	Indian Institute of Technology Kharagpur	20-04-2018 (AN)
	Department of Chemical Engineering	Time: 3 Hrs
	End Semester Examination, Spring 2017-18	Full Marks: 50
	Subject: Mass Transfer-II (CH31010)	No. students: 90

Instructions: Answer all questions. **Closed book, closed notes examination. Formulae sheet is provided with this question paper.** Assume any missing data suitably. State all assumptions clearly and explicitly. All symbols carry their usual meaning. Use the four step problem solving methodology. **For all questions, draw a schematic and show all known and unknown quantities clearly.**

1. (12 marks) We wish to extract a solute (A) from its aqueous solution using an organic solvent. The feed rate is 20 kg/h which contains 5% A. The aqueous and organic phases are essentially immiscible and the distribution coefficient of the solute is given by:
   K_d = kg A per kg water/kg A per kg organic phase = 0.12
   (a) (4 marks) Derive the mass balance equation in solute free co-ordinate to relate various flow rates and concentrations.
   (b) (4 marks) If 10 kg of pure organic solvent is used in a single stage extraction, obtain the fractional recovery of the solute.
   (c) (4 marks) If 10 kg of pure organic solvent is used in each stage of a two stage cross current extractor, calculate the improvement in fractional recovery.

2. (12 marks) A gas permeation system with cellulose acetate membrane will be used to purify a mixture of CO_2 and CH_4. The permeabilities are: P_{CO2} = 15E-10 and P_{CH4} = 0.48E-10 in [cc(STP) cm]/[cm^2 s cm Hg]. The effective membrane thickness $t_{ms} = 1\mu$m and the pressure of the retentate and permeate side are 12 atm and 0.2 atm respectively. The feed is 15 mol% CO_2.
   (a) (6 marks) Find out the permeate and retentate mol fraction of CO_2 if a single stage well mixed module is to be operated with 30% cut. Use graphical method of solution and explore the effect of the variable θ.
   (b) (6 marks) Obtain the membrane area required and amount of permeate and retentate for 1 kmol/h feed.

3. (12 marks) A cellulose acetate membrane is being used for RO of aqueous sucrose solution. For dilute sucrose solution, the solution density is given by $\rho = 0.997 + 0.4x$ and the osmotic pressure is given by $\pi = 60x$. Here x is wt fraction sucrose and π is in atm. This experiment was conducted in a stired tank. At 1000 rpm, with 3 wt% sucrose solution and p_r=75 atm, p_p=2 atm, we obtain J'_{solv}=4.625 g/(m^{2}s). The mass transfer coefficient k= 6.94E-5 m/s. The measurements show x_r=0.054 and x_p=3.6E-4.
   (a) (6 marks) Balance the convective and diffusive flux towards the membrane to show that the concentration polarization factor can be written as:
   $$M = \exp\left[\left(J'_{solv}/\rho_{solv}\right)/k\right]$$
   (b) (2 marks) Calculate the concentration polarization modulus M.
   (c) (4 marks) Calculate selectivity α', K'_{Solv}/t_{ms}, K'_A/t_{ms}

4. (12 marks) A 60 cm long experimental adsorption column containins activated carbon. The column is initially clean when we start to feed it with a dilute (0.01 kmol/m^3) solution of a solute. The superficial velocity of the feed is 0.2 m/s.

(a) (4 marks) Plot the breakthrough curve for this column using the non-linear theory.

(b) (4 marks) Derive the expression for the front velocity using solute movement theory.

(c) (4 marks) Compare the results from non-linear theory with the solute movement theory and discuss the results.

Data: Linear isotherm: $w = 0.09c$ where w is in kmol/kg carbon and c is in kmol/m^3. Density of fluid and solid are 1000 and 1820 kg/m^3 respectively. ϵ_e=0.434, ϵ_p=0.57, $K_c a$=10 s^{-1}.

