FILTRATION AND SEDIMENTATION

5.1 CONCEPT OF FILTRATION

- *The separation of solids from a suspension in a liquid with the help of a porous medium or screen which retains the solids and allows the liquid to pass* is termed as **filtration.**
- The operation of separating a solid from a liquid by means of a porous medium (usually a wire or fabric filter cloth) is called as filtration. The medium retains the solid in the form of a porous cake, while the liquid passes through it.
- The mechanical separation of a solid from suspension in a liquid by passage through a porous medium which retains the solid and allows the liquid to pass is called as filtration.
- In filtration operation, the volume of the suspensions to be handled may vary from extremely large quantities (as in water purification) to relatively small quantities (as in the fine chemical industry), the suspensions may contain small or large proportions of solids and the valuable product may be the solid, the liquid, or both or sometimes none of them (e.g., the waste solids to be separated from a waste liquid prior to the disposal). The driving force required for a separation by filtration based upon the nature of a suspension may be divided into four categories, namely gravity, vacuum, pressure and centrifugal.
- Separation of suspended impurities from water (in water purification), separation of solid organic and inorganic materials from their slurry such as calcium carbonate, ammonium sulphate, sugar, paranitroaniline, etc. are some examples of filtration.

5.2 TYPES OF FILTRATION : CAKE FILTRATION AND DEEP BED FILTRATION

- Basically, there are two types of filtration : (i) Cake filtration, (ii) Deep bed filtration.
- In cake filtration, the proportion of solids in the suspension is large and most of the solid particles are collected in the cake which can later be detached from the filter medium.
- In deep bed filtration, the proportion of solids is very small and the particles of the solid being smaller than the pores of the filter medium will penetrate a considerable depth and ultimately get trapped inside the filter medium and usually no layer of solids will appear on the surface of the medium (e.g., water filtration).
- Thus, filters are divided into two main groups, **clarifying filters** and **cake filters**. Clarifying filters also called as deep bed filters are used to remove small amounts of solids to produce sparkling clear liquids, whereas cake filters separate large amounts of solids in the form of a cake of crystals. Clarifying filters find applications in water treatment. In this chapter, we will deal with cake filtration.

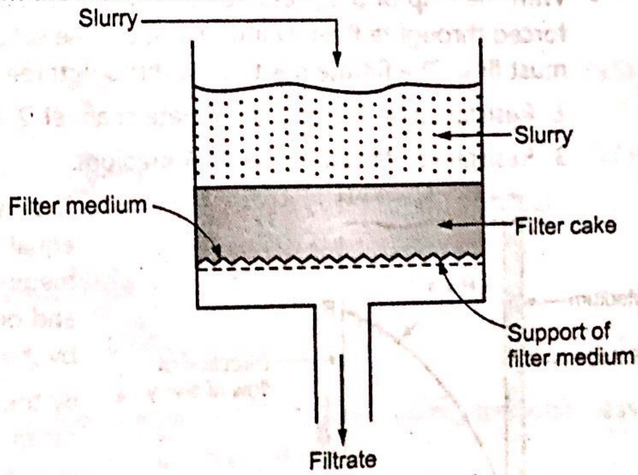


Fig. 5.1 : Principle of filtration

Principles of Cake Filtration :

- In cake filtration, the feed to be handled (two phase mixture) is called **slurry**, the bed of deposited solids on a porous membrane (filter medium) is called **cake** and the clear liquid leaving the filter medium is called **filtrate.**

- A typical cake filtration operation is shown in Fig. 5.1. During the initial period of flow, solid particles are trapped within the pores of a medium forming a true filter medium. The liquid passes through the bed of the solids and through the filter medium. In the early stage of filtration, the rate of filtration is high. As the cake thickness increases, the rate of filtration decreases for a given pressure differential across the filter medium. This is due to the fact that as the cake gradually builds upon the medium, the resistance to flow progressively increases.

5.3 CONSTANT RATE AND CONSTANT PRESSURE FILTRATION

Types of filtration (based on the pressure drop across a filtering medium) :

There are two types of filtration : 1. Constant pressure filtration, 2. Constant rate filtration.

- *The method in which the pressure drop over the filter is held constant throughout a run so that the rate of filtration is maximum at the start of filtration and decreases continuously towards the end of the run* is called **constant pressure filtration.** If the outlet pressure is constant, constant pressure filtration is carried out by applying a certain pressure at inlet and maintaining it constant throughout the run.
- *The method in which the pressure drop is varied usually from a minimum at the start of filtration to a maximum at the end of filtration so that the rate of filtration is constant throughout the run* is called **constant rate filtration.**
- In constant rate filtration, nearly constant rate of filtration is maintained by starting at low inlet pressure, and continuously increasing the pressure to overcome the resistance of cake, until the maximum pressure is reached towards the end of the run.
- In constant pressure filtration, application of high initial pressure results in a low rate of filtration as the first particles filtered will be compacted into a tight mass that largely fills the pores of cloth. In constant rate filtration, as the maximum pressure is reached towards the end of the run whole cycle is operated at less than the maximum capacity. To overcome the difficulties faced in the filtration types cited above, a practical solution is found out by carrying out the filtration at constant rate until the inlet pressure reaches a specified maximum and then to continue at constant pressure until the end of the run.

Distribution of overall pressure drop

- With the help of the pressure difference applied between the slurry inlet and the filtrate outlet, the filtrate is forced through a filter. During filtration, the solids are retained in the form of cake through which the filtrate must flow. The filtrate has to pass through three resistances in series –

  1. Resistance of the feed and filtrate channel, 2. Resistance of the cake, and
  3. Resistance offered by the filter medium.

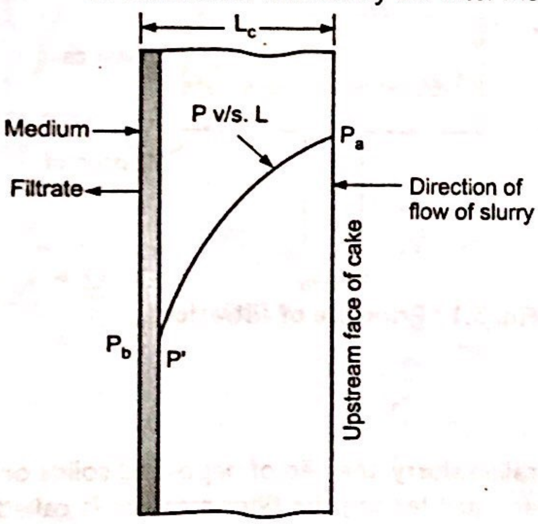


Fig. 5.2 : Section through filter medium cake showing pressure drop

- The overall or total pressure drop over the filter at any time is equal to the sum of the individual pressure drops over the medium and cake. Usually, the resistances offered by the inlet and outlet connections are small as compared with those offered by the cake and medium and thus, can be neglected.
- By the resistance of filter medium or filter medium resistance, we mean it is the entire resistance built up in the filter medium, including that from the trapped particles. Filter medium resistance is important in the early stages of filtration. The cake resistance is the one which is offered by all solids not associated with the filter medium. It is zero at the start of filtration and goes on increasing with time of filtration.

As $A/A_T = f$, the rate of solids production divided by the total area of the filter using Equations (5.30), (5.31) and (5.32) thus becomes

$$\frac{\dot{m}_c}{A_T} = \frac{[2c\,\alpha\,\Delta P\,fn/\mu + (n\,R_m)^2]^{1/2} - n\,R_m}{\alpha} \quad \text{... (5.33)}$$

The filter-medium resistance R_m includes the resistance offered by the cake which is not removed by the discharge mechanism provided and carried through the next cycle. If the filter medium is washed after the cake discharge, R_m is usually negligible. Therefore, neglecting R_m, Equation (5.33) becomes

$$\frac{\dot{m}_c}{A_T} = \left(\frac{2c\,\Delta P\,fn}{\alpha\,\mu}\right)^{1/2} \quad \text{... (5.34)}$$

If the specific cake resistance (α) varies with overall pressure drop as per Equation (5.19), then Equation (5.34) becomes

$$\frac{\dot{m}_c}{A_T} = \left(\frac{2\,c\,(\Delta P)^{1-s}\,f\,n}{\alpha_o\,\mu}\right)^{1/2} \quad \text{... (5.35)}$$

- Equations (5.33) and (5.34) are applicable to continuous vacuum filters as well as to continuous pressure filters.
- When R_m is negligible, Equation (5.34) predicts that the rate of filtrate flow varies inversely with the square root of the viscosity and of the cycle time. This is true in practice for thick cakes and long cycle times. But for short cycle times, it is not true and Equation (5.33) must be used.

5.4 FILTER MEDIUM (CHARACTERISTICS OF FILTER MEDIUM)

- In case of cake filtration, the choice of a filter medium is often the most important consideration in assuring satisfactory operation of a filter. The filter medium in any filter must meet the following requirements :
  1. It should retain the solids to be filtered, giving a reasonably clear filtrate.
  2. It should not plug or blind (low rate of entrapment of solids within its interstices).
  3. It should be mechanically strong to withstand the process conditions.
  4. It should be resistant to the corrosive action of fluid.
  5. It should offer as little resistance as possible to the flow of filtrate.
  6. It should possess ability to discharge cake easily and cleanly.
  7. It should have acceptable resistance to mechanical wear.
  8. It should be cheap.
  9. It should have long life.
- In cake filtration, the filter medium is frequently a textile fabric.
- Canvas cloth, woolen cloth, metal cloth of monel or stainless steel, glass cloth and synthetic fibre cloth - nylon, polypropylene, etc., are commonly used as filter media in industrial filtration practice depending upon the process conditions.
- For an alkaline slurry, nylon cloths are used while for an acidic slurry, polypropylene cloths are used as a filter medium.

5.5 FILTER AIDS

- Filtration of slurries containing very finely divided solids or slimy, deformable flocs is very difficult due to formation of a dense, impermeable cake that quickly plug the filter media. In such cases the porosity of the cake must be increased to allow passage of the filtrate at a reasonable rate. This is achieved by adding a filter aid to the slurry before filtration.

- A filter aid is a granular or fibrous material which packs to form a bed of very high voidage. Because of this, they are capable of increasing the porosity of the filter cake. A filter aid should be of *low bulk density*, should be *porous*, should be *capable of forming a porous cake*, and must be *chemically inert to the filtrate*.
- The commercial filter aids are diatomaceous earth - almost pure silica prepared from deposits of diatom (marine organisms) skeletons, expanded pearlite, and asbestos fibres. The filter aids are used for sludges that are difficult to filter and the use of filter aids is normally restricted to filtration technique in which the filtrate is valuable and the cake is the waste product.
- Methods of using filter aids :
  (i) adding a filter aid to the slurry before filtration, and
  (ii) precoating, i.e., by depositing a layer of a filter aid on the filter medium before filtration.
- Precoats prevent gelatinous solids from plugging the filter medium and give a clear filtrate. The precoat is a part of the medium rather than that of the cake. When the filter aid is directly added to the slurry before filtration, the presence of it increases the porosity of the sludge, decreases its compressibility and reduces the resistance of cake during the filtration operation.

5.6 FACTORS AFFECTING THE RATE OF FILTRATION

The rate at which the filtrate is obtained in a filtration operation, i.e., the rate of filtration depends upon the following factors :

1. Pressure drop across the feed inlet and far side of the filter medium.
2. Area of the filtering surface.
3. Viscosity of the filtrate.
4. Resistance of the filter medium and initial layers of cake.
5. Resistance of the filter cake.

- The rate of filtration is directly proportional to the pressure difference across a filter medium. Therefore, higher the pressure difference across a filter medium, higher will be the rate of filtration.
- The rate of filtration is directly proportional to the square of the area of a filtering surface. Therefore, higher the area of a filtering surface, higher will be the rate of filtration.
- The rate of filtration is inversely proportional to the viscosity of the filtrate. Therefore, higher the viscosity of the filtrate, lower will be the rate of filtration.
- The rate of filtration is inversely proportional to the resistance of a cake or filter medium. Therefore, higher the resistance of a cake or filter medium, lower will be the rate of filtration.

5.7 TYPES OF FILTRATION EQUIPMENTS

(a) Filters are generally divided into two major groups based on the function or goal of filtration (i.e., based on whether to produce a cake or sparkling liquid).
(i) Cake filters. (ii) Clarifying filters.

- *Filters that retain appreciable quantities of filtered solids on the surface of the filter medium* are referred to as cake filters.
- *Filters that remove small amounts of solids to produce sparkling clear liquids* are referred to as clarifying filters or deep bed filters. These filters are commonly employed in water treatment.

