UNIVERSITI
TEKNOLOGI
PETRONAS

FINAL EXAMINATION
JANUARY 2025 SEMESTER

COURSE : **CEB2013/CFB2013 - SEPARATION PROCESS I**
DATE : **15 APRIL 2025 (TUESDAY)**
TIME : **2.30 PM - 5.30 PM (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 **TEN (10)** pages in this Question Booklet including the cover page and appendices.
- ii. **DOUBLE-SIDED** Question Booklet.
- iii. **Graph papers will be provided.**

1. Gas (A) is diffusing in equimolar counterdiffusion through a uniform tube 0.10 m long containing gas (B) with an inside diameter of 20.00 mm at 1.0132×10^5 Pa and 298 K. At point 1, $p_{A1} = 1.013 \times 10^4$ Pa and at point 2, $p_{A2} = 0.507 \times 10^4$ Pa. The diffusivity $D_{AB} = 0.230 \times 10^{-4}$ m²/s and R = 8314 m³.Pa/kg.mol.K.

   a. Illustrate the above system with a diagram and explain the diffusion path of component A and component B.

   [6 marks]

   b. Calculate the diffusion rate of Gas A.

   [8 marks]

2. a. With the aid of diagram, describe the operational principles of distillation column. Discuss the impact of reflux in designing efficient separation processes.

[10 marks]

b. A 100 kg mol/h feed of liquid mixture of benzene–toluene contains 45 mol% benzene and enters a distillation tower at 327.6 K at 101.32 kPa. A distillate containing 95 mol% benzene and a bottom containing 10 mol% benzene are to be obtained. The Vapour-Liquid Equilibrium (VLE) data for benzene–toluene system are given in **TABLE Q2.**

TABLE Q2: VLE data for benzene-toluene system

Temperature (˚C)	Vapor Pressure	
	Benzene (kPa)	Toluene (kPa)
80.10	101.32	-
85.00	116.90	46.00
90.00	135.50	54.00
95.00	155.70	63.30
100.00	179.20	74.30
105.00	204.20	86.00
110.60	240.00	101.32

i. Calculate the distillate and bottoms product in mol/h.

[6 marks]

ii. If total reflux is used to design the distillation column, estimate the minimum number of theoretical trays using McCabe–Thiele method. Discuss whether the design is optimal and justify your answer.

[16 marks]

3. An absorption tower is to be designed to remove 96 mol% of solute-A from carrier B stream containing 10 mol% of solute-A at 293 K and 1 atm. The feed gas mixture stream enters the tower at flow rate of 150 mol/h, whereas the pure solvent-C enters at flow rate of 400 mol/h. The equilibrium data is given in **TABLE Q3**.

TABLE Q3: Equilibrium data for solute-A and solvent-C.

Mole fraction of solute-*A* in liquid, x	Mole fraction of solute-*A* in gas, y
0.000	0.000
0.010	0.013
0.040	0.052
0.060	0.078
0.077	0.100

a. Estimate the number of theoretical stages required for the desired absorption using both graphical method and Kremser's equation and compare on your result.

[20 marks]

b. Identify **THREE (3)** key design considerations to ensure optimal performance and cost-effectiveness of the system. Justify your answers.

[6 marks]

4. a. With the aid of diagrams, discuss the operational principles of **THREE (3)** liquid-liquid extraction equipment. Compare the advantages and disadvantages of the selected equipments.

[12 marks]

b. Pure solvent isopropyl ether at the rate of 600 kg/h is being used to extract an aqueous solution of 200 kg/h containing 30 wt% acetic acid (A) by countercurrent multistage liquid-liquid extraction process. The desired exit acetic acid concentration in the aqueous phase is 4 wt%. The equilibrium data are given in **TABLE Q4**. Estimate the number of stages of the liquid-liquid extraction process.

