CHEMICAL and BIOMOLECULAR ENGINEERING 140

Exam 1

Friday, September 27, 2018

Closed Book

Name: _____

Section: _____

Student ID Number: _____

Person to your left: _____ Person to your right: _____

Total score: _____ /100

Problem 1: _____ /30

Problem 2: _____ /35

Problem 3: _____ /35

1. Short Answer. 3 points each
Note: *questions are underlined - answer all questions.*

a) In a steady state flow reactor, the time rates of change of all reactants and products are all zero. Explain, using the general material balance equation, how can there be any reaction if the species concentrations are not changing with time.

b) It is generally possible to achieve maximum conversion of a desired product in a chemical reactor if the residence time is large enough. Why is this generally not the way industrial chemical reactors are designed to be operated?

c) Sketch a distillation column, including the feed line, the column itself, the reboiler and the condenser and the two outlet streams. What is the physical basis for separation using distillation?

d) What is the physical basis for separation using crystallization?

e) Three chemical species (A, B and C) are involved in a three separate chemical reactions (1, 2 and 3). Write the equations describing the mole numbers of each species in terms of the extents of each reaction and the appropriate stoichiometric coefficients. (This can be done using a single equation with subscripts if desired.)

f) What is the general material balance equation - in words - for atomic species entering and leaving a chemical reactor with flow?

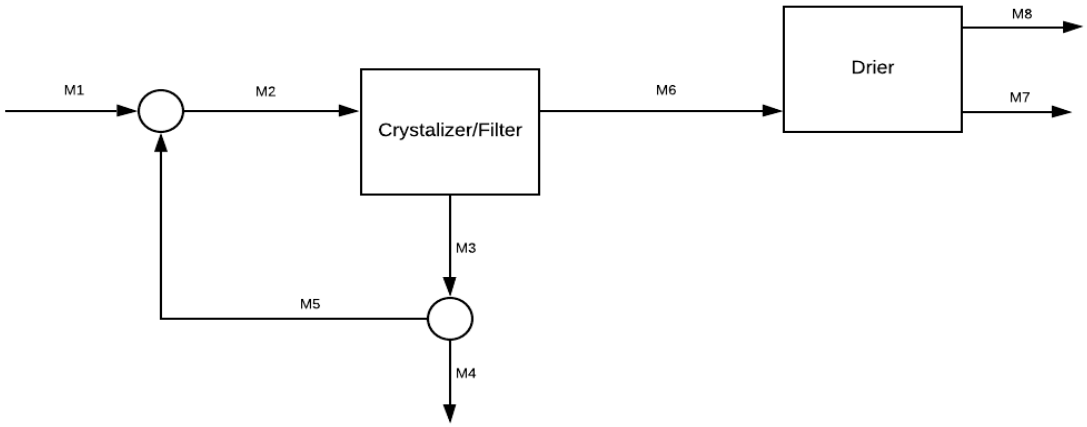
g) A mixture of water and ethanol is placed in a closed drum and the mixture is maintained at a temperature and pressure that allows a vapor-liquid equilibrium to be established. Is any water moving from the vapor phase to the liquid phase at equilibrium? Explain.

h) A gas at temperature 300K flows into a furnace at volumetric flowrate 10 m^3/s where it is heated to 900K. Assuming steady state, no reactions and constant pressure, derive the expression for the volumetric flowrate Q (m^3) out of the furnace.

i) A tank (volume V (m^3), cross sectional area A (m^2)) is being filled with a liquid (density ρ (kg/m^3)) with an inlet flow rate of Q_0 (m^3/min), and an outlet flowrate of Q (m^3/min). Derive an expression for the time rate of change of liquid height (i.e. $\frac{dh}{dt}$) in the tank.

j) If a reversible chemical reaction $A \leftrightarrow B$ takes place in the tank of problem i (assuming steady state here), what is the quantity that will determine if this reaction approaches equilibrium?

2. You have been hired at a chemical plant to work on a crystallization process with Sodium Sulfate in a water stream. The inlet is fed to a Crystallizer/Filter which results in a filtrate stream (Stream 6, which is mostly Sodium Sulfate), and an effluent stream (stream 3 which is mostly water) which is mixed back with the feed stream after some of the stream is purged. The wet Sodium Sulfate crystals are then sent to a drier where most of the water is pulled off.



Your boss has told you he is suspicious that the upstream process is not operating correctly and the concentration of Sodium Sulfate is different than it should be. You know that the feed stream is coming in at 360 kg/hr, and you're producing 100 kg/hr of the solid which contains 0.2% water. The concentration of the purge stream (stream 4) is 94% water, and stream 8 is pure water. Your boss told you that based on some tests they have done so far they know that 12% of the wet solid's weight is lost from drying (you may assume that all of the mass lost is water, which is represented by stream 8). Additionally, you know that 80% of the sodium sulfate entering the crystallizer, goes to the wet solid leaving the filter.

a) Solve for the concentration of Sodium Sulphate in the feed stream. (16 points)

b) The amount of Sodium Sulphate is close to what your boss was expecting, but they want to be sure that this new level of Sodium Sulphate won't exceed the tolerances of the crystallizer. The maximum concentration of Sodium Sulphate the crystallizer can handle is 25% by mass. Solve for the mass percent of Sodium Sulphate in the stream feeding to the crystallizer. If you were unable to solve part a, assume the concentration of sodium sulphate in the feed stream is 25% by mass. (14 points)

c) Your boss decides they would like to lower the mass percent of Sodium Sulphate in the stream going to the crystallizer. What could you change about the process to accomplish this (not including changing the mass percent in the feed stream? (5 points)

3. (35 points)

a) Water gas shift is an important industrial reaction. $CO + H_2O \leftrightarrow CO_2 + H_2$

If 20 mol/min H_2O and 15 mol/min CO are fed to a reactor running this reaction, what is the limiting reactant? (1 point) What is the percent excess of the other reactant? (3 points)

b) At 100% conversion, how many mol/min of CO_2 would be produced? How many mol/min of H_2 would be produced? (3 points)

c) The equilibrium constant for this reaction is 6.0. You can assume your reaction from part (a) is elementary. What is the extent of reaction? HINT: quadratic formula is $x = \frac{-b \pm \sqrt{(b^2 - 4ac)}}{2a}$ (6 points)

d) What is the fractional conversion of CO? (3 points) What is the fractional conversion of H_2O? (3 points)

e) Carbon monoxide and water can also react to form hydrocarbons. Write a balanced reaction for the production of ethanol (C_2H_5OH), H_2, and O_2 from CO and H_2O. (3 points)

f) Assuming the equilibrium from part (c) is maintained, what is the maximum amount of ethanol that could be produced? (4 points)

g) If the amount of ethanol you found in part (f) is produced, what is the selectivity for CO_2? (3 points)

h) Natalie and Zach both calculate the fractional yield of ethanol and get 1.0 and 0.3, respectively. Write out equations for each calculated value of yield. Explain the difference between the two equations. (6 points)