(b) Filters may be classified according to the method of operation or operating cycle as
(i) Batch filters, (ii) Continuous filters

(c) Filters may be classified based on the driving force used for separation, e.g., gravity, pressure, vacuum or centrifugal.

- In filtration operation, the filtrate is forced to flow through a filter medium by virtue of a pressure difference across the medium. The pressure difference may be created by gravity, superatmospheric pressure on the upstream of the filter medium, sub-atmospheric pressure on the downstream of the filter medium or centrifugal force across the medium. Therefore, filters may be classified as
  (i) gravity filters, (ii) pressure filters, (iii) vacuum filters, (iv) centrifugal filters.

Industrial cake filters are usually classified as follows :

1. Batch (discontinuous) pressure filters
   e.g., filter press - plate and frame press, pressure leaf filters.
2. Continuous pressure filters
   e.g., pressure filter-thickener, continuous rotary pressure filters.
3. Batch vacuum filters
   e.g., vacuum nutsches, vacuum leaf filters.
4. Continuous vacuum filters
   e.g., rotary drum filters, vacuum precoat filters.
5. Centrifugal filters (batch and continuous)
   e.g., suspended basket centrifuge - top driven or bottom driven, continuous filtering centrifugals.

- The most important **cake filters** which will be referred to are : plate and frame filter press, rotary drum filter, and basket centrifuge.
- In many cases, in the chemical industry, it is the solids that are wanted.
- The factors to be considered while selecting equipment for filtration and operating conditions are :
  1. Properties of the fluid such as viscosity, density and corrosiveness/chemical reactivity.
  2. Nature of the solid which includes particle size, size distribution, particle shape and packing characteristics of solid particles.
  3. Concentration of solids in slurry, i.e., feed slurry concentration.
  4. Quantity of slurry to be handled and its value.
  5. Valuable product of operation.
  6. Necessity of washing the solids.
  7. Initial investment.
  8. Necessity of pretreatment of the slurry for ease in filtration.
  9. Cost of labour and power.

5.7.1 Primary Filter - Sand Filters

- Sand filters (clarifying filters) are used for water treatment and water purification. The medium of this filter is sand of varying grades. When we have to remove taste and odour, the sand filter may include a layer of activated carbon. There are several kinds of sand filters : rapid (gravity) sand filters, slow sand filters, pressure sand filters and upflow sand filters.

5.7.1.1 Rapid Sand Filter

- It is a gravity filter and is widely used filter in the treatment of water. It consists of an open water tight tank 3 to 3.5 m deep, containing a filter bed, a layer of coarse sand 0.6 to 0.75 m thick. The size of sand particles ranges from 0.4 to 1 mm. The sand bed is supported by a layer of graded gravel (of the size range of 1 to 50 mm) 0.45 m thick. Below the gravel there is an under drainage system consisting of a central longitudinal conduit or manifold with strainers mounted on the top and pipes of small diameter called laternals that carry perforations on the sides and bottom. In the operation, water to be filtered is introduced from the top, it passes downward through the filter bed. During its flow the suspended impurities get trapped in the bed and almost clear water leaves the filter from the bottom. The filter bed is periodically cleaned by backwashing. During backwashing with water, the upward flow carries the deposited floc with it. The essential characteristics of rapid sand filters are :
  (i) rate of filtration is high
  (ii) cleaning is done through backwashing and
  (iii) careful pre-treatment of water is necessary.

5.7.1.2 Pressure Sand Filters

- Pressure sand filters are essentially same as rapid sand filters, except that the water is filtered through the filter bed under a suitable pressure and the filter medium is contained in a steel tank. These filters are commonly used for the treatment of boiler feed water. The water, instead of gravity fed, is pumped through the bed under pressure. Such units are built as vertical or horizontal units. The former being used for a relatively small amount of water and the latter for greater volumes. Pressure sand filtration is often carried after coagulation and sedimentation and if not, the coagulants are introduced to the filtered water pipe ahead of the filters. These filters are operated with a feed pressure of 2 to 5 bar.
- Vertical pressure filters range in diameter from 0.5 to 2.5 m and height from 2 to 2.5 m, while horizontal units are usually 2.5 m in diameter and are of any desired length upto 7.5 m. The pressure filters occupy less space than the gravity filters of the same capacity.

5.7.2 Pressure Filters

- *Filters which operate with super-atmospheric pressure on the upstream side of the filter medium and atmospheric or greater pressure at the downstream side of the filter medium* are termed as **pressure filters.** In these devices, the filtering pressure is applied on the upstream side by a liquid pump or by a compressed gas. Hence, pressure filters are fed by plunger, screw, diaphragm or centrifugal pumps. Since the cake discharge from a pressure environment is difficult, continuous filters are in limited use and most of the pressure filters are batch operated.

Advantages of Pressure filters :

(i) Use of high filtration pressure results in relatively rapid filtrations.

(ii) These filters are compact so they provide a large filtration area per unit of floor space occupied by the filter.

(iii) Batch pressure filters offer greater flexibility than any other filter at relatively low initial investment.

Disadvantages of Pressure filters :

(i) Difficult to adapt to continuous processes and the operating cost is high in many applications.

(ii) Continuous pressure filters are inflexible to some extent and are expensive.

- A filter press is the simplest and the most commonly used filtration equipment. Two main forms in which this press is made are : the plate and frame press, and the recessed plate press/chamber press.

5.7.2.1 Plate and Frame Filter Press

Construction :

- It consists of plates and frames arranged alternately and supported on a pair of rails. The plate is a solid piece having a ribbed surface. The frame is hollow and provides the space for the filter cake. The alternate arrangement of plates and frames results in the formation of chambers. The plates and frames are square or rectangular in shape and can be made of cast iron, stainless steel, nickel, aluminium, monel, hard rubber or plastics (polypropylene). Coated materials are also used (rubber or lead or epoxy resin covered).
- Filter cloths are placed over each plate to cover the plate surface on both sides so that hollow frame is separated from the plate by the filter cloth. The plates and frames have circular holes on the corners for feed and discharge as shown in Fig. 5.5. The filter cloths are also having holes that match the holes on the plates and frames. The filter cloths themselves act as gaskets.
- When the press is closed by means of a hand screw or hydraulically, a continuous channel is formed along the whole length of the press out of the corner holes in the plates, cloths, and frames. The frames have openings in the interior from the corner holes so that the slurry channel opens into the interior of frame (i.e., in the chamber formed between each pair of successive plates). At the bottom of the plates, holes are cored which connect the faces of the plates to the outlet cocks.

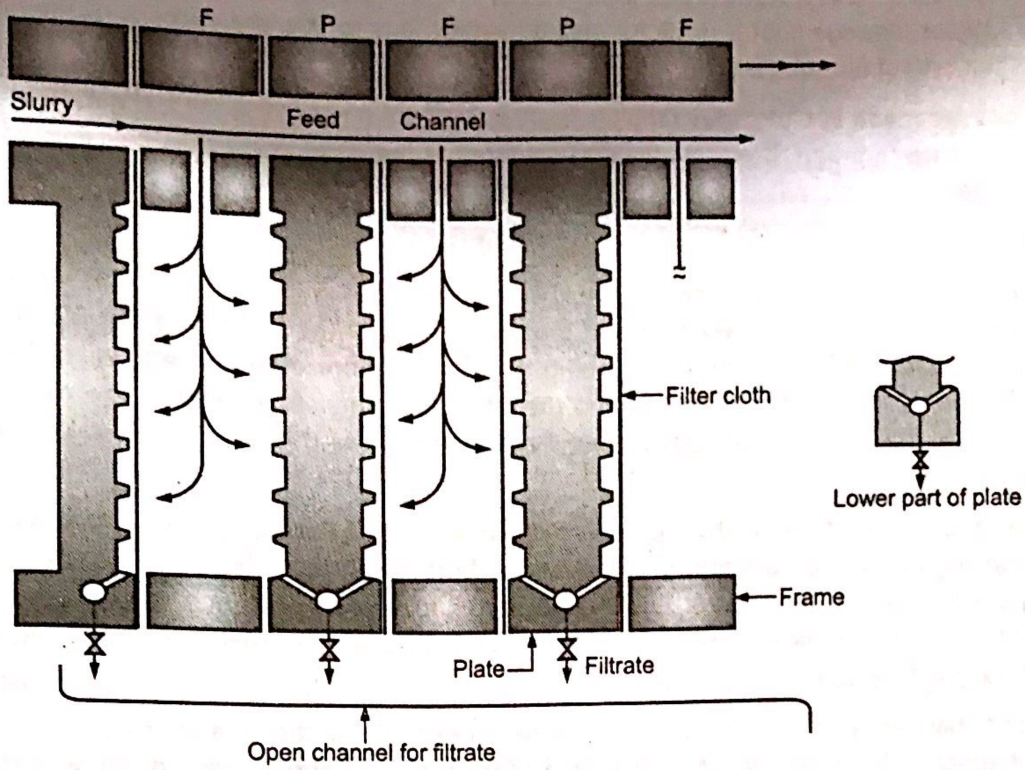


Fig. 5.4 : Plate and frame filter press (sectional view)

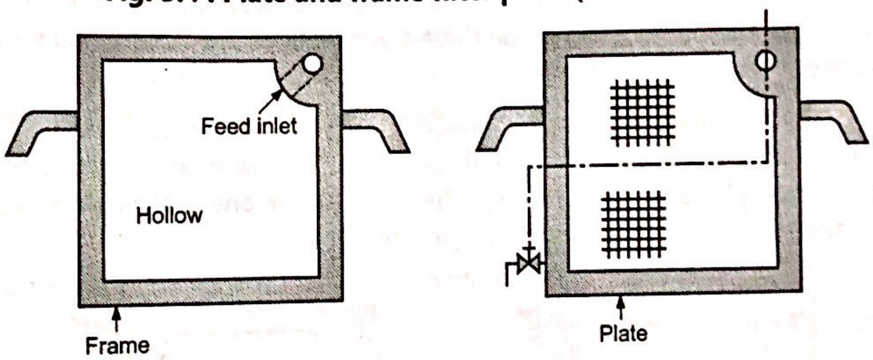


Fig. 5.5 : Plate and frame

Working :

- Slurry to be filtered is pumped through the feed channel. It runs into the chambers formed and fills the chamber completely (i.e., frames). As the feed pump continues to supply the slurry to be filtered, the pressure goes on increasing. Because of this, the filtrate passes through the cloth, runs down the faces of plates and finally leaves the filter through discharge cocks. (Fig. 5.4). The solids are deposited on the filter cloth. The two cakes are formed simultaneously in each chamber and these join when the frame is full and no more slurry can enter into it. The press is then said to be jammed. Wash liquid may be introduced in the press to remove soluble impurities from the solids and the cake is then blown with air to remove the residual liquid from it. The press is then dismantled, and the cake of solids scrapped off from each plate.
- In simple washing, the wash liquor is introduced through the feed channel and leaves the filter through the outlet cocks (i.e., it follows the same path as the slurry and filtrate). It is suited when the cake is uniform and permeable.
- In open discharge type, the filtrate is discharged through cocks into an open launder, so that the filtrate from each plate can be inspected and any plate can be isolated from the service by shutting off the cock if it is not giving a clear filtrate. Hence, it is used when absolutely clear filtrate is required. In closed discharge, the filtrate channel runs the entire length of press into a discharge pipe at one end. The closed technique is used when toxic or volatile materials are to be filtered.

- In many presses, arrangement is done for steam heating. Due to this, the viscosity of the filtrate is reduced and a higher rate of filtration is achieved.
- These units are made in plate sizes ranging from 100 × 100 mm to 1500 × 1750 mm. Operating pressures upto 700 kPa are common. The press may be operated at pressure upto 7 MPa by using a suitable material of construction.

Washing Press

- Washing of the precipitate is more easy in the plate and frame press than in the chamber press. Two methods of washing are simple washing and thorough washing. The simple washing is ineffective when the frame is completely full. In thorough washing, which is a more effective technique, the wash liquor is admitted through a separate channel behind the filter cloth on alternate plates. These plates are called as washing plates. The wash liquor thus passes through the entire thickness of the cake and is discharged through the drain cocks.
- The plates and frames of the washing press are shown in Fig. 5.6. For ease in identification and quick proper assembling the press, it is common practice to cast buttons on the sides of plates and frames. The non-washing plate is having one button, the frame is having two buttons, and the washing plate is having three buttons. The press is assembled in such a way as to give the order of plate and frame in the form 1 – 2 – 3 – 2 – 1 ...... etc. (Refer Fig. 5.7).
- The various channels lead to connections on the fixed head. During the filtration run, a wash channel is closed by a valve on the head of the press. Filtration is carried out as in the non-washing plate and frame press described earlier. When the frames are filled (by solids retained on filter cloths), the feed channel is closed, the outlet cocks on all three button plates are closed, and wash liquor is introduced into a wash channel.
- As the wash channel has cored openings connecting with both faces of three botton plates, wash liquid enters between the plate and the cloth on all these plates. The wash liquid passes through the cake, down the faces of one botton plates, and out through the cocks on the one button plates as cocks on one bottom plates are open and that on three botton plates are closed.

