

Code: 9A23401

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B.Tech II Year II Semester (R09) Regular & Supplementary Examinations, April/May 2013

MASS TRANSFER OPERATIONS

(Biotechnology)

Time: 3 hours

Max Marks: 70

Answer any FIVE questions
All questions carry equal marks

- 1 (a) State Ficks' law of diffusion. Prove that for steady-state equimolar counter diffusion in gases,

$$N_A = \frac{D_{AB}}{RTz} (p_{A1} - p_{A2})$$
- (b) A small diameter tube closed at one end was filled with acetone to within 18 mm of the top and maintained at 290 K with a gentle stream of air blowing across the top. After 15000 seconds the liquid level had fallen to 27.5 mm. The vapor pressure of acetone was 21.95 kN/m². Calculate the diffusivity of acetone in air. Total pressure is 99.75 kN/m².
- 2 (a) Show that the relationship between individual-phase transfer coefficients and the overall coefficient takes the form of addition of resistances.
- (b) The solute A is being absorbed from a gas mixture of A and B in a wetted wall tower with the liquid flowing as a film downwards along the wall. At a certain point in the tower the bulk gas concentration is 0.380 mole fraction and the bulk liquid concentration is 0.100. The tower is operating at 298 K and 1.013 X 10⁵ Pa and the equilibrium data are as follows:

x_A	0	0.05	0.10	0.15	0.20	0.25	0.30	0.35
y_A	0	0.022	0.052	0.087	0.131	0.187	0.265	0.385

The solute A diffuses through stagnant B in the gas phase and then through a non diffusing liquid. Using correlations for dilute solutions in wetted wall towers the film mass transfer coefficient for A in the gas phase is predicted as 1.465 X 10⁻³ kgmol A/s.m².mol frac and for the liquid phase as 1.967 X 10⁻³ kgmol A/s.m².mol frac. Calculate the interphase concentrations and the flux.

- 3 (a) What is steam distillation? How is steam distillation temperature computed?
- (b) Oil containing 2.55 mole % of a hydrocarbon oil is stripped by running down a column in which live steam is passed at a rate 4 kmol/100 kmol of oil. Evaluate the number of theoretical stages required to reduce the hydrocarbon content to 0.05 mol% assuming oil is non volatile. The equilibrium relationship is $y = 33x$.
- 4 (a) Explain the different liquid equilibria with the help of equilateral triangular coordinates. Explain the notation scheme adopted.
- (b) An original mixture weighing 100 kg and containing 30 kg of isopropyl ether, 10 kg of acetic acid and 60 kg water is equilibrated and the equilibrium phases separated. What are the compositions of the two equilibrium phases? Use the following equilibrium data :

Water Layer (wt%)			Isopropyl Ether Layer (wt%)		
Acetic Acid	Water	Isopropyl Ether	Acetic Acid	Water	Isopropyl Ether
0	98.9	1.2	0	0.6	99.4
0.69	98.1	1.2	0.18	0.5	99.3
1.41	97.1	1.5	0.37	0.7	98.9
2.89	95.5	1.6	0.79	0.8	98.4
6.42	91.7	1.9	1.93	1.0	97.1
13.30	84.4	2.3	4.82	1.9	93.3
25.5	71.1	3.4	11.40	3.9	84.7
36.70	58.9	4.4	21.6	6.9	71.5
44.30	45.1	10.6	31.10	10.8	58.1
46.4	37.1	16.5	36.20	15.1	48.7

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- 5 (a) What is crystallization process? Discuss the different classes of crystals.
 (b) Soya bean flakes containing 20% oil are to be leached to recover 97.5% oil using hexane as solvent. Solvent used is 1 kg per kg of flakes and is free from oil. The under flow slurry is generally free of solids except in first stage where the underflow is 10% solids. The tie lines are vertical and given the laboratory test equilibrium data find the number of ideal stages needed.

% oil in solution	Y	0	20	30
Kg solid/ kg solution	N	1.725	1.515	1.429

- 6 (a) Draw the typical rate of drying curve generated under constant drying conditions. Explain the different periods giving the mechanism and relevant equations.
 (b) A material was dried in a tray type batch dryer using constant drying conditions. When the initial free moisture content was 0.28 kg free moisture /kg dry solid, 6.0 h was required to dry the material to a free moisture content of 0.08 kg free moisture/kg dry solid . The critical free moisture content is 0.14. Assuming a drying rate in the falling-rate region where the rate is a straight line from the critical point to the origin, predict the time to dry a sample from a free moisture content of 0.33 to 0.04 kg free moisture/kg dry solid.
- 7 (a) Explain gas permeation process with the help of neat schematic diagrams.
 (b) Discuss the different types of flow in gas permeation.
- 8 Give the applications of mass transfer operations in the following bioprocesses:
 (a) Oxygen transfer in production of penicillin
 (b) Drying of baker's yeast.

