INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

End -Autumn Semester 2022-23

Date of Examination: 16/11/2022 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: 4 graph papers per candidate

Special Instructions (if any): Assume, any missing data 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.

Part 1

1. 100 kg/hr of Nicotine (C) in water (A) solution containing 1.0 % nicotine is to be extracted with kerosene (B) at 20 ºC. Water and Kerosene are completely insoluble. Graphically determine the number of stages required to reduce the nicotine content to 0.1%, when 1150 Kg/h of solvent is used in a counter current extractor. You must draw a next flowsheet, show the overall balance equations, and discuss the methodology by which the problem can be solved. (7 marks)

   [2 marks for flow-sheet and methodology, 2 marks for drawing the equilibrium data on the graph paper with proper marking and 3 marks for drawing the stages accurately]

   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 %	*Water %*	*IE %*	*Acetic acid %*	*Water %*	*IE %*
0.69	98.1	1.2	0.18	0.5	99.3
1.41	97.1	1.5	0.37	0.7	98.9
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
36.70	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

   (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. (3) [PTO]

   (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. (4)

   (c) Calculate the Extract and Raffinate amount and composition when the Feed rate is 8000 Kg with 30% acid and 16,000 Kg of pure solvent is used. (3)

3. (a) Why it is preferred to do leaching at an elevated temperature? What is decoction? (1+1)

(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 (2)

(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. (2)

(d) Discuss how the above plot will change if some fine insoluble remains suspended in the liquid phase but no solute remains un-leached within the insoluble. (2)

Part 2

Psychrometric chart will be necessary. It is attached with the question paper.

Q4. Nitrogen dioxide (NO2) is adsorbed on activated carbon, which follows the Langmuir isotherm.

$q = \frac{A\,p}{1+B\,p}$, where p is pressure in kPa, q in mmol/g, A = 13 and B = 4 in appropriate units.

(i) Calculate the maximum amount of NO2 adsorbed (in kg) per kg of the activated carbon.

(ii) Will the maximum amount of NO2 adsorbed change (increase or decrease) if there is another co-adsorbate (say SO2) ? you must justify your answer. [3+1 = 4]

Q5. (i) Why make-up water is needed in cooling tower operation? Which process constitutes the maximum proportion of the make-up water?

(ii) How you can de-humidify air (reduction in moisture or humidity content and not percent humidity) by cooling operation. Explain with the help of a process operating curve in enthalpy-temperature diagram. [2+3 = 5]

Answer EITHER Q6A OR Q6B [BOTH CARRY EQUAL MARKS]

Q6A. Estimate the wet-bulb temperature of toluene-air mixture at 80 C (dry bulb temperature), and humidity of 0.2 kg vapour/kg dry air at 1 std. atm. [6]

You can consider the constant thermophysical properties,

$D_{AB} = 9.2 \times 10^{-6}\, m^2/s; \rho_{air} = 1.06\, kg/m^3; \mu = 1.95 \times 10^{-5}\, Pa.s$

The Prandtl number for air can be considered to 0.7, and the latent heat of vaporization of toluene vapour is 404 kJ/kg.

The Antoine's equation for relating the vapour pressure of Benzene with temperature is:

$$\log_{10} P[\text{in bar}] = 4.1 - \frac{1344}{T\,[\text{in } K] - 54}$$

OR

Q6B. 0.08 m³/s of air at 305 K and 60% <u>humidity</u> is to be cooled to 275 K. Calculate, using a psychrometric chart, the amount of heat to be removed for each 10 (deg) K interval of the cooling process. What is the total mass of moisture will be deposited ? [6]

Q7: A cooling tower is to be designed to cool water from 45 C to 30 C, by counter current contact with air at dry-bulb temperature of 30 C and wet bulb temperature of 25 C. The water flow rate is 5500 kg/m2.h and the air flow rate is 3279 kg/m2.h. The mass transfer coefficient of water vapour is $k_Y, a = 2500\ kg/h.m3$, and the water side heat transfer is sufficiently large.

Determine the height of the cooling tower. Please ask for a graph sheet from the invigilator. [10]