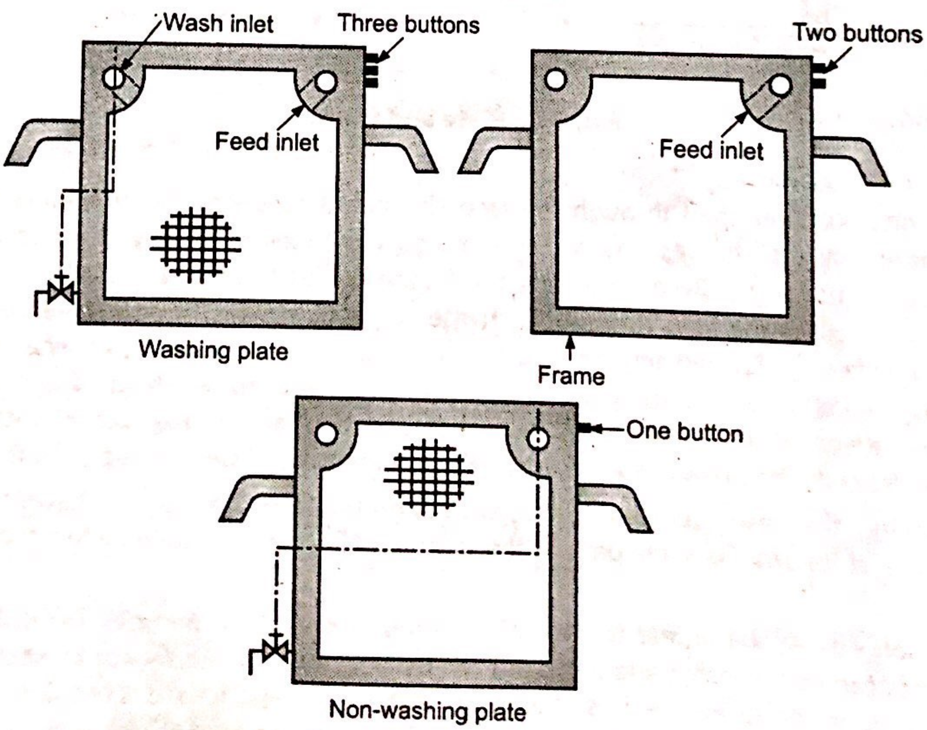


Fig. 5.6 : Plates and frames of washing press

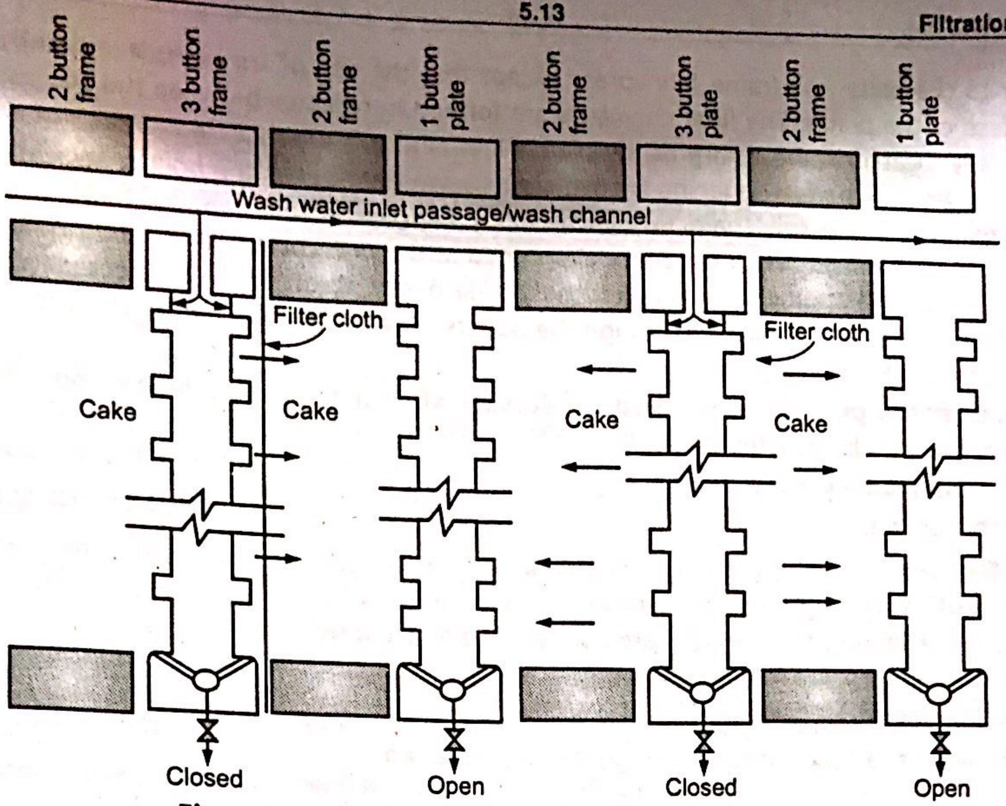


Fig. 5.7 : Section through Washing Press (Washing cycle)

- After washing, the excess liquid from the cake is removed by compressed air for easy discharge of the cake.
- In this press, the wash liquid passes through the whole thickness of the cake whereas the filtrate (during filtration) passes through only half the thickness of cake. The added resistance of the cake causes the liquid to distribute itself uniformly over the faces of three botton plates and thus, to pass through the cake uniformly.

Recessed Plate or Chamber Press :

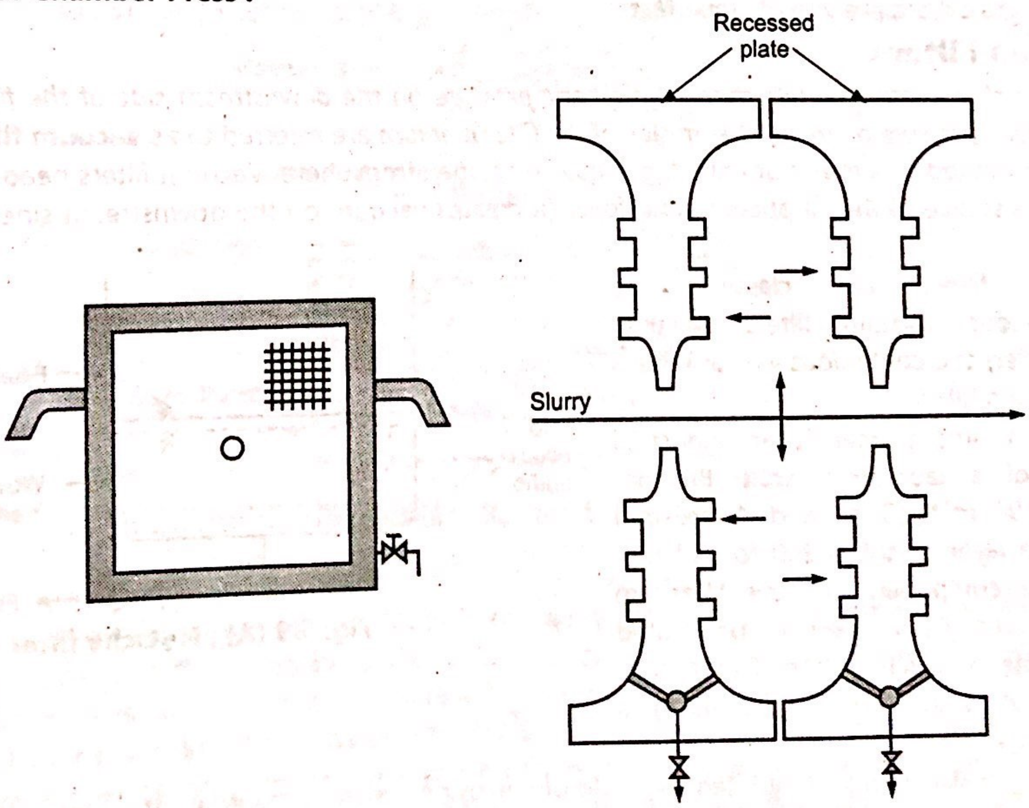


Fig. 5.8 : Recessed plate and chamber press

It is similar to the plate and frame filter press except that the use of frames is avoided by recessing the ribbed surface of the plates. The filter chambers are formed in recesses between the successive plates. The fed is generally located in the centre of the plate. Filter cloth on the recessed surface of each side of the plate is sealed around the feed opening by two cloths sewn together at the hole or by clip nuts. The slurry containing relatively large solid particles can be easily handled in this press as there are no chances of blocking the feed channels. When the slurry is pumped in the press, it will fill all the opening between the cloths and afterwards as pumping continues, the filtrate passes through the cloths, runs down the ribbed surface of the plates and finally leaves through the outlets provided on each plate. This press is not adopted for washing of the cake.

- The **plate and frame press** is widely used, particularly when the cake is valuable and relatively small in quantity. It can handle slimy material.

Advantages of Plate and Frame press :

1. Simple in construction.
2. Low first cost.
3. Maintenance cost is low.
4. It provides a large filtering area per unit area of floor space occupied.
5. High operating pressures are easily developed.
6. It is possible to alter the capacity.
7. The majority of joints are external, so leakage is easily detected.
8. Flexibility.

Disadvantages of Plate and Frame press :

1. Labour requirement is very high.
2. Discontinuous in operation. Periodic manual dismantling results in high wear on the cloths. So the filter cloth life is relatively short.
3. Not suitable for high throughputs.
4. Presses frequently drip and leak, making housekeeping in the area a problem.
5. Washing of cake is likely to be imperfect.

5.7.3 Vacuum Filters

- *Filters which operate with less than atmospheric pressure on the downstream side of the filter medium and atmospheric pressure on the upstream side of the filter medium* are referred to as **vacuum filters**. Thus, these filters are limited to a maximum filtering pressure of one atmosphere. Vacuum filters need a vacuum pump which is a source of the filtration driving force (it creates vacuum on the downstream side) and is costly to operate.
- Vacuum filters are classified as discontinuous vacuum filters (vacuum nutsch filter) and continuous vacuum filters (rotary drum filter).
- A vacuum nutsch filter is an industrial version of a laboratory scale Buchner funnel, 0.90 m to 3 m in diameter and forming a layer of solids 100 to 300 mm thick. The components of this filter are vessel, woven mesh screen or perforated metal plate and filter cloth. Filtration is carried out under vacuum by using a vacuum pump.

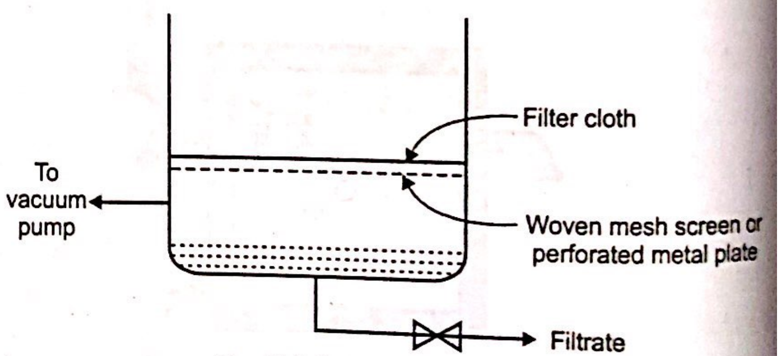


Fig. 5.9 (A) : Nutsche filter

- It is simple in construction and thus can be made of corrosion resistant materials. It is especially useful to filter experimental batches of corrosive materials.

Advantages of Vacuum filters :

(i) These filters can be designed as effective continuous filters.
(ii) Low labour requirement.
(iii) The filtering surface is easily accessible for inspection and repair as it can open to the atmosphere.
(iv) Low maintenance costs.

Disadvantages of Vacuum filters :

(i) We have to maintain a vacuum system.
(ii) Not suitable with filtrates that are volatile.
(iii) These units cannot handle difficulty filterable compressible solids.
(iv) Continuous vacuum filters are inflexible.

