Dividing both sides by t, we get

$$\frac{V}{At} = \frac{[(R_m/t)^2 + 2\,\Delta P\, c\, \alpha/\mu\, t]^{1/2} - R_m/t}{c\,\alpha} \qquad \text{... (5.30)}$$

where V/t is the rate of filtrate collection and A is the submerged area of the filter.

If $\dot{m}_c$ is the rate of solids production, t_c is the cycle time, A_T is the total filter area, n is the drum speed and f is the fraction of the drum submerged, then

$$t = f\, t_c = f/n \qquad \text{... (5.31)}$$

The rate of solids production using Equation (5.8) becomes

$$\dot{m}_c = \frac{m_c}{t} = \frac{cV}{t} = c\left(\frac{V}{t}\right) \qquad \text{...(5.32)}$$

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

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

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

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

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

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

- 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.

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.

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.

FACTORS AFFECTING 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.

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.

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.

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.

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.

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.

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).

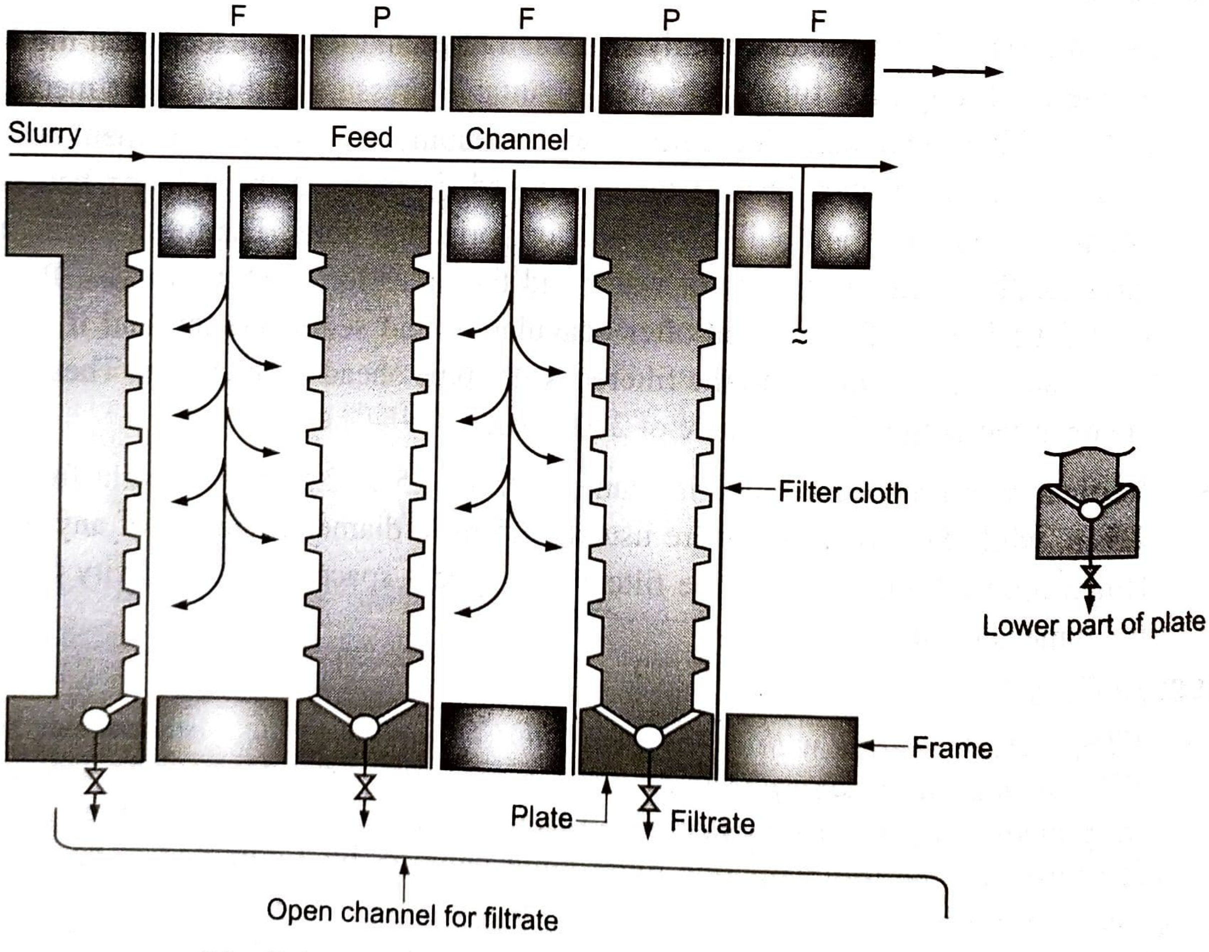

Fig. 5.4 : Plate and frame filter press (sectional view)

