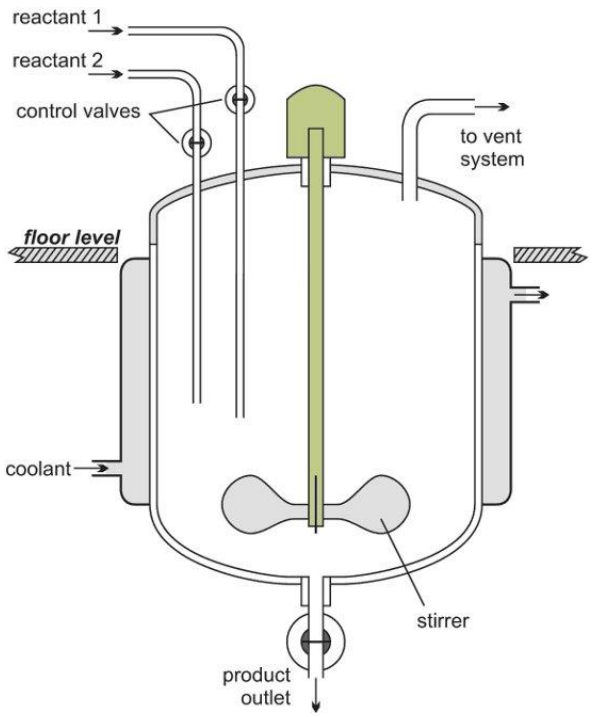
Chemical rectors

Chemical reactors are types of enclosed volumes where different reactions are take place.

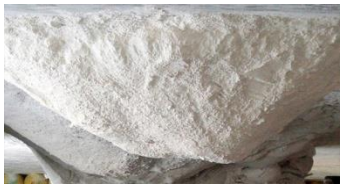
We can also identify it as process vessel for carrying out diverse chemical reactions as well as chemical process analysis

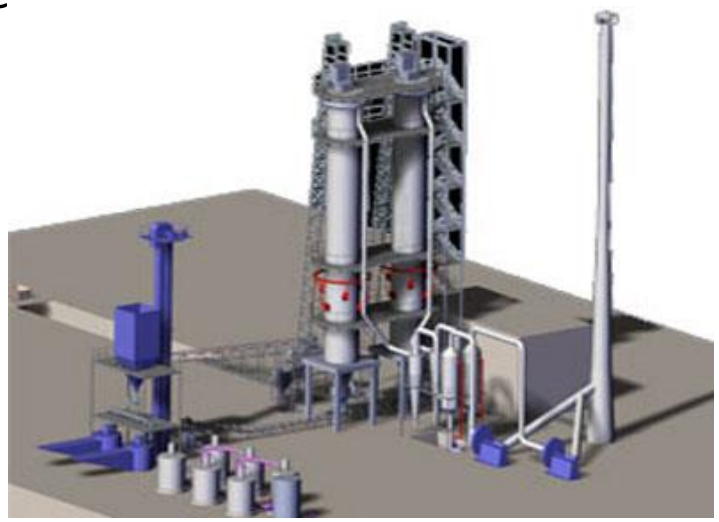


Chemical Reactors

Equipment used to carry on a chemical reaction.

-kilns that produce lime from limestone may be over 25 meters high and hold, at any one time, well over 400 tons of materials.





-The design of the reactor is determined by many factors but of particular importance are the **thermodynamics** and **kinetics** of the chemical reactions being carried out.

Types of chemical reactors

- There are three main types of chemical reactors which can choose depending on the application requirements.

1- Batch chemical reactors

2- Continuous chemical reactors

3- Semi-batch chemical reactors

Batch reactors

- **A batch reactor is a closed vessel in which reactions happen and it is a non-continuous type of reactor.**
- **The reactants are fed in to the reactor all at once initially.**
- **The vessel contains an agitator.**
- **The purpose of the agitator is to mix the reactants thoroughly so that the contact makes them react together efficiently and produce products.**

- **In order to handle exothermic reactions the batch reactor is often equipped with cooling coils.**
- **In order to work with endothermic reactions the batch reactor has provisions for heating the reaction mixture.**
- **Examples of processes that use batch reactors include the manufacture of colorants and margarine.**

Batch reactors

Advantage

- The greatest advantage of operating a batch reactor is its versatility.
- Same batch reactor can be used to chemically react quite different variety of reactants.
- Batch reactors are especially used in cases where the reaction produces lots of products.
- Batch reactors are often used in labs to study kinetics of the liquid phase reaction systems.

