Total number of printed pages: 4 **UG/5th/UFET504**

2023

FUNDAMENTALS OF HEAT AND MASS TRANSFER

Full Marks : 100

Time : Three hours

The figures in the margin indicate full marks for the questions.

Answer any five questions.

1. a) Write Fick's first law of diffusion. 4

   b) How diffusivity varies with temperature, pressure, molecular weight, molecular size? 6

   Mention diffusivity range of solute in gas and liquid phase at ambient temperature.

   c) A molecule is being transported by diffusion through a fluid at steady state. At a given point 1, concentration is 1.37×10^{-2} g/m^3 and 0.72×10^{-2} g/m^3 at point 2. The distance in between is 0.4 m. Diffusivity 0.013m^2/s and cross sectional area is constant. Calculate flux. Derive the equation for concentration as a function of distance. Calculate concentration at the middle point of 1 and 2. 10

2. a) What is interphase mass transfer? 5

   b) The equilibrium distribution of a solute (O_2) between air and water at low concentration at a particular temperature is given by y=1.2x 15

   At a certain point in a mass transfer device, the concentration of solute in bulk air is 0.04 mole fraction and in bulk liquid phase is 0.025. The individual mass transfer coefficients are k_y= 7.2 kmol/h m^2 and k_s= 4.6 kmol/h m^2.

   Calculate

   In which direction solute transport will happen?

   Overall gas phase and overall liquid phase driving force for mass transfer.

   Interfacial concentration in gas & liquid phase.

   Flux N_A

   Overall mass transfer coefficients K_x & K_y.

   Which resistance controls the mass transfer?

3 a) Write solute transfer process for the following unit operation: 5

Absorption

Adsorption

Liquid –liquid extraction

Leaching

Distillation

b) What is countercurrent multiple equilibrium contact stages for solute transfer. Discuss briefly with graphical plot for theoretical stages required for separation. 10

c) A polyethylene film 0.15 mm thick is considered for packaging for pharmaceutical product at 30 ^{O}C. The partial pressure of oxygen outside is 0.21 atm and inside is 0.01 atm. Calculate the permeation flux of oxygen through the film at steady state. Permeability PM= 4.17 x 10^{-12} $m^3/s\ m^2$ atm/m. 5

4. a) Explain Thermal Resistance 3

b) Calculate the rate of heat transfer per unit area through a copper plate 45 mm thick, whose one face is maintained at 350 °C and the other face at 50 °C. Take thermal conductivity of copper as 370 W/m °C. 4

c) Derive **Fourier's Equation** 10

$$\nabla^2 t = \frac{1}{\alpha} \cdot \frac{\partial t}{\partial \tau}$$

For Unsteady heat conduction through a homogeneous and isotropic material without internal heat generation.

d) Consider a slab of thickness **L = 0.25 m.** One surface is kept at 100 °C and the other surface at 0 °C. Determine the heat transfer per unit area across the slab if the slab is made from pure copper. Thermal conductivity of copper may be taken as 387.6 W/m K. 3

5. a) A furnace wall is composed of **220 mm** of fire brick, **150 mm** of common brick, **50 mm** of 85% magnesia and 3 mm of steel plate on the outside. If the inside surface temperature is **1500 °C** and outside surface temperature is **90 °C**, estimate the temperatures between layers and calculate the heat loss in kJ/h-m^2. Assume k (for fire brick) = 4 kJ/m-h-°C, k (for common brick) =**2.8** kJ/m-h-°C, k (for 85% magnesia) = **0.24** kJ/m-h-°C, and k (for steel) = **240** kJ/m-h-°C 5

b) Show that heat conduction through a composite layer of 'n' numbers of concentric cylinders is 6

$$Q = \frac{2\pi L(t_{hf} - t_{cf})}{\left[\frac{1}{h_{hf} \cdot r_1} + \frac{\ln(r_2/r_1)}{k_A} + \frac{\ln(r_3/r_2)}{k_B} + \frac{1}{h_{cf} \cdot r_3}\right]}$$

c) A steam pipe of outer diameter 120 mm is covered with two layers of lagging, inside layer 45 mm thick (k= 0.08 W/m °C) and outside layer 30 mm thick (k = 0.12 W/m °C). The pipe conveys steam at a pressure of 20 bar and temperature 262.4 °C. The outside temperature of lagging is 25 °C. If the steam pipe is 30 m long, determine: 6

(i) Heat lost per hour.

(ii) Interface temperature of lagging.

d) Explain logarithmic mean area for hollow sphere. 3

6. a) Explain critical thickness of insulation for a hollow cylinder and its physical significance. 5

b) A uniform sheathing of plastic insulation (k = 0.18 W/m °C) is applied to an electric cable of 8 mm diameter. The convective film coefficient on the surface of bare cable as well as insulated cable was estimated at 12.5 W/m^2 °C and a surface temperature of 45 °C was observed when the cable was exposed to ambient air 20 °C. Determine: 5

(i) The thickness of insulation to keep the wire as cool as possible

(ii) The surface temperature of insulated cable if the intensity of current flowing through the conductor remains unchanged.

c) What is Logarithmic Mean Temperature Difference (LMTD) for a Heat Exchanger? What are the necessary assumptions required to made in deriving an expression for LMTD. Derive the expression for LMTD for a parallel flow heat exchanger 10

7. Write short notes on **any five** of the following. 20

a) Various modes of Heat Transfer

b) Heat Conduction through a composite wall

c) Heat Conduction through a hollow sphere

d) Critical thickness for a hollow sphere

e) Types of heat exchangers based on relative direction of fluid motion

f) Effectiveness of a heat exchanger

g) Number of Transfer Units (NTU)

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