4. Applications of the Design Equations for Continuous-Flow Reactor I

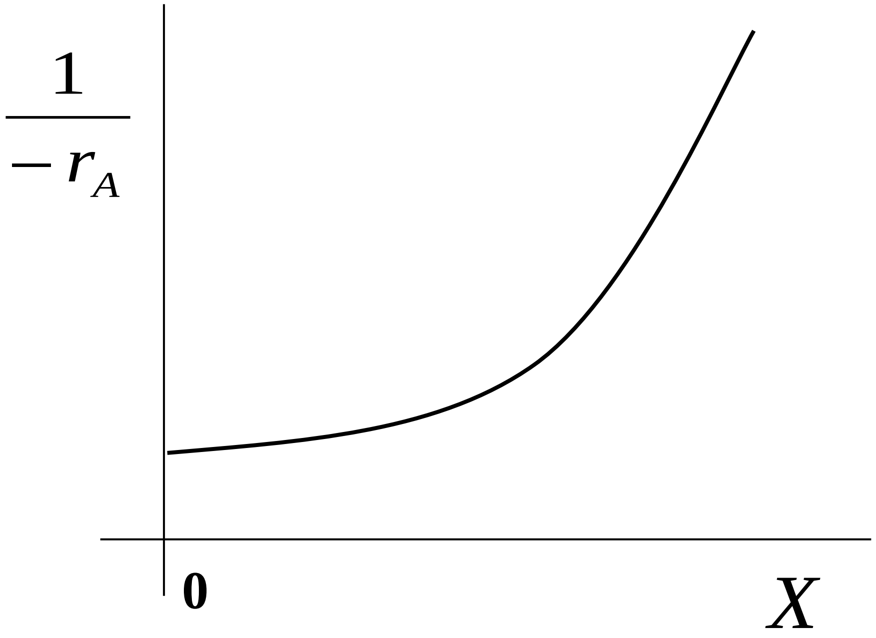
- 1^{st} order dependence

$$-r_A = kC_A = kC_{A0}(1 - X)$$

  - k is specific constant, ftn of only Temp.
    C_{A0}, entering concentration

- Rearrange

$$\frac{1}{-r_A} = \frac{1}{kC_{A0}}\left(\frac{1}{1 - X}\right)$$



4. Applications of the Design Equations for Continuous-Flow Reactor II

- Reactor size of CSTR and PFR

  - Raw data

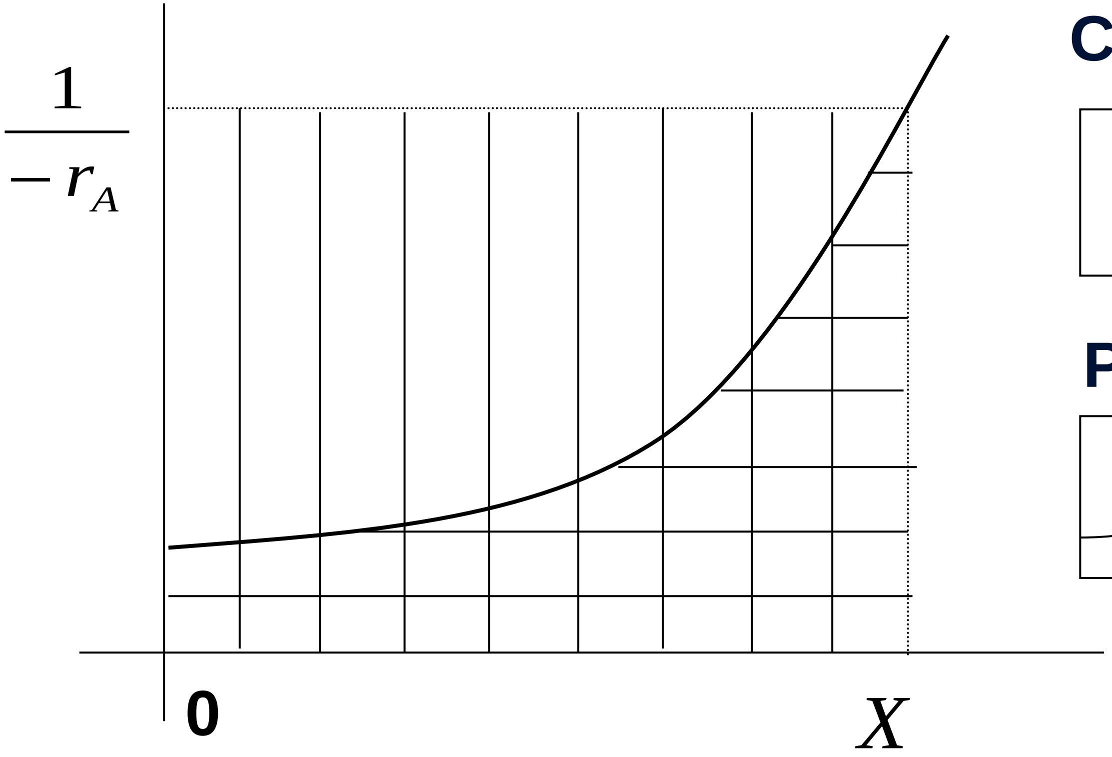
X	0.0	0.1	0.2	0.4	0.6	0.7	0.8
$-r_A$(mol/m^{3}s)	0.45	0.37	0.30	0.195	0.113	0.079	0.05
$(1/-r_A)$(m^{3}s/mol)	2.22	2.70	3.33	5.13	8.85	12.7	20

