9

Filtration

Filtration may be defined as a process of separation of solids from a fluid by passing the same through a porous medium that retains the solids, but allows the fluid to pass through.

The suspension to be filtered is known as *slurry.* The porous medium used to retain the solids is known as *filter medium.* The accumulated solids on the filter are referred to as *filter cake,* while the clear liquid passing through the filter is *filtrate.*

When solids are present in a very low concentration, i.e., not exceeding 1.0% w/v, the process of its separation from liquid is called *clarification.*

Clarification is generally employed when contaminating material is finely subdivided, amorphous or colloidal in nature. These solids tend to plug the filter medium. Several other processes having similar mechanisms are decolouration, decantation, colation, expression etc.

Process of Filtration

A typical filtration operation is shown in Figure 9-1. The pores of the filter medium are smaller than the size of particles to be separated. Filter medium (for example filter paper or muslin cloth) is placed on a support (a sieve). When slurry (feed) is passed over the filter medium, the fluid flows through the filter medium by virtue of a pressure differential across the filter. Gravity is acting on the liquid column. Therefore, solids are trapped on the surface of the filter medium.

Once the preliminary layer of particles is deposited, further filtration is brought about wherein the filter medium serves only as a support. The filter will work efficiently only after an initial deposit. In an industrial scale, large quantities of suspensions are mechanically handled. After a particular point of time, the resistance offered by the filter cake is high that virtually filtration is stopped. For this reason, a positive pressure is applied on the filter cake (upstream) or negative pressure (suction) is applied below the filter medium (downstream).

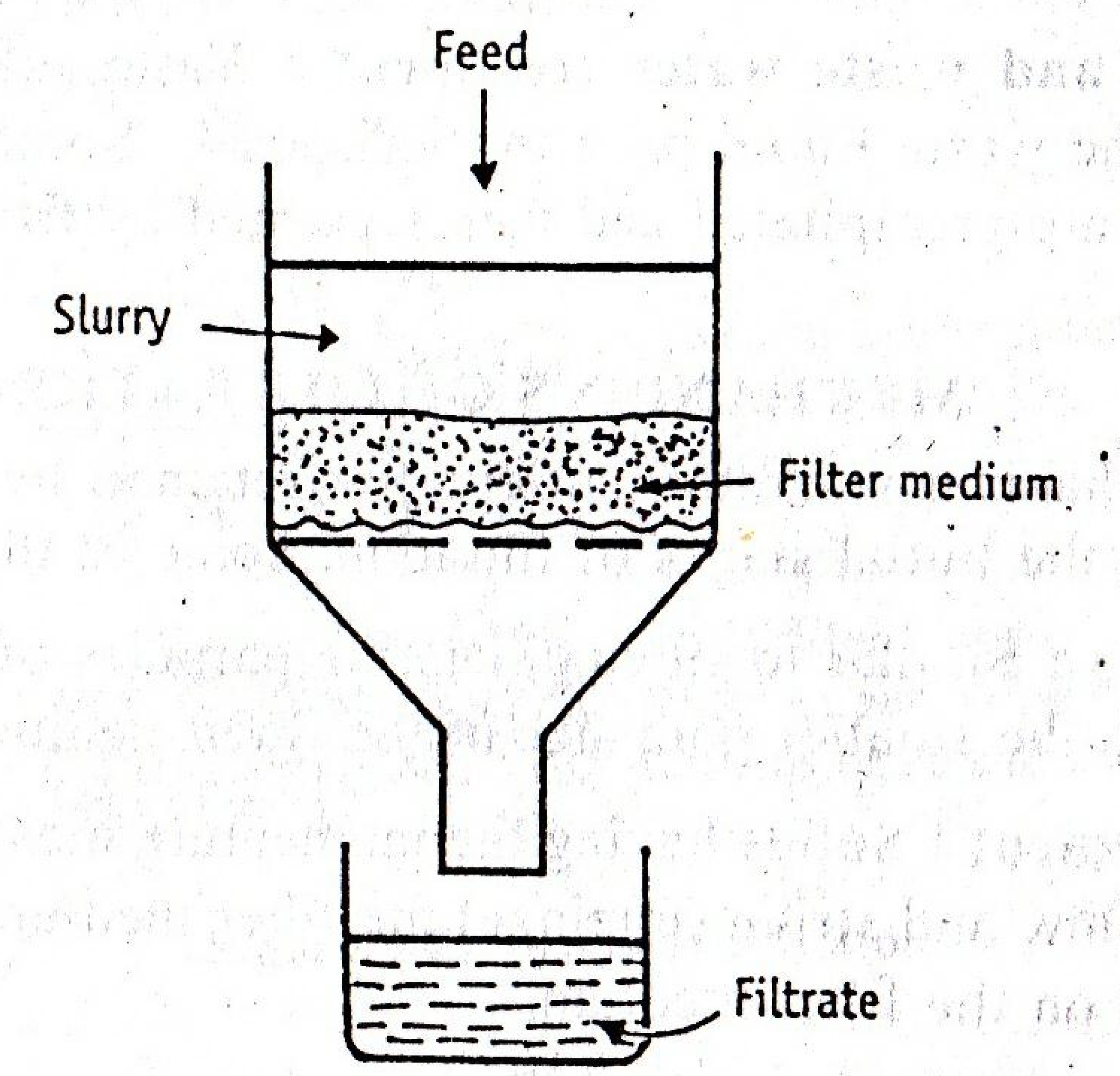


Figure 9-1. Principle of filtration.

Applications

Production of sterile products : Air is filtered through HEPA filters (high efficiency particulate air filters) or laminar air-bench to obtain sterile air, which maintains good environment prior to and during manufacture of sterile products.

A solution is passed through a bacteria proof filter in order to obtain sterile solution, particularly when heat sterilisation is not suitable on account of thermolabile nature of the contents. In case of sterile products, particles as small as 0.2 µm should be removed, which includes the bio-burden of fungi, bacteria etc.

Similar facilities are required for the production of antibiotics by fermentation, recombinant technologies of biological products and vaccines.

Production of bulk drugs : Solids of intermediates and finished products are separated from the reaction mixture by filtration techniques. By this method, impurities can be removed.

Production of liquid oral formulations : Filtration is an essential step in the production of liquid orals for obtaining clear solutions (clarification).

(a) Dewaxing of oils.

(b) Removing suspended oils from aqueous solutions. Examples are aromatic waters, syrups, elixirs, eye drops etc.

(c) Removing of undesirable solids, which interfere with the transparency of the liquids. Examples are honey and fruit juices.

(d) Clarifying the potable water.

Affluent and waste water treatment : Waste solids must be separated from the waste liquid prior to its disposal. Sometimes, the soluble components are precipitated and then separated by filtration.

MECHANISMS OF FILTRATION

The mechanism whereby particles are retained by a filter is significant only in the initial stages of filtration. Some of the mechanisms are:

Straining : Similar to sieving, i.e., the particles of larger size cannot pass through the smaller pore size of the filter medium.

Impingement : Solids having the momentum move along the path of streamline flow and strike (impinge) the filter medium. Thus, the solids are retained on the filter medium.

Entanglement : Particles become entwined (entangled) in the mass of fibres (of cloth with a fine hairy surface or porous felt) due to smaller size of particles than the pore size. Thus the solids are retained on the filter medium.

Attractive forces : Solids are retained on the filter medium as a result of attractive forces between particles and filter medium, as in case of electrostatic precipitation.

In practice, filtration may combine various mechanisms.

Types of Filtration

Based on the mechanism, two types of filtration are broadly identified.

Surface filtration (Screen filtration) : It is a screening action by which pores or holes of the medium prevent the passage of solids.

The mechanisms, straining and impingement are responsible for surface filtration. For this purpose, plates with holes or woven sieves are used (Figure 9-2). Its efficiency is defined in terms of mean or maximum pore size.

Depth filtration : In this process, slurry penetrates to a point where the diameter of solid particles is greater than that of the tortuous void or channel.

Depth filtration is aided by the mechanism entanglement. The solids are retained with a gradient density structure by physical restriction or by adsorption properties of the medium (Figure 9-2). It is extensively used for the removal of small amounts of contaminants from relatively large volumes of liquids (clarification). These are also used for roughing or prefiltering pharmaceutical solutions. Examples are ceramic filters, sintered (bed) filters.

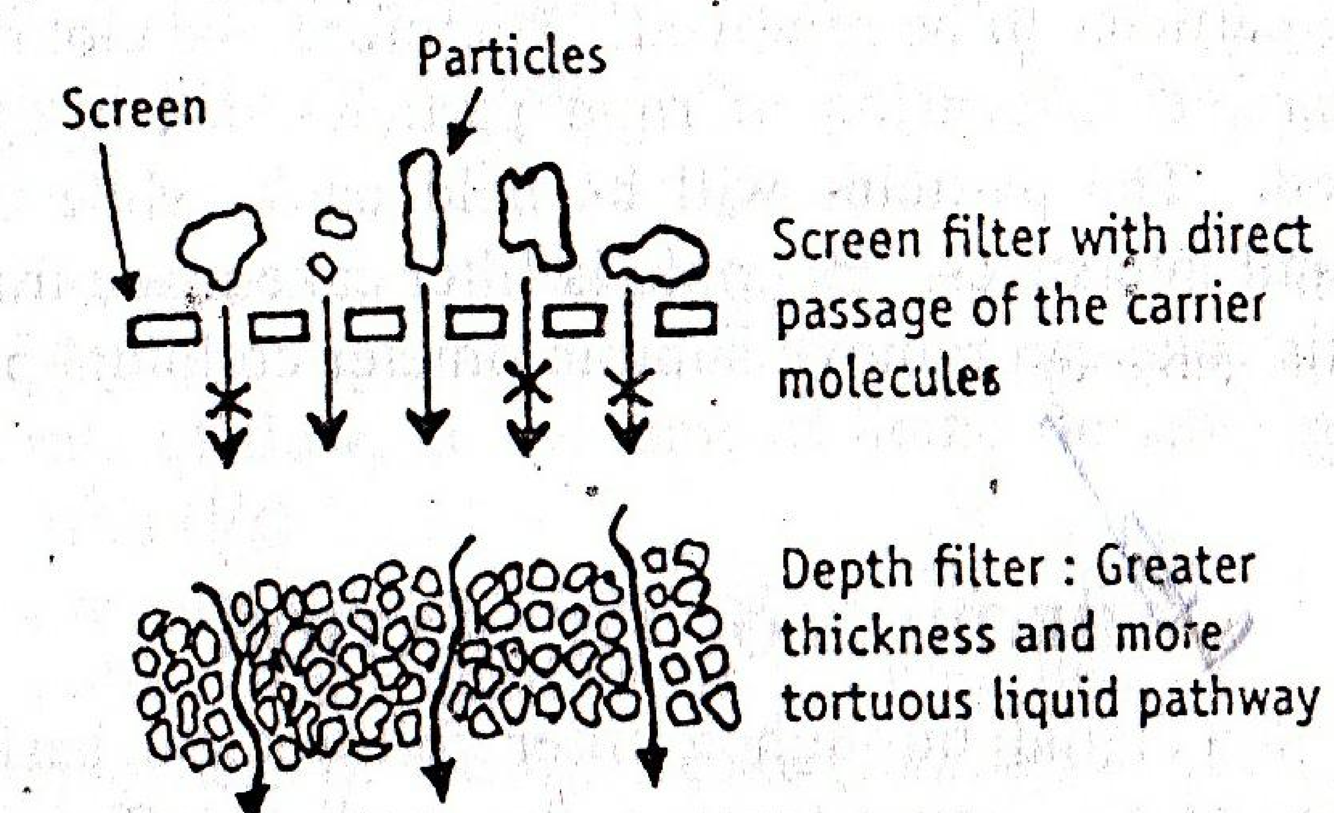


Figure 9-2. Types of filtration.