Disadvantage

- it requires lots of labour force to constantly charge reactants, discharge products and then to clean the reactor for the next batch.

Continuous reactors

- Feed the reactants continuously into the reactor at one point.

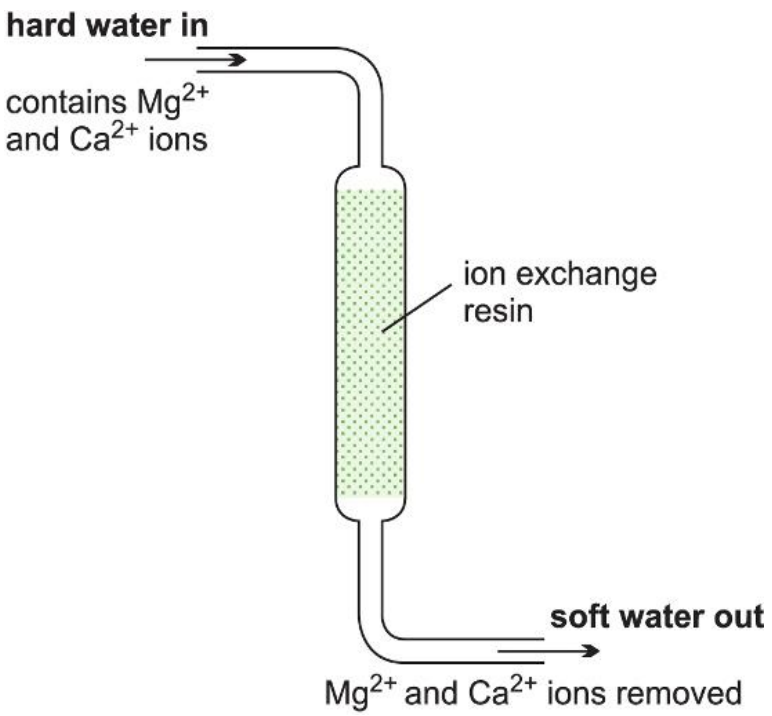
- Allow the reaction to take place and withdraw the products at another point.

- There must be an equal flow rate of reactants and products.

- Rarely used in the laboratory.

-Example of this reactor is a *water-softener*

Hard water from the mains is passed through a tube containing an ion-exchange resin. Reaction occurs down the tube and soft water pours out at the exit.



Continuous reactors

- Normally installed when large quantities of a chemical are being produced.
- It is important that the reactor can operate for several months without a shutdown.
- The residence time is controlled by the feed rate of reactants to the reactor.
- The volume is fixed and therefore the residence time in the reactor is also well controlled.
- The product tends to be of a more consistent quality from a continuous reactor because the reaction parameters (e.g. residence time, temperature and pressure) are better controlled than in batch operations.
- They also produce less waste and require much lower storage of both raw materials and products resulting in a more efficient operation.
- Capital costs per ton of product produced are consequently lower. The main disadvantage is their lack of flexibility as once the reactor has been built it is only in rare cases that it can be used to perform a different chemical reaction.

Types of Continuous Reactors

(a) Tubular reactors.

(b) Fixed bed reactors.

(c) Fluid bed reactors.

(d) Continuous stirred tank reactors, CSTR.

Tubular reactors

- Fluids (gases and/or liquids) flow through it at high velocities.
- Example: along a heated pipe, they are converted to products.
- At these high velocities, the products are unable to diffuse back and there is little or no back mixing.
- The conditions are referred to as plug flow in order to reduce the occurrence of side reaction and increase the yield of the product.

