MIDTERM #1 PART II EXAMINATION - September 30th, 2020
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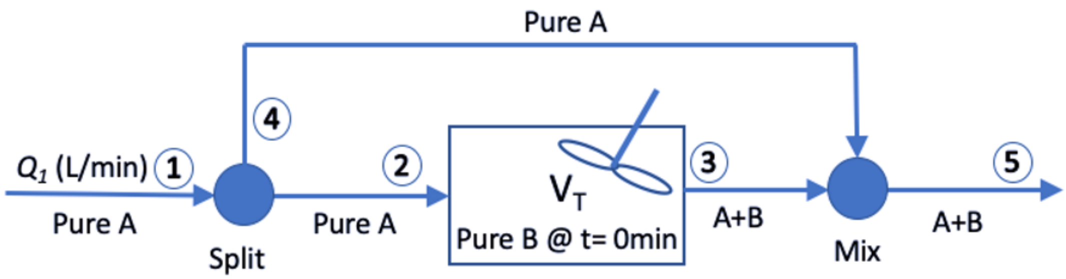
Chemical Engineering 140
Fall 2020
50 Points

1. (15 pts total) A well-mixed tank initially contains V_T (in L) of pure species B. At t=0 min, pure species A ($\rho_A = \rho_B$ [=] kg/L) is pumped into the tank at Q (in L/min) and fluid is withdrawn from the tank at an equal volumetric flowrate.

   a) (10 pts) Write a species balance and solve the resulting differential equation to find the concentration of A, ($C_{A,Out}$, in kg/L) in the outlet stream from the tank as a function of time. Assume that mixtures of A and B have the same overall mass density as each individual species. Express your answer in terms of the other parameters provided in the problem statement (V_T, Q, ρ_A, t).
   b) (5 pts) What is the concentration of species A when t = $\theta/2$, half the residence time of the tank? Express your answer as a fraction of ρ_A.

2. (35 pts total) In a related system, the well-mixed continuously stirred tank from question 1 is placed in parallel with a <u>bypass</u> stream, as shown in the diagram below:



The tank initially contains only pure B with fluid volume V_T. At t = 0 min, the flow rate of stream 1 is Q_1 (L/min) of pure A (with density ρ_A [=] kg/L), and stream 4 and 5 have an equivalent volumetric flowrate, $Q_5 = Q_4 = Q_1$ [=] L/min at t = 0 min. In other words, all flow bypasses the CST such that stream 2 and 3 have no flowrate at t = 0 min (i.e., at t = 0 min, $Q_2 = Q_3 = 0$ L/min). Q_1 and Q_5 remain constant throughout this problem, and the overall mass densities of all streams can be assumed to be equal. However, at t > 0 min, the flow rate in streams 4 and 2 change with time, such that stream 2 flow increases linearly at the same rate that stream 4 flow decreases, i.e.:

$Q_2 = Q_3 = 3t$ (L/min) for $0 < t < Q_1/3$ t [=] min [eqn. 1]
$Q_4 = Q_1 - 3t$ (L/min) for $0 < t < Q_1/3$ t [=] min [eqn. 2]

$Q_2 = Q_3$ at all times. The goal of this overall problem is to find an expression for the mass concentration of species A in stream 5, ($C_{A,5}$, in kg/L) as a function of time.

a) (3 pts) What are the units of '3' in equation 1 and 2 above?

b) (15 pts) For the time period $0 < t < Q_1/3$, write a balance around the CST to obtain a differential equation that relates the time change in the species A concentration in stream 3, $\frac{dC_{A,3}}{dt}$, to t, V_T, ρ_A, and $C_{A,3}$. Evaluate this differential equation and use the initial condition to solve for $C_{A,3}$ as a function of t and the constants V_T and ρ_A (your answer should only contain these parameters).

c) (10 pts) For the time period $0 < t < Q_1/3$, perform appropriate mass/species balances to find an expression that relates $C_{A,5}$ to t, Q_1, ρ_A and $C_{A,3}$ (your expression should only contain these parameters).

d) (3 pts) For the time period $0 < t < Q_1/3$, what is the final expression for $C_{A,5}$ as function of t and the constants Q_1, V_T and ρ_A (your answer should only contain these parameters)?

e) (4 pts) Evaluate your answer in part d) to find the concentration of species A at t = 0 min <u>and</u> $t = Q_1/3$ [min].