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- 1 (a) Discuss diffusion in biological gels.
(b) Nitrogen is diffusing under steady-state conditions through C_4H_{10} at 298 K and a total pressure of 100 kN/m^2 . The partial pressure of nitrogen at two planes 0.01 m apart are 13.3 and 6.67 kN/m^2 respectively. If the diffusivity of nitrogen through C_4H_{10} is $9.6 \times 10^{-6} \text{ m}^2/\text{s}$, calculate the rate of diffusion of nitrogen across the two planes.
- 2 (a) Explain mass transfer to suspensions of small particles in an agitated solution. Give the relevant equations.
(b) Calculate the maximum rate of absorption of oxygen in a fermenter from air bubbles at 1 atm abs pressure having diameters of $100 \mu\text{m}$ at 37°C into water having a zero concentration of dissolved oxygen. The solubility of oxygen from air into water at 37°C is $2.26 \times 10^{-7} \text{ g mol O}_2 / \text{cm}^3 \text{ liquid}$. The diffusivity of oxygen in water at 37°C is $3.25 \times 10^{-9} \text{ m}^2/\text{s}$. Agitation is used to produce the air bubbles. At 37°C $\mu_c(\text{water}) = 6.947 \times 10^{-4} \text{ Pa.S}$, $\rho_c(\text{water}) = 994 \text{ kg/m}^3$, $\rho_p(\text{air}) = 1.13 \text{ kg/m}^3$.
- 3 (a) What is differential distillation? Derive the Rayleigh equation for differential distillation.
(b) A mixture containing 70 mol % benzene and rest toluene is distilled under differential conditions at 101.32 kPa . A total of one third of the moles in the feed is vaporized. Calculate the average composition of the distillate and the composition of the remaining liquid. Equilibrium mole fraction data for benzene-toluene system at 101.325 kPa :

x_A	0	0.130	0.258	0.411	0.581	0.780	1.00
y_A	0	0.261	0.456	0.632	0.777	0.900	1.00

- 4 (a) Discuss the computation of theoretical stages when the extraction solvent and feed solution are insoluble and remain so at all concentrations of the distributed solute occurring in the liquid extraction operation.
(b) 100 kg of solution of acetic acid in water is to be extracted with isopropyl ether in a three stage cross current extraction system using 40 kg solvent each time. The concentration of acid is 30% in feed. Evaluate the quantities and compositions of various streams, quantity of solvent required if same final raffinate composition is to be obtained in a single stage. The equilibrium data is as follows:

Raffinate	Weight fraction B	0.12	0.16	0.23	0.034	0.044	0.165
	x	0.0069	0.029	0.133	0.255	0.367	0.464

Extract	Weight fraction B	0.993	0.984	0.933	0.847	0.715	0.487
	Y	0.0018	0.0079	0.0482	0.114	0.216	0.367

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- 5 (a) Discuss Miers' qualitative explanation of crystallization using solubility and super solubility curves.
- (b) In a single stage leaching of soybean oil from flaked soybeans with hexane, 100 kg of soybeans containing 20 wt % oil is leached with 100 kg of fresh hexane solvent. The value of N for the slurry underflow is essentially constant at 1.5 kg insoluble solid /kg solution retained. Calculate the amounts and compositions of the overflow and the underflow slurry leaving the stage.
- 6 (a) Discuss the criteria for selection of dryers.
- (b) A granular insoluble solid material wet with water is being dried in the constant-rate period in a pan 0.61 m X 0.61 m and the depth of the material is 25.4 mm. The sides and the bottom are insulated. Air flows parallel to the top drying surface at a velocity of 3.05 m/s and has a dry bulb temperature of 60 °C, wet bulb temperature of 29.4 °C and a humidity of 0.01 kg water/kg dry air. The pan contains 11.34 kg of dry solid having a free moisture content of 0.35 kg water/kg dry solid and the material is to be dried in the constant rate period to 0.22 kg water/kg dry solid. Predict the drying rate and the time in hours needed.
- 7 (a) Explain the reverse osmosis process with the help of diagrams.
- (b) What are the applications of reverse osmosis?
- 8 Give the applications of mass transfer operations in the following bioprocesses:
- (a) Distillation of alcohol from fermentation broth
- (b) Drying of baker's yeast.

