UNIVERSITI SAINS MALAYSIA

First Semester Examination
2012/2013 Academic Session

January 2013

EKC 511 – Advanced Separation Processes

Duration : 3 hours

Please check that this examination paper consists of SEVEN pages of printed material before you begin the examination.

Instruction: Answer **ALL** (5) questions.

Write your index number in the space provided on the question paper. You are NOT ALLOWED to take the question paper out of the examination hall.

Answer ALL questions.

1. Nur Azreen conducted her research work to adsorb a waste stream of alcohol vapour in air using activated carbon(AC) particles in a packed bed having a diameter of 4 cm and length of 14 cm containing 100 g of AC. The inlet gas stream having a concentration c_0 of 500 ppm and a density of 0.00115 g/cm^3. The break point concentration is set at c/c_0 = 0.01. Based on the experimental data, she found the breakthrough concentration as shown in Table Q.1. :

Table Q.1.

Time, hr	c/c_0
0.0	0.000
3.0	0.000
3.5	0.002
4.0	0.030
4.5	0.155
5.0	0.396
5.5	0.658
6.0	0.903
6.2	0.933
6.5	0.975
6.8	0.993

She asked her friends Munirah, Siti Hawa and Sew Heang to further analyze the data to calculate:

[a] [i] the break point time
[ii] the fraction of total capacity used up to the break point
[iii] the length of the unused bed
[iv] the saturation loading of the AC

What are their answers to item [i] to [iv] above.

[b] They were not satisfy with the performance of the adsorption in part [a]. They redesign the column as such the breakpoint time for this new column is to be 8.5 hr. Calculate the total length of the column required , the column diameter and the fraction of total capacity used up to the break point. (Note: the flowrate is to remain constant at 754 cm^3/s).

[c] Now they decided to increase the flowrate to 2000 cm^3/s. If they kept other experimental conditions constant as in part [b] including the length of the column, what possibly the new diameter of the column.

[20 marks]

2. In their term paper project of EKC 511, Syazwan, Mun'im, Faizal and Muaz designed a Single Feed and Bleed Ultrafiltration (UF) plant for the following wastewater treatment processes.

[a] Treatment of 100 m^3 perday of a protein-containing waste stream.

[b] The waste contains 0.5% by weight of protein which has to be concentrated to 4% so as to allow recycle to the main process stream.

[c] A tubular membrane is used with 25 m^2 module.

[d] A PhD student in the Membrane Cluster Research Group has derived a relationship between the membrane flux (J) and the solute concentration as the following:

$$J = 0.02 \ln [\, 25/c_f \,]$$

where c_f is the concentration of protein in the feed (kg/m^3)

[e] The operation period is 20 hr per day and due to the membrane fouling, the flux never exceed 0.08 m/hr.

In their design, what is the maximum number of module required in the UF plant.

[20 marks]

3. Describe 4 different regeneration methods for ion exchange process.

[10 marks]

4. [a] [i] Magnetic separation has been widely implemented in various industrial scale processes. If you're about to design a magnetic separator for waste water treatment purposes, which separation strategy, either High Gradient Magnetic Separation (HGMS) or Low Gradient Magnetic Separation (LGMS), would you be using? Explain your decision

[3 marks]

[ii] The one dimensional B(x) magnetic field and dB(x) magnetic field gradient extended out from a cylindrical magnet can best be described as:

$$B(x) = \frac{Br}{2}\left[\frac{L+x}{\sqrt{(L+x)^2+R^2}} - \frac{x}{\sqrt{x^2+R^2}}\right]$$

$$\frac{dB(x)}{dx} = \frac{Br}{2}\left[\frac{1}{\sqrt{L^2+2Lx+x^2+R^2}} - \frac{(L+x)^2}{(L^2+2Lx+x^2+R^2)^{3/2}} - \frac{1}{\sqrt{x^2+R^2}} + \frac{x^2}{(x^2+R^2)^{3/2}}\right]$$

where R and L are the radius and length of the magnet, respectively. Br is the remnant magnetic field in the magnet and for NdFeB magnet Br is typically equal to 1 Tesla. By using equations provided, calculate both B(x) and dB(x) at 1 cm away from a cylindrical NdFeB magnet with dimension of 20 cm in length and 10 cm in diameter. Do this field gradient within the limit of LGMS?

[3 marks]

[iii] For a spherical iron oxide particles with 10 nm in diameter, the magnetophoretic velocity experienced by this particle in water as induced by B(x) and dB(x) of section [ii] can be estimated as:

$$u_{mag} = \frac{\Delta\chi V_{pt}}{6\pi\eta r\, \mu_0}\left[B(x) \cdot \frac{dB(x)}{dx}\right]$$

where r and V_{pt} is the radius and volume of the particle, respectively, $\Delta\chi$ is the different of magnetic susceptibility between iron oxide and water and is equal to 0.0072, η is the viscosity of water and is taken as 0.001 N·s/m^2 and $\mu_0 = 4\pi \times 10^{-7}$T·m/A.

