Batch and Continuous Flow Reactors

3.044 April 4, 2005

Mechanics:
- Problem set 4 solution error
- Problem Set 6 is on the way...

Today's lecture:
- Old muddy issues
- Batch and continuous flow reactors

Chemical Reactor Behavior

Basic methodology: accumulation = in - out + generation

$$V\frac{\partial C}{\partial t} = \text{in} - \text{out} + G$$

Reaction: A -> B, A is consumed, B builds up.

Questions:
- Batch reactor: how does the concentration change with time?
- Continuous flow reactor: what is the concentration at the exit?

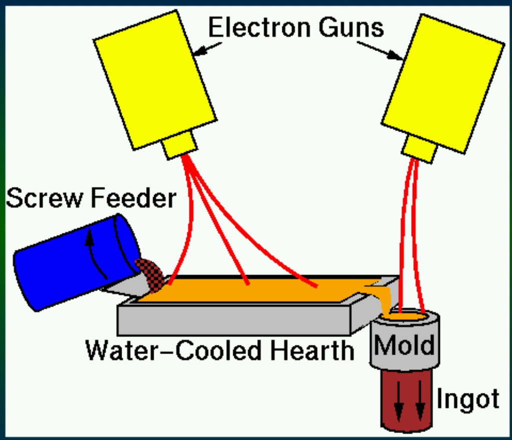
Homogeneous reaction: concerned with G throughout volume

$$G_B = V \cdot kC_A,\ G_A = -V \cdot kC_A$$

Heterogeneous reaction: concerned with J at surface/interface

$$G_A = A \cdot k''_A C_A,\ \text{or}\ A \cdot h_D C_A$$

Electron Beam Melting and Refining



Solid metal is fed continuously into water-cooled copper hearth
E-beams melt metal in hearth, control solidification in mold

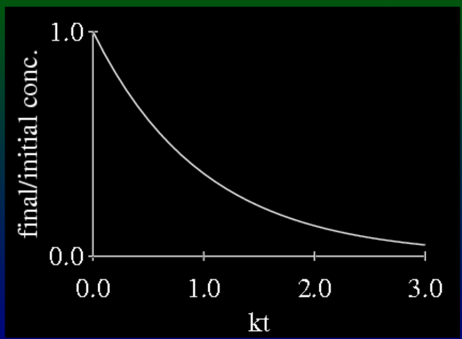
Batch reactors

Put the reactants in, let them sit and react, take the products out.
Homogeneous reaction throughout the volume:

$$V \cdot \frac{\partial C_A}{\partial t} = -V \cdot kC_A$$

Initial condition: $t = 0 \longrightarrow C_A = C_{A0}$

Resulting concentration vs. time: $\frac{C_A}{C_{A0}} = \exp(-kt)$



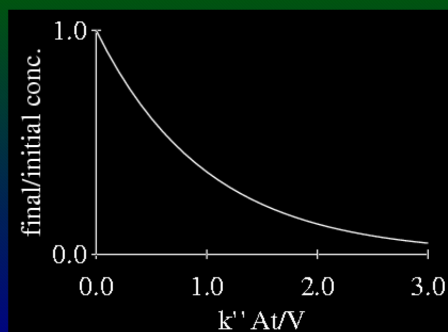
Batch reactors

Put the reactants in, let them sit and react, take the products out.
Heterogeneous reaction at the surface/interface:

$$V \cdot \frac{\partial C_A}{\partial t} = -A \cdot k''_A C_A, \text{ or } -A \cdot h_D C_A$$

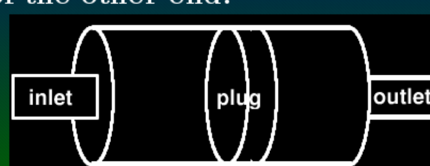
Initial condition: $t = 0 \longrightarrow C_A = C_{A0}$

Resulting concentration vs. time: $\frac{C_A}{C_{A0}} = \exp\left(-\frac{k'' A}{V} t\right)$



Continuous Reactors

Reactants flow continuously into one end, react, products flow continuously out of the other end.



Plug flow approximation: fluid moves through the reactor in "plugs", each of which is a mini-batch reactor.
Each bit of fluid spends exactly time V/Q in the reactor.

Homogeneous reaction: $\frac{C'_A}{C_{A0}} = \exp(-k t_R) = \exp\left(-\frac{kV}{Q}\right)$

Heterogeneous: $\frac{C'_A}{C_{A0}} = \exp\left(-\frac{k'' A}{V} t\right) = \exp\left(-\frac{k'' A}{V}\frac{V}{Q}\right) = \exp\left(-\frac{k'' A}{Q}\right)$

Continuous Reactors

Reactants flow continuously into one end, react, products flow continuously out of the other end.

Perfect mixing approximation: reagents entering are immediately mixed throughout the volume

Conservation equation applies to the whole reactor

Homogeneous reaction: $V \cdot \frac{\partial C_A}{\partial t} = QC_{A0} - QC'_A - V \cdot kC'_A$

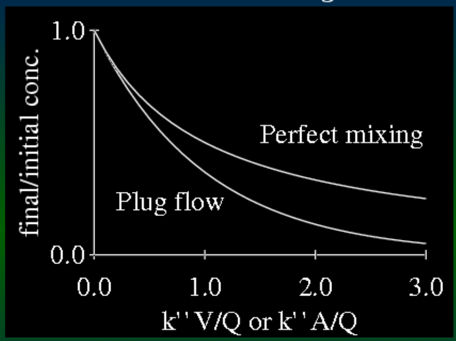
Hetetrogeneous reaction: $V \cdot \frac{\partial C_A}{\partial t} = QC_{A0} - QC'_A - A \cdot k''C'_A$

For steady-state (zero left side), solve for concentration ratio:

$$\frac{C'_A}{C_{A0}} = \frac{1}{1+\frac{kV}{Q}} \text{ or } \frac{1}{1+\frac{k''A}{Q}}$$

Continuous Reactors

Summary: Plug Flow and Perfect Mixing



Plug flow is much more efficient! But also difficult to achieve

More mixing can give more uniform (higher quality) output

Without dead zones, reality is somewhere between the two.