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- 1 (a) Explain Stefan' experiment with the help of a neat schematic diagram.
- (b) Oxygen is diffusing through a non diffusing gaseous mixture of methane and hydrogen in the volume ratio 4:1. The diffusion takes place at a total pressure of 1 atm and 2 °C. The partial pressure of oxygen at two planes 0.35 cm apart are 115 mm and 65 mm mercury, respectively. Determine the rate of diffusion of oxygen. At 2 C and 1 atm pressure, the diffusivity for the mixture oxygen-hydrogen is $0.728 \text{ cm}^2/\text{s}$ and that for oxygen-methane is $0.197 \text{ cm}^2/\text{s}$.
- 2 (a) Discuss about the convective mass transfer coefficient. How is it evaluated using different dimensionless numbers.
- (b) The solute A is being absorbed from a gas mixture of A and B in a wetted wall tower with the liquid flowing as a film downwards along the wall. At a certain point in the tower the bulk gas concentration is 0.380 mole fraction and the bulk liquid concentration is 0.100. The tower is operating at 298 K and $1.013 \times 10^5 \text{ Pa}$ and the equilibrium data are as follows:

x_A	0	0.05	0.10	0.15	0.20	0.25	0.30	0.35
y_A	0	0.022	0.052	0.087	0.131	0.187	0.265	0.385

The solute A diffuses through stagnant B in the gas phase and then through a non diffusing liquid. Using correlations for dilute solutions in wetted wall towers the film mass transfer coefficient for A in the gas phase is predicted as $1.465 \times 10^{-3} \text{ kgmol A/s.m}^2.\text{mol frac}$ and for the liquid phase as $1.967 \times 10^{-3} \text{ kgmol A/s.m}^2.\text{mol frac}$. The interphase concentration of A in the gas phase is 0.197 and in the liquid phase is 0.257. Calculate the overall mass transfer coefficient, flux, and the percent resistance in the gas and liquid films.

- 3 (a) Discuss the equilibrium solubility of gases in liquids for two-component systems with the help of schematic diagram.
- (b) It is desired to absorb 90% of the acetone in a gas containing 1.0 mol % acetone in air in a countercurrent stage tower. The total inlet gas flow to the tower is 30.0 kg mol/h, and the total inlet pure water flow to be used to absorb the acetone is 90 kg mol water/h. The process is to operate isothermally at 300 K and a total pressure of 101.3 kPa. The equilibrium relation for the acetone (A) in the gas-liquid is $y_A = 2.53 x_A$. Determine the number of theoretical stages required for this separation.
- 4 (a) Draw the flow sheet for continuous countercurrent multistage extraction. Explain the computation of number of ideal stages using graphical treatment.
- (b) 100 kg/hr of a 25% solution of dioxane in water is extracted using benzene to recover 95% of dioxane. The equilibrium data is:

Weight % dioxane in water	5.1	18.9	25.2
Weight % dioxane in benzene	5.2	22.5	32.0

What is the minimum solvent rate needed? If 900 kg/h solvent is used how many theoretical stages are needed?

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- 5 (a) Explain the adsorption process. Give the applications of adsorption. What are the desirable physical properties of adsorbents?
- (b) A slurry of flaked soybeans weighing a total of 100 kg containing 75 kg of inert solids and 25 kg of solution with 10 wt% oil and 90 wt % solvent hexane. The slurry is contacted with 100 kg of pure hexane in a single stage so that the value of N for the outlet underflow is essentially constant at 1.5 kg insoluble solid /kg solution retained. Calculate the amounts and compositions of the overflow and the underflow slurry leaving the stage.
- 6 (a) Explain the construction and working of a typical rotary drier with the help of schematic diagram. Give the major types of rotary driers.
- (b) It is necessary to dry a batch of 160 kg of wet solid material from 30% to 5% moisture content, under constant rate and falling rate period. The falling rate is assumed to be linear. Calculate the total drying time considering an available drying surface of $1 \text{ m}^2/40 \text{ kg}$ of dry solid. A constant drying flux of $3 \times 10^{-4} \text{ kg/m}^2\text{s}$ is given. Critical moisture content is 0.2 kg water/kg solid and equilibrium moisture content is 0.05 kg water/kg solid.
- 7 (a) Explain ultra filtration process with neat schematic diagram.
- (b) Write about dialysis process.
- 8 Give the applications of mass transfer operations in the following bioprocesses:
- (a) Oxygen transfer in production of penicillin.
- (b) Crystallization of citric acid.