TABLE 9-1

Differences Between Surface and Depth Filtration

Surface filtration	*Depth filtration*
The size of the particles retained is slightly higher than the mean pore size of the medium.	The size of the particles retained is much smaller than the pores through which fluid passes.
Mechanical strength of the filter medium is less, unless it is made of stainless steel.	Mechanical strength is high.
It has low capacity	It has high capacity
The size of the particles retained is more predictable.	The size of the particles retained is less predictable.
Equipment is expensive because it should require ancillary equipment such as edge clamps, which should be much finer tolerances.	Cheaper because ancillary equipment is not required.
Example is cellulose membrane filter.	Examples are ceramic filters, and sintered (bed) filters.

A special case of depth filtration is the *sheet filtration*, in which the slurry is passed through a series of pads mounted endwise to the flow of fluids. The pads commonly consist of a mixture of asbestos fibres embedded in cellulose.

The differences between surface and depth filtration are given in Table 9-1.

Cake filtration : A filter consists of a coarse woven cloth through which a concentrated suspension of rigid particles is passed so that they bridge the holes and form a bed.

The cloth may be ineffective when the holes are likely to be much larger than the particles to be removed. Therefore, the cloth is presented with a concentrated suspension of rigid particles that bridge the holes and form a bed. The particles will be held back, while liquid passes through the small interstices. Example is filter cake made from diatomite (100 μm). This cake can remove submicrometer colloidal particles with high efficiency.

THEORIES OF FILTRATION

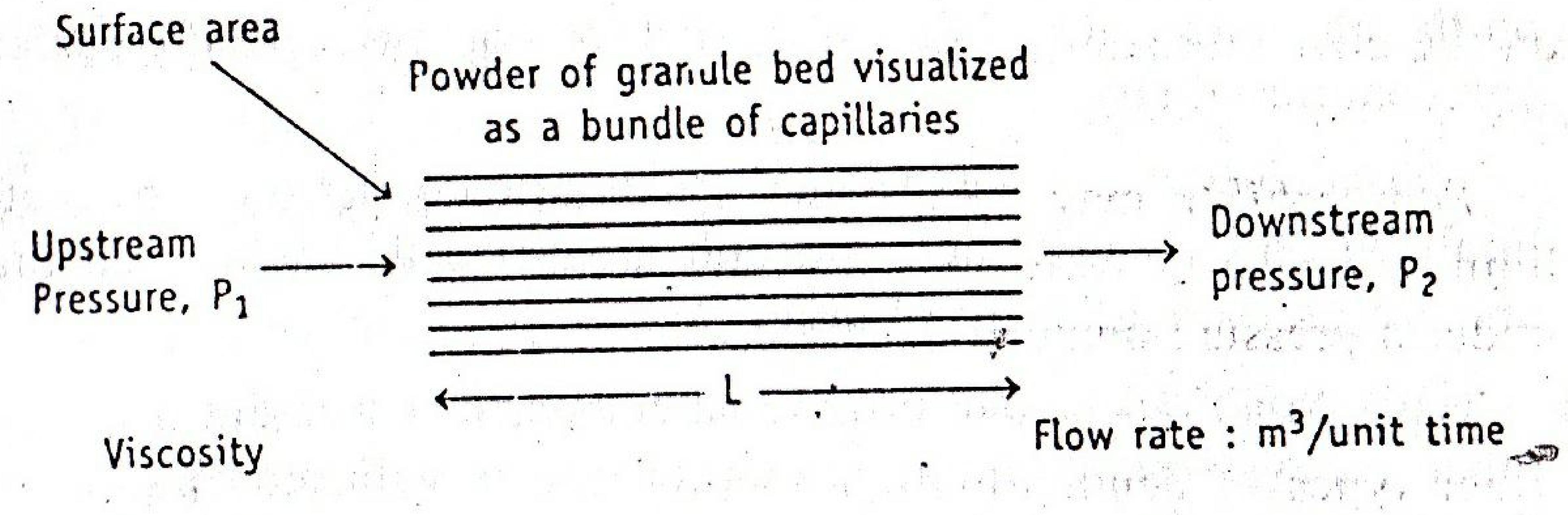
The flow of a liquid through a filter follows the basic rules that govern the flow of any liquid through the medium offering resistance. The rate of flow may be expressed as:

$$Rate = \frac{\text{driving force}}{\text{resistance}} \tag{1}$$

The rate of filtration may be expressed as volume (litres) per unit time (*dv/dt*). The driving force is the pressure differential between the upstream and downstream of the filter. The resistance is not constant. It increases with an increase in the deposition of solids on the filter medium. Therefore filtration is not a steady state.

The rate of flow will be greatest at the beginning of the filtration process, since the resistance is minimum. Once the filter cake is formed, its surface acts as filter medium and solids continuously deposit adding to the thickness of the cake. The resistance to flow is related to several factors as mentioned below.

$$\text{Resistance to movement} = \frac{\text{pressure upstream} - \text{pressure downstream}}{\text{length of capillaries}} \tag{2}$$



Poiseuille's Equation

Poiseuille considered that filtration is similar to the streamline flow of a liquid under pressure through capillaries. Poiseuille's equation is:

$$V = \frac{\pi \Delta P r^4}{8 L \eta} \tag{3}$$

where V = rate of flow, i.e., volume of liquid flowing in unit time, m^3/s (l/s)

ΔP = pressure difference across the filter, Pa

r = radius of the capillary in the filter bed, m

L = thickness of the filter cake (capillary length), m

η = viscosity of the filtrate, Pa·s

If the cake is composed of a bulky mass of particles and the liquid flows through the interstices (correspond to a multiplicity of capillary tubes), then the flow of liquids through these may be expressed by Poiseuille's equation.

Darcy's Equation

Poiseuille's law assumes that the capillaries found in the filter are highly irregular and nonuniform. Therefore, if the length of a capillary is taken as the thickness of the bed, a correction factor for radius is applied so that the rate equation is closely approximated and simplified. The factors influencing the rate of filtration has been incorporated into an equation by Darcy, which is:

$$V = \frac{K A \Delta P}{\eta L} \tag{4}$$

where K = permeability coefficient of the cake, m^2

A = surface area of the porous bed (filter medium), m^2

Other terms are same as shown in equation (3). The term K depends on the characteristics of the cake, such as porosity, specific surface area and compressibility.

Permeability may be defined quantitatively as the flow rate of a liquid of unit viscosity across a unit area of cake having unit thickness under a pressure gradient of unity.

This model relates not only to filter beds or cakes but also applies to other types of depth filter. Equation (4) is valid for liquids flowing through sand, glass beads and various porous media. Darcy's equation is further modified by including characteristics of K by Kozeny-Carman.

Kozeny-Carman Equation

Poiseuille's equation is made applicable to porous bed, based on a capillary type structure by including additional parameters. Thus the resultant equation, which is widely used for filtration is Kozeny-Carman equation.

$$V = \frac{A}{\eta S^2} \cdot \frac{\Delta P}{KL} \cdot \frac{\varepsilon^3}{(1-\varepsilon)^2} \qquad (5)$$

where ε = porosity of the cake (bed)

S = specific surface area of the particles comprising the cake, m^2/m^3

K = Kozeny constant

Other terms are same as shown in equations (3) and (4). The Kozeny constant is usually taken as 5. The effect of compressibility of the cake on flow rate can be appreciated from equation (1), since the flow rate is proportional to $\varepsilon^3/(1-\varepsilon)^2$. A 10 per cent change in porosity can produce almost 3-fold change in V.

Limitations of Kozeny Carman equation : Kozeny Carman equation does not take into account of the fact that the depth of the granular bed is lesser than the actual path traversed by the fluid. The actual path is not straight throughout the bed, but it is sinuous or tortuous.

FACTORS INFLUENCING FILTRATION

A simple straining process does not provide a complete description of how particles are removed from a suspension. The particles are exposed to a number of forces including gravity or electrical fields. Some of the factors influencing the filtration are:

(1) Properties of the liquids—density, viscosity and corrosiveness.

(2) Properties of the solids—particle shape, particle size, particle charge, density, particle size distribution, rigidity or compressibility of the solid under pressure and tendency of particle to flocculate or adhere together.

(3) Proportion of solids in the slurry—rate at which the filter cake is formed, especially in the early stages of the filtration.

(4) Objectives—whether the solids or the liquid or both are to be collected.

(5) Temperature of the suspension.

Surface Area of the Filter Medium

According to equation (5), rate of flow of filtrate flowing through the filter is inversely proportional to the specific surface of the filter bed. On the other hand, if the surface area of the filter medium is considered, the rate of filtration is directly proportional to the surface area of the filter medium (equation 4). Hence, the rate can be increased either using a larger filter or connecting a number of small units in parallel. For example, filter press works on the principle of connecting the units in parallel. Pleating the filter paper or using a pleated funnel increases the effective surface area for filtration.

Pressure Drop Across the Filter Medium

According to equation (5), rate of filtration is directly proportional to the overall pressure drop across filter medium and filter cake. The pressure drop can be achieved in a number of ways:

Gravity : A simple method of obtaining a pressure difference is maintaining a head of slurry above the filter medium. The pressure developed depends on the density of the slurry. As a rough guide, a head of 10 metres of water creates a pressure difference of 100 kilopascals.

Applying pressure : The most common method of obtaining a pressure difference is applying pressure on the surface of the slurry, i.e., pumping the slurry onto the filter.

The pressure difference obtained by this method is greater than that is achieved by reduced pressure. Industrial plant may be operated at pressure up to 1500 kilopascals. However, in the early stages of filtration, pressure difference should be less. This is to prevent the pores of the filter medium from clogging or plugging, which subsequently increases resistance to the flow.

Reducing pressure : The pressure underneath the filter medium may be reduced below atmospheric pressure by connecting the filtrate receiver to a vacuum pump. This creates a pressure differential across the filter. This factor has limited applications, because the pressure difference of about 100 kilopascals may be achieved. Reduction of pressure lowers the boiling point of liquids so that it is possible for the filtrate to boil in the receiver. Apart from the loss of liquid, the vapour may damage the vacuum pump.

Advantage of this method is that it is safe. If a part of the equipment fails, it will collapse and not explode. Therefore, this method is commonly applied in a laboratory, where the apparatus is usually made of glass. However, in the industrial scale, the plant is usually constructed with a metal that is able to withstand high pressure.

Centrifugal force : Centrifugal force could replace the gravitational force and is used to increase the rate of filtration. The principle behind centrifugation is discussed separately in the chapter 10.

Viscosity of Filtrate

According to equation (5), rate of filtration is inversely proportional to the viscosity of the fluid. The viscosity of the liquid, not the slurry is important, since the resistance to flow occurs as the filtrate flows through the filter cake.

Raising the temperature of the liquid, which lowers the viscosity, may increase the rate of filtration. This is not practicable, if thermolabile materials are involved or if filtrate is volatile. Another alternative to decrease the viscosity is to dilute the filtrate. In this case, it is important to ensure that by doubling the volumes, the rate must be more than double, which should indicate the advantage.

In brief, surface area and pressure differences are the two factors, which are applied, in industrial practice. According to equation (5), other factors such as porosity also influences the rate of filtration. These are discussed below with filter aids.

FILTER MEDIA AND FILTER AIDS

Filter Media

The *filter medium* acts as a mechanical support for the filter cake and is also responsible for the collection of solids.