- With a constant flow rate, the conditions at any one point remain constant with time and changes in time of the reaction are measured in terms of the position along the length of the tube.

Tubular reactors

- The reaction rate is faster at the pipe inlet because the concentration of reactants is at its highest and the reaction rate reduces as the reactants flow through the pipe due to the decrease in concentration of the reactant.

- Example of tubular reactors, in the steam cracking of ethane, propane and butane and naphtha to produce alkenes.

-A tubular reactor used in the production of methyl 2-methylpropenoate. The reactor is heated by high pressure steam.

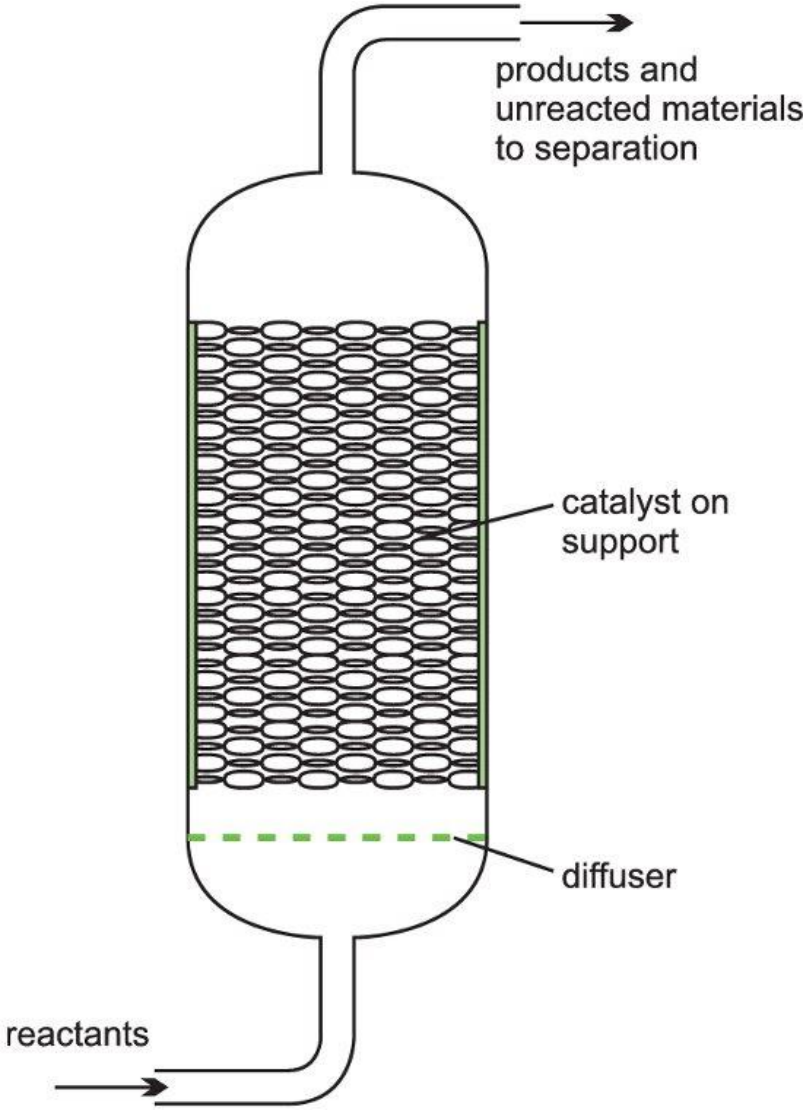
Fixed bed reactors

-A heterogeneous catalyst is used frequently in industry where gases flow through a solid catalyst (which is often in the form of small pellets to increase the surface area). It is often described as a fixed bed of catalyst.

- Among the examples of their use are the manufacture of sulfuric acid (the Contact Process, with vanadium(V) oxide as catalyst), the manufacure of nitric acid and the manufacture of ammonia (the Haber Process, with iron as the catalyst).