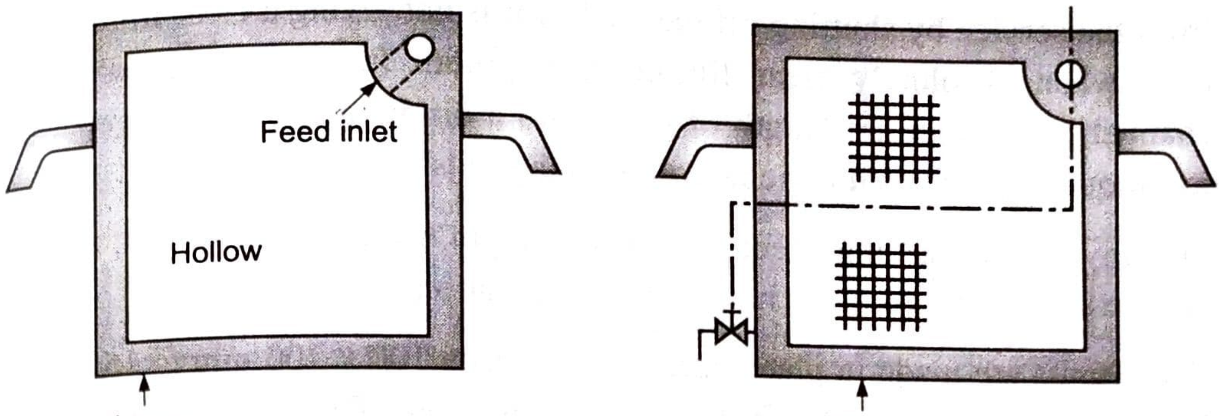

Fig. 5.5 : Plate and frame

- 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.

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.

