
UNIVERSITI SAINS MALAYSIA

First Semester Examination
2011/2012 Academic Session

January 2012

EKC 511 – Advanced Separation Processes

Duration : 3 hours

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

Instruction: Answer **ALL** (4) questions.

In the event of any discrepancies, the English version shall be used.

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. A membrane process is being designed to recover solute A from a dilute solution where $c_1 = 2.0 \times 10^{-2} \text{ kg mol A/m}^3$ by dialysis through a membrane to a solution where $c_2 = 0.3 \times 10^{-2} \text{ kg mol A/m}^3$.
- [a] With a neat sketch, derive the equation to calculate the steady-state flux N_A .
- [b] Calculate the individual resistances, total resistance and the total percent resistance of the two films.
- [c] Calculate the flux at steady state and the total area in m^2 for a transfer of 0.01 kg mol A/h.
- [d] Increasing the velocity of both liquid phases flowing by the surface of the membrane will increase the mass transfer coefficients, which are approximately proportional to $v^{0.6}$, where v is velocity. If the velocities are doubled, calculate the total percent resistance of the two films and the present increase in flux.

Given data:

Membrane thickness, $L = 1.59 \times 10^{-5} \text{ m}$

Distribution coefficient, $K' = 0.75$

Diffusivity of A in solid, $D_{AB} = 3.5 \times 10^{-11} \text{ m}^2/\text{s}$

Mass transfer coefficients, $K_{C1} = 3.5 \times 10^{-5} \text{ m/s}$ and $K_{C2} = 2.1 \times 10^{-5} \text{ m/s}$

[25 marks]

2. [a] For the ternary system, normal hexane-methanol-methyl acetate at 1 atm, all the components, binary and ternary azeotrope with its normal boiling point is provided in Table Q.2.[a]. By using the information provided in Table Q.2.[a], determine for each azeotrope and pure component whether it is a stable node, an unstable node, or a saddle by referring to the approximate residue-curve map Figure Q.2.[a] on a right triangular diagram. Explain what this residue-curve can be used for?

Table Q.2.[a].

Component or Azeotrope	Normal Boiling point, °C
n-Hexane	69.0
Methanol	64.7
Methyl acetate	57.0
n-Hexane/Methanol	50.6
n-Hexane/Methyl acetate	51.8
Methanol/Methyl acetate	53.5
n-Hexane/Methanol/Methyl acetate	47.4

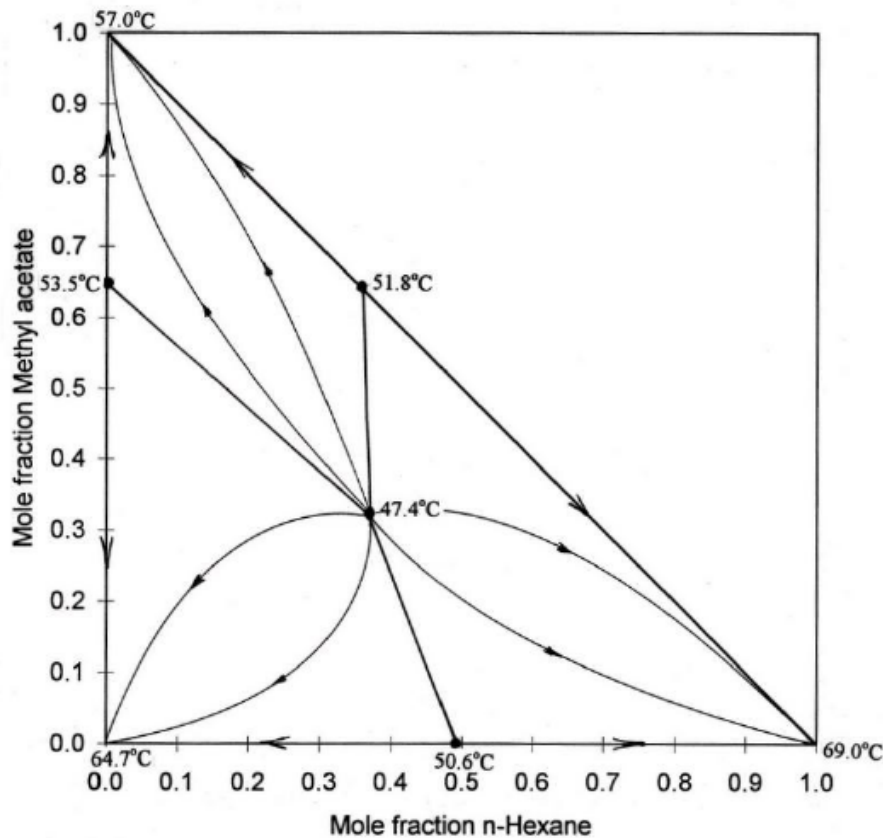


Figure Q.2.[a]. Computed residue curve map from van Dongen and Doherty, IEC Fundamental Vol. 24, 454 (1985)