5.7.3.1 Rotary Drum Filter

- A rotary drum filter is the most common type of continuous vacuum filter. In this filter filtration, washing, partial drying and discharge of cake all take place automatically.

Construction :

- A rotary drum filter is shown in Fig. 5.9 (B). It consists essentially of a cylindrical sheet metal drum mounted horizontally. It may be from 50 to 400 cm in diameter and 50 to 800 cm long.
- The outer surface of the drum is formed of perforated plate. A filter medium such as canvas covers the outer surface of the drum which turns at 0.1 to 2 r/min in an agitated slurry trough. Inside the outer drum, there is a smaller drum with a solid surface.
- The annular space between the two drums is divided into number of compartments/sectors by radial partitions and separate connection is made between the compartments and a special type of rotary valve. As the drum rotates, vacuum and air are alternately applied to each compartment.
- Apart from cast iron, the other materials of construction of this filter include stainless steel, titanium, plastics such as PVC, etc. These materials give much improved corrosion resistance for many slurries.

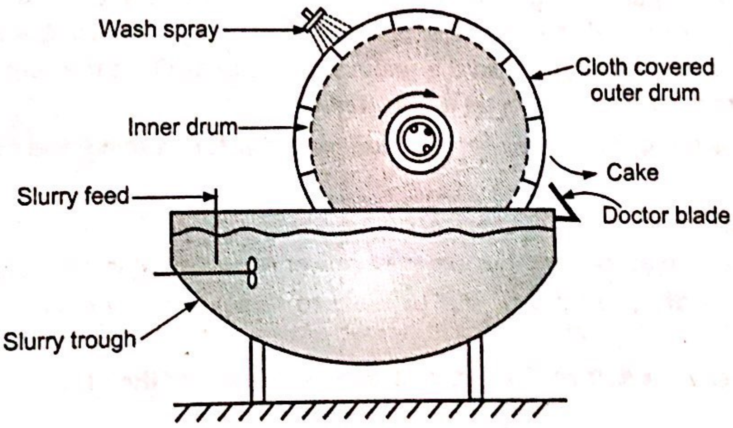


Fig. 5.9 (B) : Rotary drum filter

Working :

- The drum is immersed to the desired depth in the slurry which is mildly agitated to prevent the settling of the solids. Vacuum is then applied to the portion of drum which is submerged in the slurry through the rotary valve. Because of this, the liquid (filtrate) is sucked into the compartment and solids get deposited on the cloth to form a cake of the desired thickness which can be regulated by adjusting the speed of the drum. With higher speeds, thinner cake will be formed and consequently, high rate of filtration will be achieved. The filtrate from the compartment then goes to a filtrate collecting tank through the internal pipe and rotary valve.

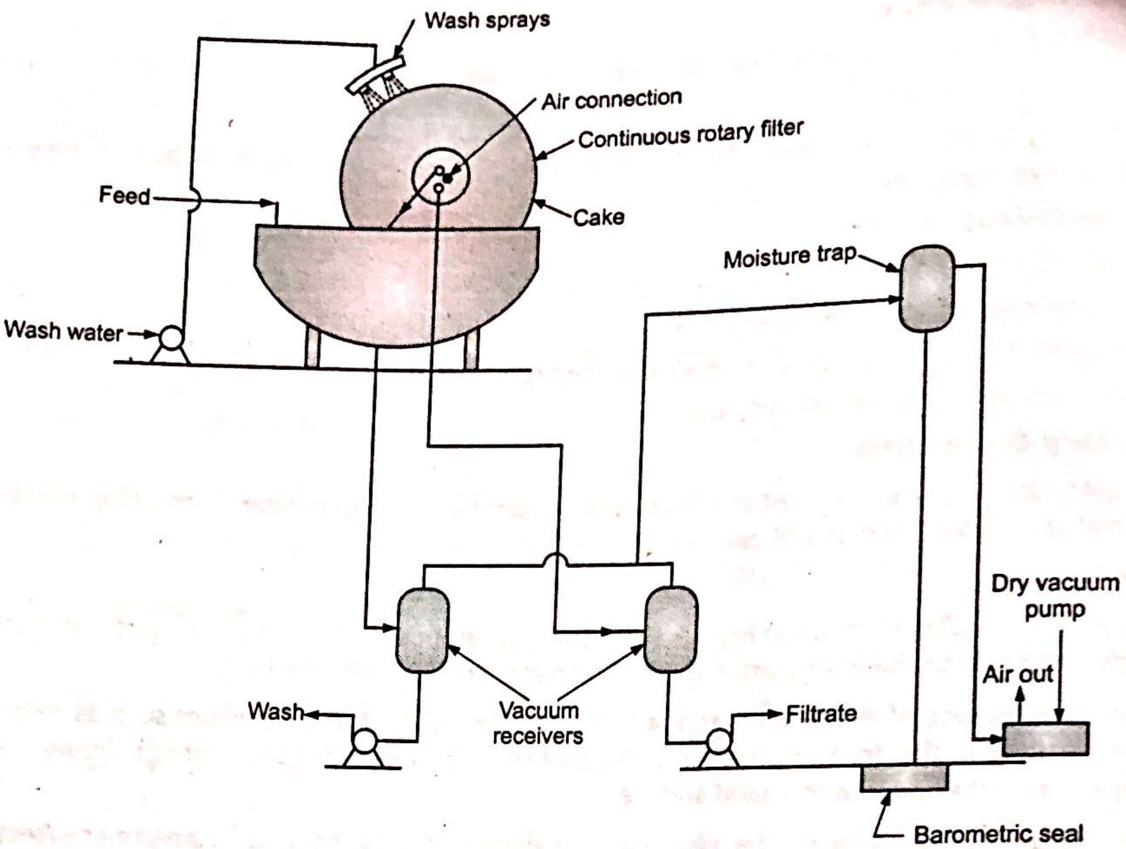


Fig. 5.10 : Flow sheet for continuous vacuum filtration

- As the portion of the drum on which the cake is formed comes out of the slurry, the cake is washed by spraying wash liquid. The wash liquid leaves the filter through the rotary valve and is collected separately in a separate tank. After washing, the cake enters into a drying zone as the drum rotates where the cake is partially dried by sucking air through the cake of solids. After the cake of solids has been sucked as dry as possible, vacuum is cut off and the cake is removed by scrapping it off using a adjustable doctor's knife. A little air is blown in under the cloth to aid the removal of the cake. Once the cake is removed from the drum sector, it re-enters the slurry and the cycle is repeated.
- Usually, one-third of the cycle is used for filtration, one-half for washing and air drying and one-sixth for cake removal.

Advantages of Rotary drum filter :

1. It is entirely automatic in action and thus the man-power requirement is very low.
2. With cake consisting of coarse solids, it is possible to remove most of the liquid from the cake before discharging.
3. It has a large capacity for its size. Therefore, it is widely used for the filtration of large quantities of free filtering material.
4. By changing the speed, it is possible to built up cakes of varying thickness. With fine solids, the thickness of cake is small and is large with coarse solids.

Disadvantages of Rotary drum filter :

1. The maximum available pressure difference is limited to less than one atmosphere.
2. As it being a vacuum filter, a difficulty is encountered in the filtration of hot liquids due to their tendency to boil.
3. It cannot be employed for materials forming relatively impermeable cakes or cakes that cannot be easily removed from cloth.
4. Initial cost of the filter and vacuum equipment is high.

5.8 CENTRIFUGAL FILTRATION

- In case of slurries containing coarse granular or crystalline solids forming a porous cake, the filtration operation can be carried by using centrifugal force rather than the pressure force.
- Centrifugal filters can be operated batchwise or in a continuous fashion. In these filters, the slurry is fed centrally to a rotating basket. The perforations in the walls of the basket are covered by a filter medium. The slurry is forced against the basket sides by pressure resulting from the centrifugal action, i.e., by centrifugal force. The liquor passes through the filter medium and the solids are retained by the medium. After building the cake to a predecided thickness, the feed is stopped and the cake of solids is spun for a short period to remove residual liquid from the cake.
- The principles of centrifugal separation and filtration are illustrated in Fig. 5.11.
- In Fig. 5.11 (a), a stationary cylindrical bowl contains a slurry (liquid + particulate solids of greater density than liquid). Since the bowl is not rotating, solids will settle at the bottom with a horizontal liquid surface above the solids.
- Fig. 5.11 (b) shows that the bowl is rotating about its vertical axis. In this case, the liquid and solids are acted upon by two forces – the gravity force acting downward and the centrifugal force acting horizontally. Normally, the centrifugal force is very large as compared to the gravity force and hence, the same may be neglected in comparison with the centrifugal force. Under the action of the centrifugal force, the solid particles are tightly pressed against the vertical bowl wall and the liquid layer assume the equilibrium position with an almost vertical inner surface as shown in Fig. 5.11 (b).
- If the wall of the bowl is perforated and perforations are covered with a filter medium such as a fine wire screen as shown in Fig. 5.11 (c), the liquid is free to flow outward but the solids are not. Almost all the liquid quickly flows out of the bowl, leaving behind the cake of filtered solids.

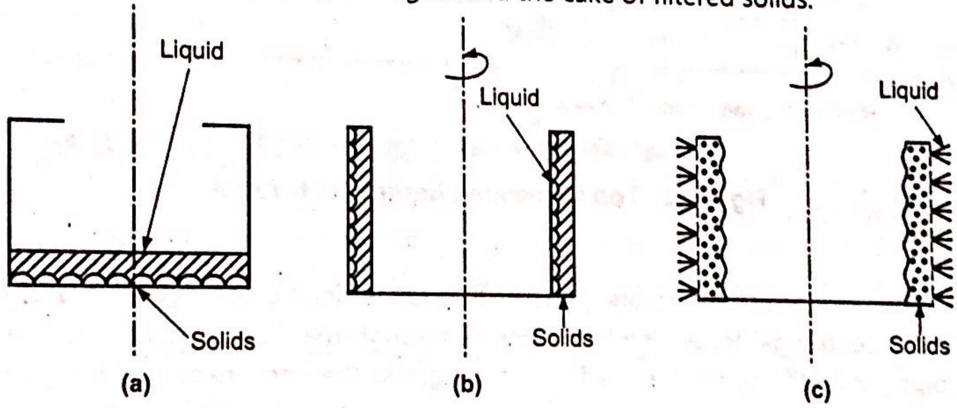


Fig. 5.11 : Principles of centrifugal separation and filtration

(a) Bowl stationary, (b) Sedimentation in rotating imperforated bowl,

(c) Filtration in rotating perforated basket

5.8.1 Centrifugal Filters

- A centrifuge or centrifugal is any rotating machine that utilises a centrifugal force for the separation of liquid from solids as well as for the separation of immiscible liquids of different densities. The essential components of a centrifuge machine are :
  1. a rotor or bowl in which centrifugal force is applied to the contents of bowl,
  2. a drive shaft,
  3. a drive mechanism e.g. electric motor,
  4. a frame for support, and align these and
  5. a casing.

Suspended batch centrifugal – Batch centrifuge

Construction :

- A batch centrifuge which is commonly used in industrial processing is the top-suspended centrifug (See Fig. 5.12). It consists of a basket with perforated sides. The diameter of the basket ranges from 750 t 1200 mm and depth from 450 to 750 mm. The basket rotates at speeds between 600 to 1800 rpm. Th basket is held at the lower end of a free swinging vertical shaft. The shaft is driven from above by a electric motor. The perforated sides (walls) of the basket are covered with a filter medium on the inside. The basket is surrounded by a casing provided with a filtrate discharge connection at the bottom. Th basket and other parts may be constructed of mild steel, monel and stainless. In case of mild steel, they may be lined with lead, rubber, etc.

