MODULE - 3

FILTRATION

3.1 WATER TREATMENT

The following process involved in water treatment system

- Screening
- Aeration
- Sedimentation
- Sedimentation aided with coagulation
- Filtration
- Disinfection

3.2 SCREENING

Screens are provided before the intake works so as to prevent the entry of big objects like debris, branches of trees, part of animals, etc. Screens may be of two types, coarse screen and fine screens. Coarse screens (trash racks) are parallel iron rods placed vertically or at a small slope at about 2.5 cm to 10 cm apart. The fine screens are made up of fine wire or perforated metal with small openings less than 1 cm size. The screens may be manually cleaned or mechanically cleaned depending upon the requirement. Fig. 3.1 shows fixed bar type screen.

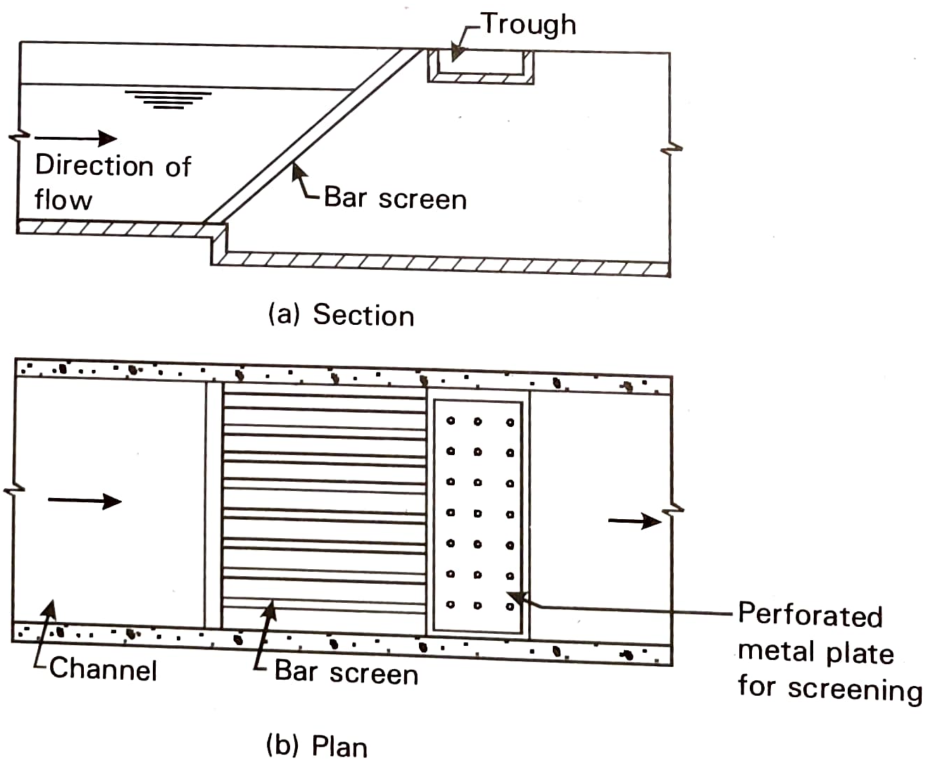


Fig. 3.1 : Screening

3.3 AERATION

This is the process of bringing waters into intimate contact with air. Aeration is done to remove taste and odour and aeration is necessary to promote the exchange of gases between the water and the atmosphere.

3.3.1 Objects of aeration:

1. To add oxygen to water for imparting freshness, for example water from underground sources may have lesser oxygen.
2. Drive out objectionable dissolved gases like carbon dioxide, hydrogen sulphide and other volatile substances causing taste and odour.
3. To precipitate impurities like iron and manganese specially from underground water.

To ensure proper aeration it is necessary to,

- Increase the area of water in contact with the air.
- Keep the surface of the water constantly agitated so as to reduce the thickness of the water film which would govern the resistance offered to the rate of exchange of the gas.
- Increase the time of contact of water droplets with air.

Aeration is effected through instruments called Aerators. These are based on the following mechanics of aeration :

1. By formation of drops or thin sheets of water exposed to the atmosphere : Based on this, we have spray aerators, water fall or multiple-tray aerators and cascade aerators.
2. By formation of small bubbles of compressed air rising through water being aerated, as in the case of diffused air aerators.

Of the above, spray aerators are considered to be most effective aerators.

3.3.2 Aeration fountain

The function of an aeration fountain is to remove the tastes and odour which are unpleasant and the dissolved gases other than oxygen and nitrogen from raw water.

It essentially consists of water pipe, nozzle and stop-cocks. When water under pressure is forced through the nozzle. Sprays and the droplets of water come in contact with the atmospheric oxygen. The water absorbs oxygen from atmosphere and gets aerated. The dissolved gases like CO_2. H_2S, etc. escape into the atmosphere and the oxidation of organic matter takes place which reduces the ordour. The aeration fountain works efficiently at a pressure of 10 to 14 m head of water.

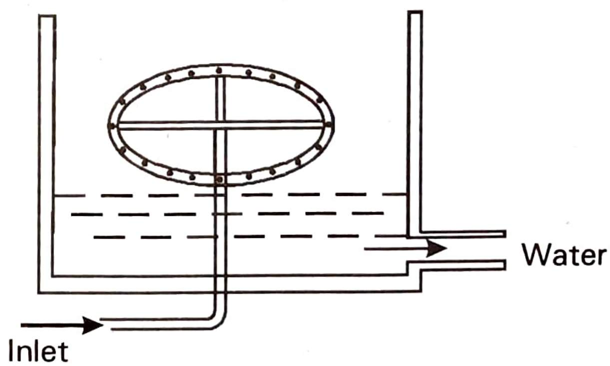


Fig. 3.2 : Spray nozzles

3.3.3 Cascade Aerators

In cascade aerators water is allowed to flow downwards after spreading over inclined surface in thin sheets and the turbulence is secured by allowing the water to pass through a series of steps or baffles. The number of steps is usually 4 to 6. Exposure time can be increased by increasing the number of steps and the area to volume ratio improved by adding baffles to produce turbulence.

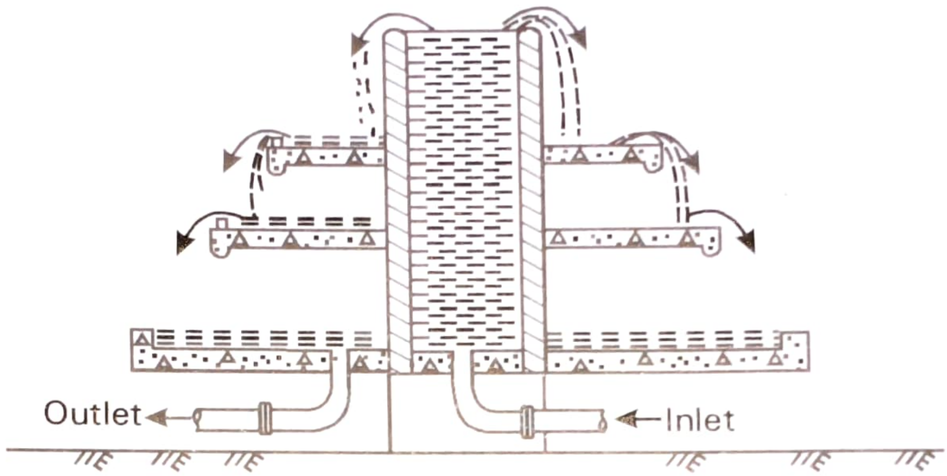


Fig. 3.3 : Cascade Aerator

3.3.4 Diffused Air Aerators

This type of aerator consists of a basin in which perforated pipes, porous tubes or plates are used for release of fine bubbles of compressed air which then rise through the water being aerated. As the rising bubbles of air have a lower average velocity than the falling drops, a diffused air type provides a longer aeration time than the water fall type for the same power consumption.

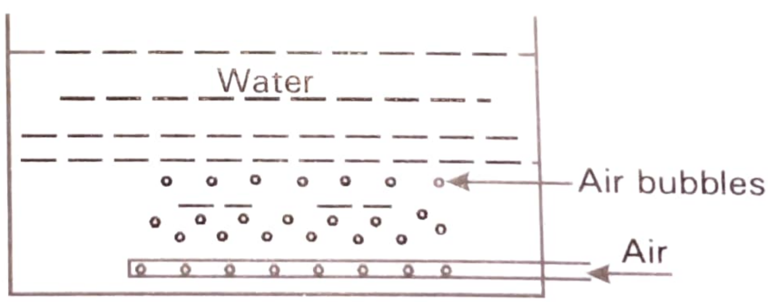
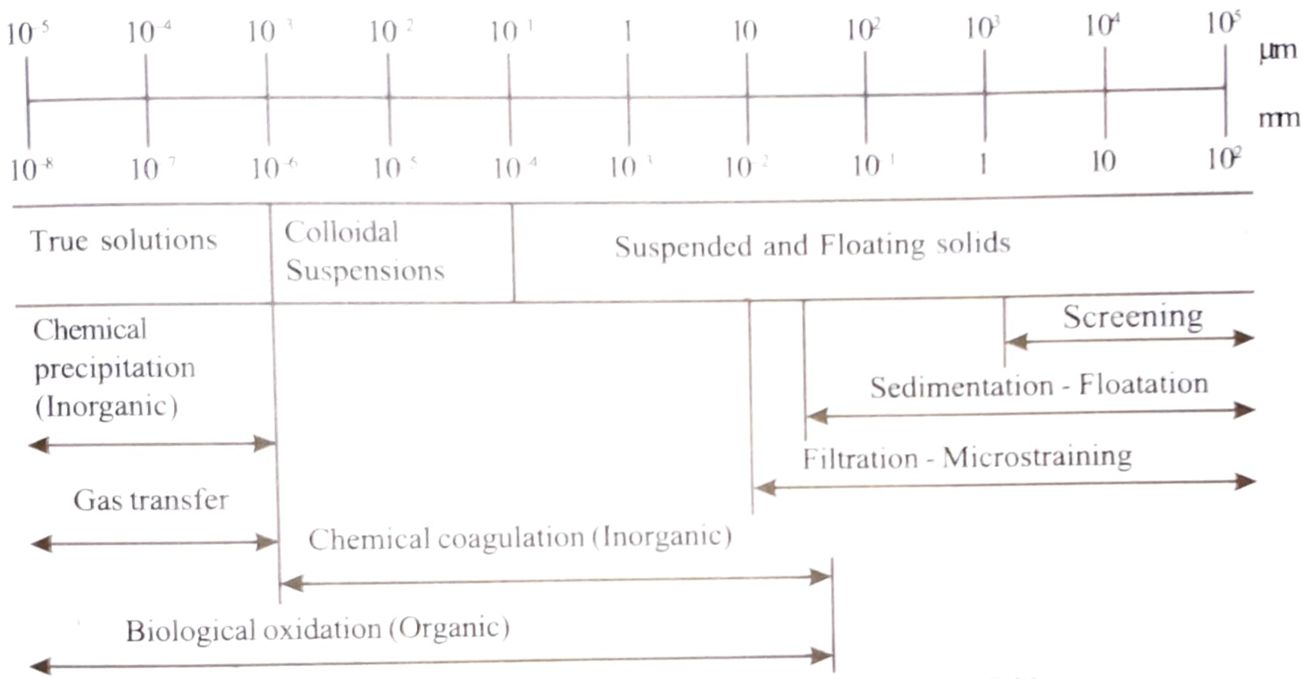


Fig. 3.4 : Diffused air

3.4 SEDIMENTATION

The impurities in water may be present as floating and suspended solids(e.g., leaves, branches, sand, grit etc.); colloidal solids(e.g., clay silt, micro-organisms), dissolved solids (e.g., inorganic salts, tannic acid) and dissolved gases (e.g., carbon dioxide, hydrogen sulfied). Such a classification of impurities is function of particle size as shown in Fig. 3.5 which also depicts the zones of application for common treatment unit operations and processes for their removal.

Many of the impurities such as sand, grit, silt, clay etc., are kept in suspension in flowing water due to sufficient velocity and turbulence. Such impurities settle out, under the effect of gravity, in quiescent or semi-quiescent conditions i.e., when the velocity and turbulence are minimal. This process of settlement of particles in water, under quiescent conditions, due to gravitational force is called sedimentation. Sedimentation is a physical unit operation aimed at the separation of solids in water. Sedimentation is also called clarification or settling.



Adopted from : Principles of water treatment by T.H.Y. Tebbut

Fig. 3.5 : Particle size, type of impurity and removal mechanism

3.5 TYPES OF SETTLING

Depending on the nature of particles to interact and their concentration there are basically four different types of settling:

- Discrete particle settling : Type I
- Flocculant settling : Type II
- Hindered settling : Type III
- Compression settling : Type IV

During settling operation, it is possible that more than one type occurs at a given time in the same sedimentation tank. It is even possible that all the four types of settling occur in one tank.

Type I Discrete particle settling

The particles settle *discretely* and individually at a constant settling velocity. While settling they do not coalesce and hence their shape, size and density are preserved. Sand and grit particles in water follow Type I Settling.

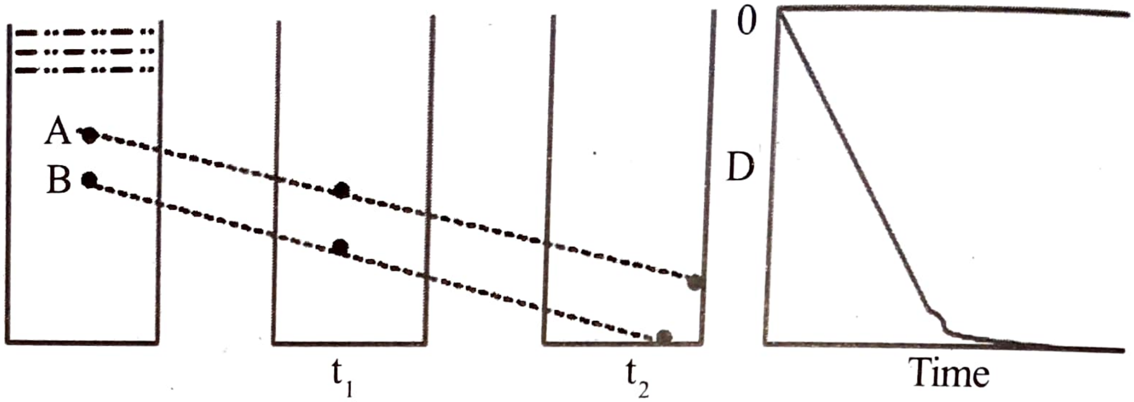


Fig. 3.6 : Type I : Discrete particle settling - particles settle independent of each other

Examples:

- Pre-sedimentation for sand removal prior to coagulation in water treatment plant.
- Grit chamber for removal of grit in wastewater treatment plant.
- Settling of sand particles during backwashing (cleaning) of rapid sand filters.

Type II Flocculant settling

The particles coalesce and *flocculate* hence increase in size exhibiting increased velocity during the settling. In fact, the particles continuously change in shape, size and density (due to entrapped water in the floc) as they settle to the bottom of the tank. Hence, this type of settling cannot be adequately described by mathematical relationship like the Stokes' Law. For modelling the behaviour of the flocculant settling e.g., chemical flocs, laboratory tests with settling column are performed.

Examples:

- Alum and Iron coagulation in water treatment.
- Primary sedimentation tank, upper part of the secondary sedimentation tank, chemical flocs in physical-chemical treatment of wastewater.

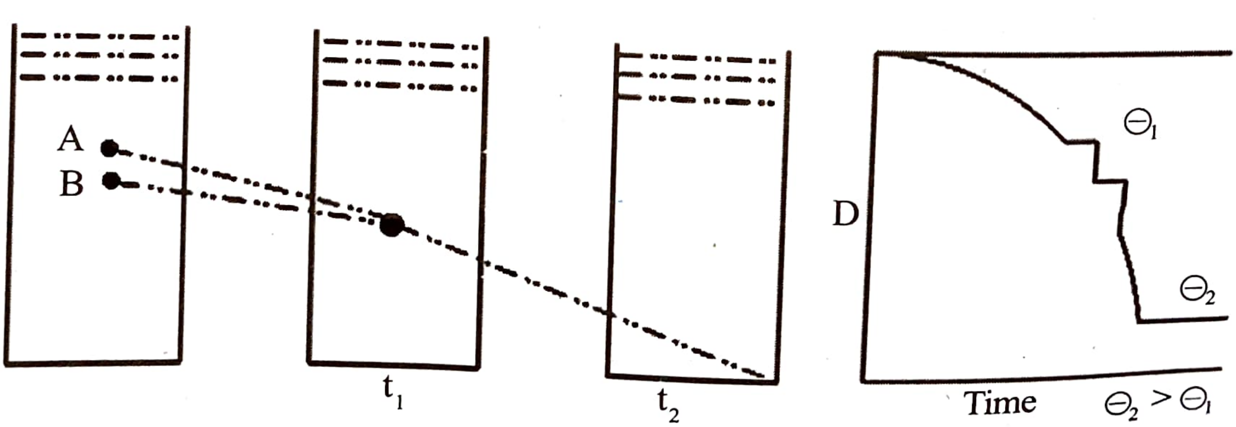


Fig. 3.7 : Type II : Flocculant settling - Two particles 'flocculate' grow in size and settle at velocity higher than the individual

Type III Hindered or Zone Settling

When the concentration of particles is high (e.g., greater than 1000mg/*l*)the settling of one particle *hinders* the settling of neighbouring particle due to inter-particle forces which hold the particles infixed position relative fixed (position) relative to one another so that the suspension settles as a *blanket* or *zone* or a *unit*.

A distinct solids—liquid phase interface can be observed which moves downwards as a result of particle settling. The settling velocity of the 'interface' is used in the design of settling tanks rather than the settling of individual particles.

Due to inter-particle fluid velocities the settling velocity of individual particle in the blanket is less than that of an individual particle.

