MASS TRANSFER I
(CHE3103)

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) Unit of molar flux is
(a) kmol/m^2 s (b) kmol/s (c) kmol/m^3 (d) m^2/kmol

(ii) 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

(iii) During diffusion of A through non-diffusing 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) $\frac{p_{BM}}{(p_{A1} - p_{A2})}$

(iv) In a tray tower, high gas and low liquid flowrates result in
(a) Weeping (b) Coning (c) Dumping (d) Flooding

(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) Peclet number
(c) Thiele modulus (d) Hatta modulus

(vi) Maximum boiling azeotrope is formed when
(a) solutions show negative deviation from ideality
(b) Raoult's law is followed
(c) solutions show positive deviation from ideality
(d) Henry's law is followed

(vii) 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

(viii) Liquid residence time in the downcomer remains in the range
(a) 3 – 5 s (b) 5-15 s (c) 20 s-1 min (d) 1 min-1.5 min

(ix) Adsorption of a pure gas on activated carbon follows Langmuir isotherm $q = \frac{6.4p}{1+1.53p}$ where p in kPa and q in mmol/g. if the molecular weight of A is 65, what is the maximum quantity of gas (in g adsorbate per kg carbon) that can be adsorbed?
(a) 0.712 (b) 0.272 (c) 1 (d) 0.523

(x) The major use of carbon molecular sieve is
(a) Separation of lower hydrocarbons
(b) Separation of air to produce N_2
(c) Adsorption of organics to produce drinking water
(d) All of the above

Fill in the blanks with the correct word

(xi) Stanton number for mass transfer is _____.

(xii) The overall gas phase mass transfer coefficient is related to individual coefficients as _____.

(xiii) The S.I. unit of binary diffusivity is_____.

(xiv) The number of theoretical plates calculated by Kremser equation is expressed as _____.

(xv) When the reflux ratio is increased in case of binary distillation, the intersection of two operating lines move _____ the diagonal.

Group - B

2. (a) Explain the concept of constitutive equations. Write the constitutive equation of diffusive flux in gradient form. *[(CO1)(Remember/LOCQ)]*

(b) The equilibrium solubility of SO_2 in water at 30°C is given as below. At a point in the absorption column operating at a total pressure of 4.5 bar, the bulk gas and liquid mole fractions are 0.0014 and 0.02. The individual gas and liquid mass transfer coefficients are 15 kmol/h.m^{2}Δy and 80 kmol/h.m^{2}Δx. Calculate the interfacial concentrations at the location. *[(CO2)Analyze/IOCQ)]*

(c) A gas mixture containing 5% N_2, 15% H_2, 76% NH_3 and 4% Ar flows through a pipe 25.4 mm diameter at 4.05 bar total pressure. If the velocities of the components are 0.03 m/s, 0.035 m/s, 0.03 m/s and 0.02 m/s respectively, calculate the mass average, molar average and volume average velocities of the mixture. *[(CO1)(Apply/LOCQ)]*

(1 + 2) + 4 + 5 = 12

3. (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

Group - C

4. (a) A coal gas is to be freed of light oil by scrubbing with wash oil. The following data is available for absorption in a tray tower: Gas inlet flow rate: 0.2 m^3/s at 26°C and total pressure =1.07×10^5 Pa. Inlet gas contains 2% light oil vapour. Light oil is entirely benzene and 95% of it is to be removed. Wash oil enters at 26°C containing 0.004 mole fraction benzene, average molecular weight = 260. Oil circulation rate is 1.5 times minimum is to be used. Wash oil-benzene solutions are ideal and follow Raoult's law and the equilibrium relation is given as $p^* = 13330x$ where p* is the partial pressure of benzene vapour, Pa and x is the mole fraction of benzene in light oil.

(i) Compute the minimum liquid flowrate, and the actual oil circulation rate

(ii) Compute the benzene concentration in the exit oil stream and plot the operating line. *[(CO3)(Apply/HOCQ)]*

(b) The following data were collected by analysing the gas and liquid samples to and from an nth tray in an experiment on plate efficiency in an absorption column. Gs=90 kmol/h, Ls=100 kmol/h, y_{n+1}=0.12, x_n=0.078, x_{n-1}=0.06. The equilibrium relation is of the form y=1.01x. If the liquid on the tray is well mixed, calculate the Murphree tray efficiency. *[(CO3)(Analyze/IOCQ)]*

(4 + 3) + 5 = 12

5. (a) Ammonia is to be removed from a 10 % ammonia-air mixture by countercurrent scrubbing with water in a packed tower at 293 K so that 99 % ammonia is removed when working at a total pressure of 101.3 kN/m^2. If the gas rate is 0.95 kg/m^2 s of tower cross-section and the liquid rate is 0.6 kg/m^2 s, find the necessary height of the tower if the overall absorption coefficient is 0.001 kmol/m^{3}s(kN/m^2) partial pressure difference. The equilibrium data are:

kmol NH_3/kmol water	0.02	0.03	0.04	0.05	0.08	0.11	0.16
Partial pressure NH_3: (kN/m^2)	1.6	2.4	3.3	4.2	6.7	9.3	15.2

[(CO3)(Analyse/HOCQ)]

(b) Explain the method of prediction of pressure drop and flooding characteristics in a packed absorption tower using the generalized pressure drop correlation curve. *[(CO3)(Remember/LOCQ)]*

8 + 4 = 12

Group - D

6. A stream of aqueous methanol having 46 mol.% methanol is to be separated into a top product having 94 mol.% methanol and a bottom liquid with 5% methanol. The feed is at bubble point and operating pressure is 1 atm. A reflux ratio of 1.6 is suggested. Determine the number of actual trays if the overall efficiency is 40%. The vapour-liquid equilibrium data is given below.

x	0	0.04	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95	1.0
y	0	0.23	0.42	0.58	0.67	0.73	0.78	0.83	0.87	0.92	0.96	0.98	1.0

[(CO4)(Evaluate/HOCQ)]

(10 + 2) = 12

7. (a) Explain following operating characteristics in a sieve tray tower: (i) flooding, (ii) weeping, (iii) dumping, (iv) coning *[(CO4)(Understand/LOCQ)]*

(b) A distillation column has to operate a mixture of A and B to yield a top product x_D= 0.97 and a bottom product of $x_{W=}$ 0.04. Calculate the minimum number of ideal trays required to achieve this separation. Given: Relative volatility, α_{AB} = 1.9 at the bottom condition and α_{AB} = 2.1 at top condition. *[(CO4)(Evaluate/HOCQ)]*

6 + 6 = 12

Group - E

8. (a) In case of Plate column, define the following: i) Point efficiency, ii) Murphree efficiency, iii) Overall efficiency *[(CO4)(Analyse/HOCQ)]*

(b) With example, discuss in brief about azeotropic distillation. *[(CO4)(Remember/LOCQ)]*

(c) Mention the desirable properties of an entrainer. *[(CO2)(Apply/IOCQ)]*

6 + 4 + 2 = 12

9. (a) A ternary mixture of A,B and C (mole fraction in feed 0.12, 0.50 and 0.38 respectively and relative volatility of 3.8, 1.0, 0.70 respectively) is fed to a distillation column at a rate of 150 kg. mol./hr. to recover 98% of component 2(LK) in the distillate and 99% of component 3 (HK) in the bottom product. Determine the amount and composition of top product and bottom product and minimum number of ideal trays required. *[(CO3)(Evaluate/HOCQ)]*

(b) Mention the types of trays used in distillation column. *[(CO4)(Remember/LOCQ)]*

11 + 1 = 12

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	27.08	20.83	52.08