6.1 For a second order reaction: $k\tau = \dfrac{C_{A0}-C_A}{C_A^2}$, so for the two reactors

$$\frac{V_2}{V_1} = 2 = \frac{k\tau_2}{k\tau_1} = \frac{(C_{A1}-C_{A2})/C_{A2}^2}{(C_{A0}-C_{A1})/C_{A1}^2} = \frac{(0.5-C_{A2})/C_{A2}^2}{(1-0.5)/0.5^2}$$

or

$$4C_{A2}^2 = 0.5 - C_{A2}$$

therefore $C_{A2} = 0.25$ mol/lit. ←

6.3 For the second order reaction

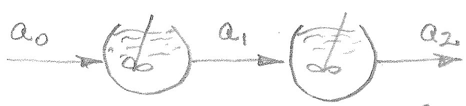
for the mixed flow reactor: $k\tau_m = \dfrac{C_{A0}-C_{A1}}{C_{A1}^2} = \dfrac{4-1}{1} = 3$

so for the plug flow reactor: $k\tau_p = 3k\tau_m = 9$

and $\dfrac{C_{A2}}{C_{A1}} = \dfrac{1}{1+k\tau_p C_{A1}} = \dfrac{1}{1+9(1)} = 0.1$

$\therefore$ $C_{A2} = 0.1\,(C_{A1}) = 0.1$ mol/lit ←

6.5



$\therefore\ \bar{t}_i = 2$ weeks $= 20160$ min

Radioactive decay follows first order kinetics, so here

$$k = \frac{\ln 2}{t_{1/2}} = \frac{0.6931}{14\text{ min}} = 0.0495\text{ min}^{-1}$$

so $\dfrac{a_2}{a_0} = \dfrac{a_2}{a_1}\cdot\dfrac{a_1}{a_0} = \dfrac{1}{(1+k\bar{t}_i)} = \dfrac{1}{[1+0.0495(20160)]^2} = 1.0017\times10^{-6}$

For plug flow

$$\frac{a_2}{a_0} = 1.0017\times10^{-6} = e^{-k\tau_p} = e^{-0.0495\,\tau_p}$$

$$\tau_p = \frac{\ln(1.0017\times10^{-6})}{-0.0495} = 279\text{ min} = 4.65\text{ hr}$$ ←

instead of 2 weeks for the MFR

6.7

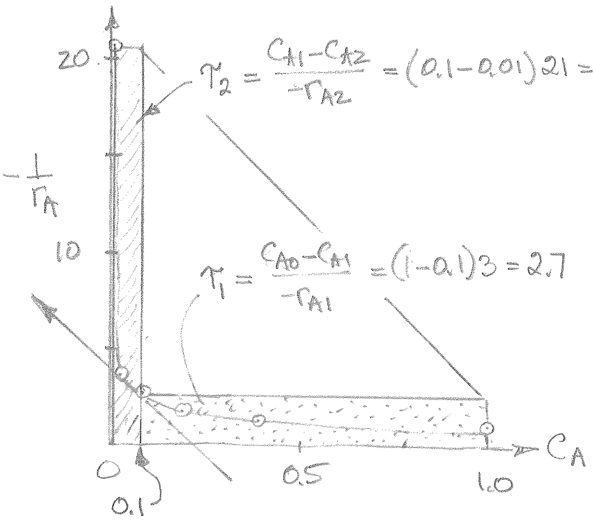
$C_{A0} = 1\ \text{mol/lit}$, $v = 10\ \text{lit/min}$ → C_{A1} → $C_{A2} = 0.01$

$\tau_1 = \frac{V_1}{v}$ $\tau_2 = \frac{V_2}{v}$

$$-r_A = \frac{C_A}{0.2 + C_A}, \frac{\text{mol}}{\text{lit}\cdot\text{min}}$$

It is best to solve this graphically. Thus by the method of maximization of rectangles

C_A	$-\frac{1}{r_A} = \frac{0.2+C_A}{C_A}$
1	1.2
0.4	1.5
0.2	2
0.1	3
0.08	3.5
0.01	21



$$\therefore V_1 = \tau_1 v = 2.7(10) = 27\ \text{lit}$$

$$V_2 = \tau_2 v = 1.9(10) = 19\ \text{lit}$$

6.9 With recycle for a first order reaction we have

$$k\tau = (R+1)\ln\left[\frac{C_{A0} + RC_{Af}}{(R+1)C_{Af}}\right] = (2+1)\ln\left[\frac{10+2(1)}{(2+1)1}\right] = 3\ln 4$$