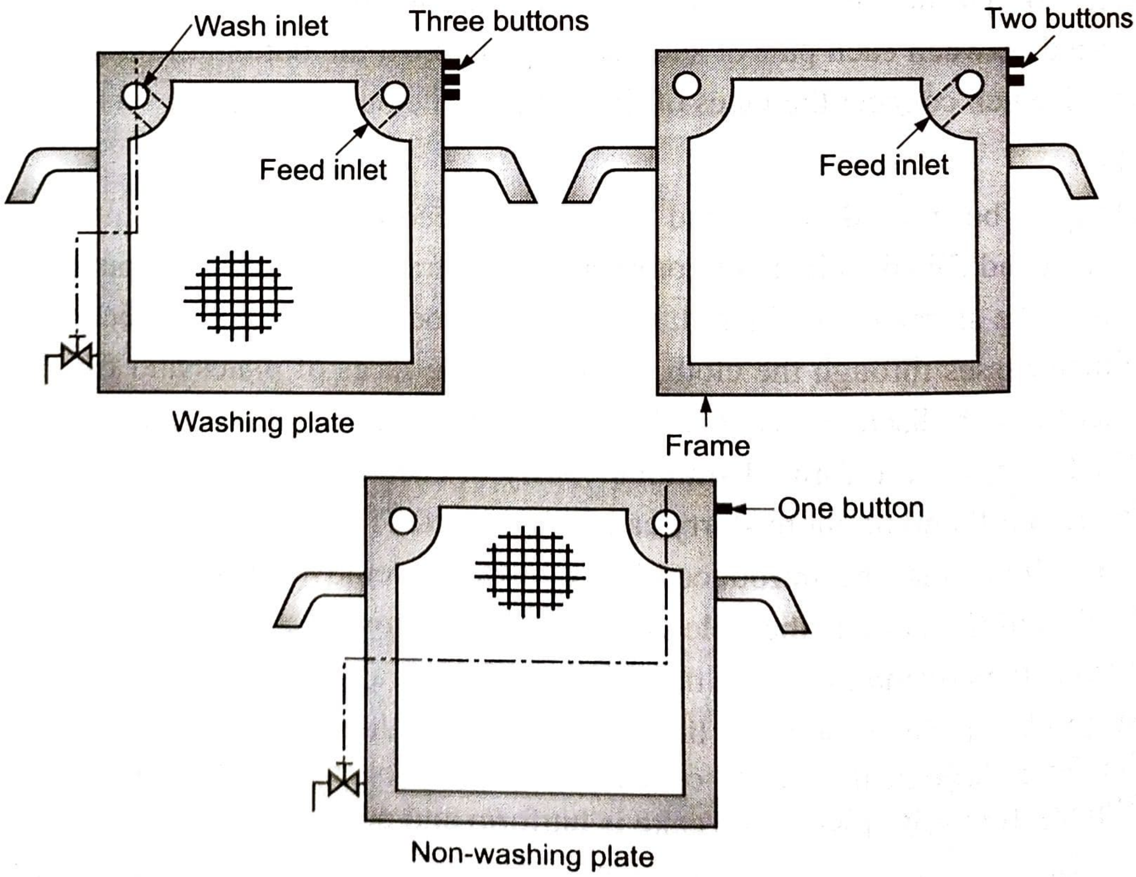

Fig. 5.6 : Plates and frames of washing press

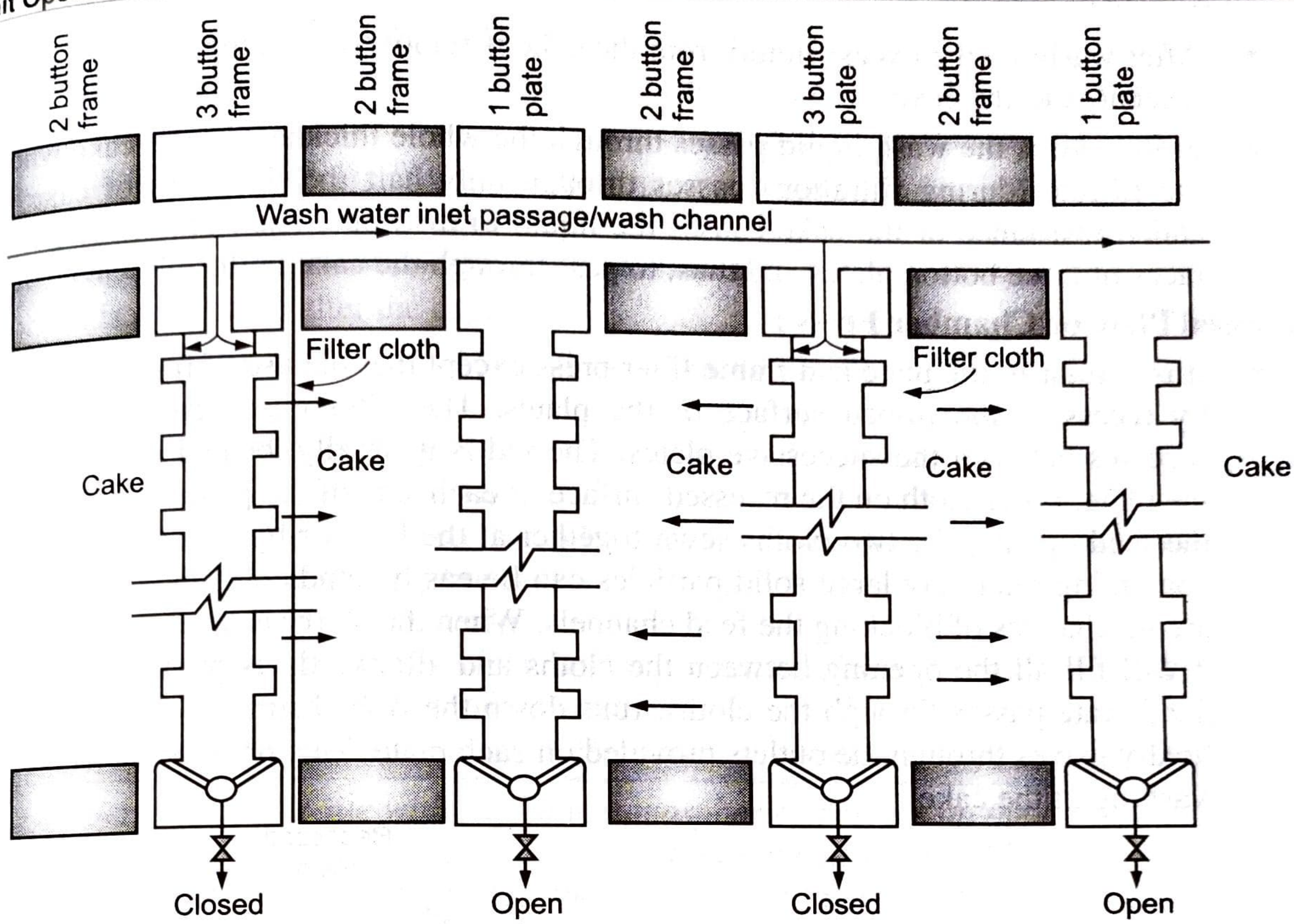

Fig. 5.7 : Section through Washing Press (Washing cycle)

- 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. (See 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.

- 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 :

- 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.

