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 any 4 (four) from Group B to E, taking one 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) Mole ratio Y is related to mole fraction y as

(a) Y=y (b) $Y = \frac{y}{1+y}$ (c) $Y = \frac{1-y}{y}$ (d) $Y = \frac{y}{1-y}$

(ii) As per Wilke Chang equation, the diffusivity of a solute A in a dilute solution with solvent B is

(a) $D_{AB} \alpha T$ (b) $D_{AB} \alpha 1/T$ (c) $D_{AB} \alpha T^2$ (d) independent of temperature.

(iii) 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.

(iv) The condition in a packed tower 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 minimum liquid to gas flowrate during absorption in a tray tower is obtained when
(a) the operating line is tangent to the equilibrium line
(b) the operating line is parallel to the equilibrium line
(c) the operating line lies below the equilibrium line
(d) the operating line is perpendicular to the equilibrium line.

(vi) Murphree efficiency equals point efficiency
(a) if the liquid is in plug flow (b) if the liquid is in laminar flow
(c) if the liquid is completely mixed (d) always, irrespective of the flow.

(vii) 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) $H_{toG} = H_{tG} + H_{tL}$

(viii) Minimum boiling azeotrope is formed when
(a) solutions show positive deviation from ideality
(b) solutions show negative deviation from ideality
(c) solutions are ideal
(d) none of these

(ix) When the feed to a distillation column is a saturated liquid, the slope of the feed line is
(a) zero (b) unity (c) infinity (d) negative.

(x) Removal of organic contaminants from water is preferably carried out using
(a) silica gel (b) activated alumina
(c) carbon molecular sieves (d) activated carbon.

Fill in the blanks with the correct word

(xi) The unit of binary diffusivity is _____.

(xii) Example of a gas dispersed liquid continuous type of contacting equipment used in absorption is _____.

(xiii) The expression for Hatta modulus is _____.

(xiv) _____ equation is used to calculate minimum number of plates at total reflux.

(xv) Freundlich isotherm is expressed as _____ .

Group - B

2. (a) Consider steady state diffusion in a binary liquid A-B at constant temperature and pressure. The mole fraction of A at two different locations are 0.8 and 0.1. Let N_{A1} be the diffusive flux of A calculated assuming B is non-diffusing and N_{A2} be diffusive flux of A assuming equimolar counterdiffusion. Calculate $\frac{(N_{A1} - N_{A2})}{N_{A1}} \times 100$. *[(CO1)(Analyse/LOCQ)]*

(b) Diffusion of water vapour occurs from a narrow tube. At time t, level of water is z m from the top. As diffusion proceeds, the level drops slowly. Derive the equation for time taken for the level to drop from z_0 m at t=0 to z_F at t=t_F. *[(CO1)(Analyze/IOCQ)]*

(c) Oxygen is diffusing through carbon monoxide under steady state conditions with the carbon monoxide non-diffusing. The total pressure is 1×10^5 N/m^2 and the temperature 0 °C. The partial pressure of oxygen at two planes 2 mm apart is 13000 and 6500 N/m^2. The diffusivity of the mixture is 1.87×10^{-5} m^2/s. Calculate the rate of diffusion of oxygen through each square meter of the two planes. *[(CO1)(Apply/IOCQ)]*

(d) The equilibrium distribution of a solute between air and water at low concentration at a temperature T is given as y=1.2x. At a certain point in the mass transfer device, the concentration of solute A in bulk air is 0.04 mole fraction and in bulk aqueous phase is 0.025. In what direction does the solute transport occur? Compute the interfacial concentrations in both phases. Which resistance controls mass transfer? *[(CO2)(Apply/IOCQ)]*

3 + 3 + 2 + 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 CCl4 at 321 K is 37.6 kPa and liquid density is 1540 kg/m^3. Molecular volume is 22.4 m^3. *[(CO1)(Analyse/HOCQ)]*

Time (ks)	0	10	80	169	200	383
Liquid level (mm)	0	12.9	44	67	74	105

(b) Estimate the diffusivity of acetic acid in water at 293K. Molar volume of acetic acid at normal boiling point is 0.0641 m^3/kmol, viscosity of solvent water at 293 K is 0.001 Kg/ms, association factor for the solvent is 2.26. *[(CO1)(Remember/LOCQ)]*

(c) Derive the expression relating the overall molar flux with diffusive flux and molar average velocity in a binary gaseous mixture. *[(CO1)(Apply/IOCQ)]*