Characteristics : Filter medium should have the following characteristics.

(1) It should have sufficient mechanical strength.

(2) It must be inert, for example, it should not show chemical or physical interaction.

(3) It should not absorb the dissolved material.

(4) It should allow the maximum passage of liquid, while retaining the solids. It means that it must offer low resistance to flow. The resistance offered by the filter medium is not significant in large scale operations and can be neglected.

The magnitude of the resistance of the filter medium will change due to the layers of solids deposited earlier, which may block the pores or may form bridges over the entrances of the channels. Therefore, the pressure should be kept low at the beginning to avoid the plugging of the pores. The usual procedure is to filter at constant rate by increasing the pressure as necessary. When normal working pressure is reached, it is maintained. On continued filtration, the thickness of the cake further builds up and hence the rate of filtration decreases. When the rate is uneconomical, filtration is stopped. The filter cake is removed and filtration is restarted.

Materials : The following materials are used as filter media.

(1) *Woven materials such as felt or cloth.* Woven material is made of wool, cotton, silk, glass, metal or synthetic fibres (rayon, nylon etc.). Synthetic fibres have greater chemical resistance than wool or cotton, which are affected by alkali and acid, respectively. The choice of the fibre depends on the chemical reactivity with the slurry.

(2) *Perforated sheet metal.* For example stainless steel plates have pores which act as channels as in case of metafilter (edge filter).

(3) *Bed of granular solid built up on a supporting medium.* In some processes, a bed of graded solids may be formed to reduce the resistance to the flow. Typical examples of granular solids are gravel, sand, asbestos, paper, pulp and keiselguhr. The choice of solids depends on the size of the solids in the process.

(4) *Prefabricated porous solid unit.* Porous solids prefabricated into a single unit are being increasingly used for its convenience and effectiveness. Sintered glass, sintered metal, earthenware and porous plastics are some of the materials used for the fabrication.

(5) *Membrane filter media.* Cartridge units are economical and available in pore size of 100 μm to even less than 0.2 μm. These can be used either as surface cartridges or depth type cartridges.

(a) *Surface type cartridges* : These are corrugated and resin treated papers. These are used in hydraulic lines. Ceramic cartridges are advantageous in cleaning for reuse by back flushing or firing. Porcelain filter candles are used for sterile filtration.

(b) *Depth type cartridges* : These are made of cotton, asbestos or cellulose. These are disposable items, since cleaning is not feasible.

Filter Aids

Filter aid forms a surface deposit which screens out the solids and also prevents the plugging of the supporting filter medium.

Justification : The object of the filter aid is to prevent the medium from becoming blocked and to form an open, porous cake, hence, reducing the resistance to flow of the filtrate.

(a) Usually, low resistance is offered by the filter medium itself, but as the layers of solid built up the resistance will be increased. The cake may become impervious by blocking of the pore in the medium. Flow rate is inversely proportional to the resistance of the solid cake.

(b) Slimy or gelatinous material and highly compressible substances form impermeable cakes. The filter medium gets plugged and the flow of filtrate stops.

Characteristics : The important characteristics of the filter aids are:

(a) Chemically inert to the liquid being filtered and free from impurities.

(b) Low specific gravity, so that filter aids remain suspended in liquid.

(c) Porous rather than dense, so that pervious cake can be formed.

(d) Recoverable

Disadvantages : The filter aids remove the coloured substances by absorbing them. Sometimes active principles such as alkaloids are adsorbed on the filter aid. Rarely, filter aids are a source of contaminants such as soluble iron salts, which can provoke degradation of sensitive ingredients. Liquid retained in the pores of the filter cake is lost in the manufacturing process.

Examples of filter aids are:

Keiselguhr	Talc	Charcoal	Asbestos
Paper pulp	Bentonite	Fullers earth	

Activated charcoal is used for removal of organic and inorganic impurities. Kieselguhr is a successful filter aid and as little as 0.1 percent can be added to the slurry. The rate of filtration is increased by 5 times or more, at the above concentration, though the slurry contains 20% solids.

Handling of filter aids : Filter aids are mostly used for clarification processes, i.e., where solids are discarded. Different flow rates can be achieved depending on the grade of the aids.

Low flow rate (fine solids)—Fine grade filter aids—mainly intended for clarity.

Fast flow rate (coarse solids)—coarse grade filter aids—acceptable filtrate.

The filter aid can be employed in either one or both ways.

(1) Firstly, a pre-coat is formed over the medium. For this purpose, a suspension of the filter aid is filtered to give a coating up to 0.5 kg per metre square.

(2) Secondly, a small proportion of filter aid (0.1 to 0.5% of total batch weight) is purposely added to the slurry. So the filter cake has a porous structure and filtration can be efficient. The filter aid of 1 to 2 parts per each part of contaminant is mixed in the feed tank. This slurry is recirculated through the filter until a clear filtrate is obtained. Filtration then proceeds to completion. The body mix method minimizes equipment requirements and cross contamination potentials.

CLASSIFICATION OF FILTRATION EQUIPMENT

Equipment are classified based on the application of external force.

(1) *Pressure filters*—Plate and frame filter press and metafilter.

(2) *Vacuum filters*—Filter leaf.

(3) *Centrifugal filters*—These are discussed in the centrifugation chapter

Classification based on the operation of the filtration.

(a) *Continuous filtration*—Discharge and filtrate are separated steadily and uninterrupted.

(b) *Discontinuous filtration*—Discharge of filtered solids is intermittent. Filtrate is removed continuously. The operation should be stopped to collect the solids.

Classification based on the nature of filtration.

(a) *Cake filters*—Remove large amounts of solids (sludge or crystals).
(b) *Clarifying filters*—Remove small amounts of solids.
(c) *Cross-flow filters*—Feed of suspension flows under pressure at a fairly high velocity across the filter medium.

EQUIPMENT

In the bulk drug industry, solid is the desired product. Its size, physical properties and purity are important. These factors should be considered, while selecting the equipment and operating conditions. Some of them are:

Materials related:

(a) Properties of the fluid—viscosity.
(b) Nature of the solids—particle size, shape, size distribution and packing characteristics.
(c) Concentration of solids in suspension.
(d) Quantity of material to be handled.
(e) Whether it is necessary to wash the filtered solids
(f) Whether any form of pretreatment will be helpful

Equipment and process related:

(a) Flow rate.
(b) It should be absolute in the sense, the limit to size of particles passing through the filter should be known.
(c) It should be sterilisable by heat, radiation or gas (examples are ethylene oxide, formaldehyde etc.).
(d) Independently checking the efficiency of filter. It should be economical.

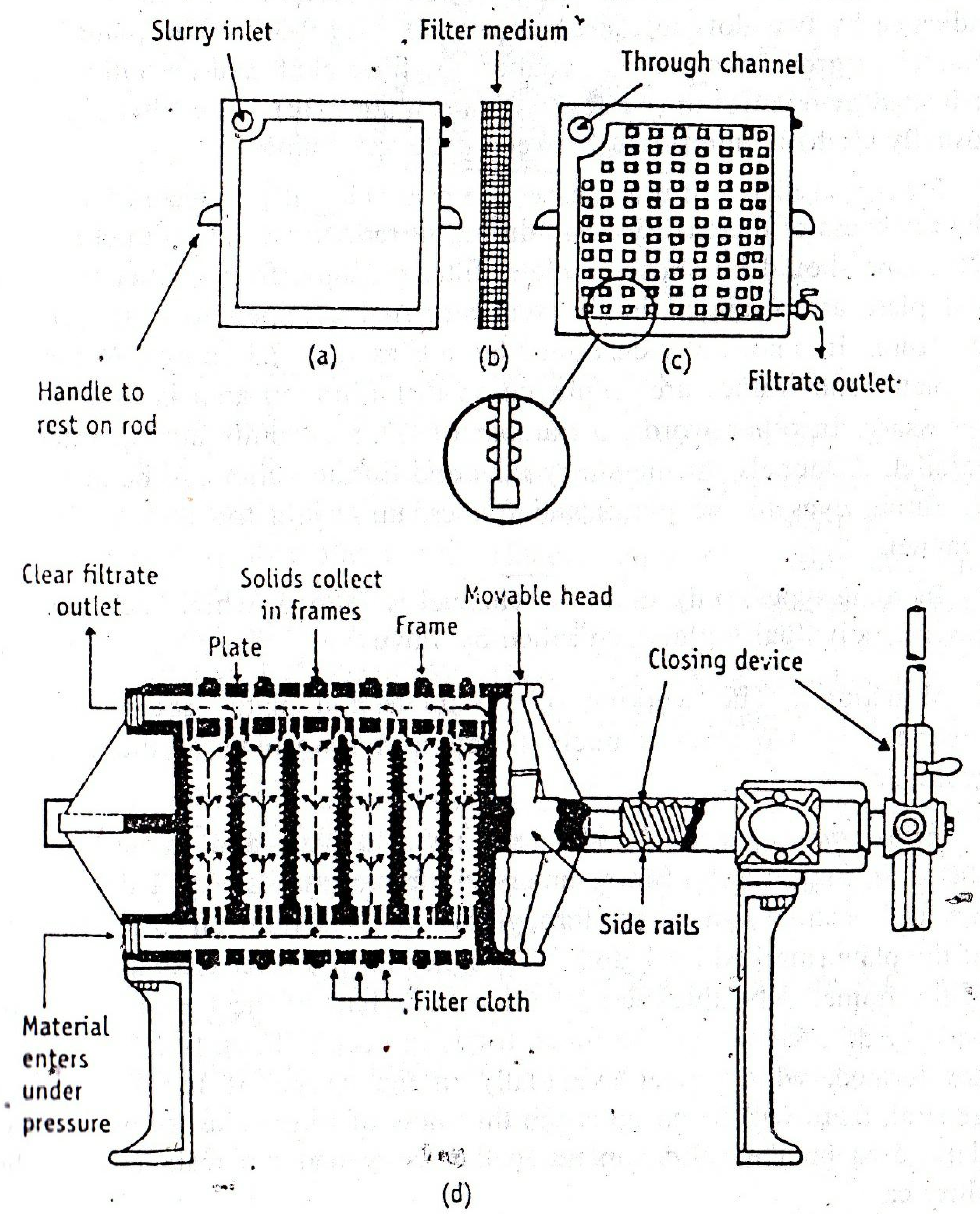
Different forms of equipment are employed for filtration. Some of them are discussed below.

PLATE AND FRAME FILTER PRESS

Principle : The mechanism is surface filtration. The slurry enters the frame by pressure and flows through the filter medium. The filtrate is collected on the plates and sent to the outlet. A number of frames and

plates are used so that surface area increases and consequently large volumes of slurry can be processed simultaneously with or without washing.

Construction : The construction of a plate and frame filter press is shown in Figure 9-3. The filter press is made of two types of units,



(a) Frame—Maintains the slurry reservoir, inlet (eye) for slurry.
(b) Filter medium.
(c) Plate along with section—supports the filter medium, receiving the filtrate and outlet (eye).
(d) Assembly of plate and frame filter press.

Figure 9-3. Plate and frame filter press.

plates and frames. These are usually made of aluminium alloy. Sometimes, these are also lacquered for protection against corrosive chemicals and made suitable for steam sterilisation.

Frame contains an open space inside wherein the slurry reservoir is maintained for filtration and an inlet to receive the slurry. It is indicated by two dots in the description (Figure 9-3a). The plate has a studded or grooved surface to support the filter cloth and an outlet. It is indicated by one dot in the description (Figure 9-3c). The filter medium (usually cloth) is interposed between plate and frame.

