MASS TRANSFER II
(CHEN 3202)

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) In a cooling tower, blow down loss is related to
(a) high liquid flow rate (b) low flow rate
(c) high dissolved salt concentration (d) low dissolved salt concentration

(ii) Algal growth is more prevalent in _____ cooling tower
(a) natural draft (b) cross-flow induced draft
(c) counter flow induced draft (d) forced draft

(iii) In liquid-liquid extraction, selectivity should not be
(a) less than 1 (b) more than 1
(c) equal to 1 (d) equal to 0

(iv) In case of liquid liquid extraction, if distribution coefficient is more than 1, then for a given separation,
(a) more solvent is required (b) less solvent is required
(c) solvent requirement cannot be predicted (d) extraction is not possible

(v) In an experiment on the growth of a sample of uniform-size particles (L= 1 mm) in a supersaturated solution, it is found that the volume of a particle increases at a rate of $\frac{dv_p}{dt} = 5.2\times10^{-14} m^3/s$. If the volume shape factor is 0.42, the growth rate is
(a) 4.13×10^{-8} m/s (b) 4.13×10^{-2} m/s
(c) 4.13×10^{8} m/s (d) 4.13 m/s

(vi) The overall crystal growth coefficient KG can be expressed in terms of diffusion mass transfer coefficient and deposition mass transfer coefficient kr as
(a) $K_G = k_d + k_r$ (b) $\frac{1}{K_G} = \frac{1}{k_d} - \frac{1}{k_r}$
(c) $\frac{1}{K_G} = \frac{1}{k_r} - \frac{1}{k_d}$ (d) $\frac{1}{K_G} = \frac{1}{k_d} + \frac{1}{k_r}$

(vii) If the convective heat transfer coefficient is 43.3 W/m² K, dry and wet bulb temperatures of air are 120 °C and 41.5 °C respectively, latent heat of vaporization of water is 2400 kJ/kg, the constant rate of drying is
(a) 5.08 kg/m².h (b) 0.001 kg/m² h
(c) 0.5 kg/m² h (d) 50.8 kg/m² h

(viii) While drying a solid from 33% to 1% moisture (dry basis), it is found that the constant rate drying time is same as the falling rate drying time. The equilibrium moisture is negligible. If the falling rate of drying is linear in moisture content, what is the critical moisture content of the solid?
(a) 0.2 (b) 0.07 (c) 0.01 (d) 0.1

(ix) As per gel polarization model, the expression for limiting flux is
(a) $k_L \ln\frac{(C_g - C_p)}{(C_b - C_p)}$ (b) $k_L \ln\frac{C_b}{C_p}$
(c) $k_L \ln\frac{C_g}{C_p}$ (d) $k_L \ln\frac{(C_b - C_p)}{(C_g - C_p)}$

(x) The limiting flux through a UF membrane is 0.042 m³/m².h and the membrane surface mass transfer coefficient is 5×10^{-6} m/s. If the membrane rejects the solute completely, the polarization modulus is
(a) 8.3 (b) 25.3 (c) 15 (d) 10.3

Fill in the blanks with the correct word

(xi) The pore size range of UF membrane is _____.

(xii) The driving force for dialysis is _____ .

(xiii) The expression for critical crystal radius is _____

(xiv) The expression for constant rate drying in terms of dry and wet bulb temperatures of air is given by _____

(xv) Preparation of absolute alcohol from a near azeotropic mixture of alcohol and water is carried out using _____.

