ID No. ____________________

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ChE 150 B

December 11, 2002

Final Examination

(Open Books, Open Notes)

Answer all questions in the space provided after each question.

Problem 1	**_______ / 30**
Problem 2	**_______ / 20**
Problem 3	**_______ / 20**
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Problem 6	**_______ / 25**
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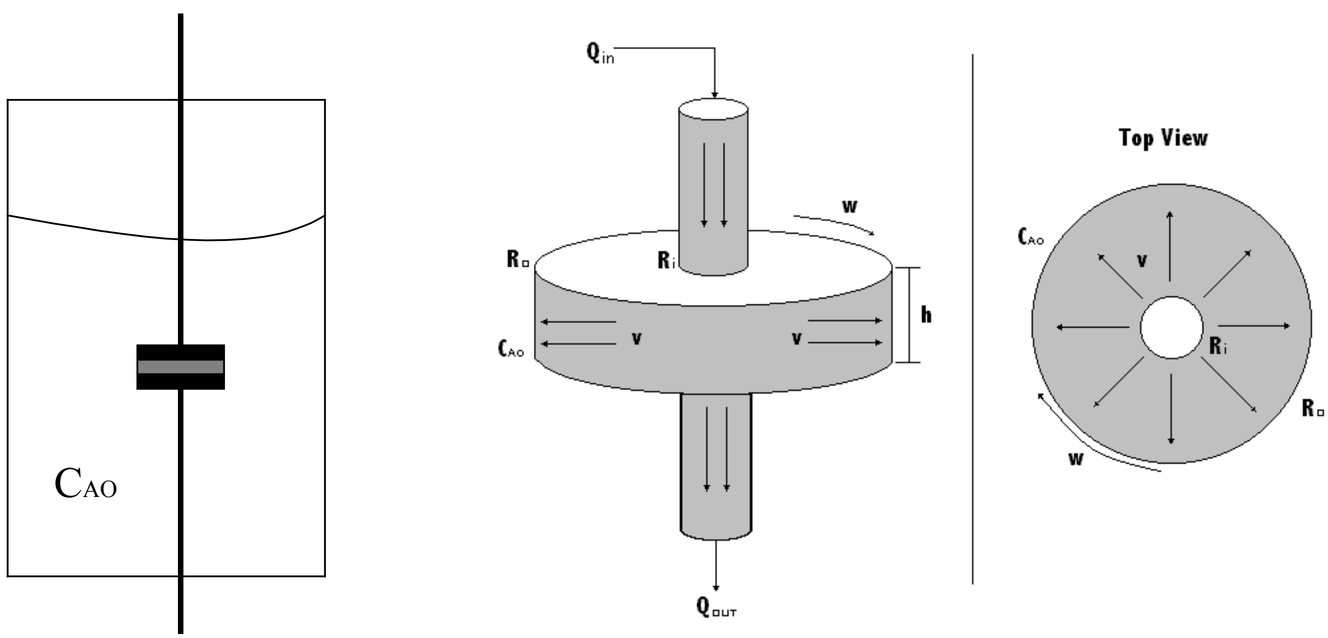
Problem 8	**_______ / 20**
Problem 9	**_______ / 25**
Total	**_______ / 200**

1. (30 Pts.)

A rotating dye (see schematic below) is used to supply fresh water to a microorganism in a biochemical reactor. Water flows down the inner cylinder and out through a porous disk into the reactor as shown below. A byproduct of the organisms' lifecycle (species A) is found in the reactor at concentration $\mathbf{c_{A0}}$. It is desired to prevent this material from entering into the inner cylinder, as it will foul the equipment, and the water that does not flow into the reactor is to be used elsewhere in the process.

The rotation rate is **w**, the disk height is **h**, the inner cylinder radius is $\mathbf{R_i}$, and the outer radius is $\mathbf{R_o}$ as shown below. The flowrate into and out of the disk is given by $\mathbf{Q_{in}}$ and $\mathbf{Q_{OUT}}$. The diffusion coefficient of species A in the in the disk is given by $\mathbf{D_{AD}}$. You may assume that the apparatus operates at steady state.



a. (7 Pts.) Using a mass balance on the dye, find the radial dependence of v_r, $v_r = f(r)$. You may assume that v_r is the only non-zero velocity component and it is not a function of any variable except r.