  - Manipulated

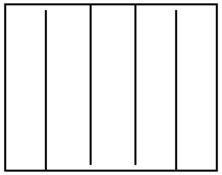
X	0.0	0.1	0.2	0.4	0.6	0.7	0.8
$-r_A$(mol/m^{3}s)	0.45	0.37	0.30	0.195	0.113	0.079	0.05
$(1/-r_A)$(m^{3}s/mol)	2.22	2.70	3.33	5.13	8.85	12.7	20
$[F_{A0}/-r_A]$(m^3)	0.89	1.08	1.33	2.05	3.54	5.06	8.0

4. Applications of the Design Equations for Continuous-Flow Reactor II

- **Reactor sizing**

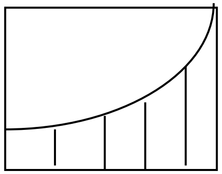


CSTR



$$\frac{1}{-r_A}X$$

PFR



$$\int_0^X \frac{1}{-r_A}dX$$

Plots for sizing CSTR and PFR

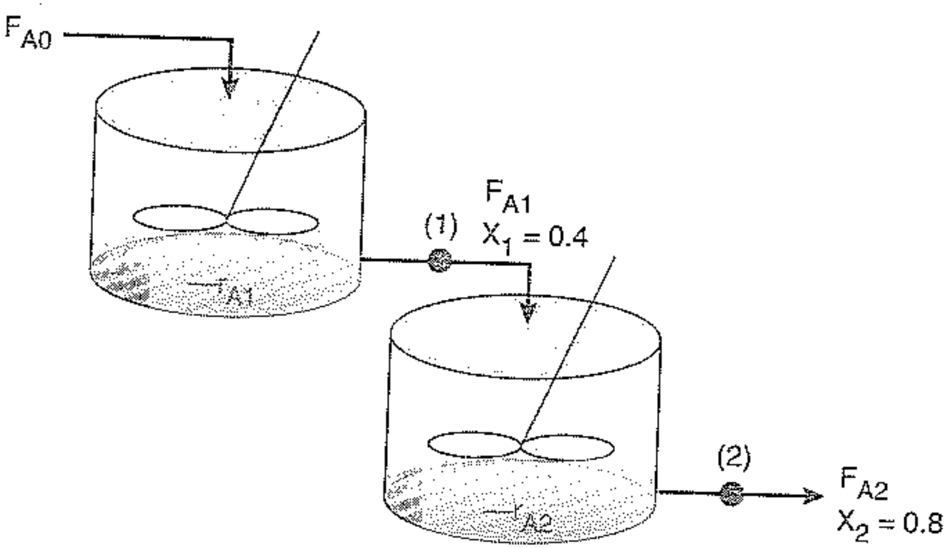
5. Reactors in Series I

- Given $-r_A$ as a function of conversion, one can also design any sequence of reactors