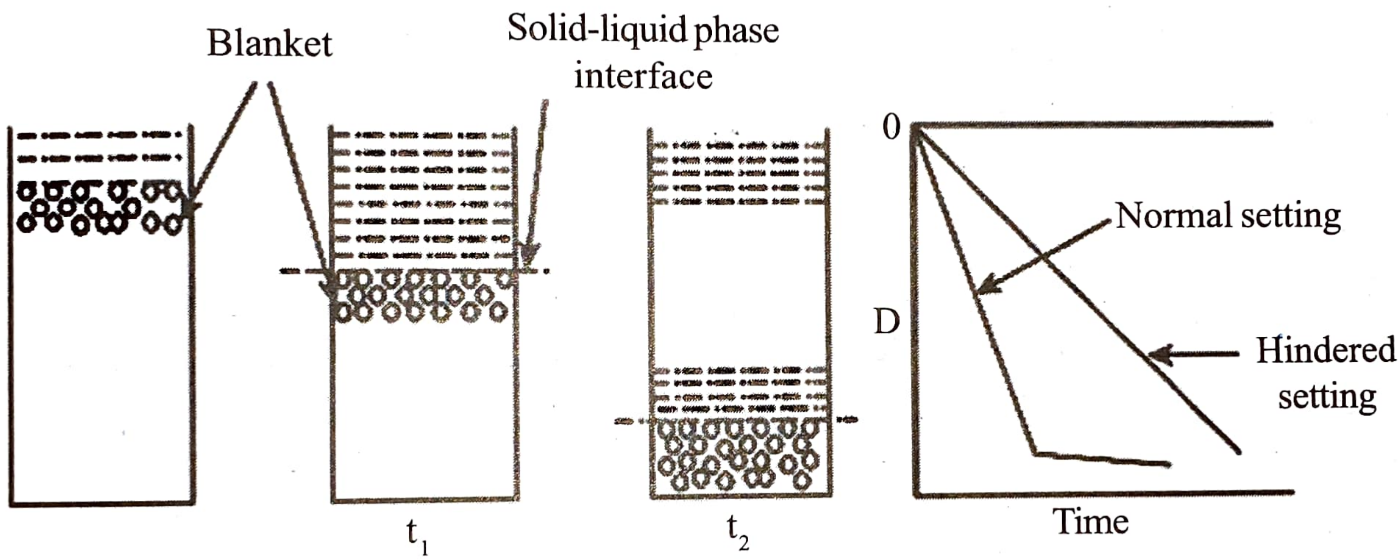


Fig. 3.8: Type III : Zone or hindered settling - Particles are so close to each other that they settle as a zone or a blanket maintaining their relative position fixed

Examples:

- Secondary sedimentation tank and sludge gravity thickener in wastewater treatment.
- lime softening sedimentation for removal of hardness in water treatment.

Type IV Compression settling

Occurs in the *sludge zone* i.e., at the bottom of the sedimentation tank where compression of the particles structure occurs due to the weight of particles being constantly added as they keep settling from the supernatant liquid. The particles, in fact, do not really settle but with compression the water is removed from the floc matrix exhibiting the fall in level of the interface over a period of time. The particles are in contact and the lower layer of solids support the upper ones. This is why it is called the *compression* settling. The thickness of the sludge layer decreases as the water oozes out from the solids/floc matrix due to compression of the particles structure on continuous addition of particles settling from the supernatant liquid.

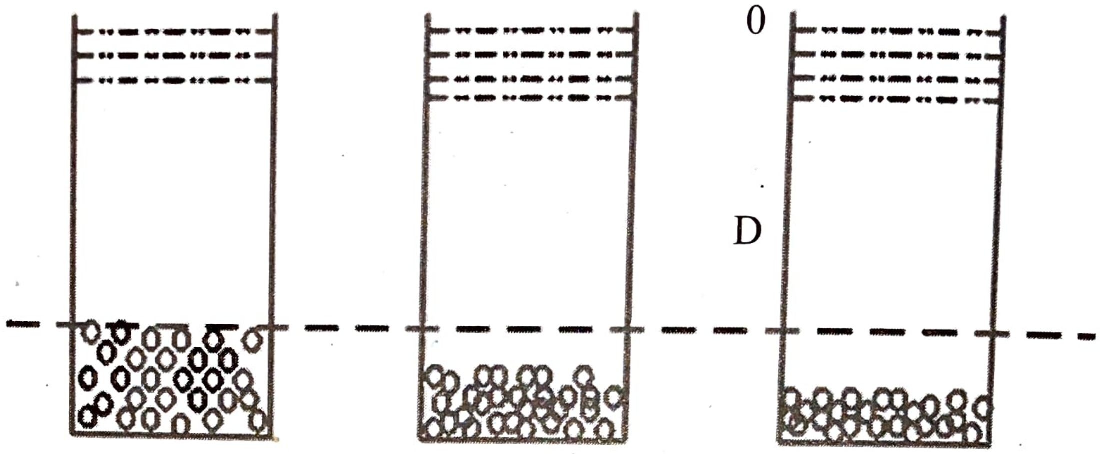


Fig. 3.9 : Type IV : Compression Settling - The thickness of the sludge layer decreases as the water oozes out from the solids / floc matrix due to compression of the particles structure or continuous addition of particles settling from the supernatant liquid

Examples:

Bottom thick layer of solids (i.e., sludge) observed in any type of sedimentation tank in water and wastewater treatment including sludge gravity thickeners.

3.6 SEDIMENTATION TANK ZONES

Irrespective of the shape, all the sedimentation tanks have four zones, each with its own function as shown in Table 3.1.

Table 3.1 : Sedimentation tank zones

Zone	Function
Inlet	To decrease the velocity of incoming water and uniformly distribute it across the basin.
Settling Zone	To provide quiescent conditions for suspended solids to settle.
Outlet	To provide smooth transition from calm conditions to outlet flow without causing currents or eddies to prevent re-suspension of settled solids. This will otherwise impair the treated water quality.
Sludge	To collect the settled solids intact and keep them separated from the other particles in the settling zone.

For efficient operation, the sedimentation basins are designed so that water may enter the tank and pass through and leave without creating much turbulence while preventing any short circuiting.

3.7 THEORY OF SEDIMENTATION

The particles which are heavier than water are naturally likely to settle down due to the force of gravity. In water, there are mainly two types of impurities, inorganic suspended solids having specific gravity about 2.65 and organic suspended solids having specific gravity of about 1.04.

The particles having specific gravity of about 1.20 or so easily settle down at bottom of tank.

But it is difficult to cause the settlement of lighter particles. This phenomenon of settling down of particles at the bottom of sedimentation tank is known as hydraulic subsidence and every particle has its own hydraulic settling value which will cause hydraulic subsidence.

But the lighter particles cannot settle down due to force of gravity. Such particles are converted to settleable size by application of some coagulant in water.

The velocity of flow can be decreased by increasing length of travel and thus a particle is allowed to stay for longer period in sedimentation tank. Due to maximum detention time, particle settle at the bottom of tank.

The size and shape of the particle are altered by adding chemicals known as coagulants in water.

Velocity of flow, viscosity of water, size and shape and, more importantly, density or specific gravity of the solid influence the settling velocity of discrete particles in water. When buoyancy and drag forces counterbalance the gravity forces, solid particles reach the terminal velocity as given by the Stokes's law

$$v_s = \frac{gD^2}{18\nu}(G_s - 1)$$

where v_s is the terminal settling velocity, g the acceleration due to gravity, D the diameter of the discrete particle, G_s the specific gravity of particle and ν is the kinematic viscosity of water.

Since viscosity is dependent on temperature, the above equation is modified to introduce variation with temperature, T (°C)

$$v_s = 418D^2(G_s - 1)\left(\frac{3T + 70}{100}\right)$$

However, the above equation is valid for particles of sizes < 0.1 mm and $N_R < 1$, that is, laminar flow conditions. If, however, the settling particles are larger than 1.0 mm, the nature of settling is of turbulent type and settling velocity is determined by Newton's equation

$$v_s = 1.8\sqrt{gD(G_s - 1)}$$

For particles falling in the range of 0.1–1.0 mm, as in the case of grit particles, the settling velocity is given by Hazen's equation

$$v_s = 418D(G_s - 1)\left(\frac{3T + 70}{100}\right)$$

Factors that influence sedimentation

The factors that influence sediment an on are:

- Size, shape, density and nature (discrete or flocculent) of the particles,
- Viscosity, density and temperature of water,
- Surface over flow rate,
- Velocity of flow,
- Inlet and outlet arrangements,
- Detention period, and
- Effective depth of settling zone.

The operation of a settling tank can be shown as four distinct zones as shown in a typical rectangular basin Fig.3.10 to get clear visualisation.

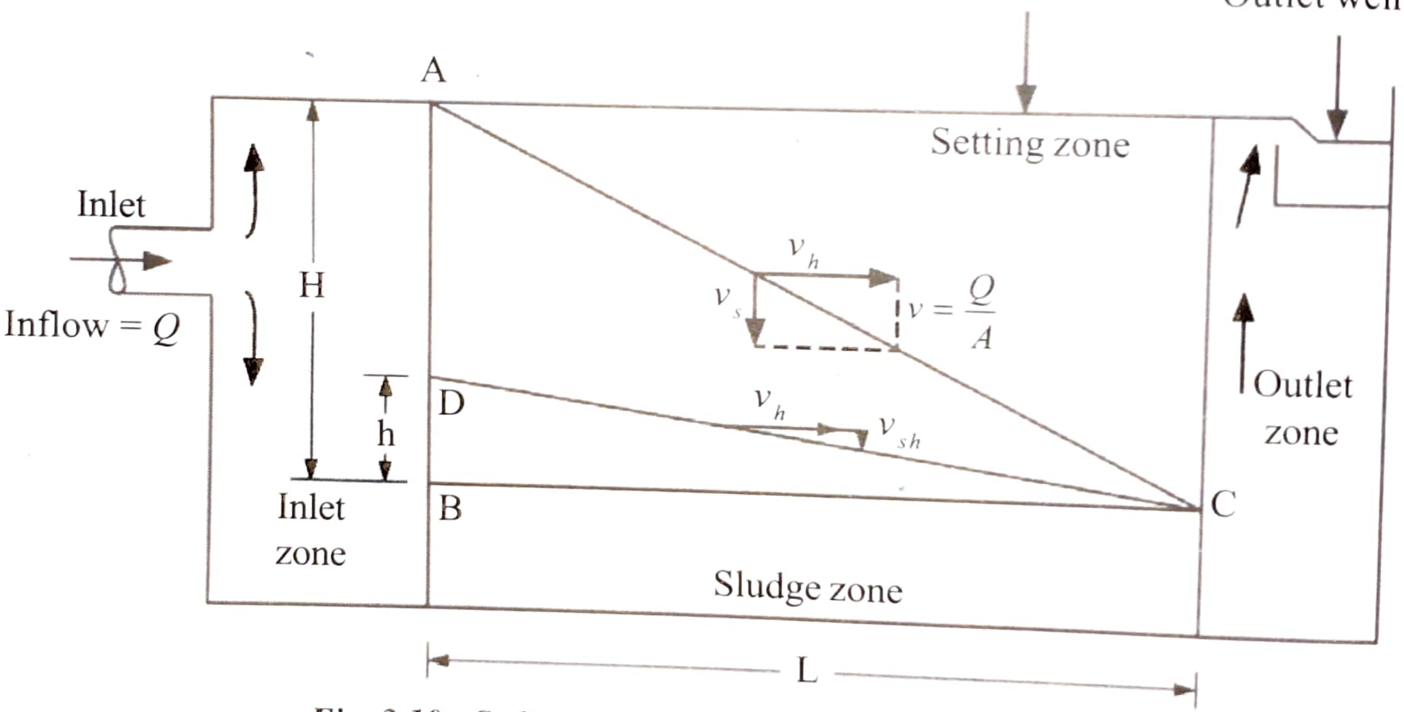


Fig. 3.10 : Sedimentation Basin and Settling Zones

Consider a discrete particle in suspension at a height H and moving with a velocity such that it reaches the bottom of the settling zone before removal. The particle at any instant moves with a velocity that is a vector sum of the velocity in the horizontal direction v_h and settling velocity v_s. All particles in suspension, which have settling velocities more than v_s will obviously be removed. However, the particles with settling velocities less than v_s will also be removed depending on the depth at which they enter the settling zone.

Now consider a discrete particle at a height h. This would move with a velocity which is compounded to the horizontal velocity of the flow v_h and its settling velocity v_{sh}. This particle would be removed when it traverses the settling zone and reaches the sludge zone before it reaches the outlet zone.

From Fig. 3.10, it is clear that if the area of the triangle ABC having sides H and L represents 100% removal of the particles, the area of the triangle DBC with sides h and L represents removal of the particle in the ratio h/H. If t is the detention time

$$\frac{h}{H} = \frac{v_{sh}t}{v_s t} = \frac{v_{sh}}{v_s}$$

If Q is the rate of flow and A is the surface area of the settling zone then $v_s = Q/A$.

Therefore, the proportion of the particles of a given size, which are removed in a horizontal flow tank is

$$\frac{v_{sh}}{v_s} = \frac{v_{sh}}{Q / A}$$

If $v_s = Q/A$ is a limiting velocity of the fall to reach the bottom of the settling tank, all particles with settling velocity faster than Q/A will be 100% removed; whereas all particles with velocity less than Q/A will be removed in the ratio of their velocity to Q/A (the velocity of the slowest particle which will be 100% removed).

3.8 DESIGN PARAMETERS FOR SEDIMENTATION TANK

Three most important design parameters are:

a) Detention time

b) Surface over flow rate(SOR) or surface loading rate(SLR) and

c) Weir loading rate

a) Detention Time

It is defined as the theoretical amount of time water (or the particle) remains in a sedimentation tank. It can be mathematically represented as:

$$T_d = \frac{V}{Q}$$

T_d = Detention time, hours (h)

V = Volume of water in tank, m^3

Q = Average volumetric flow rate of incoming water, m^3/hr

Most commonly, a minimum detention time of 2.5h is recommended by most water supply or environmental agencies as most of the settleable solids reach the sludge layer within this time period.

b) Surface Over Flow Rate

It is defined as the volumetric flow rate(Q) of water flowing over the surface with plan area 'A'.

Typically, the value ranges from 20 to 33 $m^3/m^2.d$. In colder temperatures, the settling velocities decrease due to an increase in density and viscosity of water. Thus, the plant capacity goes down during the winter months. To compensate for reduced settling rate, weighted agents may be applied, especially in light density floc.

Mathematically it can be represented as:

$$V_0 = \frac{Q}{A}$$

where,

V_0 = Surface overflow rate $m^3/d.m^2$

Q = Average flow rate, m^3/d

A = Tank surface area (plan), m^2

c) Weir loading rate

It is also called the weir hydraulic loading rate with units of expression as $m^3/d.m$. It is defined as average flow rate (Q) per unit length(m) of the weir at the outlet. The typical values ranges between 140$m^3/d.m$ to 270$m^3/d.m$ with a recommended maximum of 250$m^3/d.m$.

Table 3.2 : Common surface loading and detention periods

Tank Type	Surface loading, $m^3/m^2/d$*		Detention period, hr*		Particles normally removed
	Range	Typical design values	Range	Typical design values	
1. Plain sedimentation	0 - 6000	15 - 30	0.01 - 15	3 - 4	Sand, silt and clay
2. Horizontal flow circular sedimentation	25 - 75	30 - 40	2 - 8	2 - 2.5	Alum and iron floc
3. Vertical flow (up flow) clarifiers	—	40 - 50	—	1 - 1.5	Flocculent

* at average design flow.

3.9 TYPES OF SETTLING TANKS

A rectangular, square or circular tank, designed to hold water for a time long enough, to allow suspended particles to settle is called the sedimentation tank, a settling tank or a clarifier.

Sedimentation tanks can be classified into two types:

i) Plain Sedimentation
   - Horizontal flow tanks
   - Vertical or up flow tanks

ii) Sedimentation aided with coagulation

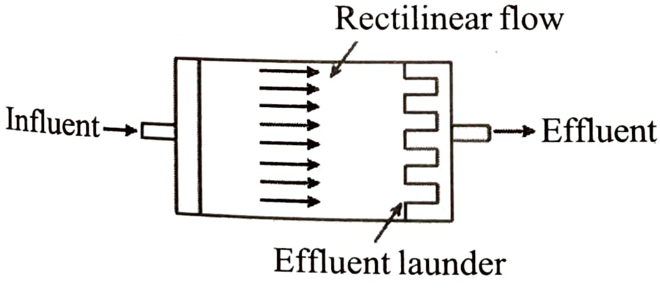
When the impurities are separated from the suspending fluid by gravitation and natural aggregation, the operation is called Plain Sedimentation.

When chemical or other substances are added to increase aggregation and settling of finely divided suspended matter and colloidal substances, the operation is called sedimentation with çoagulation.

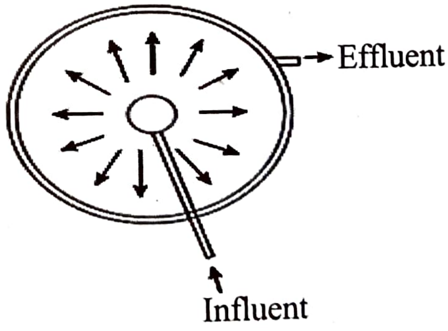
Commonly used sedimentation tank is a rectangular type, but circular type of tank is also used. Sometimes the spiral type of tank may used for sedimentation.