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- 1 (a) Give Ficks' law of diffusion for diffusion occurring in the solid phase. Discuss the different types of solid diffusion.
- (b) A tube or bridge of a gel solution of 1.05 wt % agar in water at 278 K is 0.04 m long and connects two agitated solutions of urea in water. The urea concentration in the first solution is 0.2 g mol urea per liter solution and 0 in the other. Calculate the flux of urea in kgmol/s.m^2 at steady state. For the solute urea at 278 K, $D_{AB} = 0.727 \times 10^{-9} \text{ m}^2/\text{s}$.
- 2 (a) Explain the film theory model for predicting mass transfer coefficient.
- (b) A total of 5.0 g of wet microorganisms having a density of 1100 kg/m^3 and a diameter of $0.667 \mu\text{m}$ are added to 0.100 L of aqueous solution at 37°C in a shaker flask for a fermentation. Air can enter through a porous stopper. The solubility of oxygen from air into water at 37°C is $2.26 \times 10^{-7} \text{ g mol O}_2/\text{cm}^3 \text{ liquid}$. The diffusivity of oxygen in water at 37°C is $3.25 \times 10^{-9} \text{ m}^2/\text{s}$. At 37°C $\mu_c(\text{water}) = 6.947 \times 10^{-4} \text{ Pa.S}$, $\rho_c(\text{water}) = 994 \text{ kg/m}^3$, $\rho_p(\text{air}) = 1.13 \text{ kg/m}^3$. Calculate the maximum rate possible of mass transfer of oxygen to the surface of the microorganisms assuming that the solution is saturated with air at 101.32 kPa abs atmosphere.
- 3 (a) How is minimum liquid-gas ratio computed in the design of absorbers?
- (b) A mixture of 50 g mol of liquid benzene and 50 g mol of water is boiling at 101.32 k Pa pressure. Liquid benzene is immiscible in water. Determine the boiling point of the mixture and the composition of the vapor. Vapor pressure data of the pure components are as follows:

Temperature $^\circ\text{C}$	P_{water} in mm Hg	P_{benzene} in mm Hg
35.3	43	150
52.7	106	300
72.6	261	600
80.1	356	760

- 4 (a) What is liquid liquid extraction? Draw the different liquid equilibria and explain them.
- (b) An inlet water solution of 100 kg/h containing 0.010 wt fraction nicotine in water is stripped with a kerosene stream of 200 kg/h containing 0.0005 wt fraction nicotine in a counter current stage tower. The water and the kerosene are essentially immiscible in each other. It is desired to reduce the concentration of the exit water to 0.0010 wt fraction nicotine. Determine the number of theoretical stages needed. The equilibrium data are as follows with x the weight fraction of nicotine in water solution and y in the kerosene.

X	0.001010	0.00246	0.00500	0.00746	0.00988	0.0202
y	0.000806	0.001959	0.00454	0.00682	0.00904	0.0185

- 5 (a) Discuss the common types of adsorption isotherms with the help of equations and schematic diagram.
- (b) A waste water solution having a volume 1.0 m^3 contains $0.21 \text{ kg phenol/m}^3$ of solution. A total of 1.40 kg of fresh granular activated carbon is added to the solution which is then mixed thoroughly to reach equilibrium. Using the isotherm $q = 0.199 c^{0.229}$, what are the final equilibrium values, and what percent of phenol is extracted? q is kg phenol/kg carbon and c is kg phenol/ m^3 solution.

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- 6 (a) Discuss the mechanism of batch drying with the help of schematic diagram.
(b) A porous solid is dried in a batch dryer under constant drying conditions. Six hours is needed to remove the moisture from 30 to 10 kg water/kg dry solid. The critical moisture content is 16 kg water/kg dry solid and the equilibrium moisture is 2. All moisture contents are on a dry basis. Assume the drying rate during the falling rate period is a straight line through the origin. Calculate the time required to dry the solids from 30 to 6 kg water/kg dry solid.
- 7 (a) Explain micro filtration process with neat schematic diagram.
(b) Write about hemodialysis.
- 8 Give the applications of mass transfer operations in the following bioprocesses:
(a) Extraction of penicillin using butyl acetate.
(b) Absorption of ammonia in water.

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