SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
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SCHOOL OF ELECTRICAL AND ELECTRONICS ENGINEERING

DEPARTMENT OF ELECTRONICS &INSTRUMENTATION ENGINEERING

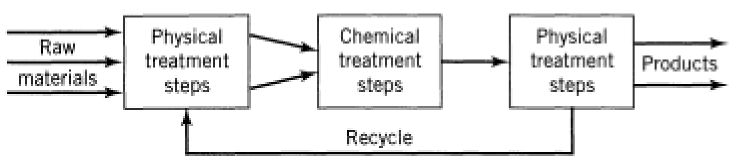
UNIT – I

Industrial Unit Operations – SIC 1308

1. Introduction to Unit Operation

1.1 Every industrial chemical process is designed to produce economically a desired product from a variety of starting materials through a succession of treatment steps. Figure 1shows a typical situation. The raw materials undergo a number of physical treatment steps to put them in the form in which they can be reacted chemically. Then they pass through the reactor. The products of the reaction must then undergo further physical treatment-separations, purifications, etc.- for the final desired product to be obtained. Design of equipment for the physical treatment steps is studied in the unit operations. Economically this may be an inconsequential unit, perhaps a simple mixing tank. Frequently, however, the chemical treatment step is the heart of the process, the thing that makes or breaks the process economically. Design of the reactor is no routine matter, and many alternatives can be proposed for a process. In searching for the optimum it is not just the cost of the reactor that must be minimized. One design may have low reactor cost, but the materials leaving the unit may be such that their treatment requires a much higher cost than alternative designs. Hence, the economics of the overall process must be considered. Reactor design uses information, knowledge, and experience from a variety of areas-thermodynamics, chemical kinetics, fluid mechanics, heat transfer, mass transfer, and economics. Chemical reaction engineering is the synthesis of all these factors with the aim of properly designing a chemical reactor. To find what a reactor is able to do we need to know the kinetics, the contacting pattern and the performance equation.

Figure 1. Typical chemical processes.



1.2 Classification of Reactions

There are many ways of classifying chemical reactions. In chemical reaction engineering probably the most useful scheme is the breakdown according to the number and types of phases involved, the big division being between the homogeneous and heterogeneous systems. A reaction is homogeneous if it takes place in one phase alone. A reaction is heterogeneous if it requires the presence of at least two phases to proceed at the rate that it does. It is immaterial whether the reaction takes place in one, two, or more phases; at an interface; or whether the reactants and products are distributed among the phases or are all contained within a single phase. All that counts is that at least two phases are necessary for the reaction to proceed as it does. Sometimes this classification is not clear-cut as with the large class of biological reactions, the enzyme-substrate reactions. Here the enzyme acts as a catalyst in the manufacture of proteins and other products. Since enzymes themselves are highly complicated large-molecular-weight proteins of colloidal size, 10-100 nm, enzyme-containing solutions represent a gray region between homogeneous and heterogeneous systems. Other examples for which the distinction between homogeneous and heterogeneous systems is not sharp are the very rapid chemical reactions, such as the burning gas flame. Here large non homogeneity in composition and temperature exist. Strictly speaking, then, we do not have a single phase, for a phase implies uniform temperature, pressure, and composition throughout. The answer to the question of how to classify these borderline cases is simple.

1.3 Variables Affecting the Rate of Reaction

Many variables may affect the rate of a chemical reaction. In homogeneous systems the temperature, pressure, and composition are obvious variables. In heterogeneous systems more than one phase is involved; hence, the problem becomes more complex. Material may have to move from phase to phase during reaction; hence, the rate of mass transfer can become important. For example, in the burning of a coal briquette the diffusion of oxygen through the gas film surrounding the particle, and through the ash layer at the surface of the particle, can play an important role in limiting the rate of reaction. In addition, the rate of heat transfer may also become a factor. Consider, for example, an exothermic reaction taking place at the interior surfaces of a porous catalyst pellet. If the heat released by reaction is not removed fast enough, a severe nonuniform temperature distribution can occur within the pellet, which in turn will result in differing point rates of reaction. These heat and mass transfer effects become increasingly important the faster the rate of reaction, and in very fast reactions, such as burning flames, they become rate controlling. Thus, heat and mass transfer may play important roles in determining the rates of heterogeneous reactions.

1.4 Unit operations

Unit operations play an important role in the development of chemical processes. They provide building blocks, process segments that can be designed individually and then combined into larger process systems. Unit operations include physical and chemical phenomena such as mass transport, mixing, distillation, separation, heat transfer, evaporation and drying. Many industrial plants include one or more of these elements. In addition, various chemical reactions with special characteristics can be carried out in specialized reactors or sequences of unit operations.

Every industrial chemical process is designed to produce economically a desired product from a variety of starting materials through a succession of treatment steps.

•The raw materials undergo a number of physical treatment steps to put them in the form in which they can be reacted chemically.

•Then they pass through the reactor. The products of the reaction must then undergo further physical treatment-separations, purifications, etc.-for the final desired product to be obtained.

•Design of equipment for the physical treatment steps is studied in the unit operations. Economically this may be an inconsequential unit, perhaps a simple mixing tank.

1.5 Chemical reactions

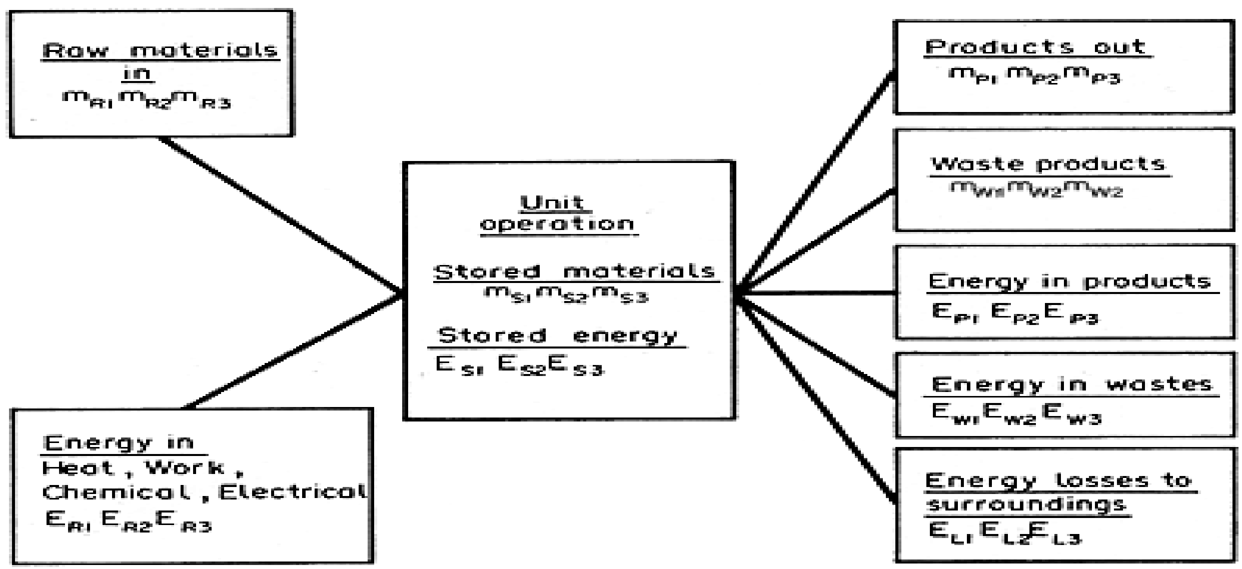
- There are many ways of classifying chemical reactions.
- According to the number and types of phases involved, the big division being between the homogeneous and heterogeneous systems.
- A reaction is homogeneous if it takes place in one phase alone. The reaction between acid and metal is a heterogeneous reaction. In contrast, a reaction between two miscible liquids or between two gases is homogeneous.
- A reaction is heterogeneous if it requires the presence of at least two phases to proceed at the rate that it does. A reaction between a gas and a liquid, as between air and seawater, is heterogeneous. A reaction at the surface of a catalyst is heterogeneous

1.6 Material Balance

The law of conservation of matter states that matter can not be created or destroyed. Conservation of mass requires that the materials entering any process must accumulate or leave the process. The process is debited with everything that enters it and it is credited with everything that leaves it. The sum of the credit must be equal to the sum of debits. A mass balance, also called a material balance, is an application of conservation of mass to the analysis of physical systems. By accounting for material entering and leaving a system, mass flows can be identified which might have been unknown, or difficult to measure without this technique. The exact conservation law used in the analysis of the system depends on the context of the problem, but all revolve around mass conservation, i.e. that matter cannot disappear or be created spontaneously.

1.6 Energy Balance

Figure 2. Energy Balance.



An energy balance may be made for a process or part of a process, that is separated from the surrounding by an imaginary boundary. As is a mass balance, input across the boundary must be equal output , if conditions are steady and unvarying with time, input equals output.

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UNIT – II

Industrial Unit Operations – SIC 1308

2.1 INTRODUCTION - TRANSPORT OF LIQUIDS, SOLIDS AND GASES

One of the most basic unit operations is the movement of materials in different forms from one point to another between processes or within process segments. The method of transport depends on whether the material is a liquid, gas or solids. Fluids are usually transported through pipes in which the driving force is a pressure drop created by a pump, compressor, or blower. The description of a fluid transport system must include the operating characteristics of the pump, compressor, or blower expressed as a function of speed of the driving device, pressure drop, pipe dimensions and so forth.

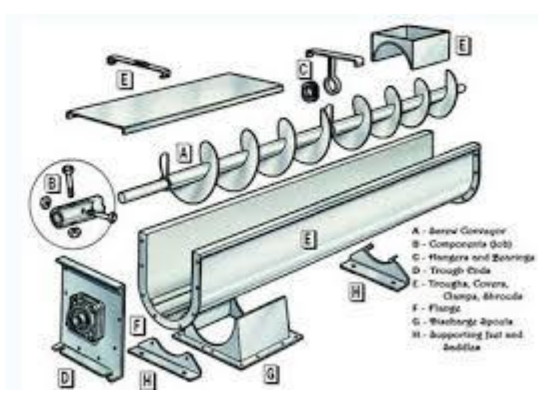
A major difference between liquids and gases is that for most practical purposes most liquids can be assumed to be incompressible. This makes liquid systems much simpler than to analyze gases and liquids in the same manner and account for the differences as a function of the distance between individual practice.Blowers and compressors are often used to provide the pressure differential needed to move gases through chemical processes. Blowers are effective up to pressures of about 0.3 bar, while comressors can develop up to about 4000 bar. A gas compressor is based upon the same principle as a pump that uis used for liquids.

2.2 Transport of solids

Many industrial processes must handle bulk solids, often in granular or powdered form. Various devices, such as conveyors, screw augers, vibrating platforms, pneumatic tubes, bucket elevators and so on can be used for transporting and metering these materials.

Automatic control requires that the transport device be controllable over a reasonable range by means of some type of control variable. The screw conveyor shown in figure 1., varies the flow by varying the speed of the screw. Here, the amount of material allowed to drop from the silo onto the conveyor belt is controlled by the opening of the discharging chute from the silo. Even though, the belt has constant speed, the total material delivered will be controlled. Flow form, the hopper in figure is controlled either by rotation speed of the table or the position of the scraper.

Figure 1-The screw conveyor



2.3 Methods of adjusting particle size of bulk solids

Many industrial processes include operations for reducing the size of the bulk raw materials or intermediate products through crushing, milling or grinding. Other industries use unit processes for increasing particle size through agglomeration , palletizing. Most of these processes must be automatically controlled.

2.3.1 Continuous ball mill:

The raw material enters the center of a large rotating cylinder lined with steel or rubber plates. The cylinder contains a large number of steel balls , becase of wear and tear , usually have different diameters. The rotation of the cylinder causes the steel balls to rise and fall inside the cylinder, applying a grinding and crushing action on the material. The speed with which the size of the material is reduced depends on many characteristics of both mill and the material. Most important characteristics are

- Level of the material in the mill
- Solid – liquid ratio in the case of wet milling process
- Rotation speed of the mill
- No. of balls in the mill

The dynamics of a mill depend primarily on whether the mill is operated as a closed circuit system, with a classifier and recycle of the rejects. The mill is followed by a classifier that separates the oversized particles and sends them back to the mill. A step closed circuit process used for wet grinding also.In this system, a primary mill is followed by a rake classifier that returns the larger particles (rejects) to the primary feed, while the fine particles(accepts) are sent to bowl classifier. The rejects from this classifier are sent to another rake classifier that feeds the secondary mill. The accepts from the bowl classifier are sent to a thickening device, often a sedimentation tank.