TABLE Q4: Acetic acid-water-isopropyl ether system, liquid-liquid equilibria at 293 K

Water Layer (wt%)			Isopropyl Ether Layer (wt%)		
Acetic Acid	Water	Isopropyl Ether	Acetic Acid	Water	Isopropyl Ether
0.00	98.80	1.20	0.00	0.60	99.40
0.69	98.10	1.20	0.18	0.50	99.30
1.41	97.10	1.50	0.37	0.70	98.90
2.89	95.50	1.60	0.79	0.80	98.40
6.42	91.70	1.90	1.93	1.00	97.10
13.30	84.40	2.30	4.82	1.90	93.30
25.50	71.10	3.40	11.40	3.90	84.70
36.70	58.90	4.40	21.60	6.90	71.50
44.30	45.10	10.60	31.10	10.80	58.10
46.40	37.10	16.50	36.20	15.10	48.70

[16 marks]

- END OF PAPER -

APPENDIX A

Partial pressure correlation

$$P = p_{A1} + p_{B1}$$

$$P = p_{A2} + p_{B2}$$

Raoult's Law

$$x_A = \frac{P - P_B}{P_A - P_B}$$

$$y_A = \frac{x_A P_A}{P}$$

Equimolar counter-diffusion in gases

$$J_{AZ}\frac{= D_{AB}(p_{A1} - p_{A2})}{RT(z_2 - z_1)}$$

$$J_{BZ} = \frac{D_{BA}(p_{B1} - p_{B2})}{RT(z_2 - z_1)}$$

$$D_{AB} = D_{BA}$$

General case for diffusion of gases A and B plus convection

$$N_A = -cD_{AB}\frac{\mathrm{dx_A}}{\mathrm{d}z} + \frac{c_A}{c}(N_A + N_B)$$

$$N_B = -cD_{BA}\frac{\mathrm{dx_B}}{\mathrm{d}z} + \frac{c_B}{c}(N_A + N_B)$$

Special case for A diffusing through stagnant, non- diffusing B

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

$$p_{BM} = \frac{p_{B2} - p_{B1}}{ln\left(\frac{p_{B2}}{p_{B1}}\right)} = \frac{p_{A1} - p_{A2}}{ln\left(\frac{P - p_{A2}}{P - p_{A1}}\right)}$$

Diffusion through varying cross-sectional area

i. Diffusion from a sphere to surrounding medium

$$\frac{N_A}{4\pi r_1{}^2} = \frac{D_{AB}P}{RTr_1}\frac{p_{A1} - p_{A2}}{p_{BM}}$$

APPENDIX A (CONT.)

ii. Diffusion through a conduit of non-uniform cross-sectional area

$$\frac{\overline{N_A}}{\pi}\int_{z1}^{z2}\frac{dz}{\left[\left(\frac{r_2-r_1}{z_2-z_1}\right)z+r_1\right]^2}=\frac{D_{AB}}{RT}\int_{p_{A1}}^{p_{A2}}\frac{dp_A}{1-p_A/P}$$

Rate of diffusion

$$Rate of diffusion = J_{AZ}S$$

Surface area

$$S=\pi r^2$$

Distillation with Reflux

Total material balance

$$F=D+W$$

Component A balance

$$Fx_F=Dx_D+Wx_w$$

Enriching section operating line

$$y_{n+1}=\frac{L_n}{V_{n+1}}x_n+\frac{Dx_D}{V_{n+1}}$$

$$y_{n+1}=\frac{R}{R+1}x_n+\frac{x_D}{R+1}$$

Stripping section operating line

$$y_{m+1}=\frac{L_m}{V_{m+1}}x_m-\frac{Wx_W}{V_{m+1}}$$

Condition of the feed, q

$$q=\frac{heat\ needed\ to\ vaporize\ 1\ mol\ of\ feed\ at\ entering\ conditions}{molar\ latent\ heat\ of\ vaporization\ of\ feed}$$

$$q=\frac{H_v-H_F}{H_v-H_L}$$

For cold liquid feed

$$q=1+\frac{c_{pL}(T_b-T_F)}{\lambda}$$

For superheated vapor

$$q = 1 + \frac{\breve{c}_{pV}\left(T_F - T_d\right)}{\lambda}$$

q-line

$$y = \frac{q}{q-1}x - \frac{x_F}{q-1}$$

Guideline for q-condition

q = 0	Saturated vapor
q = 1	Saturated liquid
q > 1	Subcooled liquid
q < 0	Superheated vapor
0 < q < 1	Mix of liquid and vapor

