B.E. CHEMICAL ENGINEERING THIRD YEAR SECOND SEMESTER EXAM 2025
3rd Year, 2nd Semester

SEPARATION PROCESSES - II

Time: 3 Hours Full Marks: 100

Use separate answer scripts for each Part

Part I (50 Marks)

Answer Q1 ***and*** *any One (1) from the rest*

CO1: Understand & **Analyze** the equilibrium diagrams and **Formulate** mass balance and/or energy balance equations to solve staged, mass transfer-based separation processes.
CO2: Evaluate & **Formulate** various governing equations for different operational conditions of mass transfer-driven separation processes.
CO3: Apply theoretical background and **Choose** various mass transfer equipment as per applications.
CO4: Recognize the mechanism of the steps involved in the processes and **Describe** the design methodologies of the equipment.

Q.1 *[CO3+CO4]* **[4+8+5+8+5=30]**

a) With the help of a schematic diagram for a cross-flow sieve plate in a distillation column, analyze the effect of vapor flow conditions on the tray, under flooding, and weeping.

b)
   i) Why a kettle-type reboiler, located at the bottom of a column, is considered a partial reboiler equivalent to one equilibrium stage?
   ii) Mention three operating conditions where thermosyphon-type reboilers are favored.
   iii) With the help of a schematic diagram of a vertical thermosyphon-type reboiler, with reboiler liquid being withdrawn from the bottom-tray downcomer, give suitable reasons for considering it an equilibrium stage.

c) Explain [with the help of a rough sketch] the *Internal Reflux Ratio* in the light of *subcooled external reflux* for a plate-type distillation column with a *total condenser*. Specify the operating condition, under which the external reflux will be subcooled for both partial and total condensers.

d)
   i) The McCabe–Thiele construction becomes inviable when relative volatility or product purities are such that innumerable stages must be stepped off. Mention any one technique that may be applied in such a case.
   ii) Explain, with the help of two different diagrams, how a typical McCabe–Thiele method for a single feed and two products may be extended to (i)

[Turn over

multiple feed streams, and (ii) one side stream in the stripping section of a plate-type distillation column. You may use modified material balance [overall and species-specific] relations to justify the modified diagrams.

e)

i) Discuss McCabe's "ΔL" Law of crystal growth in the light of the Mass Transfer Theory of crystal growth.

ii) Represent the expression of Freundlich isotherm in terms of the fraction of surface covered by adsorbed molecules, adsorption-desorption kinetic constants, and maximum loading corresponding to complete surface coverage. How do we estimate the parameters of the isotherm using experimental data to fit into the linearized form of Freundlich isotherm.

Q.2 *[CO2+CO1]* **[5+15=20]**

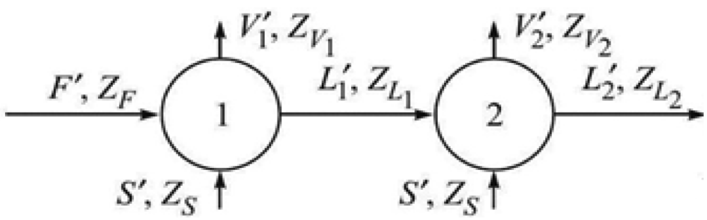
a) Carry out the overall material balance and species balance in case of the following two-stage crosscurrent leaching set-up. Standard nomenclature is followed.

Concentration of solute in clear liquid = Overflow;
Fraction of liquid in slurry = Underflow
Mass fraction of species in the overflow = *y*; Mass fraction of species in the slurry = *x*;

Insoluble carrier solid = A; Pure solvent = B; Soluble solute = C

Underflow (Leached solid): $X_C = \frac{x_C}{x_B+x_C}$, $Z_L = \frac{x_A}{x_B+x_C}$

Overflow (Leach solution): $Y_C = \frac{y_C}{y_B+y_C}$, $Z_V = \frac{y_A}{y_B+y_C}$



b) Oil is to be leached using the set-up, mentioned in part (a), from 90,000 kg/h of soybean flakes, containing 19 wt% oil, using 50,000 kg/h of hexane (as solvent) <u>*in each stage*</u>. Experimental data indicate that the oil content of the flakes will be reduced to 0.5 wt%.