Frames of different thicknesses are available. It is selected based on the thickness of the cake formed during filtration. Optimum thickness of the frame should be chosen. Plate, filter medium, frame, filter medium and plate are arranged in the sequence and clamped to a supporting structure. It is normally described by dots as 1.2.1.2.1 so on. A number of plates and frames are employed so that filtration area is as large as necessary. In other words, a number of filtration units are operated in parallel. Channels for the slurry inlet and filtrate outlet can be arranged by fitting eyes to the plates and frames, these join together to form a channel.

In some types, only one inlet channel is formed, while each plate is having individual outlets controlled by valves.

Working : The working of the frame and plate process can be described in two steps, namely filtration and washing of the cake (if desirable).

Filtration operation : The working of a plate and frame press is shown in Figure 9-4. Slurry enters the frame (marked by 2 dots) from the feed channel and passes through the filter medium on to the surface of the plate (marked by 1 dot). The solids form a filter cake and remain in the frame. The thickness of the cake is half of the frame thickness, because on each side of the frame filtration occur. Thus, two filter cakes are formed, which meet eventually in the centre of the frame. In general, there will be an optimum thickness of filter cake for any slurry, depending on the solid content in the slurry and the resistance of the filter cake.

The filtrate drains between the projections on the surface of the plate and escapes from the outlet. As filtration proceeds, the resistance of the cake increases and the filtration rate decreases. At a certain point, it is preferable to stop the process rather than continuing at very low flow rates. The press is emptied and the cycle is restarted.

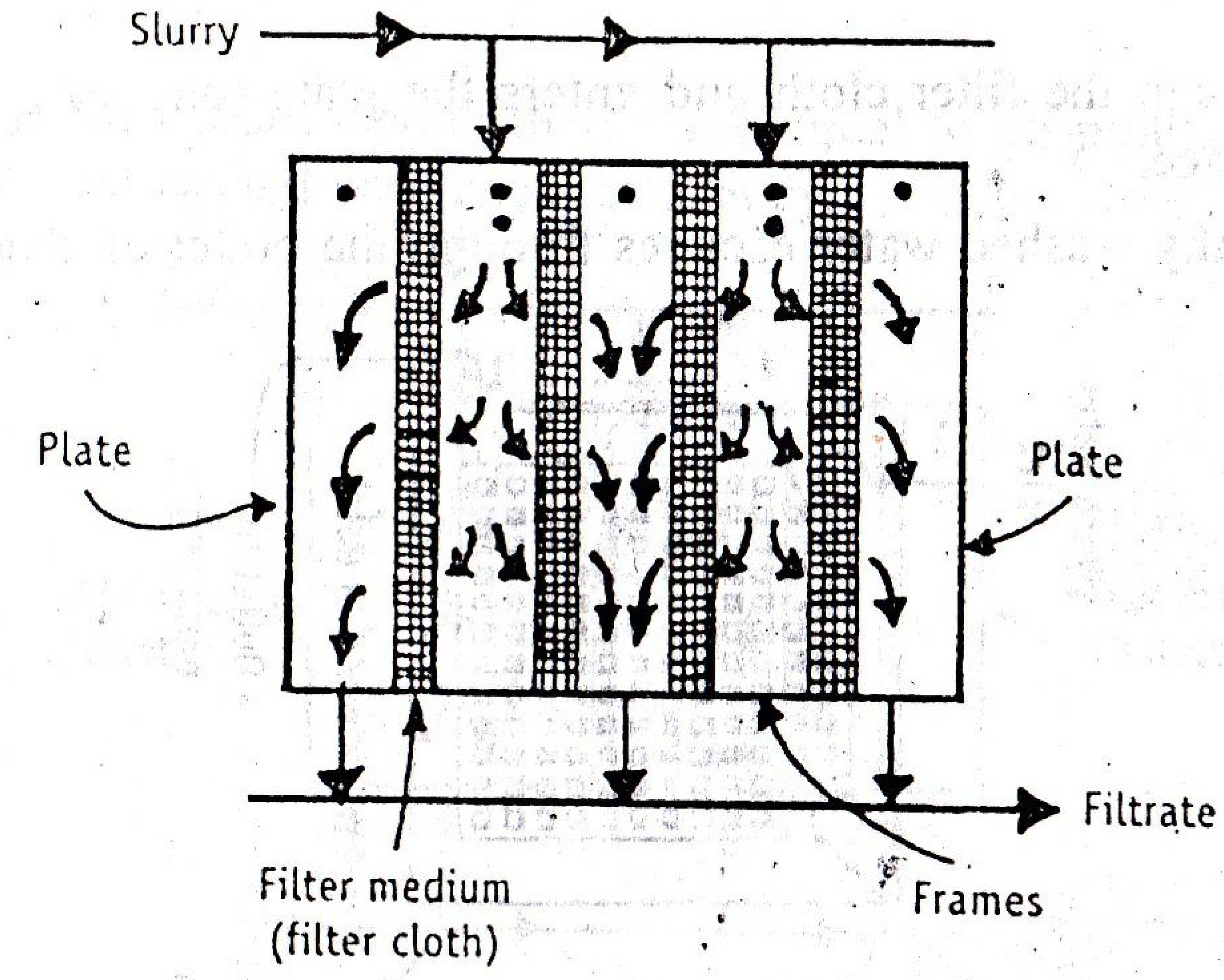


Figure 9-4. Plate and frame filter press, principle of operation (filtering).

Washing operation : If it is necessary to wash the filter cake, the ordinary plate and frame press is unsatisfactory. Two cakes are built up in the frame meeting eventually in the middle. This means that flow is brought virtually to a stand still. Hence, water wash using the same channels of the filtrate is very inefficient, if not impossible. A modification of the plate and frame press is used. For this purpose, an additional channel is included (Figure 9-5). These wash plates are identified by three dots. In half the wash plate, there is a connection from the wash water channel to the surface of the plate.

The sequence of arrangement of plates and frames can be represented by dots as 1.2.3.2.1.2.3.2.1.2.3.2.1 so on (between 1 and 1, 2.3.2 must be arranged). Such an arrangement is shown in Figure 9-6 (a) and (b) for the operations of filtration and water washing, respectively.

The procedure for washing the press is shown in Figure 9-6. The steps are as follows.

(1) Filtration proceeds in the ordinary way until the frames are filled with cake.

(2) To wash the filter cake, the outlets of the washing plates (three dots) are closed.

(3) Wash water is pumped into the washing channel. The water enters through the inlets on to the surface of the washing (three dots) plates.

(4) Water passes through the filter cloth and enters frame (two dots) which contains the cake. Then water washes the cake, passes

through the filter cloth and enters the plate (one dot) down the surface.

(5) Finally washed water escapes through the outlet of that plate.

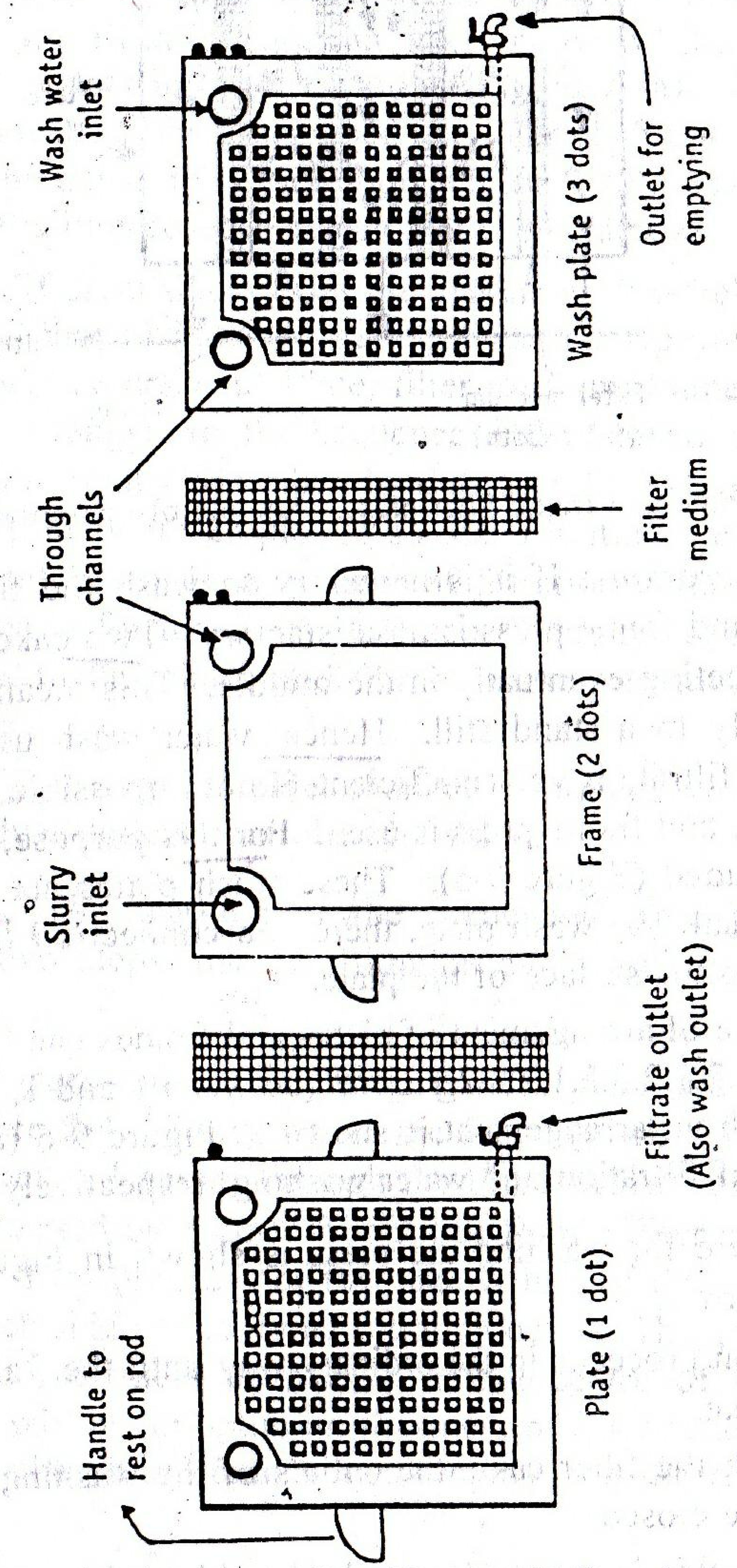
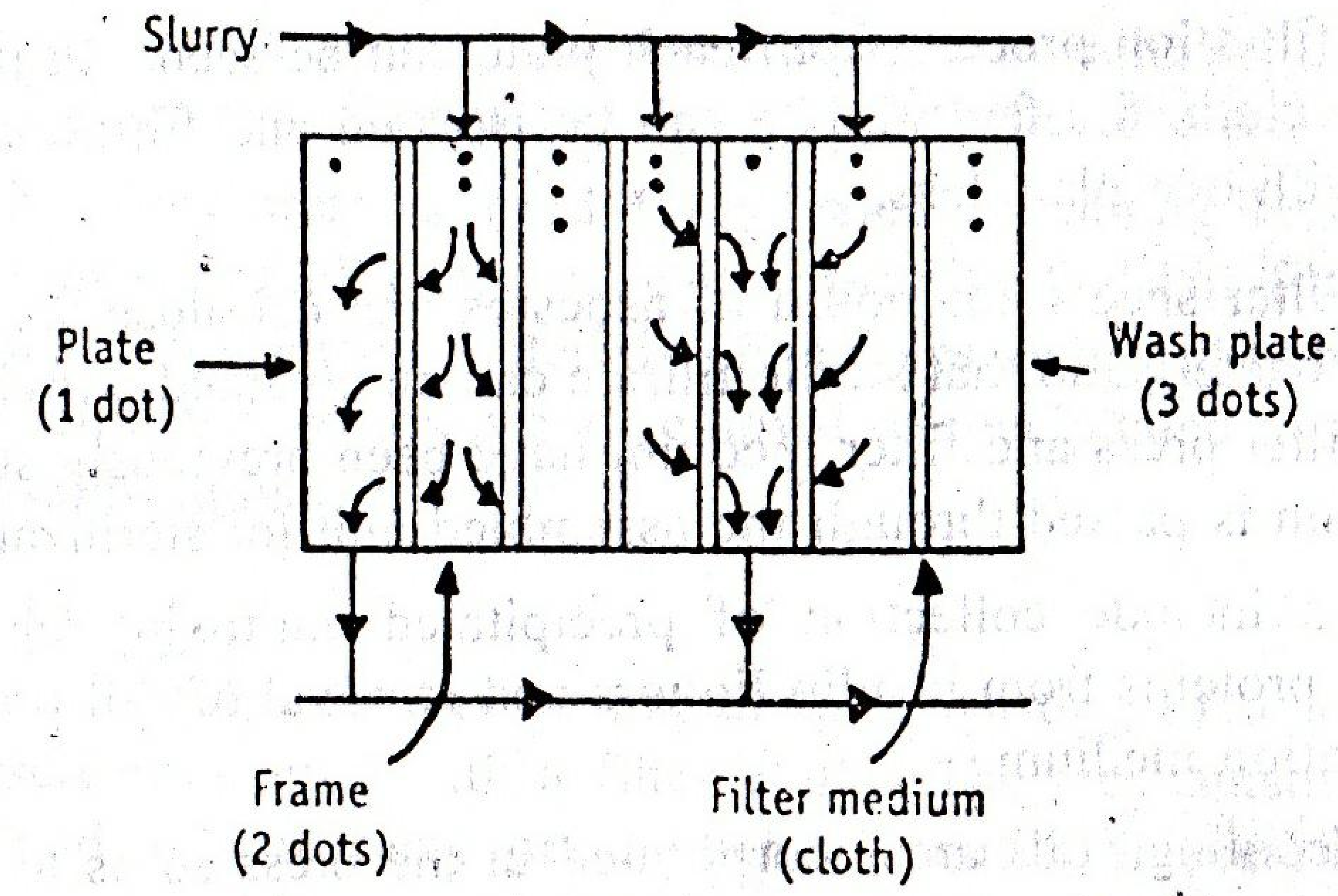


