Principles of Chemical Engineering

Reaction Engineering

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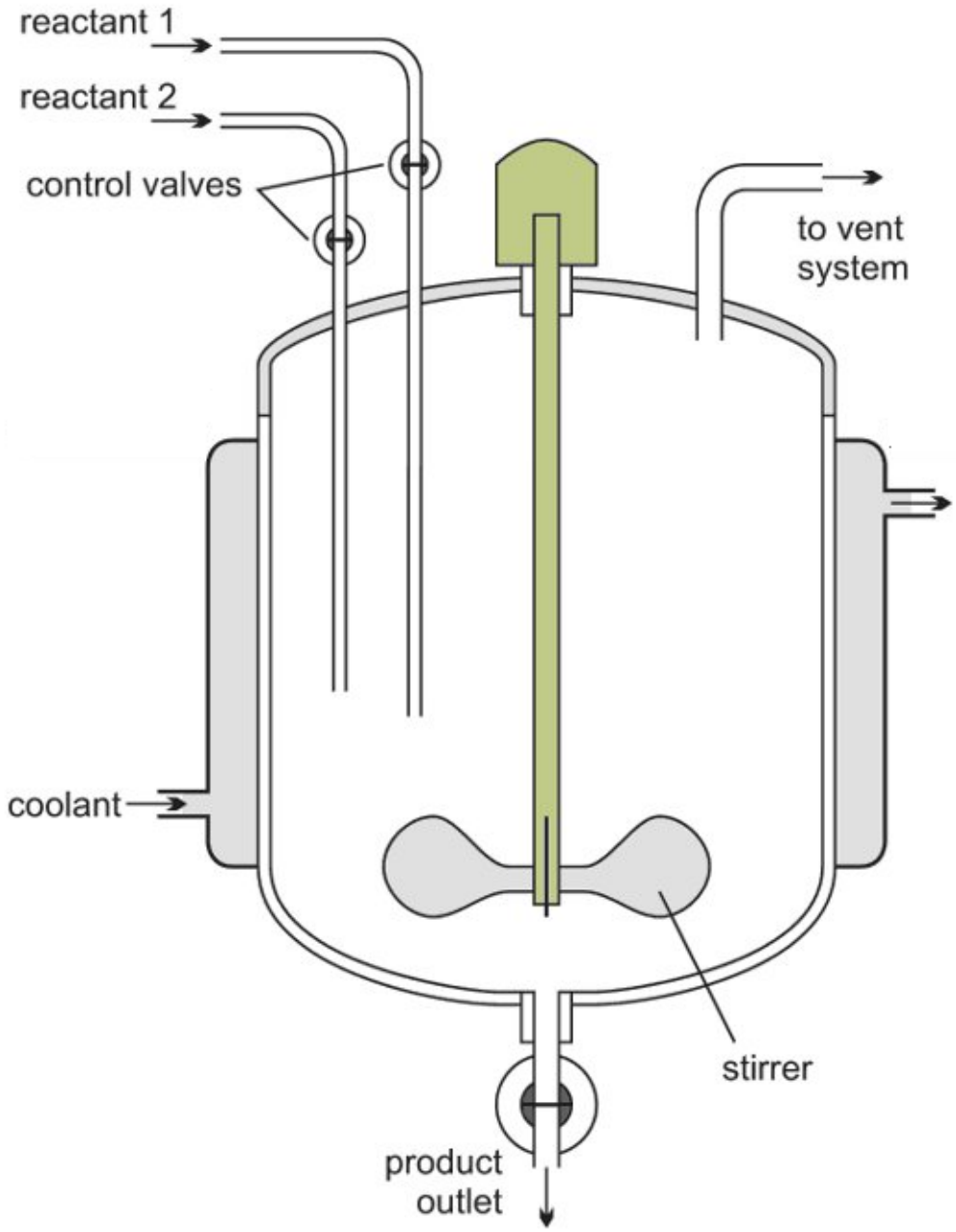
Syllabus Contents