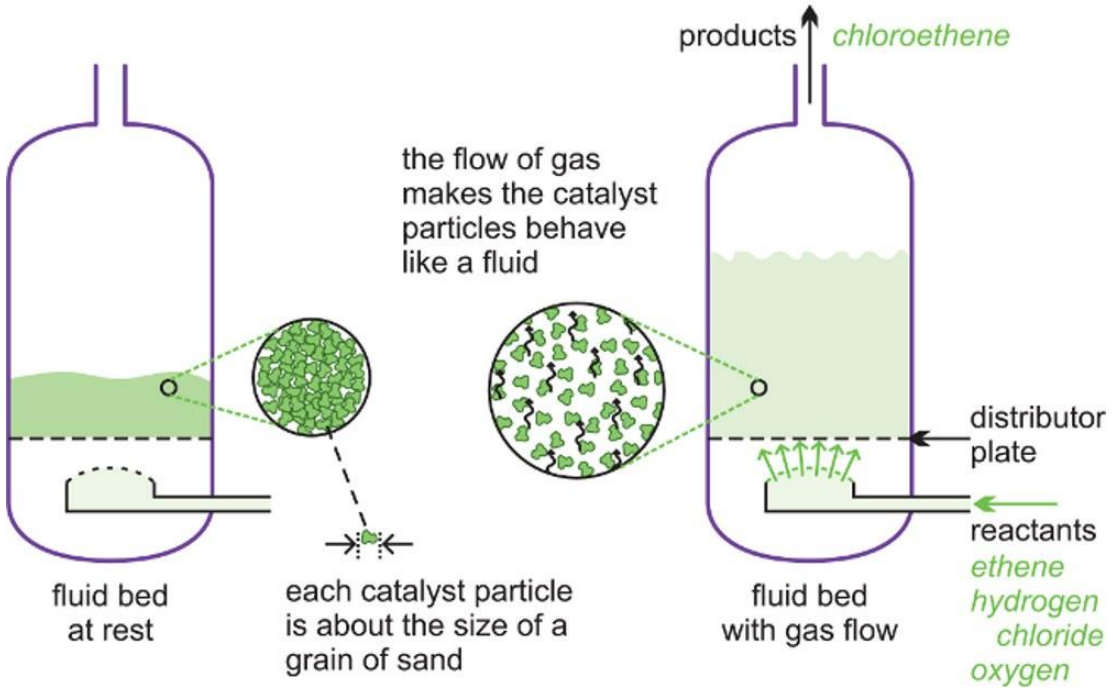
- Example of a fixed bed reactor is in catalytic reforming of naphtha to produce branched chain alkanes, cycloalkanes and aromatic hydrocarbons using usually platinum or a platinum-rhenium alloy on an alumina support.

Fixed bed reactors



Fluid bed reactors

- **Used whereby the catalyst particles, which are very fine, sit on a distributor plate. When the gaseous reactants pass through the distributor plate, the particles are carried with the gases forming a fluid.**



Fluid bed reactors

-This ensures very good mixing of the reactants with the catalyst, with very high contact between the gaseous molecules and the catalyst and a good heat transfer.

-This results in a rapid reaction and a uniform mixture, reducing the variability of the process conditions.

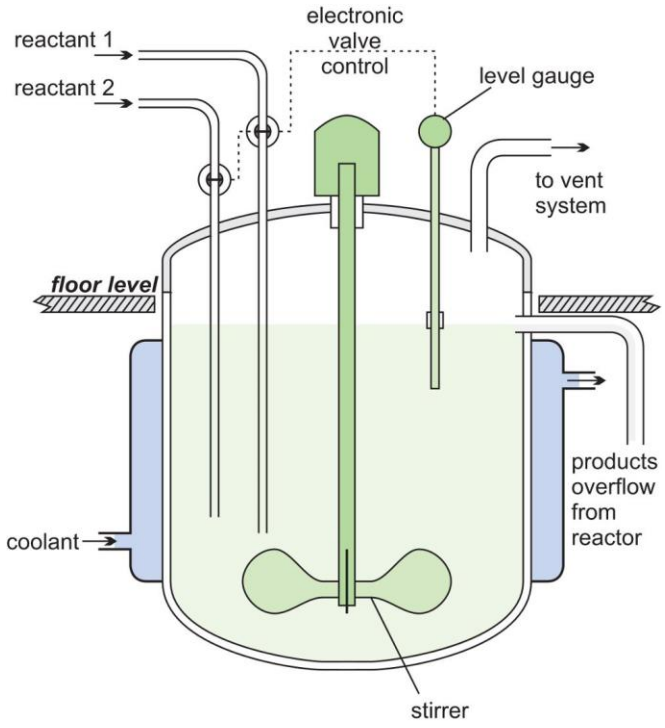
-One example of the use of fluid bed reactors is in the oxychlorination of ethene to chloroethene (vinyl chloride), the feedstock for the polymer poly(chloroethene) (PVC).