Henry's Law

$$p_A = Hx_A$$

$$y_A = H'x_A$$

$$H' = \frac{H}{P}$$

Single Equilibrium Stage Absorption

Material balance

$$L'\left[\frac{x_{Ao}}{1-x_{Ao}}\right] + V'\left[\frac{y_{A2}}{1-y_{A2}}\right] = L'\left[\frac{x_{A1}}{1-x_{A1}}\right] + V'\left[\frac{y_{A1}}{1-y_{A1}}\right]$$

Inlet flow

$$L' = L_o$$

$$V' = V_2\left(1 - y_{A2}\right)$$

Outlet flow

$$L' = L_1\left(1 - x_{A1}\right)$$

$$V' = V_1\left(1 - y_{A1}\right)$$

Countercurrent Multiple-Contact Stages Absorption

Total overall balance

$$L_o + V_{N+1} = L_N + V_1 = M$$

Overall component mole balance

$$L_o x_o + V_{N+1} y_{N+1} = L_N x_N + V_1 y_1 = M x_m$$

Making a total balance over the first n stages

$$L_o + V_{n+1} = L_n + V_1$$

Making a component balance over the first n stages

$$L_o x_o + V_{n+1} y_{n+1} = L_n x_n + V_1 y_1$$

Operating line

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

Kremser Equation

$$N = \frac{ln\left[\frac{y_{N+1} - m x_o}{y_1 - m x_o}\left(1 - \frac{1}{A}\right) + \frac{1}{A}\right]}{ln A}$$

$$A = \sqrt{A_N A_1}$$

$$A_N = \frac{L_N}{m_N V_{N+1}}$$

$$A_1 = \frac{L_o}{m_1 V_1}$$

Multistage Liquid Liquid Extraction

$$x_{AM} = \frac{L_o x_{Ao} + V_{N+1} y_{AN+1}}{L_o + V_{N+1}}$$

$$x_{CM} = \frac{L_o x_{Co} + V_{N+1} y_{CN+1}}{L_o + V_{N+1}}$$

APPENDIX B

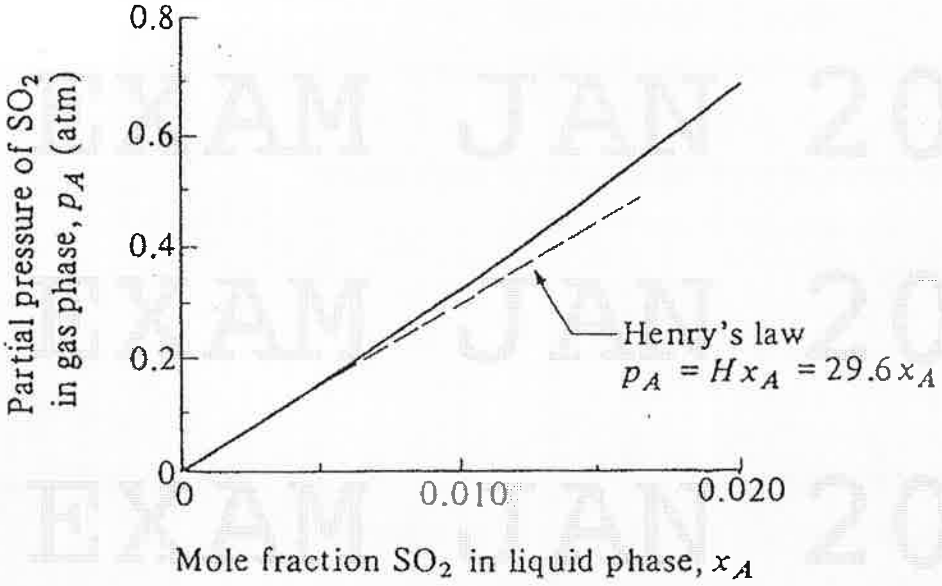

Figure B1 : Equilibrium plots of SO_2-water system