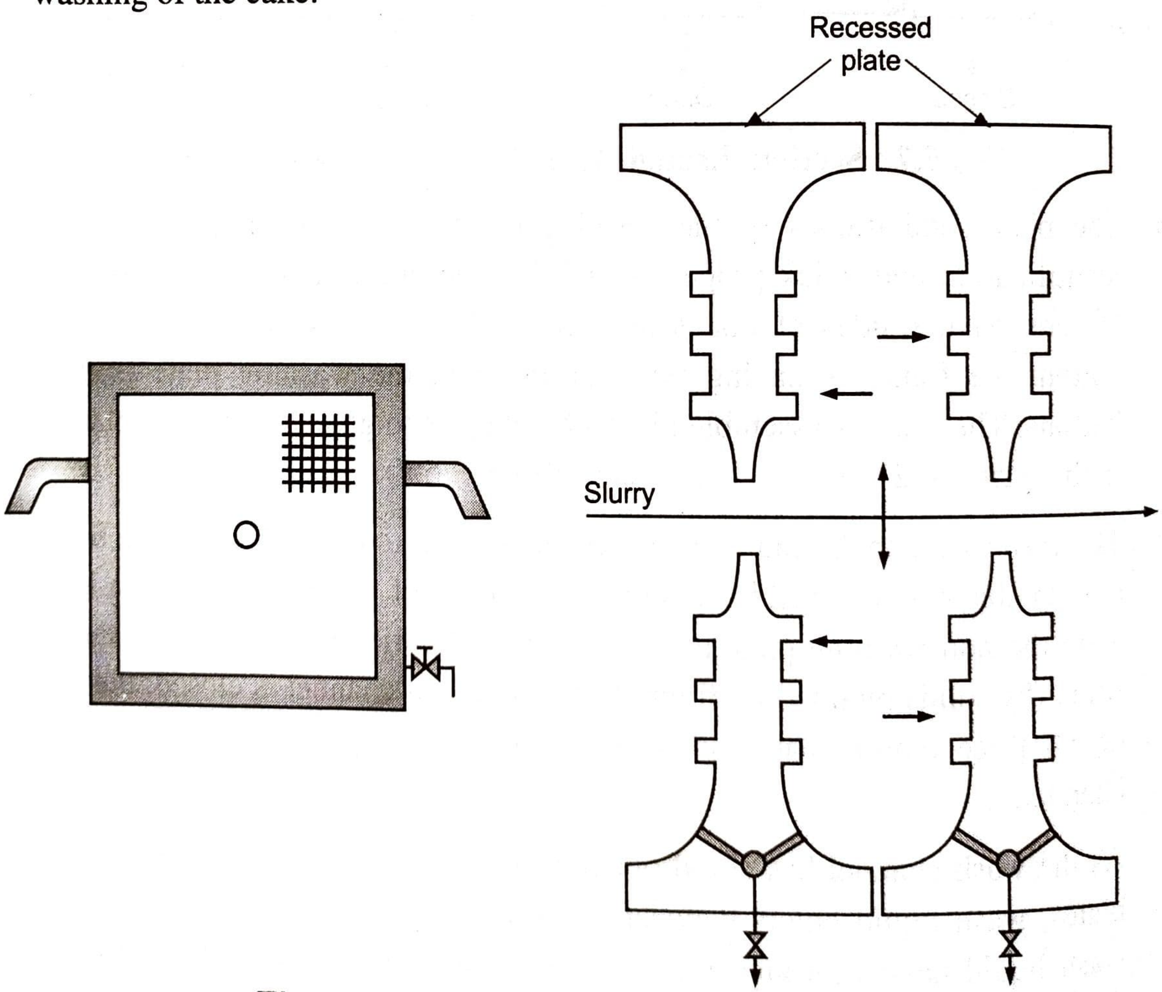

Fig. 5.8 : Recessed plate and chamber press

- 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.

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.
- 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.

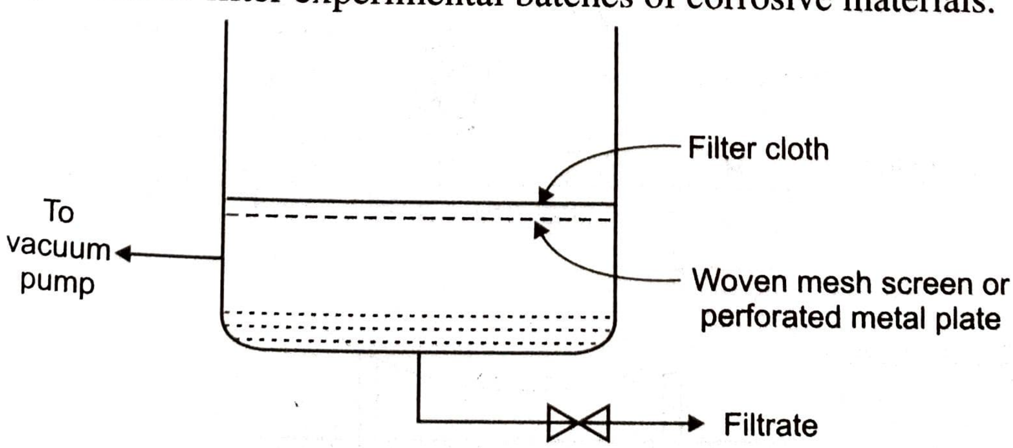

Fig. 5.9 (A) : Nutsch filter

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.

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.

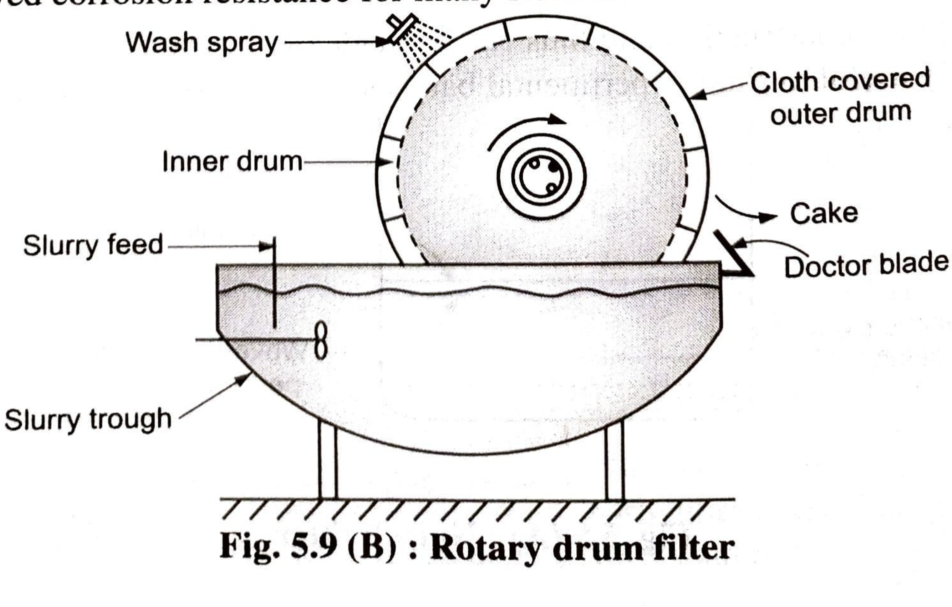

Fig. 5.9 (B) : Rotary drum filter

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.
- 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.