Figure 2-Continuos ball mill

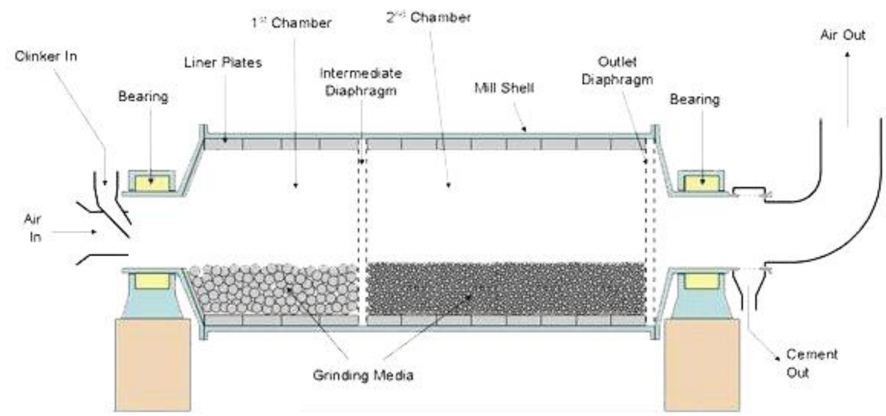
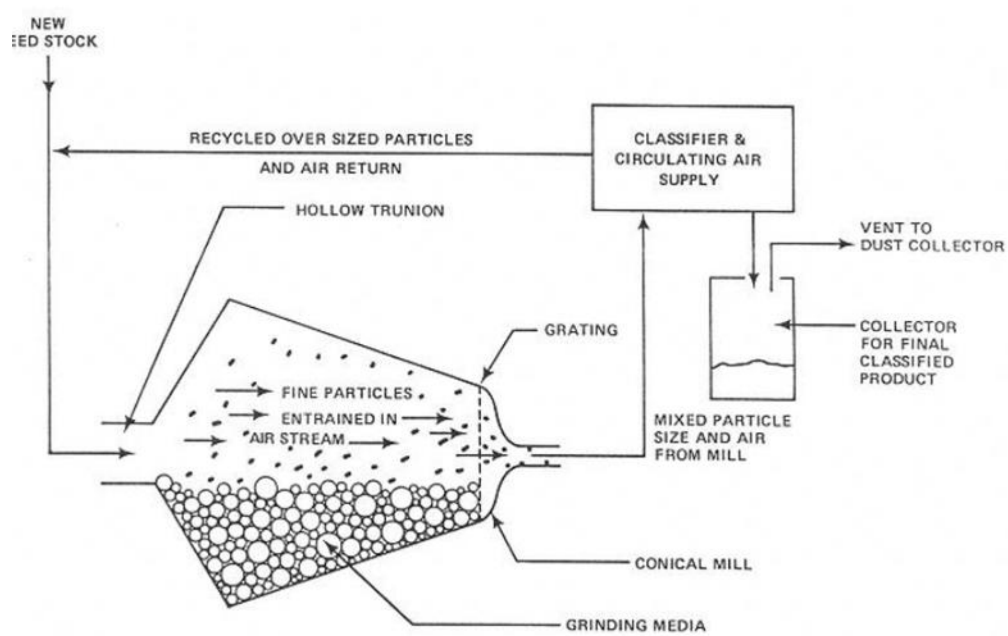


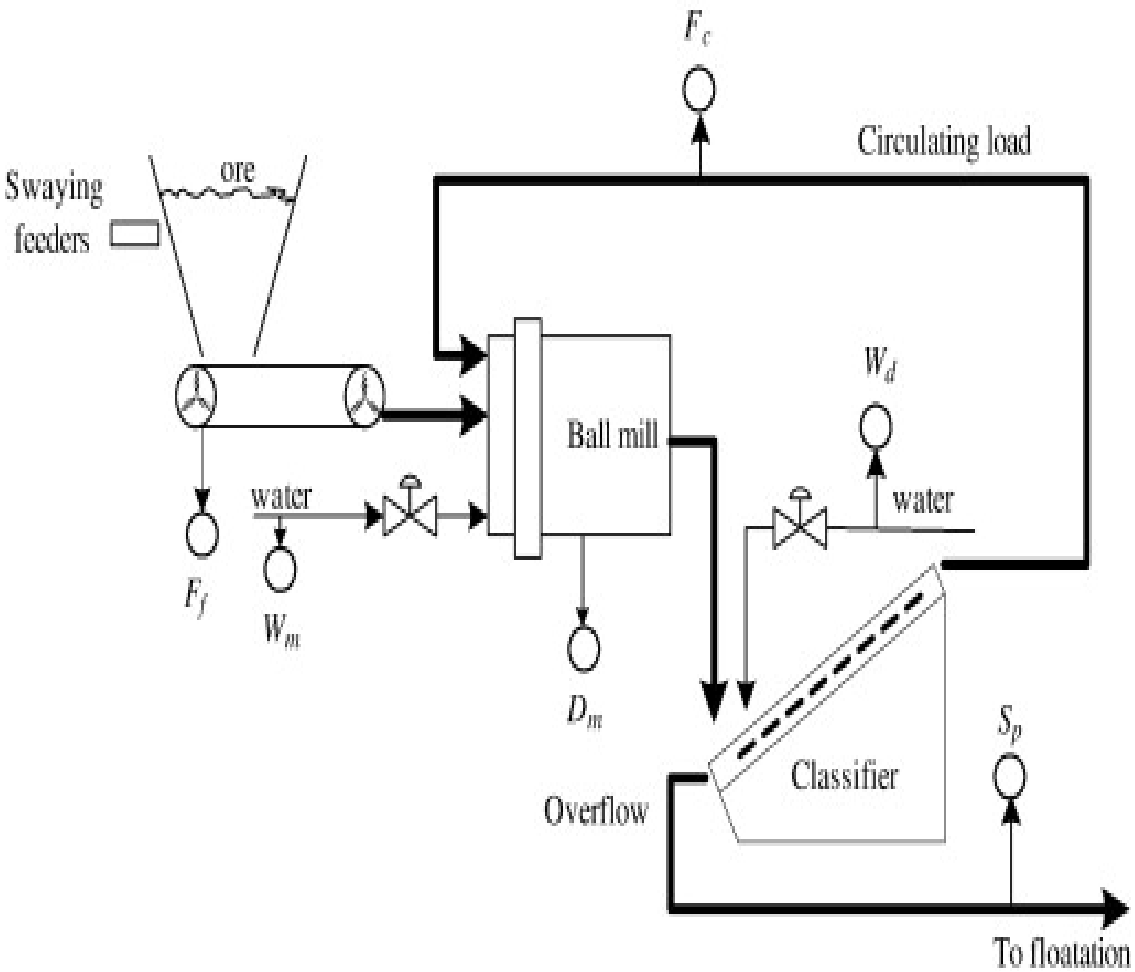
Figure 2-Closed loop control of Continuous ball mill



Particle size increase

C. continuous closed-circuit ball milling.

Figure3 – 2 stage Closed loop control of Continuous ball mill



2.4

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2.4 -Agglomeration of powdered and granulated materials.

Many industrial process require that the raw materials have minimum particle size in order to assure proper processing or chemical reaction. Ex. Reduction of iron ore.

Perhaps, the most common method of forming pellets (granules) is to roll dry powdered materials together with little moisture(the choice of the actual liquid depends upon the material and the use). This action causes the powdered particles to stick together, forming granules of increasing size. Two such processes are shown in figure. This action produces an even distribution of granules up to the desired size. The larger granules will tend to move outward on the plate and eventually fall off the edge, thus undergoing a natural size selection process. The powder and liquid are added and each of the supply streams must be carefully controlled and a possible control variable of granule size is the rotation speed of the disc. The angle of inclination of the disc could also be a control variable.

Figure 4 – Fluidized bed agglomeration

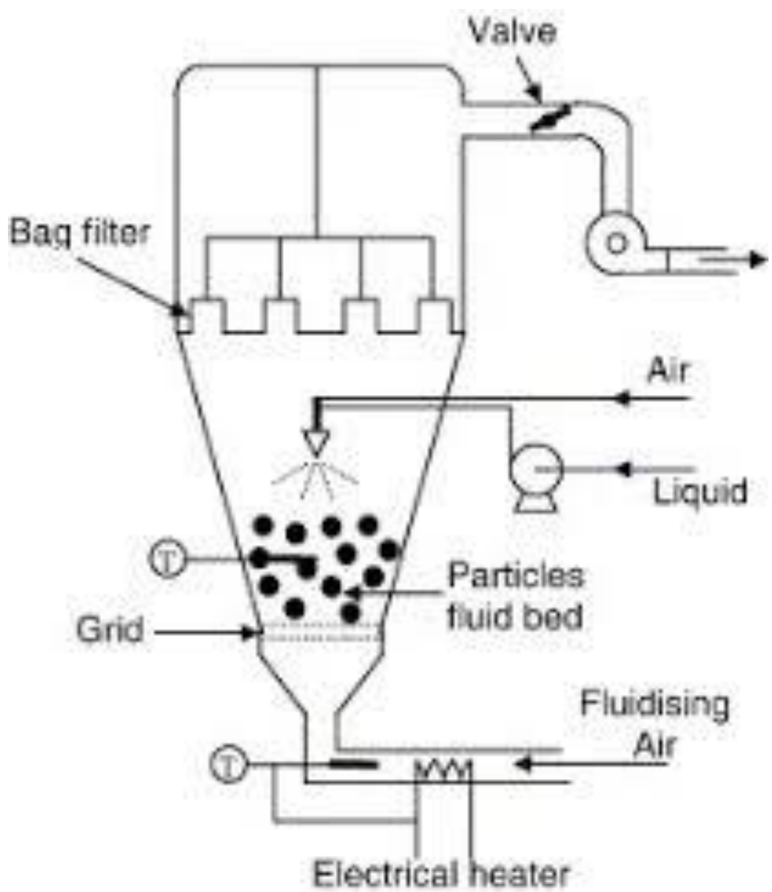
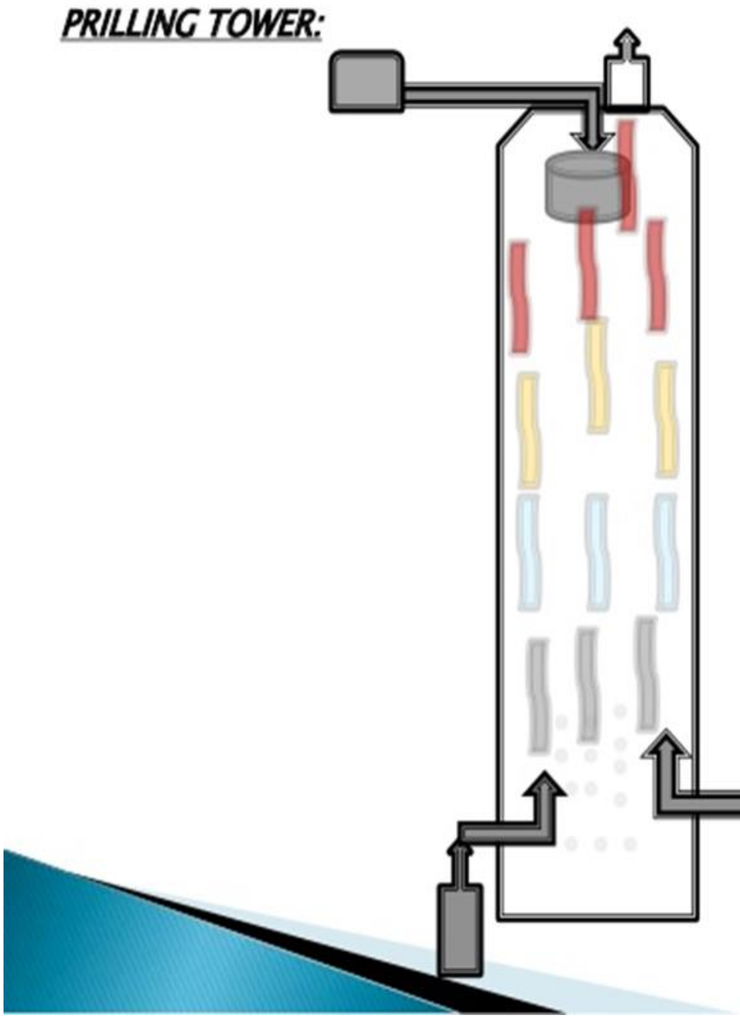


Figure 5 – Prilling Tower



Prilling is a dynamic process where jets of concentrated/molten liquid are formed at the showerhead and broken into droplets. The droplets fall down while they are solidified and cooled by heat transfer to a counter-current air stream. Prilling is a method of producing reasonably uniform spherical particles from molten solids, strong solutions or slurries. ... Higher temperatures require taller towers, as do larger particle sizes. Prilling towers in the **f**ertilizer industry are typically over 50 m high for a mean particle size of about 2 mm

2.5 Crusher

A crusher is a machine designed to reduce large rocks into smaller rocks, gravel, or rock dust. Crushers may be used to reduce the size, or change the form, of waste materials so they can be more easily disposed of or recycled, or to reduce the size of a solid mix of raw materials (as in rock ore), so that pieces of different composition can be differentiated.

Types of crushers

Crushers are divided into two main categories on the basis of crushing property.

- Primary crusher
- Secondary crushers

Primary Crushers

The primary crusher mainly refers to the jaw crusher and impact crusher. They reduce 1.5 meter feed to approximately 10-20 cm particles. In the designing of a crushing plant of any nature and size, to select the right type and size of primary gyratory crusher is of great significance. Generally speaking, this machine is the largest and most expensive single item in the plant; a mistake in the choice may lead to a full replacement. Therefore, you have to pay close attention when choosing primary crushers. The following tips may be helpful for the selection of primary crushers.

