CHE 402 Kinetics & Reactor Design

Dr. Eid Al-Mutairi

Announcements

- **Quiz I**

Oct. 29th

Material: Chapters 1&2

- **HW#2**

Chapter 2:
Conversion and Reactor Sizing

Dr. Eid Al-Mutairi

Reactor Staging

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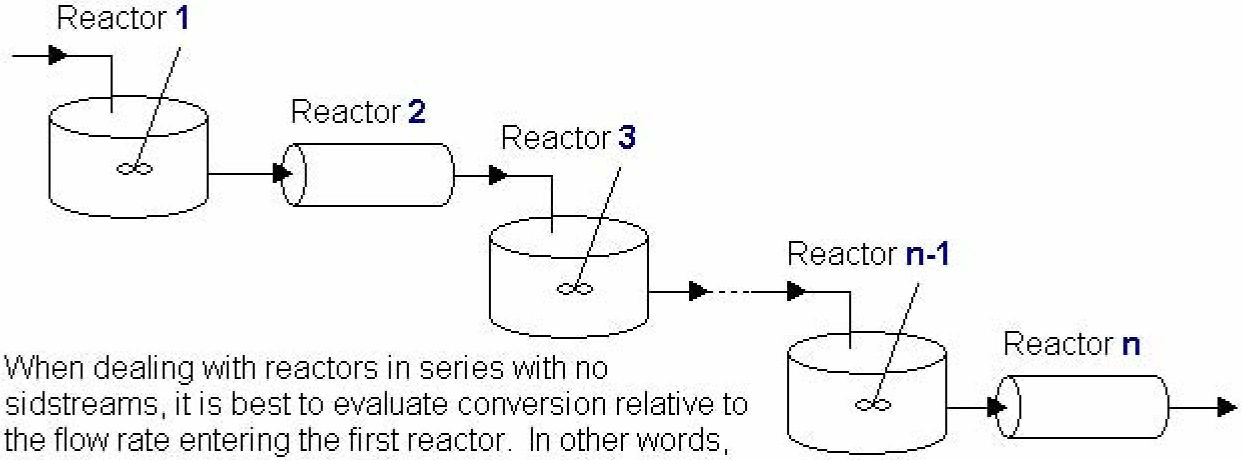
Reactor Staging

Many times, reactors are connected in series, so that the exit stream of one reactor is the feed stream of the next. One possible arrangement is shown below:



When dealing with reactors in series with no sidestreams, it is best to evaluate conversion relative to the flow rate entering the first reactor. In other words, the conversion at the **n**th reactor would be:

$$X_n = \frac{\text{total moles reacted up to point } n}{\text{moles of A fed to the first reactor}}$$