Without recycle (plug flow)

$$k\tau = \ln\frac{C_{A0}}{C_{Af}} = \ln 10$$

Therefore

$$\frac{v_{without}}{v_{with}} = \frac{\tau_{with}}{\tau_{without}} = \frac{3\ln 4}{\ln 10} = 1.8$$

no recycle is better

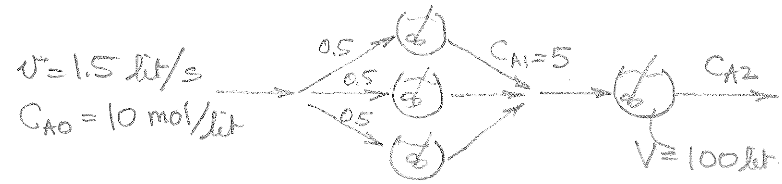
6.11 For this autocatalytic reaction the maximum rate occurs where $C_A = C_R$. Thus operate at $C_A = 5$, if possible. Here

$$-r_A = 0.001 C_A C_R = 0.001 \times 5 \times 5 = 0.025$$

So for mixed flow

$$\tau = \frac{10-5}{0.025} = \frac{5}{0.025} = 200\,s = \frac{V}{v} = \frac{V}{1.5}$$

Thus $V = 300$ lit, or 3 mfr side by side. Thus we should hook the 4 reactors as shown



For the fourth reactor $\tau = V/v = 100/1.5 = 66.7s$, so

$$\underset{66.7s}{\tau} = \frac{5 - C_{A2}}{k C_{A2} C_{R2}} = \frac{5 - C_{A2}}{0.001\, C_{A2}(10 - C_{A2})}, \text{ or } C_{A2} = 3.486 \frac{mol}{lit}$$

6.13 From ½ life data for radioactive decay (first order kinetics) we have

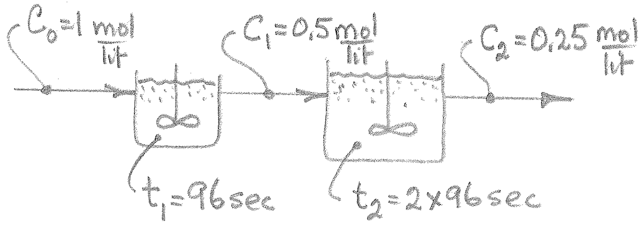
$$-\frac{dC}{dt} = kC \;\cdots\text{or}\cdots\; \ln\frac{C_0}{C} = kt \;\cdots\text{or}\cdots\; \ln 2 = k(20\,hrs) \;\cdots\text{or}\cdots\; k = \frac{\ln 2}{20\,hr}$$

and for 2 equal sized tanks in series Eq 6.6a gives

$$\frac{C_{out}}{C_0} = \frac{1}{(1 + k\tau_i)^2} = \frac{1}{\left(1 + \frac{\ln 2}{20}(400)\right)^2} = \frac{1}{(1 + 20 \ln 2)^2} = 0.00453$$

∴ Only 0.453% of the activity remains,
99.5% of the activity has disappeared

6.15



We have 2 pieces of kinetic information, what happens in the 2 reactors, thus we can fit a kinetic equation with 2 constants. So let us try an n^{th} order equation.

For 1^{st} reactor: $\tau_1 = \dfrac{C_0 - C_1}{k C_1^n}$

For 2^{nd} reactor: $\tau_2 = \dfrac{C_1 - C_2}{k C_2^n}$

combining … $\dfrac{\tau_1}{\tau_2} = \dfrac{C_0 - C_1}{C_1 - C_2}\left(\dfrac{C_2}{C_1}\right)^n$

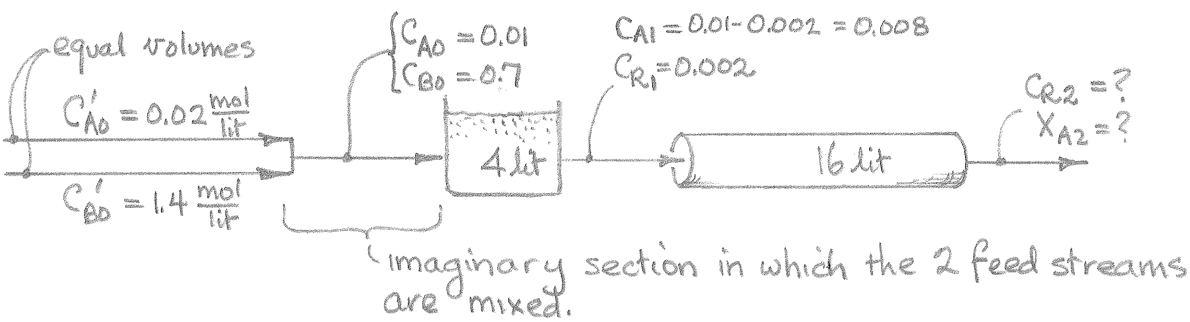
$$\therefore\ n = \frac{\log\frac{\tau_1}{\tau_2} + \log\frac{C_1 - C_2}{C_0 - C_1}}{\log\frac{C_2}{C_1}} = \frac{\log\frac{1}{2} + \log\frac{1}{2}}{\log\frac{1}{2}} = 2$$

and on replacing in the 1^{st} equation $k = \dfrac{C_0 - C_1}{\tau_1 C_1^n} = \dfrac{0.5}{96(0.5)^2} = \dfrac{1}{48}\ \dfrac{lit}{mol \cdot s}$

Hence the rate

$$-r_A = \left(\frac{1}{48}\ \frac{lit}{mol \cdot sec}\right) C_A^2 = \left(1.25\ \frac{lit}{mol \cdot min}\right) C_A^2$$

6.17



Simplification: Since $C_{A0} = 1/70 \cdot C_{B0}$ we may assume that $C_{B0} \cong$ constant, and that the reaction is 1^{st} order with respect to A.