- The name, hardness, humidity of material
- Pay attention to the hourly, daily or yearly capacity
- The discharging granularity or the final particle size of the finished products
- Crushing machine type and size
- Feeding method

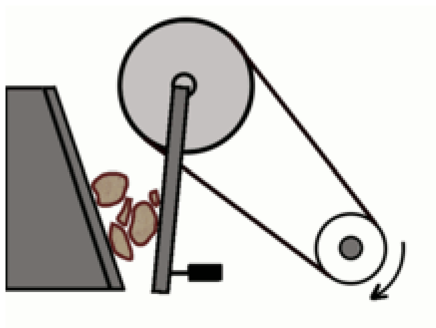
Secondary Crushers

Secondary crushers mainly handle rocks of smaller particle size that have already been impacted and crushed from their original size. They reduce feed in .5-2 cm particles.In recent years, with the rapid development of infrastructure projects, rock crushers have found more applications in various fields and industries, such as mining, chemical industry, road construction, metallurgy, construction etc.

2.5.1 Jaw Crusher

A jaw or toggle crusher consists of a set of vertical jaws, one jaw being fixed and the other being moved back and forth relative to it by a cam or pitman mechanism. The jaws are farther apart at the top -than at the bottom, forming a tapered chute so that the material is crushed progressively smaller and smaller as it travels downward until it is small enough to escape from the bottom opening. The movement of the jaw can be quite small, since complete crushing is not performed in one stroke.

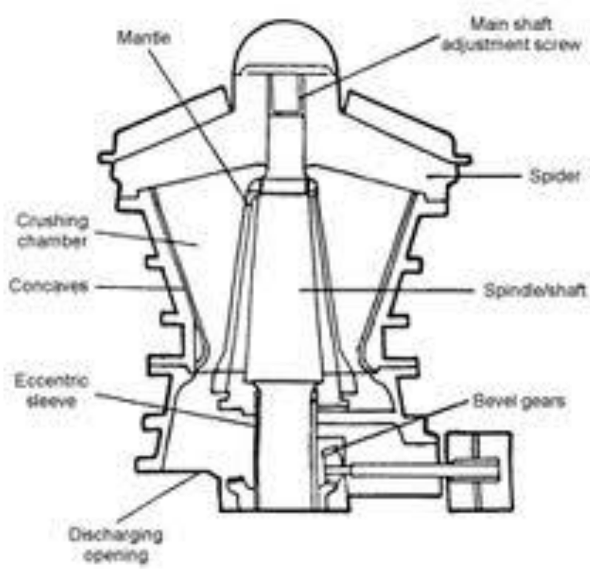
Figure 6 – Jaw Crusher



2.5.2 Gyratory Crusher

A gyratory crusher is similar in basic concept to a jaw crusher, consisting of a concave surface and a conical head;both surfaces are typically lined with manganese steel surfaces. The inner cone has a slight circular movement, but does not rotate; the movement is generated by an eccentric arrangement. As with the jaw crusher, material travels downward between the two surfaces being progressively crushed until it is small enough to fall out through the gap between the two surfaces.

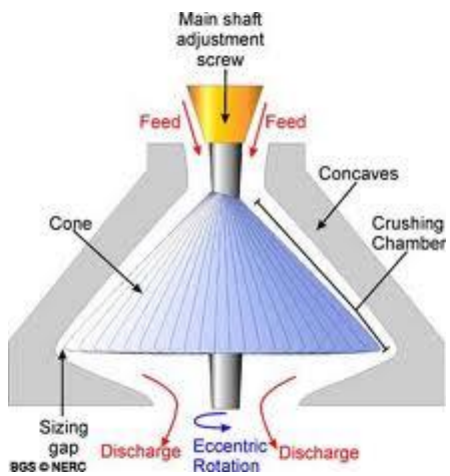
Figure 6 – Jaw Crusher



2.5.3 Cone Crusher

A cone crusher is similar in operation to a gyratory crusher, with less steepness in the crushing chamber and more of a parallel zone between crushing zones. A cone crusher breaks rock by squeezing the rock between an eccentrically gyrating spindle, which is covered by a wear resistant mantle, and the enclosing concave hopper, covered by a manganese concave or a bowl liner. As rock enters the top of the cone crusher, it becomes wedged and squeezed between the mantle and the bowl liner or concave. Large pieces of ore are broken once, and then fall to a lower position (because they are now smaller) where they are broken again. This process continues until the pieces are small enough to fall through the narrow opening at the bottom of the crusher.

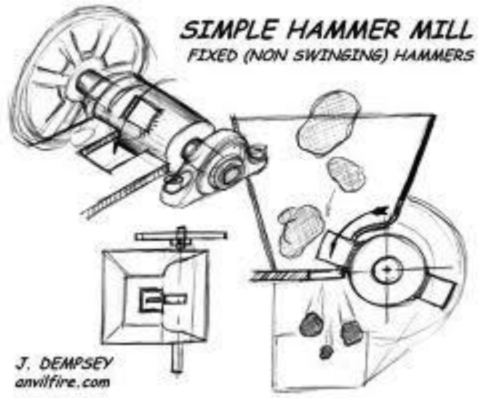
Figure 7- Cone Crusher



2.5.5 Horizontal shaft impactor (HSI) / Hammer mill:-

The HSI crushers break rock by impacting the rock with hammers that fixed upon the outer edge of a spinning rotor. The practical use of HSI crushers is limited to soft materials and non abrasive materials, such as limestone, phosphate, gypsum, weathered shales.

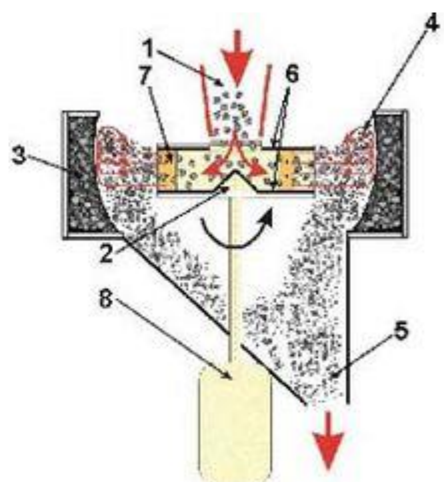
Figure 8 - Hammer Mill



2.5.6 Vertical shaft impactor (VSI)

VSI crushers use a different approach involving a high speed rotor with wear resistant tips and a crushing chamber designed to 'throw' the rock against. The VSI crushers utilize velocity rather than surface force as the predominant force to break rock. In its natural state, rock has a jagged and uneven surface. Applying surface force (pressure) results in unpredictable and typically non-cubicle resulting particles. Utilizing velocity rather than surface force allows the breaking force to be applied evenly both across the surface of the rock as well as through the mass of the rock. Rock, regardless of size, has natural fissures (faults) throughout its structure. As rock is 'thrown' by a VSI Rotor against a solid anvil, it fractures and breaks along these fissures. Final particle size can be controlled by 1) the velocity at which the rock is thrown against the anvil and 2) the distance between the end of the rotor and the impact point on the anvil.

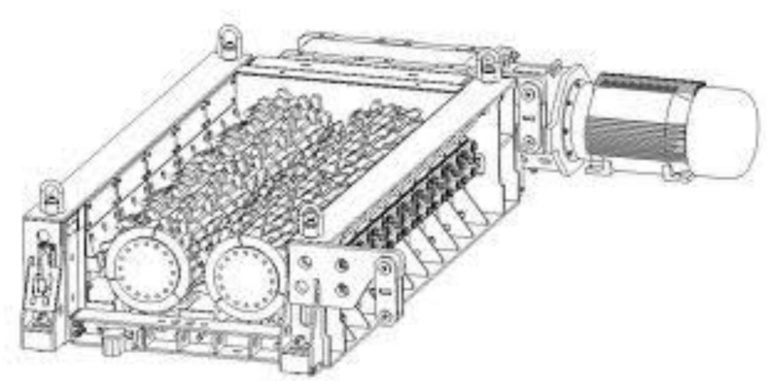
Figure 9 - Vertical shaft impactor



2.5.7 Mineral Sizers

The basic concept of the mineral Sizer, is the use of two rotors with large teeth, on small diameter shafts, driven at a low speed by a direct high torque drive system. This design produces three major principles which all interact when breaking materials using Sizer Technology. The unique principles are; The Three-Stage Breaking Action, The Rotating Screen Effect, and The Deep Scroll Tooth Pattern.

Figure 10 - Mineral Sizers



The Three-Stage Breaking Action: Initially, the material is gripped by the leading faces of opposed rotor teeth. These subject the rock to multiple point loading, inducing stress into the material to exploit any natural weaknesses. At the second stage, material is broken in tension by being subjected to a three point loading, applied between the front tooth faces on one rotor, and rear tooth faces on the other rotor. Any lumps of material that still remain oversize, are broken as the rotors chop through the fixed teeth of the breaker bar, thereby achieving a three dimensional controlled product size.

2.6 Mixing

There are many kinds of mixing operations needed in the process industries and there are nearly as variations of mixing devices and systems. Some liquids are soluble in each other while others are not. Insoluble liquids can be mixed to promote a chemical reaction to heat or cool one of the liquids. Or to form permanent emulsions.. Solids of various types, usually powders or granules, must also be mixed with each other.

Good mixing is defined as , which is actually, the best possible distribution of one material in the other- requires creation of an internal mixing (or transport) velocity high enough to create a high probability of contact between elements of the different materials. The physical form of mixing depends on what is to be mixed. The basic phase possibilities are: gas-gas, gas-liquid, gas-solid, liquid-liquid ,liquid-solid, solid-solid.

Gas-gas mixing is probably the simplest problem, and he comments regarding liquid-liquid mixing also apply in principle to the mixing of gases. Contact between liquids and gases is important in the following unit operations;

Distillation, absorption, adsorption, evaporation, humidification, de humidification etc.,

Mixing of gases and solids

This is especially important in drying and chemical reactions. One very common mixer for this combination is a rotating drum, mounted at a slight angle to the horizontal, in which the solid material is tumbled, preferably counter current to the flow of gas. An increasingly popular and very efficient method is the fluidized bed, where gas at high velocity actually floats the solid. In this case, the solid circyulates in the bed as the gas moves upward. This floating or fluidization provides excellent contact between the solid particles and the gas. A third method is prilling tower.

Liquid- solid mixing

The choice of equipment can be used for liquid – solid mixing will depend on whether the liquid or the solid is the dominant material. For very viscous materials(dominated by the solid), a screw mixer, similar to the familiar kitchen meat grinder The mixing efficiency is strongly dependent on hold up time and internal velocity. If a chemical reaction accompanies the mixing , then the hold up time must be sufficient for the reaction to reach the desired degree of completion. It consists of a silo fitted with a screw conveyor that has the dual function of mixing the materials and in lower section, removing the mixture from silo. A conical screw mixer for mixing various viscous materials is shown in figure

2.7 SEPARATION

The possible combinations that might have to be separated inindustrial processes are:

Gas-gas, gas-liquid, gas-solid, liquid-liquid, liquid –solid,solid-solid.

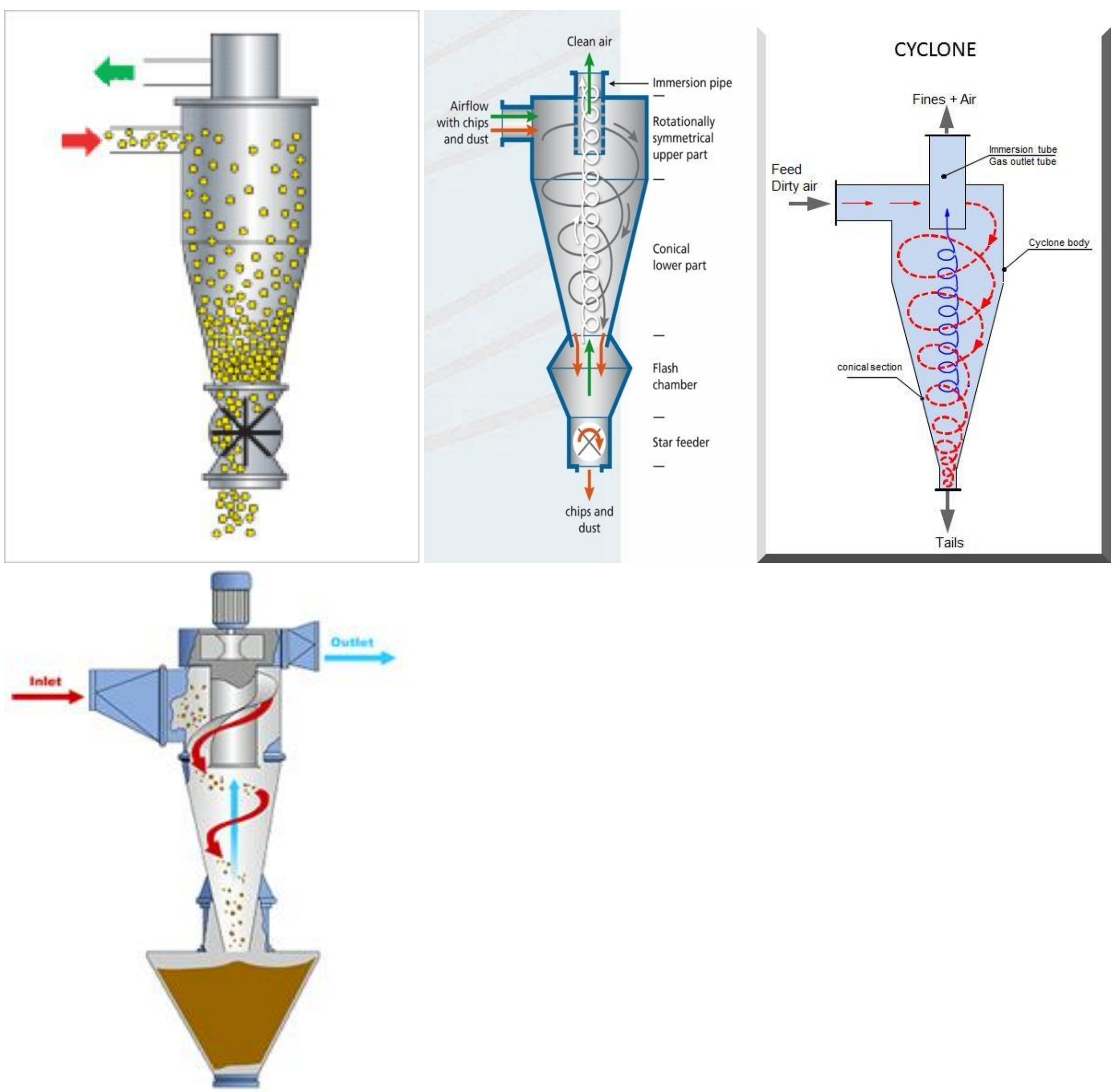
The choice of equipment for separation depends upon the materials to be separate. We can use screens or fiber filters for separating solids from liquids., fiber or electrostatic filters for separating solids from gases and centrifuges for separating solids from gases and liquids, magnetic separators for separating magnetic from non magnetic materials, floatation cells for separating materials with different surface properties.