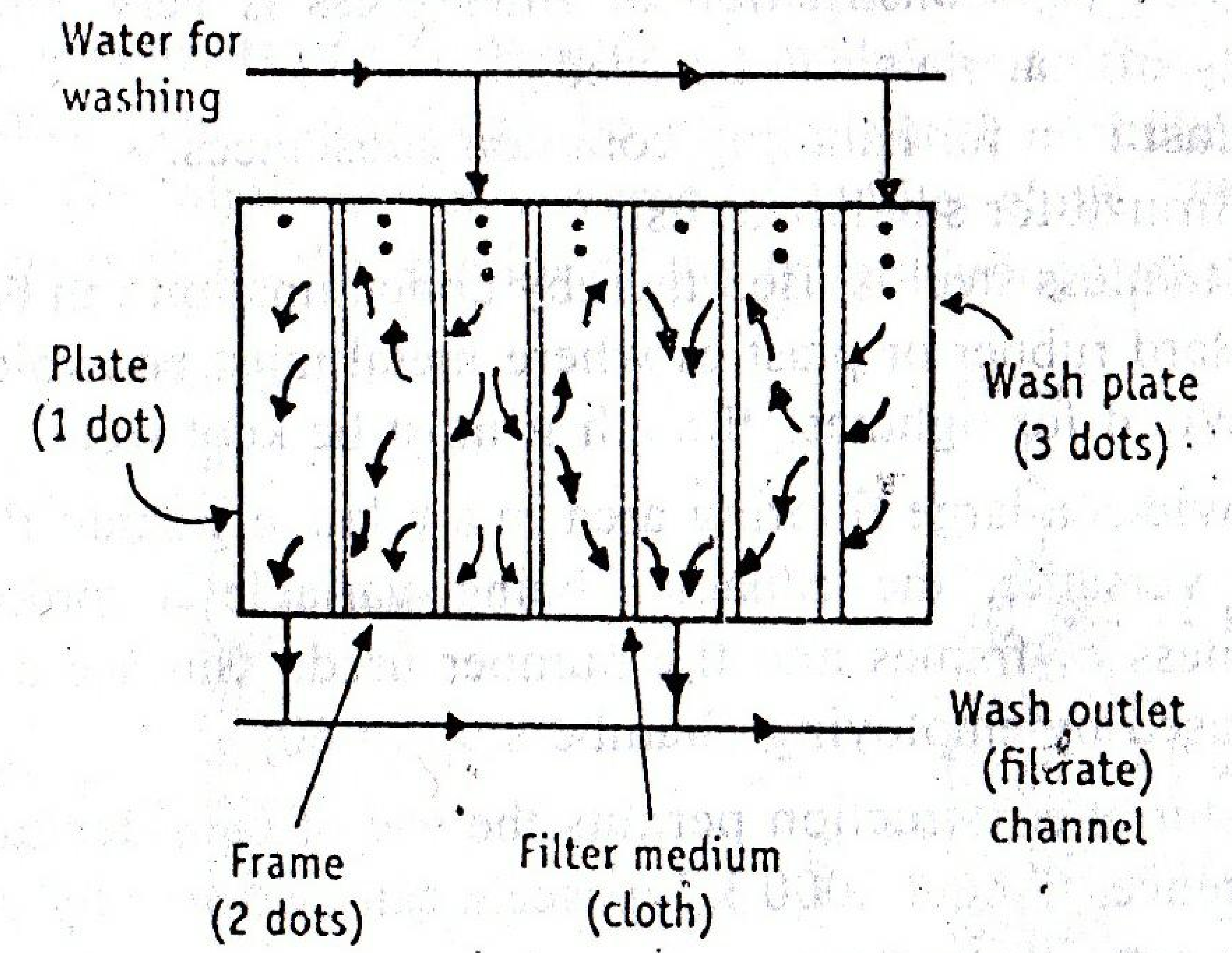
Figure 9-5. Plate and frame filter press with water wash facility.

Thus with the help of special washing plates, it is possible for the wash-water to flow over the entire surface of washing (three dots) plate,

so that the flow resistance of the cake is equal to all points. Hence, the entire cake is washed with equal efficiency.



(a) Principles of filtration operation using the three types of plate and frame.



(b) Principles of cake washing using three types of plate and frame.

Figure 9-6. Plate and frame filter press. Principles of filtration and washing.

It should be noted that water-wash is efficient only if the frames are full with filter cake. If the solids do not fill the frame completely, the wash water causes the cake to break (on the washing plate side of the frame), then washing will be less effective. Hence, it is essential to allow the frames become completely filled with the cake. This helps not only in emptying the frames but also helps in washing the cake correctly.

Special provisions : (1) Any possible contamination can be observed by passing the filtrate through a glass tube or sight glass from the outlet on each plate. This permits the inspection of quality of the filtrate. The filtrate goes through the control valve to an outlet channel.

(2) The filtration process from each plate can be seen. In the event of a broken cloth, the faulty plate can be isolated and filtration can be continued with one plate less.

Uses : Filter sheets composed of asbestos and cellulose are capable of retaining bacteria, so that sterile filtrate can be obtained, provided that the whole filter press and filter medium have been previously sterilized. Usually steam is passed through the assembled unit for sterilization.

Examples include collection of precipitated antitoxin, removal of precipitated proteins from insulin liquors and removal of cell broth from the fermentation medium.

Heating/cooling coils are incorporated in the press so as to make it suitable for the filtration of viscous liquids.

Advantages : (1) Construction of filter press is very simple and a variety of materials can be used.
- Cast iron for handling common substances.
- Bronze for smaller units.
- Stainless steel is used thereby contamination can be avoided.
- Hard rubber or plastics where metal must be avoided.
- Wood for lightness though it must be kept wet.

(2) It provides a large filtering area in a relatively small floor space. It is versatile, the capacity being variable according to the thickness of frames and the number used. Surface area can be increased by employing chambers up to 60.

(3) The sturdy construction permits the use of considerable pressure difference. About 2000 kilopascals can be normally used.

(4) Efficient washing of the cake is possible.

(5) Operation and maintenance is straight forward, because there are no moving parts, filter cloths are easily renewable. Since all joints are external, a plate can be disconnected if any leaks are visible. Thus contamination of the filtrate can be avoided.

(6) It produces dry cake in the form of slab.

Disadvantages : (1) It is a batch filter, so there is a good deal of 'down-time', which is non-productive.

(2) The filter press is an expensive filter. The emptying time, the labour involved and the wear and tear of the cloth resulting in high costs.

(3) Operation is critical, as the frames should be full, otherwise washing is inefficient and the cake is difficult to remove.

(4) The filter press is used for slurries containing less than 5% solids. So high costs make it imperative that this filter press is used for expensive materials. Examples include the collection of precipitated antitoxin and removal of precipitated proteins from insulin liquors.

FILTER LEAF

Principle : Filter leaf is an apparatus consisting of a longitudinal drainage screen covered with a filter cloth. The mechanism is surface filtration and acts as sieve or strainer. Vacuum or pressure can be applied to increase the rate of filtration.

Construction : The general arrangement of a filter leaf is shown in Figure 9-7. It consists of a narrow frame enclosing a drainage screen or grooved plate. The frame may be of any shape, circular, square or rectangular. The whole unit is covered with filter cloth. The outlet for the filtrate connects to the interior of the frame through suction.

