MASS TRANSFER I
(CHEN 3103)

Time Allotted : 3 hrs **Full Marks : 70**

Figures out of the right margin indicate full marks.

Candidates are required to answer Group A and any 5 (five) from Group B to E, taking at least one from each group.

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

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternative for the following: **10 × 1 = 10**

(i) Diffusivity of a non-electrolytic liquid can be predicted from
(a) Wilke-Change equation (b) Gilliland Correlation
(c) Langevin Equation (d) Maxwell – Chapman correlation.

(ii) The dimension of eddy diffusivity of mass is
(a) LT^{-1} (b) L^2T^{-1} (c) LT^{-2} (d) L.

(iii) The Film theory takes into account the resistances of
(a) The laminar film only (b) The buffer zone and turbulent zone
(c) The laminar and buffer zones (d) The laminar, buffer and turbulent zones.

(iv) The relation between k_g and k_y is
(a) $k_g = k_yP$ (b) $k_g = k_yP/RT$ (c) $k_g = k_y/P$ (d) $k_g = k_y$.

(v) Hatta number <0.3 signifies
(a) system is diffusion controlled
(b) system is reaction controlled
(c) reaction and diffusion are equally important
(d) system is controlled by other factors.

(vi) A plate tower is suitable for
(a) low pressure operations
(b) revamping of a column
(c) handling high fluctuations in liquid-gas flow rate
(d) handling corrosive fluids.

(vii) The Lewis – Whitman theory takes into account the resistances of
(a) The laminar film only
(b) The buffer zone and turbulent zone
(c) The laminar and buffer zones
(d) The laminar, buffer and turbulent zones.

(viii) Which one can be considered equivalent to a theoretical stage?

(a) Partial reboiler (b) Total condenser
(c) Total reboiler (d) Partial condenser.

(ix) The number of theoretical stages for a gas absorption operation can be estimated from _____

(a) Fenske equation (b) Rayleigh's euation
(c) Underwood correlation (d) Kremser equation.

(x) Distillation column pressure is fixed according to the _____

(a) Reboiler heat load (b) Condenser pressure
(c) Condenser heat load (d) Reflux ratio.

Group- B

2. (a) In an oxygen-nitrogen gas mixture at 1 atm, 25℃, the concentrations of oxygen at 2 planes 3 mm apart are 10 and 20 volume % respectively. Calculate the diffusion flux of oxygen, where there is equimolar counter-diffusion of the two gases. The diffusivity of oxygen through nitrogen is 0.206 cm^2/s. [(CO1) (Apply/IOCQ)]

(b) "In case of distillation there is equimolar counter-diffusion, while absorption involves diffusion of a gas through a stagnant gas mixture". Justify this statement. [(CO1) (Evaluate/HOCQ)]

(c) How does diffusivity of a gas vary with its molecular weight? [(CO1)(Analyze/IOCQ)]

6 + 4 + 2 = 12

3. (a) A large volume of pure gas B at 1.5 atm is flowing over the surface of a liquid mixture of A and C from which only A is diffusing into B. The concentration of A in the liquid at the liquid-gas interface is 2×10^{-3} $kmol/m^3$ and the Henry's law constant is 10 m^3 atm/kmol. The mass transfer coefficient k_y' predicted from heat transfer experiments is 5×10^{-5} $kmol/m^2$ s mol fraction. Considering gas B to be totally insoluble in the liquid, calculate the film coefficient k_g and the molar flux N_A. [(CO2)(Apply/IOCQ)]

(b) "Stripping should be a liquid-film controlled operation". Justify the correctness of the statement. [(CO2) (Evaluate/HOCQ)]

8 + 4 = 12

Group - C

4. (a) In an absorption operation, gas A is being absorbed into a liquid solvent B, with a simultaneous first order chemical reaction. It has been experimentally determined that the controlling resistance of the process is the resistance to chemical reaction. What can be the maximum value of the Hatta number in this case? Explain. [(CO3)(Analyze/IOCQ)]

(b) Pure gas A is absorbed in water in a continuous stirred cell at 25℃ and 1 atm. The gas-liquid contact area is 50 cm^2. The rate of absorption is 4.02×10^{-3} gmol/min. The water flow rate is kept sufficiently high so that the concentration of the dissolved gas in bulk water is negligible. Solubility and diffusivity of the gas in water are 6.7 g/litre

and 1.5×10^{-5} cm^2/s. It is known that a 1st order reaction occurs between the gas and water simultaneously with the absorption process and the rate constant is 13.5 s^{-1}. Calculate the mass transfer coefficient k_L, assuming Film theory is applicable.