Separation of gas from solid

Separation of gas from solids is required in many processes. One method is drying by means of either separation or sublimation. Another gas/ solids separation process is used for removing dust or dirt from gas. This can be done by means of cyclone separator, a bag filter, scrubbers, or an electrostatic filter.

Cyclone separator is probably the most widely used , in this device, gas that contains small particles of dirt or dust that enters the upper part of the cyclone., tangentially to the cyclone wall. Because, they are heavier than the gas, the dirt particles are forced toward the wall. Then, they fall along the wall and eventually leave the cyclone converter at the bottom. The gas is forced to the center at the bottom , reverses direction and flows upward in the direction and out the top of the cylinder. A cyclone does not have control variables; but can be controlled by manipulating the pressure drop across the cyclone .In practices, a single cyclone does not provide the required degree of separation, it can be followed by additional cyclone stages or separation devices.

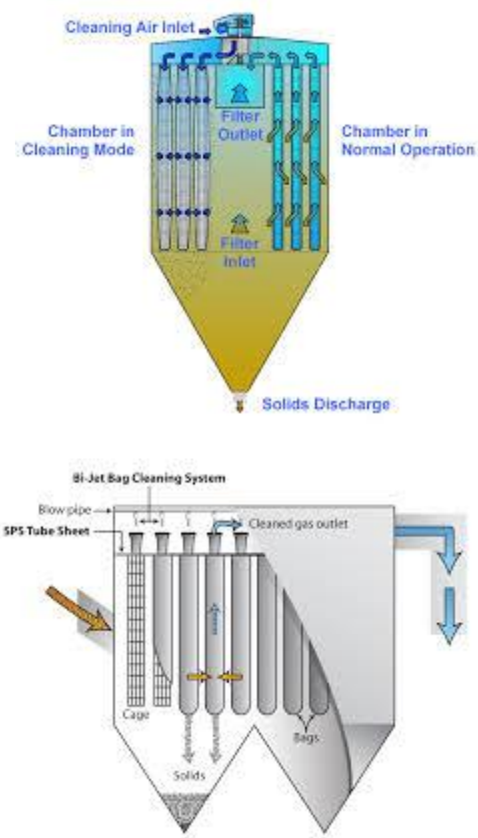
Figure 11 – Cyclone Separators



Bag filters

A rug is used in bag filter. It is thin , fine- meshed material or it can be made of quick thick filtering material. When thin material is used, the mesh size is usually larger than the size of the particles to be removed. The filtering actions are provided by a filter cake, which is build up of filtered particles on the mesh material. The filter cake will continue to build up until the pressure drop across it, provided by a filter cake, which is a buildup of filtered particles on the mesh material. It continue to build up until the pressure drop across it gets high that some of the cake must be removed. Control of the bag filter is generally limited to monitoring the pressure drop across the filter cake and measuring the particle content of the filtered gas.

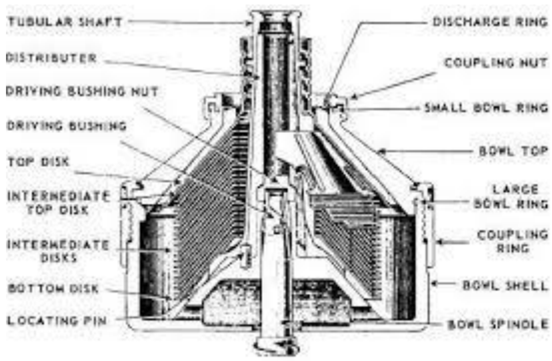
Figure 11 – Bag Filters



Disk centrifuge

The most common form of centrifuge is shown in figure12. The mixture is added at the top ocenter, but it actually enters the centrifuge at the bottom. The liquid rises through a series of conical metal plates that are to be separated by a distance of about 0.3 to 2mm, depending upon the material to be centrifuged. There are about one hundred of these plates, each of which has a number of holes. A centrifuge rotates at very high speed up to about 10000 rpm. The hold up time of a centrifuge is determined by a ratio of the hold up volume to the through put rate for each of the liquid components.

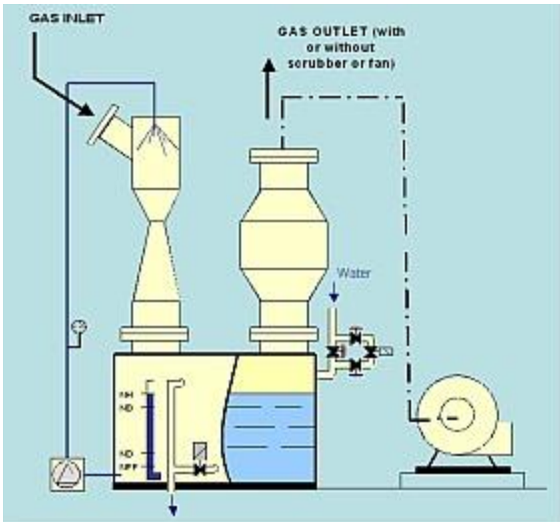
Figure 12 - Disk centrifuge



Scrubbers

The actual lay out of the scrubber system depends upon the method used to atomize the liquid. The solids can be separated from the scrubbing liquid by a filtration process. Cleaning or washing a gas in a scrubber consists of literally washing the solid particles out of the gas by means of a conter current liquidshower, usually water.

Figure 13- Scrubbers

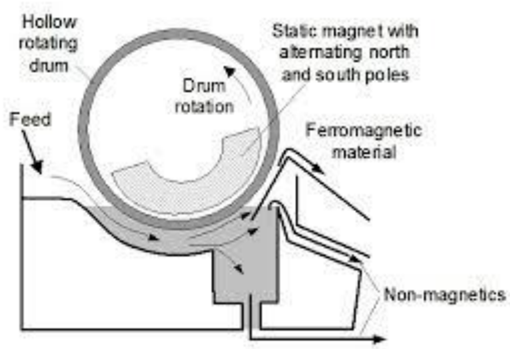


A scrubber is usually designed to remove finer particles than either a cyclone or a bag filter removes and therefore it is often installed in cascade following those devices if they cannot satisfactorily separate the solid particles from the gas.

Magnetic Separator

Separation of solid particles on the basis of density or size can also be done by dispersing the solids in a liquid. Separation of solids by magnetic means is widely used in the mining and mineral refining industries. The schematic diagram is shown in figure. A number of fixed permanent magnets mounted inside the drum create a magnetic field that holds the magnetic material. The non magnetic material remains in suspension and leaves the system. The magnetic particles remain on the drum until they leave the field of the last magnet where they will drop and or be scraped off the drum. The efficiency or separation quality of a magnetic separator is characterized by the amount of magnetic materials remaining in the suspension, relative to the amount of non magnetic material.

Figure 14- Magnetic Separators



Leaching and Extraction

Removing one constituent from a solid or liquid by means of a liquid solvent.

These techniques fall into two categories. The first called leaching or solid extraction is used to dissolve solvable matter from its mixture with an insolvable solid. The second called liquid extraction is used to separate two miscible liquids by the use of a solvent that preferentially dissolves one of them. Although the two processes have certain common fundamentals, the differences in equipment and to some extent in theory are sufficient to justify separate treatment.

LEACHING

Leaching differs very little from the washing of filtered solids and leaching equipment strongly resembles the washing section of various filters .In leaching the amount of solvable material removed is often rather greater than in ordinary filtration washing and the properties of the solids may change considerable during the leaching operation. Hard or granular feed solids may disintegrate into pulp when their content of solvable material is removed.

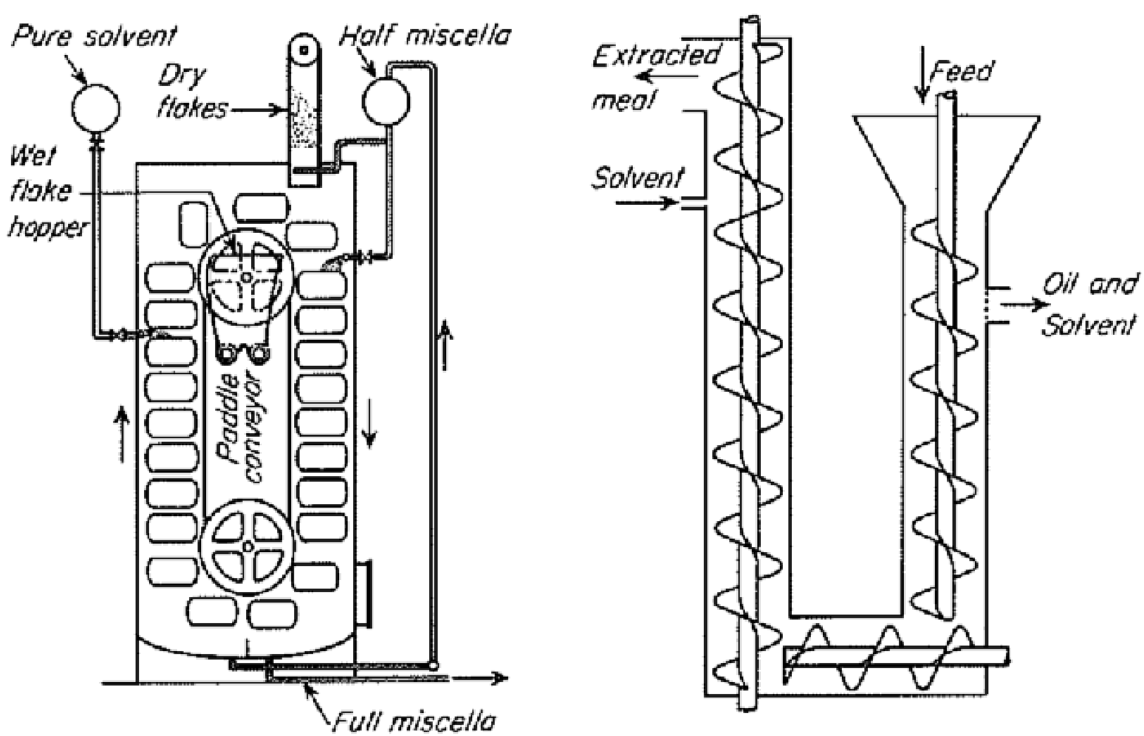
Leaching

When the solids form an open permeable mass throughtout the leaching operation, solvent may be percolated through an unagitated bed of solids. With impermeable solids or materials that disintegrated during leaching the solids are dispersed into the solvent and are later separated from it. Both methods may be either batch or continuous.

LEACHING BY PERCOLATION THROUGH STATIONARY SOLID BEDS.

Stationary solid bed leaching is done in a tank with a perforated false bottom to support the solids and permit drainage of the solvent. Solids are loaded into the tank, sprayed with solvent until their solute content is reduced to the economical minimum and excavated . In some case the rate of solution is so rapid that one passage of solvent through the materials is sufficient but countercurrent flow of Solvent through a battery of tank is more common. In this method fresh solvent is fed to the tank containing the solids that it most nearly extracted battery. The solid in any one tank is stationary until it is completely extracted .The piping is arranged so that fresh solvent can be introduced to any tank and strong solution withdrawn from any tank , making it possible to charge and discharge one tank at a time, the other tanks in the battery are kept in countercurrent operation by advancing inlet and draw off tank one at a time as material is charged and removed such a process is called sometime called shanks process.