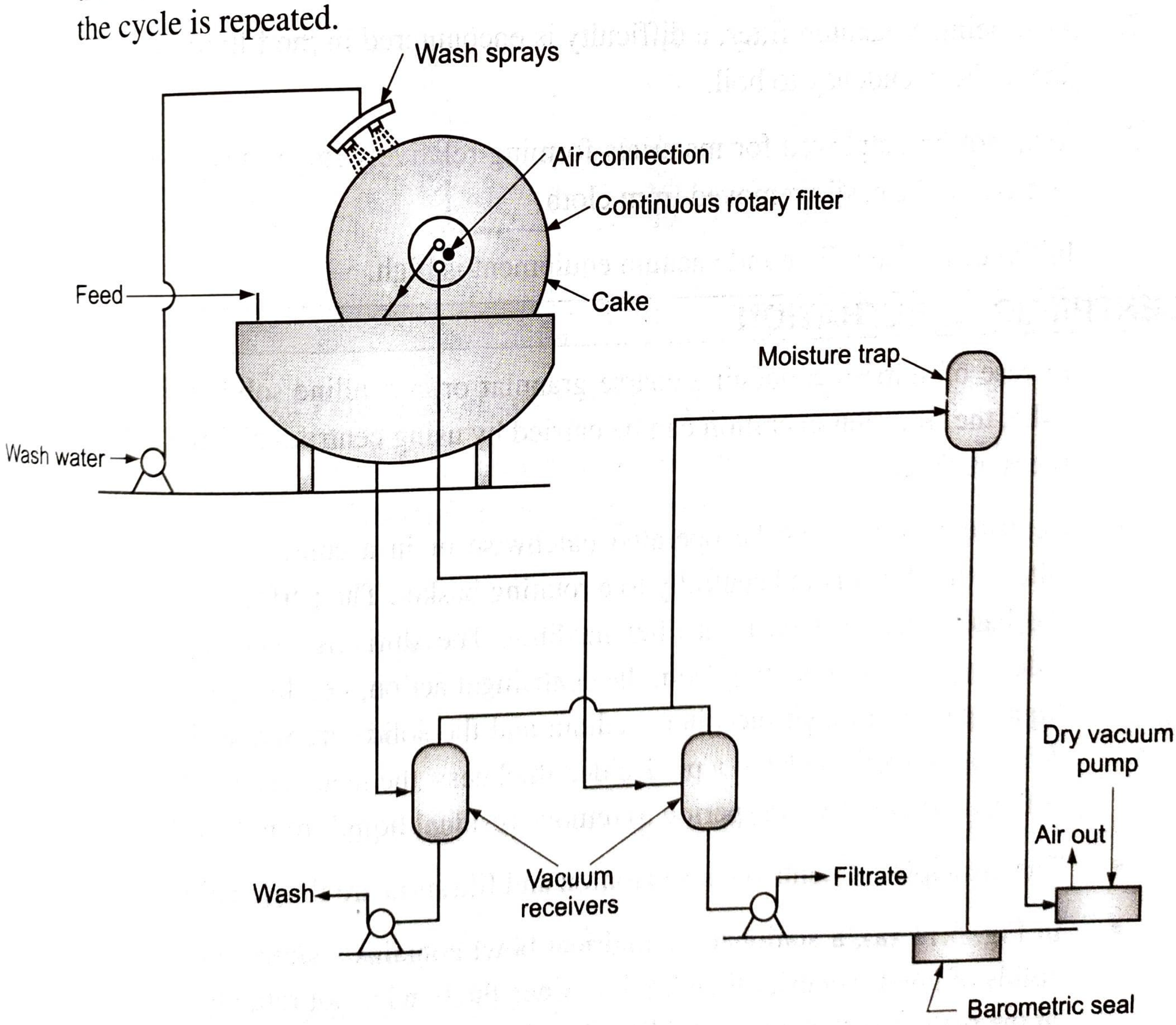

Fig. 5.10 : Flow sheet for continuous vacuum filtration

- 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.

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.