Table 3.3 : Different types of sedimentation tank

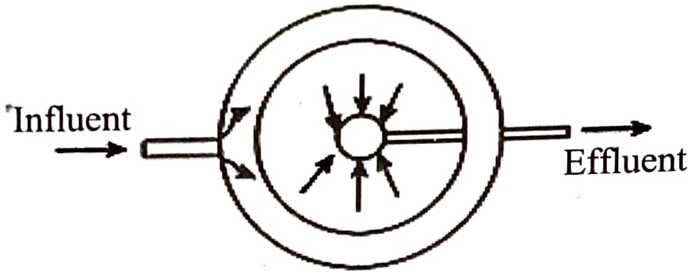
Sl.No.	Type of tank	Configuration
1	Horizontal flow	Long rectangular tanks
2	Centre feed	Circular, horizontal flow
3	Peripheral feed	Circular, horizontal flow
4	Solids - contact	Circular, up flow with sludge blanket
5	High rate settling tanks - Parallel plate and tube settler	Rectangular, square, horizontal tank



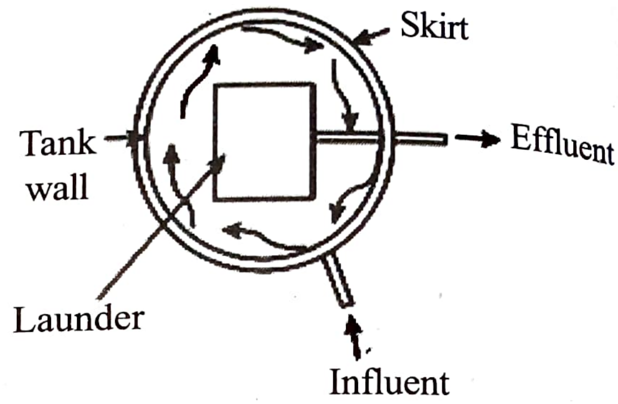
(a) Rectangular settling tank- rectilinear flow



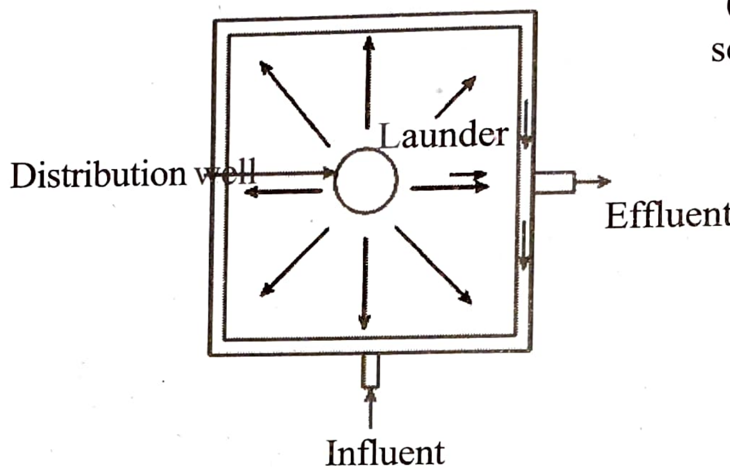
(b) Centre - feed settling tank, radial flow



(c) peripherical feed settling tank, radial flow



(d) Pheripheral - feed settling tank, spiral flow



(e) Square settling tank, radial flow

Fig. 3.12 Flow patterns in different types of sedimentation tank

1. Rectangular tanks

These tanks are designed so that the flow is parallel to the length of the basin i.e., 'rectilinear flow'. The sludge pit is usually provided on the 'inlet' side and the bottom of the tank slopes slightly downward toward the inlet end to make sludge removal easier. A mechanical scrapper is used to drag the sludge into the pit.

2. Circular Tanks

a) **Radial flow with central inlet:** The water enters through the centrally located inlet pipe/ shaft with ports, moves radically towards the peripheral outlet-launder. A mechanical scrapper pushes the sludge to centrally located sludge pit. (Fig.3.12(b))

b) **Radial flow with peripheral inlet:** The water enters from the periphery, moves radically towards the central outlet.(Fig.3.12(c))

3. Clariflocculator

Both flocculation and clarification takes place in the same unit hence the name of the unit. The water from the rapid mixer/coagulant mixing facility enters the flocculation compartment through a central shaft where it is gently mixed by a set of paddles to promote the growth of the flocs. The water then moves into the outer tank where the flocs settle under calm conditions and the clarified water moves towards peripheral collecting launder.

4. Spiral flow tanks

The water enters at an angle from one or more points on the outer edge. This causes the spiral flow in the basin and water finally moves towards the central collector (Fig. 3.12(d)).

3.10 PLAIN SEDIMENTATION

Sedimentation is the process of removal of suspended particles by gravitational settling. It occurs when particles are heavier than water. When water is moving these impurities remain in suspension due to the turbulence and as the velocity is reduced they settle down. It is not necessary to stop the motion of water completely as it will require more volume of the sedimentation tanks. This process in known as plain sedimentation.

Knowing the settling velocity of particle, that is intended to be settled, the design of the settling tank is done.

3.10.1 Advantages of plain sedimentation

a) It is a preliminary process which lightens the load on subsequent processes.

b) It gives less variable quality of water and so the operation of subsequent purification process is done in a better way.

c) Cleaning cost of chemical coagulating basins is reduced.

d) No chemical is lost with the sludge discharged from the plain settling tanks.

e) Less quantity of chemicals are needed in the subsequent treatment processes.

3.10.2 Horizontal flow tanks

Sedimentation tanks are generally made of reinforced concrete and may be rectangular or circular in plan. Long narrow horizontal tanks are generally preferred to the circular tanks.

Horizontal flow may have

a) Rectangular tanks with longitudinal flow

b) Circular tanks with radial or spiral flow

a) Rectangular tanks with longitudinal flow

These type of tanks are further divided into Intermittent tank & continuous flow type tank.

i) Intermittent tank or Fill and draw type tank

These are simple settling basins which store water for a certain period and bring it in complete rest. After 24 hrs, during which the suspended particles settle down to the bottom of the tank and clear water is drawn off. All the settled material is then removed from tank and is again fill with raw water to continue the next operations. Thus this type of tank function intermittently, i.e., after a gap of atleast 30 to 36 hrs. This necessitates a commissioning of at least two tanks. Such tanks are generally not preferred these days because lot of time and labour is wasted.

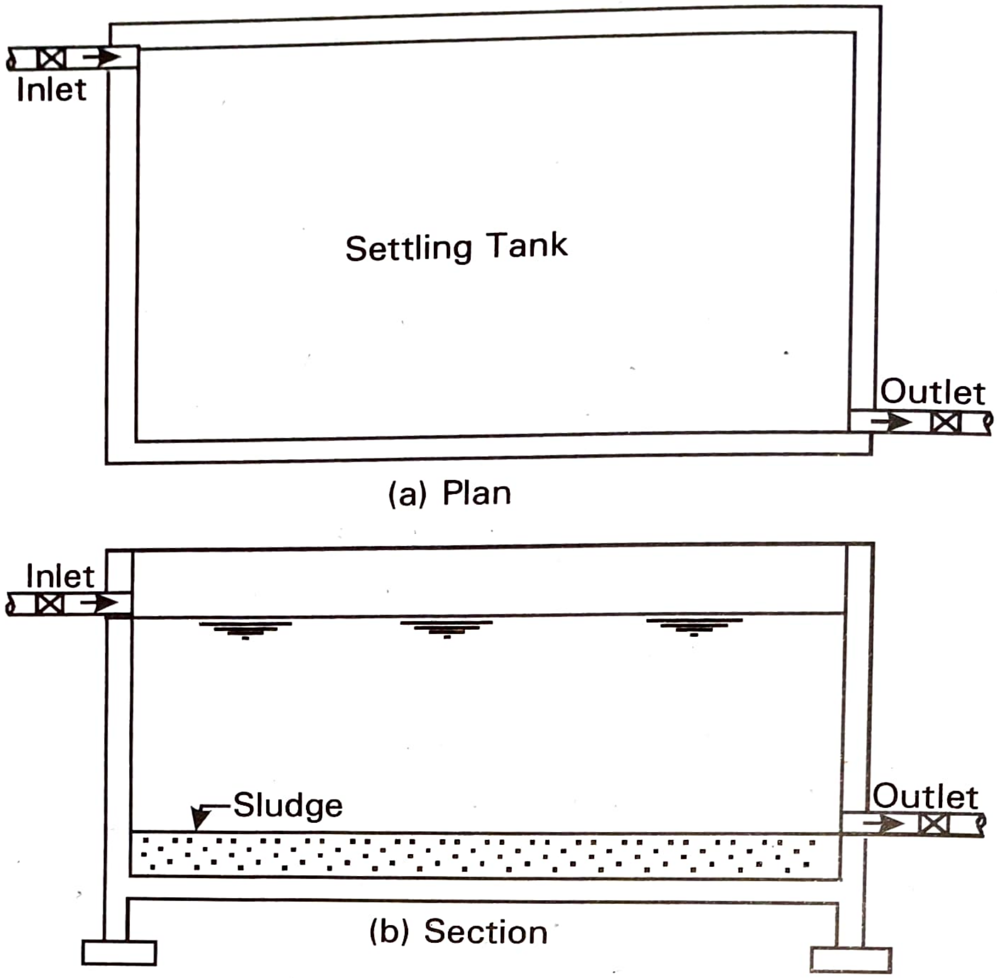


Fig. 3.13 : Fill and draw type tank

ii) Continuous flow type Tank

In the continuous flow type, the water continuously keeps on moving in tank, though with a very small velocity during which time the suspended particles settle at the bottom before they reach the outlet.

In this type of sedimentation tank, the flow velocity is only reduced and the water is not brought to complete rest. The water enters from one end and comes out from the other end. The velocity is reduced by providing large length of travel. The velocity is so adjusted that the time required by the particle to travel from one end to another is slightly more than the time required for settlement of that particle. These tanks are widely used present days.

In the horizontal flow type, the tank is generally rectangular in plan having length equal to at least twice the width. The water flows practically in the horizontal direction, with a maximum permissible velocity of 0.3 m/sec.

A plain sedimentation tank under normal conditions can remove as much as 70% of the suspended impurities present in water.

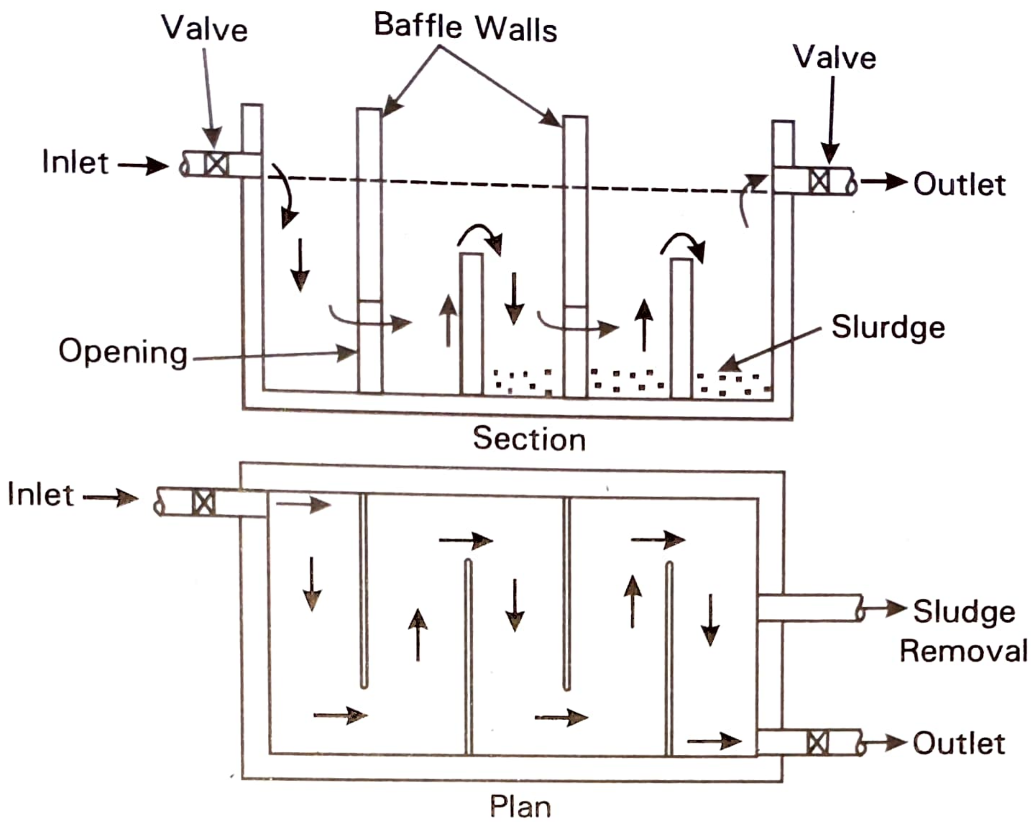


Fig. 3.14 : Continuous flow type tank

Advantages:

- Less labour and supervision.
- Loss of head is less.
- Since tanks are continuous operation, less time wasted.

b) Circular tanks with radial or spiral flow

The circular sedimentation tank may have radial or spiral flow. But the tank with radial flow is commonly adopted. Fig. 3.15(a) shows dorr clarifier which is a circular sedimentation tank with radial flow. In this type of tank, the water is admitted from the centre of tank and is taken out at the circumference through draw off channel. The impurities settle at the bottom of tank. The raking arms are slowly rotated and blades of raking arms lead the mass of impurities to sludge discharge pipe.

3.10.3 Vertical or up flow tanks (Hopper Bottom Tank)

Vertical flow type tanks are generally deep, circular or rectangular basins with hopper bottom. The water is allowed to enter through a deflector box which is provided at the centre. The water flows downwards inside the box and then it rises in upward direction through the opening between the box and the wall of the tank. When the water rises in upward direction, the particles having specific gravity more than 1.00 cannot follow the path and ultimately settle down at the bottom of the tank due to the property of hydraulic subsidence.

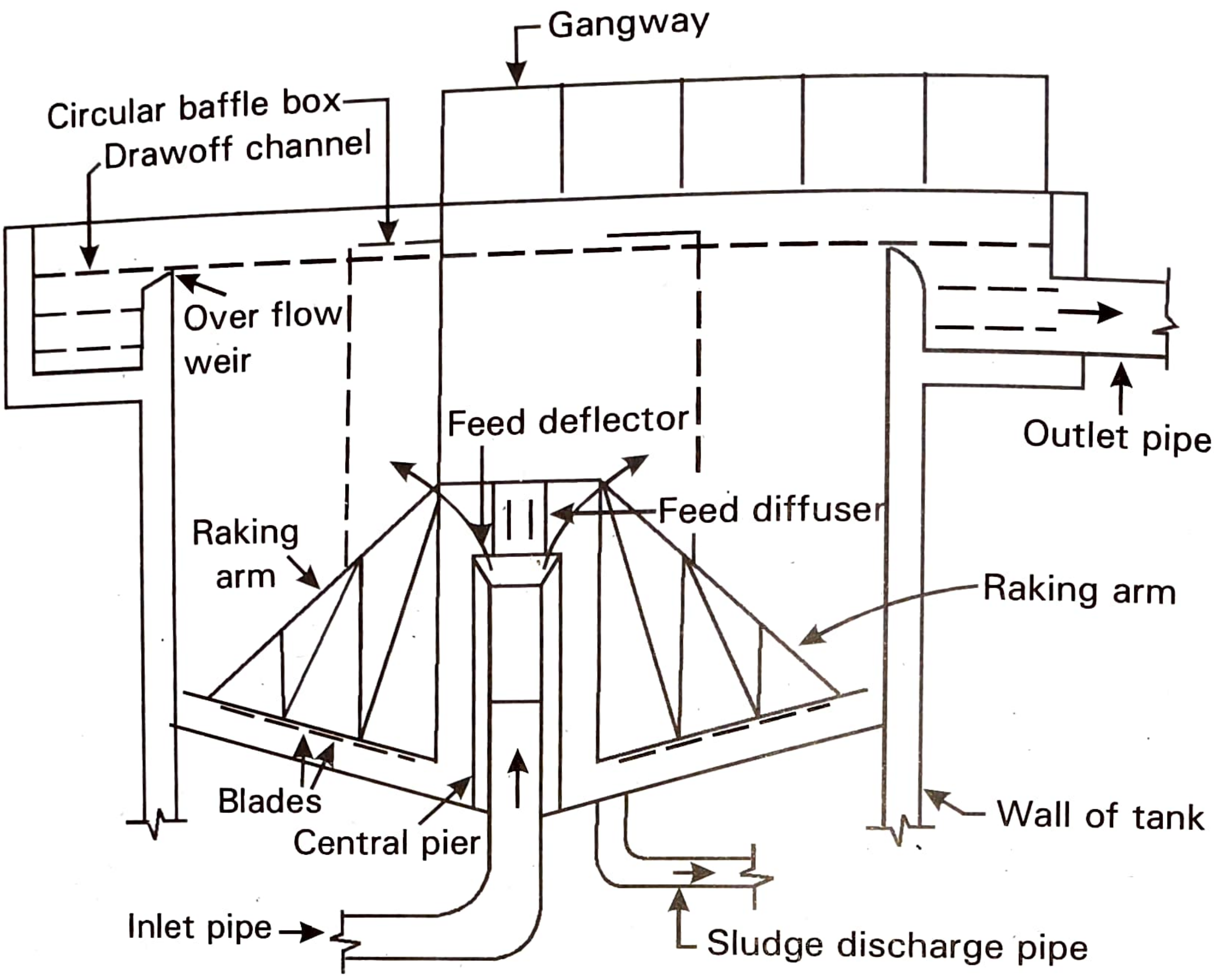


Fig. 3.15(a) : Circular tank with radial flow (Dorr clarifier)

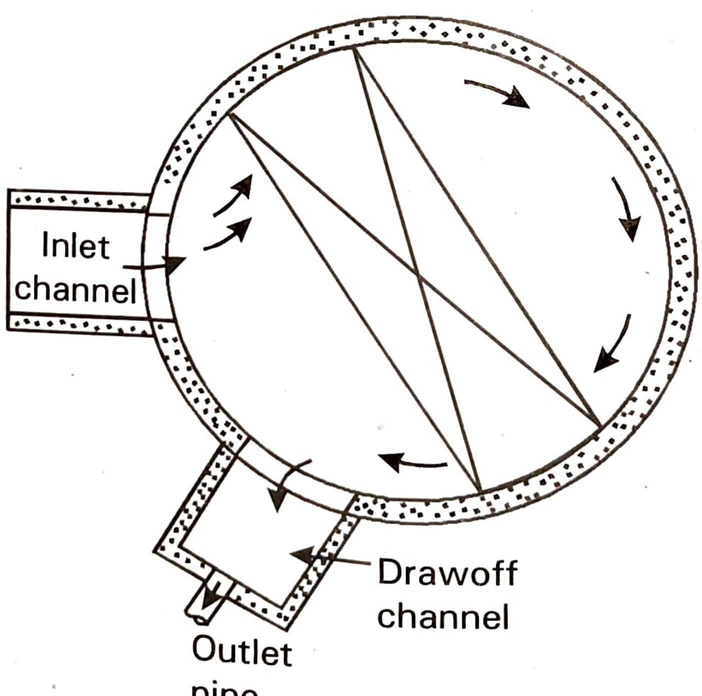


Fig. 3.15(b) : Circular tank with spiral flow

The sludge is collected at the bottom of tank and clear water is taken out from drawoff channel. The sludge is pumped out through the sludge outlet pipe.

