Introduction to Reactor Design, 3K4
Tutorial 2

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Assignment objectives: math refresher; mol balances; working with conversion

- Reminder: always state assumptions in this tutorial, in assignments, midterms and exams.

Question 1 [4]

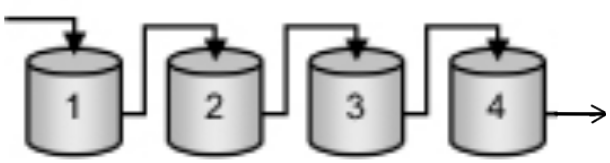
Make sure you can do these in a test/exam (i.e. without internet access). Let X be conversion; find:

1. $\displaystyle\int \frac{1}{(1-X)^2}\,dX =$
2. $\displaystyle\int_{X_1}^{X_2} \frac{1}{(1-X)^2}\,dX =$
3. And in general, what is: $\displaystyle\int \frac{a+x}{bx}\,dx =$

Question 2 [10]

For the question we covered in the end of class last week (see last page of this tutorial), we showed the volume of a PFR required is the area under the curve. The volume required was $2.16\,\text{m}^3$ to obtain 80% conversion.

If we used 4 CSTRs in series:



1. What would be the size of each reactor if we wanted 20% conversion in each reactor?
2. What is the total volume of these 4 reactors?
3. How does this total CSTR volume compare with (a) the single CSTR volume and (b) the single PFR volume?
4. What is the reaction rate in each reactor?

Question 3 [20]

The following reaction rate, $-r_A$ measured in units of $\left[\dfrac{\text{kmol}}{\text{hr.m}^3}\right]$ is observed at a particular conversion, X:

Reaction rate	Conversion
78	0.0
106	0.2
120	0.4
70	0.6

We showed in class that the area under this curve is related to volume of the plug flow reactor.

1. Start from the general mol balance and derive the equation that shows the area is equal to the plug flow reactor's volume; clearly state all assumptions used in your derivation.
2. Assuming these assumptions are all met, calculate the plug flow reactor's volume to achieve a 60% conversion given a feed rate of $15\,\text{mol.s}^{-1}$ to the reactor.
3. If there is zero conversion at the entry to the PFR and 60% at the exit; what is the conversion half-way along the reactor?
4. What is the conversion at 25% of the way along the reactor?
5. Now plot a graph a graph of conversion throughout the reactor, from start to end. The x-axis on your plot should be the volume co-ordinate, V.
6. What is the reaction rate at the entry of the reactor?
7. And at the midpoint?
8. And at the exit?
9. Plot a curve that shows the reaction rate throughout the reactor, from start to end. The x-axis on your plot should be the volume co-ordinate, V.

Question 4 [12]

A new drug is being prototyped in a batch reactor; as is becoming common-place now, this drug is grown *inside* a cell as a by-product of the regular cellular processes. So far, experiments have shown the rate of consumption of the starting material, an animal-derived cell A, is the only concentration in the rate expression.

$$-r_A = \frac{5.5C_A}{20 + C_A}$$

where $-r_A$ has units of $\left[\dfrac{\text{mol}}{\text{day.m}^3}\right]$

1. Why is a batch reactor suitable for this type of testing?

2. 30 mols of cellular material are added to a batch reactor of $0.5\,\text{m}^3$; the liquid food source is added at the same time to the reactor, in excess. Calculate the amount of cellular material remaining in the tank after 10 days.
3. How many days are required to convert 80% of the starting cellular material.
4. Show a plot of the concentration in the tank over time until there is essentially 100% conversion.

Note: in tutorial 1 you solved a similar problem, but for a CSTR and PFR.

Table 2-2. Processed Data

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
$(F_{A0}/-r_A)(\text{m}^3)$	0.89	1.08	1.33	2.05	3.54	5.06	8.0