Reactors - Batch and flow reactors

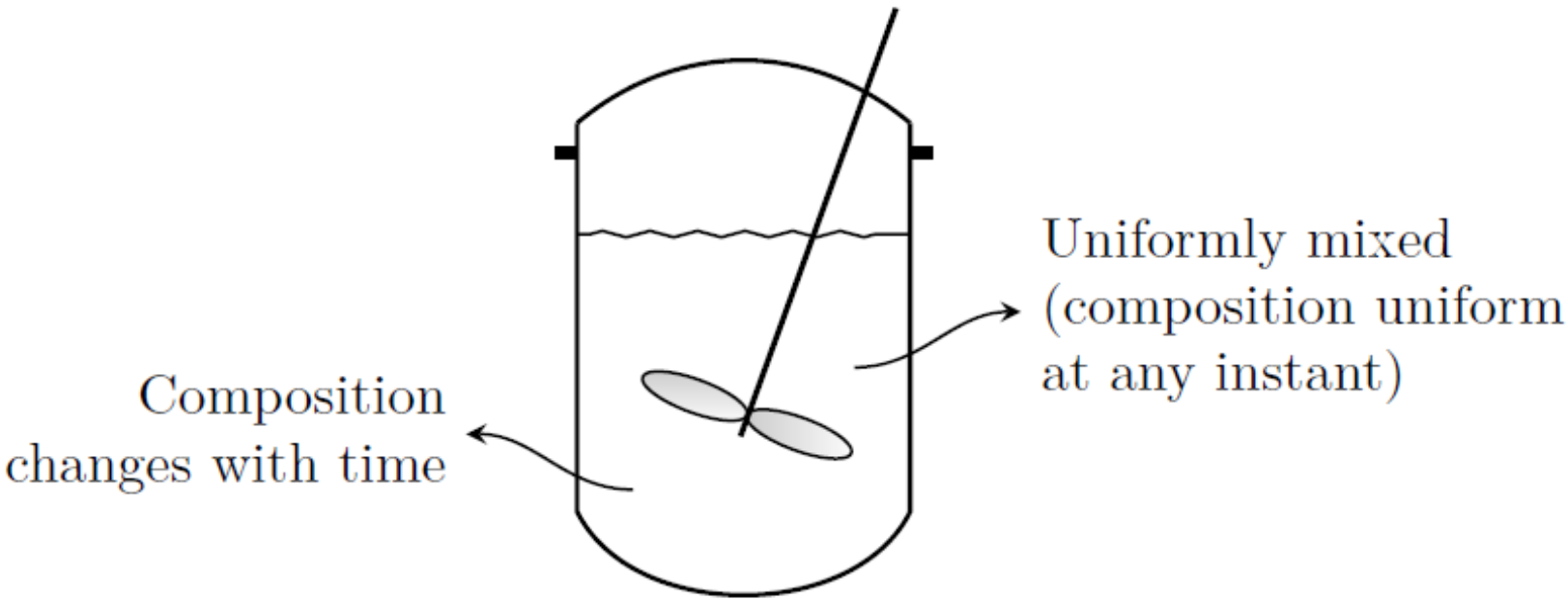
Chemical Reactor



Modes of Reactor Operation

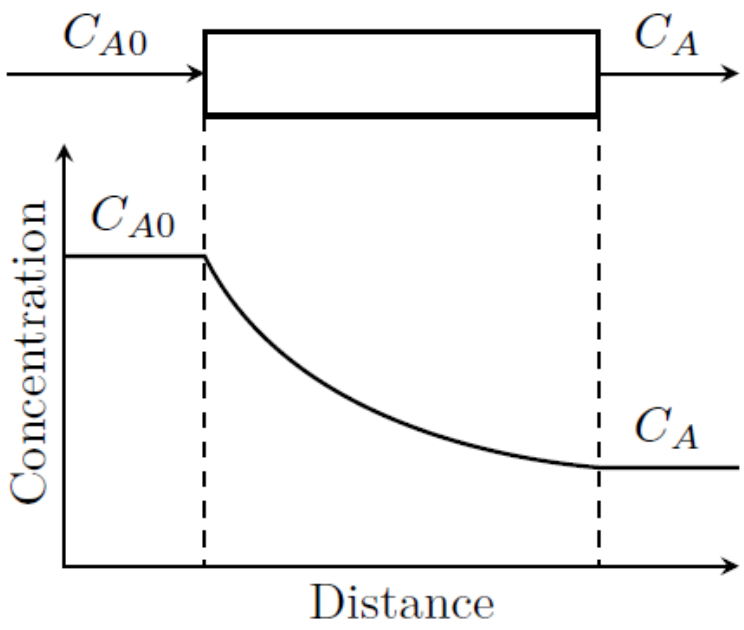
- Batch Process: reactants are initially charged and products discharged after certain time of reaction. Suitable for slow reactions.
- Continuous Process: reactants and products move continuously. Suitable for fast reactions.
- Semi-batch / Semi-continuous process: at least one reactant or one product is removed continuously. This procedure is employed for manipulating the product distribution for equilibrium-limited reactions, for playing with kinetic effects for complex reactions and for avoiding runaway effects in the case of highly exothermic reactions.

