

DHANALAKSHMI SRINIVASAN ENGINEERING COLLEGE

(AUTONOMOUS)

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COURSE PLAN

Course Code/Name	U23MET61/ Heat and Mass Transfer			
Year/Section/Department	III / Mechanical Engineering			
Credits Details	L:3	T:0	P: 0	C:3
Total Contact Hours Required	45			

Syllabus:U23MET61/ Heat and Mass Transfer

UNIT I/CONDUCTION	No.of Periods :9
General Differential equation – Cartesian, cylindrical and spherical Coordinates – One Dimensional Steady State Heat Conduction – plane and Composite Systems – Conduction with Internal Heat Generation – Extended Surfaces – Unsteady Heat Conduction – Lumped Analysis – Semi Infinite and Infinite Solids –Use of Heisler’s charts.	
UNIT II/CONVECTION	No.of Periods : 9
Conservation equations, boundary layer concept- Forced Convection: External flow-Flow over plates, Cylinders Spheres and Bank of tubes. internal flow-Enhance effects. Free Convection-Flow over vertical plate,horizontal plate. Inclined plate, cylinders and spheres. Mixed convection.	
UNIT III/PHASE CHANGE HEAT TRANSFER AND HEAT EXCHANGERS	No.of Periods:9
Nusselt’s theory of condensation - Regimes of Pool boiling and Flow boiling. Correlations in boiling and condensation. Heat Exchanger Types-TEMA Standards- Overall Heat Transfer Coefficient – Fouling Factors - Analysis – LMTD method - NTU method. Fundamental of heat pipes and its applications	
UNIT IV/RADIATION	No.of Periods:9
Introduction to thermal Radiation- Radiation laws and Radiative properties-Black Body and Grey body radiation –View factor Relations.–Electrical Analogy. –Radiation Shields.	
UNIT V/MASS TRANSFER	No.of Periods:9
Basic Concepts – Diffusion Mass Transfer – Fick’s Law of Diffusion – Steady state and Transient Diffusion Stefan Flow – Convective Mass Transfer – Momentum, Heat and Mass Transfer Analogy – Convective Mass Transfer Correlations.	

Objective:

- ✚ To understand the principles and applications of heat and mass transfer operations.
- ✚ To study about the concept, equation and application of convection.
- ✚ To understand the heat exchanger principles and applications
- ✚ To learn about the Radiation concept of thermal radiations
- ✚ To study about the mass transfer concept and its applications.

Text Book:

- ✚ T1: Holman, J.P., "Heat and Mass Transfer", Tata McGraw Hill, 2000
- ✚ T2: Yunus A. Cengel, "Heat Transfer A Practical Approach", Tata McGraw Hill, 5th Edition 2015

Reference Book:

- ✚ R1: Richard R Kibbe, John E. Neely, Roland O. Merges and Warren J. White "Machine Tool Practices", Prentice Hall of India, 1998
- ✚ R2: HMT, "Production Technology", Tata McGraw Hill, 1998.
- ✚ R3: Geoffrey Boothroyd, "Fundamentals of Metal Machining and Machine Tools", Mc Graw Hill, 1984
- ✚ R4: Roy. A. Lindberg, "Process and Materials of Manufacture," Fourth Edition, PHI/Pearson Education 2006.

Website:

- ✚ W1 Introduction to conduction <https://www.academia.edu/8541011>
- ✚ W2 convection <https://nptel.ac.in/content/storage2/courses/112105129/pdf>

Online Mode of Study (if Any):

- ✚ <http://www.iitp.ac.in/~sudheer/courses/Heat%20and%20Mass%20Transfer.pdf>

**U23MET61/ HEAT AND MASS
TRANSFER
TWO MARKS WITH ANSWER
UNIT I CONDUCTION**

1. What are the modes of heat transfer?

1. Conduction
2. Convection
3. Radiation

2. What is conduction?

Heat conduction is a mechanism of heat transfer from a region of high temperature to a region of low temperature within a medium [solid, liquid or gases] or different medium in direct physical contact.

3. Define Convection.

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

4. Define Radiation.

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

5. What is meant by steady state heat conduction?

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

6. State Fourier's law of conduction. [Apr.'97, Oct.'98 Madras Univ., May'04, May'05 &

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

$$Q \propto A \frac{dT}{dx}$$

$$Q = kA \frac{dT}{dx}$$

Where, A – Area in m²

dT/dx – Temperature gradient, K/m

k – Thermal conductivity, W/mK

7. Define Thermal conductivity. [Apr'97 MU, Oct'99 MU]

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

8. Define Thermal resistance.

Thermal resistance is a heat property and a measurement temperature difference by which an object or material resists a heat flow. Thermal resistance a reciprocal of thermal conductance.

It is denoted by R in K/W

9. What is conductors and insulators?

A thermal conductor is a material that allows energy in the form of heat, to be transferred within the material, without any movement of the material itself.