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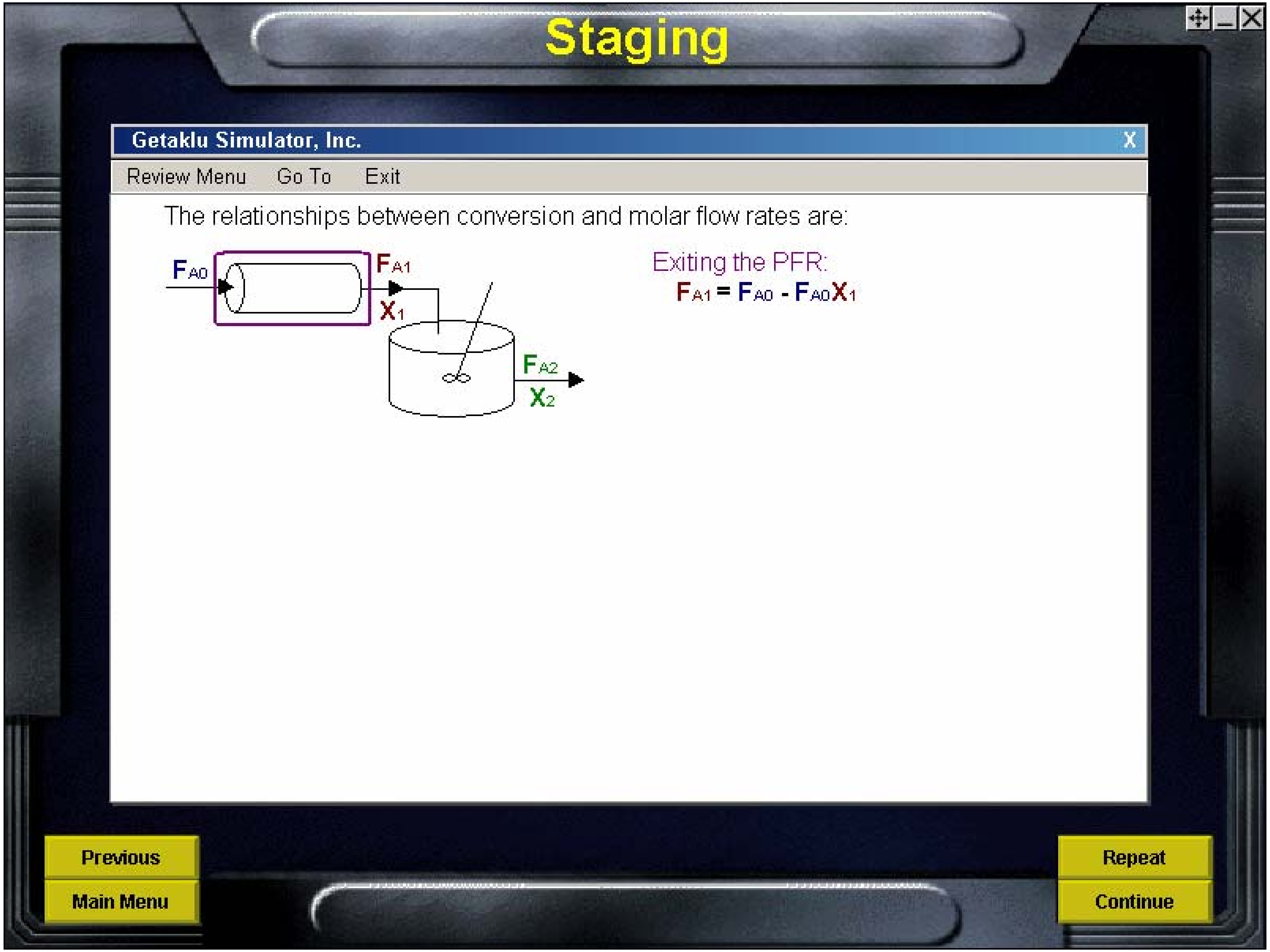
Staging
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The relationships between conversion and molar flow rates are:
FA0
FA1
X1
FA2
X2
Exiting the PFR:
FA1 = FA0 - FA0X1
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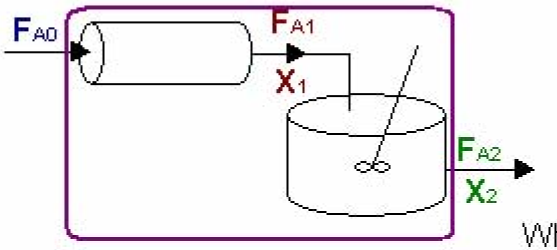
The relationships between conversion and molar flow rates are:



Exiting the PFR:

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

Exiting the CSTR:

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

$$\text{Where } X_2 = \frac{\text{Total moles reacted up to point } \mathbf{2}}{\text{moles of A fed to the first reactor}}$$

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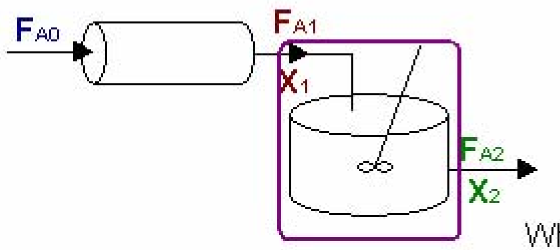
The relationships between conversion and molar flow rates are:



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$$\text{Where } X_2 = \frac{\text{Total moles reacted up to point } 2}{\text{moles of A fed to the first reactor}}$$

A mole balance on the CSTR gives:

in - out + generation = 0

$$F_{A1} - F_{A2} + V_2\, r_A|_2 = 0$$

Remember:
The reaction rate inside a CSTR is constant, and hence the reaction rate at the exit of the reactor is the same as the reaction rate inside the reactor.

