UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE AND ENGINEERING
FINAL EXAMINATIONS, April 2001
THIRD YEAR PROGRAM
CHE 311S – Separation Processes
Examiner - J.M. Shaw

Candidates are permitted an aid sheet. The final examination is worth 40 marks. The maximum possible score is 45 marks. Please attempt all questions.

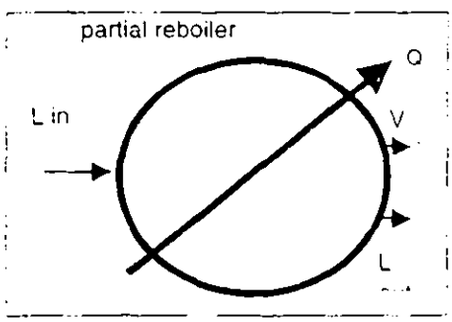
MARKS

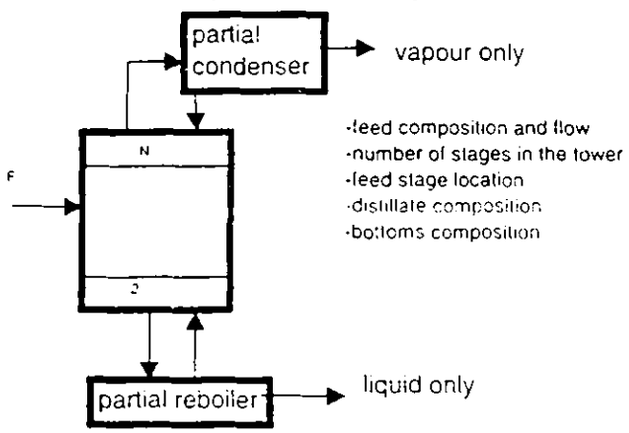
15 **1. Degree of freedom analysis**

A) Perform a degree of freedom analysis based on the equilibrium calculation approach for the partial reboiler pictured below. Provide a consistent list of specifications that would allow you to solve for all stream compositions, flows, temperatures and pressures. Assume that the liquid and vapour effluent are at equilibrium. **5 marks**

B) For the distillation column pictured below, the number of degrees of freedom, Nd, is: Nd = 2N + C + 6 where N is the number of equilibrium stages and N is the number of components. Is there sufficient information provided to solve for all stream compositions, flows, temperatures and pressures? If not, complete the list with consistent specifications that would allow you to solve for all stream compositions, flows, temperatures and pressures. **5 marks**

C) Do the specifications selected for distillation column design affect the ease/ difficulty of the solution of the design problem for a given solution technique? Explain. Give examples based on work performed during the term! **5 marks**





