Chemical Reaction Engineering
Chapter 2.

HW P 2-4$_A$, P 2-7$_B$

Example 2–1 Using the Ideal Gas Law to Calculate C_{A0} and F_{A0}

A gas of pure A at 830 kPa (8.2 atm) enters a reactor with a volumetric flow rate, v_0, of 2 dm^3/s at 500 K. Calculate the entering concentration of A, C_{A0}, and the entering molar flow rate, F_{A0}.

Example 2–2 Sizing a CSTR

The reaction described by the data in Table 2-2

$$A \rightarrow B$$

is to be carried out in a CSTR. Species A enters the reactor at a molar flow rate of 0.4 mol/s.

(a) Using the data in either Table 2-2, Table 2-3, or Figure 2-1, calculate the volume necessary to achieve 80% conversion in a CSTR.

(b) Shade the area in Figure 2-2 that would give the CSTR volume necessary to achieve 80% conversion.

TABLE 2-2 PROCESSED DATA –1

X	0.0	0.1	0.2	0.4	0.6	0.7	0.8
$-r_A\left(\frac{\text{mol}}{\text{m}^3\cdot\text{s}}\right)$	0.45	0.37	0.30	0.195	0.113	0.079	0.05
$(1/-r_A)\left(\frac{\text{m}^3\cdot\text{s}}{\text{mol}}\right)$	2.22	2.70	3.33	5.13	8.85	12.7	20

P2-4$_A$ **(a)** Revisit **Examples 2-1** through **2-3.** How would your answers change if the flow rate, F_{A0}, were cut in half? If it were doubled?

(b) **Example 2-5.** How would your answers change if the two CSTRs (one 0.82 m^3 and the other 3.2 m^3) were placed in parallel with the flow, F_{A0}, divided equally to each reactor.

(c) **Example 2-6.** How would your answer change if the PFRs were placed in parallel with the flow, F_{A0}, divided equally to each reactor?

(d) **Example 2-7.** (1) What would be the reactor volumes if the two intermediate conversions were changed to 20% and 50%, respectively. (2) What would be the conversions, X_1, X_2, and X_3, if all the reactors had the same volume of 100 dm^3 and were placed in the same order? (3) What is the worst possible way to arrange the two CSTRs and one PFR?

(e) **Example 2-8.** The space time required to achieve 80% conversion in a CSTR is 5 h. The entering volumetric flow rate and concentration of reactant A are 1 dm^3/min and 2.5 molar, respectively. If possible, determine (1) the rate of reaction, $-r_A$ = _____, (2) the reactor volume, V = _____, (3) the exit concentration of A, C_A = _____, and (4) the PFR space time for 80% conversion.

P2-7$_B$ The exothermic reaction

$$A \longrightarrow B + C$$

was carried out adiabatically and the following data recorded:

X	0	0.2	0.4	0.45	0.5	0.6	0.8	0.9
$-r_A$ (mol/dm$^3\cdot$min)	1.0	1.67	5.0	5.0	5.0	5.0	1.25	0.91

The entering molar flow rate of A was 300 mol/min.

(a) What are the PFR and CSTR volumes necessary to achieve 40% conversion? (V_{PFR} = 72 dm^3, V_{CSTR} = 24 dm^3)

(b) Over what range of conversions would the CSTR and PFR reactor volumes be identical?

(c) What is the maximum conversion that can be achieved in a 10.5-dm^3 CSTR?

(d) What conversion can be achieved if a 72-dm^3 PFR is followed in series by a 24-dm^3 CSTR?

(e) What conversion can be achieved if a 24-dm^3 CSTR is followed in a series by a 72-dm^3 PFR?