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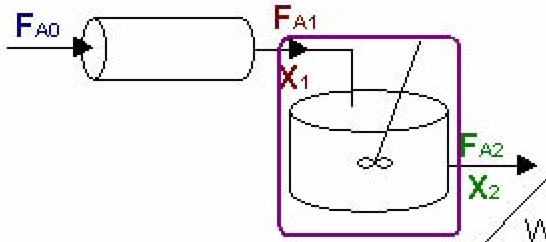

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Where $X_2 = \dfrac{\text{Total moles reacted up to point } 2}{\text{moles of A fed to the first reactor}}$

A mole balance on the CSTR gives:

$$F_{A1} - F_{A2} + V_2 \, r_A|_2 = 0$$

$$V_2 = \frac{F_{A1} - F_{A2}}{-r_A|_2}$$

Now substituting for F_{A1} and F_{A2}.

Remember:
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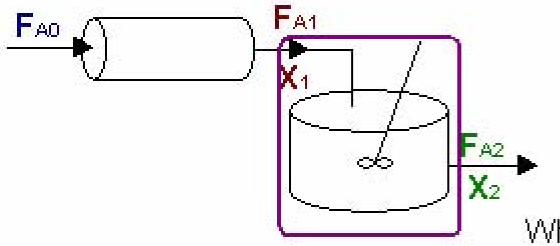

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$$F_{A2} = F_{A0} - F_{A0}X_2$$

Where $X_2 = \dfrac{\text{Total moles reacted up to point } \mathbf{2}}{\text{moles of A fed to the first reactor}}$

A mole balance on the CSTR gives:

$$F_{A1} - F_{A2} + V_2 \, r_A|_2 = 0$$

$$V_2 = \frac{F_{A0} - F_{A0}X_1 - (F_{A0} - F_{A0}X_2)}{-r_A|_2}$$

Rearraging...

Remember:
The reaction rate inside a CSTR is constant, and hence the reaction rate at the exit of the reactor is the same as the reaction rate inside the reactor.

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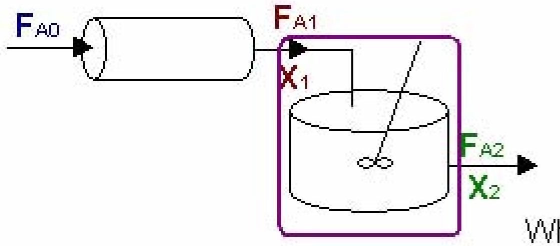

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A mole balance on the CSTR gives:

$$F_{A1} - F_{A2} + V_2\, r_A|_2 = 0$$

$$V_2 = \frac{\cancel{F_{A0}} - F_{A0}X_1 - \cancel{F_{A0}} + F_{A0}X_2}{-r_A|_2}$$

Then eliminating

Remember:
The reaction rate inside a CSTR is constant, and hence the reaction rate at the exit of the reactor is the same as the reaction rate inside the reactor.

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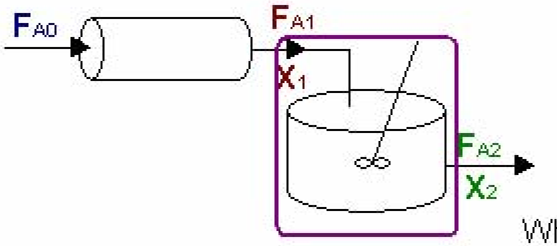

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Exiting the CSTR:

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

Where $X_2 = \dfrac{\text{Total moles reacted up to point 2}}{\text{moles of A fed to the first reactor}}$

A mole balance on the CSTR gives:

$$F_{A1} - F_{A2} + V_2\, r_A|_2 = 0$$

$$V_2 = \frac{F_{A0}X_2 - F_{A0}X_1}{-r_A|_2}$$

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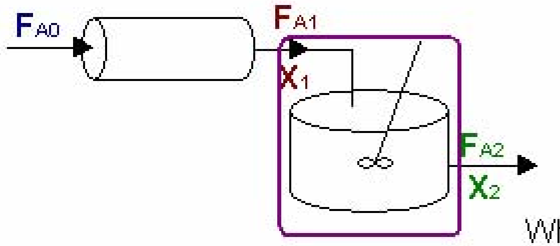