[iii].[i]. calculate the u_{mag} of this nanoparticles

[iii].[ii]. discuss where the particle is heading to and how your answer relates to the direction of this movement.

[4 marks]

[iv] Calculate the Reynolds number (Re) and the Peclet (Pe) number of this particle. Based upon your answer, discuss the contribution of thermal energy and Stoke's drag in magnetic separator design.

The iron oxide density is 5240 kg/m^3 and the Boltzman constant is 1.38x10^{-23} J/K.

(Note: 1 Tesla = 1 kg/A·s^2, Re = $\rho u d/\eta$, Pe = ur/D and D = $kT/6\pi\eta r$)

[5 marks]

[b] [i] Explain what Damköhler numbers (Da) is and why it is important for reactive distillation process analysis.

[2 marks]

[ii] Reactive distillation systems are bounded by two limiting case, namely, non reactive case, and, equilibrium reactive case. Explain what these two cases mean, and, how Damköhler numbers (Da) define these two scenarios?

[3 marks]

[iii] One of the common examples of azeotropic distillation is its use in dehydrating ethanol and water mixtures. Normally benzene can be added as entrainer to facilitate the separation of water and ethanol. Explain why benzene can play such a role?

[2 marks]

[iv] Based on the residue curve map (Figure Q.4.[b]) for isopropanol/water/acetone at 1.0 atm shown below, is acetone a feasible entrainer for separating isopropanol and water? Discuss your answer.

[3 marks]

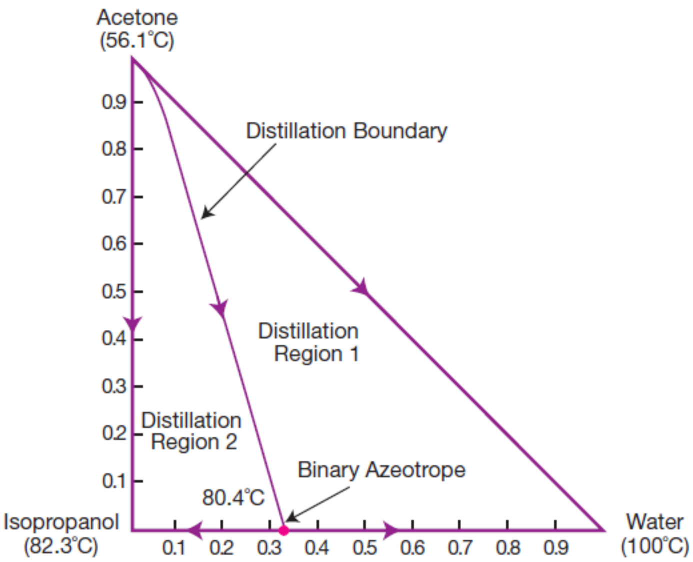

Figure Q.4.[b]. Residue curve map for isopropanol/water/aceton at 1.0 atm.

5. [a] Supercritical fluid extraction (SFE) has been used quite intensively for decaffeination of coffee bean. The extraction system consists of sieved ground coffee particles suspended in a volume (V) of supercritical fluid. It was assumed, firstly, that uptake of the fluid by the particles is essentially complete (or else has hardly begun) when significant extraction of solubles takes place. Secondly, the particles can be regarded as uniform spheres of radius (r) rand density (p). The total volume *(V')* of the coffee particles is then related to their surface area (A) and to their total mass *(m)* by the equation ($V' = m/\rho$). Figure Q.5. illustrate the profiles of caffeine concentration before (t=0), during extraction (t=t) and after the system has reached equilibrium (t=∞). All c value is expressed in volume concentration (kg/m^3).