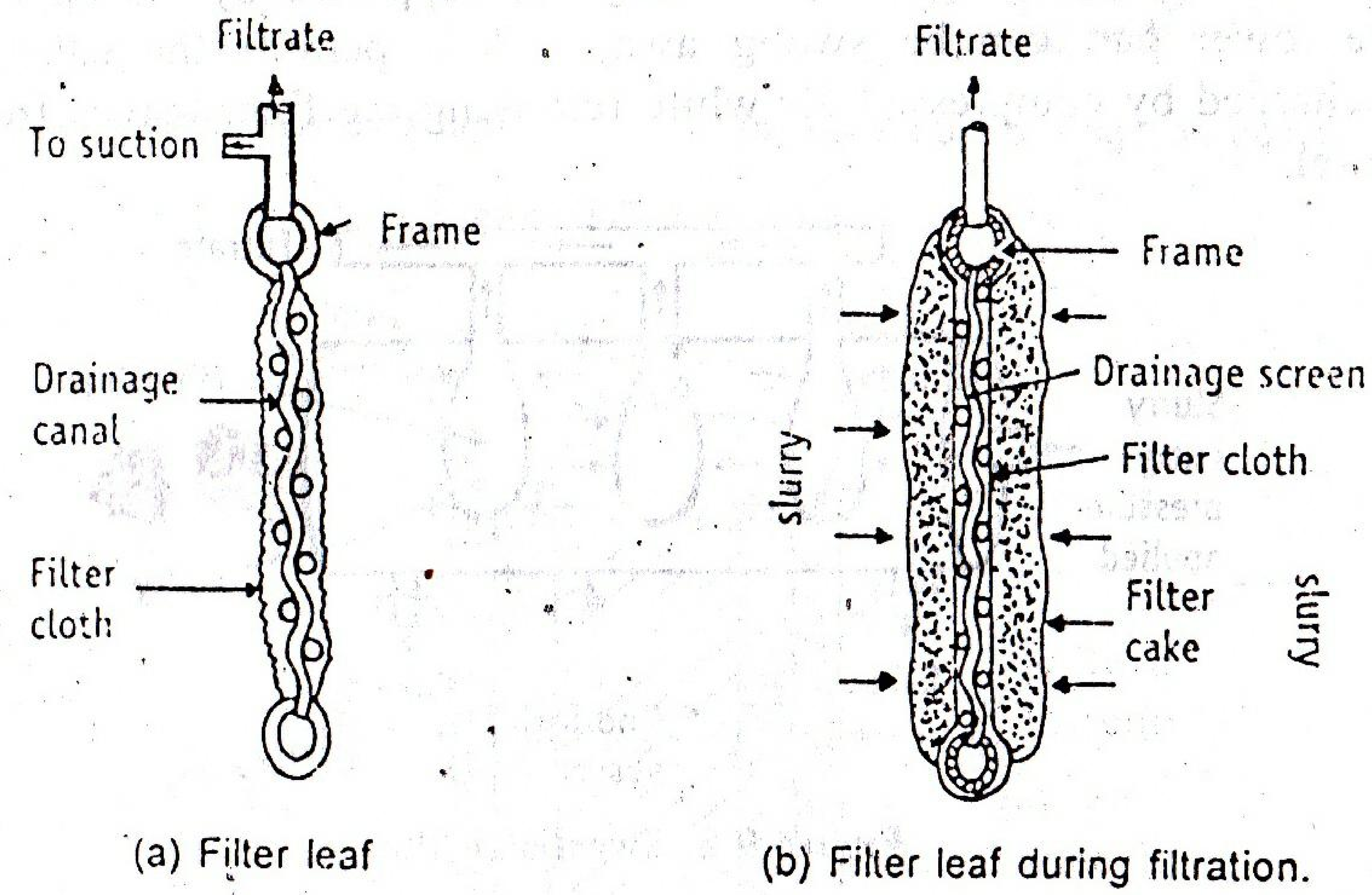


Figure 9-7. Assembly of filter leaf.

Working : The filter leaf is immersed in the slurry. Vacuum system is connected to the filtrate outlet. The slurry passes through the filter cloth. Finally filtrate enters the drainage canal and goes through the outlet into the receiver. Air is passed to flow in reverse direction which facilitates removal of cake.

Uses : The filter leaf is satisfactory, if the solid content of the slurry is not too high, about 5%, i.e., dilute suspensions.

Advantages : (1) Filter leaf is a versatile piece of equipment. Filter leaf is probably the simplest form of filter used for batch processes.

(2) A number of units can be connected in parallel to increase the surface area for filtration.

(3) Pressure difference can be obtained either with vacuum or using pressure up to the order of 800 kilopascals.

(4) Labour costs for operating the filter leaf are fairly moderate.

(5) The efficiency of washing is high.

(6) Slurry can be filtered from any vessel. Simply immersing the filter in a vessel of water can wash the cake.

Variants : *Sweetland filter* : A variation is to enclose the filter leaf in a special vessel into which the slurry is pumped under pressure. In this form, a number of leaves are connected to a common outlet to provide a large area for filtration. A typical example of this kind is the Sweetland filter shown in Figure 10-8. The vessel is cylindrical and filter leaves are arranged so that they are supported by the upper part. The lower part can be swung away. This permits the cake to be discharged by compressed air while removing the filter leaves from the vessel.

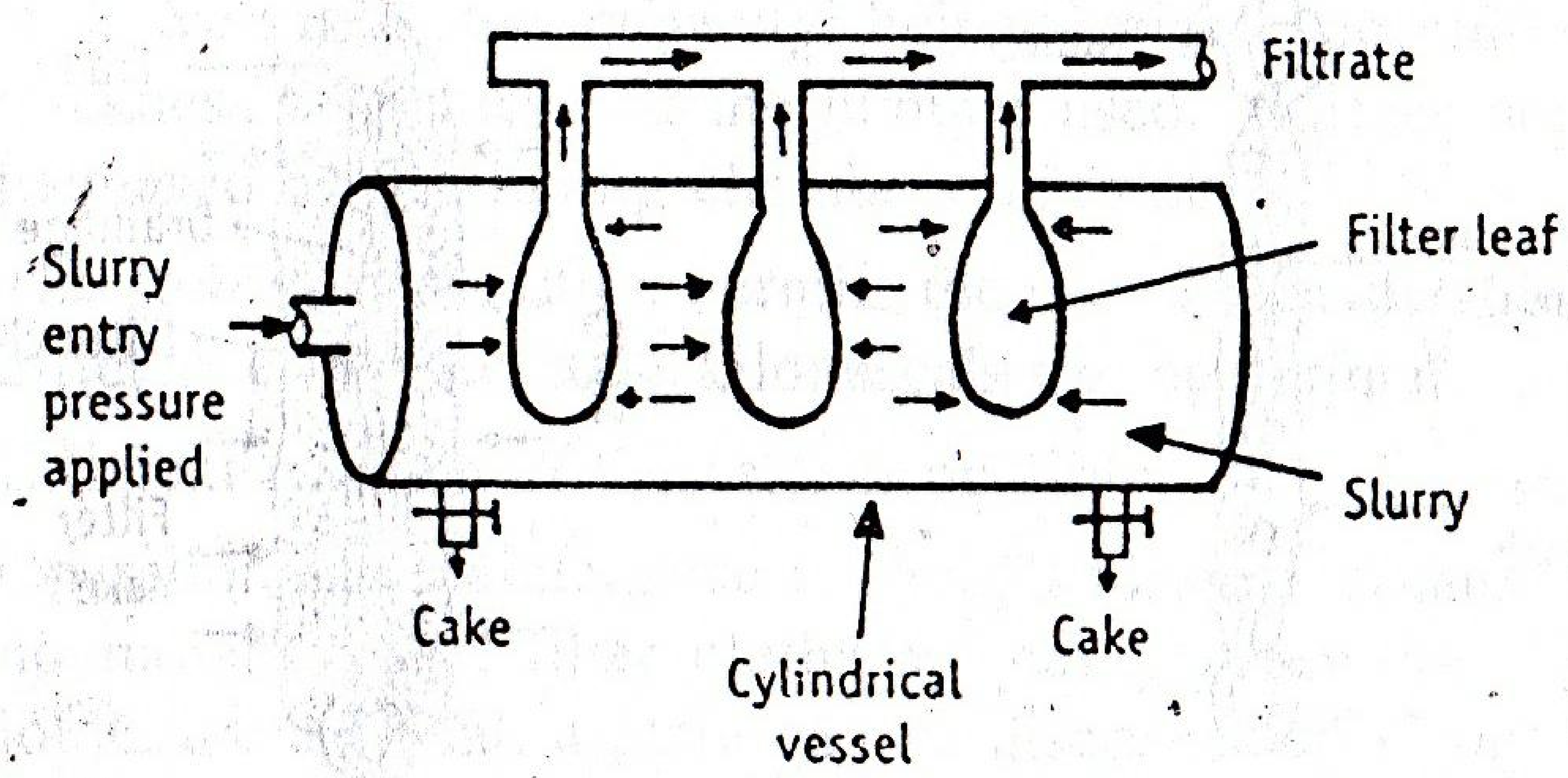


Figure 9-8. Sweetland filter

METAFILTER

Principle : Metafilter functions as a strainer (surface filtration) for the separation of particles. In this method, metal rings contain semicircular projections, which are arranged as a nest to form channels on the edges.

This channel offers resistance (strainer) to the flow of solids (coarse particles). The clear liquid is collected into a receiver from the top.

Construction : The construction and assembly of a metafilter is shown in Figure 9-9. The metafilter consists of a series of metal rings. These are threaded so that a channel is formed on the edges. It contains a grooved drainage column on which a series of metal rings are packed. These rings are usually made of stainless steel and have dimensions of about 15.0 millimetres internal diameter and 22.0 millimetres external diameter.

Each metal ring has a number of semicircular projections (0.8 millimetres in thickness) on one side of the surface as shown in Figure 9-9a. The projections are arranged the same way up. These rings are tightened

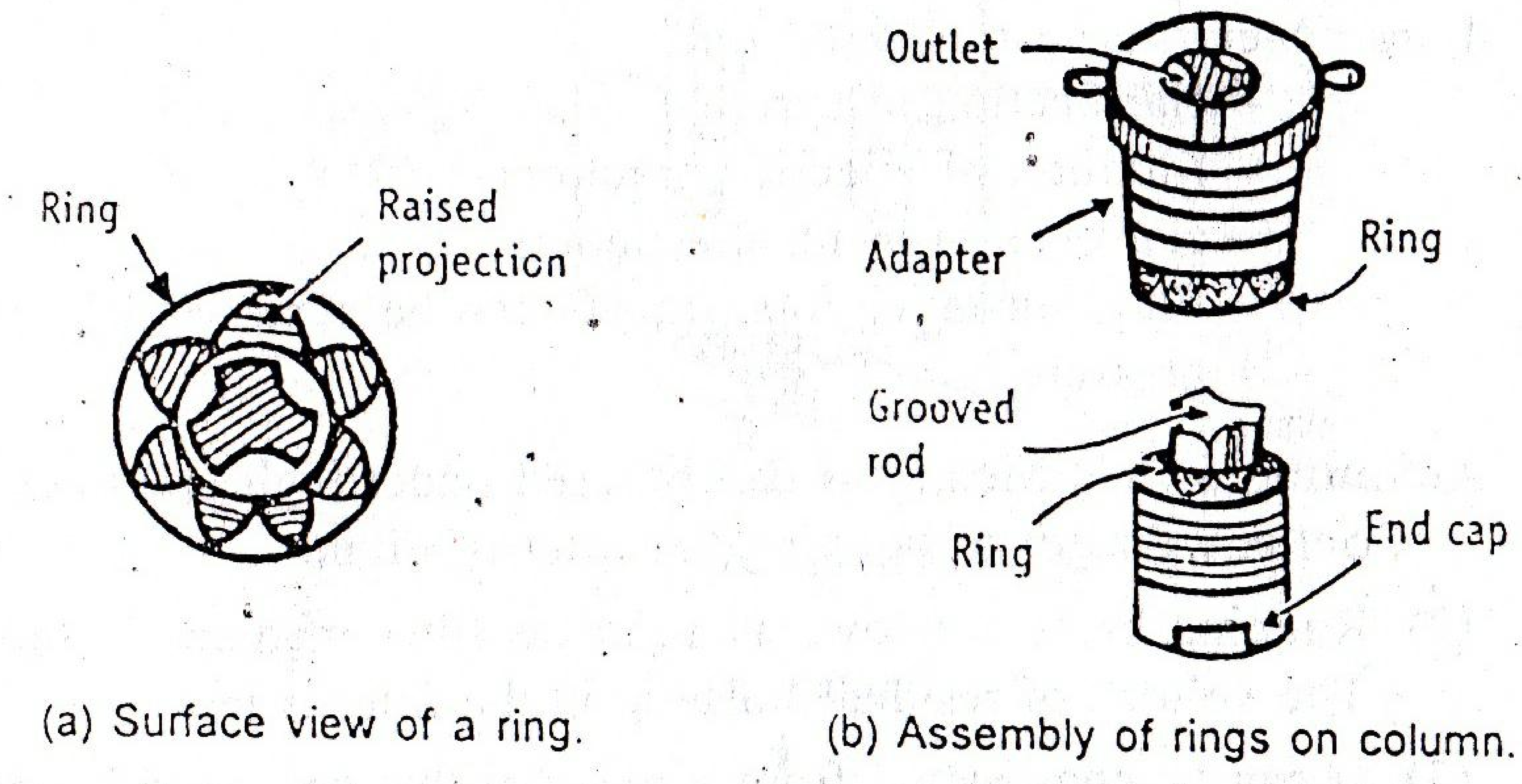


Figure 9-9. Metafilter.