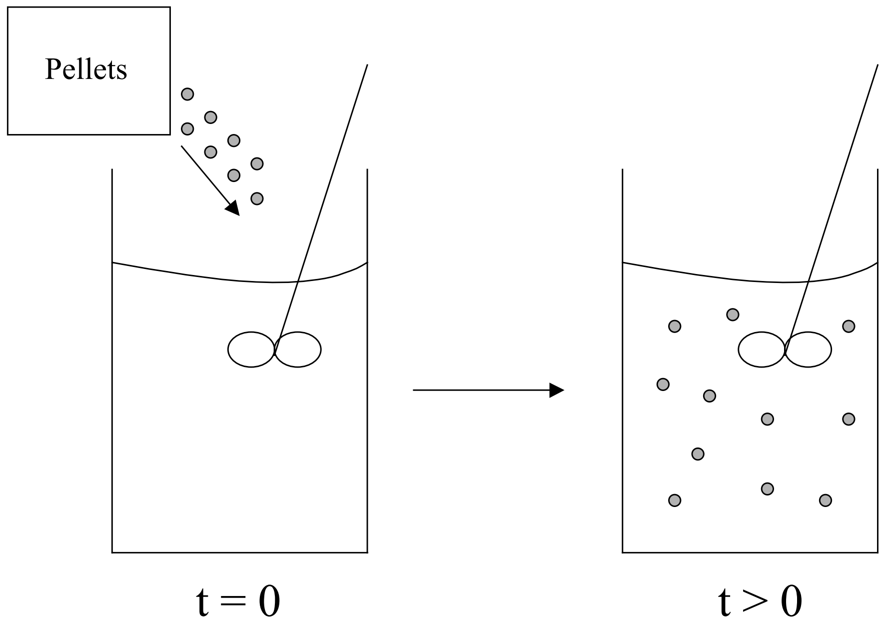
b. (10 Pts.) Starting with the equation for conservation of chemical species derive an ordinary differential equation in c_A that describes the concentration of species A in the disc between Ri and Ro. (Do not solve.)

c. (5 Pts.) State appropriate boundary conditions for the situation described above. (Again, do not solve.)

d. (5 Pts.) Which dimensionless group controls the process above? Suggest a form for it using the problem variables given.

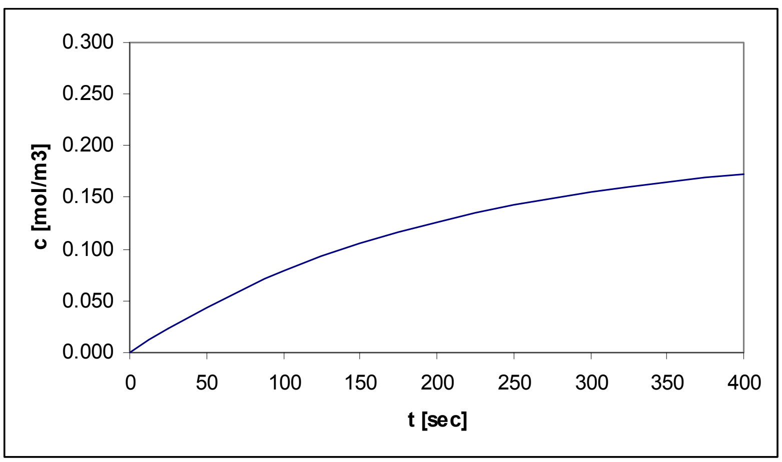
e. (3 Pts.) Which of the variables in the group above should be varied in an experiment to determine the system's performance? Give a short explanation.

2. (20 Pts.)
21,000 kg of uniform spherical pellets of a certain material are dropped in a 1000 m^3 of fluid in a tank and allowed to dissolve. The solubility of the material in the fluid is 0.2 mol/m^3. See the diagram below.



Some data for the system are given below. You may assume that the particles do not change significantly in size and that the fluid is well mixed.