[10 marks]
...4/-

- [b] JK is interested to magnetophoretically harvest *Chlorella sp.* (single-celled alga with spherical shape and having diameter around 5 μm) from its culture medium as shown in the Figure Q.2.[b]. (viscosity, $\mu \sim 8.94 \times 10^{-4} \text{Pa} \cdot \text{s}$). If the magnetophoretic force experienced by a single magnetite nanoparticle can be best described by $F_{mag} = 6 \times 10^6 V_p$, (where V_p is the volume of the magnetic nanoparticle employed)
- [i] if JK used both 5 nm and 20 nm magnetite (Fe_3O_4) spherical nanoparticles as magnetic tag for this process, can the microalga cells tagged with these two species of NPs be phase separated in real time by magnetophoresis? Assuming both species of nanoparticles achieving surface coverage of 10% and they are non-interacting, do the math to justify your answer! [9 marks]
- [ii] Based on Reynolds number and Peclet number analysis, provides your qualitative arguments on what is the competing forces that involved for magnetophoretic collection of *Chlorella sp.*? [6 marks]

Given:

$$\text{Surface area of a circle} = \pi r^2$$

$$\text{Surface area of sphere} = 4\pi r^2$$

$$\text{Volume of a sphere} = \left(\frac{4}{3}\right)\pi r^3$$

$$\text{Magnetophoretic velocity} = \frac{F_{mag}}{6\pi\mu r}$$

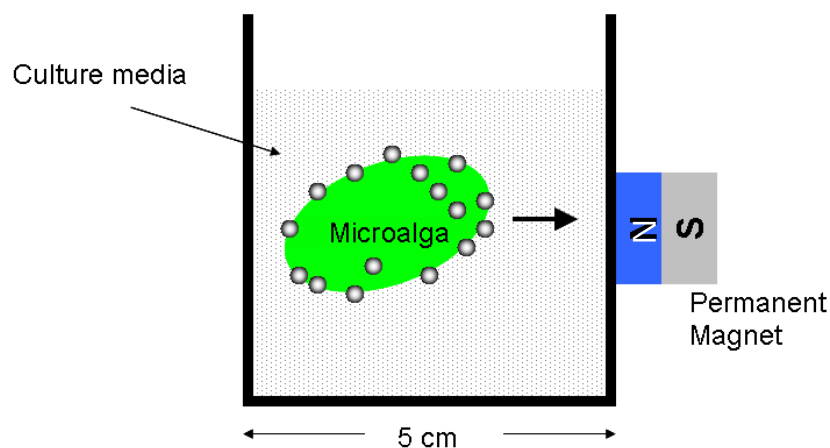


Figure Q.2.[b]. Magneophoretic collection of microalgal cell *Chlorella sp.*

3. [a] List and describe 5 different type of absorbents used commercially in industry. *[5 marks]*
- [b] In an ion exchanger process, explain:
- [i] Cation Exchanger
 - [ii] Anion Exchanger *[5 marks]*
- [c] Hydrogen ions adversely affect a downstream protein recovery process and so they are to be removed with an anion exchanger, initially of an anion exchanger is 3 milliequivalent per gram and to selectivity coefficient for the exchange of chloride with hydroxyl ion, $K = 10$. The solution concentration at the maximum ion exchange capacity is 0.2 m.
- [i] If the process is run as an equilibrium batch operation with solution volume of 250 L, what weight of ion exchanger is required to reduce hydroxyl from 0.15 m to 0.01 m.
 - [ii] The process is designed so that the ion exchanger is added in two batches of equal weight. An amount of ion exchanger is added and again allowed to equilibrate if the volume of solution and the specification are the same as in [i]. What is the total weight of the ion exchanger required. *[15 marks]*

4. [a] An important application of supercritical extraction is the removal of solutes from particles of porous natural materials. Such applications include the extraction of caffeine from coffee beans and the extraction of essential oil from black pepper (as discussed in our lectures). When CO₂ is used as the solvent, the rate of extraction is found to be independent of the flow rate of CO₂ past the particles, but dependent upon the particle size. The following discussions are steps involved to develop a suitable mathematical model for the rate of extraction that is consistent with aforementioned discussions. Read them carefully and discuss in your own words how these phenomena/assumptions aided the process of developing a suitable mathematical model.