$$X_i = \frac{\text{moles of A reacted up to a point i}}{\text{moles of A fed to first reactor}}$$

Only valid if there are no side streams

- CSTRs in series 1



5. Reactors in Series II

○ **CSTRs in series 2**

- Reactor 1

$$\text{In - Out} + \text{Generaton} = 0$$

$$F_{A0} - F_{A1} + r_{A1}V_1 = 0$$

- **molar flow rate of A at point 1 is**

$$F_{A1} = F_{A0} - F_{A0}X_1$$

$$\boxed{V_1 = F_{A0}\left(\frac{1}{-r_{A1}}\right)X_1}$$

- Reactor 2

$$\text{In - Out} + \text{Generaton} = 0$$

$$F_{A1} - F_{A2} + r_{A2}V_2 = 0$$

- **molar flow rate of A at point 2 is**

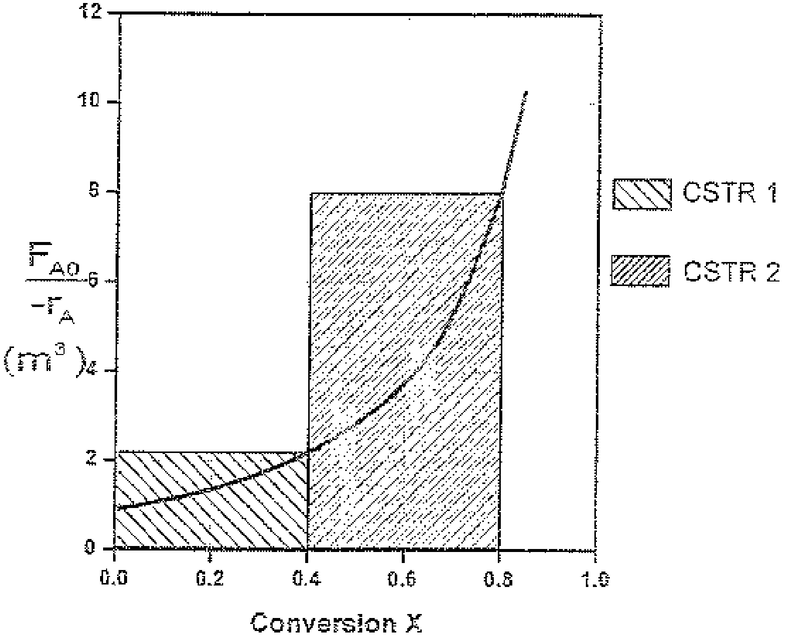
$$F_{A2} = F_{A0} - F_{A0}X_2$$

5. Reactors in Series III

- **CSTRs in series 3**
  - **Combining & rearranging**

$$V_2 = \frac{F_{A1} - F_{A2}}{-r_{A2}} = \frac{(F_{A0} - F_{A0}X_1) - (F_{A0} - F_{A0}X_2)}{-r_{A2}}$$