Thermal insulator used to prevents the heat flow from one part to another

10. Write down the three dimensional heat conduction equations in Cartesian co-ordinate system. May'05 & June'06 Anna Univ.]

The general three dimensional heat conduction equations in Cartesian co-ordinate is

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

Where

q = Heat generator – W/m²

α = Thermal diffusivity – m²/s

11. List down the three types of boundary conditions.[Dec.'05 Anna Univ.]

- a. Prescribed temperature
- b. Prescribed heat flux
- c. Convection boundary conditions.

12. Define overall heat transfer co-efficient. [MU, Apr.'97]

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. Define fins or extended surfaces.

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

14. State the Application of fins

The main applications of fins

- Cooling of electrical components
- Cooling of motor cycle engines
- Cooling of transformers
- Cooling of small capacity compressor

15. Define Fin efficiency. [Anna Univ. Dec.'04 & Dec.'05, MU, Nov.'96 & Oct.'97]

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

$$\eta_{\text{fin}} = Q_{\text{fin}}/Q_{\text{max}}$$

16. Define Fin effectiveness. [Anna Univ. Dec.'04 & Dec.'05, MU. Nov.'96, Apr.'01]

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

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

17. What are the factors affecting the thermal conductivity? [Apr.'97 MU]

1. Moisture, 2. Density, 3. Pressure, 4. Temperature and 5. Structure of material.

18. Explain the significance of thermal diffusivity. [Oct.'98 MU]

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.

19. What are Heisler charts? [Oct.'99 MU]

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

UNIT II CONVECTION

1. What is dimensional analysis? [MU. Nov.'96]

Dimensional analysis is a mathematical method which makes use of the study of the dimensions

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for solving several engineering problems. This method can be applied to all types of fluid resistances, heat flow problems in fluid mechanics and thermodynamics.

2. State Buckingham π theorem. [MU.Apr.'97]

Buckingham 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 dimensionless terms are called π terms.

3. Define Reynolds number [Re]. [Anna Univ. May 2005, June 2006]

It is defined as the ratio of inertia force to viscous force.

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

4. Define Prandtl number [Pr]. [Anna Univ. May 2005, June 2006. MU Oct.'98, Apr.'02]

It is ratio of the momentum diffusivity to the thermal diffusivity.

$$Pr = \text{Momentum diffusivity} / \text{Thermal diffusivity.}$$

5. Define Nusselt number [Nu]. Anna Univ. Dec.'05, MU Apr.'97, 98]

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

$$\text{Nusselt Number [Nu]} = q_{\text{conv}} / q_{\text{cond}}$$

6. Define Grashof number [Gr]. [MU. Oct.'97 & 99]

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

$$Gr = \text{Inertia force} \times \text{Buoyancy force} / [\text{Viscous force}]^2$$

7. Define Stanton number [St]. [Anna Univ. Dec.'05]

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

$$St = Nu / Re \times Pr$$

8. Define convection. [MU. Oct.'98]

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

9. What is meant by free or natural convection? [Anna Univ. May'04, Dec.'04, Jun.'06, MU. Nov.'96, Oct.'97]

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.

10. What is forced convection? [AnnaUniv.May'04, Dec.'04 Jun.'06 MU. Nov.'96&Apr.'98]

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.

11. What is the form of equation used to calculate heat transfer for flow through cylindrical pipes? [MU. Oct.'99]

$$Nu = 0.023 [Re]^{0.8} [Pr]^n$$

n = 0.4 for heating of fluids.

n = 0.3 for cooling of fluids.

12. According to Newton's law of cooling the amount of heat transfer from a solid surface of area A at a temperature T_w to a fluid at a temperature T_∞ is given by ____ [MU. Nov.'94]

$$\text{Ans: } Q = hA [T_w - T_\infty]$$

13. What are the dimensionless parameters used in forced convection? [MU. Oct.'99]

- d. Reynolds number [Re].
- e. Nusselt number [Nu].
- f. Prandtl number [Pr].

14. Define boundary layer thickness. [Anna Univ. May 2004,AU June 2012]

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.

15. Indicate the concept or significance of boundary layer.[Anna Univ. Dec.'04, Dec.'05 & Jun.'06]

In the boundary layer concept the flow field over a body is divided into two regions:

1. A thin region near the body called the boundary layer where the velocity and the temperature gradients are large.
2. The region outside the boundary layer where the velocity and the temperature gradients are

UNIT – III PHASE CHANGE HEAT TRANSFER AND HEAT EXCHANGERS

1. Define boiling. [Anna Univ. June 2012]

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

2. What is meant by condensation? [Anna Univ. June 2012]

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

3. What is meant by pool boiling? [Anna Univ. May 2004]

If heat is added to a liquid from a submerged solid surface, the boiling process is 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 are the modes of condensation?