Figure 15- Extractors



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UNIT – III
Industrial Unit Operations – SIC 1308

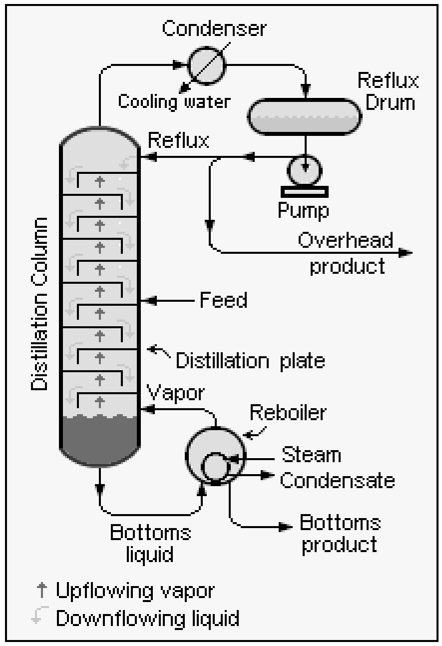
3. Distillation

It is a very important separation process. Distillation process makes use of the fact that two or more materials can be separated on the basis of their different boiling points. A schematic diagram is shown in figure. Liquid and vapor are in contact with each other at the same temperature and pressure at each tray. Each tray contains a number of holes, each with a cover. Vapor produced by the re boiler enters at the bottom and rises through the column, passing through each tray where it bubbles through the liquid. The liquid moves down through the column, through a space that acts as a liquid seal. The liquid leaves each tray by passing over a barrier that combined with the hydro dynamic conditions in the seal chamber, determines the liquid level on the tray. The holes in the trays are provided to assure good contact between the vapor and the liquid. The resistance to upward flow of the vapor gives the pressure gradient in the column, which is such that the absolute pressure is highest at the bottom and lowest at the top of the column. Likewise, there will be a temperature gradient over the column, with the highest temperature at the bottom and lowest at the top.

3.1 Binary Distillation

In binary distillation, the liquid is assumed to have two components. It is fed into the system at some tray, somewhere between the top and bottom of the column. Because of its weight, the liquid will flow downward from the tray to tray to the bottom of the column, where part of it is evaporated by the re boiler. The reminder of the liquid is removed from the system as bottom product. The vapor that leaves the column at the top is condensed and collected in an accumulator. Some of the liquid from the accumulator is recycled to the column and the remainder is drawn off as top product (distillate). It is shown in figure 3.1

Figure 1 Batch Distillation

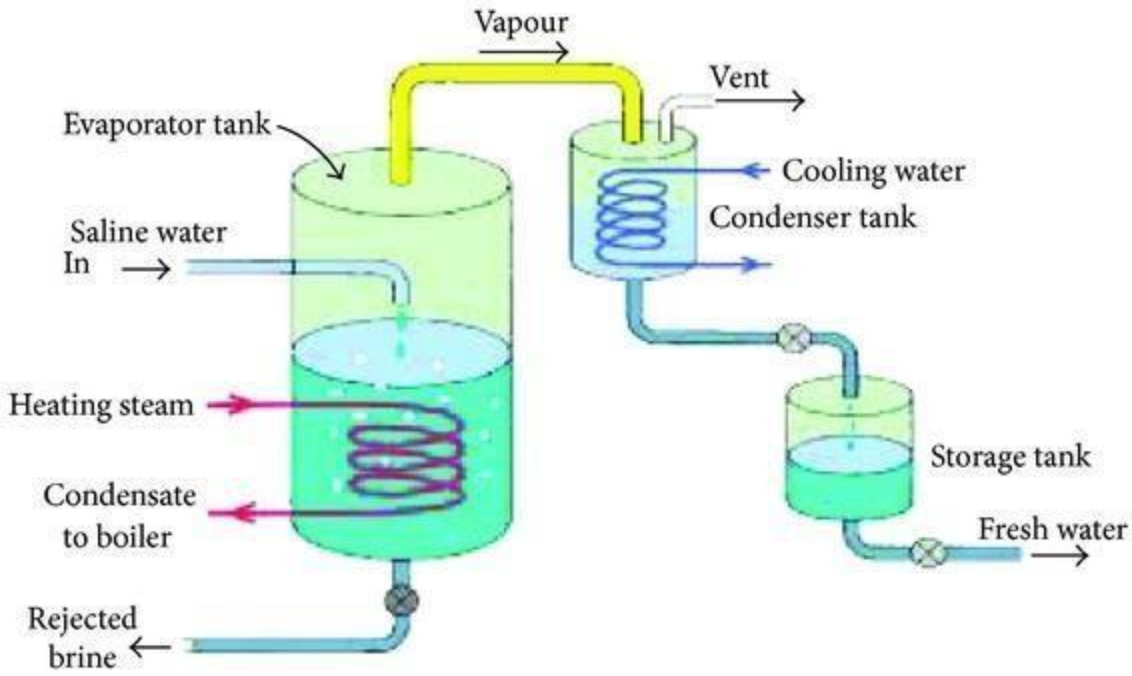


Distillation columns are used in a very broad range of applications. In sugar industries, the distillation of a mixture of water and different alcohols , produced by fermentation of sugar. Pure oxygen, used for medical purposes is produced by the distillation process. Oil refineries make use of distillation for separating all the petroleum by products.

3.2 Flash (Equilibrium) Distillation

A **single-stage** continuous operation where a liquid mixture is partially vaporized: the **vapour produced and the residual liquid** are in **equilibrium**, which are then separated and removed, which is shown in figure 2.

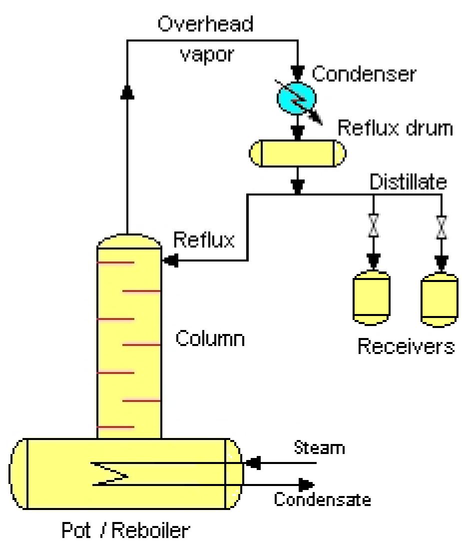
Figure 2. Flash Distillation



We again consider a binary mixture of A (MVC) and B (LVC). The feed is preheated before entering the separator. As such, part of the feed may be vaporized. The heated mixture then flows through a pressure-reducing valve to the separator. In the separator, separation between the vapor and liquid takes place. How much of A is produced in the vapor (and remained in the liquid) depends on the condition of the feed, i.e. how much of the feed is entering as vapor state, which in turn is controlled by the amount of heating. In other words, **the degree of vaporization affects the concentration (distribution) of A in vapor phase and liquid phase.**There is thus a certain relationship between the degree of heating (vaporization) and mole fraction of A in vapor and liquid (y and x). This relationship is known as the **Operating Line** Equation.**Batch distillation**] refers to the use of distillation in batches, meaning that a mixture is distilled to separate it into its component fractions before the distillation still is again charged with more mixture and the process is repeated. This is in contrast with continuous distillation where the feedstock is added and the distillate drawn off without interruption. Batch distillation has always been an important part of the production of seasonal, or low capacity and high-purity chemicals. It is a very frequent separation process in the pharmaceutical industry.

3.3. Batch distillation

Figure 3.Diagram of a Batch Rectifier



The simplest and most frequently used batch distillation configuration is the **batch rectifier**, including the alembic and pot still. The batch rectifier consists of a pot (or reboiler), rectifying column, a condenser, some means of splitting off a portion of the condensed vapour (distillate) as reflux, and one or more receivers.

The pot is filled with liquid mixture and heated. Vapor flows upwards in the rectifying column and condenses at the top. Usually, the entire condensate is initially returned to the column as reflux. This contacting of vapor and liquid considerably improves the separation. Generally, this step is named start-up. The first condensate is the *head*, and it contains undesirable components. The last condensate is the *feints* and it is also undesirable, although it adds flavor. In between is the *heart* and this forms the desired product.

The head and feints may be thrown out, refluxed, or added to the next batch of mash/juice, according to the practice of the distiller. After some time, a part of the overhead condensate is withdrawn continuously as distillate and it is accumulated in the receivers, and the other part is recycled into the column as reflux.

Owing to the differing vapor pressures of the distillate, there will be a change in the overhead distillation with time, as early on in the batch distillation, the distillate will contain a high concentration of the component with the higher relative volatility. As the supply of the material is limited and lighter components are removed, the relative fraction of heavier components will increase as the distillation progresses.

3.4 Chemical reactor

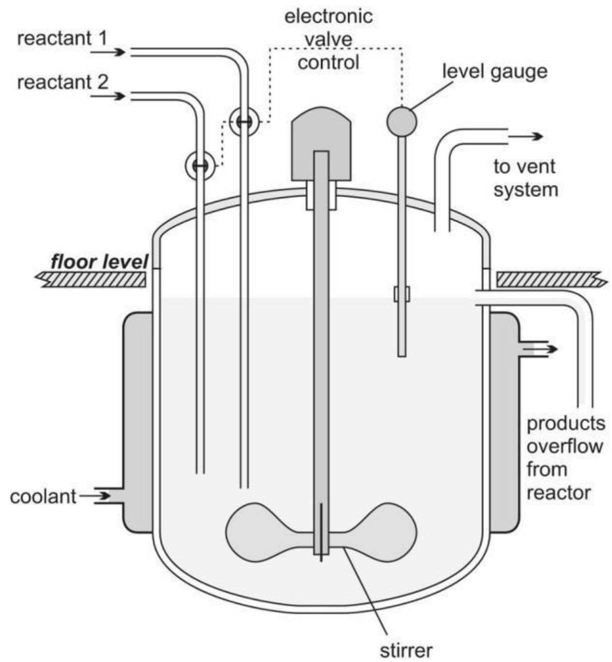
Chemical reactors are vessels which house the chemical reactions. Chemical reactors are designed re to maximize net present value for the given reaction. It is ensured that the reaction proceeds with the highest efficiency towards the desired output product, producing the highest yield of product while requiring the least amount of money to purchase and operate. Energy changes can come in the form of heating or cooling, pumping to increase pressure, frictional pressure loss

Chemical reactor designs include continuous stirred tank reactors, batch stirred tank reactors, tubular reactors, and the packed bed reactors.

3.4.1 CSTR

In a CSTR, one or more fluid reagents are introduced into a tank reactor (typically) equipped with an impeller while the reactor effluent is removed. The impeller stirs the reagents to ensure proper mixing. Simply dividing the volume of the tank by the average volumetric flow rate through the tank gives the space time, or the average amount of time a discrete quantity of reagent spends inside the tank.

Figure 4.CSTR



At steady-state, the mass flow rate in must equal the mass flowrate out, otherwise the tank will overflow or go empty (transient state). While the reactor is in a transient state the model equation must be derived from the differential mass and energy balances. The reaction proceeds at the reaction rate associated with the final (output) concentration, since the concentration is assumed to be homogenous throughout the reactor.Often, it is economically beneficial to operate several CSTRs in series. This allows, for example, the first CSTR to operate at a higher reagent concentration and therefore a higher reaction rate. In these cases, the sizes of the reactors may be varied in order to minimize the total capital investment required to implement the process.

Advantages of CSTR:

- It is possible to maintain this reactor at isothermal conditions for high heat of reaction.
- It is quite easy to maintain good temperature control with this reactor.
- Due to large volume, it provides a long residence time.
- It also has low cost of construction.

Disadvantages:

- It is not recommended for high pressure reactions because of cost consideration. For high pressure reactions it requires complex sealing arrangements for the agitator which increase the initial as well as maintenance cost.
- Conversion of these reactors is low due to this they are not preferred.
- These reactors are not suited for high heat effect since availability of both heat transfer

coefficient and heat transfer per unit area is low.

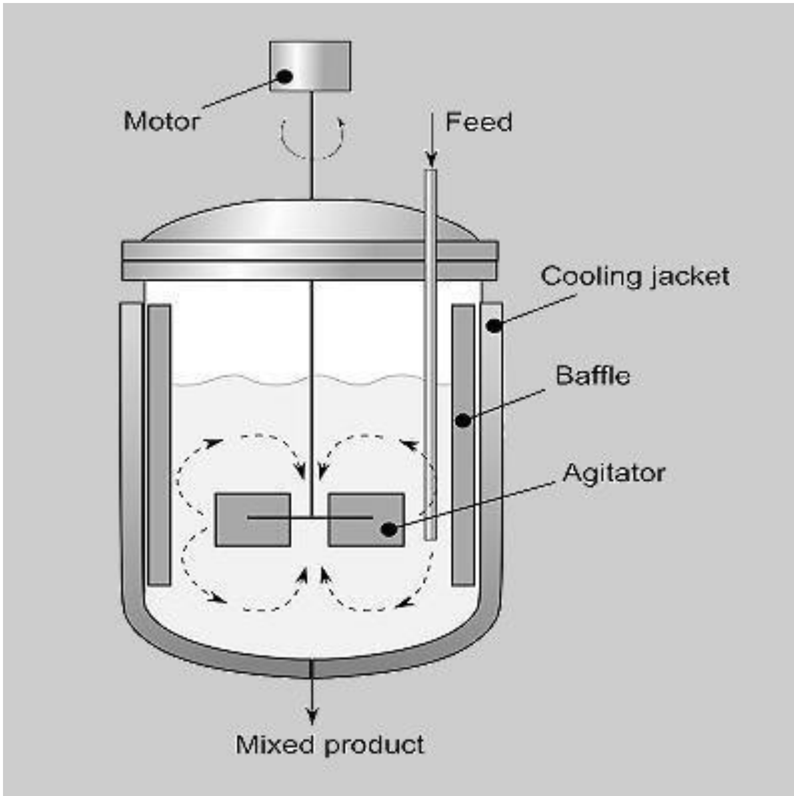
Applications:

- These reactors are normally employed on commercial scale mainly for liquid phase reaction at low or medium pressure.
- It is commonly used in industrial processing of homogeneous reactions (only liquid phase) and usuallyused in series

3.4.2 BATCH REACTOR

In the batch reactor, the reactants are charged at the beginning into the reactor, it left to the react for certain period of time. During agitation no material is fed into the reactor. After certain time the product is withdrawn from the reactor.Actually batch reactor is used in the unsteady state condition as in this reactor composition is changes with time. The batch reactor actually consist of a cylindrical vessel have agitator for mixing the contents. External jacket is provided to heating or cooling the reactor contents.

