

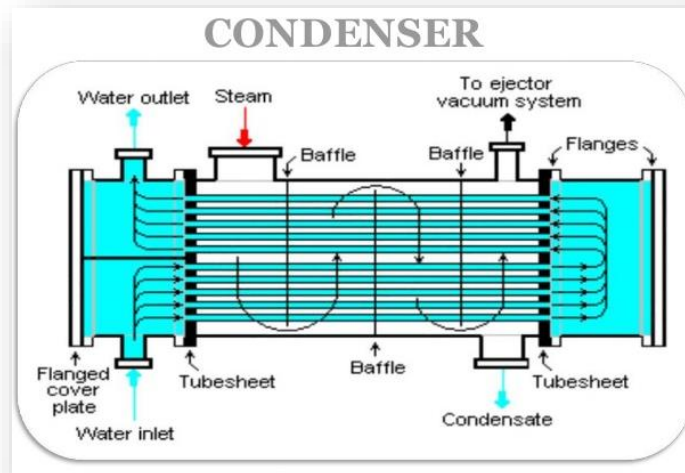
A 3D rendering of a grid of white cubes, with one red cube standing out prominently in the upper right quadrant. The cubes are arranged in a staggered pattern, creating a sense of depth and perspective. The red cube is the focal point, contrasting sharply with the white cubes.

Fondamenti dell'ingegneria di processo

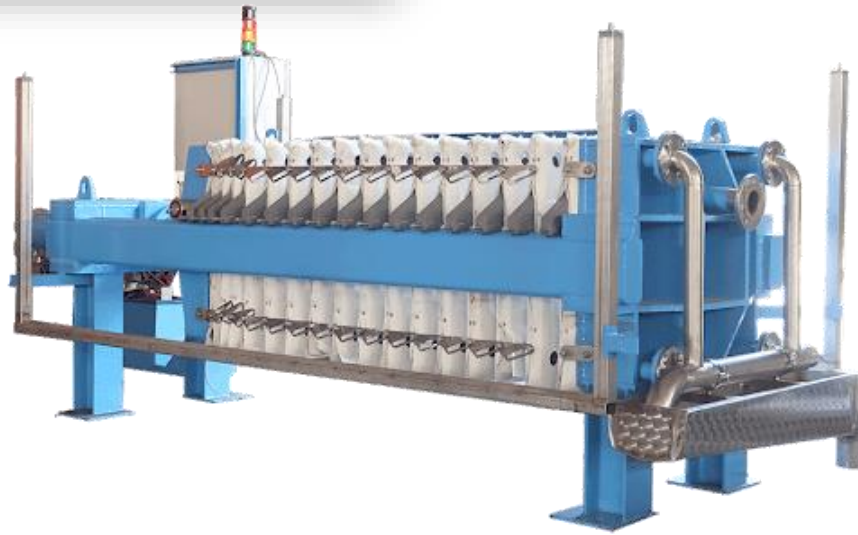
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Separation Systems

Virtually all commercial chemical processes involve operations in which material is transferred from one phase (gas, liquid. or solid) into another.



These multiphase operations include all phase-change operations on a single species such as freezing, melting, evaporation and condensation, and most separation and purification processes which are designed to separate components of mixtures from one another.



Separation Systems

The phase separations likely to be carried out are:

- gas–liquid (or vapor–liquid)
- gas–solid (or vapor–solid)
- liquid–liquid
- liquid–solid
- solid–solid



The principal methods for the separation of *heterogeneous mixtures* are:

- Settling and Sedimentation
- Centrifugal separation
- Filtration
- Scrubbing
- Drying

The principal methods for the separation of *homogenous mixtures* are:

- Absorption and stripping
- Liquid-liquid extraction
- Distillation



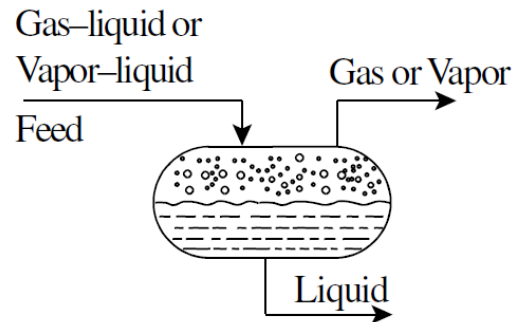
Multiphase Systems

Settling and Sedimentation

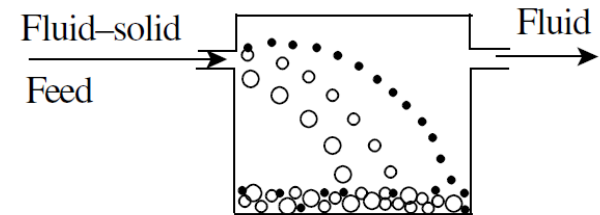
In settling processes, particles are separated from a fluid by **gravitational forces** acting on the particles.

The particles can be liquid drops or solid particles.

The fluid can be a gas, vapor or liquid.



Gravity settler for the separation of gas-liquid and vapor-liquid mixtures.

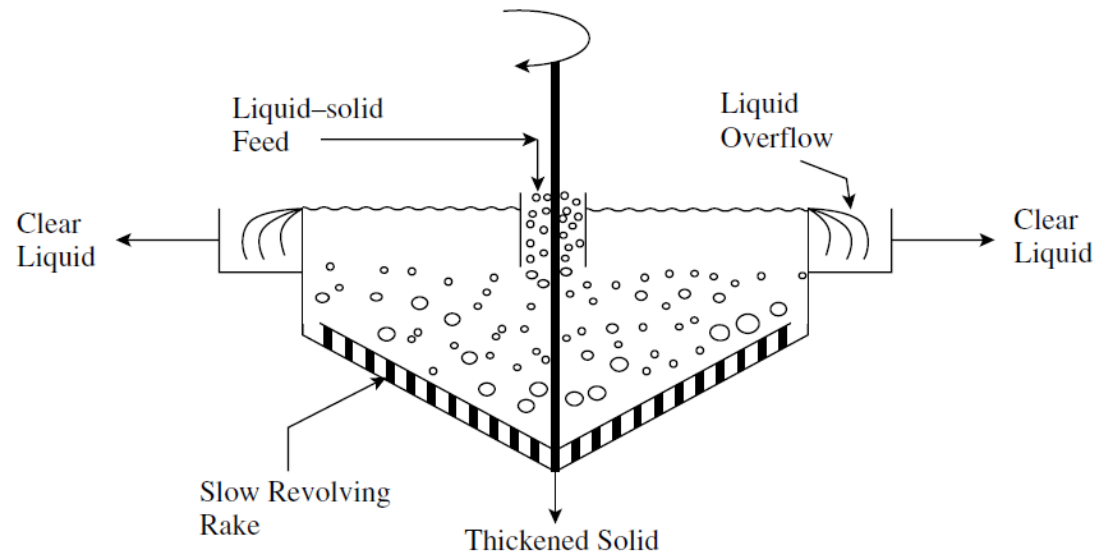


Gravity settler for the separation of fluid-solid mixtures.

Multiphase Systems

Settling and Sedimentation

The separation of suspended solid particles from a liquid by gravity settling into a clear fluid and a slurry of higher solids content is called **sedimentation**.