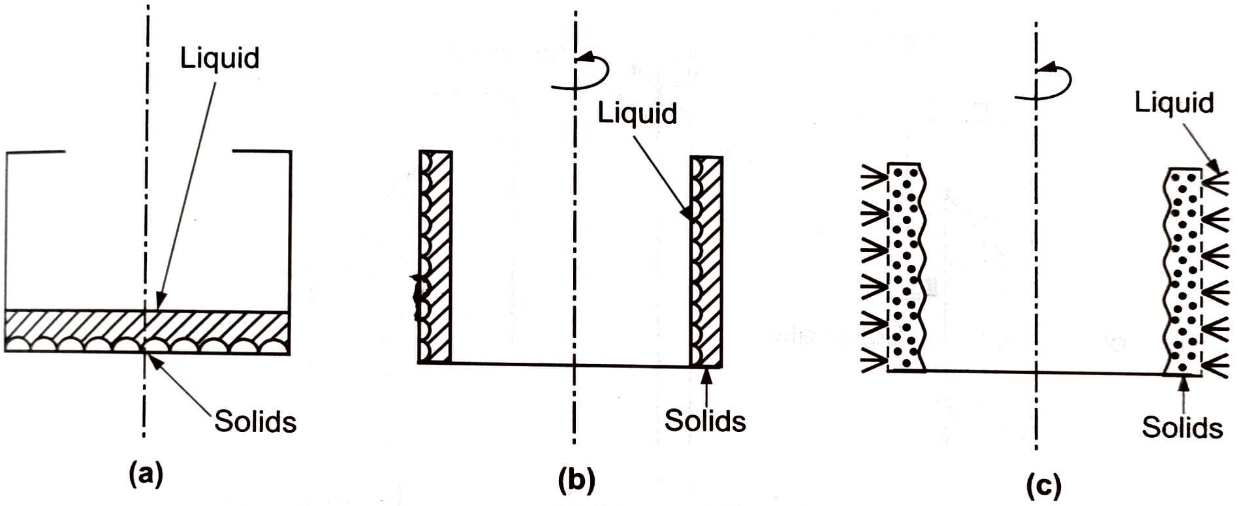

Fig. 5.11 : Principles of centrifugal separation and filtration

(a) Bowl stationary, (b) Sedimentation in rotating imperforated bowl, (c) Filtration in rotating perforated basket

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 centrifuge (See Fig. 5.12). It consists of a basket with perforated sides. The diameter of the basket ranges from 750 to 1200 mm and depth from 450 to 750 mm. The basket rotates at speeds between 600 to 1800 rpm. The basket is held at the lower end of a free swinging vertical shaft. The shaft is driven from above by an 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. The 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.

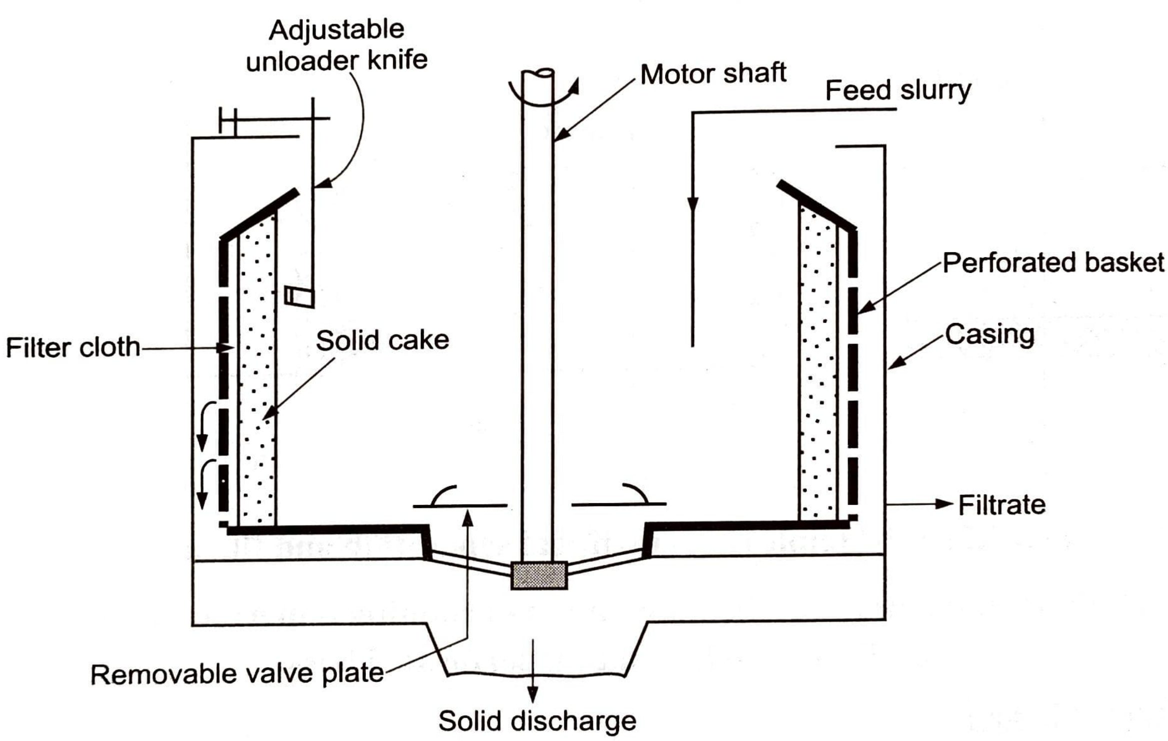

Fig. 5.12 : Top suspended basket centrifugal

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.