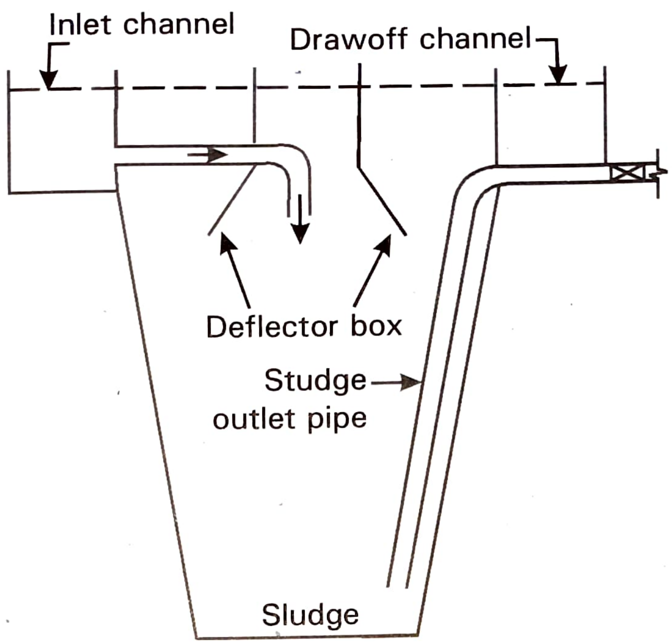


Fig. 3.16 : Hopper bottom setting tank with vertical flow

3.11 HIGH RATE SETTLING

The rate of clarification process can be increased either by

- increasing the density of the particles or
- decreasing the distance that the particle must travel prior to its removal.

While the density of the chemical floc e.g., alum or iron can be increased by adding the micro sand particles 20 to 200 μ m size, as 'ballast' the travel or fall distance of the particle can be reduced by introducing a series of 'inclined' plates or tubes in a rectangular horizontal flow settling basin. This relatively new technology is being widely used in the field when designing new sedimentation tanks or increasing the capacity and efficiency of the existing tanks.

3.11.1 Plate Settlers

The plates, inclined to the vertical, are used as shown in Fig. 3.17. The distance between the parallel plates is so designed that an upward velocity of the water is lower than the settling velocity of the particles allowing them to settle on the plate surface. While the water moves 'upward' the settled particles 'slide' down.

The plates are inclined at 60° to the horizontal. The plate area contributing to the settling is the 'horizontal projected area' of the plate. Sum total of all such area is the total effective area for particle settlement. Prefabricated units, usually of plastic, comprising of parallel plates are installed near the top of the tank to increase its 'effective' surface area. The incoming water needs to be distributed 'uniformly' among all the plates for best performance. Such an arrangement permits loading rates several times more than the conventional basin rates resulting in considerably lower 'foot print' in terms of the land area required. Typical loading rates for each plate range from 0.7 to 1.7 m/hr permitting overall basin loading from 5 to 15 m^3/m^2.hr which is several times more than the conventional basin rates.

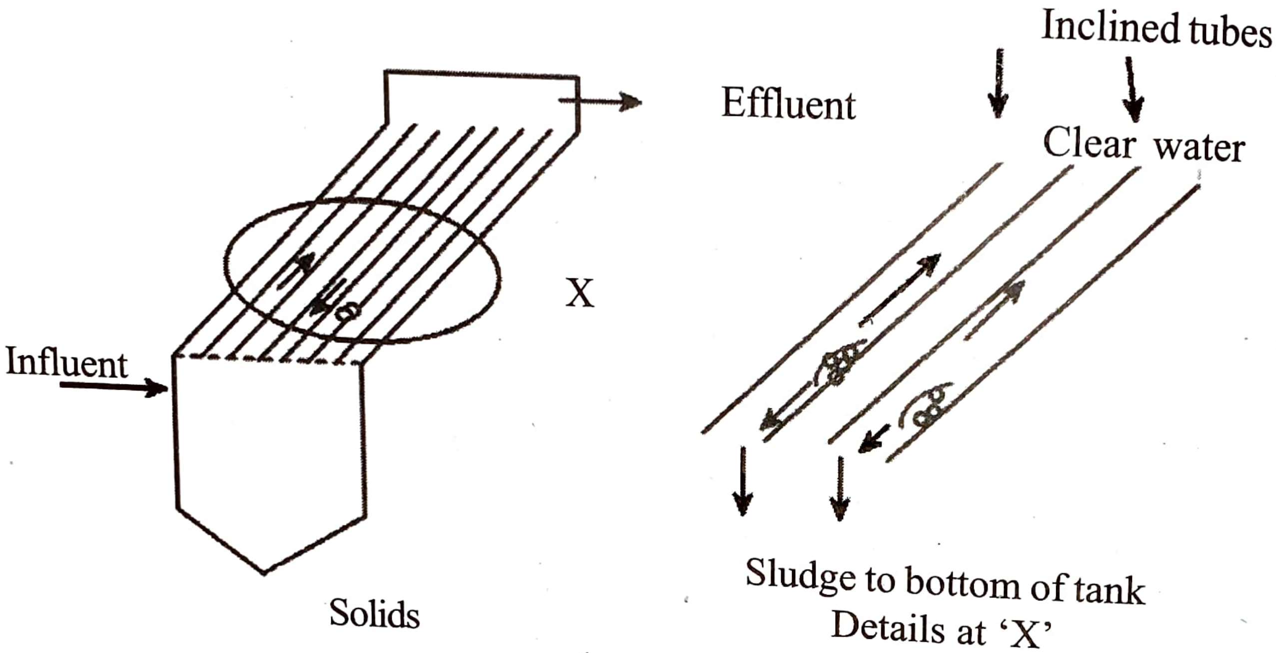


Fig. 3.17 : Plate settler : Inclined settling system - counter current flow

3.11.2 Tube Settlers

Excellent clarification of water can be achieved by using small diameter tubes with detention time of 10 minutes or less when placed in a settling tank with an inclination of 40° to 60° to horizontal.

Tube settlers consist of numerous open-ended tubes, usually plastic about 50mm in diameter and 600mm to 1000mm long, mounted in modules and placed in a basin. The water that is carrying the suspended solids moves from an influent well, upward through the small tubes and into an outlet device. The tube cross-section may be circular, square, rectangular, hexagonal, or any other suitable shape. The tube settlers may be of either slightly inclined or steeply inclined design. In a slightly inclined tube settler system the tubes are inclined from the horizontal at an angle of about 5°. Depending on the direction of water flow with respect to the direction of settled solids (leaving the plates or tubes) there can be three configurations: Counter current, Co current, and Cross-current.

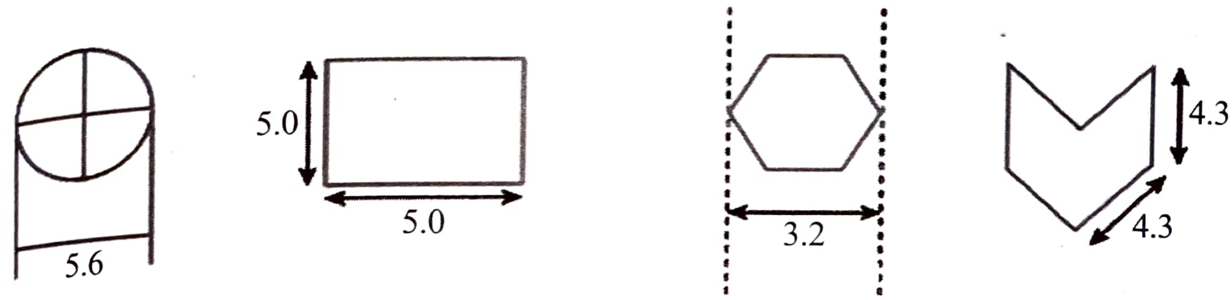


Fig. 3.18 : Various shapes of tubes-size in centimetres

There are basically three types of tube settlers available in practice. They are,

i) Horizontal tube settlers

ii) Inclined tube settlers

iii) Lamella separators

i) **Horizontal tube settlers:** With horizontal tube settlers, the settling occurs as the water to be clarified flows through the horizontal tube. The tubes are slightly inclined (5°) in the direction of flow, to facilitate easy drainage of sludge during cleaning. A typical horizontal tube settler arrangement scheme is shown in Fig. 3.19. The horizontal tube settlers require frequent cleaning to wash down the sludge accumulated at the bottom of the tubes into the sludge storage basin. Sludge deposits form in the tubes, which need to be backwashed or drained. This system is best suited for use with filters so that the tubes can be backwashed along with the filters without any need for extra water or extra cost. When water is drained from the tubes, the falling water scours the sludge down to the sludge storage tank. During cleaning, the settling operation needs to be stopped. Due to the discontinuity in operation, this type of sedimentation techniques may not be suitable for large plants (capacity about or more than 7 million liters per day).

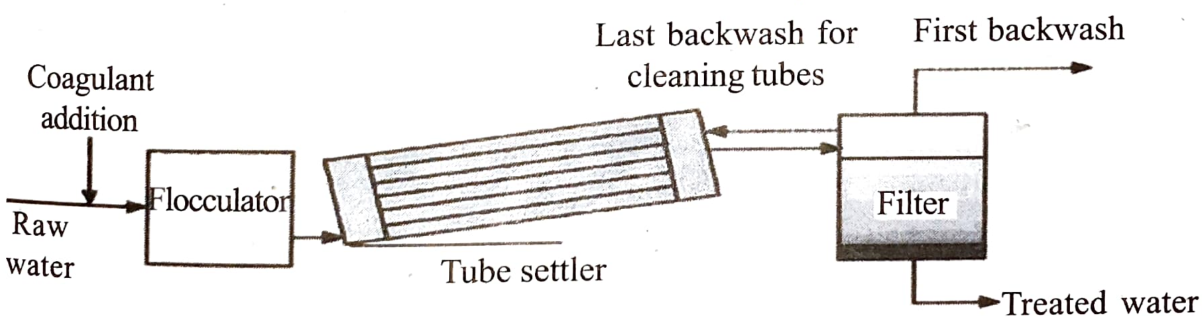


Fig. 3.19 : Typical horizontal tube settler arrangement

ii) **Inclined tube settlers:** These are the most common tube settling devices available in circular or rectangular sections, packed and fabricated to form a module. A typical inclined tube settler installation is shown in Fig. 3.20. In inclined tube settlers, water to be clarified is allowed to flow up through tubes inclined at an angle of 45° to 65° to horizontal. The steep slope facilitates the gravity drainage of sludge deposited at the bottom of the tubes into the sludge compartment for periodic removal. Because of the advantages of shallow settling depth and continuous sludge removal, inclined tube settlers are suited to high capacity installations and installations requiring little maintenance.

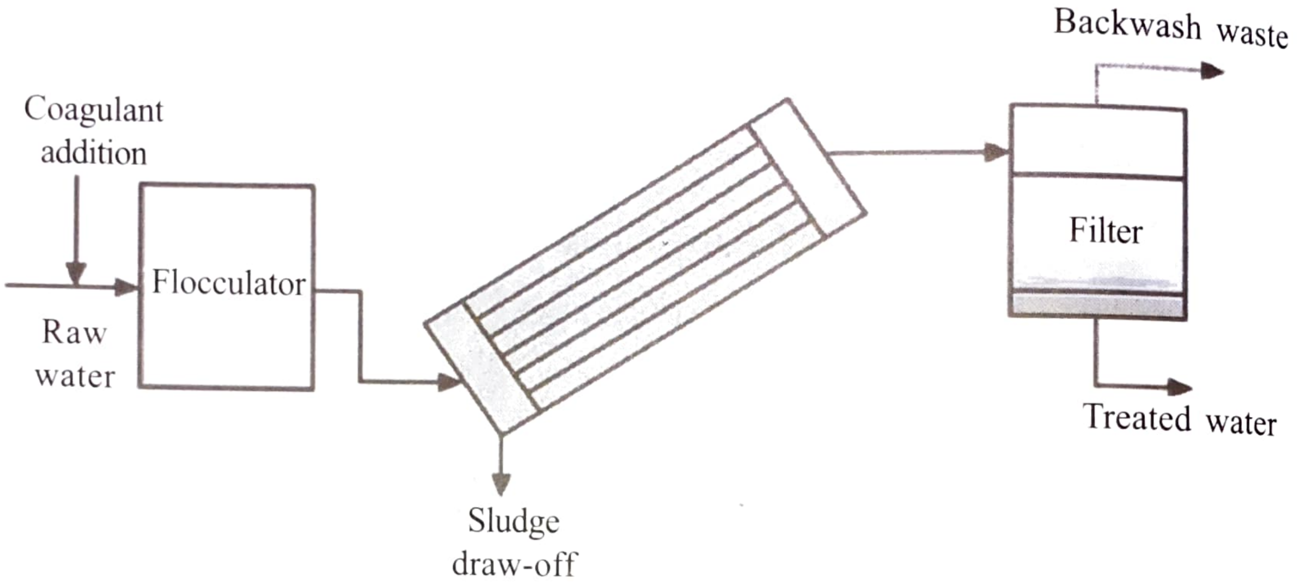


Fig. 3.20 : Typical inclined tube settler arrangement

The sediment does not accumulate in these tubes but continues to settle downward and out of the tubes into the lower influent zone, forming an adsorptive sludge blanket. No backwashing is required in this system for sludge removal from the inside of the tubes. It is necessary, however, as in all sedimentation basins the means be provided to remove the sludge from the basin.

If tube settler modules were placed in existing basins, the sludge collection method would depend on the original basin and equipment design. At new installations, mechanical cleaning equipment should be provided. Many times the tubes become dirty and unsightly due to some of the suspended solids clinging to the walls or due to biological growth on the wall surface. This may seriously affect the efficiency of the these settlers. Tube cleaning can he accomplished by providing a grid of diffused air headers beneath the tubes. The influent flow is stopped before turning on the air, which scrubs out attached floc, and then a 15-25 min quiescent period is allowed before influent is again released into the tube settlers.

iii) **Lamella separator.** Lamella separator operates by co-current downward flow of both sludge and flocculated water. The classical tilted tubes or lamella are equipped with sludge movement deflecting blades. Even though these blades may cause some turbulence (favorable for flocculation but critical for clarification), they have a general improving effect when placed in the sludge zone.

3.12 SEDIMENTATION AIDED WITH COAGULATION

The fine suspended particles like mud particles and the colloidal matter present in water cannot settle down by plain sedimentation with ordinary (lesser) detention periods. Some of the colloidal impurities will not settle even if the water is detained for long periods in the sedimentation tanks as the same charge on the clay particles repel each other and do not allow them to settle down.

In water treatment the removal of colloids is thought to be a two step process in which coagulation is the first step where the reaction of the chemical coagulant with alkalinity and colloids forms the micro flocs and the flocculation is the second step which involves gentle and prolonged mixing of the destabilised colloids to promote their agglomeration i.e., to form the readily settleable flocs.

Increasing the size of such particles is essential for their successful separation by sedimentation i.e., aggregation of these particles into large and more readily settleable aggregates is essential.

3.13 COAGULATION

Certain chemicals are added to the water so as to remove such impurities which are not removed by plain sedimentation. These chemical compounds are called coagulants.

The process of adding certain chemicals to water in order to form floc (insoluble gelatinous substance) for quick sedimentation and rapid removal of fine particles is called sedimentation with coagulation.

The theory of coagulation:

i) Floc formation: When coagulants are mixed with water thoroughly, a thick gelatinous precipitate is formed which is known as floc. This floc has got the property of attracting the suspended impurities in water and settle down towards the bottom of tank.

ii) Electric charge: It was observed that the ions of floc possess positive electric charge and the colloidal particles possess negative electric charge. Therefore, the floc attracts the colloidal particles while travel towards the bottom of tank.

The phenomenon of formation of floc is termed as flocculation. The efficiency of flocculation depends on dosage of coagulant, type of mixing and pH value of water.

Mechanisms of Coagulation

There are four major mechanisms of Coagulation/Destabilisation.

i) Double layer compression

ii) Adsorption to produce charge neutralisation

iii) Enmeshment in a precipitate

iv) Adsorption by 'polymers' to permit inter particle bridging

In practice, all four mechanisms are probably involved in the removal of colloids. However this book is restricted only to the enmeshment in a precipitate as most of the water treatment plants make use of metallic coagulants producing precipitates. Removal of colloids by addition of metallic salts i.e., by chemical coagulation.

Enmeshment in a precipitate: Removal of colloids in this manner is frequently referred to as 'sweep-floc' coagulation.

Chemical coagulation is a process which involves addition of metalic salts to form chemical flocs that absorb, entrap or otherwise bring together the colloids causing their removal more complete and more rapid than plain sedimentation.

It is a process of destabilising colloids, aggregating them and binding them together for ease of settlement.

When a metal salt such as $Al_2(SO_4)_3$ or $FeCl_3$ or metal oxides or hydroxide, in the case of lime, Cao or $Ca(OH)_2$, is used as a coagulant in concentration sufficiently high to cause rapid precipitation of a metal hydroxide (e.g., $Al(OH)_3$, $Fe(OH)_3$, $Mg(OH)_2$) or metal carbonate (e.g., $CaCO_3$) colloidal particles can be enmeshed in these precipitates as they are formed and as they settle.

The action of these metallic coagulants is complex involving

- dissolution of salts
- formation of complex metal-hydroxides or carbonate which may be highly charged (generally positively charged); and
- the entrapment of colloids in the chemical floc or precipitate formed.