There are two modes of condensation

1. Film wise condensation
2. Drop wise condensation

5. What is meant by Film wise condensation? [MU, April 2000, Oct. 2000] [Anna Univ. Dec. 2004, 2005 & June 2006]

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

6. What is meant Drop wise condensation? [MU, April 2000, Oct. 2000] [Anna Univ. Dec. 2004, 2005 & June 2006]

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

7. Give the merits of drop wise condensation. [MU, April 1999]

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

8. Draw different regions of boiling and what is nucleate boiling?[MU, April 1999, April 2002]

Nucleate boiling exists in regions II and III. The nucleate boiling begins at region II. As the excess temperature is further increased, bubbles are formed more rapidly and rapid evaporation takes place. This is indicated in region III. Nucleate boiling exists up to $\Delta T =$

9. What are the types of heat exchangers? [Anna Univ. Dec. 2005]

The types of heat exchangers are as follows

Direct contact heat exchangers, Indirect contact heat exchangers, Surface heat exchangers, and Parallel flow heat exchangers, Counter flow heat exchangers, Cross flow heat exchangers, Shell and tube heat exchangers, Compact heat exchangers

10. What is meant by parallel flow heat exchanger? [Anna Univ. May'05]

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

11. What is meant by counter flow heat exchanger? [Anna Univ. May'05]

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

12. What is meant by compact heat exchanger? [MU, Nov. 1996] [Anna Univ. June 2012]

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

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 Fouling factor? [MU, Nov.'96]

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

15. What is meant by Effectiveness?

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

$$\text{Effectiveness } \varepsilon = \text{Actual heat transfer} / \text{Maximum possible heat transfer}$$

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UNIT – IV RADIATION

1. Define Radiation.

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

2. Define emissive power.[E_b]. [Anna Univ. Dec.'05, MU, Oct.'97 & Oct. 2000]

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/m².

3. Define monochromatic emissive power. [E_{b2}]

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.

4. What is meant by absorptive? [Anna Univ. Dec.'04]

Absorptive is defined as the ratio between radiation absorbed and incident radiation.
Absorptive, $\alpha = \text{Radiation absorbed} / \text{Incident radiation}$

5. What is meant by reflectivity? [Anna Univ. Dec.'04]

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

Reflectivity, $\rho = \text{Radiation reflected} / \text{Incident radiation}$

6. What is meant by transmissivity?

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

Transmissivity, $t = \text{Radiation transmitted} / \text{Incident radiation}$

7. What is black body? [MU, Apr.'97 & Apr.'99, Anna Univ. Dec.'04, Dec.'05 June 2006]

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.

8. What is meant by gray body? [MU, April 2000, Anna Univ. Dec.'04, Dec.'05 & June]

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.

9.State Kirchoff's' law of radiation. MU, April 2001, Anna Univ. Dec.'04 & June '06]

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

$$E_1 / \alpha_1 = E_2 / \alpha_2 = E_3 / \alpha_3$$

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.

$$\alpha_1 = E_1; \quad \alpha_2 = E_2 \quad \text{and so on.}$$

10. What is the purpose of radiation shield?[Mu, Apr.'99, Oct.'99 Apr. 2001 A U.May 04]

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

11. Define irradiation [G]. [MU, Nov.'96]

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

12. What is radiosity [J]. [MU, April 2001, Anna Univ. Dec.'05]

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 and mention its physical significance? [Mu, Oct.'97, '98 Oct.'01, Anna Univ. May 2005]

The shape factor is defined as “The fraction of the radiative energy that is diffused from one surface element and strikes the other surface directly with no intervening reflections”. It is represented by F_u . Other names for radiation shape factor are view factor, angle factor and configuration factor. The shape factor is used in the analysis of radiative heat exchange between two surfaces.

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

All surfaces are considered to be either black or gray.

Radiation and reflection process are assumed to be diffuse.

The absorptivity of a surface is taken equal to its emissivity and independent of temperature of the source of the incident radiation.

15. Discuss the radiation characteristics of carbon dioxide and water vapour.[A U.Dec.

The CO₂ and H₂O both absorb and emit radiation over certain wavelength regions called absorption bands.

The radiation in these gases is a volume phenomenon.

The emissivity of CO₂ and the emissivity of H₂O at a particular temperature increases with partial pressure and mean beam length.

UNIT – IV MASS TRANSFER

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. [MU, Nov.'96, Oct.'99]

Some examples of mass transfer are

- g. Humidification of air in cooling tower
- h. Evaporation of petrol in the carburetor of an IC engine
- i. The transfer of water vapour into dry air.

3. What are the modes of mass transfer? [Anna Univ. June 2006]

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

4. What is molecular diffusion? [Anna Univ. June 2006]

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? [Anna Univ. June 2006]

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

7. State Fick's law of diffusion. [Anna Univ. Dec.'04, May'05, & June'06, MU, Oct.'97, 99, 2000 & April '98, Anna Univ. May 2012]

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.

$$m_a/A = -D_{ab} dC_a/dx$$

Where,

m_a/A – Molar flux – kg-mole / s – m²

D_{ab} – Diffusion co-efficient of species a and b, m²/s

dC_a / dx – Concentration gradient, kg/m³

8. What is free convective mass transfer? [MU,Oct.'97]

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. [MU, Apr.'97]

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 evaporation of water from an ocean when air blows over it.