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A mole balance on the CSTR gives:

$$F_{A1} - F_{A2} + V_2\, r_A|_2 = 0$$

$$V_2 = \frac{F_{A0}(X_2 - X_1)}{-r_A|_2}$$

Design Equation
CSTR in Series

Remember:
The reaction rate inside a CSTR is constant, and hence the reaction rate at the exit of the reactor is the same as the reaction rate inside the reactor.

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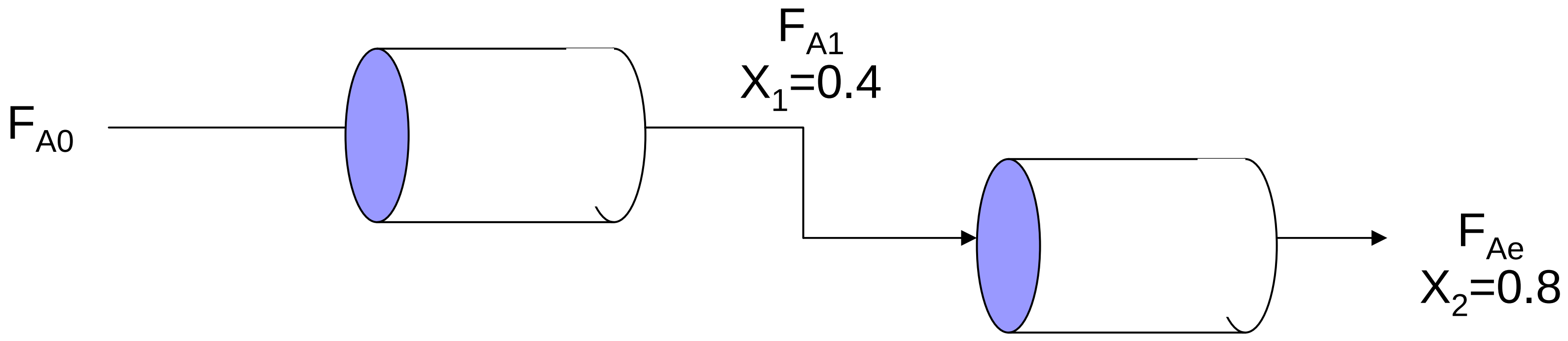
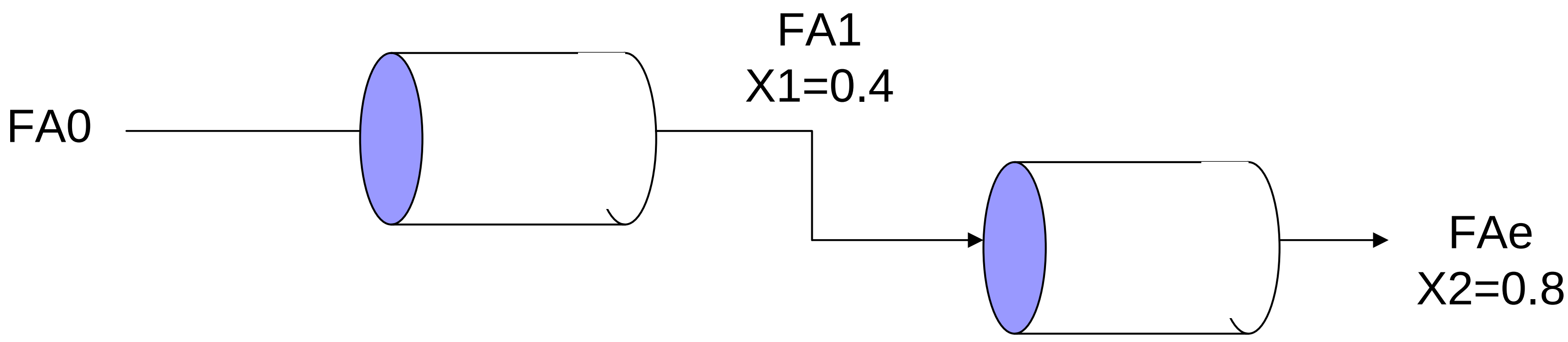
Example 2-5