$$\boxed{V_2 = \frac{F_{A0}}{-r_{A2}}(X_2 - X_1)}$$

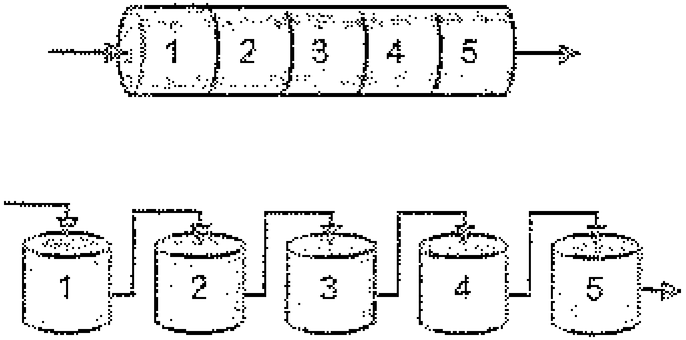


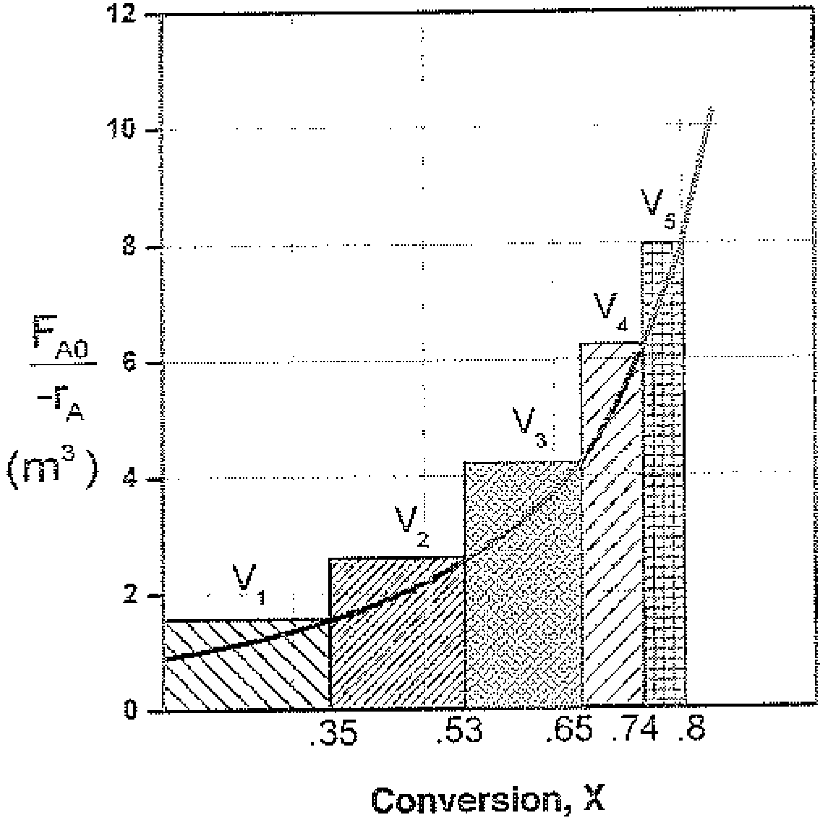
5. Reactors in Series IV

○ **CSTRs in series 4**

- Large number of CSTRs in series

⇒ PFR approximation

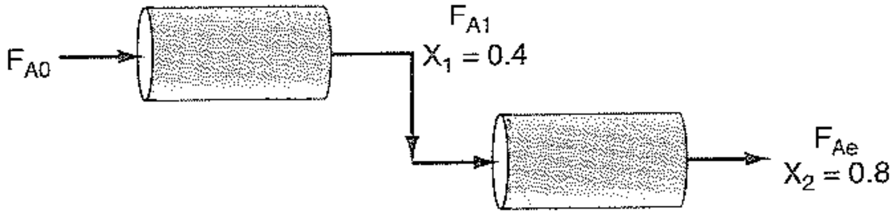