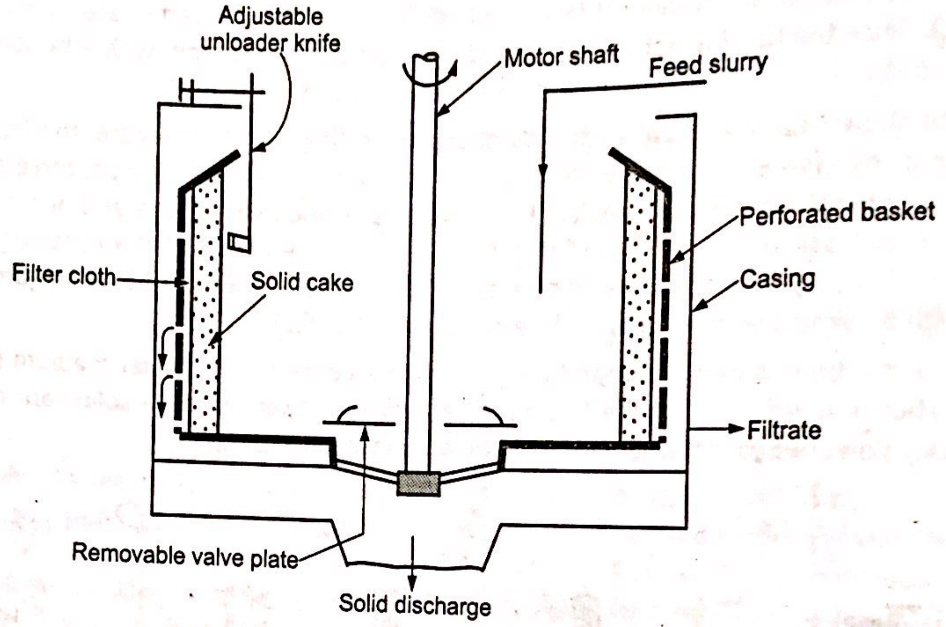


Fig. 5.12 : Top suspended basket centrifugal

Working :

- Slurry to be filtered is fed to the rotating basket through an inlet pipe or channel. It is forced against the basket sides by centrifugal force. The liquid passes through the filter medium into the casing and out a discharge pipe, while the solids form a filter cake against the filter medium. The cake thickness usually varies from 50 to 150 mm. The cake is washed by spraying wash liquid to remove the soluble material. It leaves the centrifuge through the discharge pipe. After washing is complete, the cake is spun as dry as possible, usually at a speed higher than that during the charging and washing steps. The motor is then turned off and the basket speed is reduced by the application of a brake. At the basket speed of 30 - 50 rpm, the cake is discharged by cutting it out with an unloader knife. The knife peels the cake off the filter medium and drops it through an opening in the basket floor. The valve which forms part of the bottom is opened to allow cake discharge into a receiver placed below. After unloading, the filter medium is rinsed clean and the cycle is repeated.
- These machines are widely used in sugar refining. They operate in sugar refining on short cycles of 2 to 3 minutes per load.
- Another design of basket centrifuge is the one which is driven from the bottom (under driven). In this machine, the drive motor, basket, and casing are all suspended from vertical legs mounted on a base plate. It may be top discharge or bottom discharge type.

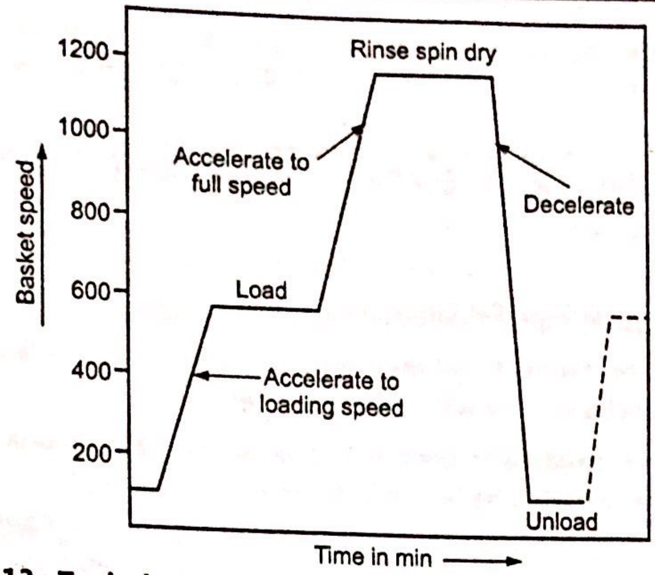


Fig. 5.13 : Typical operating cycle of a batch centrifuge machine

In case of bottom discharge under driven machines, the solids are plowed out through openings in the floor of the basket as in top-suspended machines. A typical operating cycle of a batch centrifuge is composed of various steps such as

(a) accelerate to loading speed,
(b) rinse screen,
(c) load,
(d) accelerate to full speed,
(e) wash cake,
(f) spin to dryness,
(g) decelerate to unloading speed, and
(h) unload.

- The drive may be variable-speed electric motor, either direct or through V-belts. A typical operating cycle for a variable speed automatic basket centrifuge is shown in Fig. 5.13. Centrifuge machines are also called as hydroextractor.

5.9 CONCEPT AND PRINCIPLE OF SEDIMENTATION

- *The separation of solids from a suspension in a liquid by gravity settling* is called ***sedimentation.*** The gravity force is responsible for the motion of solids through the liquid. In this operation, a dilute slurry is separated into a clear liquid and a slurry of higher solids content. The Dorr thickener is a common piece of equipment used for sedimentation.
- Removal of solids liquid sewage wastes (waste water treatment) and removal of suspended impurities from water to be used for domestic and industrial purposes (water treatment) are examples (application) of sedimentation.
- Sedimentation is one of the most widely used processes in the treatment of water. The simplest method of removing the suspended impurities is by plain sedimentation. The water is allowed to stand quiescent or move very slowly through a basin until the suspended impurities settle to the bottom of the basin and relatively clear water is drawn off from the top. The degree of removal of suspended impurities depends upon the length of retention period, the size of the suspended impurities and the temperature of water.

5.9.1 Types of Settling

- There are two types of settling processes by which particulates (solid particles) settle to the bottom of a liquid. 1. Free settling. 2.Hindered settling.

5.9.1.1 Free Settling

- It is the settling of the particles unaffeced by the other particles and the wall of the container.
- It refers to the process wherein the fall of the particle in the gravitational field through a stationary fluid is not affected by the other particles and the wall of the container.

- In this process, the individual particle does not collide with the other particles or with the wall of the container. This requires that the particles be at a sufficient distance from the wall of the container and also from each other.
- This type of settling process is possible only if the concentration of particulate solids in a suspension is very low.

5.9.1.2 Hindered Settling

- It is the settling of the particle impeded/affected by the other particles and the wall of the container.
- It refers to the process wherein the fall of the particle in the gravitational field through a stationary fluid is affected by the other particles and the wall of the container.
- In this process the particle collide with the other particles and with the wall of the container. This require that the particles be close to each other and this is turn demand the concentration of solids in a suspension to be high.
- Hindered settling is encountered when the concentration of solids in a suspension is large.
- For hindered settling, the settling velocity is considerably less than the terminal falling velocity under free settling condition.

5.9.2 Concept of Terminal Falling Velocity

- If a particle is allowed to settle in a fluid under the influence of gravity, it will increase in velocity until the accelerating force (force of gravity) is exactly balanced by the resisting force (drag force). When this happens there is no further change in the particles velocity and the particle will settle at a definite constant velocity. This velocity is known as the terminal falling or terminal settling velocity of the particle.
- The terminal falling velocity of the particle is affected by size, shape and density of the particles as well as the density and viscosity of the fluid.
- The terminal falling velocity of a particle freely falling in a fluid is the velocity of the particle when the drag force equals the downward force of gravity acting on the particle.

5.10 DIFFERENCE BETWEEN SEDIMENTATION AND FILTRATION

Sedimentation	Filtration
1. Sedimentation is defined as the removal of solid particles from a suspension by settling under gravity.	1. Filtration is defined as the separation of solid particles from a suspension by using a porous medium which retains the solid particles and allows the liquid to pass (through it).
2. The gravitation force – force due to gravity is responsible for separation (by sedimentation).	2. The pressure difference across the filter medium is responsible for separation (by filtration).
3. Filter medium is not required.	3. Filter medium is required.
4. The concentration of solids is very low in the suspension to be handled.	4. The concentration of solids is very large in the suspension to be handled in cake filtration.
5. In sedimentation, a clear liquid is the product of operation.	5. In cake filtration, wet cake of solids is the product of operation.
6. Sedimentation basins and thickeners are the equipments used for sedimentation.	6. Filters press, rotary drum filter etc. are the equipments used for filtration.
7. Usually a sludge is discarded from sedimentation.	7. Usually a filtrate is discarded from filtration.

5.11 DIFFERENCE BETWEEN SEDIMENTATION AND CENTRIFUGATION

Sedimentation	Centrifugation
1. The separation of solids from a suspension in a liquid by gravity settling is called sedimentation.	1. The separation of immiscible liquids or solids from liquids by the application of centrifugal force is called centrifugation.
2. The gravitation force is responsible for separation.	2. The centrifugal force is responsible for separation.
3. The force of gravity is comparatively very small and thus separation proceed slowly.	3. The centrifugal force is comparatively very grate/high and thus separation proceed very/ enormously fast.
4. Sedimentation basins and thickeners are used for sedimentation.	4. Various types of centrifuges are used for centrifugation.

5.12 DIFFERENCE BETWEEN SEDIMENTATION AND CLASSIFICATION

Sedimentation	Classification
1. The separation of solids from a suspension in a liquid by gravity settling is called sedimentation.	1. The separation of solid particles into fractions according to their terminal falling velocities is called classification.
2. The two products resulting by sedimentation are a clear liquid and a slurry of high solids content (sludge).	2. The two products resulting by classification are a partially drained fraction containing the coarse material and a fine fraction along with the remaining portion of the liquid medium.
3. Liquid medium is not required.	3. Liquid medium is required to effect separation.

5.13 LABORATORY BATCH SEDIMENTATION TEST AND SETTLING VELOCITY CURVE

- The mechanism of settling may be best described by batch settling test in a glass cylinder. Fig. 5.14 shows a series of observations of batch settling test.

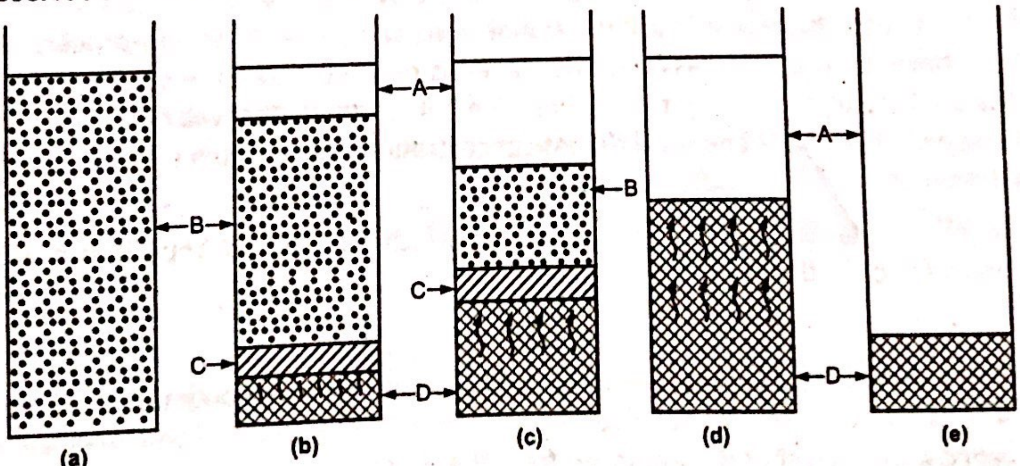


Fig. 5.14 : Laboratory Batch Settling test (Batch sedimentation)

- Fig. 5.14 (a) shows a cylinder containing a newly prepared slurry of uniform concentration of uniform solid particles throughout. As soon as the process starts, all the particles begin to settle and are believed to approach rapidly terminal settling velocities under hindered settling conditions. Various zones of concentration then are established as shown in Fig. 5.14 (b). The heavier faster settling particles settled at the bottom of a glass cylinder are indicated by zone D. Above zone D forms another layer, called zone C, a region of variable size distribution and non-uniform concentration. The boundary between C and D is usually obscure and is marked by vertical channels through which fluid is rising from the lower zone D as it compresses. Above zone C is zone B, which is a zone of uniform concentration, of approximately, the same concentration as that of the original pulp (suspension of solids is referred to as pulp in metallurgical work). Above zone B is zone A, which is a zone of clear liquid. If the original slurry is closely sized with respect to the smallest particles, the boundary between A and B is sharp.

- As sedimentation continues, the heights of each zone vary as shown in Fig. 5.14 (b), (c), (d). The heights of zones D and A increase at the expense of that of zone B while that of C remains constant. After further settling, zones B and C disappear, all the solids appear in zone D, but zone D may shrink further because of compression. During compression, the liquid associated with the solids in zone D is expelled in a clear zone.
- In a batch sedimentation operation as discussed, depths (heights) of various zones vary with time. The same zones will be present in continuous thickeners, but in a continuous sedimentation process, once the steady state is set up, the heights of each zone will be constant. Fig. 5.15 shows how the zones of Fig. 5.14 may be arranged in a continuously operating equipment such as a thickener.

