Reactor Engineering Week 8 Problem Set

Question 1 - Adiabatically Insulated Exothermic Reaction in MFR
The following liquid-phase reaction

$$\mathrm{A} \xrightarrow{\mathrm{k_1}} \mathrm{B} \tag{1}$$

is first order in A and has reaction rate constant given by the Arrhenius equation

$$k = k_0 e^{-E/RT}. \tag{2}$$

This reaction is conducted in an adiabatically insulated mixed flow reactor. The volumetric flow rate is υ, the reactor volume is V, the inlet flow rate is C_{A0} and the temperature of the inlet stream is T_0. The specific heat capacity of the liquid inside the reactor is c_p (this is independent of reaction conversion) and the heat released per mole of A reacted is $-\Delta_{\mathrm{rxn}}H$. Find an expression for the outlet temperature and for the overall reaction conversion.

Question 2a - Exothermic Reaction in MFR With Cooling Jacket
Jenny is considering an identical system to that described in question 1, except this time the reactor has a cooling jacket which is able to remove heat at a rate

$$\dot{Q} = UA(T - T_c) \tag{3}$$

where T_c is the cool temperature of the liquid flowing inside the cooling jacket, T is the temperature of the fluid in the reactor, U is an overall heat transfer coefficient and A is the surface area of the reactor. Help Jenny find an expression for the temperature inside the MFR and the overall reactor conversion.

Question 2b - Upscaling the Reactor
As we might remember from earlier weeks, Jenny has no concerns about reactor safety! She wants to upscale the reactor described in question 2a, because bigger *is* better. If the volume of the reactor were increased by some factor L^3, its surface area increased by L^2 (as would be expected for an object increasing in size but not changing shape) and the volumetric flow rate increased by L^3 (to keep τ the same) what would happen to the temperature inside the reactor? How should Jenny adjust the flow rate to ensure the reactor operates at the same temperature discussed in question 2(a)?

Fredo-Frog-Challenge-Question: Achieving Equilibrium in a PFR

Note: This is a tricky question. Any student who can solve this question within a week shall be rewarded with a Fredo Frog.

Alfred is conducting the following exothermic equilibrium reaction in an adiabatically insulated PFR:

$$\mathrm{A} \underset{k_2}{\overset{k_1}{\rightleftharpoons}} \mathrm{B} \tag{4}$$

The forward reaction is first order in A, and the backward reaction is first order in B. The reaction rate constants are each governed by their own Arrhenius equations:

$$k_1 = k_{1,0}e^{-E_1/RT} \tag{5}$$

$$k_2 = k_{2,0}e^{-E_2/RT} \tag{6}$$

Because the reaction is exothermic, $E_1 < E_2$ *(*question: why is this true for reversible exothermic reactions?*). This means that if the temperature gets too high, the* equilibrium *reaction conversion will be reduced (as predicted by Le Chatelier's principle.) On the other hand, if the temperature gets too low, the reaction will be very slow.*

Alfred is designing an adiabatically insulated plug flow reactor with initial concentration C_{A0}*, volume* V*, and volumetric flow-rate* υ*. The heat released per mole of reaction is given by* $-\Delta_{rxn}H = E_2 - E_1$*, and the specific heat capacity of the fluid inside the reactor is* c_p*. What value of the inlet temperature,* T_0*, will maximise the outlet conversion of A?*