1. **General equation**

\[ F_{\text{in}} - F_{\text{out}} + \text{Generation} = \text{accumulation} \]

Generation = \((-r_A) \Delta V (1 - \varepsilon)\)

\[ F_{A,V} - F_{A,V+\Delta V} - r_A \Delta V (1 - \varepsilon) = 0 \]

\[
=> \quad \frac{dF_A}{dV} = -r_A (1 - \varepsilon)
\]

2. \( F_i - F_{out} + G = \frac{dN_A}{dt} \)

- \( F_i = 0 \)
- \( G_j = 2.5 \times 10^{-7} \text{ mole/m}^2 \text{s} \)
- \( C_{0,\text{stink}} = 5 \times 10^{-3} \text{ mole/m}^3 \)
- \( \nu_0 = 0.1 \text{ m}^3/\text{s} \)
- \( F_{out} = \nu_0 C_{s, out} \)
- \( V = 5 \times 8 \times 2.5 = 100 \text{ m}^3 \)
- \( A = 5 \times 8 \text{ m}^2 \)

(a) steady-state

\[
F_i - F_{out} + G = \frac{dN_A}{dt}
\]

\[-\nu_0 C_{s, out} + G_j A = 0 \]

\[-0.1 \times C_{s, out} + 2.5 \times 10^{-7} \times 40 = 0 \]

\[ C_{s, out} = 10^{-4} \text{ mole/m}^3 \]

(b) not steady state

\[
F_i - F_{out} + G = \frac{dN_A}{dt}
\]

\[-F_{out} + G = \frac{dC_s V}{dt} \]

\[-\nu_0 C_s + G_j A \]

\[
\frac{dC_s}{V} = \frac{dC_s}{dt} \]

\[
\frac{\nu_0}{V} dt = \frac{dC_s}{(C_s - \frac{G_j A}{\nu_0})} \]

\[
\int_0^{3600} (-10^{-4}) dt = \int_{C_{s,0}}^{C_s} \frac{dC_s}{C_s (C_s - 10^{-7})} \]

\[ C_s = 2.34 \times 10^{-4} \text{ mole/m}^3 \]
3. $A \rightarrow B$

$X = 0.99$

$F_{A0} = 5 \text{ mol} / \text{ h}$

$\nu_0 = 10 \text{ dm}^3 / \text{ h}$

$C_{A0} = 0.5 \text{ mole} / \text{ dm}^3$

For CSTR \[ V = \frac{F_{A0} X}{-r_A} \]

For PFR \[ \frac{dF_A}{dV} = r_A \]

$F_A = F_{A0}(1-X) \Rightarrow dF_A = -F_{A0}dX$

$F_{A0} \frac{dX}{dV} = -r_A$

(a) $-r_A = k \quad k = 0.05$

$0$

For CSTR \[ V = \frac{5 \times 0.99}{0.05} = 99 \text{ dm}^3 \]

For PFR \[ \int_0^{0.99} \frac{dX}{0.05} = \int dV \]

$V = 99 \text{ dm}^3$

(b) $-r_A = kC_A \quad k = 0.0001 \text{ s}^{-1}$

For CSTR \[ V = \frac{F_{A0} X}{-r_A} = \frac{F_{A0} X}{kC_A} = \frac{\nu_0 C_{A0} X}{kC_{A0} (1-X)} = \frac{\nu_0 X}{k(1-X)} = 2750 \text{ dm}^3 \]

$\frac{dF_A}{dV} = -F_{A0} \frac{dX}{dV} = r_A = -kC_A$

For PFR \[ \nu_0 C_{A0} \frac{dX}{dV} = kC_{A0} (1-X) \]

$\frac{\nu_0}{k} \int_0^{0.99} \frac{dX}{(1-X)} = \int dV$

$V = 127.92 \text{ dm}^3$

(c) $-r_A = kC_A^2 \quad k = 3 \text{ dm}^3 / \text{ mol h}$

For CSTR \[ V = \frac{F_{A0} X}{-r_A} = \frac{\nu_0 C_{A0} X}{kC_{A0}^2 (1-X)^2} = \frac{\nu_0 X}{kC_{A0}^2 (1-X)^2} = 66000 \text{ dm}^3 \]
\[
\frac{dF_A}{dV} = -F_{A0} \frac{dX}{dV} = r_A = -kC_A^2 = -kC_{A0}^2 (1 - X)^2
\]

For PFR

\[
\frac{\nu_0}{kC_{A0}} \frac{dX}{(1 - X)^2} = dV
\]

\[V = 660 \text{dm}^3\]

4. (for 3rd edition)

<table>
<thead>
<tr>
<th>X</th>
<th>0</th>
<th>0.2</th>
<th>0.4</th>
<th>0.6</th>
<th>0.8</th>
<th>0.9</th>
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<tbody>
<tr>
<td>r_A</td>
<td>10</td>
<td>16.67</td>
<td>50</td>
<td>50</td>
<td>12.5</td>
<td>90.9</td>
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<tr>
<td>1/r_A</td>
<td>0.1</td>
<td>0.06</td>
<td>0.02</td>
<td>0.02</td>
<td>0.8</td>
<td>0.11</td>
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(a)

\[V_{CSTR} = \frac{F_{A0} X}{-r_A} = \frac{300 \times 0.4}{50} = 2.4 \text{ dm}^3\]

\[V_{PFR} = F_{A0} \int_0^X \frac{dX}{-r_A} = 300 \times \frac{(0.1 + 0.02)}{2} \times 0.4 = 7.2 \text{ dm}^3\]

(b) Between 0.4 ~ 0.6, because the rate is constant over this conversion range.