The net effect of a metallic coagulant is seen to be the formation of large, voluminious, insoluble, gelatinous, positively charged flocculent precipitates and production of free hydrogen ion from water involved in hydrolysis as under:

$$Al_2(SO_4)_3 + 6\ H_2O \rightarrow 2\ Al(OH)_3 + 3\ H_2SO_4$$

Effectiveness of this process, enmeshment in the precipitate, is dependent on:

i) **Colloidal concentration :** Higher the concentration of colloids, better is their removal since colloids themselves can serve as nuclei for the precipitation.

ii) **Optimum coagulant dosage (determined through multiple Jar Test) :** Uniform coagulant dosage in the system is must along with uniform pH.

iii) **pH:** Solubility of the metal ions and the metal hydroxides is strongly related to pH.

iv) **Presence of sufficient Alkalinity :** Presence of sufficient Alkalinity in water is required for formation of metal hydroxide precipitates. Therefore, it is important factor in determining the effectiveness of a coagulant.

v) **Electric charge of the ion or molecule used as coagulant :** The higher the charge of ion, more effective the coagulant will be.

vi) **Size of the ion or molecule used as coagulant :** The larger the size of the molecule, more effective the coagulant will be.

vii) **Type of Coagulant :** Different coagulants may give different results.

viii) **Water Temperature :** Most chemical reactions proceed faster at warm temperatures.

ix) **Coagulant Mixing :** For effective treatment, the chemical must be completely and rapidly mixed. This is also known as flash mixing.

x) **Hydraulic Detention Time :** The time allowed for mixing and coagulation to occur is important.

xi) **Turbidity :** Higher turbidity levels usually help to improve coagulation.

3.14 COMMON COAGULANTS

The common chemicals generally used for coagulation are:

1. Aluminium sulphate (Alum)
2. Iron salts
3. Sodium aluminate

Coagulants are chosen depending upon the PH of water. Alum or Aluminium sulphate is normally used in all treatment plants because of the low cost and ease of storage as solid crystals over long periods.

1. Alum, $Al_2(SO_4)^3$, $18H_2O$: This is the most widely used coagulant presently found in water treatment plants. It reacts quite quickly giving excellent stable flocs. It is cheap and can be easily stored and handled. It reacts with the natural alkalinity in water and if that is not sufficient, lime may be added and forms aluminium hydroxide floc. It increases the sulphate hardness and corrosiveness of water to a small extent.

Another variety known as 'Black Alum' contains 2 to 5% of activated carbon when used in coagulation it helps in removal of taste and odour.

Chemical reactions

(i) $Al_2(SO_4)_3\ 18H_2O + 3Ca\ (HCO_3)_2 = 2Al\ (OH)_3 \downarrow + 3CaSO_4 + 6CO_2 + 18H_2O$

Natural alkalinity   Floc

(ii) $Al_2(SO_4)_3\ 18H_2O + 3Ca(OH)_2 = 2Al\ (OH)_3 \downarrow + 3CaSO_4 + 18H_2O$

Floc

(iii) $Al_2(SO_4)_3\ 18H_2O + 3Na_2\ CO_3 = 2Al\ (OH)_3 \downarrow + 3Na_2SO_4 + 3CO_2 + 18H_2O$

Floc

From the above reactions it is clear that the 666 parts by weight of alum will require 3 × 162 parts of natural alkalinity, which is again equivalent to 3 × 100 parts of alkalinity as $CaCO_3$. For many practical purposes it is often assumed that 2 parts by weight of alum will require 1 part by weight of natural alkalinity (as $CaCO_3$) for reactions.

Advantages of using alum as a·coagulant are as follows:

a) It produces crystal clear water.
b) It gives better floc formation.
c) The floc formed is quite tough and it is not broken easily.
d) Promotes better settling and longer filter runs.
e) Aids in reduction of tastes and odours.
f) It is cheap.
g) It is superior in tests against other coagulants.

h) It is high in quality.

i) It is simple in working and does not require skilled supervision.

2. Iron Salts : These are generally used for soft water having a low pH value. They also remove colour present in the water. The only exception is with ferrous sulphate which can react in high pH value. They can react in a longer range of pH values than alum. They are quite cheap, react quickly and form heavy flocs. But as they are corrosive and deliquescent, they are difficult to handle and store. They are also staining and promote the growth of iron bacteria in the distribution system.

Ferric salts being good oxidising agents can remove hydrogen sulphide and the tastes and odour due to that. A coagulant 'chlorinated coppers' which is a mixture of ferric chloride and sulphate is frequently used in water treatment.

Iron salts are used as coagulant more for sewage than water treatment.

Chemical reactions

(i) $FeSO_4.7H_2O + Ca(OH)_2 = Fe(OH)_2 + CaSO_4 + 7H_2O$

$4Fe(OH)_2 + O_2 + H_2O = 4Fe(OH)_3 \downarrow$

Floc

(ii) $6FeSO_4 . 7H_2O + 3Cl_2 = 2Fe_2(SO_4)_3 + 2FeCl_3 + 42H_2O$

$Fe_2(SO_4)_2 + 3Ca(OH)_2 = 2Fe(OH)_2 \downarrow + 3CaSO_4$

(iii) $2FeCl_3 + 3Ca(OH)_2 = Fe(OH)_3 \downarrow + 3CaCl_2$

From the above reaction it may be noted that 278 parts by weight of $FeSO_4.7H_2O$ requires 74 parts by weight of $Ca(OH)_2$ for reaction.

3. Sodium Aluminate ($Na_2Al_2O_4$) : This is an alkaline compound sometimes used as coagulant. It can react in water which does not have natural alkalinity. It reacts quickly with the non-carbonate hardness in the process of coagulation and is, therefore, useful in treating hard turbid, waters.

It is much costlier than alum.

Chemical reactions

(i) $Na_2Al_2O_4 + Ca(HCO_3)_2 = CaAl_2O_4 \downarrow + Na_2CO_3 + CO_2 + H_2O$

(ii) $Na_2Al_2O_4 + CaSO_4 = CaAl_2O_4 \downarrow + Na_2SO_4$

(iii) $Na_2Al_2O_4 + CaCl_2 = CaAl_2O_4 \downarrow + 2NaCl$

Aluxiliary Chemicals : These chemicals are not primarily used for coagulation but they help it in the process of other treatments. Lime and sodium carbonate are used in controlling pH value of water. But with their use floc formation is found to be better and minimum amount of coagulants are consumed. Similarly the main function of chlorine is for disinfection, but side by side it helps in coagulation.

Table 3.4 : Advantages and disadvantages of coagulants

Sl. No.	Type	Coagulant	Suitable pH Range	Advantages	Disadvantages
1.	Hydrolysing Metallic Salts	Alum (Aluminium Sulphate)	pH = 5.5 to 7.5	A standard in coagulation. Attracts inorganic suspended solids very effectively.	Fast mixing is critical to proper functioning. Non-optimal pH leads to excessive dosage requirements.
		Ferric Chloride Ferric Sulphate	pH = 5.5 to 11	Ferric chloride is good at attracting inorganic SS. Gives more compact sludge. pH sensitivity is somewhat less than alum.	Lower efficiency for removing organic suspended solids than alum. Fast mixing is critical to proper functioning.
2.	Pre-Hydrolysed Metal Salts	PACl/PAC (Polyaluminum Chloride) Polyaluminum Sulphate Polyiron Chloride	pH = 4.5 to 9.5	Does not require addition of alkali to raw water for coagulation, and is much less sensitive to pH	Generally requires an on - site production process to prepare pre - hydrolysed metallic alum. Generally requires an on-site production process to prepare pre-hydrolysed metallic salts from iron chloride
3.	Synthetic Cationic Polymers	Epichlorohydrin Dimethylamine (epi-DMA) Aminomethyl polyacrylamide Polyalkylene Polyamines polyethylenimine		Lower dosages required, producing denser sludge. When used in combination with metal salts, greatly reduces their dosage requirement, resulting in substantial economic benefits	Determining correct proportion for mixing with inorganic coagulants and other additives has been challenging due to a historical lack of instrumentation for determining relative amounts of inorganic, organic, and biological suspended solids in raw water

3.15 COAGULANT AIDS

While alum is perhaps the most commonly used coagulant, cationic polymers are used as both the primary coagulant and the coagulant aid. An ionic (negatively charged) and non-ionic (neutral) polymers have also been proved to be effective in certain applications as flocculation aids. These types are suitable for treating water containing both positive and negative charges and varying zeta potential. There are three types of coagulation flocculation aids: activated silica, weighting agents and polyelectrolytes. Table 3.5 shows the typical coagulant aids and their doses.

Table 3.5 : Common Coagulants Aids and Doses

Coagulant aid	Typical dose, mg/*l*
Activated silica	7-10% of the coagulant
Cationic polyelectrolyte	0.1-1
Anionic polyelectrolyte	0.1-1
Non-ionic polyelectrolyte	1-10
Bentonite (clay)	10-50
Coagulant	**Typical dose ratio**
Aluminium sulphate + caustic soda	3:1
Aluminium sulphate + hydrated lime	3:1
Aluminium sulphate + sodium aluminate	4:3
Aluminium sulphate + sodium carbonate	1:1 to 2:1
Copper sulphate and hydrated lime	3:1
Ferric sulphate + hydrated lime	5:2
Ferrous sulphate + hydrated lime	4:1
Ferrous sulphate + chlorine	8:1
Sodium aluminates + ferric chloride	1:1

a) Activated Silica

The key chemical in activated silica is sodium silicate. Activated silica improves coagulation by strengthening the floc and widens the pH range for effective coagulation. It may also improve the extent of decoloration and enhance floc formation in colder temperatures. The main disadvantage is the precise control required in preparation and feed rate.

b) Weighting Agents

As the name indicates, their primary role is to add weight to the floc to improve settleability.

Bentonite clay is a very common agent for this purpose. Weighting agents are used where water is high in colour, low in turbidity and low in mineral content. Typically, the dosages of 10–50 mg/*l* are used. Keep in mind though, this adds to the amount of solids in the sludge.

c) Polymers/Polyelectrolytes

Polymers are long-chain synthetic organic compounds commonly referred to as polyelectrolytes.

Based on their electrical charges, polymers are classified into three groups: Anionic (negatively charged), cationic (positively charged), and non-ionic — neutral (no charge). Cationic polymers can be used as primary coagulants or coagulant aids.

The primary advantage of polymers lies in reducing the quantity of alum sludge produced. The sludge produced is also easily dewatered. Alum sludge is otherwise difficult to dewater.

Advantages of Coagulant Aids

- Improved coagulation process.
- Aids in overcoming temperature drops that slows coagulation.
- Improved quality of the filtered water.
- Reduced chemical costs.
- Increased plant capacity.
- Reduced amount of sludge produced.

3.16 FEEDING DEVICES FOR ADDING CHEMICALS

Coagulants can be fed in raw water in two forms:

a) Wet form

b) Dry powder form.

a) Wet feeding

The liquid coagulant from coagulant storage tank is allowed to flow in the coagulant feeding tank through the inlet pipe. The level of solution in feeding tank is kept constant by a ball valve.

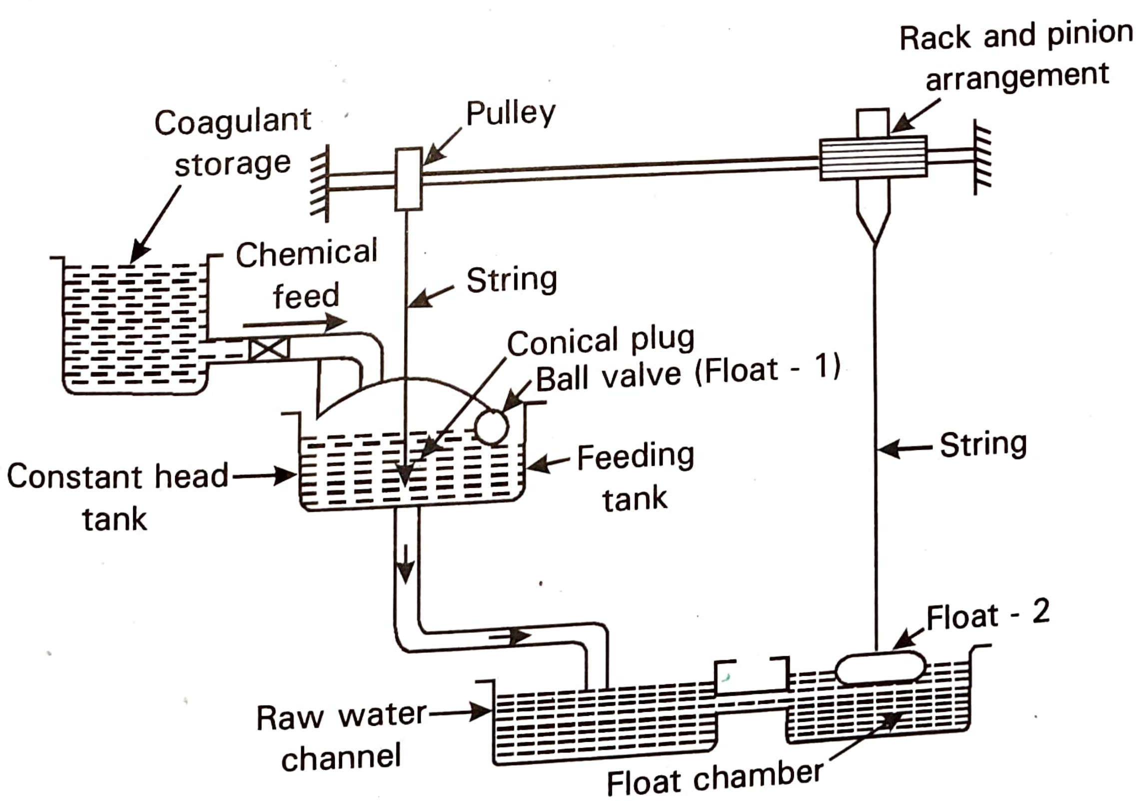


Fig. 3.21 : Conical Plug and Float Device

If the liquid level of this tank rises, float-1 rises up and the curved lever closes the mouth of inlet pipe. Again, when the level goes down, the mouth is opened. A conical plug is provided at the bottom of this tank which controls the flow of coagulant into the raw water chamber.

The raw water chamber is connected to the float chamber. If the water level in the raw water chamber rises, the water level in the float chamber will also rise and the float-2 will rise. Thus, the rack and pinion will move in one direction (clockwise or anticlockwise) and the pulley will also move in the same direction. The conical plug will be lifted automatically and more quantity of coagulant solution will enter the raw water chamber. The feeding of coagulant becomes slower when the water level of raw water chamber goes down. Thus, the conical plug controls the rate of feeding according to the volume of raw water.

b) Dry feeding

In this type of feeding, the coagulant is stored in a powder form and is then allowed to fall in the mixing channel in measured quantity.

The dry feeding is done by the device shown in Fig. 3.22. In this device, the coagulant is stored in powder form in a conical hopper. Agitating plates are provided inside the hopper. An agitator constantly goes on agitating the plates so that the coagulant can remain in loose powder form.

A toothed wheel is provided at the bottom of the hopper. The toothed wheel goes on rotating at an uniform speed and the coagulant also goes on dropping in raw water at a uniform rate. By adjusting the speed of the wheel the dose of coagulant can be adjusted.

It is simple in operation & requires less space for its working.