A thickener for liquid–solid separation

Multiphase Systems

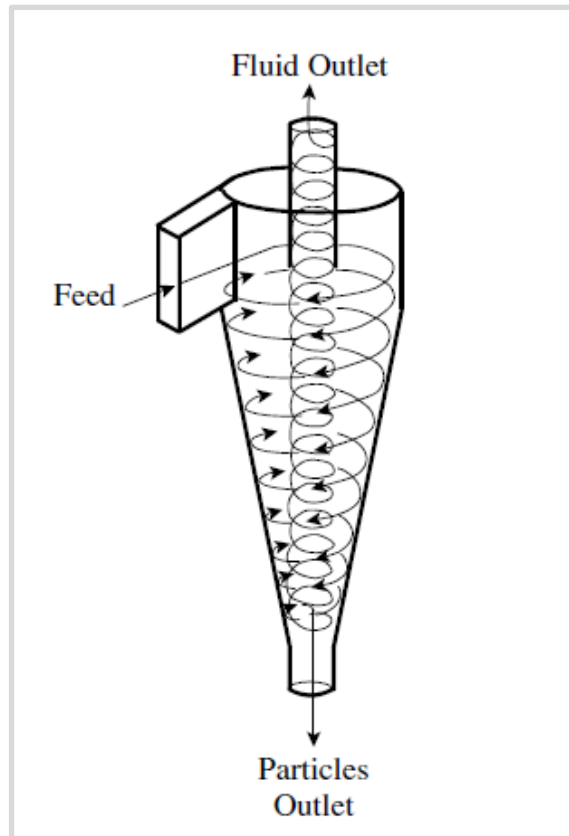
Settling and Sedimentation



Multiphase Systems

Centrifugal separation

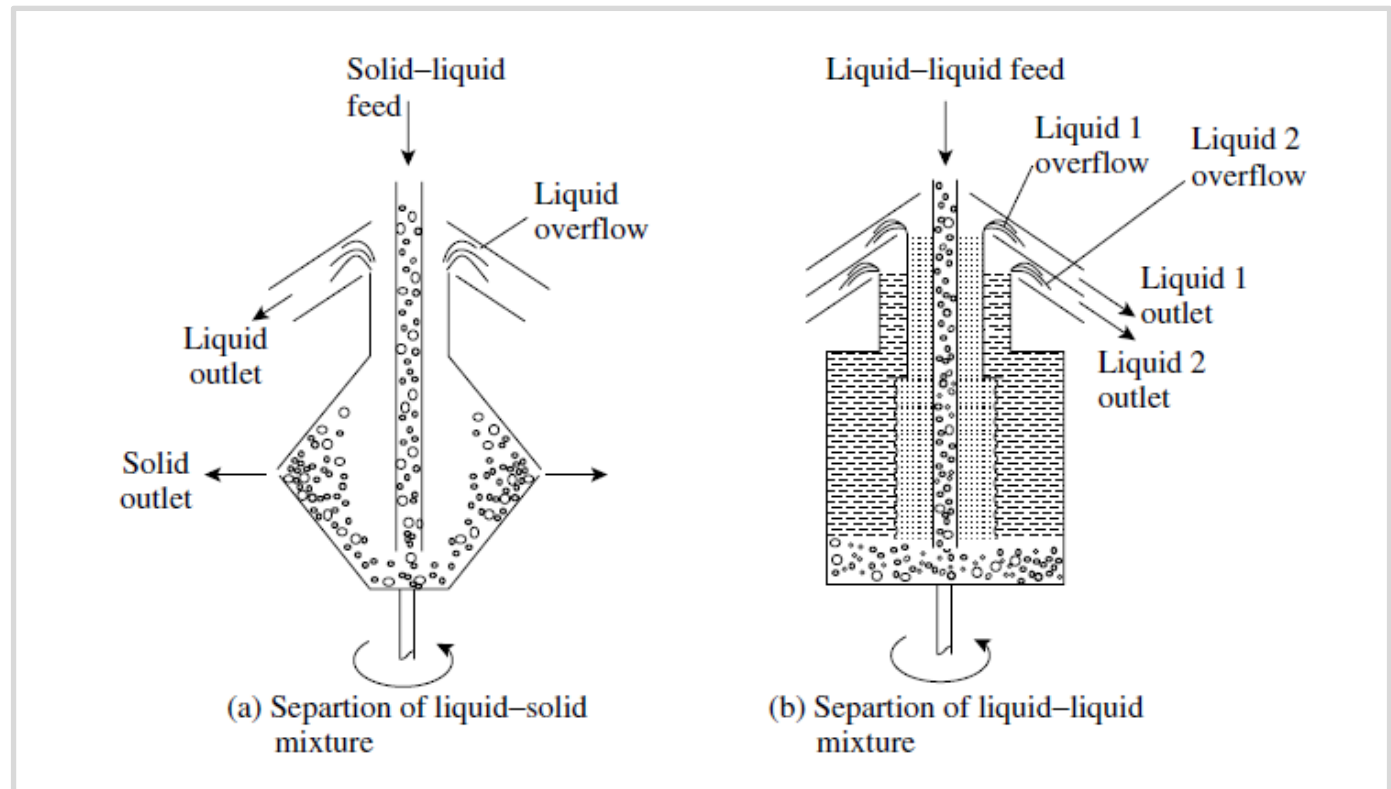
The simplest type of centrifugal device is the **cyclone** separator for the separation of solid particles or liquid droplets from a gas or vapor.