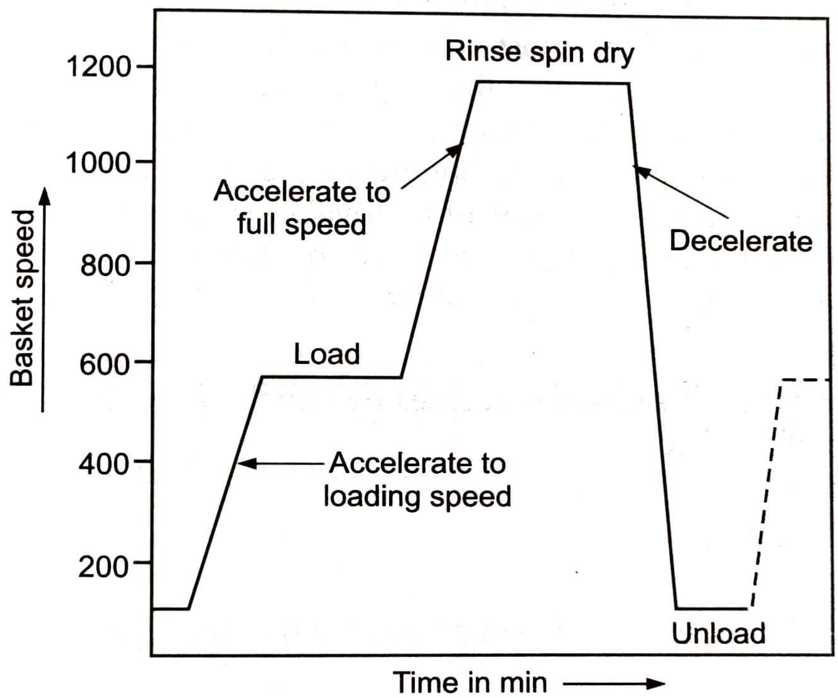

Fig. 5.13 : Typical operating cycle of a batch centrifuge machine

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.

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.

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.

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.

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.

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.

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.

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.

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.

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 (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.

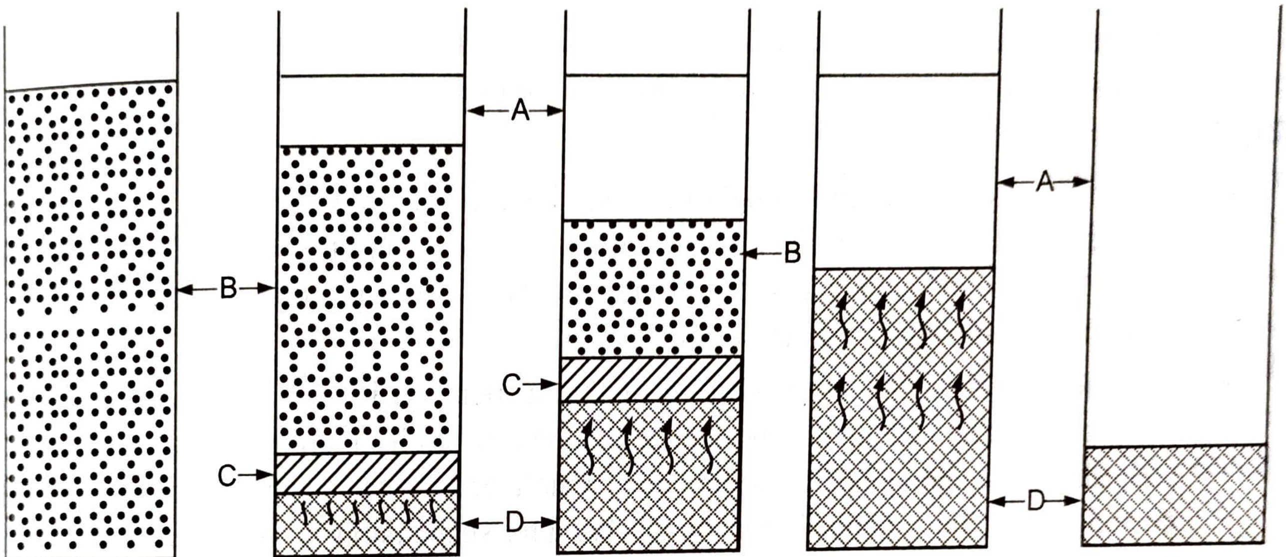

Fig. 5.14 : Laboratory Batch Settling test (Batch sedimentation)

- 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.

