UNIVERSITI TEKNOLOGI PETRONAS

FINAL EXAMINATION
MAY 2024 SEMESTER

COURSE	**:**	**YBB2083 - SEPARATION PROCESS**
DATE	**:**	**5 AUGUST 2024 (MONDAY)**
TIME	**:**	**9:00 AM - 12:00 NOON (3 HOURS)**

INSTRUCTIONS TO CANDIDATES

1. Answer **ALL** questions in the Answer Booklet.
2. Begin **EACH** answer on a new page in the Answer Booklet.
3. Indicate clearly answers that are cancelled, if any.
4. Where applicable, show clearly steps taken in arriving at the solutions and indicate **ALL** assumptions, if any.
5. **DO NOT** open this Question Booklet until instructed.

Note :

i. There are **THIRTEEN (13)** pages in this Question Booklet including the cover page .

ii. **DOUBLE-SIDED** Question Booklet.

iii. Graph paper(s) will be provided

1. a. Removal of organic pollutants from wastewater is common to many industrial processes. Several separation methods can be used to separate organic contaminates from wastewater. Outline the advantages and disadvantages of the following separation methods.

   i. Adsorption

   [2 marks]

   ii. Vapour-liquid extraction

   [2 marks]

   iii. Membrane separation

   [2 marks]

   b. Oxygen diffuses in a mixture of oxygen-nitrogen at 1 std. atm and 25 °C. The concentration of oxygen at planes 2 mm apart are 10 and 20 vol.%, respectively. Nitrogen is a non-diffusing gas.

   i. Construct the appropriate expression to calculate the flux of oxygen. Define the units for each term.

   [3 marks]

   ii. Calculate the flux of oxygen. Given that the diffusivity of oxygen in nitrogen is 1.89×10^{-5} m^2/s.

   [2 marks]

c. A solute A is to be recovered from an inert carrier gas B by absorption into a solvent. The gas entering into the absorber flows at a rate of 400 kmol/h with yA = 0.3 and leaving the absorber with yA = 0.01. Solvent enters the absorber at the rate of of 2000 kmol/h with xA= 0.001. The equilibrium relationship is yA = 2.8 xA. The carrier gas may be considered insoluble in the solvent and the solvent may be considered non-volatile. Calculate the amounts and compositions of the two outlet phases.

[5 marks]

d. Water in the bottom of a narrow metal tube is held at a constant temperature of 298 K. The dry ambient air outside the tube is at 1 atm and 298 K. Water evaporates and diffuses through the air in the tube, and the diffusion path $z_2 - z_1$ is 50 cm long. Given that the diffusivity of water vapor (A) in air (B) at 1 atm and 298 K is 0.25 cm^2/s, and vapour pressure of water at 298 K is 3.17. Assume that air is insoluble in water. Calculate the rate of evaporation at steady state in $mol/s.cm^2$.

[4 marks]

2. a. The gas adsorption process can be divided into two categories: physisorption and chemisorption.

i. Define the physisorption and chemisorption processes.

[2 marks]

ii. Outline the **THREE (3)** differences between physisorption and chemisorption processes.

[3 marks]

b. A wastewater solution having a volume of 1.0 m^3 contains 0.21 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. Given the isotherm, $q = 0.199c^{0.229}$.

i. Calculate the final equilibrium value.

[4 marks]

ii. Calculate the percent of phenol extracted.

[2 marks]

c. Draw **THREE (3)** isotherm profiles that are typically encountered in an adsorption process for a single adsorbate and illustrate the behaviour through equilibrium relations.

[6 marks]

d. Adsorption chromatography involves the analytical separation of a chemical mixture based on the interaction of the adsorbate with the adsorbent. Outline the forces of attraction involves in adsorption chromatographic separation process.

[3 marks]

3. a. Vapor-liquid equilibrium (VLE) is a state at which a pure component or mixture exists in both the liquid and vapor phases.

i. Name the factors ~~those are~~ affecting the VLE.

[2 marks]

ii. Explain the cause of azeotrope formation during the separation of two different liquids.

[3 marks]

b. A saturated liquid feed of 100 mol/h at the boiling point containing 42 mol% heptane and 58 mol % ethyl benzene is to be fractioned at 101.32 kPa abs to give a distillate containing 97 mol % heptane and a bottoms containing 1.1 mol% heptane. The reflux ratio used is 2.5:1. Equilibrium data at 101.32 kPa abs pressure for the mole fraction of n-heptane is given in **TABLE Q3.**

TABLE Q3: Equilibrium data at 101.32 kPa abs pressure for the mole fraction of n-heptane, x_H and y_H

Temperature		x_H	y_H
K	°C		
409.3	136.1	0	0
402.6	129.4	0.08	0.230
392.6	119.4	0.250	0.514
383.8	110.6	0.485	0.730
376.0	102.8	0.790	0.904
371.5	98.3	1.000	1.000

i. Construct the McCabe Thiele diagram.

