Chemical Engineering 140 **September 30, 2015**

Midterm Examination #1

(100) 1. A chemical precursor, denoted species A, is to be converted to a product P in a continuous stirred tank reactor. The reaction is first order and irreversible, with forward rate constant k_1. Simultaneously, precursor A irreversibly decomposes into an undesired by-product B via a first-order reaction with rate constant k_2. Initially, at time $t = 0$, the tank is filled to a volume V with liquid solvent and has species A dissolved in it such that the initial concentration of species A is $C_{A_{t0}}$. For times $t > 0$, an inlet stream containing only solvent and dissolved species A at a concentration C_{A0} is fed to the reactor with volumetric flowrate Q. Simultaneously, the reactor's contents are drained at the same volumetric flowrate Q. The reactor is well mixed, isothermal, the dissolved species A, B, and P are dilute, and the reactions are elementary. For each reaction, one mole of A converts to one mole of P or B.

(25) a) Draw and label a diagram of the process with inlet and outlet stream conditions labelled, the initial condition(s), and also the chemical reaction equations with the rate of species A generation.

(35) b) Derive an unsteady state mole balance for species A in the tank and use it to obtain a differential equation describing the concentration of A in the tank as a function of time. Express the differential equation in terms of C_A, C_{A0}, k_1, k_2, and the residence time τ, and write the initial condition.

(20) c) Find expressions for the steady state outlet concentration of the A reactant, C_A, and the steady-state conversion X of reactant A.

(20) d) Find an expression for the steady concentration of species B. What is the concentration of B at large residence times?

(100) 2. Calcium carbonate and sodium nitrate are often produced industrially via the following irreversible reaction in aqueous solution:

$$Na_2CO_3 + Ca(NO_3)_2 \rightarrow Na_2(NO_3)_2 + CaCO_3$$

The reactant species sodium carbonate and calcium nitrate as well as one of the product species, sodium nitrate, are readily soluble in water. However, the product calcium carbonate precipitates into insoluble solids upon formation.

In a two-step steady state process, calcium carbonate is formed via the above reaction in a reactor, and the effluent is subsequently filtered to remove the insoluble calcium carbonate.

In the first step, 100.0 kg/hr of a water and sodium carbonate solution with 20.0 wt% dissolved sodium carbonate is fed to a reactor. Also fed to the reactor is a stream containing 25.0% excess calcium nitrate with a mass flowrate of water that is equal to that in the sodium carbonate stream. In the reactor, the sodium carbonate and calcium nitrate react with 75.0% conversion on the limiting reactant basis.

In the second step, a filtration unit rejects and discharges 90.0% of the calcium carbonate as well as 20.0% of the water and soluble ionic species fed to it, allowing the remainder of the reactor effluent to permeate through.

Molecular Weights

Na_2CO_3: 106.0 kg/kmol H_2O: 18.0 kg/kmol $Ca(NO_3)_2$:164.1 kg/kmol

$Na_2(NO_3)_2$: 85.0kg/kmol $CaCO_3$: 100.1 kg/kmol

(30) a) Construct a process flow diagram of the system. Label each stream with the species that are present and fill out the diagram with all of the information that is known about the process.

(40) b) Determine the composition of the reactor effluent on a molar basis.

(30) c) Determine the molar flowrate of calcium carbonate rejected by the filter, and the species molar flowrates of the effluent that is **not** rejected by the filter.