$R_{pellet} = 0.06$ m
$\rho_{pellet} = 1200$ kg / m^3



t	c	dc/dt
[sec]	[mol/m3]	[mol/ (m3 sec)]
0	0.000	1.00E-03
25	0.024	8.82E-04
50	0.044	7.79E-04
75	0.063	6.87E-04
100	0.079	6.07E-04
125	0.093	5.35E-04
150	0.106	4.72E-04
175	0.117	4.17E-04
200	0.126	3.68E-04
225	0.135	3.25E-04
250	0.143	2.87E-04
275	0.149	2.53E-04
300	0.155	2.23E-04
325	0.161	1.97E-04
350	0.165	1.74E-04
375	0.169	1.53E-04
400	0.173	1.35E-04

a. (3 Pts.) What is the asymptotic limit of the concentration in the system? (i.e. What is lim c(t) as t tends to infinity?) Hint: You do not need to find c(t) to answer this.

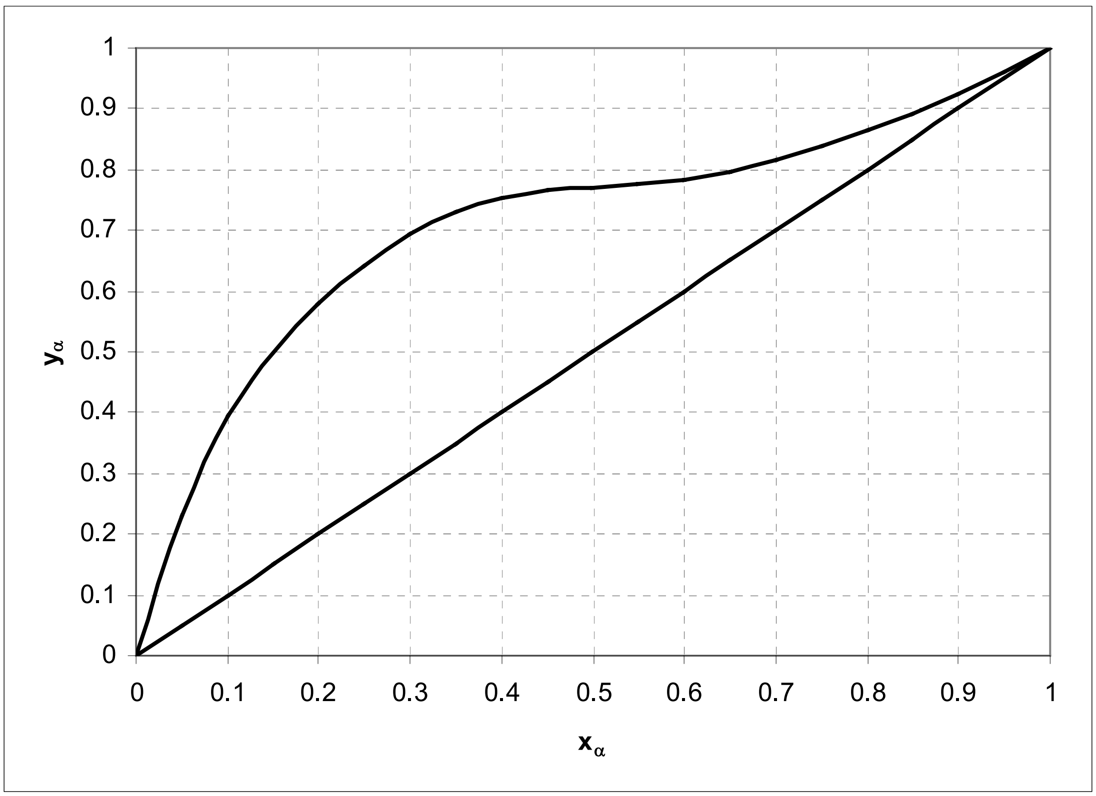
b. (12 Pts.) Determine the mass transfer coefficient (k_c) for this process.

c. (5 Pts.) Suggest two changes that could be made to the system to speed the dissolution of the pellets. Give a short explanation for your suggestions.

3. (20 Pts.)

A stream of 50 mol% α and 50 mol% β is sent to a distillation column with a flow rate of 300 moles per hour. The distillate flow rate is 160 moles per hour and is 85 mol% α. The feed quality is $q = -0.50$. The column is operating with a boilup ratio ($V_B = \dot{V} / \overline{B}$) of 2.

Equilibrium Data:



a. (4 Pts.) For the given conditions circle which is correct:

I. $L > \overline{L}$ + liquid in feed

II. $L = \overline{L}$ + liquid in feed

III. $L < \overline{L}$ + liquid in feed

Explain. What type of feed is this characteristic of?

b. (6 Pts.) For the given conditions, what is the reflux ratio (R)?

c. (4 Pts.) For the given conditions, what is R_{min}? Explain.

