MASS TRANSFER I
(CHEN 3103)

Time Allotted: 2½ hrs **Full Marks : 60**

Figures out of the right margin indicate full marks.

Candidates are required to answer Group A and <u>any 4 (four)</u> from Group B to E, taking <u>one</u> from each group.

Candidates are required to give answer in their own words as far as practicable.

Group – A

1. Answer any twelve: **12 × 1 = 12**

Choose the correct alternative for the following

(i) The unit of mass transfer coefficient ky is
(a) moles/(area)(time)(pressure) (b) moles/(area)(time)(mole fraction)
(c) moles/(area)(time)(mole/volume) (d) moles/(area)(time).

(ii) Diffusivity of a gas in a binary mixture is related to temperature and pressure as follows
(a) $D_{AB} \alpha\, T/P$ (b) $D_{AB}\ \alpha\, T/P^{1.75}$ (c) $D_{AB} \alpha\, T^{1.75}/P$ (d) $D_{AB} \alpha\, P/T$

(ii) During diffusion of A through nondiffusing B, the molar flux N_A is proportional to
(a) $\frac{(p_{A1}-p_{A2})}{p_{BM}}$ (b) $(p_{A1}-p_{A2})$ (c) p_{BM} (d) $(p_{A1}-p_{A2})\, p_{BM}$

(iv) In a packed tower, condition in which liquid holdup increases rapidly with gas flowrate with increase in pressure drop is known as
(a) Loading (b) Flooding (c) Channelling (d) Entrainment.

(v) The maximum possible conversion in the film compared with the maximum transport through the film during absorption of a component with chemical reaction is
(a) Damkohler number (b) Liquid film enhancement factor
(c) Instantaneous enhancement factor (d) Hatta modulus.

(vi) As per film theory, the mass transfer coefficient is
(a) directly proportional to diffusivity of the solute in the fluid
(b) inversely proportional to diffusivity of the solute in the fluid
(c) independent of diffusivity of the solute to the fluid
(d) directly proportional to square root of diffusivity of the solute to the fluid.

(vii) In case of distillation, as the reflux ratio is increased, the intersection of both the operating lines
(a) moves towards the diagonal (b) moves away from the diagonal
(c) does not at all move (d) may move or may not move.

(viii) If G' is the gas mass velocity, K_Ga, the overall mass transfer coefficient, and P the total pressure, the expression for height of an overall gas phase mass transfer unit is
(a) G'/K_Ga*P (b) $G'*K_Ga$ (c) G'/P (d) K_Ga/G'.

(ix) For dilute solutions, the overall height of transfer unit (H_{tOG}) in terms of height of transfer unit in gas (H_{tG}) and liquid phases (H_{tL}) is given as

(a) $H_{toG} = H_{tG} + \frac{L}{mG} H_{tL}$ (b) $H_{toG} = H_{tG} + \frac{mG}{L} H_{tL}$

(c) $H_{toG} = \frac{mG}{L} H_{tG} + H_{tL}$ (d) $H_{toG} = H_{tG} + H_{tL}$

(x) If L and G be the molar flowrate per unit area of solute free liquid and gas, and m be the slope of equilibrium curve, absorption factor is given by

(a) L/m*G (b) m*L/G (c) L/G (d) G/m*L.

Fill in the blanks with the correct word

(xi) According to penetration theory, the expression for mass transfer coefficient is ______.

(xii) Example of gas dispersed liquid continuous type of contacting device is_________.

(xiii) The expression for number of overall gas phase transfer units in terms of mole ratio is_________.

(xiv) The reflux ratio at total reflux condition is _________.

(xv) In distillation, minimum number of theoretical stages can be obtained by_________ equation.