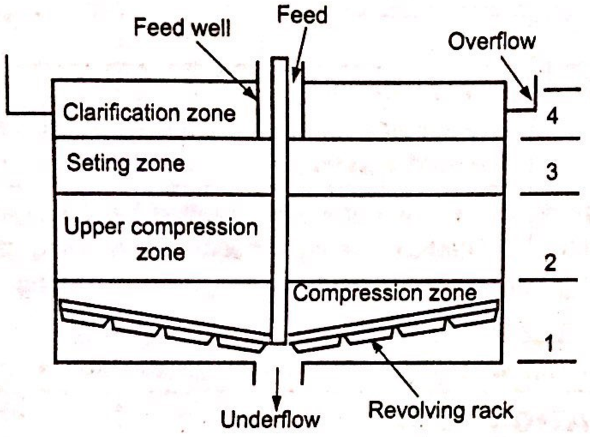


Fig. 5.15 : Settling zones in continuous thickener

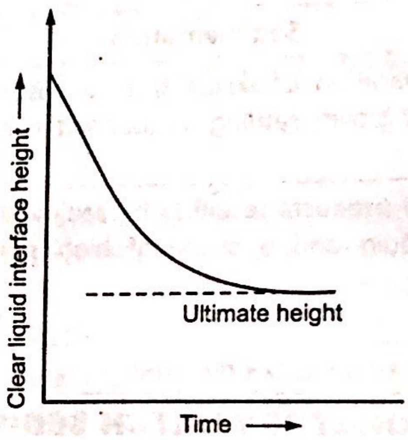


Fig. 5.16 : Batch-settling results

- In batch settling test carried out in the laboratory, the height of the liquid-solid interface (between zones A and B) is measured as a function of time. When the experimental data of height of interface v/s time are plotted, we get the curve as shown in Fig. 5.16. The slope of this curve at any point of time represents the settling velocity of suspension at that instant. During the early stage of settling process, the rate of settling is constant, as shown by the first portion of the curve. As time increases, the settling velocity decreases and steadily drops until the ultimate height is reached. The batch settling test will give a different curve for every sludge and somewhat different one for different concentrations. Such batch tests are the basis for design of continuous thickener.
- Thickening in sedimentation tanks is the process in which the settled impurities are concentrated and compacted on the floor of the tank.

Thickener

- Industrially, sedimentation operations may be carried out batchwise or continuously in an equipment called a *thickener*. A thickener consists of a relatively shallow tank from the top of which a clear liquid is taken off and the thickened liquid is withdrawn/removed from the bottom.
- In majority cases, the concentration of the suspension is high and hindered settling takes place. The rate of sedimentation can be artificially increased by the addition of coagulating agents such as alum, etc. which causes the precipitation of colloidal particles and the formulation of flocks. The suspension is also frequently heated which causes reduction in the viscosity of the liquid. Further, the thickener is frequently provided with a slow stirrer which helps in the consolidation of the sediment and also reduces the apparent viscosity of the suspension.

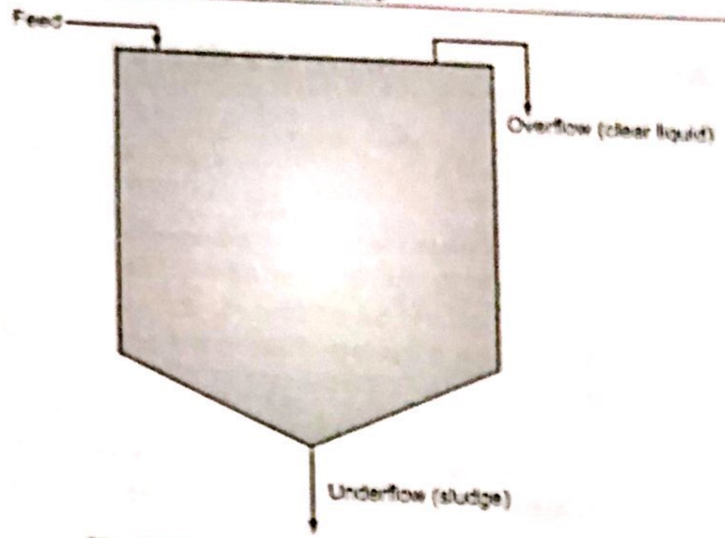


Fig. 5.17 : Schematic diagram of a thickener

5.14 TYPES OF THICKENERS

5.14.1 Batch Thickener

- A batch thickener usually consists of a cylindrical tank provided with openings for a slurry feed and product discharge. The bottom of the cylindrical tank is conical. The tank is filled with a dilute slurry, and the slurry is allowed to settle. After the sedimentation has proceeded for an adequate time, the clear liquid is decanted until sludge appears in the draw-off and the thickened liquid (sludge) is withdrawn from the bottom opening as indicated in Fig. 5.17.

5.14.2 Continuous Thickener

- A continuous thickener, such as the Dorr thickener consists of a flat bottomed, large diameter shallow-depth tank. It is provided with slow-moving radial rakes driven from a central shaft for removing the sludge. The slurry is fed at the centre of tank at a depth of 0.3 m to 1 m below the surface of the liquid, with a very little disturbance. The clarified liquid is continuously removed from an overflow which runs around the top edge of the tank (a launder) and the thickened liquor is continuously withdrawn from the outlet at the bottom. The slowly revolving rakes scrape the sludge towards centre of the bottom for discharge and remove water from the sludge as it stirs only the sludge layer. Thus, the solids are continuously moving downwards, and then inwards to the sludge outlet, whereas the liquid is moving upwards, and then rapidly outwards (Refer Fig. 5.18).

  The two functions of the thickener are :

  1. To produce a clear liquid, and 2. To produce a given degree of thickening of the suspension.

- For the production of clear liquid the upward velocity of the liquid must always be less than the settling velocity of particles. Thus, for a given throughput, the diameter of the tank determines the clarifying capacity of the thickener.

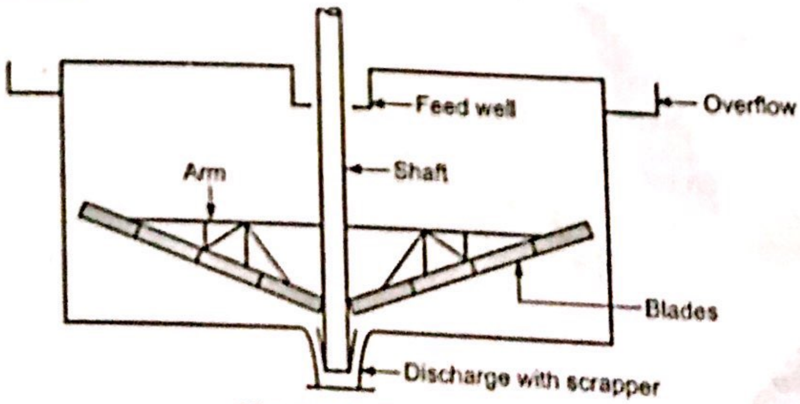


Fig. 5.18 : Dorr thickener

5.15 COAGULANTS AND ROLE OF COAGULANTS IN FILTRATION AND SEDIMENTATION

- The most widely used coagulants are : aluminium sulphate (usually called alum or filter alum) and ferrous sulphate (also known as copperas).
- Alum is the most commonly used chemical for the coagulation of water because of its excellent floc formation tendency, its relative economy, its stability and ease of cleaning. In order to react alum to form precipitate, it is necessary that the water should have some alkalinity and for this it is necessary to add soda ash or lime to water. It is found that alum coagulates best in the pH range of 6 to 8. It may be added in powdered form or in the form of solution.
- Chemical coagulation consists of adding small amounts of coagulants to water which form flocculant precipitates which coalesce with the suspended impurities and cause them to sink rapidly. When the coagulants are added to sedimentation tanks, the settling of solid particles will occur rapidly and the supernant liquid will be very clear.
- It is not possible to remove, as such, finely divided and colloidal particles, micro-organisms and colour producing compounds from water by use of sand filters. In order to remove these from water, coagulants are added to the water prior to filtration. When alum is added to water, it gets hydrolysed by natural or artificially created alkalinity of water with formation of the flocculant precipitate of aluminium hydroxide. The finely divided suspended matter, etc. gets adhered to this precipitate and are removed in sand filters.

SOLVED EXAMPLES

Example 5.1 : *For a sludge filtered in a washing plate and frame the filtration equation $V^2 = Kt$ holds good, where V is the volume of the filtrate obtained in time t. When the pressure is constant, 30 m^3 of filtrate is obtained in 10 h.*

(i) Calculate the washing time if 3 m^3 of wash water is forced to the cake at the end of filtration.

(ii) If the filtering area/surface is doubled keeping all other things constant, how long would it take to obtain 30 m^3 of filtrate ?

***Given :** The rate of washing is one-fourth the final rate of filtration.*

Solution : The filtration equation provided/given for a constant pressure filtration is

$$V^2 = Kt$$

where V is the volume of the filtrate obtained in time t.

Differentiating the above equation, we get

$$2V\,dV = K\,dt$$

$$\frac{dV}{dt} = \frac{K}{2V}$$

We have : $V^2 = Kt$

$$\therefore \quad K = \frac{V^2}{t}$$

Given : $V = 30\ m^3,\ t = 10\ h,\ K = \frac{(30)^2}{10} = 90\ m^6/h$

The final rate of filtration is given by

$$\left(\frac{dV}{dt}\right)_f = \frac{K}{2V} = \frac{90}{2 \times 30} = 1.5\ m^3/h$$

Given : Rate of washing $= \frac{1}{4}$ (final rate of filtration)

$$= \frac{1}{4} \times (1.5) = 0.375\ m^3/h$$

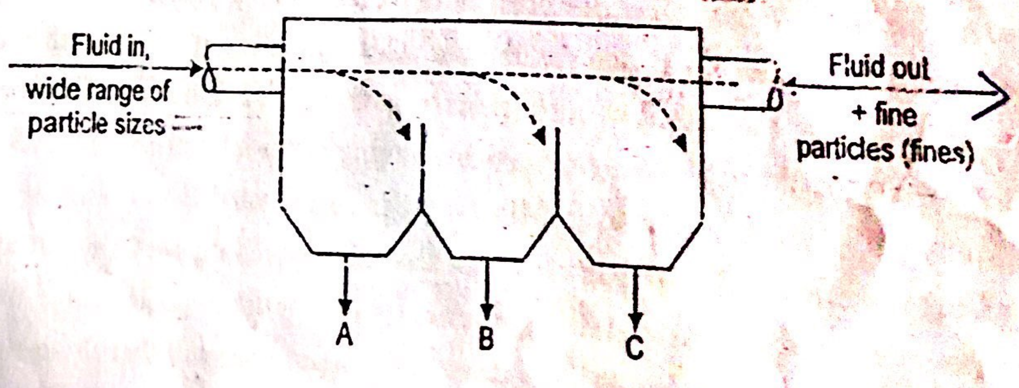
In the classification operation, the coarse solids that are settled at the bottom of a pool of fluid pulp are removed by gravity, mechanical means or induced pressure while the solids which do not settle report as overflow from the pool.

All wet classifiers depend upon the difference in rate of settling/settling rate between coarse and fine particles. The settling rate of a particle depends upon its size and density and the particle will settle under the conditions of free settling or hindered settling depending upon the concentration of solids. When the particle is at sufficient distance from the vessel walls and from other particles, so that its fall is not affected by them, the process is called free settling. In practice, the concentrations of suspensions (high concentrations of solids to liquid) used in the industry is usually high so that the particles are very close together and thus the collision between the particles is practically continuous. When the motion of the particle is impeded by other particles as they being very close to each other, the process is called hindered settling.

Gravity settling tank:

It is the simplest type of classifier. It consists of a large tank with provisions for a suitable inlet and outlet.

A slurry feed enters the tank through an inlet connection. As soon as the slurry feed enters the tank, its linear velocity decreases as a result of the enlargement of cross-sectional area. Solid particles start to settle under the influence of gravity. The faster-settling particles (coarse particles) will be collected at the bottom of the tank near the inlet/entrance, while the slower- settling particles (small particles) will be carried farther into the tank before they reach the bottom of the tank. The very fine particles are carried away in the liquid overflow from the tank. Vertical baffles placed at various distances from the inlet within the tank allow for the collection of several fractions (different grades of particles) according to the terminal falling velocities. Because of occurrence of considerable overlapping of size, no sharp separation is possible with this classifier.