Assumptions: (1) Entering Feed in the 1st stage is free of solvent [X_C =1]; (2) insoluble solids-free and soluble solute-free solvent in both stages, S [Y_A= 0; Y_C= 0]; (3) equilibrium between exiting liquid solutions in the underflow, and overflow [X_C = Y_C; (4) insoluble solids-free overflow [Y_A= 0] in both stages.

i) Estimate the compositions, and flow rates of the underflow and overflow streams using the Ponchon-Savarit diagram [solid-free basis], assuming each of the two stages, to be ideal.

ii) What % of oil in the feed is recovered?

Expected contents of the underflows is as follows:

Mass ratio of insoluble solid A to (solvent B + soluble solute C) in the underflow stream [X_A]	2.13	2.03	1.86	1.63	1.38	1.13
Mass ratio of soluble solute C to (solvent B + soluble solute C) in the underflow stream [X_C]	0.0	0.2	0.4	0.6	0.8	1.0

Q.3 *[CO2+CO1]* **[4+16=20]**

a) Use a set of tentative liquid–liquid equilibrium data for any Solute-Carrier-Solvent system at 25°C and 1 atm to draw a miscibility curve in a Right Triangular diagram. Assume that the carrier and the solvent are immiscible. Draw five (5) nos tie lines *arbitrarily* on the equilibrium miscibility curve plotted on the Right Triangular diagram. Generate the equilibrium distribution diagram [with x representing the mass fraction of the solute in the raffinate phase, and y representing the mass fraction of the solute in the extract phase] by t*ranslating the data points corresponding to the two ends of each of the tie lines onto a x-y diagram. Only by Graphical method.*

b) Isopropyl ether (E) is used to separate acetic acid (A) from water (W). The liquid–liquid equilibrium data for the system at 25°C and 1 atm are given below. A solution of 52 kg acetic acid (A) and 48 kg water (W) is contacted with 40 kg of pure ether (E) in a single batch. Calculate the extract and raffinate compositions and quantities. **Assume the solvent (E) and the carrier (W) are almost immiscible**.

LIQUID–LIQUID EQUILIBRIUM DATA FOR ACETIC ACID (A), WATER (W), and ISOPROPYL ETHER (E) AT 25°C AND 1 ATM					
Water-Rich Layer (Raffinate Phase)			Ether-Rich Layer (Extract Phase)		
Wt% A	Wt% W	Wt% E	Wt% A	Wt% W	Wt% E
1.41	97.1	1.49	0.37	0.73	98.9
2.89	95.5	1.61	0.79	0.81	98.4
6.42	91.7	1.88	1.93	0.97	97.1
13.30	84.4	2.3	4.82	1.88	93.3
25.50	71.1	3.4	11.4	3.9	84.7
36.70	58.9	4.4	21.6	6.9	71.5
45.30	45.1	9.6	31.1	10.8	58.1
46.40	37.1	16.5	36.2	15.1	48.7

You may use this data to plot the miscibility curve using a Right Triangular Diagram along with the equilibrium distribution diagram in the graph paper provided **or** directly use the miscibility plot given below and attach with the answer script.