Figure 5.BSTR



Advantages :

- It is simple in construction
- It is so easy to operate
- Cost is relatively low
- It can give high amount of conversion

Disadvantages:

- It has high labour cost per unit volume of production.
- It requires considerable amount of time to empty, refill and clean out.
- Large scale production is difficult in this reactor.

Applications:

- Batch reactors are usually used in small scale industries.
- It is also used to produce many different product from small piece of equipments
- It is used for the manufacturing of expensive products like pharmaceuticals, dyes, dye intermediates etc.

3.5 Steam Boilers

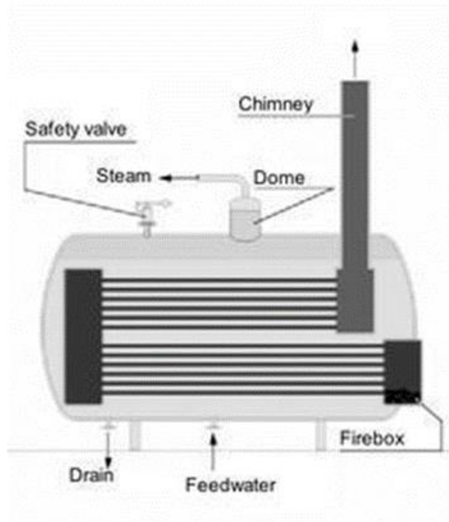
A boiler is a closed vessel in which water or other fluid is heated. The fluid does not necessarily boil. The heated or vaporized fluid exits the boiler for use in various processes or heating applications include water heating, central heating, boiler-based power generation, cooking, and sanitation. Types of boilers are Pot boiler, fire tube boiler, water tube boiler are some of the types of steam boilers.

Pot boiler or Haycock boiler/Haystack boiler: a primitive "kettle" where a fire heats a partially filled water container from below. 18th century Haycock boilers generally produced and stored large volumes of very low- pressure steam, often hardly above that of the atmosphere. These could burn wood or most often, coal. Efficiency was very low.

3.5.1 Fire-tube boiler.□

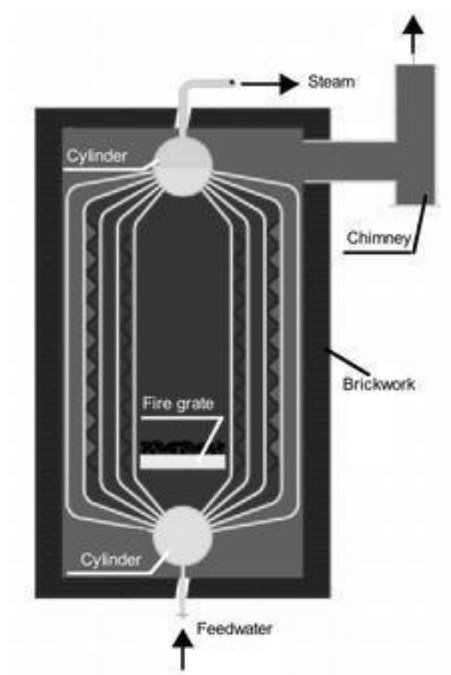
Here, water partially fills a boiler barrel with a small volume left above to accommodate the steam This is the type of boiler used in nearly all steam locomotives. The heat source is inside a furnace or firebox that has to be kept permanently surrounded by the water in order to maintain the temperature of the heating surface below the boiling point. The furnace can be situated at one end of a fire-tube which lengthens the path of the hot gases, thus augmenting the heating surface which can be further increased by making the gases reverse direction through a second parallel tube or a bundle of multiple tubes alternatively the gases may be taken along the sides and then beneath the boiler through flues . Fire-tube boilers usually have a comparatively low rate of steam production, but high steam storage capacity. Fire-tube boilers mostly burn solid fuels, but are readily adaptable to those of the liquid or gas variety.

Figure 6. Fire-tube boiler



3.5.1 Water tube boiler

Figure 7. Fire-tube boiler



In this type, tubes filled with water are arranged inside a furnace in a number of possible configurations. Often the water tubes connect large drums, the lower ones containing water and the upper ones steam and water; in other cases, such as a mono-tube boiler, water is circulated by a pump through a succession of coils. This type generally gives high steam production rates, but less storage capacity than the above. Water tube boilers can be designed to exploit any heat source and are generally preferred in high-pressure applications since the high-pressure water/steam is contained within small diameter pipes which can withstand the pressure with a thinner wall.

3.6 Furnaces

Furnaces are devices in which heat energy is transferred to a charge or feed in a controlled manner. The typical furnace usually takes the form of a metal housing lined with a heat conserving refractory. The charge can enter as a solid, liquid or gas, and may or may not be transformed to a different state by the energy be supplied. The charge can be carried through the furnace or heater continuously, through metal tubes or toughs.

Main functions of furnaces:

1. To heat and/ or vaporize the charge

2. To provide heat of reaction to reacting fluids

3. To provide an elevated and controlled temperature for the physical change of charge materials.

An example of a heating and vaporizing furnace is a refinery crude oil heater, where crude oil is heated and partially vaporized preparatory to distillation.

A blast furnace is a type of metallurgical furnace used for smelting to produce industrial metals, generally iron, but also others such as lead or copper.

In a blast furnace, fuel, ores, and flux (limestone) are continuously supplied through the top of the furnace, while a hot blast of air

(sometimes with oxygen enrichment) is blown into the lower section of the furnace through a series of pipes called tuyers, so that the chemical reactions take place throughout the furnace as the material moves downward. The end products are usually molten metal and slag phases tapped from the bottom, and flue gases exiting from the top of the furnace. The downward flow of the ore and flux in contact with an up flow of hot, carbon monoxide-rich combustion gases is a countercurrent exchange and chemical reaction process

Figure 8. Blast Furnace

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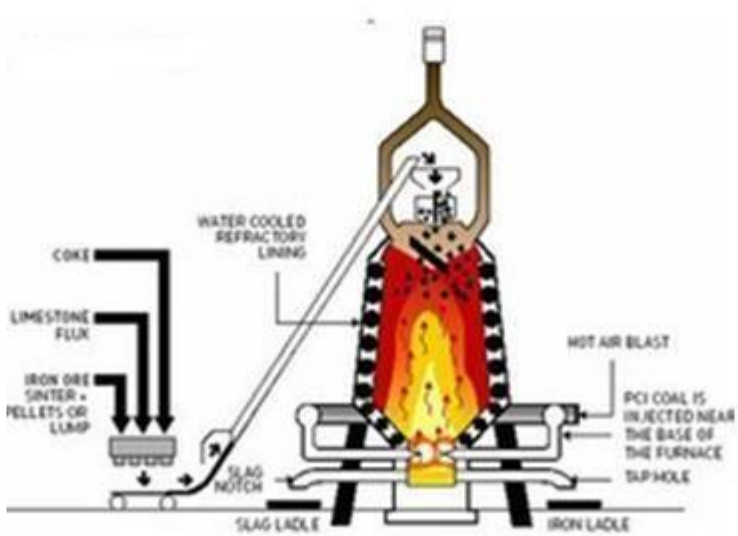

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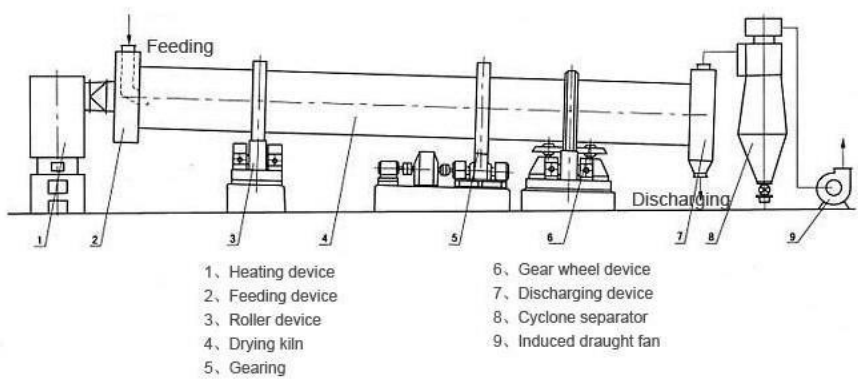
4.1 Dryers

The purpose of drying unit operation is to separate liquids from solids. Many commercial dryers are available. Various factors are considered in determining the correct type of dryer for any given application, including the material to be dried, drying process requirements, production requirements, final product quality requirements and available facility space.

4.2 Rotary dryer

Rotary dryer in which, a long cylinder with an axis tilted slightly with respect to the horizontal. Cylinders of this type contain baffles or plates on the inner surface, which carry the solid material around part of the inner periphery of the cylinder in order to increase exposure of the material to the drying medium and to agitate the solid material. The rotary dryer is shown in figure 1

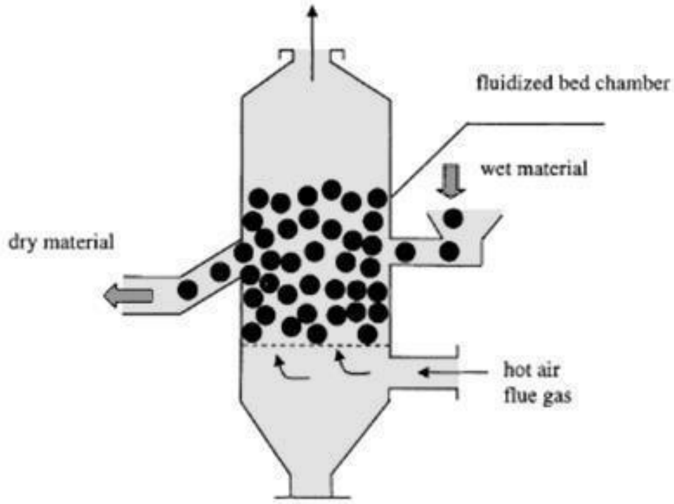
Figure 1. Rotary dryer



4.3. Fluidized bed

In a fluidized bed method, the solid material is suspended in fluidized form by a strong gas stream. This provides very effective contact between the material and the drying gas, which leads to the evaporation of the liquid in the solid material.

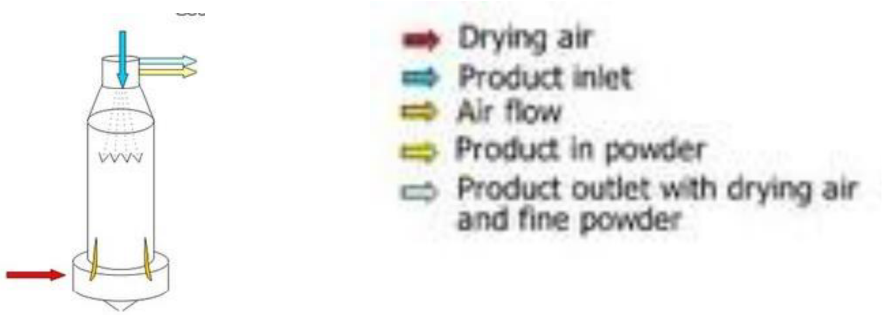
Figure 2. Fluidized bed dryer



4.4 Counter current gas stream

In this, Moist particles can be dried by simply dropping them through a counter current gas stream.