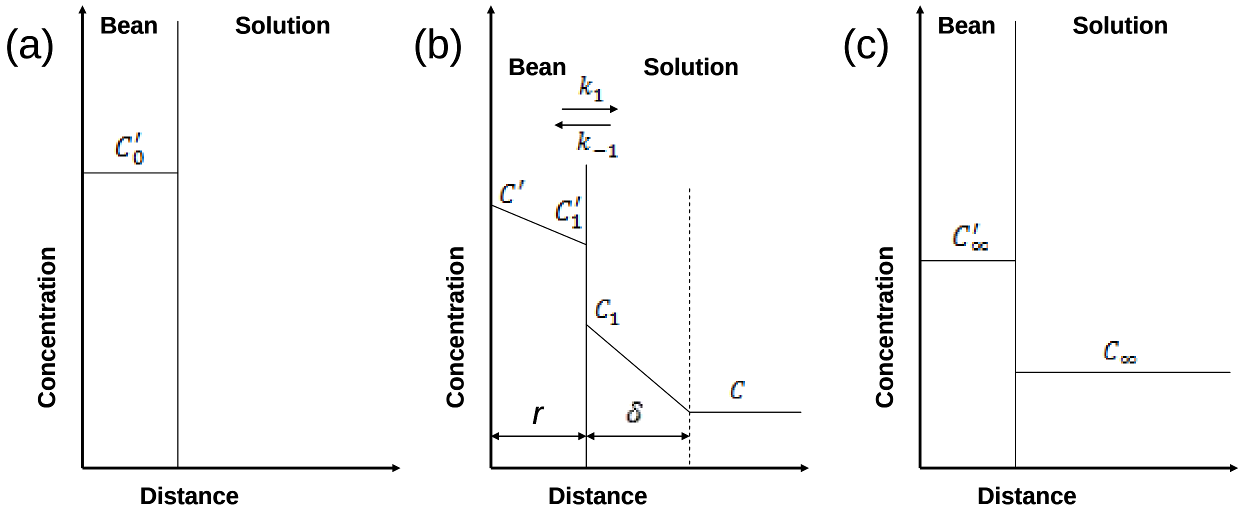

Figure Q.5. Schematic concentration profiles during coffee infusion at (a) t=0, (b) t=t, and (c) t=∞. (Spiro, M.; Selwood, R.M. *J. Sci. Food Agric.* **1984**, *35*, 915 – 924.).

[i] According to Figure Q.5.[b]. and Figure Q.5.[c]., define the particle coefficient **K** for caffeine between coffee particle and solution.

[2 marks]

[ii] At the beginning of the experiment, the total amount of caffeine in the system (T_{total}) can be expressed as $T_{total} = V'c_0'$. Write an equation to represent the total amount of caffeine in the system at equilibrium. (Hint: The mass should always be conserved).

[2 marks]

[iii] By taking the coffee particles under SFE is surrounded by a Nernst diffusion layer of effective thickness of δ, the kinetic equation of caffeine leaving the coffee bean in unit time at steady state can be written as:

$$J = AD_{bean}\left(c' - c_1'\right)/r \qquad (5.1)$$

$$= A(k_1 c_1' - k_{-1} c_1) \qquad (5.2)$$

$$= AD_{sol}(c_1 - c)/\delta \qquad (5.3)$$

In which D_{bean} and D_{sol} is the diffusivity of caffeine in bean and in supercritical fluid, respectively. By using equations above, derive an equation to relate c' to c and K. (Also suggest a way that can be practice in industry to vary the Nernst diffusion layer thickness δ).

[7 marks]

[iv] The variation of caffeine concentration with time can be represented by first-order kinetic equation of the kind:

$$ln\left(\frac{c_\infty}{c_\infty - c}\right) = k_{obs}\, t \qquad (5.4)$$

where

$$\frac{1}{k_{obs}}\left(1 + \frac{V'}{KV}\right) = \frac{1}{k'} \qquad (5.5)$$

$$\frac{1}{k'} = \frac{r^2}{12D_{bean}} + \frac{r}{3k_1} + \frac{r\delta}{3KD_{sol}} \qquad (5.6)$$

Equations 5.4 – 5.6 have separated the observed rate constant into contribution from each of three infusion steps (as shown in Figure Q.5.). Three special cases can therefore be distinguished as:

$$k' = 12D_{bean}\,/r^2 \qquad (5.7)$$
$$k' = 13k_1/r \qquad (5.8)$$
$$k' = 3KD_{sol}\,/r\delta \qquad (5.9)$$

Explain in your own words what physically equation 5.7, 5.8 and 5.9 implied? (Hint: related these equation to SFE stages in Figure Q.5.).

[6 marks]

[b] [i] One of the unique features of the supercritical fluid is its density increase drastically with small pressure change at critical point. Explain why this properties is important for extraction.

[2 marks]

[ii] In SFE, the solvation power of the fluid can be manipulated by changing pressure and/or temperature. What is the advantage of this feature?

[2 marks]

[iii] Peng-Robinson equation of states (PB EOS) is widely employed for calculation and prediction of supercritical fluids properties. Why PB EOS is selected for this purpose?

[2 marks]

[iv] Most of the supercritical fluid, like CO_2, exhibit rather interesting properties near the critical point, $0.9 < T_r < 1.2$ and $1.0 < P_r < 3.0$, where T_r and P_r are reduced temperature and pressure. Name two fluid properties that change drastically within this range.

[2 marks]

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