PRINCE OF SONGKLA UNIVERSITY

FACULTY OF ENGINEERING

Midterm Examination : Semester I Academic Year : 2004

Date : 8 August 2004 Time : 09.00 — 12.00

Subject : 230 — 531 Membrane Separation Processes Room : R 200

Student Name: .... **ID no.** : ....

Number of questions : 4

Time : 3 hours

Total marks : 100

Calculators are allowed.

Books and notes are not allowed.

Necessary equations are provided on pages 11-13

Question	Full Marks	Marks Received
1	25	
2	25	
3	25	
4	25	
Total	100	

ทุจริตในการสอบโทษขั้นต่ำคือ ปรับตกในรายวิชาที่ทุจริต และพักการเรียน 1 ภาคการศึกษา

Student Name: .... ID No.: ....

1) a) Briefly explain transport mechanisms for permeation of gas through porous membranes. Discuss the relationships between pore sizes and permeability.

(5 marks)

b) Explain the effects of applied pressure on flux for ultrafiltration. Describe how ultrafiltration flux be predicted from a commercial hollow-fiber module.

(5 marks)

c) Please give membrane specifications for the following applications.

c.1) Clarification of pineapple juice by ultrafiltration.

c.2) Removal of cadmium from industrial wastewater by electrodialysis.

(5 marks)

d) Describe the transport mechanisms by the KSA model. Predict the effect of operating pressure on permeate rate and the rejection by using this model.

(5 marks)

e) What are the economic factors that should be considered in designing a reverse osmosis plant for a power plant using seawater?

(5 marks)

Student Name: .... ID No.: ....

2) A brackish water feed of 700 m^3/day and 2,500 ppm of NaCl is to be desalinized by electrodialysis. The process will be conducted in two stages, with three stacks in parallel in the first stage. There are150 cell pairs in each stack. The conversion will be 40% and are the same in each stage. The permeate from the first stage contains 400 ppm of NaCl. The expected current efficiency is 90%. The average voltage drop across each cell pair is 1 V. Each cell pair has an area of 0.4 m^2. Molecular weight for NaCl is 58.5 g/mole.

a) Calculate the current density in mA/cm^2, the current in A (or amp), and the power requirement in kW for the first stage.

b) Sketch the flow diagram for the system.

c) Calculate the total percent conversion.

(25 marks)

Student Name: .... ID No.: ....

3) The following experimental data were obtained from the pervaporation of liquid mixtures of ethanol (1) and water (2) at feed temperature of 60°C for a permeate pressure of 76 mmHg, using a commercial polyvinylalcohol membrane.

	Wt % ethanol		Total Permeation flux
	Feed	Permeate	Kg/m^2-h
Experiment 1	9.0	11.0	2.50
Experiment 2	68.8	13.0	0.58

Molecular weights for ethanol and water are 46.07 and 18.02 respectively.

At 60°C, vapour pressures for ethanol and water are 352 and 149 mmHg, respectively.

Liquid-phase activity coefficients at 60°C for the ethanol(1)-water(2) system are given by the van Laar equations as:

$$\ln \gamma_1 = 1.6276\left[\frac{0.9232x_2}{1.6276x_1 + 0.9232x_2}\right]^2$$

$$\ln \gamma_2 = 0.9232\left[\frac{1.6276x_1}{1.6276x_1 + 0.9232x_2}\right]^2$$

a) For experiment 1, calculate values of permeance for water and ethanol in kmol/(h-m^2-mmHg) and separation factors for water $\alpha_{2/1}$.

b) If experiment 2 showed the permeance $\bar{P}_{M_i}$ of 7.93×10^{-6} and 6.98×10^{-4} kmol/(h-m^2-mmHg) for ethanol and water respectively, compare experiment 1 and 2 and comment on the use of this membrane for pervaporation of ethanol-water mixture.

c) If experiment 2 was performed at the feed rate of 100 kg/h, calculate the required membrane area in m^2 in order to obtain 93 wt% ethanol product.

(25 marks)

Student Name: .... **ID No.:** ....

4) A reverse osmosis plant has performance data as follows. A feed solution at 25°C contains 3500 mg NaCl/L (ρ = 999.5 kg/m^3). Feed rate is at 300 m^3/day and recovery is 80%. The permeability constant for water A_B = 3.50 x 10^{-4} kg solvent/(s.m^2.atm). The solute rejection is 98%. The applied pressure is 30 atm.

a) Calculate the permeate concentration in mg NaCl/L.

b) Calculate the permeate flux in kg/(s.m^2)

c) Calculate the required membrane area in m^2.

d) Calculate the permeability constant for solute NaCl, A_A in m/s.