Group - B

2. (a) A dryer requires 1.6 m^3/s of air at 60^0C and 25%humidity. This is to be prepared from air at dry-bulb temperature 28^0C and 18^0C wet-bulb temperature by direct injection of steam into the air stream followed by passage of the air over steam-heated tubes. Calculate the kilograms of steam per second required for direct injection. *[(CO1)(Evaluate/HOCQ)]*

(b) In case of re-circulating liquid-gas humidification cooling in a horizontal spray chamber, obtain the design equation for determining the length of active part of the chamber. *[(CO1)(Apply/LOCQ)]*

7 + 5 = 12

3. A counter - flow induced draft cooling tower operates with inlet and exit water temperatures of 41^0C and 28^0C respectively when the inlet air dry-bulb and wet-bulb temperatures are 29^0 C and 25^0C respectively. The tower has 1.3 m of stacked plastic fill and operates with air (dry basis) mass velocity of 9,800 $kg/m^2.h$ and water mass velocity of 10,800 $kg/m^2.h$. Determine

(i) enthalpy of inlet air and outlet air,
(ii) number of overall enthalpy transfer units
(iii) height of overall enthalpy transfer unit
(iv) the temperature approach. *[(CO1)(Evaluate/HOCQ)]*

12

Group - C

4. (a) An original mixture weighing 120 kg and containing 40 kg isopropyl ether, 15 kg acetic acid and 65 kg water is equilibrated at 25^0C and the equilibrium phases separated.
(i) What are the amount and composition of the two equilibrium phases?
The equilibrium data at 25^0C are given below:

Water Layer (wt%)			**Isopropyl ether layer (wt%)**		
Acetic acid	Water	Isopropyl ether	Acetic acid	Water	Isopropyl ether
0.0	98.8	1.2	0	0.6	99.4
2.89	95.5	1.6	0.79	0.8	98.4
6.42	91.7	1.9	1.93	1.0	97.1
13.3	84.4	2.3	4.82	1.9	93.3
25.5	71.1	3.4	11.4	3.9	84.7
36.7	58.9	4.4	21.6	6.9	71.5
44.3	45.1	10.6	31.1	10.8	58.1
46.4	37.1	16.5	36.2	15.1	48.7

[(CO2) (Evaluate/HOCQ)]

(b) Mention the properties of a good solvent for Liquid-liquid extraction. *[(CO2)(Remember/LOCQ)]*

10 + 2 = 12

5. (a) With example, discuss the 'super critical fluid extraction' process, stating its advantages. *[(CO2)(Analyse/IOCQ)]*

(b) In a single stage leaching of soybean oil from flaked soybeans with hexane, 120 kg of soybeans containing 20 wt% oil is leached with 100 kg of solvent containing 1 wt% soybean oil. The value of N (kg insoluble solid/kg solution) for the slurry underflow is essentially constant at 1.52 kg insoluble solid/kg solution retained. Calculate the amount and compositions of the overflow and the underflow leaving the stage. *[(CO2)(Apply/HOCQ)]*

3 + 9 = 12

Group - D

6. (a) Wet porous catalyst pellets in the form of small cylinders, 13.5 mm diameter and 13 mm long are to be dried of their water content in a through circulation drier. The pellets are to be arranged in beds 50 mm deep on screens and dried by air flowing at 1.1 kg dry air/m^2 bed cross-section entering at 82°C dry bulb temperature, humidity 0.01kg water/kg dry air. Apparent bed density is 600 kg dry solids/m^3 and particle surface 280 m^2/m^3 bed volume. Estimate the rate of drying during constant rate period. Given: viscosity of air =1.9×10^{-5} kg/m.s and saturation humidity =0.031 kg water/kg dry air corresponding to wet bulb temperature = 32°C, void fraction ε =0.237, Sc=0.6 for air-water vapour. The expression for Colburn j-factor is given as

$$j_D = \frac{2.06}{\varepsilon}\mathrm{Re}^{-0.575} \text{ and } k_Y = \frac{j_D G_s}{Sc^{2/3}}$$ *[(CO3)(Evaluate/HOCQ)]*

(b) Discuss the working principle of a spray dryer with a diagram. Sketch and explain the solid and gas temperature profiles in a counter current rotary dryer. *[(CO3)(Analyse/IOCQ)]*

(c) Explain the different moisture contents of a solid with the aid of a relative humidity of gas - moisture content profile.