MIDTERM #1 PART I EXAMINATION - September 30th, 2020
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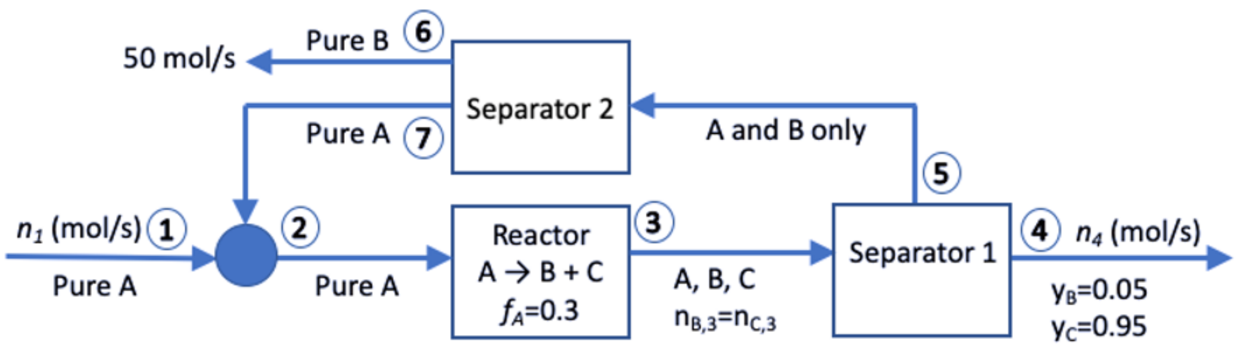
Chemical Engineering 140
Fall 2020
50 Points

1. (22 pts) Consider the steady-state process flowsheet below, where a desirable chemical, B, is produced from reactant A *via* the balanced reaction A → B + C. All known stream compositions are labelled, with the species that exist in each stream indicated. Additionally, the mol fractions of B and C in stream 4 are provided. In the reactor, species A converts into species B and C with a single pass conversion of 0.3 (as is labelled on the reactor). I am interested in producing 50 mol/s of pure species B (stream 6) using this process.



Using appropriate species mole balances, calculate the following values:

a) (8 pts) The total molar flowrate of stream 4 in mol/s.
b) (7 pts) The total molar flowrate of stream 2 in mol/s.
c) (7 pts) The total molar flowrate of stream 1 in mol/s.

2. (28 pts total) You're a process engineer working at a chemical plant and you've been tasked with designing a new reactor. This process will involve a second order, irreversible, homogeneous reaction, converting species A to species B (balanced equation: $A \rightarrow B$).

   a) (3 pts) Write out the homogeneous rate law for species A consumption (it should be a negative quantity!) in terms of species A concentration, C_A. Specify the units of the rate constant, k, and the overall units for the rate law (use min. for time units and L for volume units). For the remainder of this problem, assume that the numerical value for k in these units is 0.0100.
   b) (7 pts) You decide you want this reaction to occur in a well-mixed continuous stirred tank reactor, with a volumetric flow in/out of the reactor (Q=10.0 L/min), a constant fluid volume in the tank (V_T=500. L), and concentration of species A in the inlet ($C_{A,I}$=10.0 mol/L). Assume that the CSTR has been operating for a long time (greater than a day) in this configuration. Write a balance on species A in the reactor in terms of the variables V_T, Q, $C_{A,o}$ (the outlet stream species A concentration), $C_{A,I}$, and k. If you make any assumptions about the CSTR beyond what's given, please list them.
   c) (4 pts) Solve for the concentration of species A and species B in the outlet given the numerical values provided in the problem statement.
   d) (4 pts) Solve for the fractional conversion of species A.

You show the calculations for fractional conversion to your boss and he tells you they need a higher conversion from this reaction without increasing reactor cost. You decide to use two CSTRs in series, where the outlet of the first reactor is fed directly to the inlet of the second reactor and, to keep costs manageable, each CSTR has half the fluid volume of the CSTR in the above set of problems (V_T=250. L).

   e) (8 pts) Using balances around each reactor, what is the overall process conversion of species A when using this 2 half-sized CSTR process? Assume all other process parameters remain the same as in parts a-d (in/out volumetric flowrates, inlet species A concentration, and rate constant in each reactor).
   f) (2 pts) Provide a simple 1-2 sentence explanation of why the conversion in part e is higher/lower/equal to the conversion in part d).