A = Coarse particles

B = Intermediate particles

C = Small particles

Fig. 4.1 : Gravity settling tank

Cone Classifier :

A cone classifier is simply a cone (conical vessel), installed point down, with a discharge launder around the top (of the cone). The feed is introduced in the form of a suspension through a fed inlet provided at the centre at the top. The coarse fraction (the partially drained fraction containing the coarse material) collects at the point of the cone (i.e., at the apex) and is withdrawn periodically or continuously. The fine fraction along with the remaining portion of the liquid is removed from the launder as an overflow. The separation achieved with this unit is only an approximate one. Cone classifiers, though one of the oldest types, are still used for relatively crude work because of low cost of installation. They are used in ore-dressing plants.

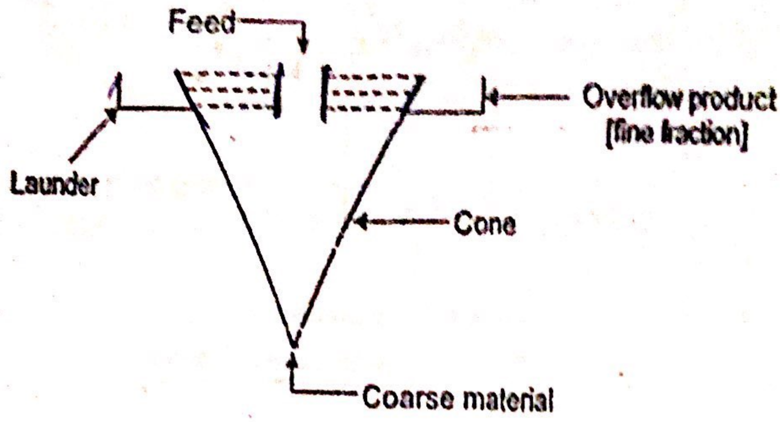


Fig. 4.2: Cone classifier

Double-cone classifier :

This classifier uses hydraulic water for classification (a stream of additional water supplied to a classifier is called hydraulic water).

The double-cone classifier is shown in Fig. 4.3. It consists of a conical vessel inside of which is a second hollow cone. The inner cone is slightly larger in angle, arranged apex downwards and is movable in a vertical direction. The bottom portion of the inner cone is cut away and its position (height) relative to the outer cone is regulated by a screw adjustment (not shown).

The feed to be separated is fed in the form of a suspension to the centre of the inner cone. It flows downward through the inner cone and out at a baffle at the bottom of the inner cone. Hydraulic water is fed near the outlet for the coarse material. The solids from the inner cone and a rising stream of water are mixed below the inner cone and then flow through an annulus space between the two cones. Classification action occurs in the annular space, the small/fine particles are carried away in the overflow while the large particles/coarse particles settle against the hydraulic water to the bottom and are removed periodically.

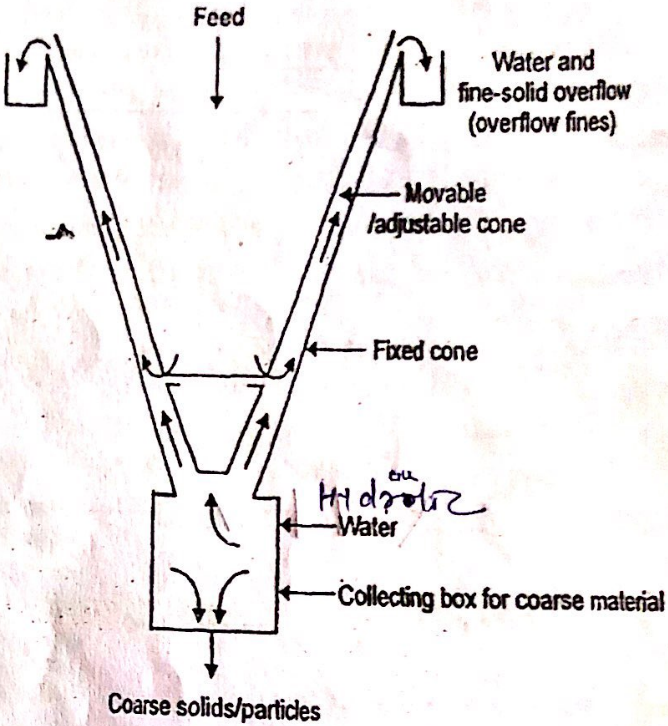


Fig. 4.3 : Double-cone classifier

Mechanical Classifiers :

Rake classifier : The rake classifier such as the Dorr classifier consists of a rectangular tank with a sloping/inclined bottom. The tank is provided with movable rakes (reciprocating rakes). The feed in the form of a suspension (slurry) is introduced continuously near the middle of the tank. The lower end of the tank has a weir overflow (discharge weir) from which the fines that are not settled leave with the overflow liquid. The heavy material (coarser particles) sink to the bottom of the tank. The rakes scrap the settled solids upward along the bottom of the tank toward the top of the tank for discharge from a sand-discharge chute. The reciprocating rakes keep the slurry in continuous agitation. The time of raking stroke is so adjusted that fines do not have time to settle and so remain near the surface of the slurry, while the heavy particles have time to settle [they settle, scrapped upward and removed as a dense slurry (called the sand)].

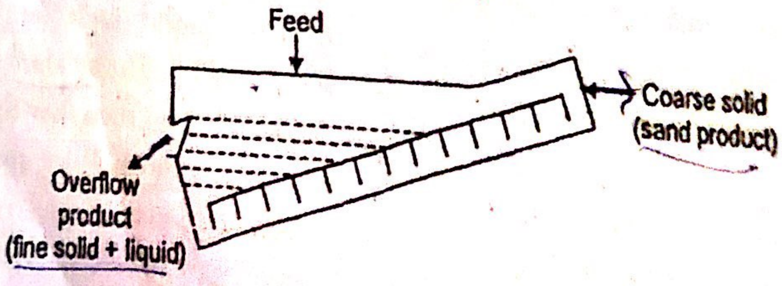


Fig. 4.4 : Rake classifier

Spiral classifier :

Another mechanical classifier is the spiral classifier. The spiral classifier such as the Akins classifier consists of a semicylindrical trough (a trough which is semicircular in cross-section) inclined to the horizontal. The trough is provided with a slow-rotating spiral conveyor and a liquid overflow at the lower end. The spiral conveyor moves the solids which settle to the bottom upward toward the top of the trough.

Slurry is fed continuously near the middle of the trough. The slurry feed rate is so adjusted that fines do not have time to settle and are carried out with the overflow liquid. Heavy particles have time to settle, they settle to the bottom of the trough and the spiral conveyor moves the settled solids upward along the floor of the trough toward the top of the trough/the sand product discharge chute.

Rake and spiral classifiers are used for close-circuit grinding.

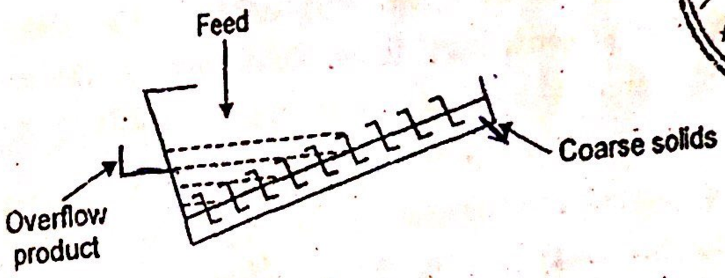


Fig. 4.5 : Spiral classifier

Cyclones / Cyclone separators :

A cyclone/cyclone separator is essentially a settling chamber in which the gravitational separating force is replaced by a much stronger centrifugal separating force (to increase the settling rate).

Cyclones/cyclone separators are used for the separation of solids from fluids. They offer one of the least expensive means of dust collection (separation of dust particles from gases) from both an operating and an investment view point. They utilize centrifugal force to effect the separation which depends on particle size and/or on particle density. Thus, cyclones are used to effect a separation on the basis of particle size or particle density or both.

It consists of a tappering cylindrical vessel, i.e., a cylindrical vessel consisting of a top vertical section and lower conical/tappering section terminating in an apex opening - a short vertical cylinder which is closed by a flat plate on top and by a conical bottom (Refer Fig. 4.6). It is provided with a tangential feed inlet nozzle in the cylindrical section near the top and an outlet for the gas, centrally on the top. The outlet is provided with a downward extending pipe - a pipe that extends inward into the cylindrical section - to prevent the gas short-circuiting directly from the inlet to the outlet and for cutting the vortex.

In this separator, used for the separation of dust particles or mist from gases, the dust laden gas is introduced tangentially into a cylindrical vessel at a high velocity (30 m/s). Centrifugal force throws the solid particles out against the wall of the vessel and they drop into a conical section of the cyclone and removed from the bottom/apex opening. The clean gas is taken out through a central outlet at the top.

Cyclones are widely used for collecting heavy and coarse dusts. These units may also be used for separating coarse materials from fine dust.

Liquid Cyclone (Hydroclone):

Cyclone separators may also be used to effect the classification of solid particles suspended in a liquid. In such cases, the commonly used liquid is water.

Liquid cyclone has a top cylindrical section and a lower conical section terminating in an apex opening. The top vertical section is covered by a flat plate and is provided with a tangential inlet at the top. The cover has a downward-extending pipe to cut the vortex and remove the overflow product since the viscosity of water is much higher than that of a gas, the fluid resistance encountered in this cyclone is greater than that in the cyclone used for dust collection. Therefore, the diameter of this cyclone must be smaller in order to get a corresponding greater/larger centrifugal force. Consequently, the diameter of cylindrical section is less than 375 mm and the cone angles are 15° to 20°. Inlet pressures of the feed (induced by means of a pump) to the cyclone lie between 5 to 120 psi.

The slurry feed is pumped into the cylindrical section tangentially. Coarse or heavy solids thrown out against the walls, travel down the sides of the cone section and are discharged in a partially dewatered form from the apex, while the smaller or lighter solids along with the remaining portion of water are removed from the downward extending pipe at the top. Liquid cyclones find applications in degritting operations in alumina production, classifying pigments and ore-dressing practice.

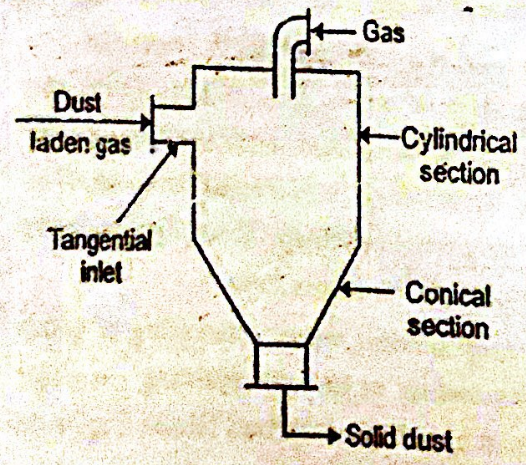


Fig. 4.6 : Cyclone separator/Cyclone

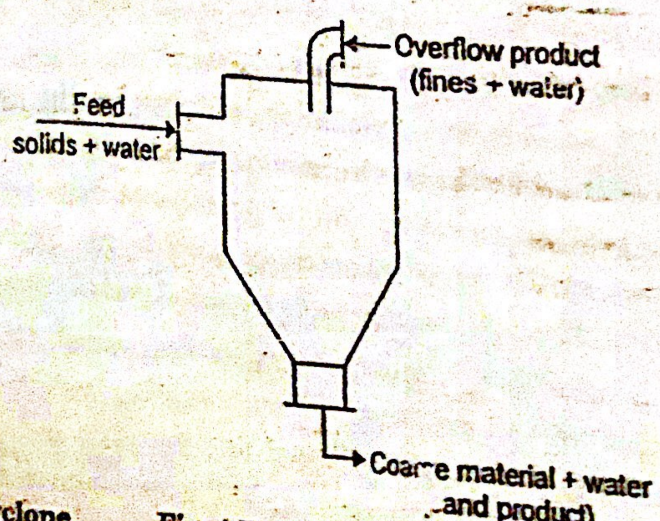


Fig. 4.7 : Liquid cyclone

Scanned with CamScanner

Jigging :

A jig is a mechanical device used for the separation of materials of different specific gravities by pulsating a stream of liquid (usually water) flowing through a bed of materials resting on a screen.

Jigging is a method of separating materials of different specific gravities by the pulsation of a stream of liquid (water) flowing through a bed of materials resting on a screen.

[pulsate ⇒ oscillate ⇒ move or swing back and forth at a regular rate.

Jig ⇒ move up and down with a quick jerky motion.]