Multiphase Systems

Centrifugal separation

Another type of centrifugal device is the **centrifuge**, in which a cylindrical bowl is rotated to produce the centrifugal force.



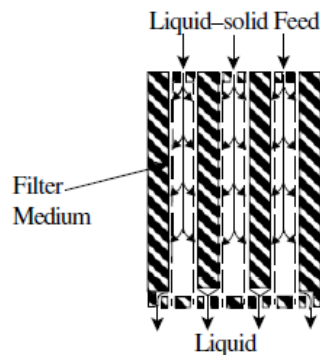
Multiphase Systems

Filtration

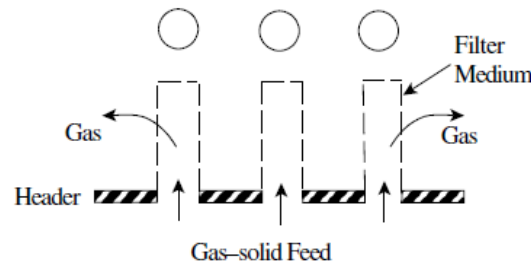
In **filtration**, suspended solid particles in a gas/vapor or liquid are removed by passing the mixture through a porous medium that retains the particles and passes the fluid (filtrate).

The solid can be retained on the surface of the filter medium, which is *cake filtration*, or captured within the filter medium, which is *depth filtration*.

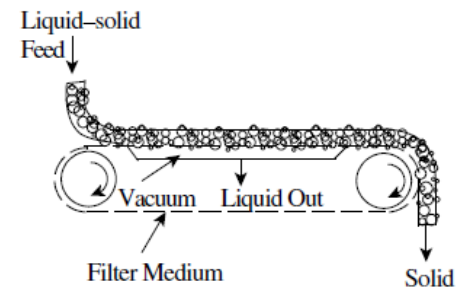
Examples of cake filtration in which the filter medium is a cloth of natural or artificial fibers



(a) Plate-and-frame filter.



(b) Bag filter.