(c) \(V_{CSTR} = 10.5 \text{ dm}^3\)

\[= \frac{F_{A0} X}{-r_A} = 300 \times \frac{X}{-r_A}\]
$$\Rightarrow \frac{X}{-r_a} = 0.035$$

You can trial and error until \( \frac{X}{-r_a} = 0.035 \), or just calculate area from the plot.

From \( X = 0.4 \) \( V_1 = 2.4 \)
\( X = 0.6 \) \( V_2 = 3.6 \)

\[ 10.5 = 300 X (0.3X-0.16) \]
Maximum conversion \( X = 0.7 \)

(d)

From part (a) we know \( X_1 = 0.4 \)
\( V_{\text{CSTR}} = 2.4 = 300(X_2-0.4)(0.3X_2-0.16) \)
\( X = 0.64 \)

(e)

From part (a) we know \( X_1 = 0.4 \)
\[ V_{PFR} = 7.2 = F_{A0} \int _0^X \frac{dX}{r_4} = 300 \int _{0.4}^{X^2} \frac{dX}{r_4} = 1.2 + 300 \int _{0.6}^{X^2} (0.3X - 0.16)dX \]

\[ X_2 = 0.905 \]
### 4. for 4th edition

<table>
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<tr>
<td>$r_A$</td>
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<td>1.67</td>
<td>5.0</td>
<td>5.0</td>
<td>1.25</td>
<td>0.91</td>
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<tr>
<td>$1/r_A$</td>
<td>1</td>
<td>0.6</td>
<td>0.2</td>
<td>0.2</td>
<td>0.8</td>
<td>1.1</td>
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<table>
<thead>
<tr>
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<th>0.2</th>
<th>0.4</th>
<th>0.6</th>
<th>0.8</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y = 3x - 1.6$</td>
<td>$y = -2x + 1$</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

(a)

$$V_{CSTR} = \frac{F_{A0} X}{-r_A} = \frac{300 \times 0.4}{5} = 24 \text{ dm}^3$$

$$V_{PFR} = F_{A0} \int_0^X \frac{dX}{-r_A} = 300 \times \frac{(1 + 0.2)}{2} \times 0.4 = 72 \text{ dm}^3$$

(b) Between 0.4 ~ 0.6, because the rate is constant over this conversion range.

(c) $V_{CSTR} = 10.5 \text{ dm}^3$

$$= \frac{F_{A0} X}{-r_A} = 300 \times \frac{X}{-r_A}$$

$$\Rightarrow \frac{X}{-r_A} = 0.035$$

You can trial and error until $\frac{X}{-r_A} = 0.035$, or just calculate area from the plot.

From $X=0.4$ 
$V_1 = 24$

$10.5 = 300 \times (-2X+1)$

Maximum conversion $X = 0.0378$
From part (a) we know $X_1 = 0.4$

$V_{CSTR} = 24 = 300(X_2 - 0.4)(3X_2 - 1.6)$

$X_2 = 0.64$

From part (a) we know $X_1 = 0.4$

$V_{PFR} = 72 = F_{A0}$

$\int_{0}^{X} \frac{dX}{-r_{d}} = 300 \int_{0.4}^{X_2} \frac{dX}{-r_{d}} = 12 + 300 \int_{0.6}^{X_2} (3X - 1.6)dX$

$X_2 = 0.905$
5.
(a) CSTR is used before PFR.
(b) One can calculate the amount of catalyst needed to carry out the same reaction to
80% conversion using a single CSTR by determining the area of the rectangle.

\[
\text{approximately } 22.4 \text{ kg catalyst}
\]
(c) for 40% conversion

\[
\Rightarrow 8 \text{ kg catalyst}
\]
Calculate the area under the curve between 0 and 0.8. Approximately 30 kg

Calculate the area under the curve between 0 and 0.4. Approximately 15 kg
(g) For different \(-r_A\) vs. \(X\) curves, reactors should be arranged so that the smallest amount of catalyst is needed to give the maximum conversion. This can be done by minimizing the area that is occupied by a given reactor. One useful heuristic is that for curves with a negative slope, it is generally better to use a CSTR. Similarly, when the curve has a positive slope, it is generally better to use a PFR.