10. Define Schmidt Number. MU, April '97 & Oct.'97]

It is defined as the ration of the molecular diffusivity of momentum to the molecular diffusivity of mass. $Sc = \text{Molecular diffusivity of momentum} / \text{Molecular diffusivity of mass}$

11. Define Sherwood Number.[Anna Univ. May '04, MU, Apr.'97 & 2001,Anna Univ. May 2012]

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

$$Sh = h_m^x / D_{ab}$$

h_m - Mass transfer co-efficient, m/s

D_{ab} - Diffusion co-efficient, m²/s

x – Length, m

12. Give two examples of convective mass transfer. [Anna Univ. May 2004]

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

13. Define the Mass Concentration. [Anna Univ. Dec.'04 & Dec.'05]

Mass of a component per unit volume of the mixture. It is expressed in kg/m^3 .

Mass concentration = Mass of a component/Unit volume of mixture.

14. Define the Molar Concentration. [Anna Univ. Dec.'04 & Dec.'05]

Molar concentration = Number of moles of component / Unit volume of mixture

15. Define the following. [Anna Univ. Dec.'04 & Dec.'05]

[i] Mass fraction. [ii] Mole fraction

[i] Mass fraction: The mass fraction is defined as the ratio of mass concentration of species to the total mass density of the mixture.

Mass fraction = Mass concentration of a species / Total mass density

[ii] Mole fraction: The mole fraction is defined as the ratio of mole concentration of a species to the total molar concentration.

Mole concentration = Mole concentration of a species / Total molar concentration

U23MET61-HEAT AND MASS TRANSFER

16MARKS QUESTIONS

UNIT-I CONDUCTION

1. A furnace wall consists of three layers. The inner layer of 10cm thickness is made of fire brick [$k = 1.04\text{W/mK}$]. The intermediate layer of 25cm thickness is made of masonry brick [$k = 0.69\text{W/mK}$] followed by a 5cm thick concrete wall [$k = 1.37\text{W/mK}$]. When the furnace is in continuous operation the inner surface of the furnace is at 800°C while the outer concrete surface is at 500°C . Calculate the rate of heat loss per unit area of the wall, the temperature at the interface of the firebrick and masonry brick and the temperature at the interface of the masonry brick and concrete. [Anna Univ. Jun.'06]
2. A composite wall consists of 10cm thick layer of building brick, $k = 0.7\text{W/mK}$ and 3cm thick plaster, $k = 0.5\text{W/mK}$. An insulating material of $k = 0.08\text{W/mK}$ is to be added to reduce the heat transfer through the wall by 40%. Find its thickness. [Anna Univ. Dec.'04 & Dec.'05]
3. A steel tube with 5cm ID, 7.6cm OD and $k = 15\text{W/m}^\circ\text{C}$ is covered with an insulative covering of thickness 2cm and $k = 0.2\text{W/m}^\circ\text{C}$. A hot gas at 330°C with $h = 400\text{W/m}^2\text{C}$ flows inside the tube. The outer surface of the insulation is exposed to cooler air at 30°C with $h = 60\text{W/m}^2\text{C}$. Calculate the heat loss from the tube to the air for 10m of the tube and the temperature drops resulting from

the thermal resistances of the hot gas flow, the steel tube, the insulation layer and the outside air.

[Anna Univ. May'05]

4. A steam pipe of 12cm outer diameter is at 197°C . It is lagged to a radius of 10cm with asbestos of thermal conductivity of 1W/mK . The temperature of surrounding is 25°C and heat transfer co-efficient outside is $12\text{W/m}^2\text{K}$. Calculate the heat loss per meter length of the pipe. [MU. Oct'99]

5. An aluminium rod [$k = 204\text{W/mK}$] 2cm in diameter and 20cm long protrudes from a wall which is maintained at 300°C . The end of the rod is insulated and the surface of the rod is exposed to air at 30°C . The heat transfer co-efficient between the rod surface and air is $10\text{W/m}^2\text{K}$. Calculate the heat lost by the rod and the temperature of the rod at a distance of 10cm from the wall. [Anna Univ. June 2006]

6. A cylinder 1m long and 5cm in diameter is placed in an atmosphere at 45°C . It is provided with 10 longitudinal straight fins of material having $k = 120\text{W/mK}$. The height of 0.76mm thick fins is 1.27cm from the cylinder surface. The heat transfer co-efficient between cylinder and atmosphere air is $17\text{W/m}^2\text{K}$. Calculate the rate of heat transfer and the temperature at the end of fins if surface temperature of cylinder is 150°C . [Anna Univ. June 2005]