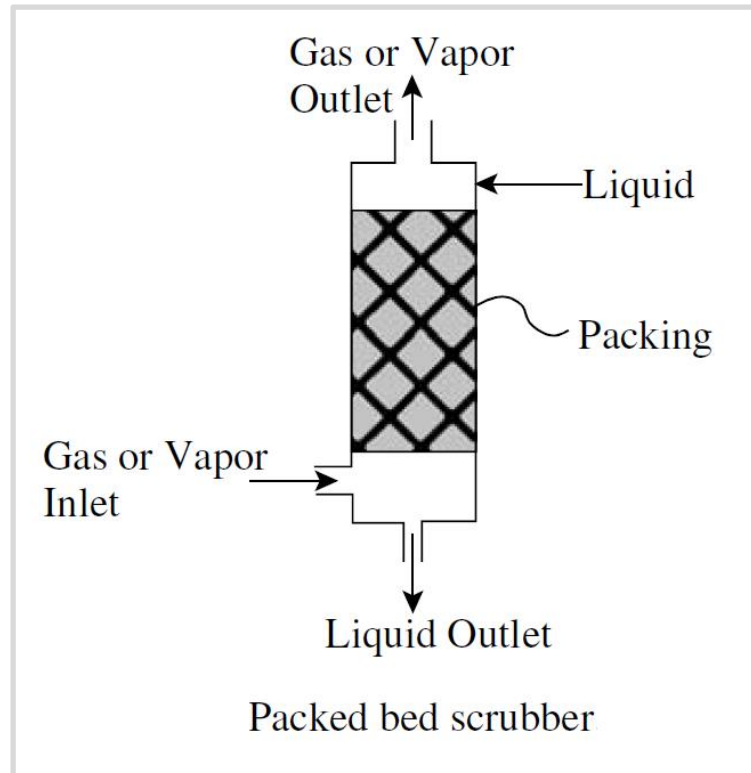
(c) Belt vacuum filter.

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Scrubbing

A gas flow is contacted with a liquid solution.

Scrubbing with liquid (usually water) can enhance the collection of particles when separating gas–solid mixtures.



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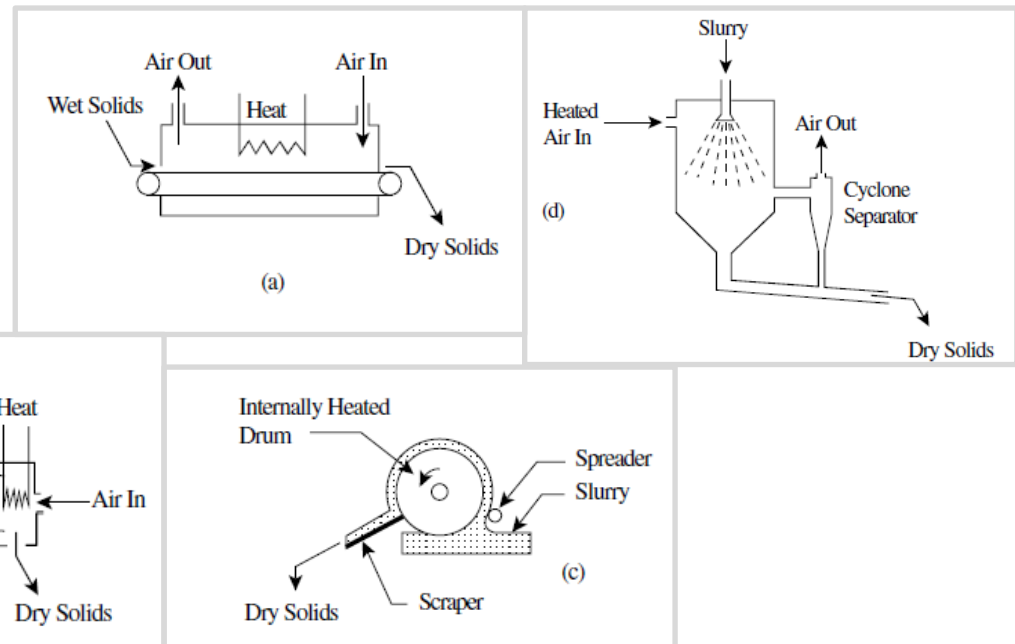
Drying

Drying refers to the removal of water from a substance. Here, consideration is restricted to the removal of moisture from solids into a gas stream (usually air) by heat, namely, **thermal drying**.

Some of the types of equipment for removal of water also can be used for removal of organic liquids from solids.