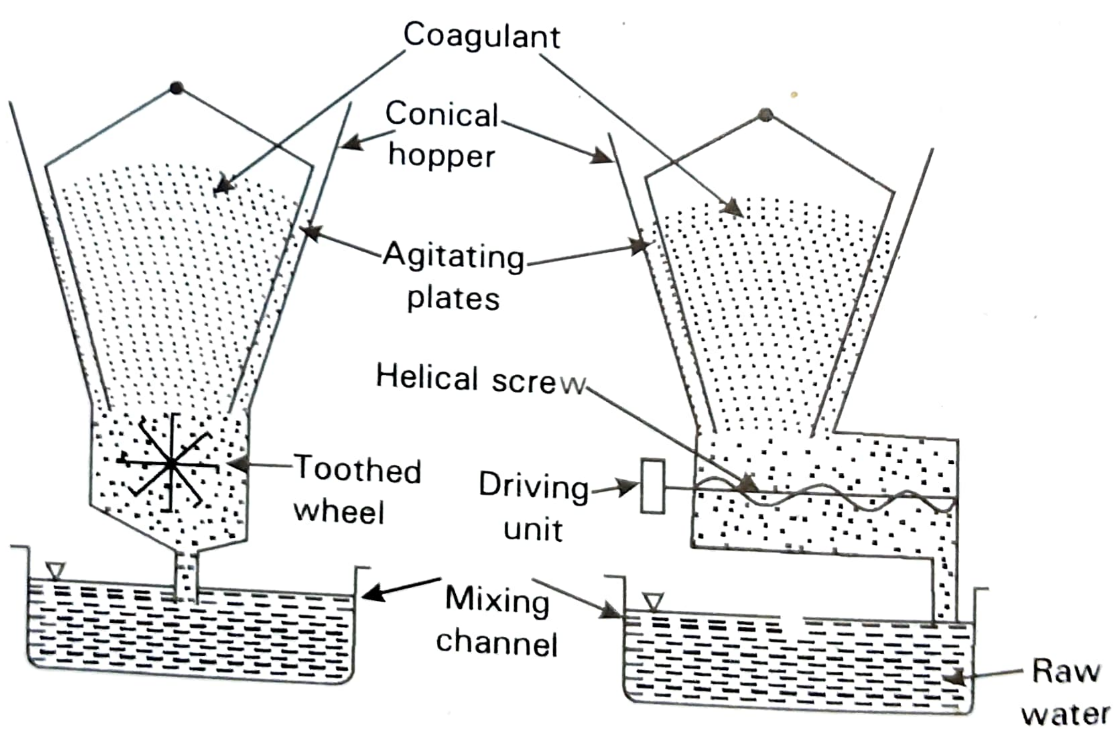


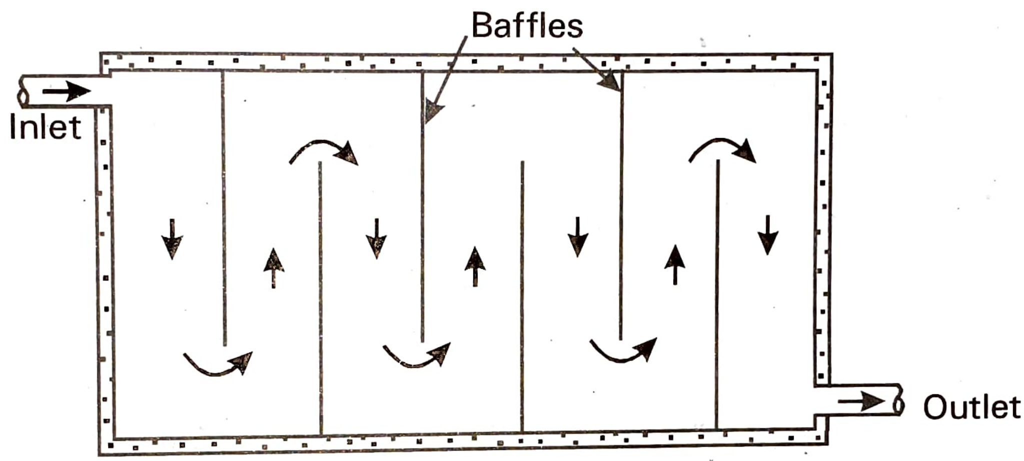
Fig. 3.22 : Dry feed devices

3.17 MIXING DEVICES

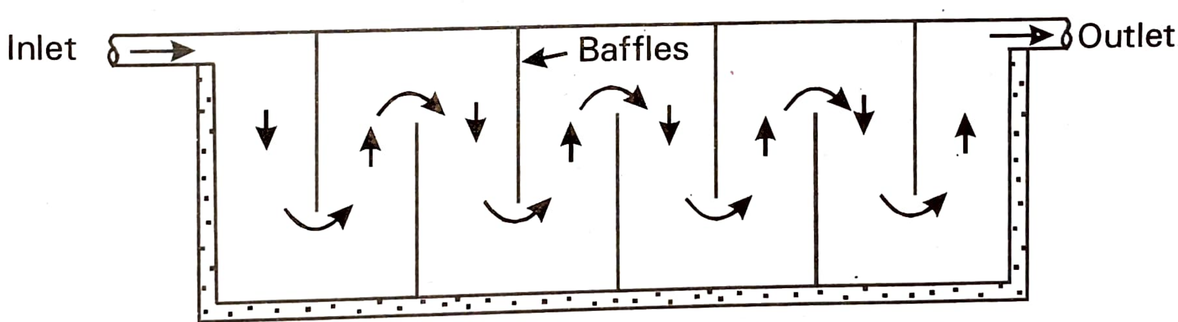
After adding coagulants in water, the next step is to mix the coagulants thoroughly in water so that it gets fully dispersed in the whole water. This mixing can be done by the following devices:

1. Mixing basins with baffle walls

In this type, the mixing tanks with baffle walls are provided to mix raw water with coagulant. These may be horizontal or vertical type. In case of horizontal type, a rectangular tank is divided into continuous series of channels by means of baffle walls which cause the water to which the coagulant have been added to flow round the ends of the baffle walls through number of channels. In case of vertical type, water flows up and down by the action of vertically hanging baffle walls.



(a) 'Round the end' Type (Plan)



(b) 'over and under type' (Vertical section)

Fig. 3.23 : Mixing Basins with baffle walls

2. Mixing basins with mechanical means

Mechanically Agitated Mixing Basins are those in which water is subjected to a violent agitation when the chemical is first added to water and then to a gentler action when the floc is forming. The first of these operations is usually obtained in Flash Mixers and the second in a Flocculator.

Flash mixer

In a Flash Mixer the rapid mixing is brought about in a rectangular tank, by number of revolutions of a propeller fixed to a propeller shaft and driven by an electric motor. The coagulant brought by coagulant feeding pipe and is discharged under the impeller. The raw water is brought from the inlet pipe and is deflected towards the impeller by the deflecting wall. The thoroughly mixed water finally goes out from outlet.

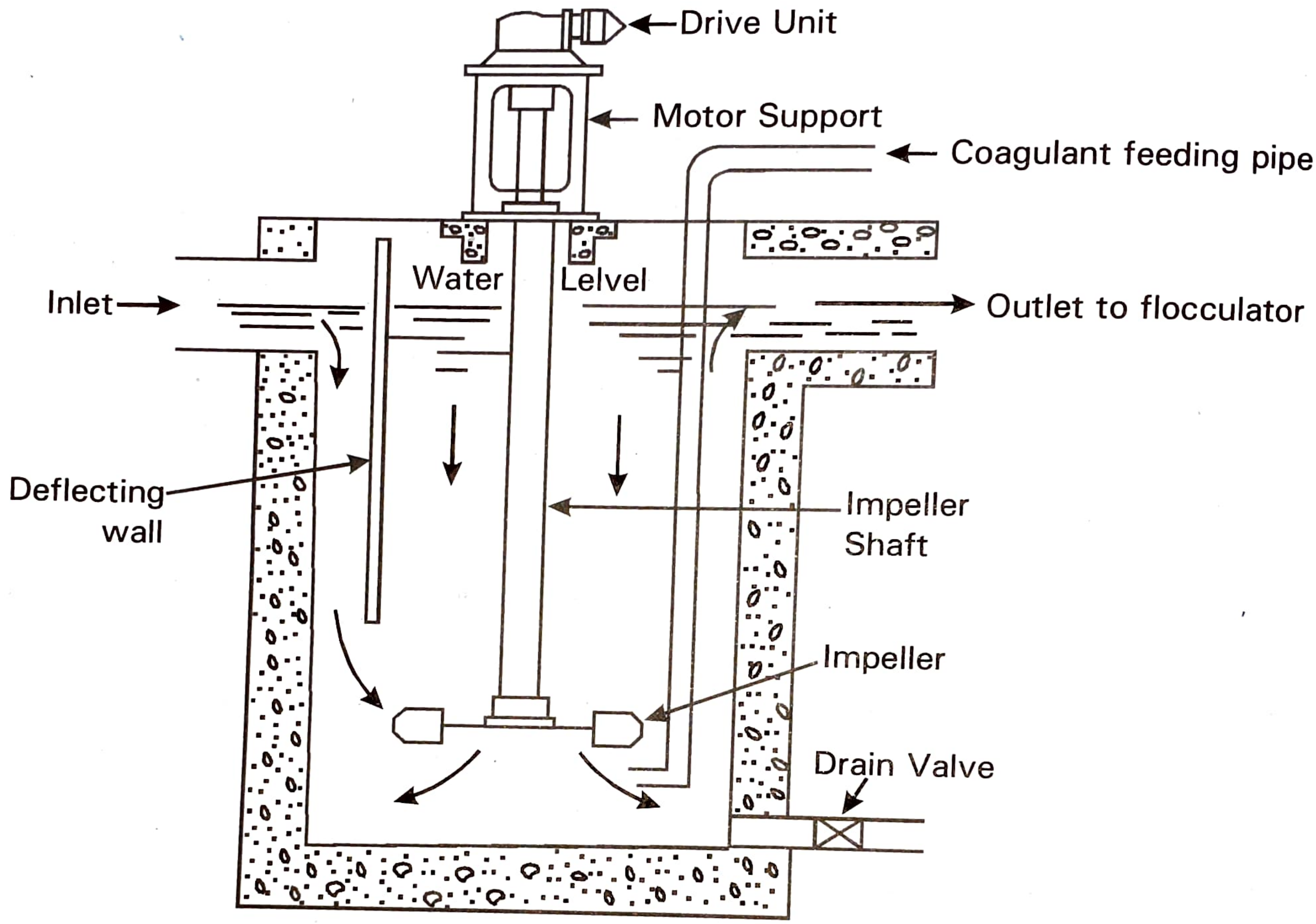


Fig. 3.24 : Flash Mixer

3.18 FLOCCULATOR

When the thorough mixing of coagulants in the water is over, the next operation is flocculation. The device by means of which floc is formed is called flocculator and the phenomena is termed as flocculation.

Flocculator essentially consists of a circular tank equipped with paddles revolving on a vertical shaft. The paddles operate at a slow speed of 2 to 3 r.p.m. The water enters from the inlet and leaves through the outlet. The detention time allowed for best flocculation varies from 30 to 60minutes.

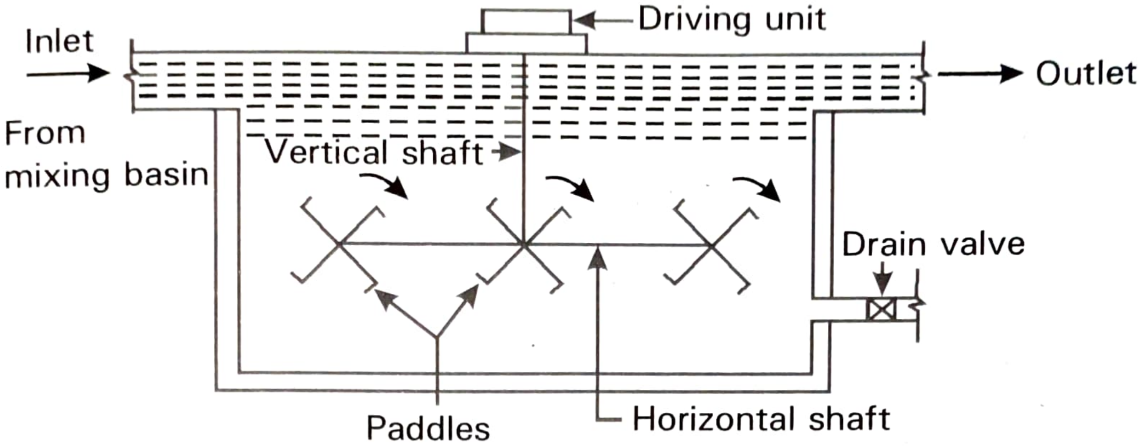


Fig. 3.25 : Flocculator

3.19 CLARIFIER

After flocculation, the water is allowed to settle in coagulation basins. In these tanks, floc settles at the bottom and clear water is taken out of tank for further purification. Coagulation basins in which water is allowed to settle are known as clarifiers. The design of a clarifier is similar to that of a plain sedimentation tank. The horizontal velocity of flow of water is kept lower than 90 cm per minute. The normal velocity is 30 cm per minute. Surface loadings vary from 40,000 to 60,000 litres per square meter per day.

The inlets and outlets are so designed that no disturbance is caused in the settling zone.

Detention period varies from 1 1/2 to 2 1/2 hours. The settled sludge is continuously drained out under hydrostatic pressure and let out into the nearby sewers. The amount of sludge produced is comparatively small. The chemical feeding and mixing can also be done at the entry point of the clarifier. Fig. 3.26 shows typical clariflocculator.

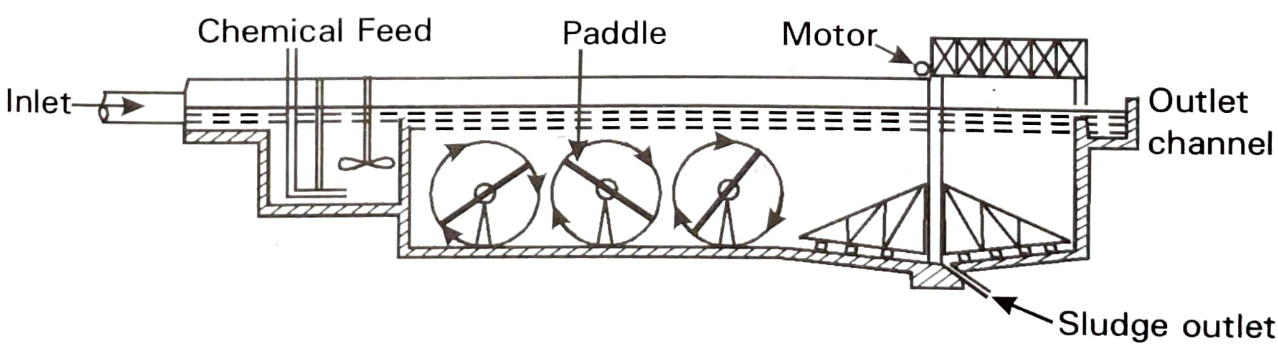


Fig. 3.26 : Clarifiocculator

Table 3.6 : Different types of flocculator

Sl. No.	Name of the Flocculator	Description
1.	Paddle Flocculator	
i)	Horizontal Shaft paddle flocculators	Horizontal flocculators are generally rectangular in shape.
ii)	Vertical shaft Flocculator	Verticale flocculators are generally square in shape. This type of flocculator usually requires less maintenance since they eliminate submerged bearings and packings.
2.	Hydraulic flocculators	In hydraulic flocculators the flow of the water is so influenced by small hydraulic structues that a stirring action results. Typical examples are channels with baffles, flocculator chambers placed in series and gravel bed flocculators.
i)	Baffled channel flocculators	This type of flocculator is well suited for very small treatment plants. The efficiency, however, is highly dependent on the depth of water in the baffled channel. Flocculators with vertical flow through baffled chambers are mostly used for medium and larger - size water treatment plants.
ii)	Alabama-type flocculators	Alabama - type flocculators are hydraulic flocculators having separate chambers placed in series through which the water flows in two directions. The water flow from one chamber to the next, entering each adjacent partition at the bottom end through outlets turned upwards. For effective flocculation in each chamber, the outlets should be placed at a depth of about 2.50 m below the water level.
iii)	Pebble Bed Flocculators	In this type of flocculator, flow is directed through gravel media in a vertical tank provides a large number of void openings in which flocculation will occur. Larger gravel media are used to provide larger void openings for mixing and to prevent cloggings.

3.20 FACTORS AFFECTING FLOCCULATION

The purpose of all flocculators is to provide gentle mixing that will produce a quick settling floc. The main factors affecting flocculation are as follows:

(a) Degree of Mixing

If mixing is too gentle or too fast, it will not form large floc. Very slow mixing fails to bring the suspended particles in contact with each other, while a too fast mixing tears the floc particles. The mixing energy is reduced in the direction of flow to achieve better results.

(b) Duration of Mixing

A certain minimum time of mixing is necessary for flocculation to be completed. In actual plant operations, depending on the temperature of the raw water, a period of 20 to 40 minutes is usually sufficient. To provide the required detention time, short-circuiting should be prevented. For this reason, at the entrance to the flocculator, the flow is directed downwards by placing a baffle.

(c) Number of Particles

Relatively clear water is harder to flocculate than turbid water containing a lot of suspended matter. A large number of particles allows more collision thus resulting in large size floc.

(d) Degree of Coagulation

Coagulation destabilizes the particles causing turbidity, and flocculation clumps these particles together forming a settleable floc. Improper dosage, change in the quality of raw water, and temperature can affect the coagulation and flocculation processes.

3.21 COAGULATION AND FLOCCULATION

Coagulation followed by flocculation promotes settling and help remove bacteria and other particles that cause turbidity, taste, odour and colour. Coagulation and flocculation process happens in the following stages:

- Alum added to the raw water reacts with the alkalinity naturally present or the alkalinity added as lime or soda ash to form alum floc as $Al(OH)_3$. A certain level of alkalinity (residual) must be present for the reaction to occur.
- The positively charged aluminium ions neutralize the negatively charged particles of turbidity and colour as soon as the coagulant is dispersed into the water.
- At this time, the particles clump together to form a microfloc. This happens in less than a minute.
- The microfloc produced during coagulation is allowed to grow or agglomerate to form a larger, denser floc. This process is called flocculation.
- Flocculation is followed by sedimentation to allow the floc to settle down. Turbidity of the settled water should be less than 10 NTU.

➤ Excessive carryover of the floc to the filter can seal or bind the filter media requiring more frequent back washings.

3.22 DOSING

The process of adding of the coagulants in correct amounts is known as dosing. This depends upon the Turbidity of Water, its Colour, pH Value, temperature of the water & time of settlement. Generally the coagulating agents are chosen on the basis of quantity of water. The maximum dose of coagulant should be used by having a test before use.

3.23 CALCULATION OF OPTIMUM COAGULANT DOSE

The Jar Test is the laboratory method to determine the optimum dosage of a particular coagulant which is required to be added to the raw water for coagulation and subsequent sedimentation in a treatment plant.

The Jar test apparatus consists of a rotary device having six number vertical stirring rods provided with pedals at lower ends and called multiple stirrer, with stirring water and alum content placed in six number beakers or jars each of 1 litre capacity. A horizontal shaft which is geared directly to an electric motor. The motor is provided with speed-reducing gears which enable the pedals to revolve at different speeds as required in the first and second stages of the coagulation process.

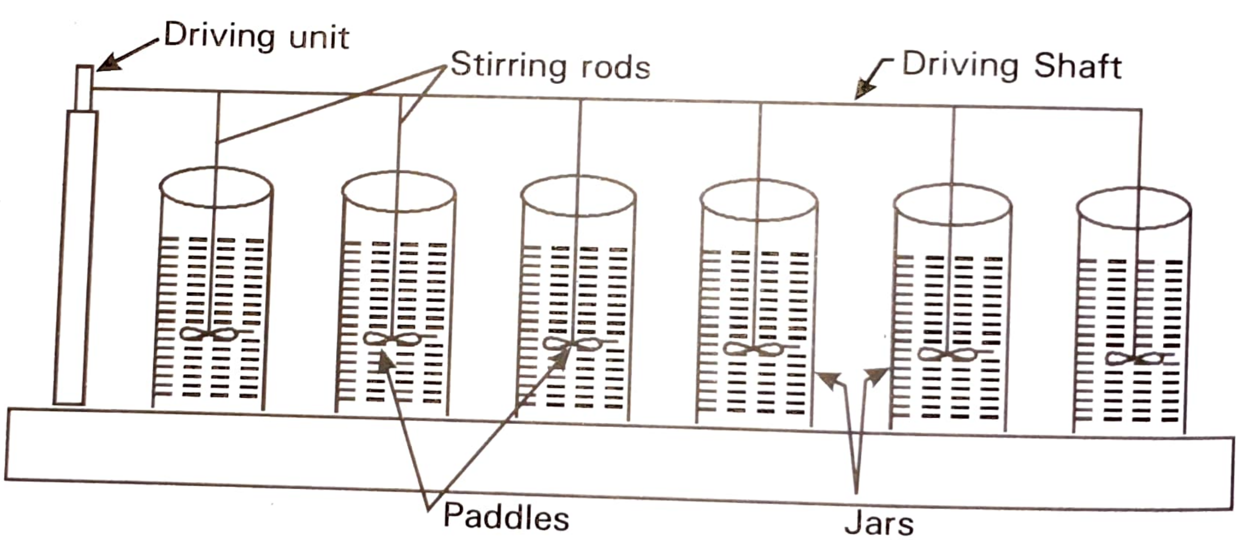


Fig. 3.27 : Jar test

The different amounts of alum solution are added to each jar containing the same amount of water sample and the contents stirred rapidly at first for 2-3 minutes and slowly later for about 30 minutes. The liquid is finally allowed to stand so that floc may form.