7. An aluminium plate [$k = 160\text{W/m}^{\circ}\text{C}$, $\rho = 2790\text{kg/m}^3$, $C_p = 0.88\text{KJ/kg}^{\circ}\text{C}$ of thickness $L = 3\text{cm}$ and at a uniform temperature of 225°C is suddenly immersed at time $t = 0$ in a well stirred fluid maintained at a constant temperature $T_{\infty} = 25^{\circ}\text{C}$. Take $h = 320\text{W/m}^2\text{C}$. Determine the time required for the centre of the plate to reach 50°C [Anna Univ. Dec.'2005]

8. A steel ball [specific heat = 0.46kJ/kgK . And thermal conductivity = 35W/mK having 5cm 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 ball to attain a temperature of 150°C . Take $h = 10\text{W/m}^2\text{K}$. [MU., Apr.'2000, 2001, Barathiar Univ. Apr.'98]

9. A slab of aluminium 10cm thick is originally at a temperature of 500°C . It is suddenly immersed in a liquid at 100°C resulting in a heat transfer co-efficient of $1200\text{W/m}^2\text{K}$. Determine the temperature at the centre line and the surface 1 minute after the immersion. Also calculate the total thermal energy removed per unit area of the slab during this period. The properties of aluminium for the given conditions are $\alpha = 8.4 \times 10^{-5} \text{m}^2/\text{s}$ $k = 215\text{W/mK}$ $\rho = 2700\text{kg/m}^3$ $C = 0.9\text{kJ/kgK}$ [Anna Univ. May 2005]

10. A large iron plate of 10cm thickness and originally at 800°C is suddenly exposed to an environment at 0°C where the convection co-efficient is $50\text{W/m}^2\text{K}$. Calculate the temperature at a depth of 4cm from one of the faces 100 seconds after the plate is exposed to the environment.

How much energy has been lost per unit area of the plate during this time? [Anna Un. June 2006]

11. A composite wall consists. of 10 cm thick layer of building brick, $k = 0.7 \text{ W/mK}$ and 3 cm thick plaster, $k = 0.5 \text{ W/mK}$. An insulating material of $k = 0.08 \text{ W/mK}$ is to be added to reduce the heat transfer through the wall by 40%. Find its thickness. [Anna Univ. June 2012]

12. Circumferential aluminium fins of rectangular profile (1.5cmwide and 1mm thick) are fitted on to a 90 mm engine cylinder with a pitch of 10 mm. The height of the cylinder is 120 mm. The cylinder base temperature before and after fitting the fins are 200°C and 150°C respectively. Take ambient at 30°C and $h(\text{average}) = 100 \text{ W/m}^2 \text{ K}$ Estimate the heat dissipated from the finned and the unfinned surface areas of cylinder body. [AU June 2012]

13. Derive the general heat conduction equation for a hollow cylinder. [AU June 2012]

UNIT – II CONVECTIVE HEAT TRANSFER

14. Air at atmospheric pressure and 200°C flows over a plate with a velocity of 5m/s. The plate is 15mm wide and is maintained at a temperature of 120°C . Calculate the thickness of hydrodynamic and thermal boundary layers and the local heat transfer coefficient at a distance of 0.5m from the leading edge. Assume that the flow is on one side of the plate.

$$\rho = 0.815 \text{ kg/m}^3, \quad \nu = 24.5 \times 10^{-6} \text{ m}^2/\text{s}; \quad \text{Pr} = 0.7, \quad k = 0.0364 \text{ W/mK} \quad [\text{Anna Univ. May'04}]$$

15. Air at 20°C is flowing along a heated plate at 134°C at a velocity of 3m/s. The plate is 2m long and 1.5m wide. Calculate the thickness of the hydrodynamic boundary layer and the skin friction coefficient at 40cm from the leading edge of the plate. The kinematic viscosity of air at 20°C is $15.06 \times 10^{-6} \text{ m}^2/\text{s}$. [Anna Univ. Dec.'05]

16. Air at 25°C flows over 1 m x 3 m [3 m long] horizontal plate maintained at 200°C at 10m/s. Calculate the average heat transfer coefficients for both laminar and turbulent regions. Take $\text{Re}_{[\text{critical}]} = 3.5 \times 10^5$. [Anna Univ. Dec.'04]

17. Air at 15°C , 30km/h flows over a cylinder of 400mm diameter and 1500mm height with surface temperature of 45°C . Calculate the heat loss.

18. In a surface condenser, water flows through staggered tubes while the air is passed in cross flow over the tubes. The temperature and velocity of air are 30°C and 8m/s respectively. The longitudinal and transverse pitches are 22mm and 20mm respectively. The tube outside diameter is 18mm and tube surface temperature is 90°C . Calculate the heat transfer coefficient.