Principle of operation :

Jigging is a process of gravity concentration where solids are separated based upon the differences in behaviour of particles through a moving fluid which in turn, depends upon densities/specific gravities. Separation of solids of different specific gravities is achieved by the pulsation of a liquid stream flowing through a bed of solids on a screen. The liquid pulsates or jigs up and down and this action causes the heavy material to move towards the bottom of the bed and the lighter material to rise to the top. Each product is taken out separately.

Applications :

Jigging is used for concentrating heavy minerals from the light minerals. It is commonly employed for coarse material having a size 20-mesh and above and where there is a sizeable/fairly large difference between the effective specific gravity (effective sp. gr. = sp. gr. of mineral – sp. gr. of water) of the valuable and the waste material.

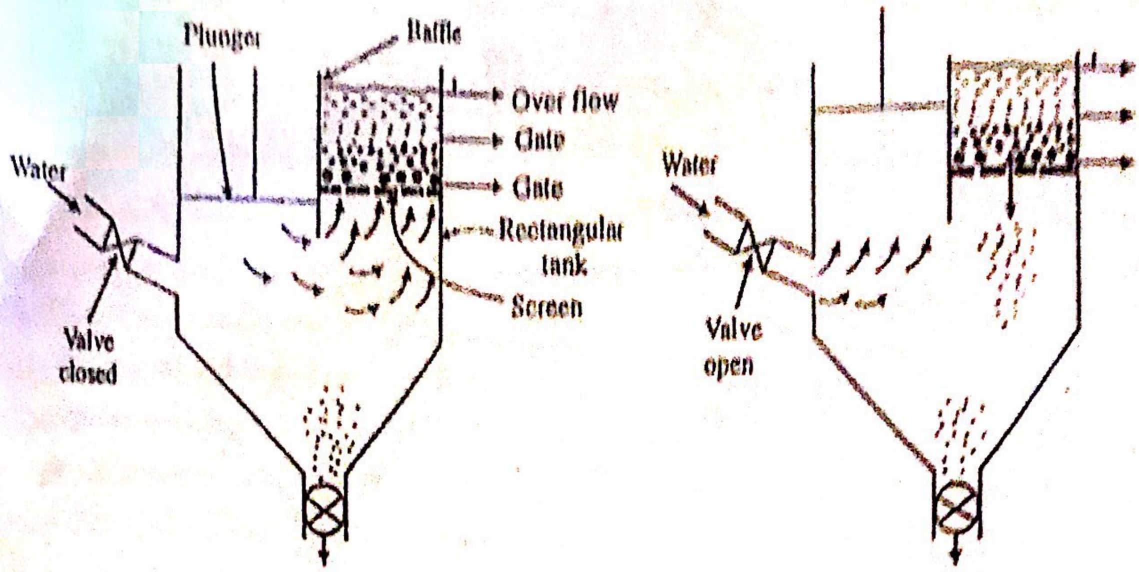
Jigs are simple in operation, consume very large quantities of water and have high tailings losses on metallic ores. They are used mostly to treat iron ores, few lead-zinc ores, etc. Jigging is widely used for the concentration of coal.

Hydraulic Jig :

It operates by providing very short periods for material to settle due to which the particles do not attain their terminal falling velocities and initial velocities cause the separation. Thus, it is suitable for the separation of materials of wide size range into their constituents.

Construction :

The hydraulic jig is shown in Fig. 4.8. It consists of a rectangular section tank with a tappered bottom. The tank is divided into two portions/compartments by a vertical baffle. In one compartment, a plunger is incorporated. It operates in a vertical direction giving a pulsating motion to the liquid. In the other compartment, a screen is incorporated. The separation of material is carried out over this screen. It is provided with a connection for feeding liquid during the upstroke. It is also provided with a bottom discharge connection for the removal of small particles of heavy material and gates at the side of jig for the removal of particles settled on the screen and for overflow.



(a) Downward stroke (b) Upward stroke

Fig. 4.8 : Hydraulic jig

Working :

The material to be separated is fed over a screen and is subjected to a pulsating action by oscillating liquid with the help of a reciprocating plunger. During the upward stroke of the plunger, input water is taken into the jig and there is no net flow through the bed of solids. During the downward stroke, water inlet is closed and particles on the screen are brought into suspension and they segregate according to their size and density such that the dense material is collected near the bottom of screen. Very small particles of the dense material will pass through the screen and are collected at the bottom of the jig. Small particles of the less dense material (light material) carried by the liquid water are removed through an overflow. The material retained on the screen is removed through gates provided at the side.

Four fractions obtained from the jig are :

1. Small and dense material passing through the screen collected at the bottom of the tank.
2. Small size less dense material in the liquid overflow.
3. Large size dense material segregated near a screen removed through a gate at the side.
4. Large size less dense material segregated above the dense material removed through a gate at the side.

Froth Flotation :

Flotation refers to *an operation in which one solid is separated from another by floating one of them at or on the liquid surface*. In froth flotation, separation of a solid feed mixture depends upon the difference in surface properties of the materials involved. This technique is commonly used in mineral dressing. Mineral dressing refers to the method of treating ores at or near the mine site to produce one or more concentrates of valuable minerals and a tailings composed of waste or less valuable minerals.

[Flotating ⇒ the action of floating ⇒ also flotation]

Froth flotation is used for treating the metallic ores that are finer than 48 to 65 mesh, or coal and certain non-metallics that are finer than 10 to 48 mesh. It is not possible to treat a coarser feed by froth flotation as the same cannot be suitably mixed and suspended by a floatation machine.

Principle of operation :

Seperation of a mixture of solids using froth flotation methods depends on the difference in surface properties of the materials involved (hydrophobic or hydrophilic). If the mixture is suspended in an aerated liquid, the gas bubbles will tend to adhere preferentially to the constituent which is more difficult to wet by the liquid (hydrophobic) and so its effective density will be reduced to such an extent that it will rise to the surface (i.e., it will float on the surface of the liquid) and the material which has affinity for the liquid gets surrounded by the liquid and it will simply sink, thus, achieving a separation. Frothing agents inducing the formation of a froth of sufficient stability are added to suspend or retain the particles in the froth on the surface before they are discharged.

Promotors, Collectors, Modifiers and Frothing Agents :

Almost all the minerals and inorganic solids are hydrophilic, as the surfaces of these solids get easily wetted by water. Hydrophilic solids are unflotable as air bubbles do not surround or cover them to form a particle bubble aggregate. However, these solids can be made hydrophobic (water repellent) with the help of reagents known as collectors or promotors. The collectors or promotors are the materials which selectively render the desired particles air-avid and water repellent.

- Promotors are materials which are adsorbed on the surface of the particles forming a unimolecular layer. A commonly used promotor is sodium ethyl xanthate.
- Collectors are materials which form surface films on the particles. A commonly used collector is pine oil.
- Frothing agents/Frothers are materials which induce the formation of a froth (which produce a froth) of sufficient stability in order to retain the particles of the constituent which is to be floated to be discharged as an overflow. Commonly used frothers are liquid soaps, pine oil, cresylic acid, methyl amyl alcohol and methylisobutylcarbinol.

The valuable concentrates from froth flotation may be either the froth product which is collected and removed from the top, or the underflow product. In case of metallic sulfide ores of copper, zinc, nickel, lead and native gold and silver, the valuable product collects in the froth and removed is from the top. In glass-sand flotation, iron bearing minerals collect in the froth while valuable product (high grade silica) is removed as underflow product.

Flotation Machine/Flotation Cell :

Construction :

The mechanically agitated cell consists of a tank having square or circular cross-section. It is provided with an agitator which violently agitates the pulp. The air from a compressor / blower is introduced into the system through a downpipe surrounding the impeller shaft. The bottom of the tank is conical and is provided with a discharge for tailings. An overflow is provided at the top for mineralised froth removal.

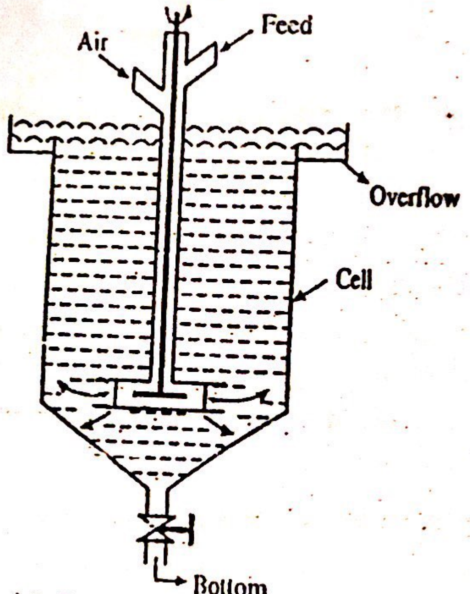


Fig. 4.9 : Froth flotation cell (Lab. model)

Working :

Water is taken into the cell, material is fed to the cell. The promotors and frothers are added. Agitations are given and air is bubbled in the form of fine bubbles. Air-avid particles due to reduction in their effective density, will rise to the surface and be held in the froth before they are discharged from the overflow. Hydrophilic particles will sink to the bottom and removed from the discharge for tailings.

Electrostatic Separation :

Principle : If one or more of the materials of a granular mixture can acquire a surface charge on or just before entering an electrostatic field, the grains/particles of that material will be attracted towards the active electrode or repelled from it depending upon the sign of the charge on grains/particles.

Electrostatic separation is a method of separation of solid particles based on the differential attraction or repulsion of charged particles under the influence of an electric field. Basically, the difference in electrical properties of different materials is responsible for such a separation.

Charging of particles is an essential step in this separation. Solid particles can receive a surface by any one of the following methods :

(i) Contact electrification.

(ii) Electrification by conductive induction.

(iii) Electrification by bombardment.

Electrification by conductive induction is one of the major electrification mechanisms for the separation or concentration of solid materials by this method. When an uncharged solid particle is placed on a grounded conductor in the presence of an electric field (i.e. when it comes in contact with a charged surface), the particle will rapidly acquire a surface charge by induction. A conductive particle acquires the same charge as the grounded conductor (it becomes charged to the same potential as the grounded conductor within a very short period of time) through its contact with the conductor while a dielectric particle is polarised and thus no net charge is generated on it. As a consequence of this induction, the conducting particle will be repelled by the surface/grounded conductor, while the dielectric particle will be unaffected. Charging by conductive induction can be used to make a finite separation between relative conductors and non-conductors.

Electrostatic Separator :

In electrostatic separator, the difference in electrical properties of different materials (present in the mixture to be separated) is exploited to effect a separation.

The electrostatic separator shown in Fig. 4.10 consists of a grounded rotor/rotating drum, a hopper for feeding the solids, an active electrode, situated/placed at a small distance from the drum and collecting bins.

The solids to be separated are fed on to a rotating drum, either charged or grounded, from a hopper. The conductive particles in a very short time will assume the potential of the rotating drum, which is opposite to that of an active electrode and hence, they get attracted towards the active electrode. The non-conductive material is repelled by the electrode and attracted by the drum. The non-conductive material falls down straight under the influence of gravity and is collected in a separate bin.

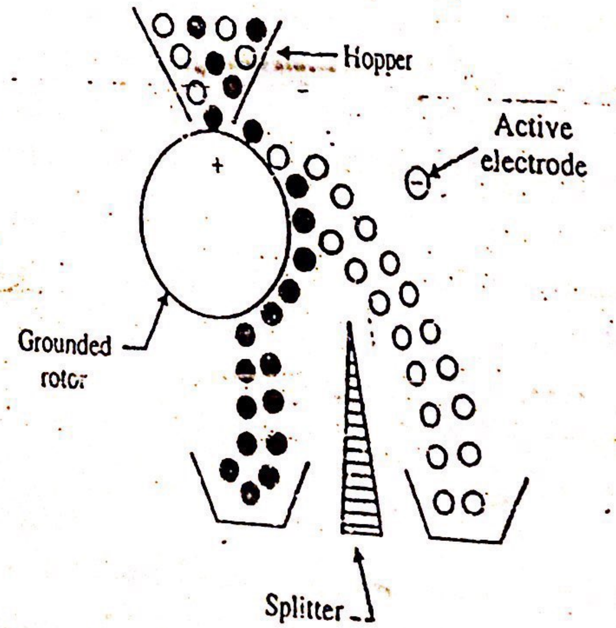


Fig. 4.10 : Electrostatic separator (separation by conductive induction)

Magnetic Separation :

Magnetic separation is a method of separation of solid particles by means of a magnetic field. In this method, materials having different magnetic attractability are separated by passing them through a magnetic field. The difference in magnetic properties of different materials is responsible for such a separation.