Four of the more common types of thermal dryers used in the process industries:

- a. Tunnel dryers
- b. Rotary dryers
- c. Drum dryers
- d. Spray dryers



Multiphase Systems

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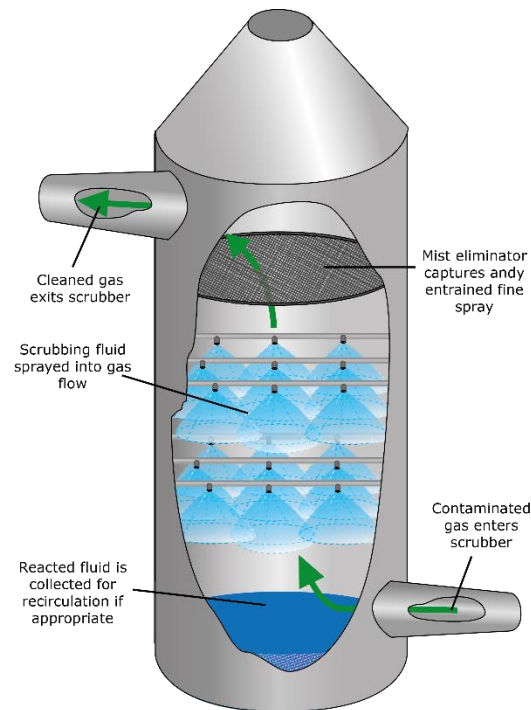
Multiphase Systems

Absorption and stripping

In **absorption** or *scrubbing*, a gas mixture is contacted with a liquid solvent that preferentially dissolves one or more components of the gas.

Absorption processes often require an extraneous material to be introduced into the process to act as liquid solvent.

Stripping is the reverse of absorption and involves the transfer of solute from the liquid to the vapor phase.

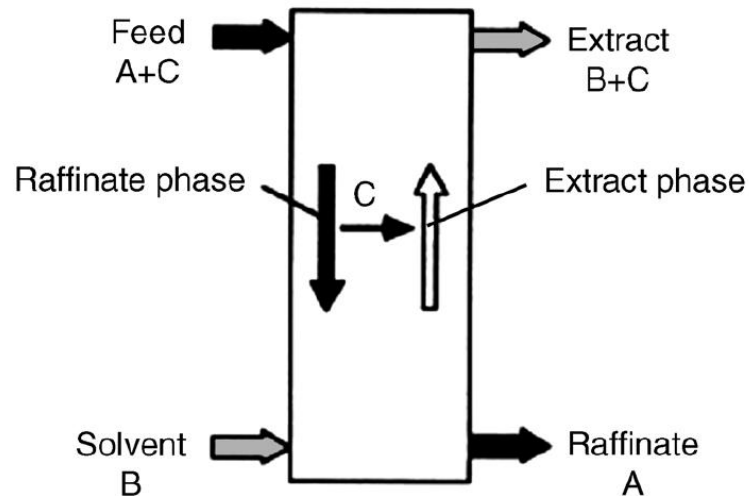


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Liquid-liquid extraction

Liquid–liquid extraction separates a homogeneous mixture by the addition of another phase – in this case, an immiscible liquid.

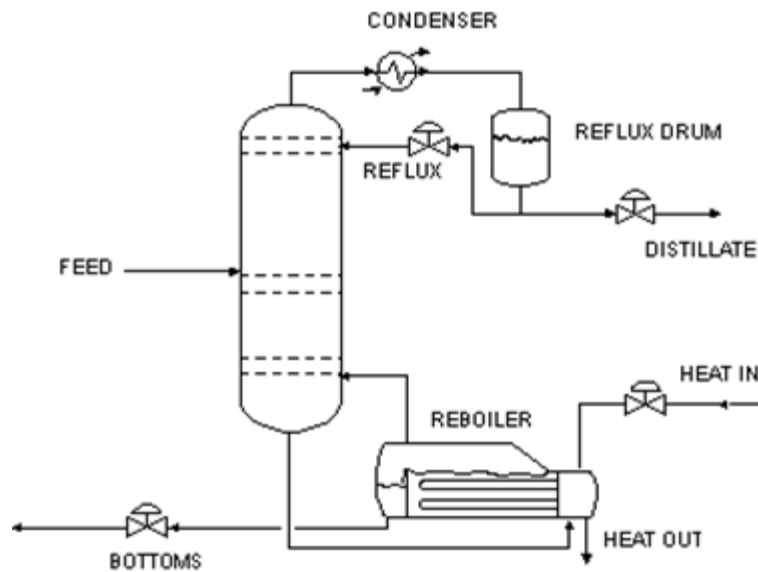
Liquid–liquid extraction carries out separation by contacting a liquid feed with another immiscible liquid.