19. In a long annulus [3.125cm ID and 5cm 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 30m/s. Estimate the heat transfer coefficient between air and the inner tube.[MU, April 2000]

20. Engine oil flows through a 50mm diameter tube at an average temperature of 147°C . The flow velocity is 80cm/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. [MU, Oct.'02]

21. A large vertical plate 5 m height is maintained at 100°C and exposed to air at 30°C . Calculate the convective heat transfer coefficient. [Anna Univ. June 2006]

22. A steam pipe 10cm outside diameter runs horizontally in a room at 23°C . Take the outside surface temperature of pipe as 165°C . Determine the heat loss per metre length of the pipe. [Anna Univ. Dec. 2004]

23. A thin 80cm long and 8cm wide horizontal plate is maintained at a temperature of 130°C in large tank full of water at 70°C . Estimate the rate of heat input into the plate necessary to maintain the temperature of 130°C . [Anna Univ. May 2005]

24. Air at 400 K and 1 atm pressure flows at a speed of 1.5 m/s over a flat plate of 2 m long. The plate is maintained at a uniform temperature of 300 K. If the plate has a width of 0.5 m, estimate the heat transfer coefficient and the rate of heat transfer from the air stream to the plate. Also estimate the drag force acting on the plate. [Anna Univ. June 2012]

25. A steam pipe 10 cm OD runs horizontally in a room at 23°C . Take outside temperature of pipe as 165°C . Determine the heat loss per unit length of the pipe. Pipesurface temperature reduces to 80°C with 1.5 cm insulation. What is the reduction in heat loss? [Anna Univ. June 2012]

26. Define Reynold's, Nusselt and Prandtl numbers[Anna Univ. June 2012]

27. A 6 – m long section of an 8 cm diameter horizontal hot water pipe passes through a largeroom in which the air and walls are at 20°C . The pipe surface is at 70°C and the emissivity of the pipe surface is 0.7. Find the rate of heat loss from the pipe by natural convection and radiation. [Anna Univ. June 2012]

UNIT – III PHASE CHANGE HEAT TRANSFER AND HEAT EXCHANGERS

28. An aluminium pan of 15cm diameter is used to boil water and the water depth at the time of boiling is 2.5cm. The pan is placed on an electric stove and the heating element raises the temperature of the pan to 110°C . Calculate the power input for boiling and the rate of evaporation. Take $C_{sf} = 0.0132$. [Anna Univ. Dec. 2005]

29. It is desired to boil water at atmospheric pressure on a copper surface which is electrically heated. Estimate the heat flux from the surface to the water, if the surface is maintained at 11°C

and also the peak heat flux. [Anna Univ. June 2006]

30. Dry saturated steam at a pressure of 2.45 bar condenses on the surface of a vertical tube of height 1 m. The tube surface temperature is kept at 117°C . Estimate the thickness of the condensate film. [Anna Univ. May 2005]

31. A tube of 2m length and 25mm outer diameter is to be condense saturated steam at 100°C while the tube surface is maintained at 96°C . Estimate the average heat transfer co-efficient and the rate of condensation of steam if the tube is kept horizontal. The steam condenses on the outside of the tube. [Anna Univ. June 2006]

32. In a double pipe counter flow heat exchanger, 10,000kg/hr of an oil having a specific heat of 2095J/kg-K is cooled from 80°C to 50°C by 8000kg/hr of water entering at 25°C . Determine the heat exchanger area for an overall heat transfer co-efficient of $300\text{W}/\text{m}^2\text{K}$. Take C_p for water as 4180J/kg-K. [Anna Univ. Dec. 2004]

33. In a counter flow double pipe heat exchanger, water is heated from 25°C to 65°C by an oil with a specific heat of 1.45 KJ/kg K and mass flow rate is 0.9 Kg/s. The oil is cooled from 230°C to 160°C . If the overall heat transfers co-efficient is $420\text{W}/\text{m}^2\text{ }^{\circ}\text{C}$, calculate the following.

- The rate of heat transfer
- The mass flow rate of water
- The surface area of the heat exchanger. [Anna Univ. May 2004]

34. A counter flow concentric tube heat exchanger is used to cool engine oil [$C = 2130\text{J}/\text{kg K}$] from 160°C to 60°C with water available at 25°C as the cooling medium. The flow rate of cooling water through the inner tube of 0.5m is 2kg/s while the flow rate of oil through the outer annulus, Outer diameter = 0.7m is also 2kg/s. If U is $250\text{W}/\text{m}^2\text{K}$, how long must the heat exchanger be to meet its cooling requirement? [Anna Univ. May 2005]

35. It is desired to use double pipe counter flow heat exchanger to cool 3kg/s of oil [$C_p = 2.1\text{kJ}/\text{kg K}$] from 120°C . Cooling water at 20°C enters the heat exchanger at a rate of 10kg/s. The overall heat transfer co-efficient of the heat exchange is $600\text{W}/\text{m}^2\text{K}$ and the heat transfer area is 6m^2 . Calculate the exit temperature of oil and water.[AU. June 2006].

