Chemical Engineering 140
Midterm Exam
Monday, April 5, 2021 3:05 pm-3:55 pm

*The exam is **100** points total*

The exam is open note, open book, open internet, but should be taken individually.

The exam should have **4** pages including the cover page.

Instructions:

1. Write your solutions on blank sheets of white paper. Box all of your answers. Use a separate sheet/s for problems 1 and 2.
2. On the first sheet of your exam, write your **name** and **student ID and leave it blank**.
3. Use calculators when necessary, and write down the answers in numbers with appropriate units. If you are unable to solve for the final values, show your work with expressions.
4. State all assumptions you deem appropriate to solve the problem, but justify them.
5. Copy down the UC Berkeley honor code statement below and sign it:

   As a member of UC Berkeley, I act with honesty, integrity, and respect for others.

Problem 1 (20 points)

Species C is produced in the following reversible, gas phase chemical reaction:

$$A + B \rightleftarrows 2C \quad (1)$$

However, an undesired side reaction also occurs:

$$2A + B \rightleftarrows 3D \quad (2)$$

These reactions occur in a CSTR. In order to separate species D and any unreacted reactants, the output of the reactor is then fed to a distillation column. Assume the process is at steady state and temperature and pressure are constant throughout. The ideal gas law applies.

The process flow diagram for the production of C is given below:

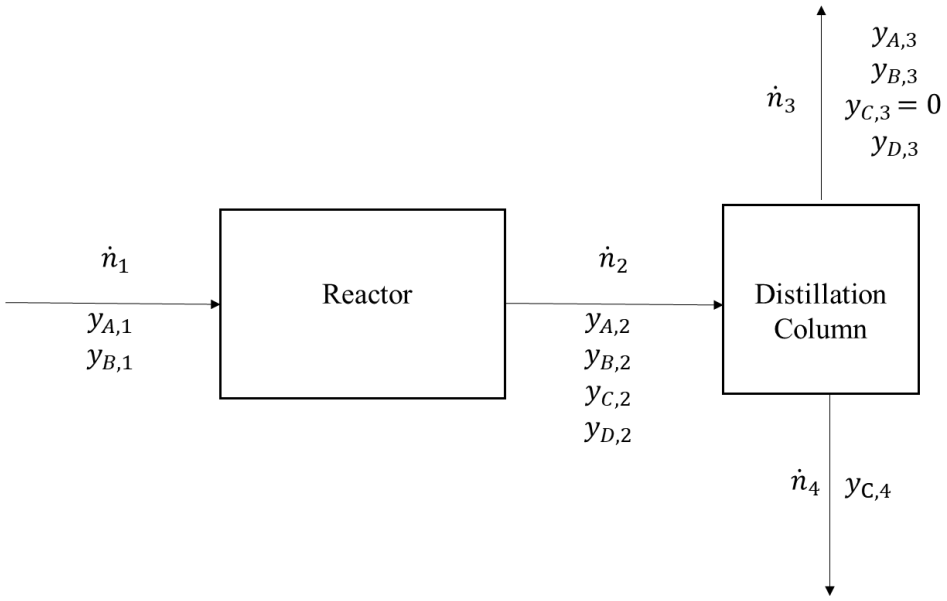

***Figure 1**: Production of species C*

The inlet stream contains equimolar amounts of species A and B and has a total flow rate of 100mol/s. If the extent of reactions for Eqs. (1) and (2) are ξ_1 = 30 moles and ξ_2 = 5 moles respectively, calculate the composition (mole fractions) of stream 3.

Problem 2 (80 points)
Species C is produced in the following reversible, gas phase reaction:

$$A(g) + B(g) \rightleftarrows 2C(g)$$

The reaction occurs in a PFR and the operating temperature and overall pressure of the reactor are kept constant throughout the process. The inlet stream contains an equimolar ratio of species A and B as shown in Fig. 2a. The following data for this reaction is provided:

ΔH_{rxn} = 15 kJ/mol (enthalpy of reaction)
K_{eq} = 4 at T = 300K
E_a = 50 kJ/mol (activation energy)
P = 1 atm
R = 8.314 J/K·mol = 0.08206 atm·L / K·mol
k = 2 $M^{-1}s^{-1}$ (Note 1M = 1 mol/L with L being a Liter)

$$r_A = -kC_AC_B + \frac{k}{K_{eq}}C_C^2$$

Assume that the ideal gas law applies.