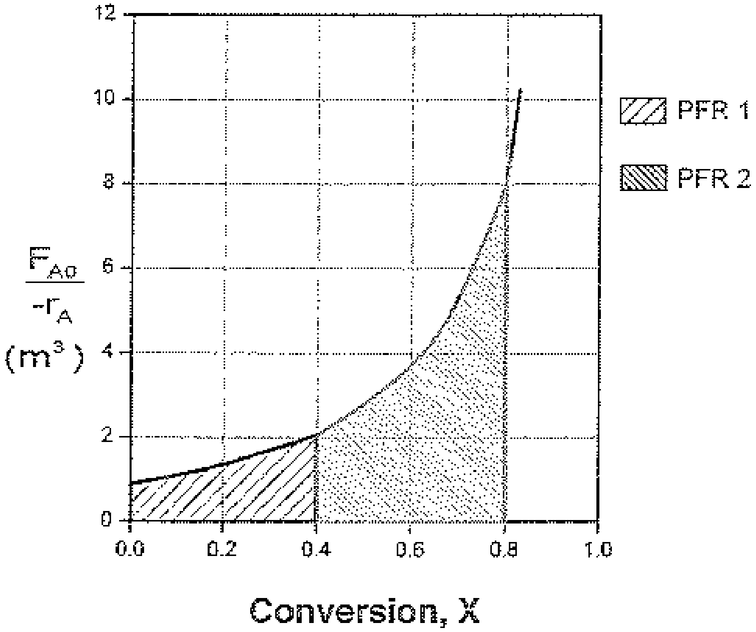


5. Reactors in Series V

- PFRs in series
  - By definition

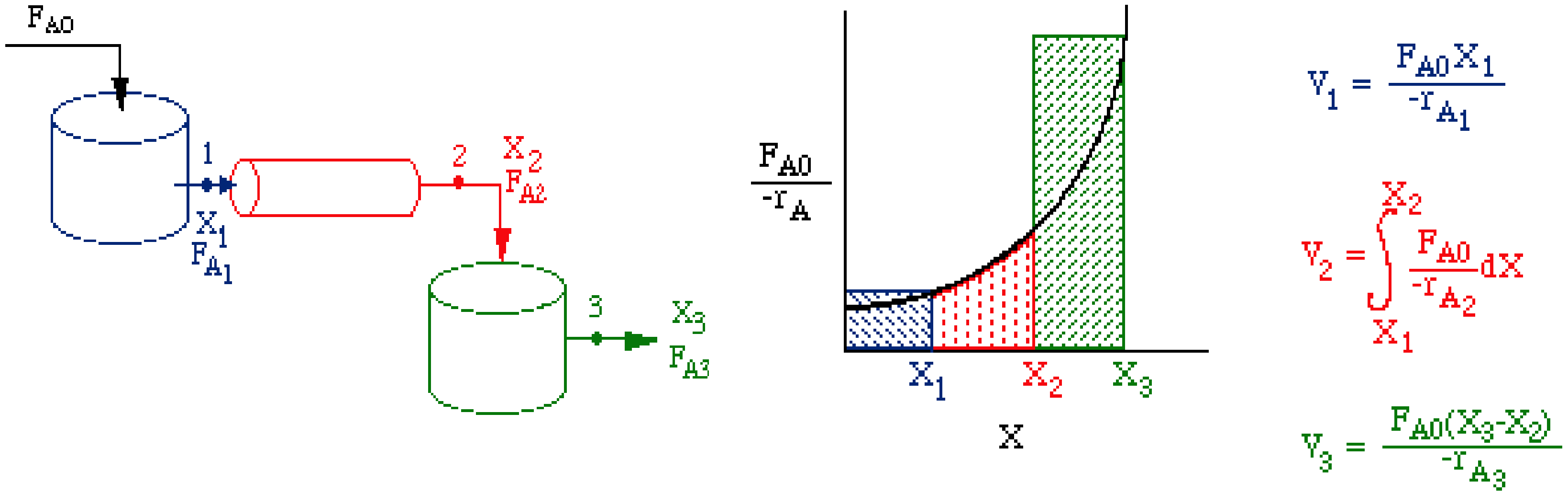
$$\int_0^{X_2} F_{A0}\frac{dX}{-r_A}=\int_0^{X_1} F_{A0}\frac{dX}{-r_A}+\int_{X_1}^{X_2} F_{A0}\frac{dX}{-r_A}$$





