ECHE 260: Intro to Chemical Systems

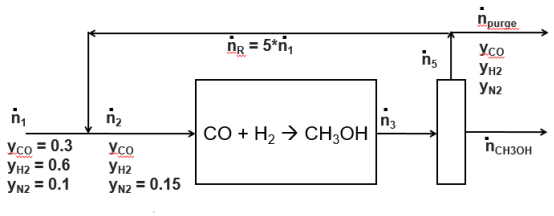
Homework #3B

Assignments are due in Canvas on the due date and time. Homework should follow the general formatting guidelines posted in Canvas.

Conceptual Questions and Short Answers

1. (5 points) Consider the reaction 2A + B → 2C in a steady state, continuous flow reactor. The feed contains 100 mol A/s, 200 mol B/s and 50 mol C/s. What is the flowrate of C exiting the reactor if A is consumed at a rate of 5 mol/s?
    a. 5 mol/s
    b. 10 mol/s
    c. 55 mol/s
    d. 60 mol/s
    e. 150 mol/s

2. (5 points) Which subsystem of the process has zero degrees of freedom?



    a. Mixing point
    b. Reactor
    c. Condenser
    d. Overall balance
    e. None of the above

Quantitative Questions

3. (20 points) Burning trash (and plastic) is a common waste management strategy in the US. Unfortunately, burning plastics also leads to high CO_2 emissions. Consider the following chemical reactions for the complete combustion (1) and partial combustion (2) of the monomer unit of polyethylene terephthalate (PET):

$$C_{10}H_8O_4 + 9O_2 \rightarrow 9CO_2 + 4H_2O + C(s) \quad (1)$$

$$C_{10}H_8O_4 + 4O_2 \rightarrow 8CO + 4H_2O + 2C(s) \quad (2)$$

In a PET-burning furnace, air is drawn into the furnace by a compressor. Oxygen is pumped into the system such that the ratio of O_2 and PET entering the furnace is 3:1. The furnace operates at 300 ^oC. Shredded PET is fed into the furnace by a conveyor belt. Burned PET, which can be approximated as solid carbon, is continuously removed from the bottom of the furnace such that this can be modeled as a continuous steady state process. You can assume that the fractional conversion of PET is 100% and the selectivity for CO over CO_2 is 4 ($\alpha_{CO/CO2} = 4$). Gases that exit a furnace are called flue gases. Here, the flue gases exit the furnace (out of the top) and enter a condenser. All of the water that enters the condenser is liquefied. The remaining gases are sent elsewhere in the plan to remove the CO_2. What is the fractional single pass conversion of oxygen?

a. For this process, work through the general material balance procedure from class. (Draw a process flow diagram, balance all chemical reactions, perform a DOF analysis and write the material balances using the extent of reaction procedure).

b. Based on your DOF analysis from part a, is it possible to solve for the desired quantity (fractional conversion of oxygen)? If so, write the algebraic equations, in order, that you would use to solve for them. If not, what additional information would have to be specified in order to solve for them?

4. (20 points) Chlorobenzene is a chemical precursor for many pharmaceutical products and commodity chemicals such as dry-cleaning agents, rubbers and dyes. It is produced by bubbling chlorine gas through liquid benzene in the presence of a catalyst. In an undesired side reaction, the chlorobenzene is chlorinated to form dichlorobenzene and in a second undesired reaction the dichlorobenzene is chlorinated to trichlorobenzene.

In a continuous steady state process, the fresh feeds to the chlorination process consist of pure liquid benzene and pure chlorine gas. Two product streams exit the reactor. The liquid product stream contains 65mol% benzene, 32mol% chlorobenzene, 2.5mol% dichlorobenzene and 0.5mol% trichlorobenzene. The gaseous product stream contains hydrochloric acid and unreacted chlorine. The gaseous product stream is fed to a condenser which liquefies most of the HCl and none of the Cl_2. The remaining gaseous stream, which is mostly chlorine with 5mol% HCl, is recycled to the reactor. To prevent accumulation of HCl in the reactor, some of the recycle stream is purged from the system. What is the single pass

fractional conversion of benzene? What is the overall fractional conversion of benzene? What is the selectivity for chlorobenzene over dichlorobenzene?

a. Set up the problem: draw a process flow diagram, balance all chemical reactions, identify the quantities for which you will solve, write additional equations from the problem statement using process variables from your PFD.

b. Perform a DOF analysis on the PURGE and the REACTOR subsystems.

c. Regardless of the results of part b, Write the material balances for Cl_2 in the REACTOR and the OVERALL. You do not need to write any other material balances. You do not need to write a "how to solve"

Reflection (2 bonus points to this assignment)

4. We have now finished unit 3 on material balances for system with chemical reactions.
    a. How did you study for Quiz 1?
    b. What concepts (if any) are unclear or do you struggle with?