Group - B

2. (a) Derive the expression for point value of mass transfer coefficient using penetration theory. *[(CO2)(Analyze/IOCQ)]*

(b) Calculate the rate of diffusion of acetic acid across a film of non-diffusing water solution 1 mm thick at 17°C when the concentration on opposite sides of the film are 9 and 3 wt% acid respectively. The diffusivity of acetic acid in the solution is 0.95×10^{-9} m^2/s. Molecular weight of acetic acid is 60. At 17°C, the density of the 9% solution is 1012 kg/m^3 and of 3% solution is 1003.2 kg/m^3. *[(CO2)(Understand/LOCQ)]*

(c) In a gas-liquid contactor, a pure gas is absorbed in a solvent and Penetration theory provides a reasonable model for describing the mass transfer. As fresh solvent exposed to the gas, the transfer rate is initially limited by the rate at which the gas molecules reach the surface. If at 293 K and 1 bar pressure, the maximum possible rate of transfer of gas is 50 m^3/m^2 s, express this as an equivalent resistance, when the as solubility is 0.04 $kmol/m^3$. If the diffusivity in the liquid phase is 1.8×10^{-9} m^2/s, at what time after the initial exposure will the resistance attributable to access of gas be equal to 10 percent of the total resistance to transfer? *[(CO2)(Evaluate/HOCQ)]*

5 + 3 + 4 = 12

3. (a) Diffusivity of the vapour of a volatile liquid in liquid is determined by Winkelmann's method in which liquid is contained in a narrow diameter vertical tube, maintained at constant temperature and an air stream is passed over the top of the tube sufficiently rapidly to ensure that the partial pressure of the vapour there is approximately zero. On the assumption that vapour is transferred from the liquid surface to the air stream by molecular diffusion alone, calculate the diffusivity of carbon tetrachloride vapour in air at 321 K and atmospheric pressure from the experimental data. Vapour pressure of CCl_4 at 321 K is 37.6 kN/m^2 and density of the liquid is 1540 kg/m^3. Molecular volume is 22.4 m^3. The equation is given as follows

$$t = \frac{\rho_L C_{BM}}{2MD_{AB}C_A C_T}(L-L_0)^2 + \frac{\rho_L C_{BM}}{MD_{AB}C_A C_T} L_0 (L-L_0)$$ *[(CO1)(Evaluate/HOCQ)]*

Time (ks)	0	1.6	11.1	27.4	80.2	117.5	168.6	199.7	289.3	383.1
Liquid level (mm)	0	2.5	12.9	23.2	43.9	54.7	67	73.8	90.3	104.1

(b) Derive the expression for overall molar flux of a component with respect to a fixed point in terms of diffusive flux and average molar velocity. *[(CO1)(Analyze/IOCQ)]*

(c) Sketch the pressure profiles along the diffusional path in equimolar counterdiffusion of components A and B and in diffusion of A through stagnant B. *[(CO1)(Understand/LOCQ)]*

7 + 3 + 2 = 12

Group - C

4. (a) A pure gas is absorbed into a liquid with which it reacts. The concentration in the liquid is sufficiently low for the mass transfer to be covered by Fick's law and the reaction is first order with respect to the solute gas. It may be assumed that film theory may be applied to the liquid and concentration of the solute gas falls from the saturation value to zero across the film. The reaction is initially carried out at 293 K. By what factor will the mass transfer rate across the interface change if the temperature is raised to 313 K? The reaction rate constant at 293 K is $2.5 \times 10^{-6} s^{-1}$. Energy of activation for the reaction is 2.643×10^7 J/kmol, universal gas constant is 8314 J/kmol K, molecular diffusivity 10^{-9} m2/s, film thickness is 10 mm and solubility of gas at 313 K is 80 percent of the solubility at 293 K. *[(CO2)(Evaluate/HOCQ)]*

(b) Derive the general rate equation during absorption of a component A from gas by a liquid. With the aid of a diagram, explain how the enhancement factor varies with the Hatta modulus. *[(CO2)(Analyze/IOCQ)]*

6 + (3 + 3) = 12

5. (a) (i) Mention the tower internals in case of a tray tower.

(ii) Name two structured packing used in case of a packed tower. *[(CO5)(Remember/LOCQ)]*

(b) Explain with the help of a sketch the following operating characteristics in a sieve tray tower.