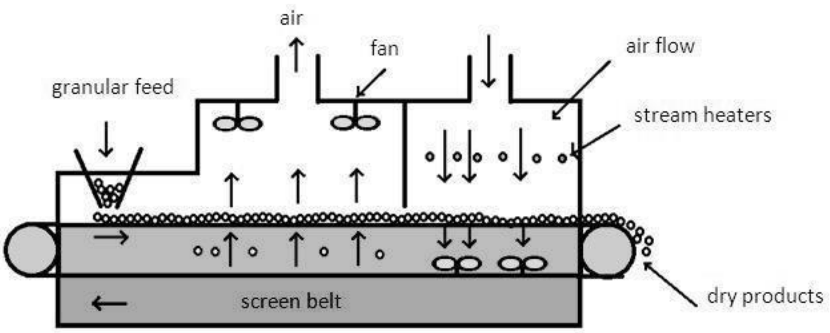
Figure 3. Counter current gas stream dryer



4.5 Perforated conveyor

The drying gas passes through the material and the conveyor from both the top and the bottom

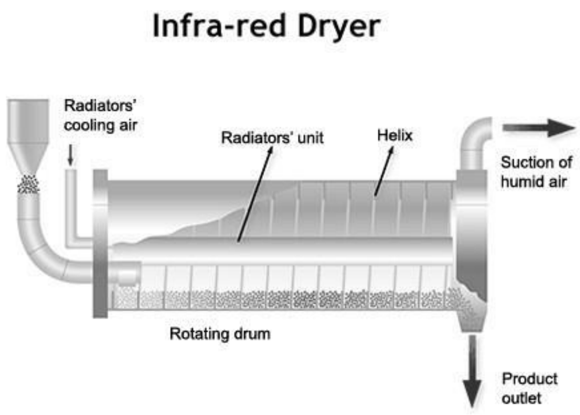
Figure 4. Perforated conveyor dryer



4.6 Infrared Radiation Dryer

Infra red radiation can be applied on a solid material on a conveyor

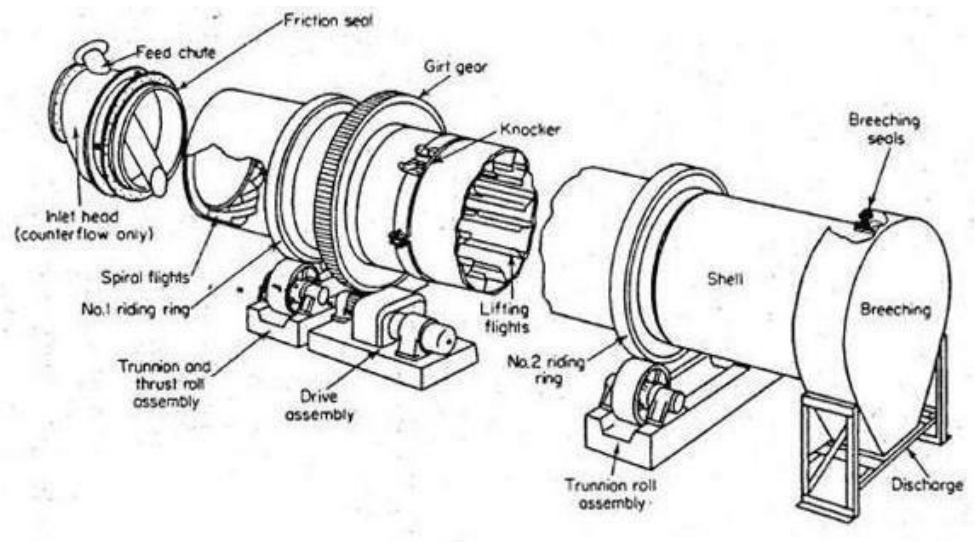
Figure 5. Infrared Radiation Dryer



4.7 **Cylindrical Dryer**

A cylindrical dryer can be used for continuous drying of wet material such as paper, textiles.

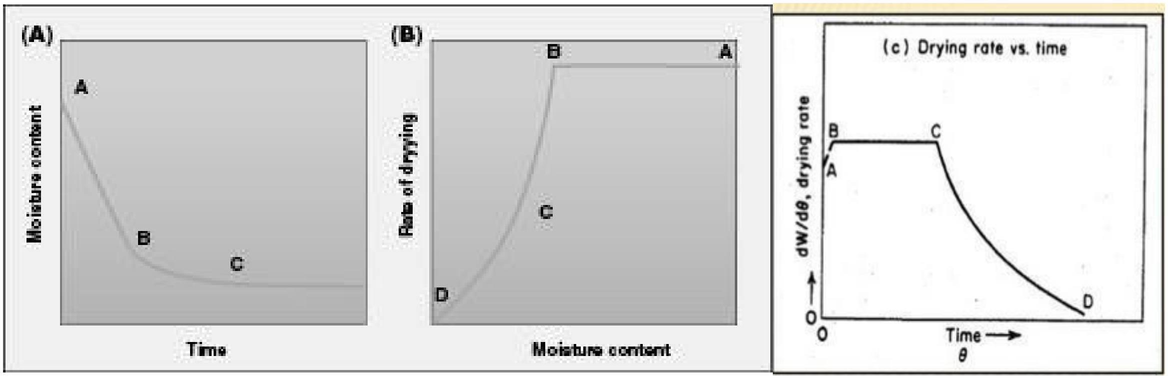
Figure 6. Cylindrical Dryer



4.8 Drying rate curves

The drying rate profile is shown in figure. Figure7. a shows the moisture content of the material as a function of time. Figure7. b shows the drying rate as a function of moisture content. Figure 7.c shows the drying rate as a function of time. From figure b, it is evident that the moisture content is high, the drying rate will be constant. It means that drying is limited by evaporation at the surface of the material and that there is good transfer of moisture from within each particle to the surface.

Figure 7. Drying rate curves



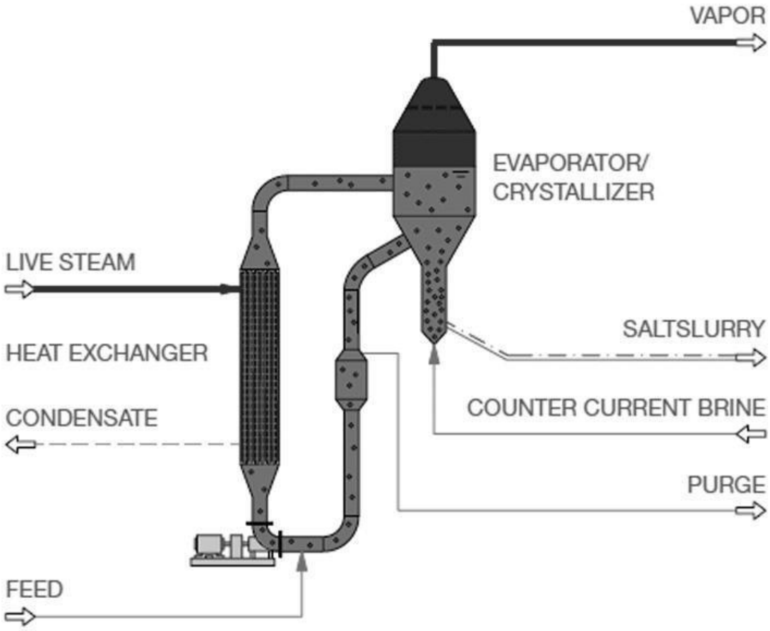
4.9 Crystallizer

Crystals are solids of very high purity that can be produced from solutions containing significant pollutants. Many products are marketed in crystalline form, making crystallization an important industrial process. The crystallization process requires very little energy compared with distillation and other methods of separation. Not all materials form crystals, so crystallization is limited to certain types of materials. The most common, but not only, solution medium in which crystallization takes place is water.

The concentration at which crystallization will occur, in a solution consisting of a solid such as a salt dissolved in a liquid, depends on temperature. The conditions for the formation and growth of crystals are

1. There must be small particles that can form the nuclei for growth
2. The solution must be super saturated.
3. Forced circulation Crystallizer

Figure 8. Crystallizer

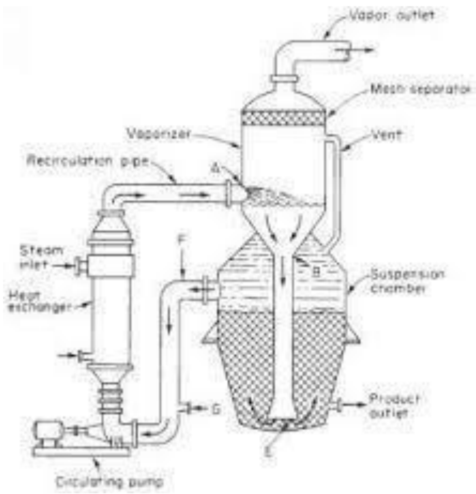


A cylindrical tank is mounted integrally with a conical section at the bottom. The solution is circulated to the bottom, out of the bottom and into a single effect evaporator and back to the cylindrical tank. The steam is driven out of the top, when the solution reaches super saturation. Crystals form and then, the crystals can be removed by means of a vacuum pump.

4.9.1 OSLO CRYSTALLIZER

A variation in the forced circulation crystallizer is the oslo crystallizer, which has an extra tank, in which crystals form and which has an extra tank in which the crystals form and which can also provide cooling to better super saturation. The growth of crystals in solution is mainly determined by the degree of super saturation and the temperature. A solution that has a certain super saturation at one temperature can be cooled to produce a higher degree of super saturation and there by provide faster crystal growth. The most important control variables are the feed of the solution to be crystallized, the flow rate of crystals out, steam supply flow to the evaporator and the vapor flow out of the tank.

Figure 9. Oslo Crystallizer

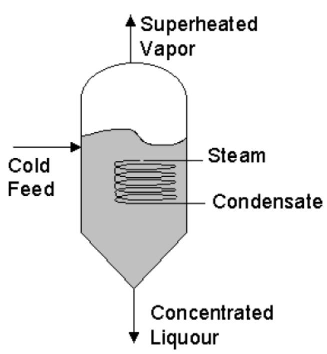


4.10 Evaporators

Evaporation is an important heat transfer process, that is treated as a separate unit operation. The purpose of an evaporator is to concentrate a solution by evaporating the more volatile portion of the solution. The material remaining after evaporation of the more volatile component of the solution is called as concentrate or thick liquor. Evaporation differs from drying in the sense that even though processes drive off a volatile, the concentrate or product of drying is a solid material , while for evaporation , it is a liquid. Evaporators are used in many industries such as pulp and paper industry, fertilizer industry, mineral processing, food processing. The amount of volatile liquid that can be evaporated in a single evaporator stage is small, many industrial processes use several stages in cascade. Such a system is usually known as a multi effect evaporator. Because, many materials cannot tolerate high temperatures. In a single effect evaporator, the vapor that is produced in condensed and removed from the system. In a multi effect evaporator, the vapor produced by one stage is used to heat the following stage and so on through the entire series of stages.

Single Effect Evaporator

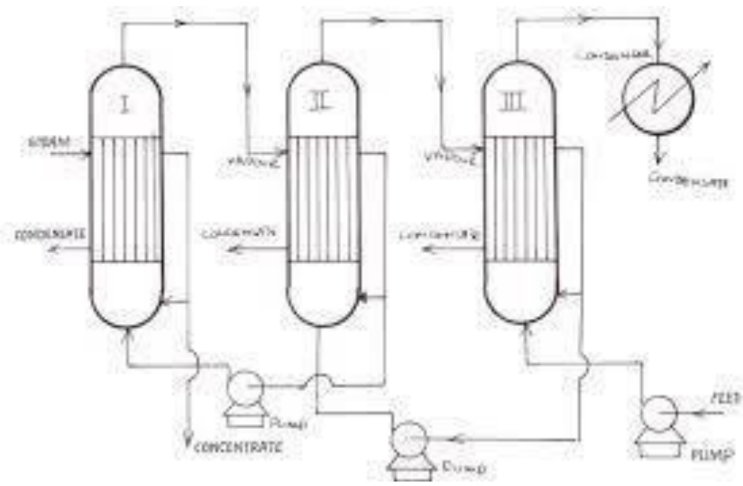
Figure 10. Single Effect Evaporator



Multi Effect Evaporator

a triple effect evaporator is shown in figure 11. In order to use the steam from one effect to heat the next effect, the pressure in the upstream effect must be higher than that in the following effect. The pressure difference, which also gives the temperature difference, because the steam is saturated, is determined by the pressure drop across the surface of the heat exchanger. The solution that is to be evaporated enters at the left side through control valve and its level is controlled just high enough to cover the heat exchanger surface. The concentrate leaves the bottom of the first effect through another control valve and flows to the second effect. The pressure difference between these two effects causes the liquid to flow.

Figure 11. Multi Effect Evaporator



Evaporators differ from each other in two major respects: the length of the evaporator tubes and the alignment of the tubes (one in horizontal and the other in vertical). There are six types of evaporators used for most applications. The length and orientation of the heating surfaces commonly determines the name of the evaporator.

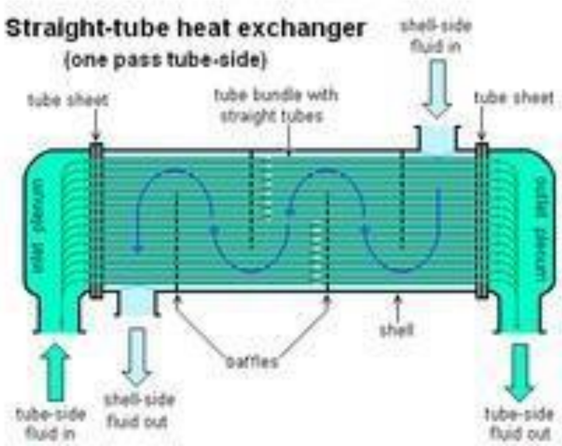
Horizontal tube evaporator, forced circulation evaporator, short tube vertical evaporator ,long tube vertical evaporator , falling tube vertical evaporator etc.,

4.11 Heat exchangers

The conversion of thermal energy from one medium to another, generally referred to as heat exchange, plays a major role in many industrial production processes. Heat exchangers are most commonly used for the transfer of energy between two fluids. Exchangers can be operated in many configurations and the fluid can be gas or liquid on either the primary or secondary side of the exchanger.