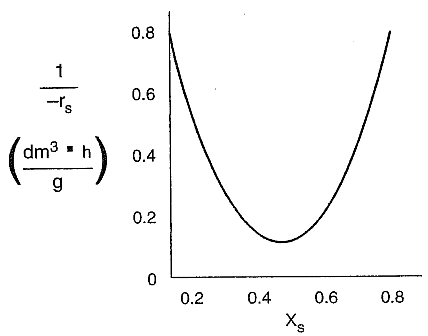
(f) Plot the conversion and rate of reaction as a function of PFR reactor volume up to a volume of 100 dm^3.

P2-8$_B$ In bioreactors, the growth is autocatalytic in that the more cells you have, the greater the growth rate

$$\text{Cells + nutrients} \xrightarrow{\text{cells}} \text{more cells + product}$$

The cell growth rate, r_g, and the rate of nutrient consumption, r_S, are directly proportional to the concentration of cells for a given set of conditions. A

Levenspiel plot of $(1/-r_S)$ a function of nutrient conversion $X_S = (C_{S0} - C_S)/C_{S0}$ is given below in Figure P2-8.



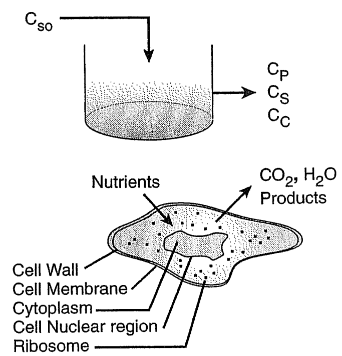


Figure P2-8 Levenspiel plot for bacteria growth.

For a nutrient feed rate of 1kg/hr with C_{S0} = 0.25 g/dm^3, what chemostat (CSTR) size is necessary to achieve.

(a) 40% conversion of the substrate.
(b) 80% conversion of the substrate.
(c) What conversion could you achieve with an 80-dm^3 CSTR? An 80-dm^3 PFR?
(d) How could you arrange a CSTR and PFR in series to achieve 80% conversion with the minimum total volume? Repeat for two CSTRs in series.
(e) Show that Monod Equation for cell growth

$$-r_s = \frac{kC_SC_C}{K_M + C_S}$$

along with the stoichiometric relationship between the cell concentration, C_c, and the substrate concentration, C_s,

$$C_C = Y_{C/S}[C_{S0} - C_S] + C_{c0} = 0.1[C_{S0} - C_S] + 0.001$$

is consistent with Figure P2-8$_B$.

P2-9$_B$ The adiabatic exothermic irreversible gas-phase reaction

$$2A + B \longrightarrow 2C$$

is to be carried out in a flow reactor for an equimolar feed of A and B. A Levenspiel plot for this reaction is shown in Figure P2-9.

(a) What PFR volume is necessary to achieve 50% conversion?
(b) What CSTR volume is necessary to achieve 50% conversion?
(c) What is the volume of a second CSTR added in series to the first CSTR **(Part B)** necessary to achieve an overall conversion of 80%?
(d) What PFR volume must be added to the first CSTR **(Part B)** to raise the conversion to 80%?
(e) What conversion can be achieved in a 6 × 10^4 m^3 CSTR and also in a 6 × 10^4 m^3 PFR?
(f) Critique the shape of Figure P2-9 and the answers (numbers) to this

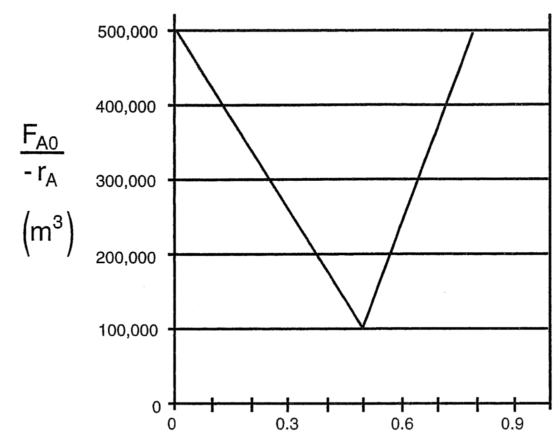


Figure P2-9 Levenspiel plot.