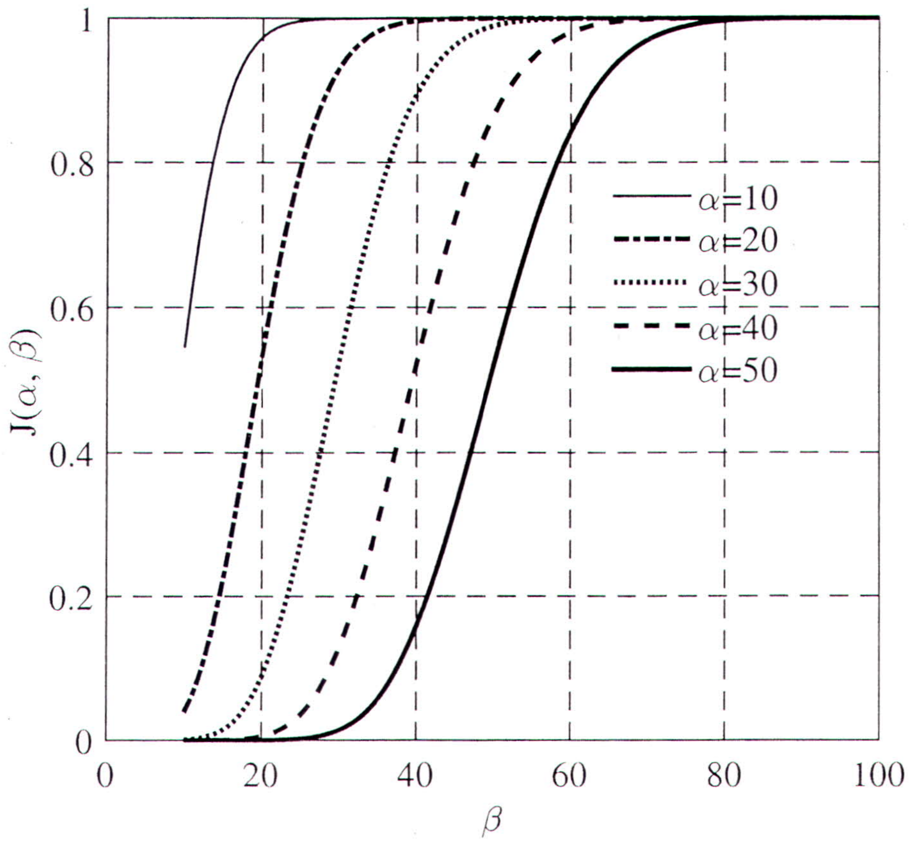
Solution for transient concentration in the bed:

$$X(t,z) = \frac{c(t,z)}{c_0} = J(N, NT)$$

$$N = \frac{K_c a z}{u_0}$$

$$T = \frac{u_0(t - \frac{z\epsilon}{u_0})}{\rho_p(1-\epsilon)z\kappa}$$

$$J(\alpha,\beta) = 1 - \exp(-\beta)\int_0^{\alpha} \exp(-x) I_0(2\sqrt{\beta x})dx$$



Description	Equation
Gas permeation flux	$J_i = \frac{P_i}{t_{ms}}(p_{tr}y_{ri} - p_{tp}y_{pi})$
Rate transfer equation (Gas permeation)	$y_r = \frac{y_p\left[1 + (\alpha - 1)(1 - y_p)(p_p/p_r)\right]}{\left[\alpha - (\alpha - 1)y_p\right]}$
Mass Balance (Gas permeation)	$y_p = -\frac{1-\theta}{\theta}y_r + \frac{y_{in}}{\theta}$
Reverse Osmosis (Solvent flux)	$J'_{Solv} = \frac{K'_{solv}}{t_{ms}}(\Delta P - \Delta\pi)$
Reverse Osmosis (Solute flux)	$J'_A = \frac{K'_A}{t_{ms}}(x_w - x_p)$
RO: Osmotic Pressure vs conc.	$\pi = a'x_w$
Concentration polarization (M)	$M = \frac{x_w}{x_r}$
Rate transfer equation (RO)	$x_r = \frac{x_p\left[x_p(\alpha'a' - 1) + \alpha'(p_r - p_p) + 1\right]}{M\left[1 + (\alpha'a' - 1)x_p\right]}$
Rejection coefficient	$R = 1 - \frac{x_p}{x_r} \quad R_0 = 1 - \frac{x_p}{x_w}$