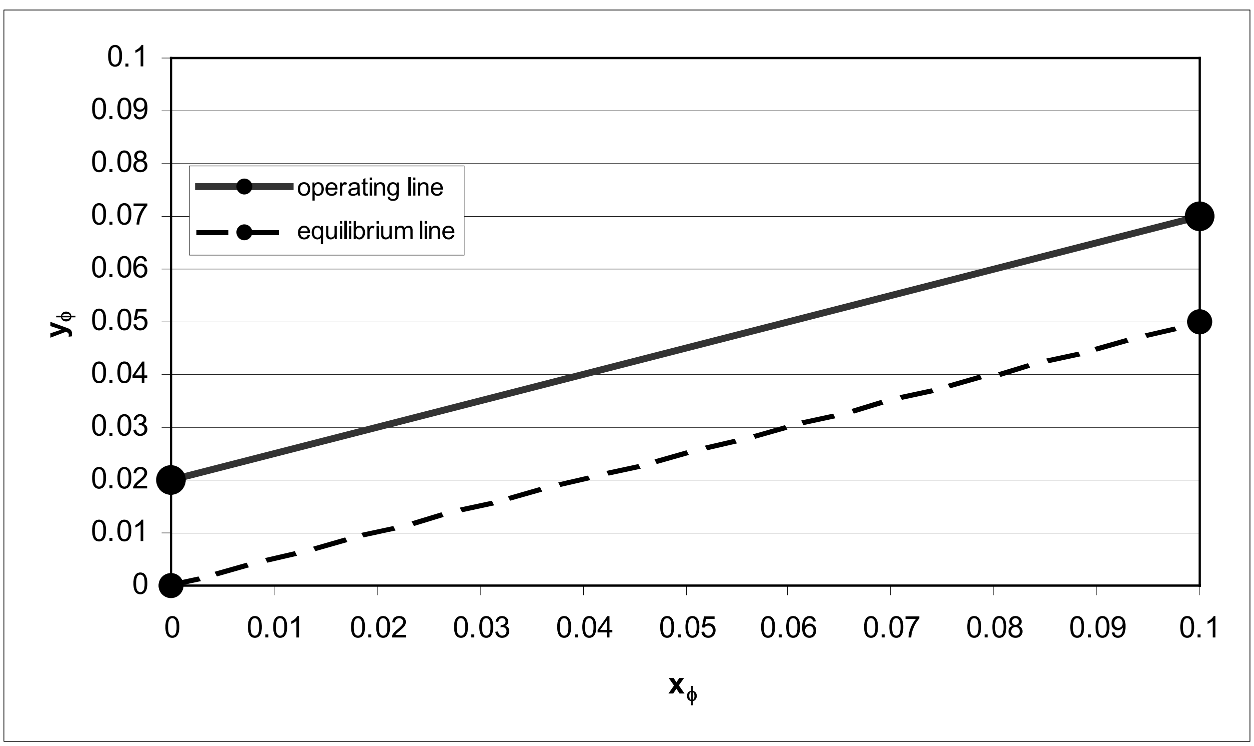
d. (6 Pts.) The feed quality is now changed to a saturated liquid, but $z_{\alpha,F}$, $x_{\alpha,B}$, and $x_{\alpha,D}$ remain unchanged, what is R_{min}? Explain.

4. (24 Pts.)

Gas at a flow rate of 15.0 moles/hour, which is 92 mol% ψ and 8 mol% ϕ, is fed counter-currently to a packed column that has a diameter of 0.50 meters. A liquid, initially 1 mol% ϕ, is fed to the column as an absorbent. It is found at the exit that the gas effluent is now 2 mol% ϕ and the liquid absorbent is now 3 mol% ϕ. Other parameters are known as follows:

$K_\phi = 0.50$
$k_x a = 150.0$ mol/(m^3*hr)
$k_y a = 75.0$ mol/(m^3*hr)

Equilibrium and operating data:



Assuming that gas and liquid flow rates throughout the column are constant, determine:

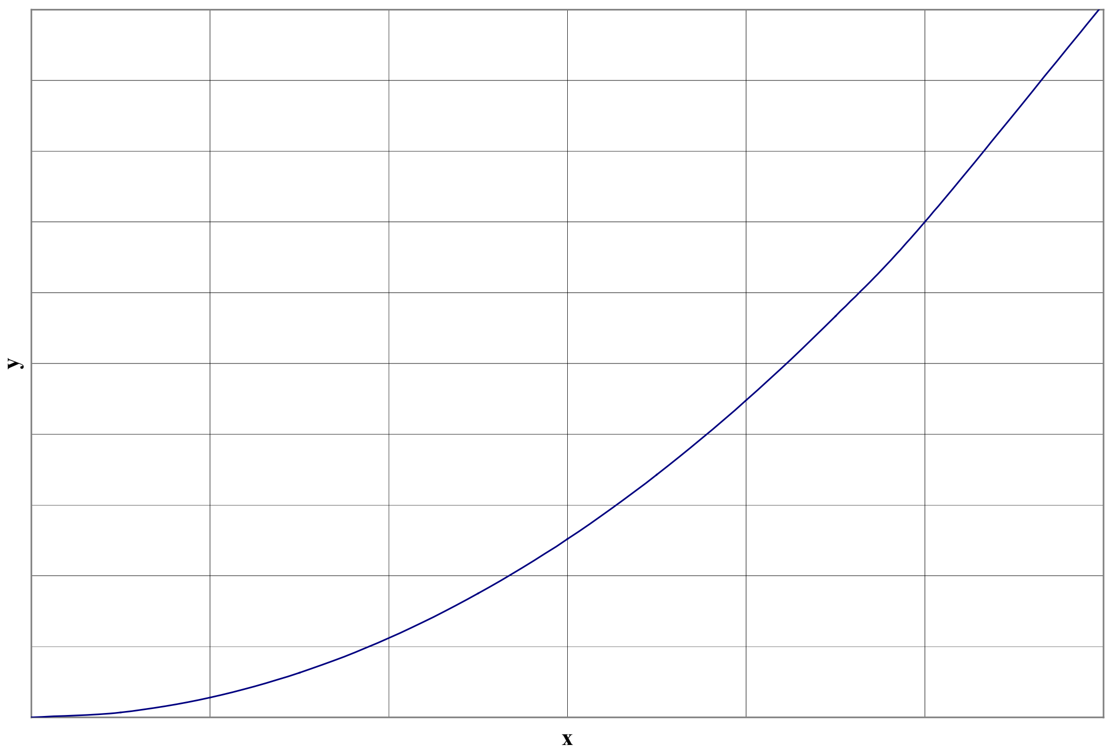
a. (6 Pts.) The height of a transfer unit.

b. (12 Pts.) The number of transfer units and the column height.

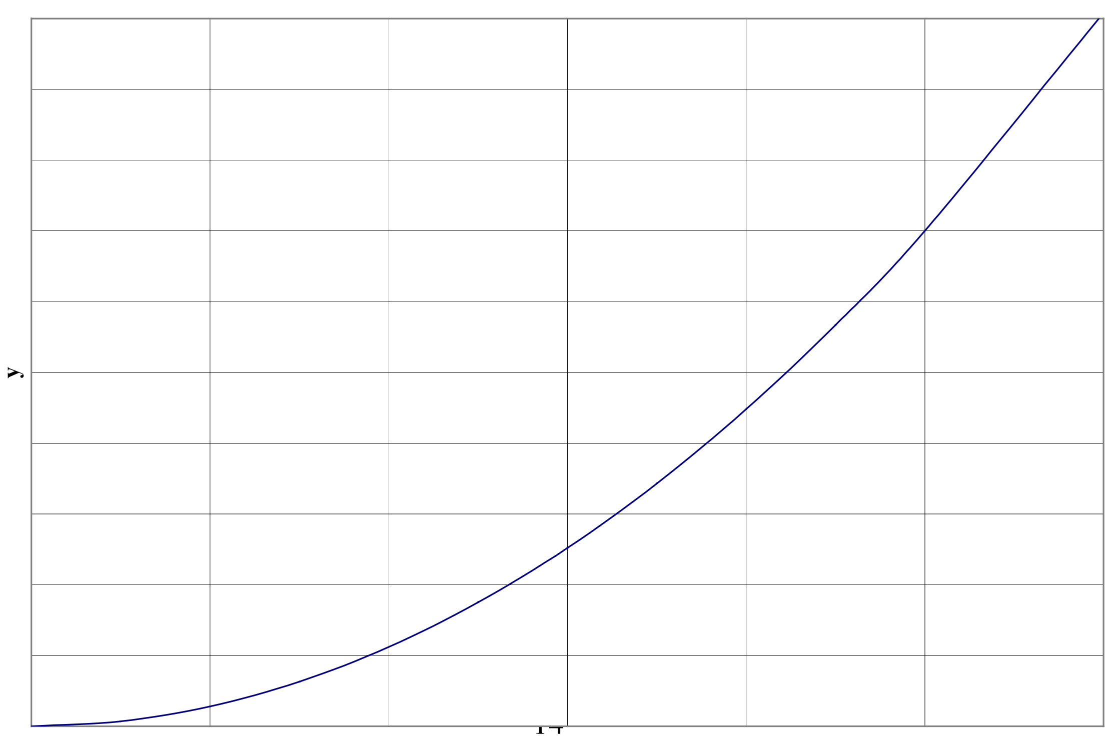
c. (6 Pts.) If the slope of the operating line is increased by a factor of 2, will the number of transfer units increase or decrease? How does this compare with the theoretical number of stages for the system? Explain.