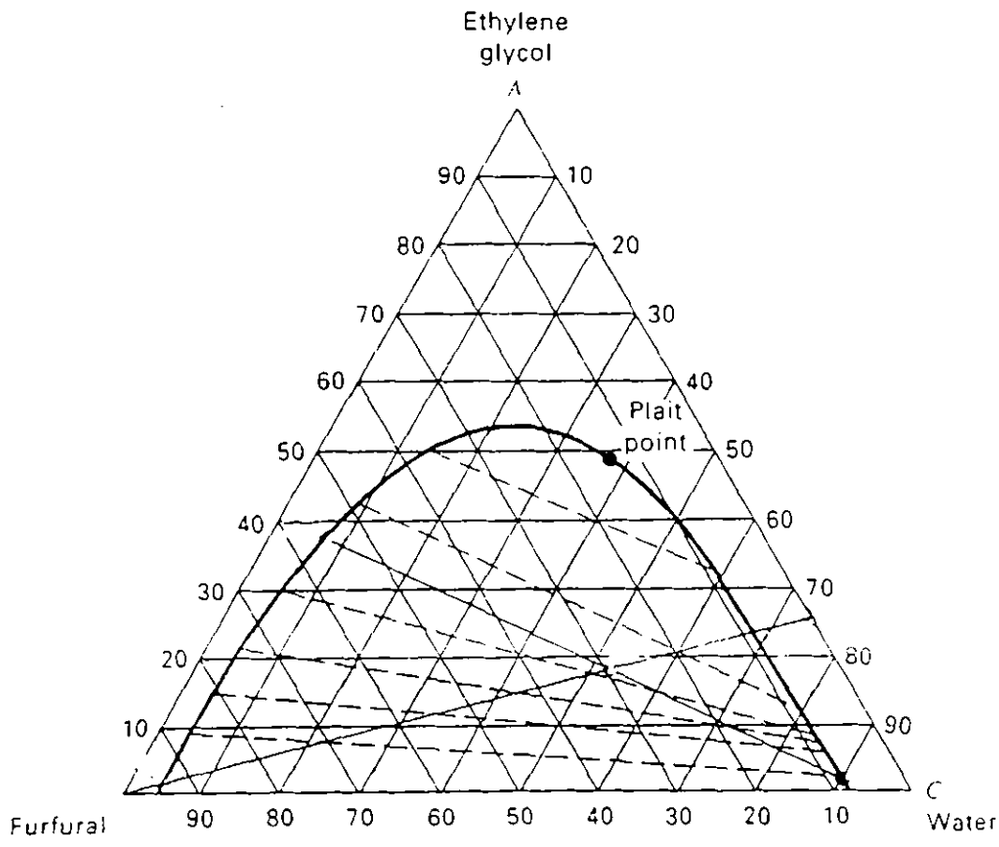
15 **2. Liquid-Liquid Extraction**

A mixture of ethylene glycol (20 mole %) and water (80 mole %) is to be separated using a counter current liquid-liquid extraction cascade. The solvent fed to the extractor is pure furfural. The flow rates of the glycol mixture and solvent into the extractor are 600 moles/s and 200 moles/s respectively. The raffinate must contain no more than 5 mole % ethylene glycol. Additional data can be found on the phase diagram below.

A) Using the graphical technique described in class, determine the number of equilibrium stages required for the separation. **5 marks**

B) Determine the flow rates and compositions of the exiting raffinate (water rich) and extract (furfural rich) phases. **5 marks**

C) Show the principal equations and an algorithm for their solution required to solve this design question numerically. Remember to include the mass and energy balances as well as phase equilibrium calculations! **5 marks**



15 **3. Distillation Column Design**

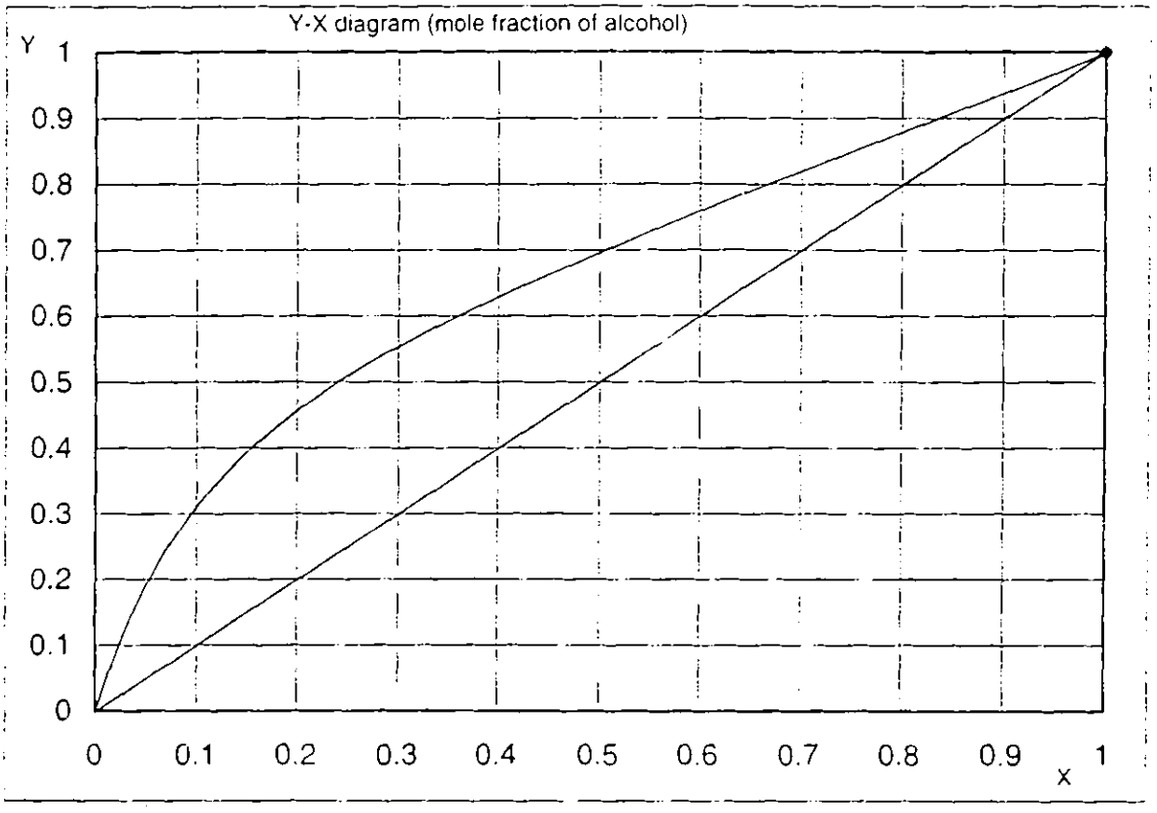
Due to process changes, the feed composition to an alcohol-water separation column has changed and the distillate and bottoms product specifications can no longer be met. Your boss has put you in charge of the situation and naturally a solution must be obtained before lunch! You have no time for detailed simulations!