[6 marks]

ii. Calculate the molar flow rate of distillate.

[3 marks]

iii. Calculate the molar flow rate of the bottom product.

[2 marks]

iv. Determine the number of theoretical plates required.

[2 marks]

v. Identify the position of the feed tray number.

[2 marks]

4. a. Illustrate the principle(s) of liquid-liquid extraction.

[3 marks]

b. A single stage extraction is performed in which 200 kg of a solution containing 20 wt.% ethylene glycol (A) in water (B) is contacted with 200 kg of pure furfural (C). Given that M, is a condition of a mixture of feed and solvent (before phase separation) containing 18.9 wt% water, 20 wt% of ethylene glycol and 61.1 wt% furfural. **FIGURE Q4** shows the ternary diagram of A, B and C.

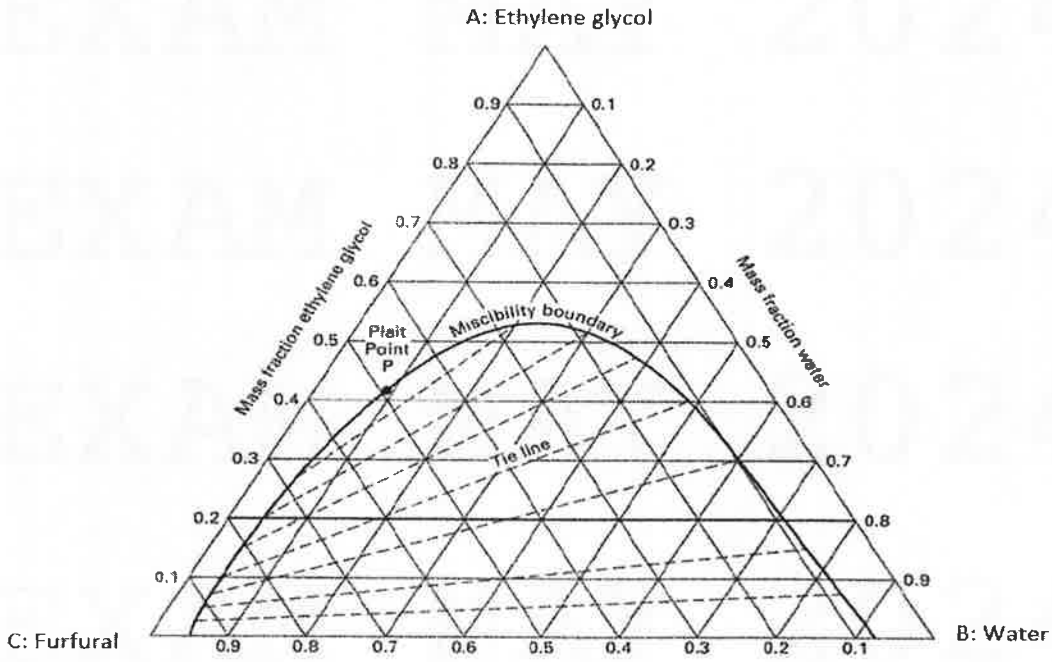

FIGURE Q4: Ternary diagram of A, B and C.

i. Determine the feed composition of plait point, *P*.

[3 marks]

ii. Determine the composition of extract, E and raffinate, R.

[4 marks]

iii. Calculate the product flow rates, L1 and V1.

[5 marks]

c. Examine the preference of utilizing the liquid-liquid extraction over distillation in separation of formic acid and water mixture. Given, B_p of formic acid is 100.6 °C, and B_p of water is 100 °C.

[5 marks]

5. a. A membrane separation process is a process where a membrane is used to separate the components in a solution by rejecting unwanted substances and allowing the others to pass through the membrane. However, the separation performance is evaluated by analyzing various parameters. Describe the **TWO (2)** parameters that are critically important to assess membrane separation performance.

[4 marks]

b. A membrane process is designed to recover solute *A* from a dilute solution by dialysis through a membrane to a solution, where $C_1 = 2\times10^{-2}$ kg mol/m^3 and $C_2 = 0.3\times10^{-2}$ kgmol/m^3. The membrane thickness is 1.59×10^{-5} m. The distribution coefficient $K' = 0.75$, $D_{AB} = 3.5\times10^{-11}$ m^2/s in the membrane. The mass transfer coefficient in the dilute solution is $k_{c1} = 3.5\times10^{-5}$ m/s and $k_{c2} = 2.1\times10^{-5}$ m/s.

i. Draw a diagram of the membrane process with necessary labels for separating solute *A* from a diluted solution.