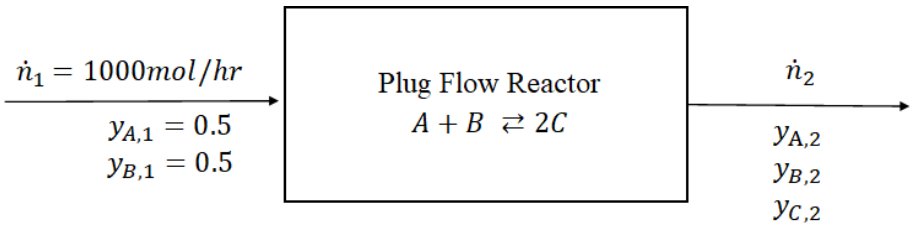

***Figure 2a**: Production of species C in a PFR.*

a. If the operating temperature of the reactor suddenly increases from T = 300K to T = 400K, will the forward or the reverse reaction be favored? Provide an explanation why.
b. Will K_{eq} increase or decrease when temperature is increased from 300K to 400K? Using the provided data, calculate K_{eq} at T = 400K to justify your answer.
c. Write an expression for r_A in terms of conversion of species A, X_A, overall pressure, P, temperature, T, and the equilibrium constant, K_{eq}.
d. Derive an expression relating reactor volume, V, to conversion of A, X_A, using only the variables X_A, k, K_{eq}, P, T, $n_{A,1}$. Leave your answer as a definite integral.
e. It is found that the reactor, shown in Figure 2a, has a single pass conversion of X_A = 0.3, when the process operates at 300K and 1atm. What is the volume of the reactor if the single pass conversion is 0.3?

f. In order to improve overall conversion, a distillation column and recycle stream are added to the process, as shown in Figure 2b below. Note that the single pass conversion of species A is still 0.3.

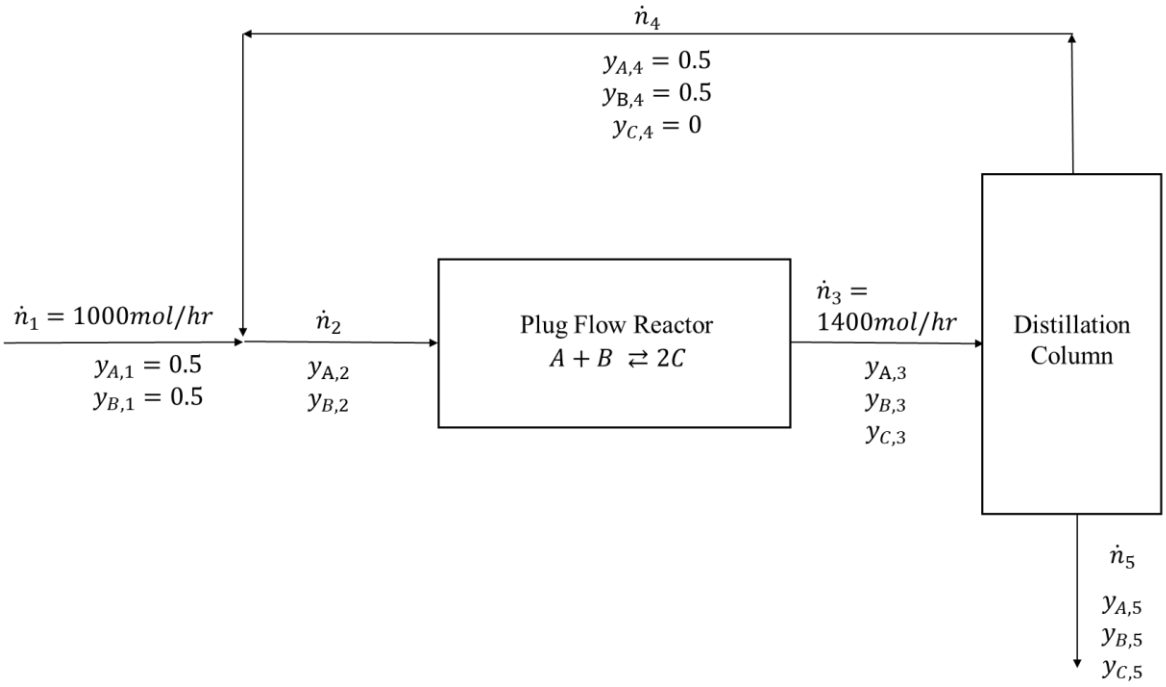

***Figure 2b**: Production of species C in a PFR with a recycle stream.*

Given the data given in figure 2b, answer the following questions. *Please provide a proper explanation if you are just proving the answer. Partial points will NOT be given for just writing the answer, even if it is correct. Show your work.*

i. What is the molar flow rate of stream 2?
ii. What is the recycle ratio?
iii. What is the molar composition of stream 3?
iv. What is the overall conversion of species A?