(25 marks)

Some Membrane Equations:

Equations for Pervaporation:

The permeant activity for component i is expressed as

$$a_i^{(1)} = f_i^{(1)}/f_i^{(0)} = p_i^{(1)}/P_i^{s(1)}$$

where a_i = activity of permeant specy i

f_i = fugacity of component i

p_i = partial pressure of component i

P_i^s = vapour pressure of the feed at the feed temperature

superscript (1) = at the upstream membrane surface

superscript (2) = at the downstream membrane surface

superscript (0) = at standard conditions

For upstream nonideal liquid

$$a_i^{(1)} = \gamma_i^{(1)} x_i^{(1)}$$

where $\gamma_i^{(1)}$ = activity coefficient of component i

x_i = mole fraction of liquid i in the upstream membrane surface

Combining the above two equations

$$p_i^{(1)} = \gamma_i^{(1)} x_i^{(1)} P_i^{s(1)}$$

The partial pressure on the downstream vapour side is

$$p_i^{(2)} = y_i^{(2)} P_p^{(2)}$$

where the subscript p denotes for permeate.

Therefore, the driving force is partial pressure difference $= p_i^{(1)} - p_i^{(2)}$

$$= \gamma_i^{(1)} x_i^{(1)} P_i^{s(1)} - y_i^{(2)} P_p^{(2)}$$

After dropping unnecessary superscripts, the permeant flux is

$$N_i = \frac{P_{M_i}}{l_M}(\gamma_i x_i P_i^s - y_i P_P)$$

where P_M = permeability

l_M = membrane thickness

or $$N_i = \bar{P}_{M_i}(\gamma_i x_i P_i^s - y_i P_P)$$

where $\bar{P}_{M_i}$ = permeance of component i

P_i^S = vapour pressure of the feed for component i at the feed temperature

P_p = the total permeant pressure

separation factor, $\alpha_{AB} = \dfrac{(y_A / y_B)_{permeate}}{(x_A / x_B)_{feed}}$

where y = mole fraction or weight percent in permeate

x = mole fraction or weight percent in feed

Equations for Electrodialysis:

The membrane area can be estimated from Faraday's law:

$$A_M = \frac{zFQ\Delta c}{i\xi}$$

where

A_M = total area of all cell pairs, m^2

Z = electrochemical valence of the ions being transported through the membranes

F = Faraday's constant (96,520 amp-s/equivalent)

Q = volumetric flow rate of the diluate (potable water), m^3/s

Δc = difference between feed and diluate ion concentration in equivalents/m^3

i = current density, amps/m^2 of a cell pair usually about 80% of i_{max}

ξ = current efficiency < 1.00

The power consumption is given by:

$$P = IE$$

Where P = power, I = electric flow current through the stack, E = voltage through the stack

The electrical current is given by:

$$I = \frac{zFQ\Delta c}{n\xi}$$

where n = the number of cell pairs

Equations for Reverse Osmosis:

$$\pi = \frac{N_2}{\text{Volume of solvent}} RT = n_2\, RT = i\frac{C}{M} RT$$

where

C = concentration of solute in g/L of solution

M = molecular weight of solute

i = number of ions for ionized solutes (e.g., I = 1 sugars, I = 2 for NaCl)

T = temperature of the solution in the absolute scale (e.g., K or ^{o}R)

R = ideal gas constant (e.g., 0.08206 atm-L/gmole K, or 8315 N-m/kmole. K, or 1545 ft-lb$_f$/lbmole. ^{o}R)

$$f = \frac{C_{A1} - C_{A3}}{C_{A1}}$$

$$f' = \frac{C_{A2} - C_{A3}}{C_{A2}}$$

solute flux, $N_A = A_A\ (C_{A2} - C_{A3})$

solvent flux, $N_B = J_V C = A_B\ (\Delta P - \Delta\pi)$

for mass fluxes,fluxes are in kg/(m^2.s), concentrations are in kg/m^3

KSA model : $N_A = \frac{D_{AM}K}{\tau}(C_{A2} - C_{A3})$

KSA model : $\frac{1}{f'} = 1 + \frac{D_{AM}K}{\tau}\frac{1}{J_v}$

Partition coefficient, $K = \frac{\text{kg solute}/\text{m}^3\ \text{membrane}}{\text{kg solute}/\text{m}^3\ \text{solution}}$