-The catalyst is copper(II) chloride and potassium chloride deposited on the surface of alumina. This support is so fine, it acts as a fluid when gases pass through it.

- Larger than fixed bed reactors and are more expensive to construct. However, it is easier to control the conditions and the process is more efficient.

Continuous stirred tank reactors, CSTR

- **One or more reactants.**
- **The reactor equipped with an impeller (stirrer) and the products are removed continuously.**
- **The impeller stirs the reagents vigorously to ensure good mixing so that there is a uniform composition throughout.**



Continuous stirred tank reactors, CSTR

- The composition at the outlet is the same as in the bulk in the reactor.

- It is opposite conditions to those in a tubular flow reactor where there is virtually no mixing of the reactants and the products.

- A steady state must be reached where the flow rate into the reactor equals the flow rate out, for otherwise the tank would empty or overflow.

-Used, for example in the production of the amide intermediate formed in the process to produce methyl 2-methylpropenoate.

- A variation of the CSTR is the loop reactor which is relatively simple and cheap to construct.

- However, the residence time in the reactor is adjusted by altering the length or number of the loops in the reactor.

Continuous Reactors

Advantage

The biggest advantage of using a C.S.T.R in industries is that it can produce a large amount of products and being a continuous steady state reactor the reactor can keep on operating hours on end.

Disadvantage

The disadvantage is that a C.S.T.R cannot be used for reactions which have very slow kinetics because it will require a reactor of very large volume. The fabrication and operational cost of the reactor may make it infeasible. Batch reactor is used in this case.

Semi-batch reactors

- **Semi-batch reactors occupy a middle ground between batch and continuous reactors. They are open systems like CSTRs and run on an unsteady-state basis like batch reactors.**
- **They usually consist of a single stirred tank, similar to a batch reactor.**
- **Semi-batch reactors are not used as often as other reactor types. However, they can be used for many two-phase (i.e. solid/liquid) reactions.**

Also, semi-batch reactors are used when a reaction has many unwanted side reactions or has a high heat reaction.

- **The semi-batch slurry reactor pictured below is used in a lab for metallocene-catalyzed polymerization of alkenes.**

Advantages and Disadvantages of Semi-Batch Operation

Advantages

- Good temperature control
- Unwanted side-reactions minimized

Disadvantages

- High labor cost per unit product
- Large scale production difficult to achieve
- Reactor operations difficult to analyze

Some developments

- In the future many chemicals may be produced in reactors about the size of a large desktop computer, known as microreactors.
- The reduced size will lead to a reduction in capital costs and a reduction in the amount of chemicals in use at any one time, resulting in an inherently safer process.
- The temperature can be kept constant more readily (as there is a much larger surface for a given volume).
- This allows for a very efficient heat transfer from the reaction to the surroundings even for very exothermic reactions such as the nitration of an aromatic hydrocarbon which can potentially be explosive.
- There is considerable amount of research being carried out in developing microreactors.
- One example is the possibility of the direct conversion of benzene to phenol. A mixture of benzene and oxygen is fed through an alumina tube, packed with palladium at ca 350-400 K and hydrogen gas is passed over it.

Some developments

- **Hydrogen permeates through the alumina tube, and is converted to atomic hydrogen by the palladium catalyst. The hydrogen atoms react with oxygen, releasing reactive oxygen species, such as hydroxyl radicals, which in turn react with the benzene to form phenol.**