[(CO3)(Remember/LOCQ)]

5 + (2 + 2) + 3 = 12

7. (a) Discuss the working principle of a draft tube baffle crystallizer with a diagram. *[(CO4)(Understand/LOCQ)]*

   (b) A salt solution weighing 1000 kg with 30% Na_2CO_3 is cooled to 293 K. The salt crystallises as decahydrate. What will be the yield of $Na_2CO_3.10\ H_2O$ if solubility is 21.5 kg anhydrous Na_2CO_3/100 kg H_2O?
   (i) Assume no water evaporated
   (ii) Assume 3% of total weight of solution was lost by evaporation.
   [Molecular weight of Na_2CO_3 is 106 and $Na_2CO_3.10\ H_2O$ is 286.2] . *[(CO4)(Evaluate/HOCQ)]*

   (c) Distinguish between circulating liquid and circulating magma crystallizers with diagram. *[(CO4)(Analyze/IOCQ)]*

4 + 4 + 4 = 12

Group - E

8. (a) Mention membrane pore size range, membrane material, driving force and separation mechanism for reverse osmosis and microfiltration process. *[(CO5)(Remember/LOCQ)]*

   (b) A liquid containing dilute solute A at a concentration of 3×10^{-2} Kmol/m^3 is flowing rapidly past a membrane of thickness 3.0×10^{-5} m. Distribution coefficient is 1.5 and diffusivity of solute A is 7.0×10^{-11} m^2/s in the membrane. The solute diffuses through the membrane and its concentration on the other side of the membrane is 0.50×10^{-2} Kmol/ m^3. The mass transfer coefficient in the feed side is large and can be considered as infinite, mass transfer coefficient on the other side of the membrane is 2.02×10^{-5} m/s. Calculate the flux and solute concentrations at the membrane interfaces. *[(CO5)(Evaluate/HOCQ)]*

4 + (6 + 2) = 12

9. (a) The following time-varying flux data were collected at 25°C for unstirred batch ultrafiltration of 2% bovine serum albumin (69000 Da) using PM-10 membrane of 10000 MWCO. The applied pressure difference was maintained constant at 30 kPa. Calculate the membrane resistance R_m and cake resistance r_c/ρ_c. Assume complete rejection. The viscosity of water is 0.9 cP. The equation for flux is as follows

$$\frac{1}{J_w^2} = \frac{R_m^2 \mu^2}{\Delta P^2} + \frac{2\mu C_b r_c R'}{\rho_c \Delta P} t$$

Time, s	10	20	30	40	50	60	70	80
$10^2 J_w$, litre/m^2.h	6.58	5.18	4.45	3.89	3.52	3.27	3.07	2.86

[(CO5)(Apply/HOCQ)]

   (b) It is required to produce 20000 m^3 per day of potable water having a salt concentration not more than 300 ppm from sea water containing 3.3% salt. An asymmetric cellulose acetate membrane (thickness 0.8 micron) having a water permeability 70 *l*/m^2.h.MPa and salt rejection of 98% is used. The feed side pressure is 75 atm and that on the permeate side is 1 atm. If 30% feed water permeates through the membrane, calculate the required membrane area. The polarization modulus is 1.2. The osmotic pressure of 5% brine (linear in salt concentration) is 39.5 atm. *[(CO5)(Evaluate/HOCQ)]*

   (c) Discuss the mechanism of mass transfer in pervaporation with the aid of a schematic diagram. Explain the significance of separation factor in pervaporation. *[(CO5)(Understand/LOCQ)]*

6 + 4 + 2 = 12

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	20.83	11.46	67.71

Course Outcome (CO):

After the completion of the course students will be able to

1. Students will be able to analyze various humidification, dehumidification processes and will be able to design cooling towers.
2. Students will be able to analyze commercial extraction and leaching operation and determine number of equilibrium stages required for a given separation.
3. Students will be able to understand mechanism of drying, calculate drying time for batch dryers and compute rate of drying in batch and continuous modes of drying operation.
4. Students will be able to develop concepts on crystal properties, kinetics and thermodynamics associated with crystallization process, and design the crystallization equipments.
5. Students will be able to classify membrane separation processes based on driving forces, understand their applications and develop ideas on some of these processes and their applications in industries.

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