Ref. No.: Ex/Che/PC/B/T/323/2025

BACHELOR OF CHEMICAL ENGINEERING EXAMINATION, 2025
(3^{rd} Year, 2^{nd} Semester)
SEPARATION PROCESSES II

Assume any missing data
Use separate answerscript

Answer ***any 2 questions** from Q.No. 1* *and* ***any 5 questions** from Q. No. 2*

PART: II

Marks: **50**

<table>
<tr><th>Q.No.</th><th>CO</th><th>Question</th><th>Marks</th></tr>
<tr><td>1.</td><td>4</td><td>(a) A distillation column for separation of methanol from water receives two feeds 100 kmol/hr saturated liquid having 30 mol% methanol and 100 mol/hr 20% vapourized feed having 60 mol% methanol. The top product should have 96 mol% methanol and the bottom product must not contain more than 3 mol% of it. If an external reflux ratio of 1.45 is used, calculate (i) the amounts of the top and bottom products; (ii) determine the number of ideal trays required for the separation and (iii) the number of real trays for this separation if the murphree efficiency is 60%.
Equilibrium data:
<table>
<tr><td>x</td><td>0</td><td>0.04</td><td>0.1</td><td>0.2</td><td>0.4</td><td>0.6</td><td>0.7</td><td>0.8</td><td>0.9</td><td>1</td></tr>
<tr><td>y</td><td>0</td><td>0.23</td><td>0.42</td><td>0.57</td><td>0.73</td><td>0.82</td><td>0.87</td><td>0.92</td><td>0.96</td><td>1</td></tr>
</table></td><td>20</td></tr>
<tr><td></td><td>3</td><td>(b) 1000 kg/hr of reaction product from an alum reactor containing 49.2% $Al_2(SO_4)_3$, 14.7% insoluble and rest water has to be washed with water in multistage countercurrent leaching unit to remove the insoluble. The strong solution is to contain 22% $Al_2(SO_4)_3$. Not more than 2% of the $Al_2(SO_4)_3$ should be lost in the washed mud. The underflow from each thickener should contain 4 Kg of liquid per Kg of solid. Equilibrium is ensured between overflow and underflow leaving each unit. Determine the amount of wash water required per hour and the number of stages provided.</td><td>20</td></tr>
<tr><td></td><td>4</td><td>(c) A feed of 1000 Kg aqueous solution of pyridine per hour (50 %</td><td>20</td></tr>
</table>

by mass) is to be extracted with pure benzene to reduce the solute content in the raffinate to 2%. Determine the number of ideal stages required if the solvent rate is 1.3 times the minimum.

Equilibrium data:

Water layer		Benzene layer	
Pyridine, mass%	Benzene, mass%	Pyridine, mass%	Benzene, mass%
1.17	0.0	3.28	94.54
7.39	0.0	18.35	79.49
13.46	0.15	26.99	71.31
22.78	0.25	31.42	66.46
32.15	0.44	34.32	66.46
42.47	2.38	36.85	59.35
49.82	4.28	39.27	55.72
56.05	19.56	48.39	40.05

2. | 1 & 2

(a) What are the differences between primary nucleation and secondary nucleation steps in crystallization? 2

(b) The coefficient of distribution of the solute C between two mutually immiscible liquids A (carrier) and B (solvent) is $K = \frac{y_c}{x_c} = 0.75$. What is the slope of the tie line if mass fraction of the solute in the solvent phase is $y_c = 0.1$? 2

(c) An aqueous solution containing a valuable solute is coloured by small amounts of an impurity. Before crystallization, the impurity is to be removed by adsorption on a decolorizing carbon which adsorbs only insignificant amounts of the principal solute. Equilibrium data at constant temperature is as follows: 2

Kg carbon/Kg solution	0	0.001	0.004	0.008	0.02	0.04
Equilibrium colour /Kg solution	9.6	8.1	6.3	4.3	1.7	0.7

Convert the equilibrium data to:

$Y^* = \frac{Kg\ colour}{Kg\ solution}$; $X = \frac{Kg\ colour}{Kg\ carbon}$

(d) Draw typical equilibrium curve for the two leaching cases (S vs x*, y plot) (i) Solute C is infinitely soluble in solvent B and carrier A is slightly dissolved in solvent B and (ii) solute C has limited solubility in solvent B and carrier A is absolutely in soluble in solvent B. 2