5. (6 Pts.) You are presented with the equilibrium data shown below.

a. (3 Pts.) Draw an operating line for cocurrent stripping.

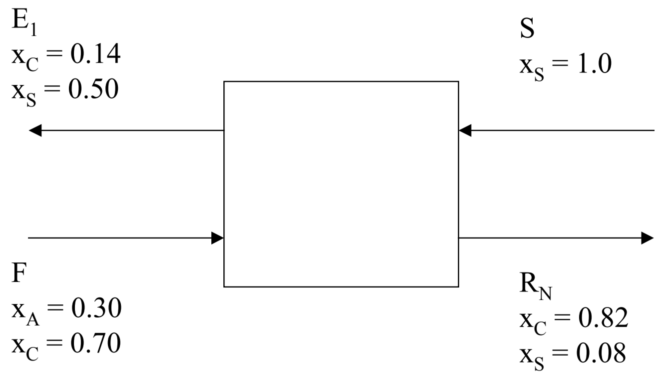


b. (3 Pts.) Draw an operating line for counter-current absorption.

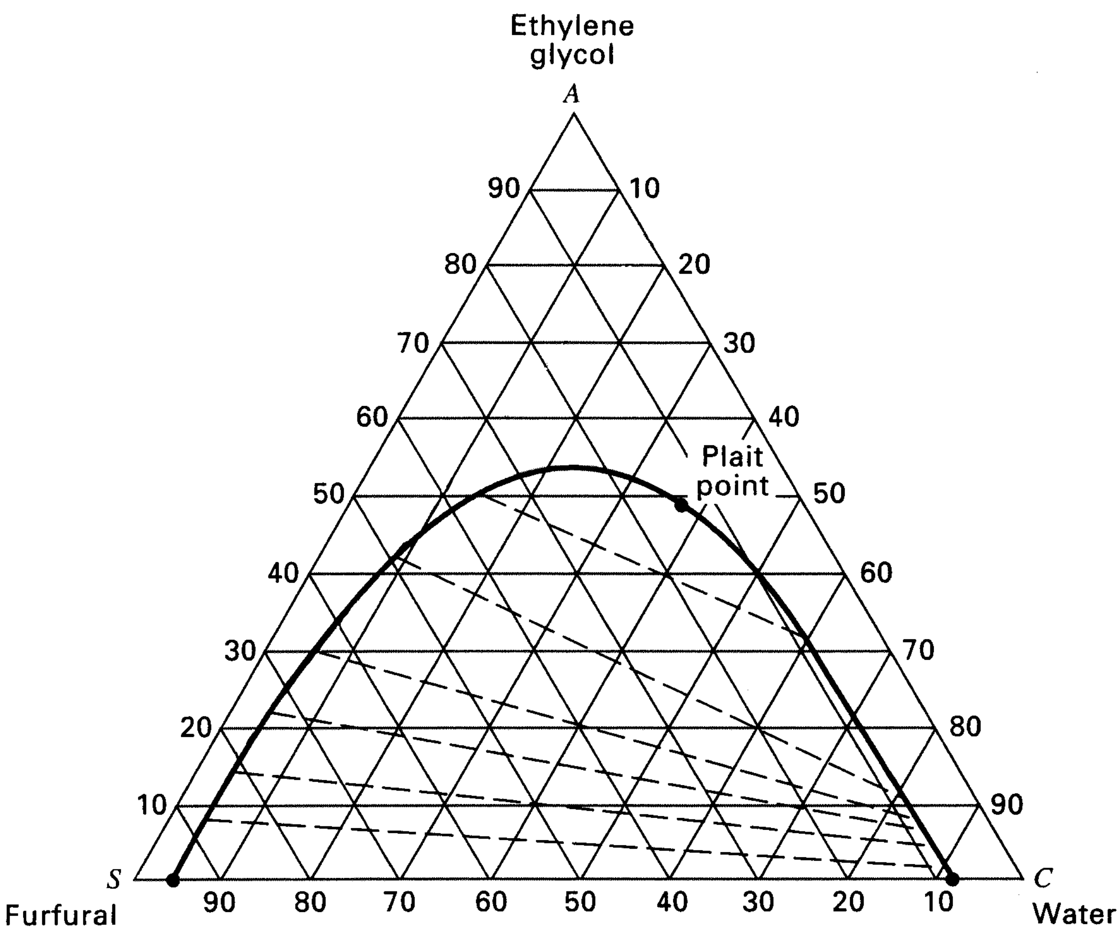


6. (25 Pts.)

You are asked to evaluate a co-current extractor of equipment currently operating in a factory, which can be expressed schematically as such:



The material in the unit is a mixture of furfural, ethylene glycol, and water, whose phase behavior is shown below.



Answer a and b in the space provided below and on the diagram on the previous page.

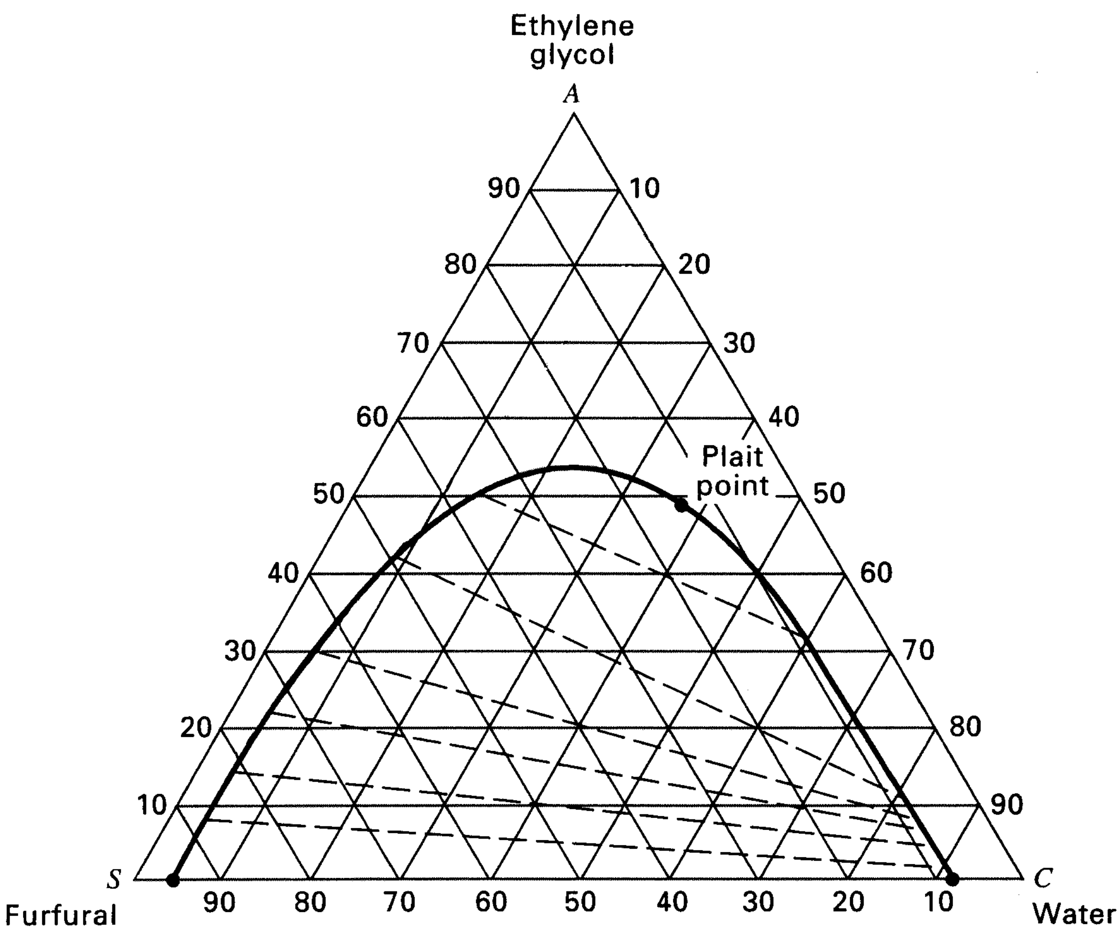
a. (6 Pts.) Find the mixing point for this system, and report the weight fractions of each of the three components. Where in the equipment does a phase of this composition exist?