[i] The particle of natural material is soaked in the solvent so that the solvent penetrates into the particle, usually causing it to swell. The material may be thought of as a porous or cellular matrix that fixes or traps the solute in the matrix. However, in the presence of the solvent, the solute is released and can diffuse from the interior of the material to the surface of the particle, and from there into the bulk of the solvent. What these 2 steps mean? [2 marks]

[ii] The interior diffusion process can be viewed as one in which the rate of diffusion in the non-extracted interior core of the particle is much slower than in the outer shell of the particle where most of the solute has been extracted. Explain why does this view is important to formulate the boundary conditions? [3 marks]

[iii] With the discussion in [ii], we can now assume that dr_c/dt , the rate of movement of the interface at the particle radius, r_c , is small with respect to the diffusion velocity of solute A, through the outer shell of the particle. This is referred to as the *pseudo-steady-state* assumption. Explain why this assumption is important? [3 marks]

[iv] The rate of diffusion of solute A through the outer shell is then can be given by Fick's second law with an effective diffusivity, D_e , for the solute through the solvent in the complex matrix of natural material:

$$\frac{D_e}{r^2} \frac{d}{dr} \left(r^2 \frac{dc_A}{dr} \right) = 0$$

where c_A is the concentration of solute in the outer shell of the particle and r is the radial distance from the center of the particle. The boundary conditions are:

$$\begin{array}{ll} c_A = c_{As} = c_{Ab} & \text{at } r = r_s \\ c_A = c_{A0} & \text{at } r = r_c \end{array}$$

where the subscripts are s for the particle surface, b for the bulk, 0 for initial condition, and c for the interface between the outer shell and core of the particle. How could these boundary conditions hold?

[4 marks]

...7/-

- [b] From 20 kg/hr of an isopropyl alcohol/water mixture with 40 wt% isopropyl alcohol, the isopropyl alcohol has to be extracted by solute free supercritical CO₂ (SC CO₂) with residual isopropyl alcohol concentration at 2 wt%. Phase equilibrium data for water/alcohol/SC CO₂ is provided in Table Q.4.[b].

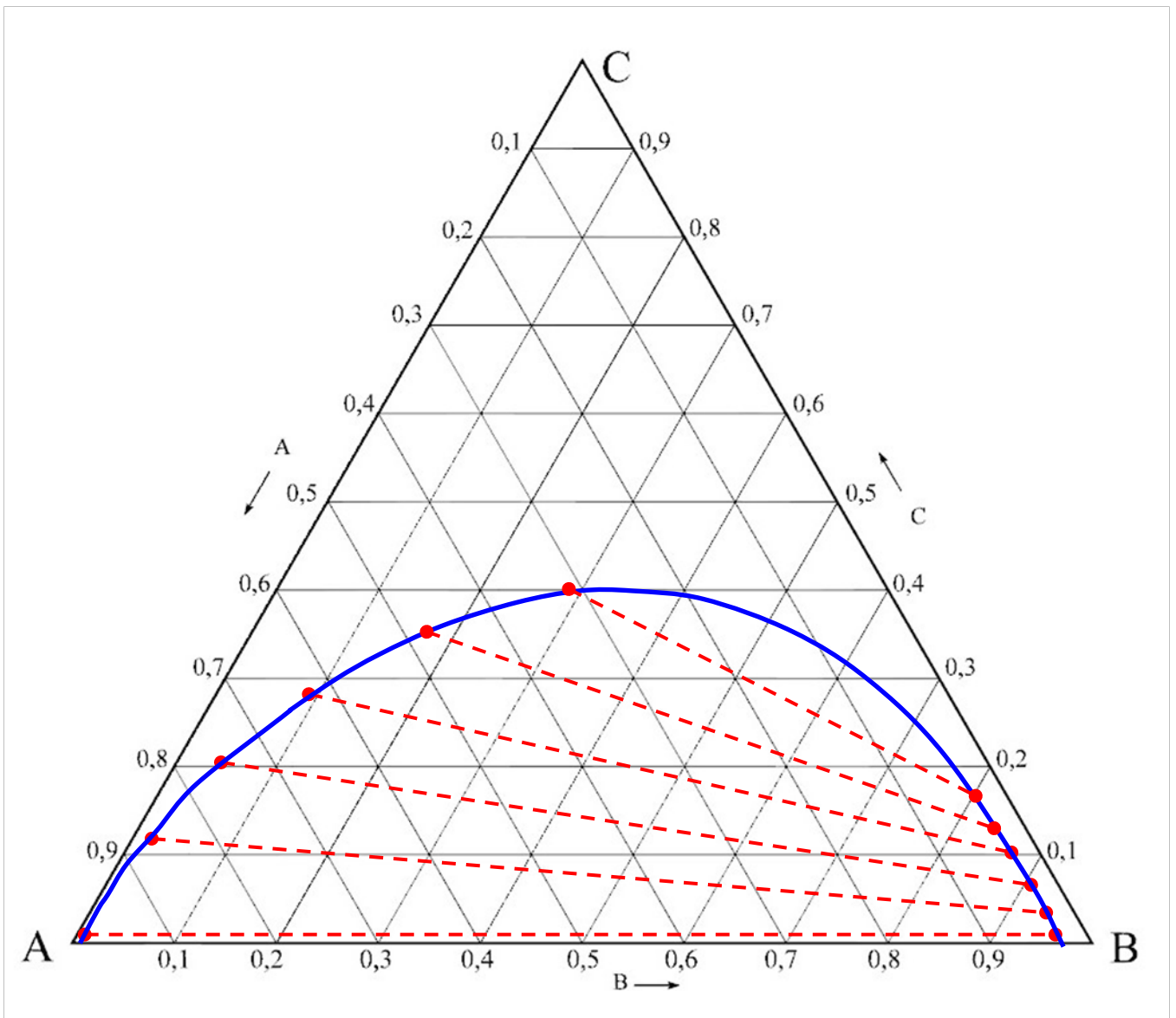
Table Q.4.[b]