The efficiency of a heat exchanger depends very much on its being designed to meet the capacity required by the particular process in which it is to be installed. The control characteristics usually a matter of secondary importance, but if the exchanger is to be operated in a dynamic mode, the overall efficiency and performance will also be determined by the control characteristics. The most common heat exchanger consists of a cylindrical tank filled with a number of parallel tubes aligned in the axial direction. If we let the primary medium flows through the tank, and the secondary medium flow through the tubes, The schematic diagram of a heat exchanger is shown in figure12.

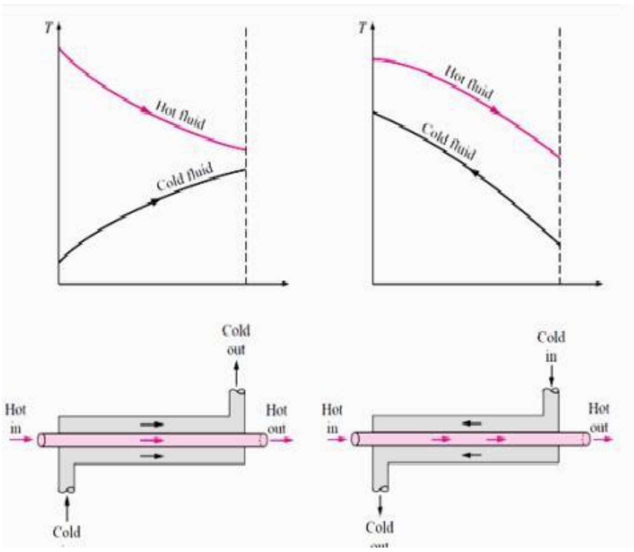
Figure 12. Multi Effect Evaporator



There are two possible configurations are possible, known as co current and counter current heat exchangers. The heating and feed are flowing in the same direction, it is known as concurrent heat exchangers.

If they pass in the opposite direction, it is known as counter current heat exchangers.

Figure 13. Temperature profile.



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UNIT – V
Industrial Unit Operations – SIC 1308

5.1 Centrifugal Pumps

The centrifugal pump is the most common type of process pump, but, its application is limited to liquids with viscosities up to 3000 centri stokes. The capacity – head curve is the operating line for the pump at constant speed and impeller diameter.
Centrifugal pumps are the most preferred hydraulic pumps used in domestic and industrial world.

5.1.2 Impeller - The Heart of Centrifugal Pumps

Centrifugal pumps are used to induce flow or raise pressure of a liquid. Its working is simple. At the heart of the system lies impeller. It has a series of curved vanes fitted inside the shroud plates. The impeller is always immersed in the water. When the impeller is made to rotate, it makes the fluid surrounding it also rotate. This imparts centrifugal force to the water particles, and water moves radially out. In Fig.1 this process is illustrated.
Fig.1 The rotating impeller imparts a centrifugal force to the water particles and the water moves radially out Since the rotational mechanical energy is transferred to the fluid, at the discharge side of the impeller, both the pressure and kinetic energy of the water will rise. At the suction side, water is getting displaced, so a negative pressure will be induced at the eye. Such a low pressure helps to suck fresh water stream into the system again, and this process continues.

Fig.1 The rotating impeller

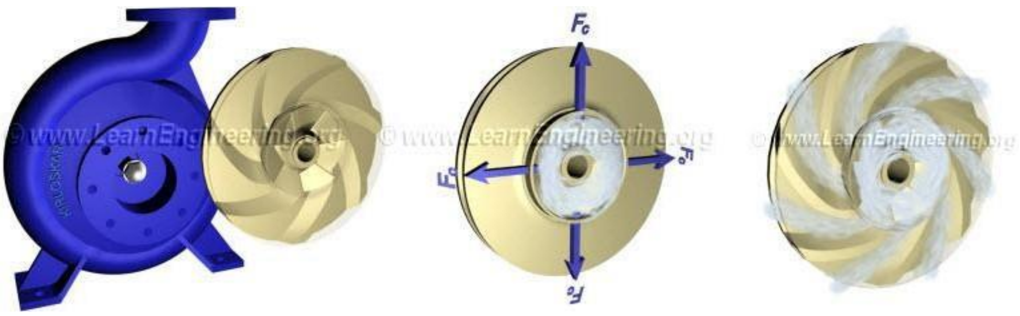
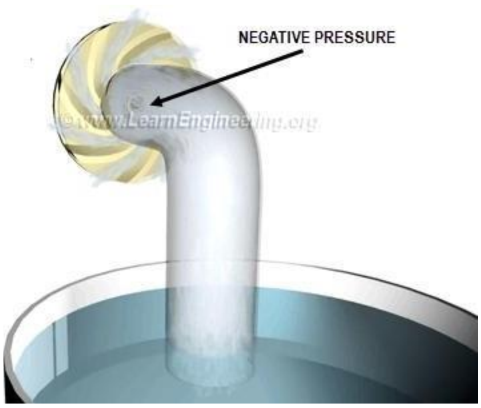


Fig.2 Negative pressure created by displacement of water from the eye helps to suck fresh stream of water



From foregoing discussions it is clear that, the negative pressure at the eye of the impeller helps to maintain the flow in the system. If no water is present initially, the negative pressure developed by the rotating air, at the eye will be negligibly small to suck fresh stream of water. As a result the impeller will rotate without sucking and discharging any water content. So the pump should be initially filled with water before starting it. This process is known as priming. The impeller is fitted inside a casing. As a result the water moves out will be collected inside it, and will move in the same direction of rotation of the impeller, to the discharge nozzle.This is shown in the Fig.3.

Fig.3 Water which leaves the impeller gets collected inside the casing, flow direction is also marked

5.2 Compressors

Compressors are gas handling machines that increase gas pressure by confinement or by kinetic energy conversion. Some commonly available types of compressors are centrifugal compressors rotary compressors and reciprocating compressors. Centrifugal compressor is a machine that converts the momentum of gas into a pressure head. A rotary-screw compressor is a type of gas compressor that uses a rotary-type positive-displacement mechanism. They are commonly used to replace piston compressors where large volumes of high-pressure air are needed, either for large industrial applications or to operate high-power air tools such as jackhammers. The gas compression process of a rotary screw is a continuous sweeping motion, so there is very little pulsation or surging of flow, as occurs with piston compressors. A reciprocating compressor or piston compressor is a positive- displacement compressor that uses pistons driven by a crankshaft to deliver gases at high pressure. The intake gas enters the suction manifold, then flows into the compression cylinder where it gets compressed by a piston driven in a reciprocating motion via a crankshaft, and is then discharged. Applications include oil refineries, gas pipelines, chemical plants, natural gas processing plants and refrigeration plants.

5.3 Extruders

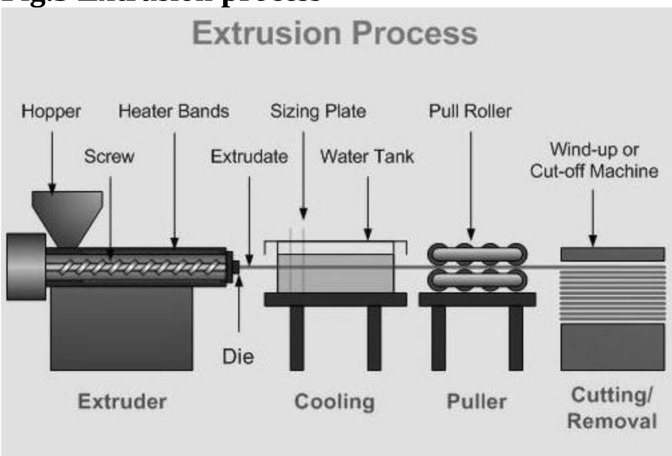
Single screw extruders are commonly used to convert granular resin feeds into sheets, films and shapes such as pipe and are described by screw diameter in inches and L/D ratio. L being the screw length and D the screw diameter. Single screw machines are supplied in 1, 11/2, 21/2,31/2, 41/2, 6, 8 and 12 inch sizes. L/D ratios from 20 to 30 are common. Machines using twin screws are generally large volume production units for pelletizing resins in petrochemical plants and are available with various combinations of intermeshing and non meshing screws tat co rotate or contrarotate. Many features of screw designs allow compounding , devolatizing, melting, blending and other processing in a single machine. Twin screw machines often are melt fed directly from polymerization reactors and perform multiple functions .

5.3.1 Extruder Dies

The shape of the output and final use is defined by the die shape. Dies can be classified as follows.
1. Sheet dies Extruding flat sheets up to 120 inches wide and ½ inch thick.
2. Shape dies for making pipe, gasketting, tubular products and many other designs.
3. Blown film dies using an annular orifice to form a thin walled envelope. The envelope is expanded with low pressure air which expands the diameter to approximately three times the annular orifice to form a thin walled envelope.
4. Spinnerette dies for extrusion of single or multiple strands of polymer for textile products, rope, tire cord and webbing.
5. Pelletizing dies for reproduction of granular products in resin production, synthetic rubbers and scrap reclaiming.
6. Crosshead dies for wire coating in which the bare wire or cable enters the die and emerges coated with semi molten polymer. The wire enters and leaves the die at 900 to the extruder axis, hence the term cross head is used.

The block diagram of extrusion process is given in the block diagram below.

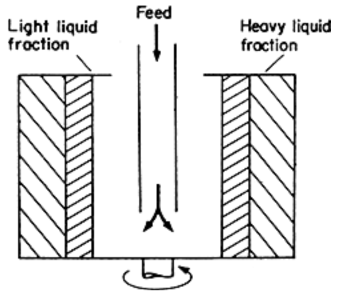
Fig.3 Extrusion process



5.4 Centrifugal Machines are employed for liquid – liquid or liquid – solid separation

Sedimentation Centrifuges
These have solid walls and separation is by sedimentation. The feed enters a solid –walled bowl rotating about a vertical axis.. The solid and liquid phases are acted upon by centrifugal force and gravity.

Fig.4 Filteration Centrifuge

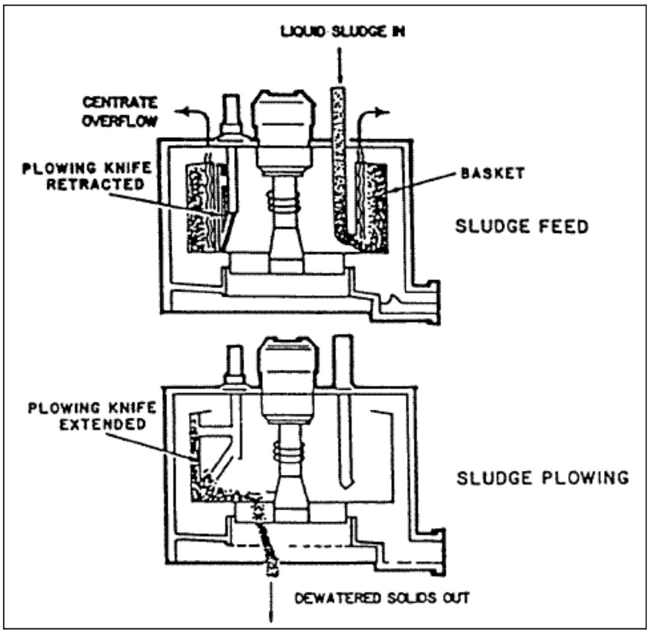


5.5 Filteration Centrifuge

These machines have perforated walls which retain the solids on a permeable surface and through which the liquid can escape. The action is similar to a filter but with much higher g force than possible in gravity or pressure filtration. The centrifugal force obtained in industrial machines is several times the force of gravity. For a particle rotating with an angular velocity w at radius r from the axis of rotation, the centrifugal separating effect is given by G= WR/g. Filtration centrifuges are also of three types: Batch, automatic batch and fully continuous.

In allo them, a cake is deposited on a filter medium held in a rotating basket, which is then washed and spun dry.

Figure.5 Centrifuge



5.6 Centrifuge selection

1. The machines' ability to process the given feed slurry or emulsion at the desired degree of separation
2. Reliability of the machine
3. Operating and maintenance requirements
4. Investment

The selection of centrifuge involves a balance between several factors:
The instrument engineer should concentrate on two aspects of the process centrifuge installations.
Feed slurry control – regulation of feed slurry at the correct continuous rate or the right batcg size is of utmost importance, since the machine cannot usually tolerate major variations in feed rate or composition. Control of wash liquor feed is equally important.
Sequencing operations
All batch machines are sequentially operated, and the related interlock design is one of the important steps in engineering a system
A fully continuous solid bowl sedimentation centrifuge is ised in petrochemical processing, polymerization and waste treatment systems.
The slurry is introduced in the revolving bowl of the machine through a stationary feed tube at the center. It is acted upon by a centrifugal force and the solids are thrown against the wall. Inside the rotating bowl is a screw conveyor with a slight speed differential with respect to the bowl rotation and it moves the solids up the beach and out of the liquid layer. It is important that a reasonably uniform slurry be supplied to the machine. For this purpose, a circulating pump with a recycle line is usually installed to keep the slurry in motion and thus preventing settling out of crystals in the tank or in the pipelines.

Figure.6 solid bowl sedimentation centrifuge