[(CO3)(Apply/IOCQ)]

4 + 8 = 12

5. (a) For carrying out a low-pressure distillation operation, a design engineer has chosen to design a plate column. Is her/his choice correct? Justify. [(CO4)(Evaluate/HOCQ)]

   (b) Under what conditions Murphree efficiency of a plate equals the point efficiency? Explain. [(CO4)(Understand/LOCQ)]

   (c) In a plate absorption tower, the liquid and gas flow rates are 60 kmol/h m^2 and 45 kmol/h m^2. The equilibrium relationship between the solute-solvent is expressed as y = 0.525x. The average point efficiency of a plate is 80%. Determine the Murphree efficiency of the plate. [(CO4)(Evaluate/HOCQ)]

4 + 2 + 6 = 12

Group - D

6. (a) A packed tower is to be designed to absorb sulphur dioxide from air by scrubbing with water. The entering gas is 20% SO_2 by volume and the leaving gas is to contain 0.5 % SO_2 by volume. The entering water is solute-free. The water flow rate to be used is twice the theoretical minimum. The air flow rate on solute free basis is 975 kg/h m^2. The temperature is 30°C and total pressure is 2 atm. The equilibrium relationship is expressed by y = 21.8 x where y and x are mole fractions of SO_2 in the gas and water phases respectively. The volumetric mass transfer coefficient K_ga is 2.05×10^{-5} kmol/h m^2 atm. Calculate the height of the packing section.

   [(CO4)(Apply/IOCQ)]

   (b) Differentiate between "Coning" and "Dumping". [(CO4)(Analyze/IOCQ)]

8 + 4 = 12

7. (a) A tower packed with 0.5 cm Raschig rings of 12 m height is to be used for absorption of hydrogen sulphide from natural gas (methane) using monoethanolamine solvent. The operation is carried out at 30°C and 1atm pressure, in a counter-current fashion. The entering gas contains 18% H_2S by volume. 85% of this has to be absorbed. The gas flow rate is 1500 m^3/m^2 hr. The equilibrium relationship is Y = 1.1 X. Determine the liquid flow rate to be used and the number of theoretical stages.

   [(CO4)(Apply/IOCQ)]

   (b) What is the significance of 'HTU' in case of a packed tower?

   [(CO4)(Understand/LOCQ)]

8 + 4 = 12

Group - E

8. A stream of aqueous methanol flowing at a rate 200 kg moles/hr. and having 45 mol% methanol is continuously fed to a distillation column. The top product of the column should contain at least 98 mol% methanol and a bottom liquid must not contain more

than 1 mol% methanol. The feed is at bubble point and operating pressure is 1 atm. A reflux ratio of 2 is suggested.

The vapor-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

(i) Find the equation of feed line.
(ii) Calculate the overhead and bottom product molar flow rates.
(iii) Determine the number of actual trays if the overall efficiency is 65%.

[(CO5)(Apply/IOCQ)]
12

9. (a) A distillation column is operating where the purity of the distillate is 95%. The plant manager wants the purity to be 99%. What is the simplest step you can take to achieve this? Explain. [(CO5)(Evaluate/HOCQ)]

(b) How does an entrainer in an azeotropic distillation operation work?
[(CO5)(Analyze/IOCQ)]

(c) Give an example of a system exhibiting negative deviation from ideal behaviour.
[(CO5)(Remember/LOCQ)]
5 + 5 + 2 = 12

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	8.33	67.7	23.9

Course Outcome (CO):

After the completion of the course students will be able to

1. Frame mathematical equations for a given steady-state or transient diffusion problem and solve 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