5. Reactors in Series VI

- Consider a PFR between two CSTRs



$$V_1 = \frac{F_{A0}X_1}{-r_{A_1}}$$

$$V_2 = \int_{X_1}^{X_2} \frac{F_{A0}}{-r_{A_2}} dX$$

$$V_3 = \frac{F_{A0}(X_3 - X_2)}{-r_{A_3}}$$

5. Reactors in Series VII

- **Example 1**

- For the irreversible gas-phase reaction: the following correlation was determined from laboratory data (the initial concentration of A is 0.2 g mol/L):

$$\text{For } X \le 0.5: \quad \frac{10^{-8}}{-r_A} = 3.0 \frac{m^3 \bullet s}{mol}$$

$$\text{For } X > 0.5: \quad \frac{10^{-8}}{-r_A} = 3.0 + 10(X - 0.5) \frac{m^3 \bullet s}{mol}$$

The volumetric flow rate is 5 m^3/s.

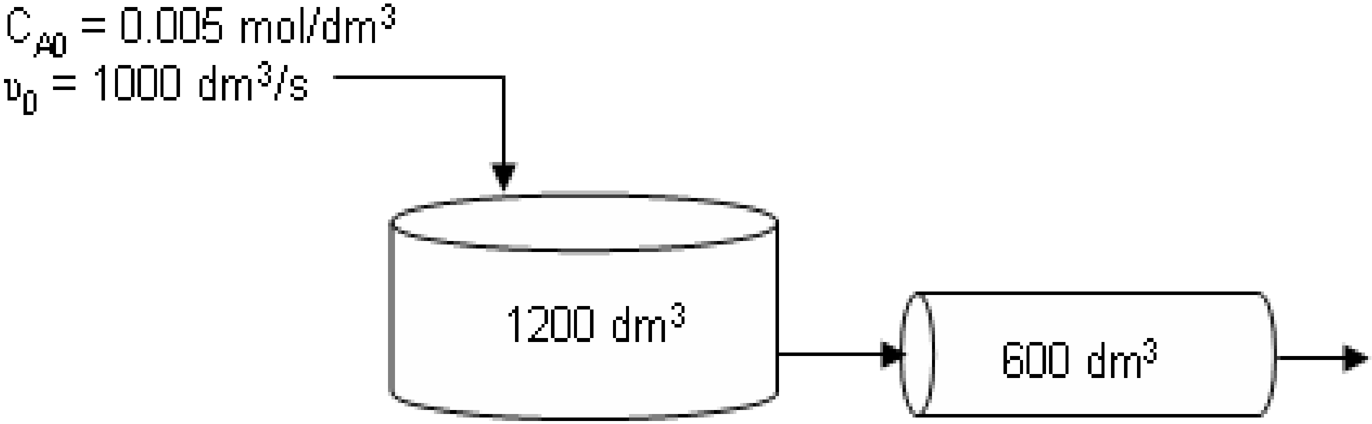
a. Over what range of conversions are the plug-flow reactor and CSTR volumes identical?

5. Reactors in Series VIII

- **Example 1**
  - **b. What conversion will be achieved in a CSTR that has a volume of 90 L?**
  - **c.** What plug-flow reactor volume is necessary to achieve 70% conversion?
  - d. What CSTR reactor volume is required if effluent from the plug-flow reactor in part (c) is fed to a CSTR to raise the conversion to 90%?
- **Example 2**

5. Reactors in Series IX

- **Example 2**
  - **Pure A is fed at a volumetric flow rate of 1000 dm^3 /h and at a concentration of 0.005 mol/dm^3 to an existing CSTR, which is connected in series to an existing tubular reactor.**



V_{CSTR} = 1200 dm^3, $V_{tubular}$ = 600 dm^3,

X_1, X_2 = ? The reciprocal rate vs. conversion given

5. Reactors in Series X

- **Example 2**
  - **The reciprocal rate vs. conversion given**

$A \longrightarrow \text{product}$