PFRs in series

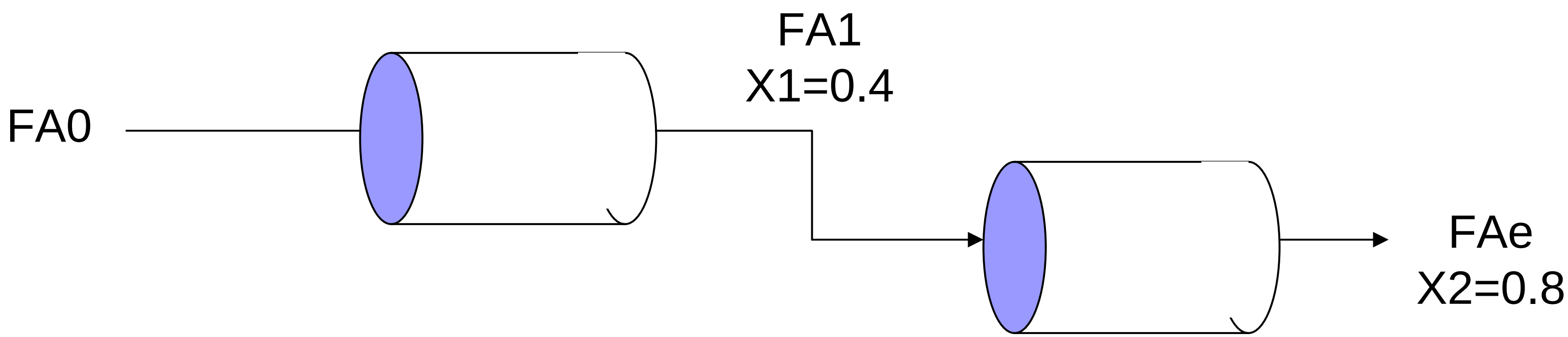


PFRs in series

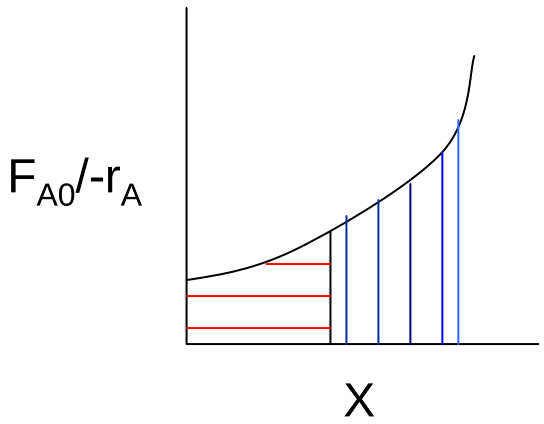


$$\int_0^{x_2} F_{A_0} \frac{dX}{-r_A} = \int_0^{x_1} F_{A_0} \frac{dX}{-r_A} + \int_{x_1}^{x_2} F_{A_0} \frac{dX}{-r_A}$$

PFRs in series



$$\int_0^{x_2} F_{A_0} \frac{dX}{-r_A} = \int_0^{x_1} F_{A_0} \frac{dX}{-r_A} + \int_{x_1}^{x_2} F_{A_0} \frac{dX}{-r_A}$$



Example 2-6

PFRs, CSTRs reactor volumes and sequencing

Space time

time necessary to process one reactor volume of fluid based on entrance conditions

$$\tau = \frac{V}{v_0}$$

Space velocity

- LHSV

-GHSV

$$SV = \frac{v_0}{V} = \frac{1}{\tau}$$

Typical Space time for Industrial Reactors

Reactor Type	Mean Residence Time Range	Production Capacity
Batch	15 min – 20 h	Few kg/h to 100,000 tons/yr
CSTR	10 min-4h	10 - 3M tons/yr
Tubular	0.5 s-1 h	50- 5M tons/yr