CE 561, Exam 2, December 17, 2001

This exam consists of 3 questions, each with multiple parts. You should be careful not to get stuck on one part. If you do not know how to do a problem, move on and return to it if you have time at the end. If you cannot find the numerical answer to a problem, explain how you would find the answer if you had more time or computational resources.

Carefully explain any assumptions you make, clearly indicate what part of what problem you are working on, and define the symbols that you use. The point value of each sub-part is indicated – budget your effort accordingly. There are 100 points total.

Please use a separate blue book for each problem.

Good luck.

1. The sequential reactions

   A → B, with rate = $k_1 C_A$ with $k_1 = 0.5$ hr^{-1} and

   B → C, with rate = $k_2 C_B$ with $k_2 = 0.25$ hr^{-1}

   are to be carried out in dilute aqueous solution in a well-mixed, isothermal, semi-batch reactor. At the start of each batch, the reactor is empty. It is then fed with a solution containing 2 moles of A per liter and no B or C. The feed flow rate is 500 liters per hour (this is the maximum allowable feed rate at which the reactor can be maintained isothermal). The reactor volume is 1000 liters, and when it is full, the feed is shut off. That is, the feed rate is 500 liters per hour for the first two hours, and 0 after the first two hours. Emptying and cleaning the reactor between batches requires 1 hour.

   (a) Find the **number of moles of species A and B** in the reactor as a function of time after the start of reactor filling (you should find solutions for all times, both before and after the feed is turned off). (20 pts.)

   (b) Find the **batch time** that maximizes the average production rate of species B. (15 pts.)

   (c) Find the **average production rate** of species B for this optimal batch time. (5 pts.)

2. The irreversible, exothermic, first-order isomerization reaction

   A → B, with rate = kC_A

   is to be carried out in aqueous solution in a perfectly mixed adiabatic stirred tank reactor. Properties of the reaction and reactor are as follows:

   Feed temperature = T_o = 300 K

   Feed Concentration of A = C_{Ao} = 2 mol/liter

   Heat of reaction = ΔH = - 41800 J/mol

   Density = ρ = 1000 g/liter

   Specific Heat = C_p = 4.18 J/(g K)

   Feed flow rate = Q = 100 liters min^{-1}

   Reactor volume = V = 500 liters

   The reaction rate constant can be expressed as

$$k = k_o + A\left(\frac{T - T_o}{T_o}\right) + B\left(\frac{T - T_o}{T_o}\right)^2$$

where T_o is the feed temperature and

$k_o = 0.002\ \text{min}^{-1}$
$A = 0.04\ \text{min}^{-1}$
$B = 0.4\ \text{min}^{-1}$

(a) Write the steady-state material and energy balances for this system and solve them to find the **steady-state temperature and composition** in the reactor. Be sure to solve for all possible steady states. (20 pts.)

(b) Carry out a **linear stability analysis** for each set of steady-state operating conditions found in part (a) to show which are **stable** and which are **unstable**. (15 pts.)

3. The second order, irreversible reaction 2A → B is to be carried out in an isothermal, partially mixed reactor. Tracer experiments show that the residence time distribution (RTD) for the reactor is well fit by the RTD for two equally-sized, perfectly-mixed tanks in series. The feed to the reactor has C_{Ao} = 3 moles/liter. The mean residence time of the reactor is 10 minutes. The reaction rate is given by

$r = 2\ C_A^2$ mol liter^{-1} hr^{-1}, with C_A in moles per liter.

(a) Derive the **dimensionless residence time distribution function** for two equally-sized perfectly-mixed tanks in series. (15 pts.)

(b) Show how you would compute the **concentration** of A in the reactor effluent using a **segregated flow** model with the RTD derived in part (a). You should set up all of the equations and take the solution as far as you can, but you may not actually be able to get a numerical answer. (10 pts.)