6 + 3 + 3 = 12

Group - C

4. (a) It is desired to absorb 95% of the acetone in a gas containing 1 mole% acetone in air in a countercurrent stage tower. The total inlet gas flow is 30 kmol/h and total inlet pure water flow is 90 kmol/h. The process operates isothermally at 300 K and 101.3 KPa. The equilibrium solubility relation of acetone in water at 300 K is given by Henry's law as y=2.53x. Determine the number of theoretical stages required for separation using graphical method. *[(CO3)(Analyse/HOCQ)]*

(b) Discuss the problems encountered during operation of a tray tower. Sketch the operating characteristic diagram of a sieve tray diagram and mark the desired operating zone. *[(CO4)(Remember/LOCQ)]*

7 + (3 + 2) = 12

5. (a) A bubble cap column with 30 plates is used to remove pentane from a solvent by steam. The inlet oil contains 6 kmol n-pentane per 100 kmol pure oil and the solute content is to be reduced to 0.1 kmol per 100 kmol solvent. Assuming isothermal operation and an overall plate efficiency of 30 percent, find the specific steam consumption (kmol steam required per kmol solvent oil treated) and the ratio of specific steam consumption and minimum steam consumption. How many plates are required if the ratio is 2? The equilibrium relation for the system is Y=3X where Y and X are the mole ratio of pentane in gas and liquid phases. Use the absorption factor method for calculations. *[(CO3)(Analyse/HOCQ)]*

(b) Derive the expression of number of theoretical plates during absorption in a tray tower in terms of absorption factor and composition of the exit and inlet streams. *[(CO3)(Apply/IOCQ)]*

(c) Discuss the criteria for selecting a solvent for absorption. *[(CO3)(Understand/LOCQ)]*

5 + 4 + 3 = 12

Group - D

6. (a) A continuous fractionating column is to be designed to separate 25,000 kg/h of a mixture of 38 mol. % benzene (Mol. Wt. 78) and rest toluene (Mol. Wt. 92) 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. A reflux ratio of 3 is to be used in the column. Benzene-toluene form a nearly ideal system with a relative volatility about 2.5. Determine
(i) The quantity of top and bottom product
(ii) The number of actual plates if the overall efficiency is 45%. *[(CO4)(Evaluate/HOCQ)]*

(b) Define relative volatility. *[(CO4)(Remember/LOCQ)]*

11 + 1 = 12

7. (a) A mixture of benzene and toluene having 40 mol. % benzene is to be separated at a rate of 180 kg. mol./hr. into a top product of 96 mol% benzene and a bottom product with 5 mol % of it. Determine the ideal trays required if the column is operated at total reflux, if average relative volatility is 3.5. *[(CO4)(Evaluate/HOCQ)]*

(b) Derive Fenske equation. *[(CO4)(Apply/IOCQ)]*

6 + 6 = 12

Group - E

8. (a) With the help of a neat sketch, discuss about extractive distillation. Give example. *[(CO4)(Analyse/HOCQ)]*

(b) Discuss the functions of weir and downcomer attached to the plates in plate columns? *[(CO4)(Remember/LOCQ)]*

8 + 4 = 12

9. (a) Name some important commercial adsorbents and discuss their applications. *[(CO5)(Remember/LOCQ)]*

(b) The experimental breakthrough data on adsorption of vinyl chloride on granular activated carbon (GAC) in a packed bed adsorption column at 20°C and atmospheric pressure is given below. The bed length is 15.2 cm, bed diameter=2.3 cm, gas flowrate = 80 cm^3/s at the above temperature and pressure, bed porosity=0.36, interstitial gas velocity=0.54 m/s, vinyl chloride concentration in feed=190 ppm by volume, y_i is the mole fraction of the solute in feed gas and y is that in the effluent. (i) Calculate the length of mass transfer zone, and the velocity of stoichiometric front of the bed at the influent gas concentration. (ii) A waste gas stream containing 190 ppm vinyl chloride is to be treated with GAC in a packed column at a rate of 20 m^3/min to reduce its concentration by 90%. Using the breakthrough data, determine the bed diameter, the height and pressure drop if an adsorption period of 10 h is allowed. The superficial gas velocity is same as that of experimental study. *[(CO5)(Evaluate/HOCQ)]*

Time (min)	141	167	226	282	318	350
y/y_i	0	0.02	0.4	0.8	0.96	1

4 + (4 + 4) = 12

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	24	23	53