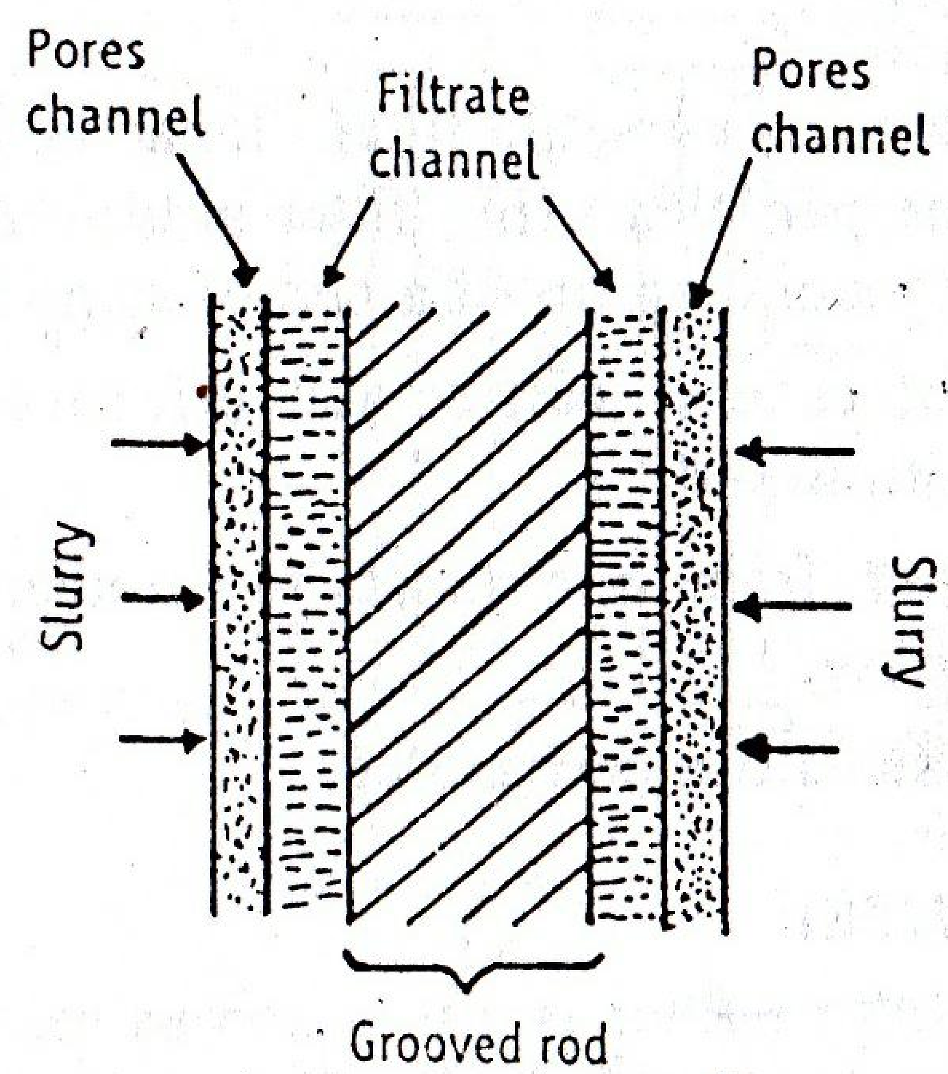


Figure 9-10. Mechanism of filtration through metafilter.

on the drainage column with a nut. Therefore, metafilter is also known as *edge filters*.

Working : The working principle of a metafilter is shown in Figure 9-10. These filters are placed in a vessel and may be operated by pumping the slurry under pressure or occasionally by the application of reduced pressure to the outlet side. The slurry passes through the channels formed on the edges between the rings. The clear liquid rises up and collected from the outlet into the receiver. Metafilter functions as a strainer (surface filtration).

For the separation of fine particles, a bed of suitable material such as kieselguhr is first built up. The pack of rings serves essentially as a base on which the true filter medium is supported.

Uses : Metafilter can be used for:

- clarification of syrups
- filtration of injection solutions
- clarification of insulin liquors
- filtration of viscous liquids can be achieved by applying pressure.

Advantages : (1) Metafilter can be used under high pressures, without any danger of bursting the filter medium.

(2) Running costs are low, as separate filter medium is not used. The volume of residual hold-up in the filter is less.

(3) It can be constructed from a material that can provide excellent resistance to corrosion and avoid contamination of sensitive products.

(4) It is an extremely versatile filter. It can be used for the filtration of very fine particles using filter aids. Large particles can be separated by building up of a bed of same particles.

(5) Removal of cake is carried out effectively, by simply back-flushing with water.

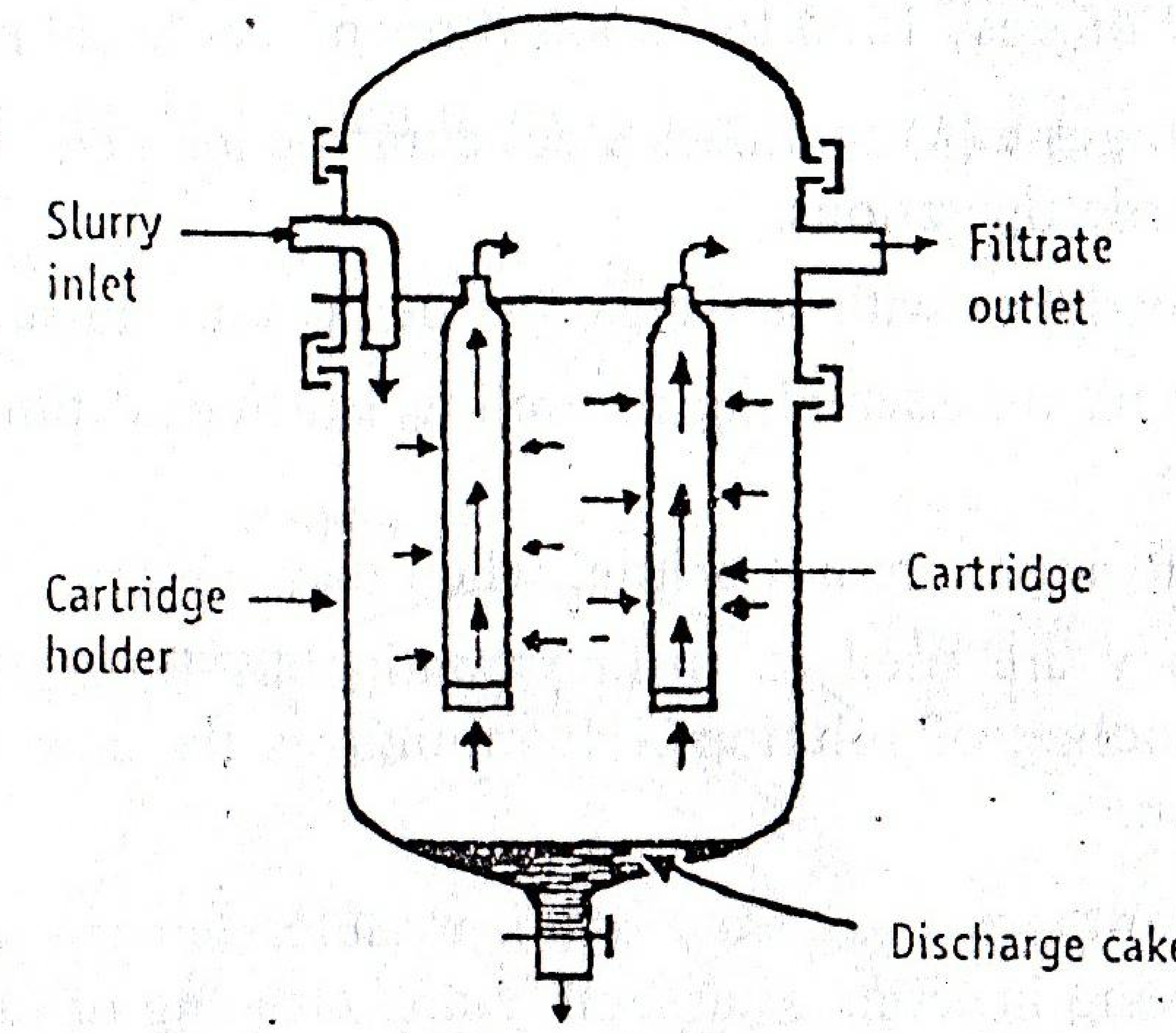
(6) Change over from one batch to another or one product to another is easy.

(7) Sterile products can be handled.

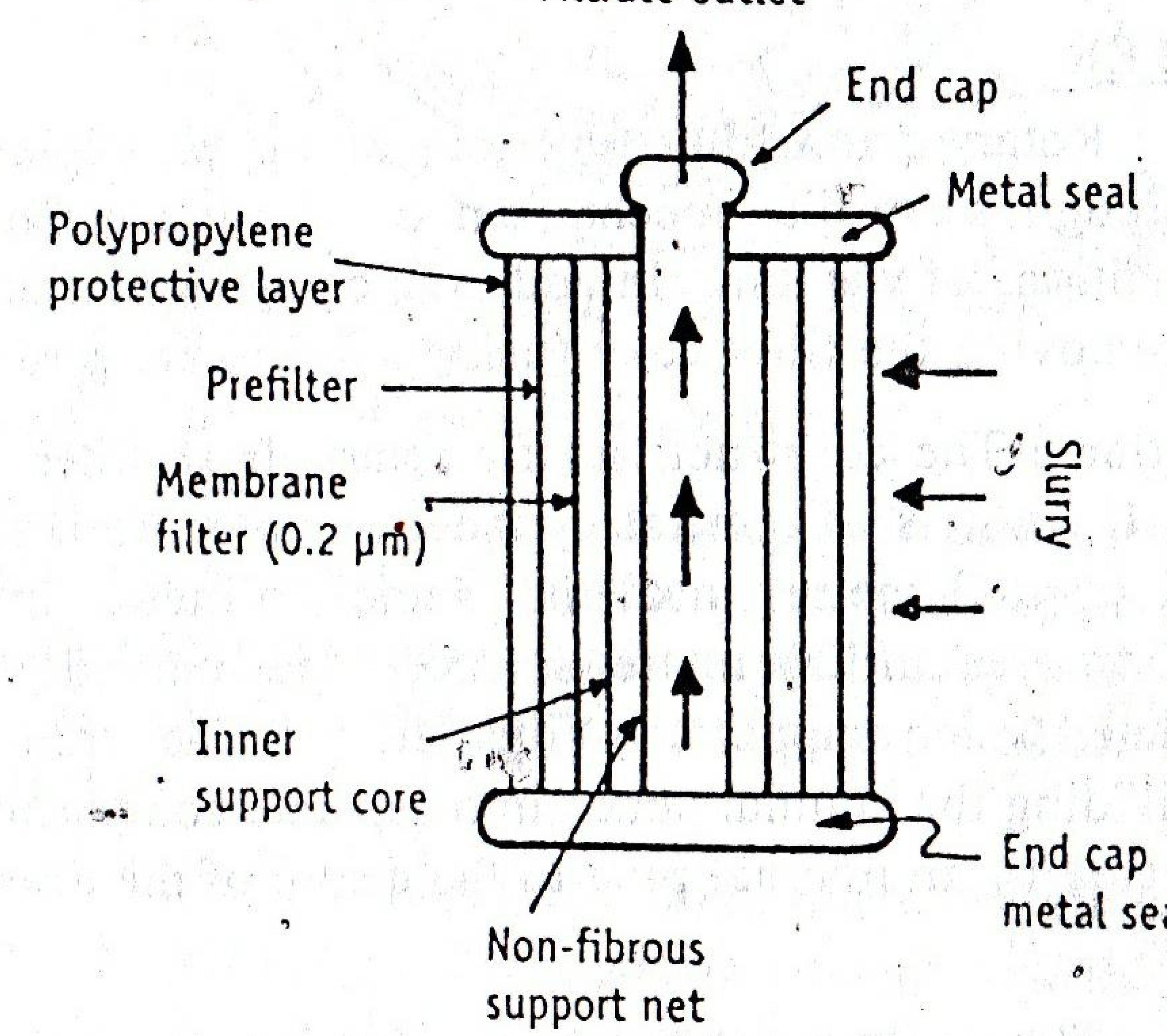
CARTRIDGE FILTER

Principle : Cartridge filter is a thin porous membrane in which pre-filter and membrane filter are combined into a single unit. The filtration action is mainly sieve-like and the particles are retained on the surface.