Extract phase			Raffinate phase		
SC CO ₂	Isopropyl alcohol	water	SC CO ₂	Isopropyl alcohol	water
97	1	2	1	1	98
94	4	2	2	12	86
91	7	2	5	20	75
88	10	3	9	27	63
84	13	3	17	35	48
80	17	3	28	40	32

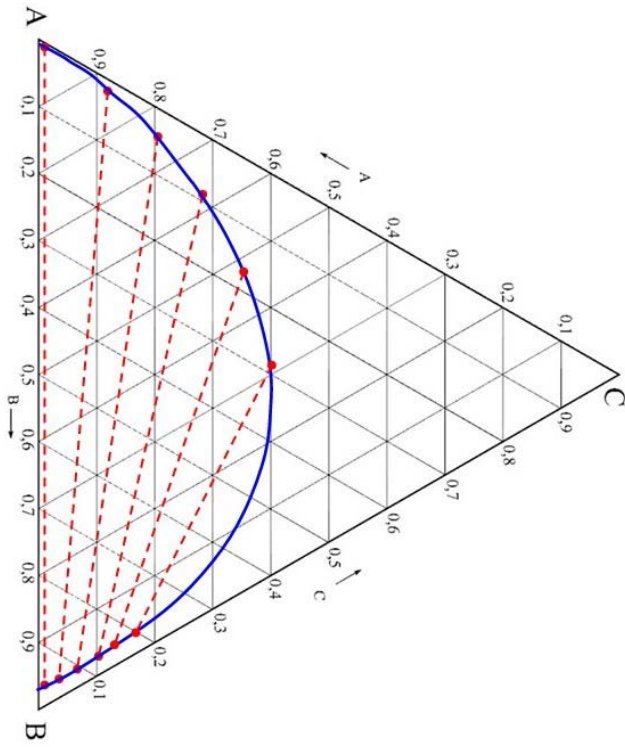
- [i] In the given three phase diagram, label point I Ext (94,4,2) and point II Raf (17,35,48) with cross 'X'. In addition, label 3 corners of the first phase diagram with (i) SC CO₂, (ii) Isopropyl alcohol, and, (iii) water. *[3 marks]*
- [ii] Determine the point M by using lever arm principle. Show your steps clearly and label points S (solvent), F (feed) and M (mixing point) in the first phase diagram provided in the Appendix. *[2 marks]*
- [iii] What is the composition of your E1? *[2 marks]*
- [iv] Use Nash-Hunter graphical method to determine the how many theoretical stages are involved for this process in the second phase diagram provided in the Appendix. *[6 marks]*

Answers part [i], [ii] and [iii] in the first, magnified three phase diagram. Whereas, answers part [iv] separately in the second three phase diagram and clearly label of your operating point P. The figure provided in Appendix.

Appendix



First Phase Diagram



Second Phase Diagram