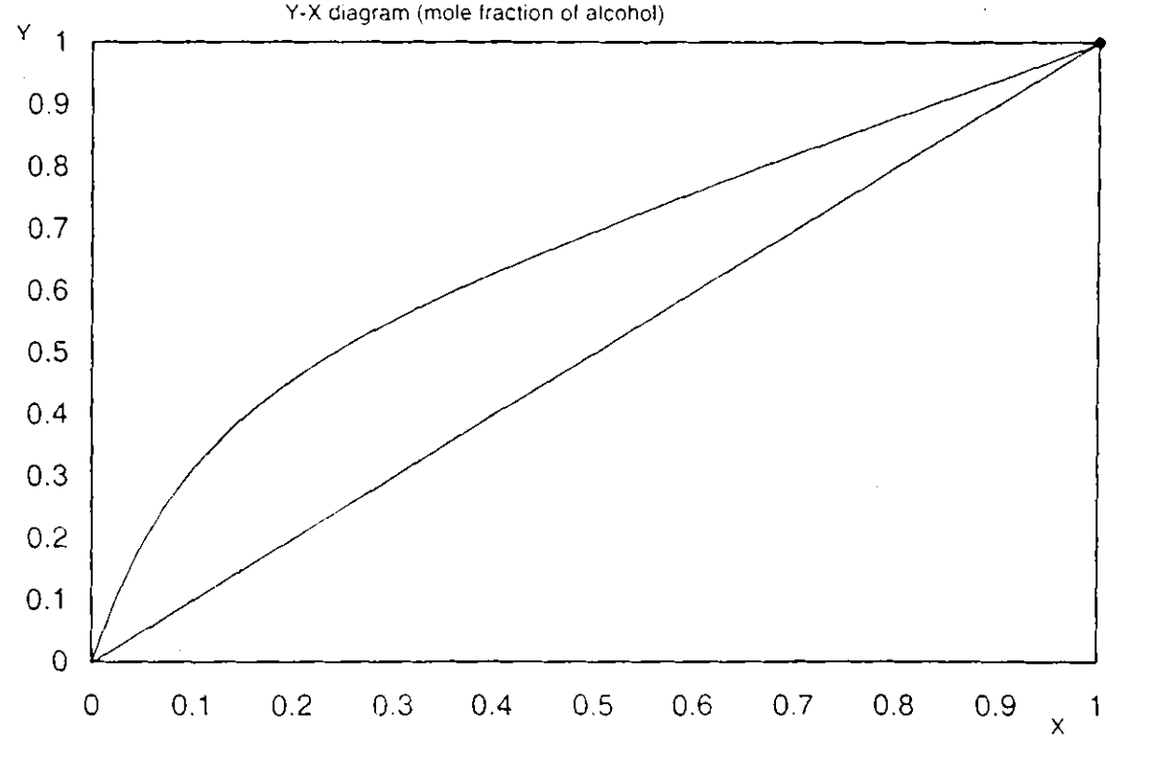
The column comprises 8 stages (100 % Murphree efficiency), plus a reboiler and a total condenser. The feed enters the column at the 5th stage from the top. The reflux ratio is 2 currently. The distillate and bottoms specifications are greater than 95 % alcohol and less than 5 % alcohol respectively. You have learned that the condenser and reboiler are both over designed and could handle larger flows if necessary. Regrettably the operating pressure cannot be adjusted. However, you also discovered that the original designers placed ports at the 7th and 3rd stages from the top. These provide alternate feed locations. The new feed composition is 70 mole % alcohol and it enters the column as a saturated liquid. Three copies of the Y-X diagram are attached. Please include them with your answer booklet.

