water vapour is 8.52 × 10^{-4} kg/h.**

4. **An open pan of 150 mm diameter and 75 mm deep contains water at 25°C and is exposed to atmospheric air at 25°C and 50% R.H. Calculate the evaporation rate of water in grams per hour.**

5. Air at 10°C with a velocity of 3 m/s flows over a flat plate. The plate is 0.3 m long. Calculate the mass transfer coefficient.

6. Explain Fick's first and second laws of diffusion.

7. Explain the phenomenon of equimolar counter diffusion. Derive an expression for equimolar counter diffusion between two gases or Liquids.

8. Define the schmidt, sherwood and Lewis numbers. What is the physical significance of each?

9. Explain briefly the similarities between heat transfer and mass transfer.

10. Explain different modes of mass transfer and derive the general mass diffusion equation in stationary media.

11. Consider air inside a tube of surface area 0.5 m^2 and wall thickness 10 mm. The pressure of air drops from 2.2 bar to 2.18 bar in 6 days. The solubility of air in the rubber is 0.072 m^3 of air per m^3 of rubber at 1 bar. Determine the diffusivity of air in rubber at the operating temperature of 300 k if the volume of air in the tube is 0.028 m^3