The smallest dose of alum that produces a good floc is taken as the optimum dosage for the particular water.

Table 3.7 : Typical design criteria for rectangular and circular sedimentation tank

For Rectangular Tanks			
Sl. No.	**Parameters**	**Typical range of values**	**Comment**
1	Surface over flow rater ($m^3/m^2.d$)	20 - 40	40 - for turbidity removal: Q >10000 m^3/d 20 - for high algae removal: Q >10000 m^3/d
2	Detention time, hours	Not less than 2.5	Maximum 8
3	Length (L), m	Generally Upto 30m	Maximum upto 60m
4	Width (W), m	6	Maximum
5	L:W L:D	4:1 to 6:1 15:1	Maximum 4:1 ≥ 6:1 Preferred Minimum
6	Depth of tank; m	2.5 to 5.0 m	
7	Bottom slope	1%	
8	Mean Horizontal Velocity, m/s	0.005 - 0.018	
9	Reynold's number	< 20,000	
10	Weir loading rate, $m^3/m.d$	140 - 270	250 recommended maximum
11	Launder length, m	1/3 to 1/2 length of basin	Evenly spaced
12	Sludge depth, m	0.6 to 1.0	Equipment dependent
13	Sludge collector speed, m/min	0.3 - 0.9	Mechanical cleaning

For Circular Clarifier of Clariflocculator			
Sl. No.	**Parameters**	**Typical range of values**	**Comment**
1	Surface over flow rater ($m^3/m^2.d$)	25 to 75	Normally 30 - 40
2	Detention time, hours	Not less than 2.5 h	Maximum 8 h
3	Diameter of tank	Upto 30 m generally	Upto 60 m (maximum)
4	Depth of the tank	2.5 to 5 m	3.00 m normally
5	Bottom slope	Not less than 1:12 for mechanical cleaning About 1:10 for manual cleaning	
6	Inlet velocity	0.3 m/minute below the bottom of the partition wall between the flocculator and clarifier	
7	Velocity in the outlet lanunder	Less than 0.6 m/s	
8	Scraper tip velocity	One revolution, in 40 to 80 minutes, of scraper	
9	Weir loading rate, $m^3/m.d$	Normally upto 300 $m^3/m.d$ (normally)	Upto 1500 $m^3/m.d$ maximum
10	Launder length, m	- length of basin	Evenly spaced
11	Sludge depth, m	0.6 to 1.0	Equipment dependent
12	Weirs at outlet	90° V notches or circular orifices at 150 to 300 mm c/c	
13	Spacing of V-notch	c/c distance is 200 to 300 mm	
14	Power requirement	0.75 watts/m^2 of tank area for scraper mechanism	
15	Diameter of sludge pipe	Normally between 100 mm to 200 mm for mechanised units and above 200 mm for non-mechanised units	

3.24 FILTRATION

Filtration is one of the most important operations in the water purification process. After removing the large size of suspended particles by screening and sedimentation, the water still have same fine suspended materials and some bacteria. The process of passing the water through a thick layer of sand and gravel which acts as a strainer is called filtration.

Filtration is a physical and chemical process for separating suspended and colloidal impurities from water by passage through a porous bed made up of gravel and sand, etc. Actually the sedimentation even aided with coagulation and flocculation cannot remove all the suspended and colloidal impurities and to make water (specially surface water) fit for drinking filtration is a must.

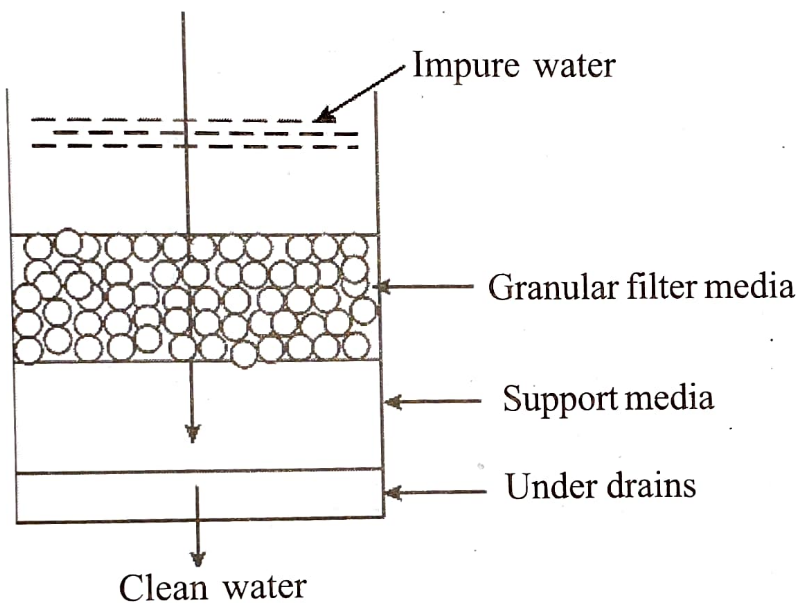


Fig. 3.28 : Filtration process

The theory of filtration includes the following actions:

- **Mechanical Straining :** The sand bed contains a large number of voids. When water is passing through these voids, the suspended matter that is too large to pass through, is retained on the surface of the sand bed. This action is called mechanical straining which removes the suspended particles.
- **Sedimentation :** Sedimentation and absorption remove small particles of suspended matter, colloids and bacteria. The voids in the sand bed form a number of small sedimentation basins in which the small suspended particles settle upon the sides of the sand grains.

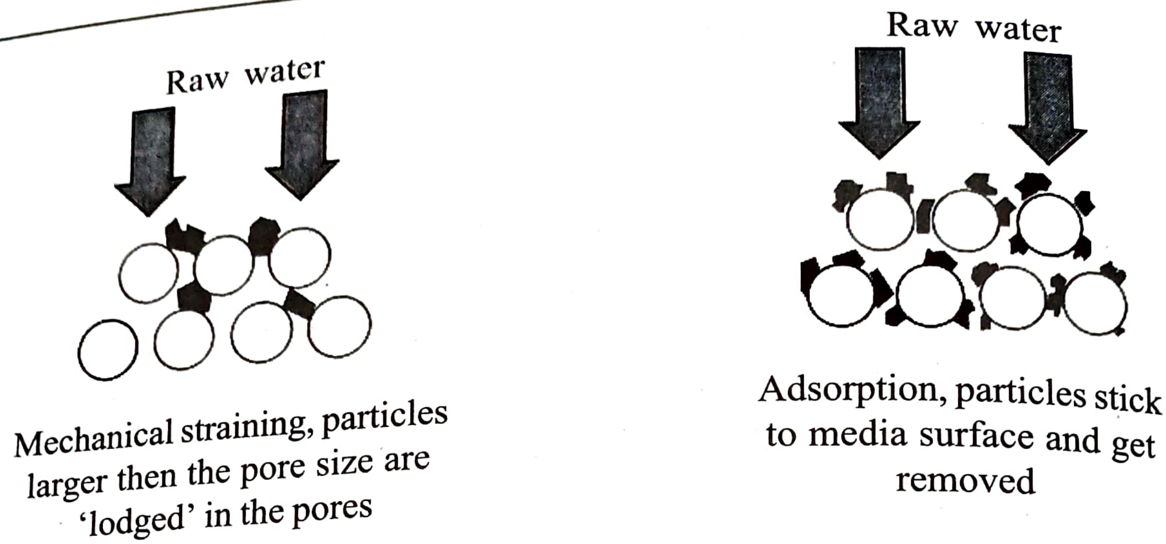


Fig. 3.29 : The principle filtration mechanisms

- **Electrolytic Action :** The electrolytic charges on the surface of the sand particles, which opposite to that of charges of the impurities are responsible for binding them to sand particles.
- **Biological Action :** Biological action due to the development of a film of microorganisms layer on the top of filter media, which absorb organic impurities.

3.25 FILTER MEDIA

The 'filter media', usually sand, is placed on top of the support media. A layer of graded gravels, with large size at the bottom and small at the top, is used to support the sand media. The function of the support media is to prevent the loss of 'filter media' along with the filtered water. The under drain blocks, at the bottom of the filter, while supporting the 'support' and 'filter' media collects the filtered water as well.

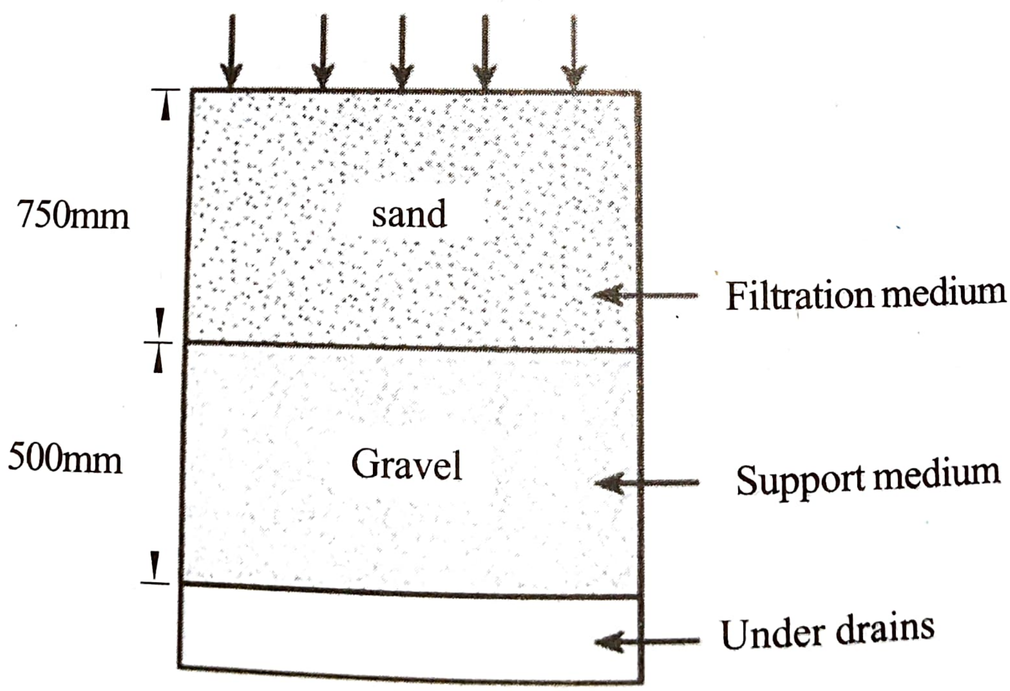


Fig. 3.30 : Filter media

Sand

It is the cheapest filter medium, and is widely used. Sand used for filters should be free from clay, silt, loam, suspended matter and other organic matter. It should be fairly uniform and of the proper size. Generally the sand either fine or coarse may be used. Sands are supported by gravels.

The sand used as filter-media should confirm the following properties:

1. It should be obtained from hard rocks such as basalt, trap and quartz.
2. It should be free from clay, loam, lime and organic matter, etc.
3. It Should be uniform in size.
4. Ignition loss should not exceed 0.7 percent.
5. If placed in hydrochloric acid for 24 hours, it should not lose more than 5% of its weight.
6. Specific gravity shall be in the range between 2.55 to 2.65.
7. Wearing loss shall not exceed 3%.
8. Sand with an effective size lying between 0.30 and 0.55 and having uniformity co-efficient between 1.30 and 1.75 is used.

Depth of sand bed: The depth of sand bed should be between 60 an to 90 cm.

Grading of sand bed: The sand bed consists of graded sand in various layers. For slow sand filters, sand having effective size between 0.3 and 0.35 mm and uniformity coefficient of 1.75 is used in Indian practice. For rapid sand filters sand having effective size between 0.45 and 0.7 mm and uniformity coefficient of 1.3 to 1.8 is used. Uniform grading or sand bed is very essential because it decreases the void spaces and makes bottom and top of filter bed equally effective, and increases the rate of filtration.

Anthracite

Crushed anthracite has been successfully used as filter medium as a substitute for sand in some filters

Garnet sand

It has high specific gravity (= 4.2) and is a dense material. Because of its high cost, it cannot be used as a sole filter material. However, it may be used as a constituent in mixed-media filter.

Gravel

The sand bed is supported on the gravel bed. Gravel bed has many functions due to which it is provided below the Sand bed.

The functions are enumerated as under:

a) It supports the sand and allows the filtered water to flow freely towards the under-drains.
b) It also allows the wash water to move upward uniformly on the sand.

The gravel is placed in 5-6 layers having finest size on the top.

The gravel used in filtration plant should be clean, hard, durable and rounded. It should be free from clay, loam, shells and foreign matter. It should not contain flat, thin or long pieces. It should have a density of about 1600 kg/m^3.

3.26 CLASSIFICATION OF FILTERS

Filters may be divided into main classes:

1. Gravity Filters
   a) Slow Sand Filters
   b) Rapid Sand Filters
2. Pressure Filters

3.27 SLOW SAND FILTER

Slow sand filters are best suited for the filtration of water for small towns.

The theory of slow sand filter is based on the principle that if water is allowed to percolate slowly through the filtering media, the biological, chemical and physical characteristics of water improved considerably.

The filtering action of a slow sand filter is a combination of straining, absorption, and biological flocculation.

Construction

Essential parts of slow sand filter are shallow tank with water-tight walls and floor, underdrainage system, base materials of coarse gravel, filter media of sand and appurtenance for efficient working of the filter such as the device for measuring the loss of head and device for controlling the rate of flow through the filter.

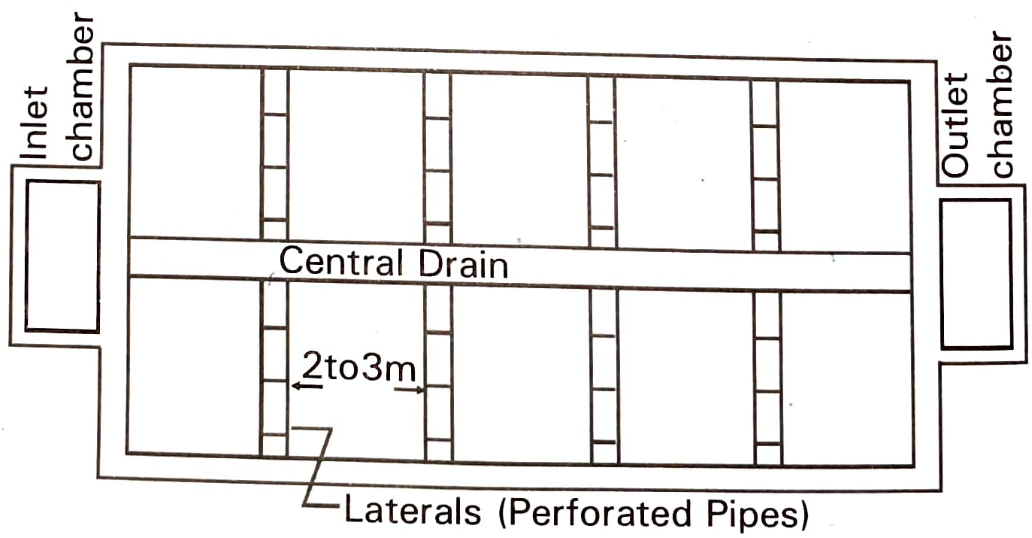


Fig. 3.31 (a) : Plan of filter with under drainage

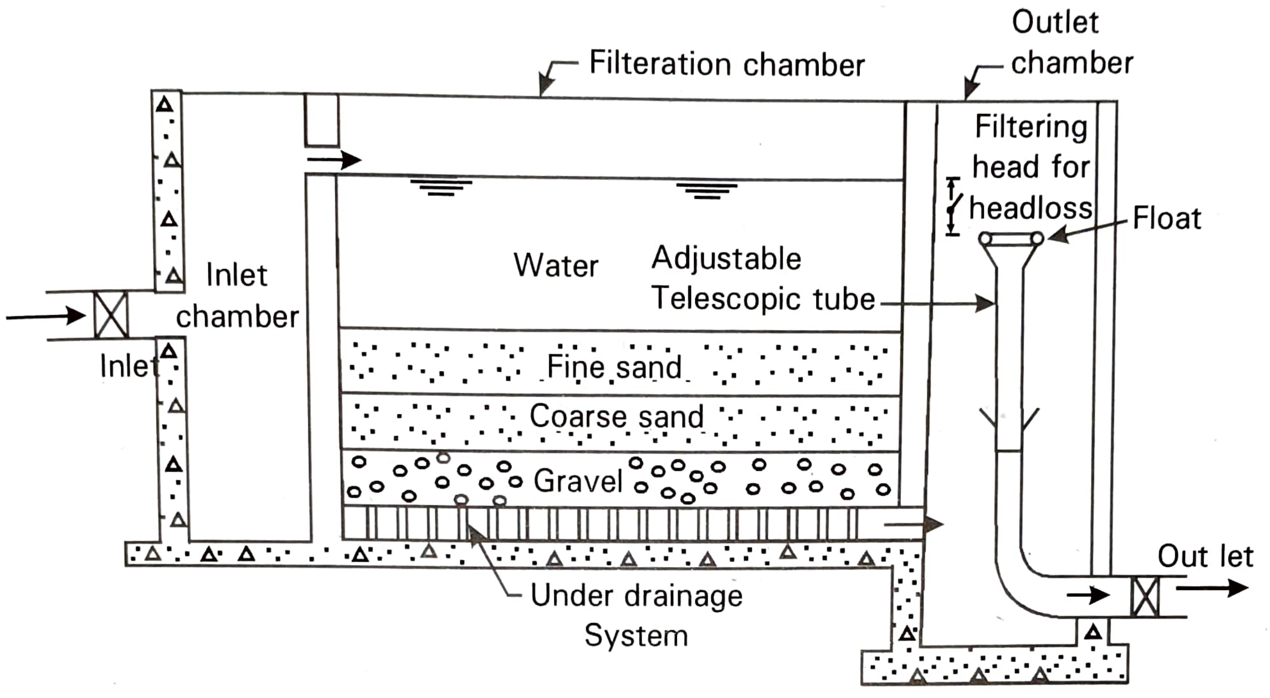


Fig. 3.31 (b) : Slow sand filter (Longitudinal Section)

Slow sand filter is made up of a top layer of fine sand of effective size 0.2 to 0.3mm and uniformity coefficient 2 to 3. The thickness of the layer may be 75 to 90 cm.