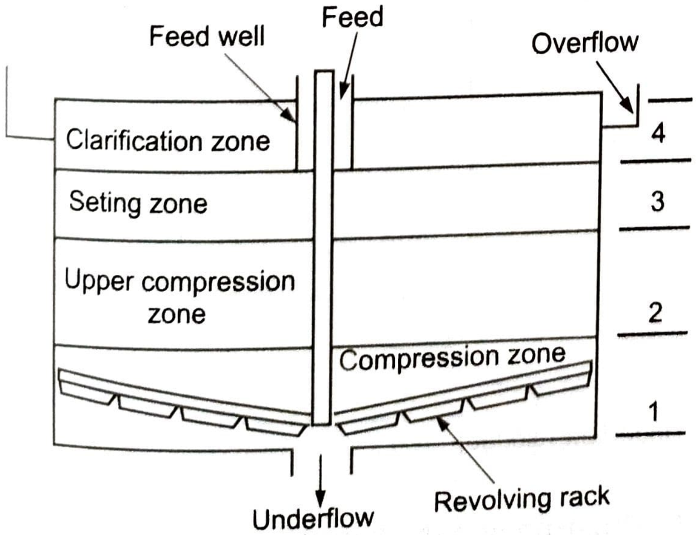

Fig. 5.15 : Settling zones in continuous thickener

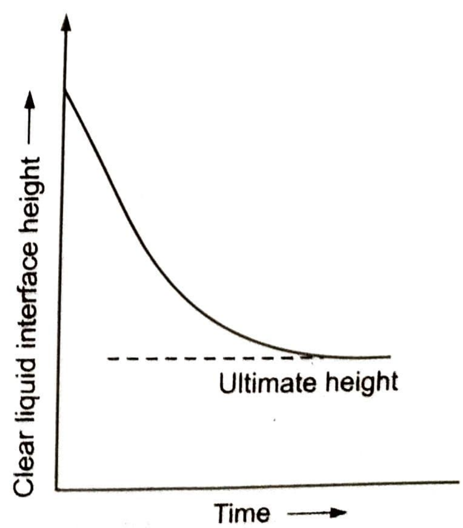

Fig. 5.16 : Batch-settling results

- 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.

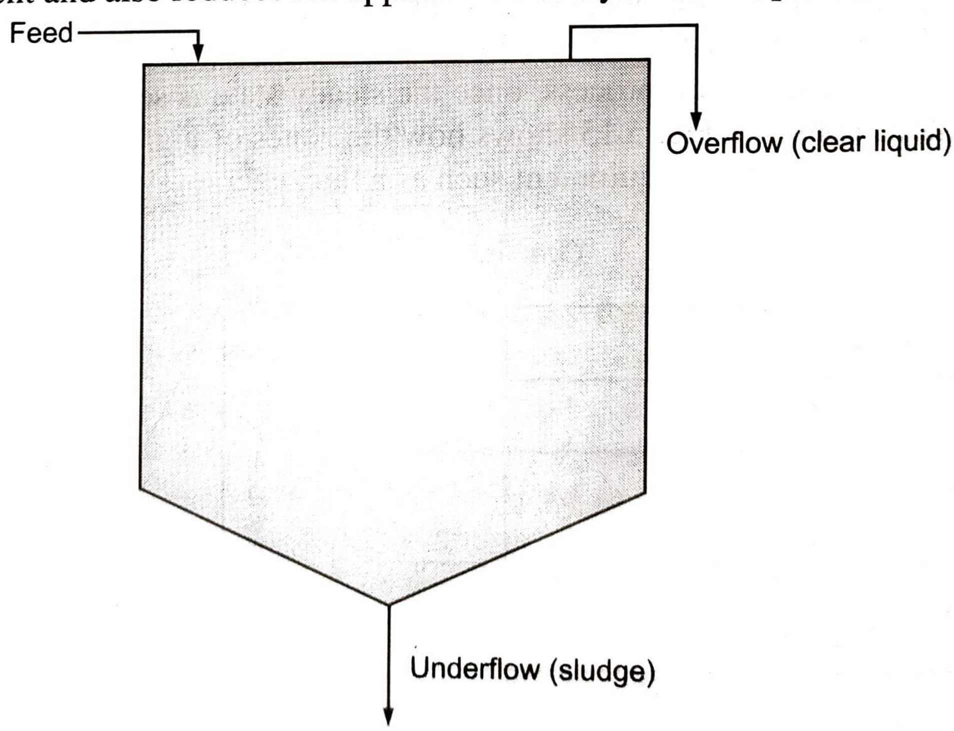

Fig. 5.17 : Schematic diagram of a thickener

Types of Thickener

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.

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 (See 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.

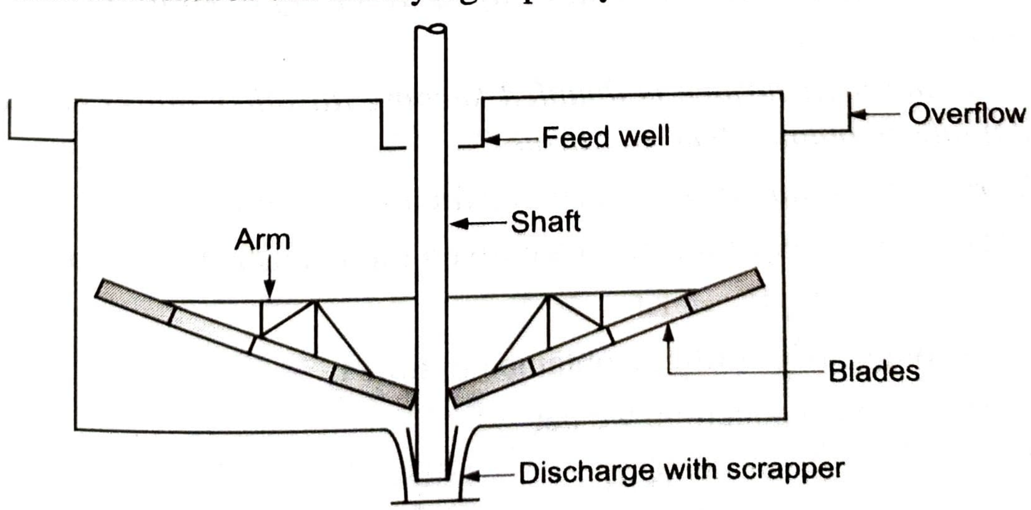

Fig. 5.18 : Dorr thickener

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

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

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