A) According to the McCabe-Thiele method, should the column be able to meet the product specifications without changing its operation? If not which product specification(s) is (are) not met? **5 marks**

B) According to the McCabe-Thiele method, can you meet the product specifications by adjusting the reflux ratio? If so what is the new value? **5 marks**

C) According to the McCabe-Thiele method, can the product specifications be met by changing the feed location to the 7th or 3rd stage while leaving the reflux ratio unchanged? Justify your answer. **5 marks**


Y-X diagram (mole fraction of alcohol)
Y
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
X


Y-X diagram (mole fraction of alcohol)
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0.9
0.8
0.7
0.6
0.5
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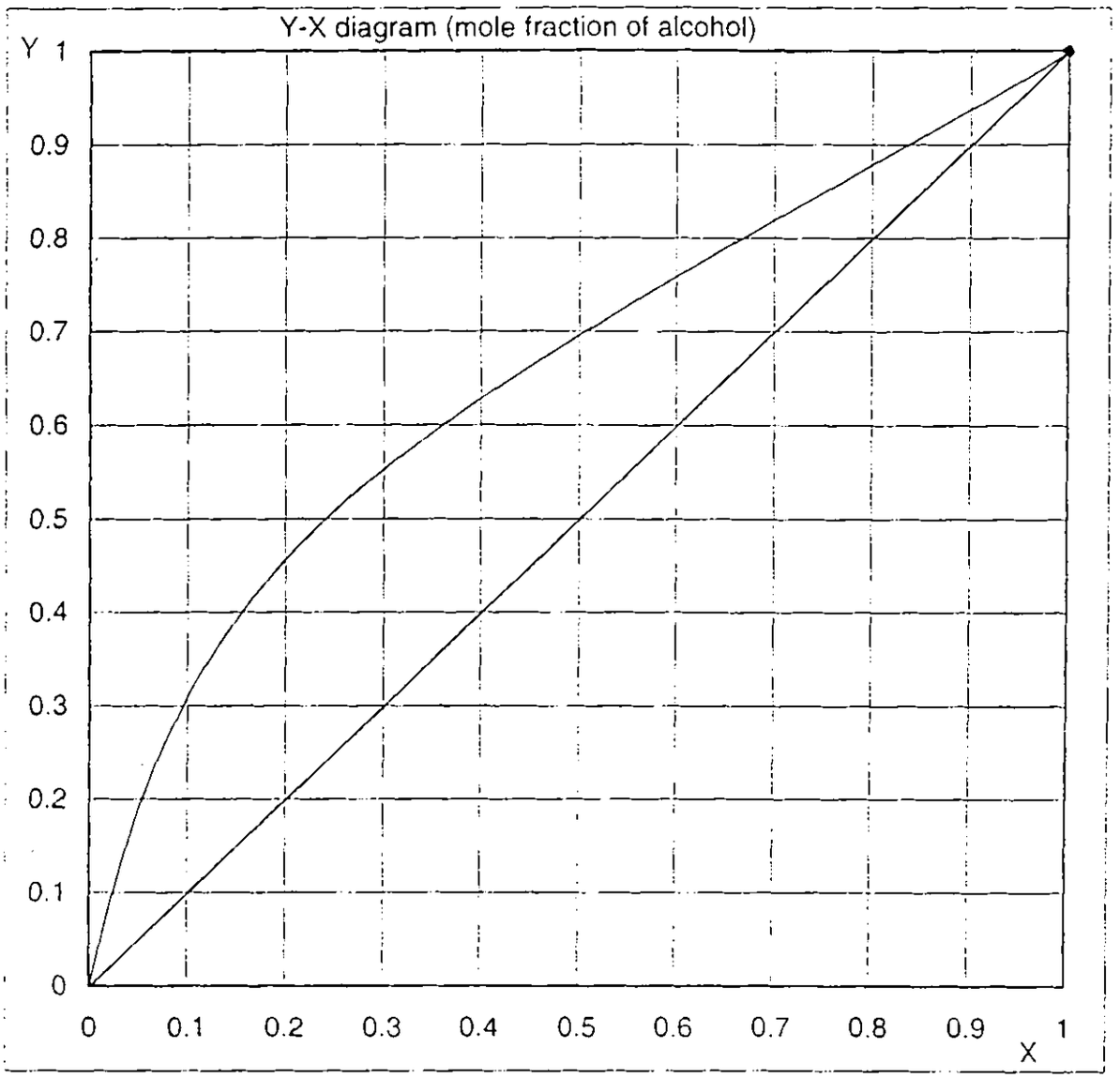
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
X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0.9
0.8
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0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
X