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Distillation

Distillation: a process of separating the component or substances from a liquid mixture by selective evaporation and condensation



Multiphase Systems

Adsorption

Adsorption is a process in which molecules of adsorbate become attached to the surface of a solid adsorbent.

Adsorption processes can be divided into two broad classes:

1. *Physical adsorption*, in which physical bonds form between the adsorbent and the adsorbate.
2. *Chemical adsorption*, in which chemical bonds form between the adsorbent and the adsorbate.

This is a commonly used method for the separation of gases, but is also used for the removal of small quantities of organic components from liquid streams.

A number of different adsorbents are used for physical adsorption processes.

All are highly porous in nature. The main types can be categorized as follows:

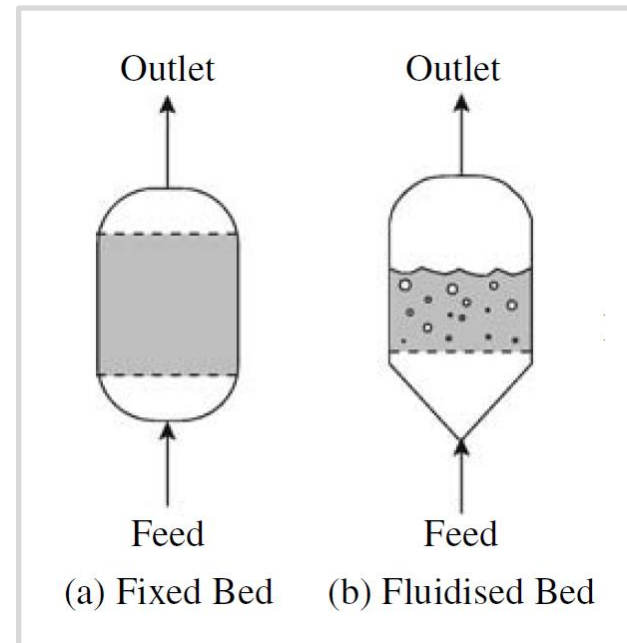
- ✓ *Activated carbon*. Activated carbon is a form of carbon that has been processed to develop a solid with high internal porosity. Almost any carbonaceous material can be used to manufacture activated carbon.
- ✓ *Silica gel*. Silica gel is a porous amorphous form of silica (SiO_2) and is manufactured by acid treatment of sodium silicate solution and then dried. The silica gel surface has an affinity for water and organic material. It is primarily used to dehydrate gases and liquids.