For the mixer: $k\tau_m = \dfrac{C_{A0} - C_{A1}}{C_{A1}} = \dfrac{0.010 - 0.008}{0.008} = \dfrac{1}{4}$

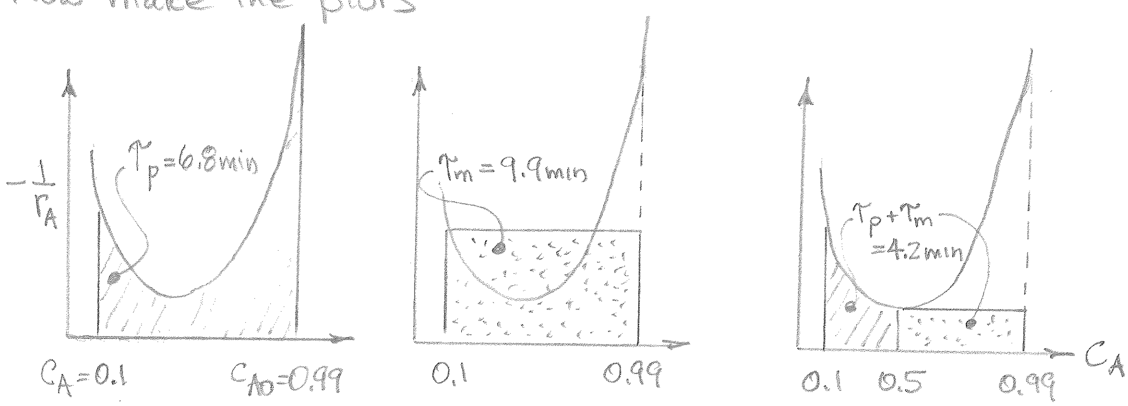
For the reactor: $k\tau_p = 4(k\tau_m) = 4\left(\frac{1}{4}\right) = -\displaystyle\int_{0.008}^{C_{A2}} \frac{dC_A}{C_A} = \ln\frac{0.008}{C_{A2}}$ … or $C_{A2} = 0.00293$

$$\therefore\ X_A = 0.707 \quad \&\quad C_{R2} = 0.00793$$

6.19 Let us solve by using the graphical procedure, and let's use concentrations, not conversions. First prepare the $1/-r_A$ vs C_A curves from the data of the table, below

C_A	C_R	$-r_A = kC_AC_R$	$\frac{1}{-r_A}$
0.99	0.01	0.0099	101.01
0.95	0.05	0.0475	21.05
0.90	0.1	0.09	11.11
0.70	0.3	0.21	4.76
0.50	0.5	0.25	4.00
0.30	0.7	0.21	4.76
0.10	0.9	0.09	11.11

Now make the plots



So

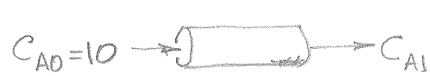
$\tau_p = 6.8\ min$ ← a)

$\tau_m = 9.9\ min$ ← b)

$\tau_{best} = \tau_m + \tau_p = 2 + 2.2 = 4.2\ min$ ← c)

6.21 Originally we had plug flow, 1^{st} order, $X_A = 0.9$

$$\frac{C_A}{C_{A0}} = e^{-k\tau}$$



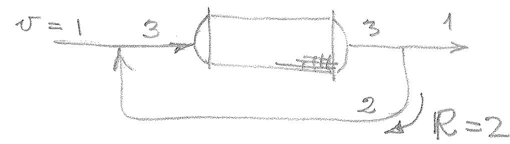
or $$k\tau = \ln\frac{C_{A0}}{C_A} = \ln 10 = 2.3 \quad \text{---- (i)}$$

With recycle

$$k\tau = (R+1)\ln\left[\frac{C_{A0} + RC_{Af}}{(R+1)C_{Af}}\right] = (2+1)\ln\left[\frac{10 + 2C_{Af}}{(2+1)C_{Af}}\right] \quad \text{---- (ii)}$$

6.21 (continued)

Combining (i) & (ii) gives



$$3 = (2+1)\ln\left[\frac{10+2C_{Af}}{(2+1)C_{Af}}\right]$$

Solving for C_{Af} gives

$C_{Af} = 2.24$, or $X_{Af} = 0.776$