36. A parallel flow heat exchanger has hot and cold water stream running through it, the flow rates are 10 and 25kg/min respectively. Inlet temperatures are 75°C and 25°C on hot and cold sides. The exit temperature on the hot side should not exceed 50°C . Assume $h_i = h_o = 600\text{W}/\text{m}^2\text{K}$. Calculate the area of heat exchangers using $\epsilon = \text{NTU}$ approach.[AU.Dec. 2005]

37. Exhaust gases flowing through a tubular heat exchanger at a rate of 0.4 kg/s are cooled from 450°C to 150°C by water initially at 15°C . The specific heats of exhaust gases and water may be

taken as 1.13 and $4.19 \text{ kJ/kg}^\circ\text{C}$ respectively, and the overall heat transfer co-efficient from gases to water is $140 \text{ W/m}^2^\circ\text{C}$. Calculate the surface area required for the following cases, when the cooling water flow is 0.5 kg/s ; [i] parallel flow [ii] counter flow.

38. Define effectiveness of a heat exchanger. Derive an expression for the effectiveness of a double pipe parallel flow heat exchanger. State the assumptions made. [Anna Univ. May 2012]

39. A tube of 2 m length and 25 mm outer diameter is to be used to condense saturated steam at 100°C while the tube surface is maintained at 92°C . Estimate the average heat transfer coefficient and the rate of condensation of steam if the tube is kept horizontal. The steam condenses on the outside of the tube. [Anna Univ. May 2012]

40. Derive the LMTD for a parallel flow heat exchanger stating the assumptions. [Anna Univ. May 2012]

41. Consider laminar film condensation of a stationary vapour on a vertical flat plate of length L and width b . Derive an expression for the average heat transfer coefficient. State the assumptions made. [Anna Univ. May 2012]

UNIT – IV RADIATION

42. The sun emits maximum radiation at $\lambda = 0.52 \mu$. Assuming the sun to be a black body, calculate the surface temperature of the sun. Also calculate the monochromatic emissive power of the sun's surface. [MU, April 98]

43. A furnace wall emits radiation at 2000 K . Treating it as black body radiation, calculate 1. Monochromatic radiant flux density at $1 \mu\text{m}$ wave length. 2. Wave length at which emission is maximum and the corresponding emissive power. 3. Total emissive power. [MU, April 98]

44. Calculate the net radiant heat exchange per m^2 area for two large parallel plates at temperature of 427°C and 27°C respectively. $\epsilon_{[\text{hot plate}]} = 0.9$ and $\epsilon_{[\text{cold plate}]} = 0.6$. If a polished aluminium shield is placed between them, find the percentage of reduction in the heat transfer. $\epsilon_{[\text{shield}]} = 0.4$. [Anna Univ. May 2004]

45. Two large parallel planes at 800 K and 600 K have emissivities of 0.5 and 0.8 respectively. A radiation shield having an emissivity of 0.1 on one side and an emissivity of 0.05 on the other side is placed between the plates. Calculate the heat transfer rate by radiation per square meter with and without radiation shield. Common on the results. [A U. Dec. 2005]

46. Two very large parallel plate with emissivities 0.5 exchange heat. Determine the percentage reduction in the heat transfer rate if a polished aluminium radiationshield of $\epsilon = 0.04$ is placed in between the plates. [Anna Univ. June 2006]

47. Emissivities of two large parallel planes maintained at 800°C and 300°C are 0.3 and 0.5

respectively. Find the net radiant heat exchange per square metre for these plates. [MU, Oct. 2001]

48. Find the velocity heat transfer between two large planes at temperature 1000 K and 500 K when they are 1. Black bodies. 2. Grey bodies with emissivities of each surface is 0.7. [MU, May 2002]

49. Two parallel plates of size 1 m x 1 m are spaced 0.5 m apart are located in a very large room, the walls of which are maintained at a temperature of 27°C . One plate is maintained at a temperature of 900°C and the other at 400°C . Their emissivities are 0.2 and 0.5 respectively. If the plates exchange heat between themselves and surroundings, find the net heat transfer to each plate and to the room. Consider only the plate surfaces facing each other. [Anna Univ. May 2004]

50. Two black square plates of size 1 by 1m are placed parallel to each other at a distance of 0.4m. One plate is maintained at a temperature of 900°C and the other at 400°C . Find the net heat exchange of energy due to radiation between the two plates. [MU, Oct.99]

51. Two circular discs of diameter 20cm each are placed 2m apart. Calculate the radiant heat exchange for these discs if they are maintained at 800°C and 300°C respectively and the corresponding emissivity are 0.3 and 0.5. [MU, Apr. 2000]

52. State and prove the following laws:

(1) Kirchoffs law of radiation

(2) Stefan - Boltzmann law [Anna Univ. May 2012]