Construction : The construction of a cartridge filter is shown in Figure 9-11a. Cartridge filter has a cylindrical configuration made with disposable or changeable filter media. These are made of either plastic or metal. It consists two membrane filters (sieve-like) made of polypropylene: a prefilter and an actual filter for filtration. A protective layer surrounds them. The cartridges are housed in a holder. A number of cartridges



(a) Filter assembly.



(b) Cartridge filter unit.

Figure 9-11. Cartridge filter.

can be placed in the same housing. The housing is closed with a lid. The housing has provisions for slurry inlet and filtrate outlet.

Working : The slurry is pumped into the cartridge holder. It passes through cartridge filter unit by the mechanism of straining. The clear liquid passes to the centre and moves up to collect through the outlet.

Uses : Cartridge filter is particularly useful for the preparation of particulate free solutions for parenteral and ophthalmic uses. This filter holder will process 1000 to 15000 litres of sterile solution per hour.

Advantages : (1) Stainless steel construction permits autoclaving for sterile operations.

(2) Cartridges with self-cleaning devices are advantageous.

(3) Rapid disassembling as well as reusing of filter media is possible.

(4) Cartridges are not brittle, when they are dry.

(5) They are used as in-line continuous filtration, which reduces handling of solutions. It minimizes the chances of contamination.

Disadvantages : (1) Cost of disposable elements offsets the labour saving in terms of assembly and cleaning of cartridge clarifier.

(2) A number of manufacturers provide the components, which are generally not interchangeable between suppliers.

DRUM FILTER

Principle : Rotary drum filter functions on the principle of filtering the slurry through sieve-like mechanism on a rotating drum surface, under the conditions of vacuum. In addition, compression, drying (using hot air) and removing the filter cake (using a knife) are possible.

Construction : The construction of a rotary drum filter is shown in Figure 9-12. It consists of a metal cylinder mounted horizontally. The drum may be up to 3 metres in diameter and 3.5 metres in length and gives a surface area of 20 metre square. The curved surface is a perforated plate, which supports a filter cloth. The drum is radially partitioned dividing the annular space into separate compartments. Each of it is connected by an internal pipe to the centre of the drum through a rotating valve.

Working : The drum is rotated at a speed less than one revolution per minute. The drum just enters the slurry in the trough (Figure 9-12).

As it dips, vacuum is applied in this segment so that the solid is build up on the surface. The liquid passes through the filter cloth into an internal pipe and valve. Finally the filtrate reaches the collecting tank.

As the drum leaves the slurry section, it enters the drainage zone. Here excess of the liquid is drawn inside. Special cake compression rollers may be included at this stage, so that the cake is consolidated by the compression of the cake. This improves the efficiency of washing and drying process.

- Vacuum is applied to carry the slurry along with the drum
- Drainage zone
- Water washing arrangement
- Drying zone - dry air supply
- Cake removal zone

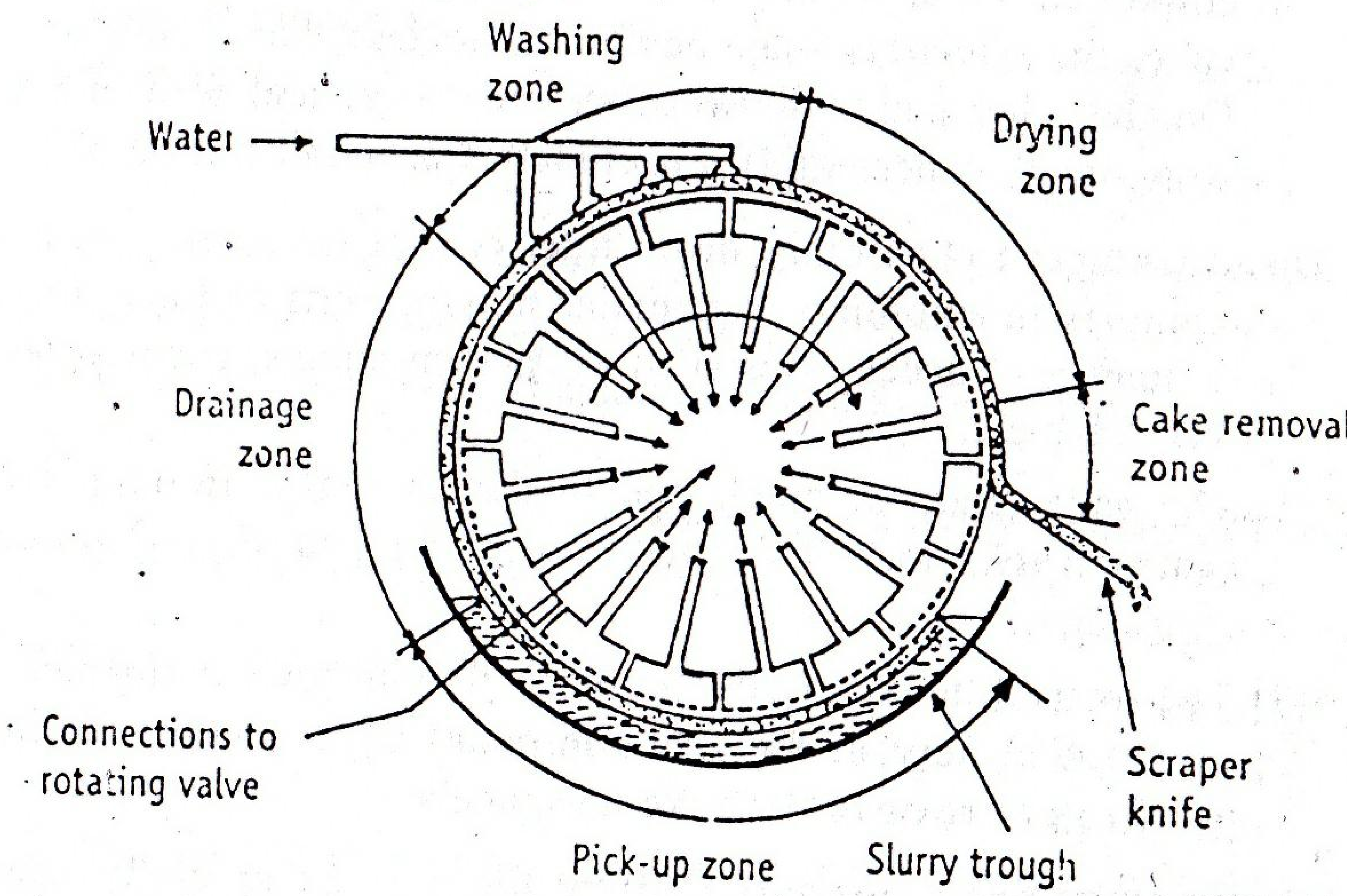


Figure 9-12. Drum filter.

As the drum leaves the drainage zone, it enters the water wash section. Water is sprayed on the cake. A separate system of vacuum is applied on the panel in order to suck the wash liquid and air through the cake of solids. Wash liquid is drawn through the filter into a separate collecting tank.

Then the cake enters the drying zone, where hot air is blown on the cake. The cake may have the moisture content less than one percent. Finally the cake is removed using a doctor knife and discharged.

All these steps are completed in one rotation of the drum. Now the drum is ready to receive a fresh lot of slurry.

Uses : Drum filter is used for continuous operation and is utilised to filter slurries containing high proportion of solids up to 15 to 30 percent. In the production of penicillins, the extract is separated from mycelium (cell mass) by drum filters. These are used for collecting calcium carbonate, starch and magnesium carbonate.

Advantages : (1) Cake is removed simultaneously during operation. Therefore, suitable for use with concentrated slurries.

(2) The labour costs are very low on account of automatic and continuous operation of the rotary filter.

(3) The filter has large surface area.

(4) The speed of rotation can be varied and the cake thickness can be controlled. For example; if the solids form an impenetrable cake, the thickness may be limited to less than 5 millimetres. On the other hand, if the solids are coarse and form a porous cake, the thickness of 100 millimetres or more, can be obtained.

Disadvantages : (1) Rotary drum filter is expensive equipment with complex functioning. It contains moving parts and also requires a number of accessories such as vacuum pumps, vacuum receivers, traps etc.

(2) The cake tends to crack due to the air drawn through by the vacuum system. This makes washing and drying processes inefficient.

(3) The rotary filter is suitable only for straightforward slurries. It is less satisfactory, if the solids form an impermeable cake or it is difficult to remove the cake adequately.

Variants : *String discharge rotary filter*: It is especially used for filtering the fermentation liquor in the manufacture of antibiotics, where the mould is difficult to filter by ordinary methods, because it forms a felt-like cake. A number of loops of string are kept on the drum surface, which pass round the drum. The cake is formed on the strings. These strings lift filter cake off the filter medium and is thus removed.

Glossary of Symbols

A = Surface area of the porous bed (filter medium), m^2.
ε = Porosity of the cake.
η = Viscosity of the filtrate, Pa·s.
K = Constant in Kozeny-Carman equation.
K = Permeability coefficient in Darcy's equation, m^2.
L = Thickness of the cake (capillary length), m.

ΔP = Pressure difference across the filter, Pa.
r = Radius of the capillary, m.
S = Specific area of the particles comprising the cake in Kozeny-Carman equation, m^2/m^3.
V = Rate of filtration, i.e., volume of liquid flowing in unit time, m^3/s.

QUESTION BANK

Each question carries 2 marks

1. List the factors influencing the rate of filtration.
2. Write Kozeny-Carman equation and give its significance.
3. List the functions of filter aids.
4. Give the principle of filtration process.
5. Differentiate between pressure filtration and vacuum filtration.
6. List the properties of filter aids.
7. Distinguish filtration and clarification.
8. What are filter aids? Give two examples.

Each question carries 5 marks

1. Explain the mechanisms of filtration.
2. What are filter aids? Name the filter aids commonly used in pharmacy practice.
3. Describe the construction and working of a rotary continuous filter.
4. Describe the construction and working of leaf filters.

Each question carries 10 marks

1. Explain the construction, working, advantages and disadvantages of filter press.
2. Explain the theories of filtration giving the principle, mechanism and factors affecting the process.
3. With a neat diagram, describe the construction and working of a suitable industrial filter for handling of high solid containing slurries.
4. With a neat diagram, describe the construction and working of an industrial filter suitable for clarification of syrups.