Multiphase Systems

Adsorption

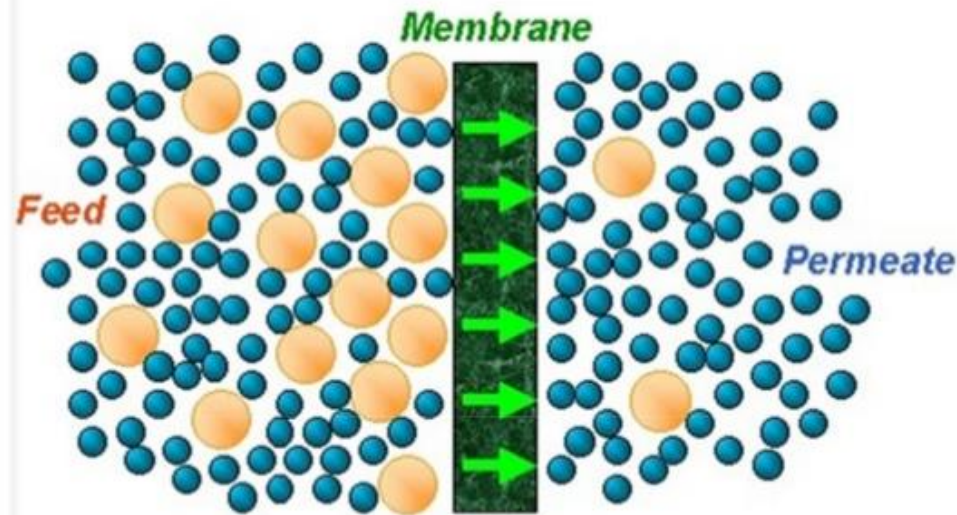
- ✓ *Molecular sieve zeolites.* Zeolites are crystalline aluminosilicates. They differ from the other three major adsorbents in that they are crystalline and the adsorption takes place inside the crystals. This results in a pore structure different from other adsorbents in that the pore sizes are more uniform. Access to the adsorption sites inside the crystalline structure is limited by the pore size, and hence zeolites can be used to absorb small molecules and separate them from larger molecules, as “molecular sieves”.



Multiphase Systems

Membranes

Membranes act as a semipermeable barrier between two phases to create a separation by controlling the rate of movement of species across the membrane. The separation can involve two gas (vapor) phases, two liquid phases or a vapor and a liquid phase. The feed mixture is separated into a *retentate*, which is the part of the feed that does not pass through the membrane, and a *permeate*, which is that part of the feed that passes through the membrane.

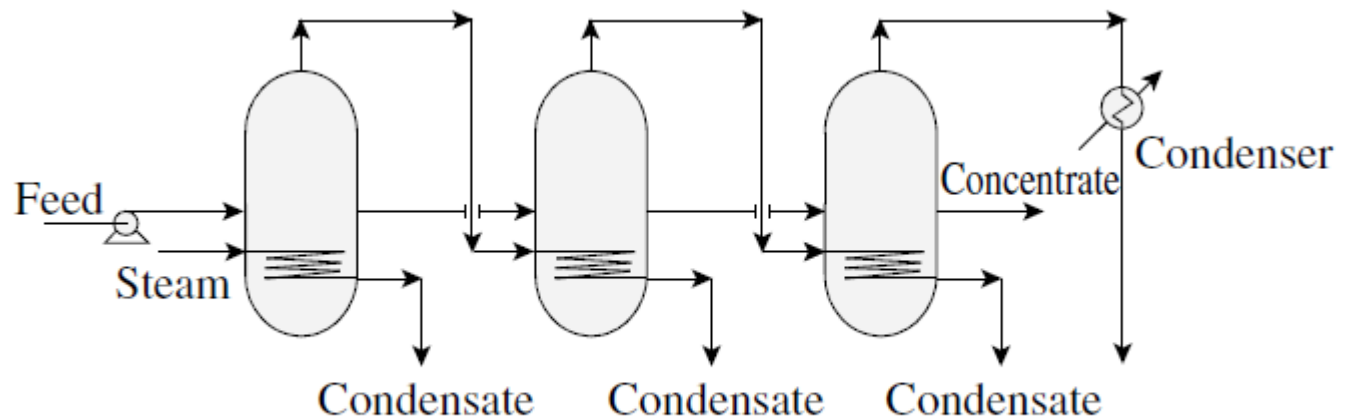


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Evaporation

Evaporation separates a volatile solvent from a solid.

Single-stage evaporators tend to be used only when the capacity needed is small. For larger capacity, it is more usual to employ multistage systems that recover and reuse the latent heat of the vaporized material.



(a) Forward feed operation.

Multiphase Systems

Crystallization

Crystallization involves formation of a solid product from a homogeneous liquid mixture. Often, crystallization is required as the product is in solid form.