Batch Reactor (BR)

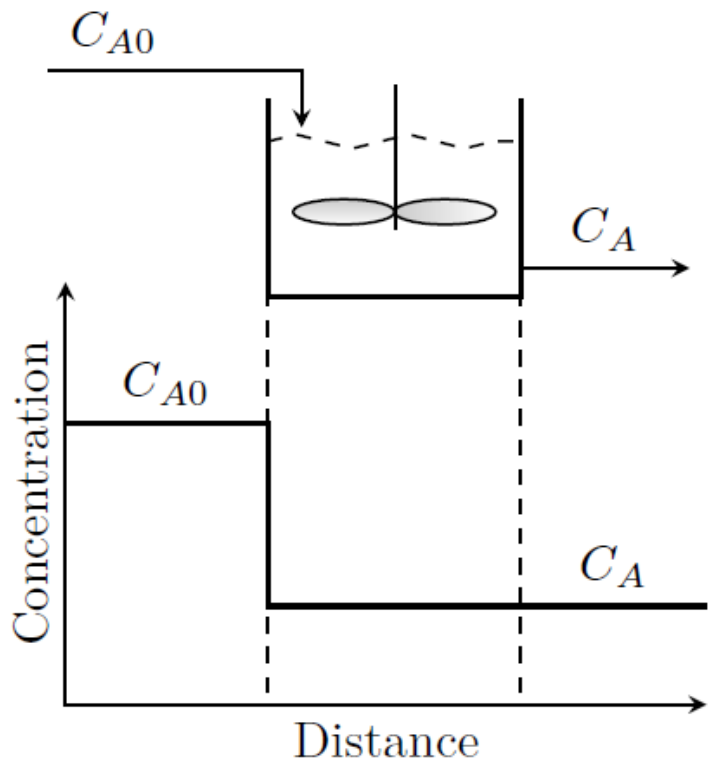


Flow Reactors

- Plug Flow Reactor (PFR)
- Continuous Stirred Tank Reactor (CSTR) or Mixed Flow Reactor (MFR)



(a) PFR



(b) MFR

Batch Reactor

- Unsteady-state operation (batch) in a tank reactor.
- Used to determine reaction kinetics on a laboratory scale.
- BR is used in the industry when small amounts of material are to be treated.
- BR is useful to produce seasonal products.
- Product quality may vary from batch to batch.

Mixed Flow Reactor (MFR)

- Steady-state operation (continuous) in a tank reactor.
- Also known as: the mixed reactor, the backmix reactor, the ideal stirred tank reactor, the constant flow stirred tank reactor (CFSTR), CSTR
- The reactor contents are well mixed and uniform throughout, (no spatial variation of composition and temperature) with the help of a stirrer.
- MFR may be used in the industry where large quantities of material are to be treated.
- MFR is useful to carryout the exothermic / endothermic reactions.
- MFR is used to conduct liquid-phase reactions.
- MFR is a good option for reactions involving high-viscous fluids.

Plug Flow Reactor (PFR)

- Steady-state operation (continuous) in a tubular reactor.
- Also known as: the ideal tubular reactor, the piston flow reactor, the unmixed flow reactor, the slug flow reactor, the rod-like flow reactor.
- There is no stirrer in the reactor.
- PFR is characterized with flat velocity profile.
- PFR is ideal to conduct gas-phase reactions or very fast reactions, since the flow velocity is maintained at a very high value ($\mathrm{Re} > 10,000$).
- The necessary and sufficient condition for plug flow is that the residence time of all the fluid elements is exactly the same in the reactor.
- PFR and MFR ensure good product quality control.

Required Volume of Reactor

From the definition of rate of a chemical reaction,

$$-r_A = -\frac{1}{V}\frac{dN_A}{dt}$$

For a given conversion rate (i.e., $d - N_A/dt$),

$$V \propto \frac{1}{-r_A}$$

From rate equation,

$$-r_A \propto C_A^n$$

Therefore,

$$V \propto \frac{1}{C_A^n}$$

Required Volume of Reactor

In a MFR, the concentration of key reactant drops suddenly to the exit concentration. Whereas in PFR, there is a progressive drop in concentration. Hence, the average concentration in PFR is higher than in MFR. Higher the average concentration, higher is its rate of conversion. Hence, smaller will be volume requirement.

For a given conversion of a zero order reaction, both MFR and PFR would be of same size. For all positive orders of reaction, the volume of MFR is always larger than the volume of PFR in order to achieve the same conversion.

Quiz

1. Differentiate between batch and flow reactors.

2. Differentiate between ‘mixed flow reactor’ and ‘plug flow reactor’.