b. (5 Pts.) If the flowrate of solvent is 500 kg/h, what is the flowrate of the feed?

Answer c and d below and on the diagram below.

c. (10 Pts.) How many equilibrium stages are contained in the equipment?

d. (4 Pts.) What are the compositions of E_2 and R_{N-1}?



7. (30 Pts.)

You are wandering hopelessly through a chemical plant and happen upon a vat of mystery chemicals that is labeled with the follow sign:

Species	K-value	Moles
α	5.0	10.0
β	97.0	30.0
χ	0.02	40.0
δ	1.0	20.0

You, the ever-interested chemical engineer, think it would be fun to distil the mystery mixture and apply a Fenske-Underwood analysis for undisclosed personal reasons. You choose a feed with quality, $q = 0.50$, and to simplify the matter, assume that non-key components do not distribute and that 5% of the light key ends up in the bottoms and that 6% of the heavy key ends up in the distillate.

a. (6 Pts.) Circle the answer that best describes each component:

Species				
α	LLK	LK	HK	HHK
β	LLK	LK	HK	HHK
χ	LLK	LK	HK	HHK
δ	LLK	LK	HK	HHK

b. (9 Pts.) Based upon your assumptions, what is the minimum number of stages required for the assumed separation (N_{min})?

c. (15 Pts.) Based upon your assumptions, what is the minimum reflux ratio (R_{min})?

8. (20 Pts.)

A gas mixture of 10% A and 90% B is to be separated using a non-porous polymeric membrane. The pressure on the feed side of the membrane is 3.5 MPa, while the pressure is 0.1 MPa on the permeate side. It can be assumed that there are no concentration gradients in the direction of flow on either side of the membrane. Values of the Henry's constant and diffusion coefficient for A and B are given below.

Species	$H_i \times 10^4$ (mol/m^3·Pa)	$D_i \times 10^{11}$ (m^2/s)
A	0.2	500
B	20.0	1

a. (15 Pts.) For a 10% cut of the feed, what will be the mole fraction of A in the retentate?

b. (5 Pts.) It is suspected that because there is no gas flow on the permeate side of the membrane that the rate of mass transfer from the membrane to the permeate will be slow. How could this affect the performance of the membrane system? Do you think that the anticipated problem is likely to occur? Explain why or why not.

9. (25 Pts.) A bed of adsorbent has been used to remove a contaminant present in a gas stream at the level of $C_{Ao} = 4x10^3$ mol/m^3. The adsorption temperature was 298 K. The bed was operated until it reached its equilibrium adsorption capacity.

a. (5 Pts.) What is the fractional loading of the bed (i.e., the fraction of the maximum capacity of the bed) if $K = 2.5x10^{-4}$ m^3/mol?

b. (5 Pts.) If the enthalpy of adsorption is -7.5 kcal/mol, how much would the loading of the bed change, if T is raised to 398 K?

c. (7 Pts.) It has been proposed that one way to regenerate the bed would be to flow pure carrier gas through the bed. Write the differential equations and boundary conditions needed to determine $q_A(t)$ and $C_A(t)$, but do not solve them.

d. (8 Pts.) Sketch the anticipated solution to the equations you have written in part c. Include plots of adsorbate concentration in the bed as a function of bed position for various times, and a plot of the exit gas composition as a function of time.