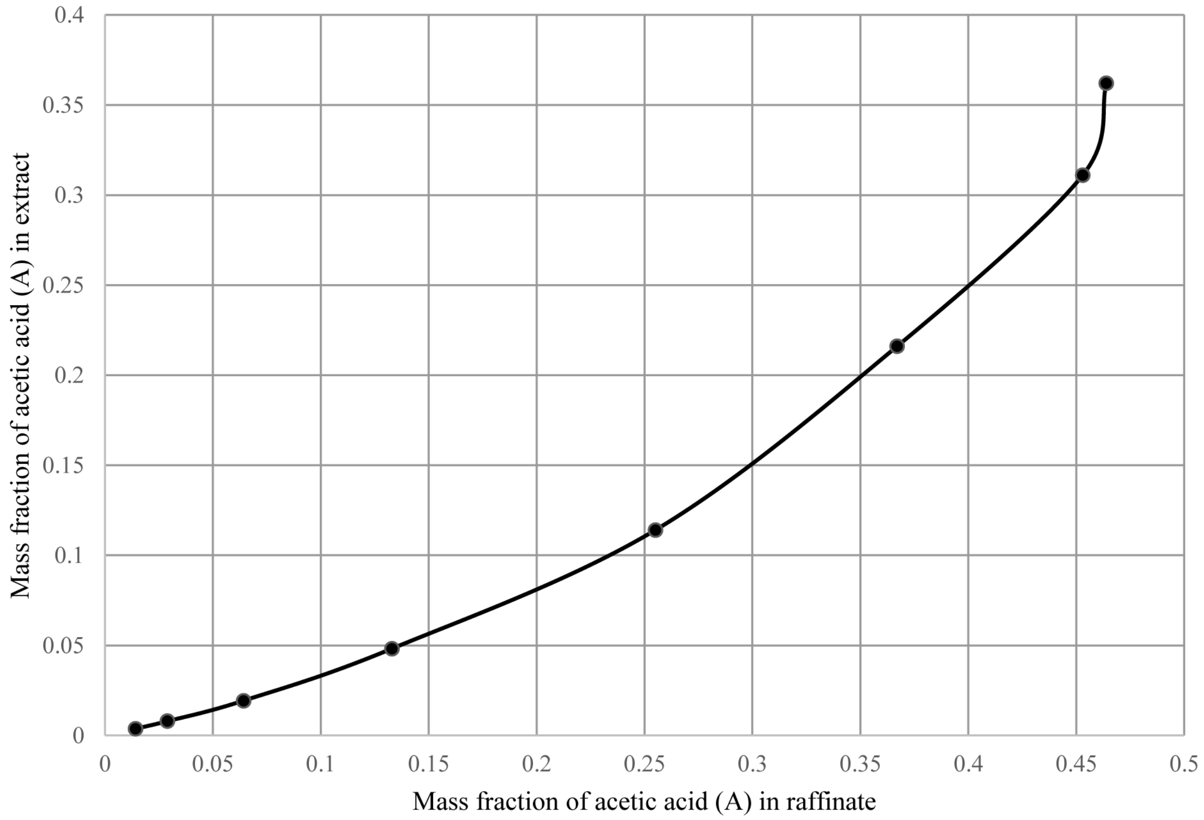
(e) Use of cold reflux decreases number of tray requirement in a distillation column. Explain. 2

(f) Critical radius of nucleus in crystallization depends on super-saturation. Explain. 2

(g) What is meant by breakthrough in fixed bed adsorption operation? 2

(h) What is "resolution" of a peak in a chromatogram? Will it be better if number of distribution plain of chromatography column increases? 2

Equilibrium Distribution diagram of acetic acid in mass fraction



Right Triangular Diagram representing LLE miscibility data for ACETIC ACID (A), WATER (W), and ISOPROPYL ETHER (E) system AT 25°C, 1 ATM