[4 marks]

ii. Calculate the individual resistances, total resistances, and total percent resistance of the two films.

[5 marks]

iii. Calculate the steady-state flux, N_A.

[2 marks]

iv. Calculate the total area for a transfer of 0.02 kg mol solute/h.

[2 marks]

c. The gas permeation membrane process performs the separation of hydrogen from methane. Using **TABLE Q5**, justify the best membrane material for the separation based on selectivity.

TABLE Q5: Permeability data of various membrane materials

Material	Permeability, P_m (barrier)	
	Hydrogen	Methane
Ethyl Cellulose	49.2	7.47
Polystyrene	56.0	2.72
Polyester	1.65	0.0035

[3 marks]

-END OF PAPER-

APPENDIX I

PHYSICAL CONSTANTS

Atomic mass unit	1 amu	= 1.661×10^{-24} g
	1 g	= 6.022×10^{23} amu
Avogadro's number	N	= 6.022×10^{23} / mol
Boltzmann's constant	k	= 1.381×10^{-23} J/K
Electron charge	e	= 1.602×10^{-19} C
Faraday's constant	$F = Ne$	= 9.649×10^{4} C/mol
Gas constant	R	= 8.314 J/mol.K =8.314 m^3.Pa/K.mol = 0.08206 L-atm/mol.K =82.057 cm^3.atm/k.mol
Mass of electron	m_e	= 9.110×10^{-31} kg
Mass of neutron	m_n	= 1.675×10^{-27} kg
Mass of proton	m_p	= 1.673×10^{-27} kg
Atomic mass constant	m_u	= 1.660×10^{-27} kg
Pi	π	= 3.142
Planck's constant	h	= 6.626×10^{-34} J-s
Speed of light	c	= 2.998×10^{8} m/s
Rydberg constant	R_H	= 1.097×10^{7} m^{-1}
	hcR_H	= 2.179×10^{-18} J

APPENDIX II

LIST OF FORMULA

$$J_A^* = -D_{AB}\frac{dc_A}{dz} = \frac{D_{AB}(P_{A1}-P_{A2})}{RT(z_1-z_2)}$$

$$N_A = -D_{AB}\frac{dc_A}{dz} + \frac{c_A}{c}(N_A+N_B)$$

$$N_A = \frac{D_{AB}P}{RT(z_2-z_1)}\left(\frac{\rho_{A1}-\rho_{A2}}{\rho_{BM}}\right)$$

$$\rho_{BM} = \frac{\rho_{B_2}-\rho_{B_1}}{\ln\frac{\rho_{B_2}}{\rho_{B_1}}}$$

$$N_A = \frac{D_{AB}P}{RT(z_2-z_1)}\ln\frac{P-p_{A2}}{P-p_{A1}}$$

$$N_A = \frac{D_{AB}C_v}{(z_2-z_1)x_{BM}}(x_{A1}-x_{A2})$$

$$N_A = \frac{c_1-c_2}{\frac{1}{k_{c1}}+\frac{1}{p_m}+\frac{1}{k_{c2}}}$$

$$\rho_m = \frac{K'D_{AB}}{L}$$

$$C_{AV} = \frac{\frac{\rho_1}{M_1}+\frac{\rho_2}{M_2}}{2}$$

$$\frac{D}{F} = \frac{z_F-x_B}{x_D-x_B}$$

$$\frac{B}{F} = \frac{z_F-x_D}{x_B-x_D}$$

$$q_F M + c_F S = qM + cS$$

$$\overline{L}\overline{X}_{A,b} + \overline{V}\overline{Y}_{A,t} = \overline{L}\overline{X}_{A,t} + \overline{V}\overline{Y}_{A,b}$$

$$L_b x_{A,b} + V_t y_{A,t} = L_t x_{A,t} + V_b y_{A,b}$$

$$\bar{X}_A = \frac{x_A}{1-x_A} = \frac{mole\ fraction\ of\ A\ in\ the\ liquid}{mole\ fraction\ of\ non-A\ components\ in\ the\ liquid}$$

$$\bar{Y}_A = \frac{y_A}{1-y_A} = \frac{mole\ fraction\ of\ A\ in\ the\ vapour}{mole\ fraction\ of\ non-A\ components\ in\ the\ vapour}$$

$$\bar{Y}_{A,t} = \frac{\bar{L}}{\bar{V}}\bar{X}_{A,t} + \left(\bar{Y}_{A,b} - \frac{\bar{L}\bar{X}_{A,b}}{\bar{V}}\right)$$

$$y_{n+1} = \frac{L_n x_n}{V_{n+1}} + \frac{V_1 y_1 - L_0 x_0}{V_{n+1}}$$

$$L_1 x_{A,1} + V_1 y_{A,1} = M x_{A,M}$$