INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR
End -Autumn Semester 2023-24

Date of Examination: **20/11/2023** Session AN Duration 3 hrs Full Marks: 50

Subject No.: CH31010 **Subject: Mass Transfer 2** **Department: CHEMICAL ENGINEERING**

Specific charts, graph paper, log-book etc., required: **5 graph papers per candidate**

Special Instructions (if any):

- **Assume, any missing data or information if necessary with justification.**
- **Answer all parts of a question together. Also all questions in a part together.**
- **Graph Papers will be provided in the examination hall.**
- **No queries will be entertained during the examination.**
- **All sub-parts of each questions and all questions of each part must be answered together.**

Part A

1. Nicotine (C) in water (A) solution containing 0.9 % nicotine is to be extracted with kerosene (B) at 20 ºC. Water and Kerosene are completely insoluble. Determine the percentage extraction of nicotine if 100 kg of feed solution is extracted in three stages in cross flow configuration. All the stages use 60 Kg of kerosene. [6]

Equilibrium data:

x′ (kg nicotine / kg water)	0	0.001011	0.00246	0.00502	0.00751	0.00998	0.0204
y′ (kg nicotine / kg kerosene)*	0	0.000807	0.001961	0.00456	0.00686	0.00913	0.0187

2. A mixture of acetic acid (C) and water (A) solution, is to be extracted with IE (isopropyl ether, B) to reduce the acid concentration The **Equilibrium data given is as follows:**

	Water Layer			*Isopropyl Ether*		
	Acetic acid % (C)	*Water %* (A)	*IE %* (B)	*Acetic acid %*	*Water %*	*IE %*
i	0.69	98.1	1.2	0.18	0.5	99.3
ii	1.41	97.1	1.5	0.37	0.7	98.9
iii	2.89	95.5	1.6	0.79	0.8	98.4
iv	6.42	91.7	1.9	1.93	1.0	97.1
v	13.3	84.4	2.3	4.82	1.9	93.3
vi	25.5	71.1	3.4	11.4	3.9	84.7
vii	36.70	58.9	4.4	21.6	6.9	71.5
viii	44.3	45.1	10.6	31.1	10.8	58.1
ix	46.4	37.1	16.5	36.2	15.1	48.7

(a) Draw the corresponding N-X-Y plot on a Graph paper. The B free data based on which this plot is drawn must be tabulated and shown. [2+2]

(b) Formulate the mass balance equations based on B free calculations when a pure solvent is used and obtain the expressions of X_M and N_M in terms of physically measurable quantities when F, S and x_F are given. [3]

3. (a) Discuss why size reduction for ore is important for leaching? [2]

(b) Draw indicative diagram for a theoretical leaching stage and mark all the components, and flowrates. Use usual symbols. Show why leached solid composition cannot be located on the N-x-y plot [3]

(c) To circumvent the above problem, discuss how the concept of concept of practical equilibrium has emerged, particularly with emphasis on the assumptions that leads to vertical tie line. Please plot an indicative phase diagram with marking of the axes and points. [3]

(d) Discuss how the above plot will change under real conditions. Please mention what are these "Real" Conditions. [4]

Part B

4. Ion-exchange resin of Dowex 50 cross-linked with 8% divinylbenzene, is used for the exchange of silver ion in methanol with sodium ion in the resin. The wet capacity of the resin = 2.5 eq/L. Resin is initially saturated with sodium ion. The experimental data for the molar selectivity coefficient as a function of equivalent fraction of sodium ion in the resin is given below:

x_{Na^+}	0.1	0.3	0.5	0.7	0.9
K_{Ag^+,Na^+}	11.2	11.9	12.3	14.1	17.0

Find the equivalent fractions if 50 L of 0.05 M Ag^+ in methanol is treated with 1 L of wet resin. Consider the molecular weight of Ag as 108 and Na as 23 g/mol. [4]

5. An aqueous stream containing 0.324 mg/L of Benzene (B) and 0.630 mg/L of xylene (X), is to be treated with Activated carbon (AC), following Freundlich adsorption isotherms: $q = 32\, c^{0.428}$ for B and $q = 125\, c^{0.333}$ for X, where q is mg adsorbed/g AC and c is mg (in solution)/L solution.
The average particle diameter of AC is 1.5 mm.
Sherwood number is 30. Particle external surface area = 5 m^2/kg.
Diffusivity can be considered to be 1.04 x 10^{-5} cm^2/s (for both solutes).

Assumptions: Mass-transfer resistance in the pores is negligible compared to the external resistance.

For an effluent of 0.002 mg each of B and X, find:

(a) The minimum amount of adsorbent needed per liter of feed solution.
(b) For batch mode with twice the minimum amount of adsorbent, the contact time.

[4+6 = 10]

6. Three fixed-bed adsorbers, each containing 4536 kg of activated carbon of $\rho_b = 480.5$ kg/m^3, to be used to reduce the concentration of 1,2-dichloroethane (D) in 946 L/min of water from 4.6 mg/L to 0.001 mg/L. Each bed has an H/D = 2. Two beds in series for adsorption (a lead bed and a trailing bed). One bed being regenerated by replacing the spent carbon. When the lead bed is saturated, it is regenerated, the trailing bed becomes the lead bed, and the regenerated bed becomes the trailing bed. The adsorption equilibrium isotherm is $q = 8\,c^{0.57}$, with q in mg/g and c in mg/L.

Assume constant pattern front so that the width of the MTZ is a constant.

How often must the carbon in a bed be replaced? The maximum width of the MTZ to allow saturation of the lead bed? [4]

7. (i) Give ONE example of practical application process of membrane based separation, for each case, where the driving force is:
(a) Pressure (b) concentration (c) electric field [3]

(ii) Describe TWO consequences of concentration polarisation effect in membrane separation. [2]

(iii) In the case of membrane filtration, what is the controlling mechanism of permeate flux decline for the separation of (a) salt, and (b) proteins or cellulose? [2]