Chemical Engineering 140 **September 24, 2007**

Midterm Examination #1

(185) 1. A dilute liquid species A reacts irreversibly and isothermally to species B in a steady continuous stirred tank reactor (CSTR) as shown in Figure 1a below. The volume of the reactor is V, inlet and outlet volumetric flow rates are equal and constant at Q, and the inlet concentration of A is C_{Ain}. Unfortunately, the reactor is poorly designed with the inlet and outlet lines located too close together causing partial short circuiting of the inlet flow directly into the outlet line as shown in Figure 1a. Hence, the reactor is <u>not</u> well mixed.

To account for the lack of well mixing we envision a conceptual flow line placed between the inlet and outlet flow lines in the model reactor of Figure 1b that carries a fraction of the inlet flow α directly to the outlet line and bypasses the reactor. Thus, the flow in the bypass line never enters the reactor at all. The remaining flow into the reactor is taken as perfectly well mixed.

Figure 1 (a) A poorly mixed CSTR with a first-order, irreversible, isothermal chemical reaction. (b) To model the lack of well mixing a fraction of the inlet flow bypasses the reactor as shown. Fluid in the conceptual bypass line never enters the reactor so no reaction occurs for this amount of flow.

(10) a. What is the volumetric flow rate into the reactor?

(10) b. What is the volumetric flow rate in the outlet line directly exiting the reactor but before joining the bypass line?

(25) c. What is the residence time in the model reactor when there is bypass flow (i.e., the residence time corresponding to material entering and leaving the model reactor)? Relate this residence time to that with no bypass (i.e., when $\alpha = 0$). Explain the meaning of the two residence times. Which residence time is longer and why? Which residence time leads to higher conversion and why?

(35) d. Derive an expression for the relative steady concentration of A in the model reactor, EMBED Equation.DSMT4 , before the bypass line joins as a function of the reaction rate constant k, the residence time in the reactor with no bypass, and the fraction of bypass flow, α.

(25) e. What is the concentration of species A in the outlet flow line after the merge with the bypass line?

(25) f. What is the overall conversion of the system (i.e., the conversion in the final outlet line)?

(20) g. Is the overall conversion of the system (based on the final outlet line) larger or smaller than that in the model reactor (based on the exit line before joining with the bypass line). Explain why quantitatively relative to the model reactor residence time in part c.

(35) h. Assume that a spectrophotometer is available to monitor the concentration of a dilute dye in the final outlet line. Obtain an expression that allows you to use the dye and the spectrophotometer to measure α quantitatively.

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