53. Liquid Helium at 4.2 K is stored in a dewar flask of inner diameter = 0.48 m and outer diameter = 0.5 m. The dewar flask can be treated as a spherical vessel. The outer surface of the inner vessel and the inner surface of the outer vessel are well polished and the emissivity of these surfaces is 0.05. The space between the two vessels is thoroughly evacuated. The inner surface of the dewar flask is at 4.2 K while the outer surface is at 300°K . Estimate the rate of heat transfer between the surfaces. [Anna Univ. May 2012]

54. Two large parallel plates of $1\text{m}\times 1\text{m}$ spaced 0.5m apart in a very large room whose walls are at 27°C . The plates are at 900°C and 400°C with emissivities 0.2 and 0.5 respectively. Find the net heat transfer to each plate and to the room. [Anna Univ. May 2012]

UNIT – V MASS TRANSFER

- 55.** Oxygen at 25°C and pressure of 2 bar is flowing through a rubber pipe of inside diameter 25mm and wall thickness 2.5mm. The diffusivity of O_2 through rubber is $0.21 \times 10^{-9} \text{ m}^2/\text{s}$ and the solubility of O_2 in rubber is $3.12 \times 10^{-3} \text{ kg-mole/m}^3\text{-bar}$. Find the loss of O_2 by diffusion per metre length of pipe. [MU, April 1998 & April 2000]
- 56.** Hydrogen gas at 2 atm and 25°C is flowing through a rubber pipe of ID = 25mm and OD = 50mm. The diffusivity of hydrogen through the rubber is $0.7 \times 10^{-4} \text{ m}^2/\text{h}$. The solubility of hydrogen = $0.053 \text{ kg-mole / m}^3\text{-bar}$. Find the loss of Hydrogen by diffusion per metre length of pipe. [MU, Apr.'97]
- 57.** Two large tanks, maintained at the same temperature and pressure are connected by a circular 0.15m diameter duct, which is 3m in length. One tank contains a uniform mixture of 60 mole % ammonia and 40 mole % air and the other tank contains a uniform mixture of 20 mole % ammonia and 80 mole % air. The system is at 273 K and $1.013 \times 10^5 \text{ pa}$. Determine the rate of ammonia transfer between the two tanks. Assuming a steady state mass transfer. [MSU, Nov.'96, MU, Nov.'96]
- 58.** CO_2 and air experience equimolar counter diffusion in a circular tube whose length and diameter are 1 m and 50mm respectively. The system is at a total pressure of 1 atm and a temperature of 25°C . The ends of the tube are connected to large chambers in which the species concentrations are maintained at fixed values. The partial pressure of CO_2 at one end is 190mm of Hg while the other end is 95mm HG. Estimate the mass transfer rate of CO_2 and air through the tube. [Bharathidasan Univ. Apr.'98, MU, Apr.'98 Oct. 2002]
- 59.** An open pan 20cm in diameter and 8cm deep contains water at 25°C and is exposed to dry atmospheric air. If the rate of diffusion of water vapour is $8.54 \times 10^{-4} \text{ kg/h}$, estimate the diffusion co-efficient of water in air. [Anna Univ. May'05]
- 60.** An open pan of 150mm diameter and 75mm deep contains water at 25°C and is exposed to atmosphere air at 25°C and 50% R.H. Calculate the evaporation rate of water in grams per hour. [MU, April 2002]
- 61.** Dry air at 20°C [$\rho = 1.2 \text{ kg/m}^3$, $\nu = 15 \times 10^{-6} \text{ m}^2/\text{s}$, $D = 4.2 \times 10^{-5} \text{ m}^2/\text{s}$] flows over a flat plate of length 50cm which is covered with a thin layer of water at a velocity of 1m/s. Estimate the local mass transfer co-efficient at a distance of 10cm from the leading edge and the average mass transfer co-efficient. [Anna Univ. June 2006]

62. Air at 1 atm and 25⁰C containing small quantities of iodine flow with a velocity of 6.2 m/s inside a 35 mm diameter tube. Calculate mass transfer co-efficient for iodine. The thermo physical properties of air are $\nu = 15.5 \times 10^{-6} \text{ m}^2/\text{s}$, $D = 0.82 \times 10^{-5} \text{ m}^2/\text{s}$. [Anna Univ. May 2004]

63. Dry air at 27⁰C and 1 atm flows over a wet flat plate 50 cm long and velocity of 50 m/s. Calculate the mass transfer co-efficient of water vapour in air at the end of the plate. Take $D = 0.26 \times 10^{-4} \text{ m}^2/\text{s}$. [MU, Oct.'99 & Oct.'01]

64. Air at 25⁰C an atmospheric pressure flows with a velocity of 3 m/s inside a 10mm diameter tube of 1 m length. The inside surface of the tube contains a deposit of naphthalene. Determine the average mass transfer co-efficient. Take for Naphthalene air, $D = 0.62 \times 10^{-5} \text{ m}^2/\text{s}$. [MU, April 2000]