(i) flooding (ii) weeping (iii) dumping (iv) coning. *[(CO5)(Remember/LOCQ)]*

(2 + 2) + 8 = 12

Group - D

6. (a) A coal gas is to be freed of its light oil by scrubbing with wash oil as an absorbent and the light oil recovered by stripping the resulting solution with steam. The inlet gas flowrate is $0.25\ m^3/s$ at 26°C, total pressure is 1.07×10^5 Pa containing 2 volume % of light oil vapours. The light oil is assumed to be entirely benzene and 95% removal is required. The wash oil enters at 26 °C, containing 0.005 mole fraction benzene and has average molecular weight 260. An oil circulation rate 1.5 times the minimum is to be used. Assume Wash oil-benzene solutions are ideal. Vapour pressure of benzene at 26 °C is 13330 Pa. Compute

(i) the oil circulation rate in the absorber

(ii) the number of theoretical trays . *[(CO4)(Evaluate/HOCQ)]*

(b) Compute the number of trays for the problem in part (a) using Kremser equation. *[(CO4)(Evaluate/HOCQ)]*

8 + 4 = 12

7. (a) A packed tower of 470 mm diameter and filled with 38 mm Berl saddle is used to remove Benzene from a mixture of Benzene and Air.
Gas phase: Mole fraction of benzene in the inlet gas is 0.02, and in the exit is 0.001.
Properties of the nonabsorbed gas: The average molecular weight of nonasbsorbed gas is 11.0, inlet flowrate of the gas is 0.25 m^3/s corresponding to 0.01051 kmol/s nonbenzene, temperature =26°C and total pressure 1.07×10^5 N/m^2, viscosity = 10^{-5} kg/ms, $D_{AB}=1.3\times10^{-5}$ m^2/s.
Liquid phase: Mole fraction of Benzene in the inlet: 0.005 and at the exit=0.1063.
Benzene-free oil: Molecular weight=270, viscosity=2×10^{-3} kg/ms, density=840 kg/m^3, flowrate=1.787×10^{-3} kmol/s, diffusivity=4.77×10^{-10} m^2/s
Equilibrium relation: y=0.1250*x
Compute the depth of packing required. *[(CO4)(Evaluate/HOCQ)]*

(b) Explain the significance of Murphree tray efficiency and overall efficiency in tray calculation. *[(CO4)(Analyse/IOCQ)]*

(c) Explain the function of liquid distributor in a packed tower? Define minimum wetting rate. *[(CO4)(Remember/LOCQ)]*

7 + 2 + 3 = 12

Group - E

8. (a) A continuous fractionating column is to be designed to separate 300 kg mole/h of a mixture of 32 mol % Benzene and rest Toluene into an overhead product containing 95 mol% Benzene and a bottom product of 96 mol% Toluene. The feed is a saturated liquid at a pressure of 1 atm. Benzene-toluene form a nearly ideal system with a relative volatility about 2.5.
(i) Determine minimum reflux ratio.
(ii) Calculate the number of ideal plates required if a reflux ratio of 1.6 times that of minimum reflux is used. *[(CO5)(Evaluate/HOCQ)]*

(b) Write down the rectifying line equation in this case. *[(CO5)(Apply/IOCQ)]*

(5 + 6) + 1 = 12

9. (a) A mixture of 45 mole % A and rest B is subjected to flash distillation at a separator pressure of 1 atm. The relative volatility α_{AB} is 2.4. Find the composition of the vapour and liquid leaving the separator if fraction of feed vaporized =0.6. *[(CO5)(Evaluate/HOCQ)]*

(b) With example discuss minimum boiling azeotrope. *[(CO5)(Remember/LOCQ)]*

(c) Distinguish between overall efficiency and point efficiency in a plate type distillation column. *[(CO5)(Apply/IOCQ)]*

6 + 3 + 3 = 12

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	23.95	20.83	55.2

Course Outcome (CO):

After the completion of the course students will be able to

1. Framemathematicalequationsforagivensteady-stateortransientdiffusionproblemandsolve them.
2. Determine mass transfer coefficients by using appropriate correlations for a given engineering problem.
3. Analyse the effect of a reaction on a specific diffusion operation.
4. Select either plate or packed column (whichever is appropriate) for a given absorption operation and design the selected type of column.
5. Design a fractional distillation column (plate-type) for a given binary distillation operation.

**LOCQ: Lower Order Cognitive Question; IOCQ: Intermediate Order Cognitive Question; HOCQ: Higher Order Cognitive Question.*