Below the fine sand layer, a layer of coarse sand of such size whose voids do not permit the fine sand to pass through it. The thickness of this layer may be 30cm. The lowermost layer is a graded gravel of size 2 to 45mm and thickness is about 20 to 30cm. The gravel is laid in layers such that the smallest sizes are at the top. The gravel layer is the retains for the coarse sand layer and is laid over the network of open jointed clay pipe or concrete pipes called under drainage. Water collected by the under drainage is passed into the outlet chamber.

Operation:

The water from sedimentation tanks enters the slow sand filter through a submersible inlet as shown in fig. 3.31. The water is allowed to stand over the sand bed to a depth equal to the depth of filter media. This depth is known as filtering head. The water percolates through the sand bed andgets collected in the outlet chamber through the under drainage system. The water from the outlet chamber is then taken to the next unit for further treatment.

It is essential to keep the rate of filtration constant. Different devices which are installed in the outlet chamber, can be used for the purpose. An open type of rate controller consists of a short piece of vertical telescopic pipe supported by an annular ring which floats on the water surface at a fixed distance above the submerged open end of the pipe.

During filtration as the filter media gets clogged due to the impurities, which stay in the pores, the resistance to the passage of water and loss of head also increases. When the loss of head reaches 60cm, filtration is stopped and about 2 to 3 cms from the top of bed is scrapped and replaced with clean sand before putting back into service to the filter. The scrapped sand is washed with the water, dried and stored for return to the filter at the time of the next washing . The filter can run for 6 to 8 weeks before it becomes necessary to replace the sand layer.

Slow sand filter is useful to remove large percentage of impurities and bacteria in comparison to the other process.

The slow sand filters are effective in removal of 98 to 99% of bacteria of raw water, Turbidity to the extent of 50 to 60ppm & colour to the extent of 25%.

Advantages of slow sand filter:

1. Simple to construct and supervise.
2. Suitable where sand is readily available.
3. Effective in bacterial removal.
4. Preferable for uniform quality of treated water.

Disadvantages of slow sand filter:

1. The slow sand filters requires large area for their construction and high initial cost for establishment.
2. The rate of filtration is also very slow.
3. Unsuitability for treating highly turbid waters (raw water turbidity should not exceed 30-50 mg/1).
4. Less flexibility in operation due to seasonal variations in raw water quality.

3.28 RAPID SAND FILTER

Rapid Sand Filters are the most common and essential treatment units at the modern water treatment plants world over. These are designed to operate at much higher loading rates of 120 m^3/d. m^2 to 240 m^3/d. m^2 which means smaller foot point. The sand bed, comprising of coarser sand, about 0.9m, is supported over a layer of graded gravel, about 0.30 to 0.45m deep.

The sand bed is 'stratified' as the method of cleaning the filter media is 'back washing'.The suspended or colloidal impurities are trapped in the pores of the sand media which extends deeper into the bed. Once the terminal head loss is reached the filters are 'cleaned' by 'backwashing' where wash water flow rates are sufficient to expand the sand bed and remove the 'accumulated impurities'. After 'backwashing' the sand bed gets 'stratified' as coarse sand particles settle first allowing a layer of fine particles to form the top layer. This is known as 'hydraulic stratification'. After backwashing the filters are restored for use.

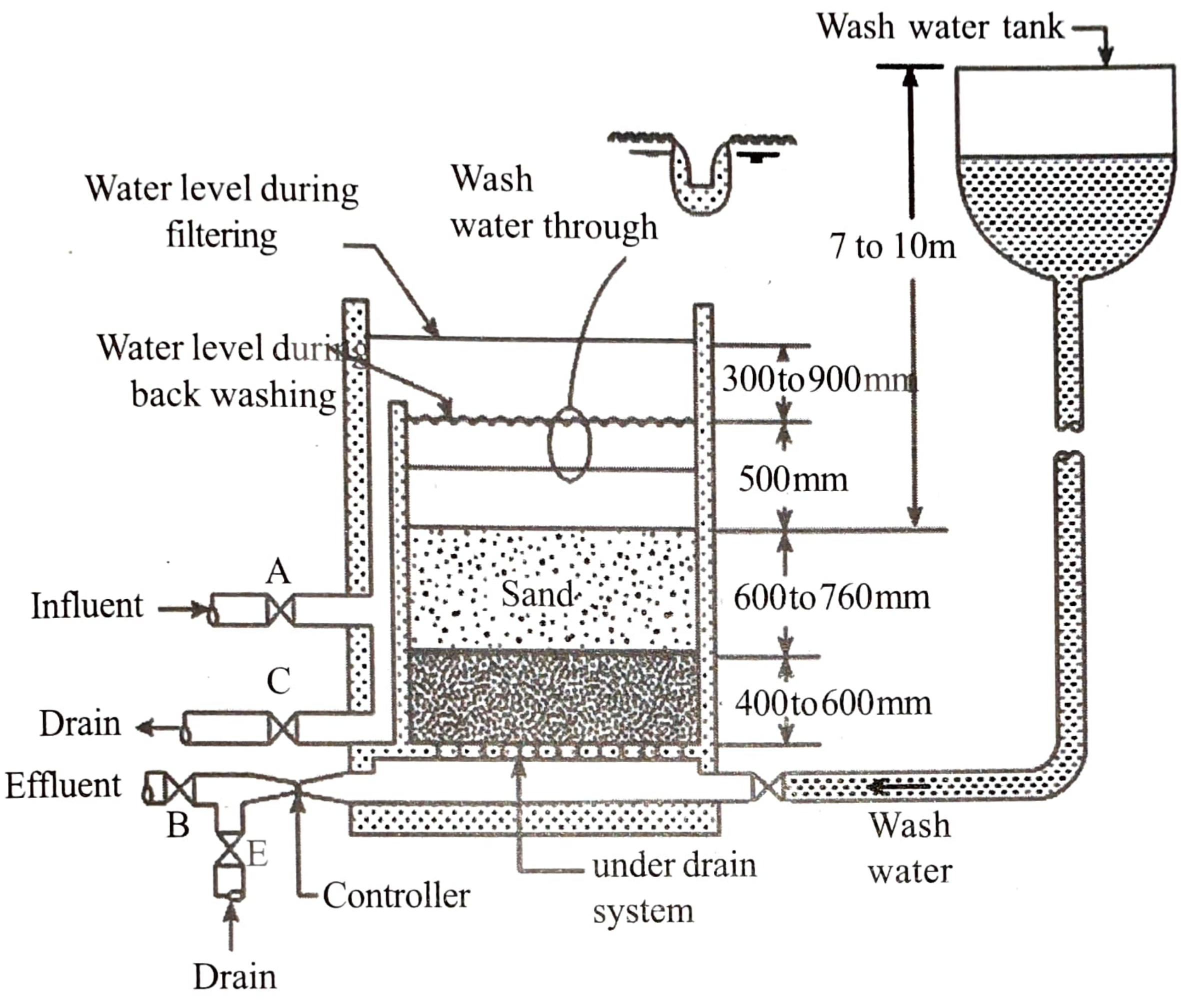


Fig. 3.32 : Rapid sand filter

As shown in Fig. 3.32 , a typical rapid sand filter box is 3.0m deep with sand bed of 0.75m supported over a 0.45m of a graded gravel layer. The gravel layer and sand bed 'rest' on the under drain system which usually comprises of a 'Manifold lateral' system. The wash water troughs are placed above the surface of the filter bed to carry away the dirty washwater during the back washing.

The filter run time is determined by the filtration rate which is expressed as $m^3/d.m^2$. i.e., the flow rate (m^3/d) divided by the surface area of the filter.

Filter Appurtenances

The filter appurtenances include the followings:

i) Sluice valves: On the influent, effluent, drains and wash water pipes. (Operated either manually, hydraulically or electrically).

ii) Measuring devices: Venturimeters, head loss and flow rate gauges.

iii) Rate controllers: Filtration and wash water controllers regulated by measuring devices.

iv) Indicators: Sand expansion indicator, water level indicator.

v) Miscellaneous: Operating platforms, water sampling devices, wash water tank and pumps, sand washers etc.

Filter Operation

The overall filtration cycle involves three operating procedures namely,

i) Filtering

ii) Backwashing and

iii) Filtering to waste

Key 'valves' position during three operations

Valve	Filtering	Back washing	Filtering to waste
Influent A	Open	Closed	Open
Filtered water B	Open	Closed	Closed
Wash water drain C	Closed	Open	Closed
Wash water supply D	Closed	Open	Closed
Filter to waste E	Closed	Closed	Open

Constant rate filtration

The filtration through the filter can be either constant rate or declining rate depending on the type of flow controller used. In case of constant rate filters, the filtration rate is controlled by 'throttling' or 'opening' the valves in relation to the build up of the resistance to the flow due to increasing accumulation of suspended solids i.e., in relation to increasing head loss with time. A constant depth of water (1–1.5m) is maintained over the media. Eventually at some time when the 'terminal head loss ' is reached.(usually 15 to 36 hours of operation) it becomes necessary to 'clean' the filter by 'backwashing'. The water from the back wash storage tank enters the filter through under drains and moves upwards through the filter bed expanding it slightly. A back wash rate of 10 L/m^2.sec to 40 L/m^2.sec is usually sufficient to provide required expansion of the bed. The wash water velocity shall be gradually increased from initial velocity, generally 7mm/sec to the final velocity say 10mm/sec. The expanded bed is washed for 5–15 minutes (typically 10 min) depending on the extent of clogging or the dirtiness of wash water. The dirty backwash water over flows in to the wash water troughs placed above the media and is either drained to municipal sewers or treated and recycled. Once the backwashing is stopped the filter media settles back on the bed. Due to 'hydraulic subsidence' the bed automatically gets 'graded' with larger particles settling at the bottom and finer at the top. The filter run cycle begins again. It is customary to waste the filtered water for initial 5 minutes by opening valve E, to prevent carryover of any suspended impurity to the clear water tank.

Declining rate filtration

In case of filters with declining rate of filtration the flow controllers are not used. As the clogging of the filter bed progresses during filtration the rate of filtration gradually decrease from initial maximum to find minimum when the bed is clogged. As the rate of filtration declines the water level over the sand media increases and when it reaches a predetermined level, the filter run is terminated and filter is cleaned by backwashing.

Rapid sand filters can give excellent quality of filtered water with turbidity levels less than 0.2 NTU.

The rapid sand filters are effective in removal of 80 to 90% of bacterial impurities present in water. Turbidity to the extent of 35 to 40ppm & highly efficient in colour removal.

Advantages of rapid sand filter

1. Turbid water may be treated.
2. Land required is less compared to slow sand filter.
3. Operation is continuous.

Disadvantages of rapid sand filter

1. Requires skilled personnel for operation and maintenance.
2. Less effective in bacteria removal.
3. Operational troubles.

Important terms related to filtration process

1. Head loss across the filter
2. Terminal head loss
3. Water head
4. Filter media
5. Filter media depth
6. Effective size of sand/media
7. Uniformity co-efficient(U)
8. Bed particle shape factor
9. Filter support
10. Under drains
11. Filtration
12. Backwash
13. Bed porosity

1. Head loss across the filter

The head lost due to the friction offered by the filter media, gravel layer and the under drains during the (passage of water) filtration of water indicated by the level difference between the water levels in two pilot tubes connected to near the top water level of the filter and the under drains.

2. Terminal head loss

It is the preselected head loss at which the filter run is terminated for backwashing. The continuation of filtration beyond this results in deterioration of filtered water quality due to increase in turbidity. It is one of the most important operating parameters.

3. Water head

The depth of water over the top of the sand media.

4. Filter media

The granular porous bed of a material like sand or anthracite to capture the suspended impurities in the pores larger size media minimises the head loss while smaller one captures particles better.

5. Filter media depth

The depth of the porous bed up to top of the gravel layer. Usual depth is 0.6 to 0.75m in case of Rapid sand filter (RSF), could be even 0.9m, however 0.75m is recommended.

6. Effective size of sand/media (D_{10})

The sieve size in millimetres (mm) which permits 10% of the total sand medium by weight to 'pass'. For RSF it varies between 0.45 to 0.7 mm.

7. Uniformity co-efficient

It is the ratio between the sieve size in millimetres which permits 60% by weight to pass and the effective size. i.e. $U=D_{60}/D_{10}$

where,

D_{60} = Sieve size in mm, permitting 60% of the total sand medium, by weight to pass

D_{10}= Sieve size in mm, permitting 10% of the total sand medium, by weight to pass

It varies between 1.3 to 1.8 for RSF.

8. Bed Particle shape factor

Used as a multiplier to the diameter of the sand grain to account for the non spherical shape of the sand particle

9. Filter Support

Several layers, usually five, of graded gravels (size ranging from 2 mm to 5 mm) laid between under drains and the filter medium to prevent the loss of sand through leaking in to the under drains and to uniformly distribute the back wash water. In case of RSF the gravel layer depth is 0.45 m and the size of gravel is 50mm at bottom and 2 to 5 mm at the top.

10. Under drains

Placed immediately below the gravel layer to support the filter medium, collect the filtered water and uniformly distribute the back wash water(and air if used for scouring). The commonly used under drain system is the 'Manifold and lateral' system which comprises of perforated pipe laterals discharging into a central (Manifold) pipe or channel.

11. Filtration

Removal of suspended impurities by passing the 'impure' water through a bed of porous medium which retains/ entraps the suspended or colloidal particles in the pore spaces.

12. Filtration rate

The flow rate(m^3/d) divided by the surface area of the filter(m^2) gives the filtration rate expressed as $m^3/d.m^2$.

13. Back wash

An operation which involves introducing the filtered water(small proportion) in to under drains for its up ward movement through the filter medium. In fact, the water is forced through to expand the bed causing the bed cleaning. Adopted under any one of the following conditions:

- Head loss reaches the 'terminal values'
- The filtrate turbidity reaches the upper permissible set value i.e. when the turbidity break through occurs.
- both terminal head loss and turbidity break through occurs simultaneously.

14. Porosity

Defined as the ratio of volume of voids to the total filter bed volume and is expressed as percent.

3.29 GENRAL OPERATING PROBLEMS DURING FILTRTION PROCESS AND REMEDIAL MEASURES

The three major areas in which most filtration problems occur are:

1. Treatment efficiencies before filtration
2. Control of the filtration rate
3. Backwashing the filter

Sudden changes in water quality indicators such as turbidity, pH, alkalinity, threshold odour number, temperature, chlorine residual or colour are an indication of problems in the filtration process or processes preceding filtration. During a normal filtration run, the operator should watch for sudden changes in head loss and turbidity breakthrough.

Probably the most common filter problem is filter breakthrough. Filter breakthrough can be defined as a steady increase in the turbidity of the filtered water. Normally, the turbidity of the filtered water stays relatively low and constant. Table 3.8 lists some of the common problems and recommended process changes as corrective measure.

Table 3.8 : Symptoms and Remedies of ill Filters

Symptoms	Possible Remedies
1. Source Water Changes	
• Turbidity, colour • pH, alkalinity • Temperature • Chlorine demand	➢ Perform jar testing and adjust dosage ➢ Adjust mixers ➢ Add or delete more filters ➢ Adjust frequency of sludge removal ➢ Start filter aid feed ➢ Adjust backwash cycle
2. Filtration Process	
• Head loss increase • Negative head • Short filter runs • Premature filter sealing • Mud balls • Media boils, separates, shrinks • Filter will not come clean	➢ Change coagulant, dosage or both ➢ Adjust flash mixer / flocculator mixing ➢ Reduce filter loading ➢ Reduce or terminate filter aid feed ➢ Adjust backwash cycle and frequency ➢ Remove Mud balls and replenish media ➢ Clean under drain system of any blockages
3. Changes in Filtered Water	
• Turbidity breakthrough • Colour • pH and alkalinity • Chlorine demand	➢ Adjust coagulant dosage ➢ Add more filters to reduce loading ➢ Adjust flocculator mixing intensity ➢ Start filter aid feed ➢ Adjust chlorine dosage

Operational problems in rapid sand filter

a) Mud Balls

Atmospheric mud gathered on the surface of sand. Due to inadequate washing of the filter, these mud sinks in to the bed, then they mixed up with the sand and other impurities to form mud balls. These mud balls will connect to the other mud ball and getting large in size. As they are gaining the sizes, they gets down to the bed and reach the gravel. They will then obstruct the upward movement of wash water at the time of cleaning.These mud balls, if allowed to remain, will cause clogged areas in the filter. Generally, proper surface washing will prevent mud ball formation.

b) Cracking of filters

The fine sand on the top layer of the bed will shrinks, and will cause the shrinkage cracks in the filter bed. Near the wall junction these cracks more prominent. Due to this the pressure on the sand bed will increase, and that will cause the cracks to open more. The mud and the other impurities will penetrate deep down into the filter through these cracks. This will effect washing as well as the efficiency of the filter.

c) Air Binding

When the filter is newly commissioned, the loss of head of water percolating through the filter is generally very small. However, loss of head goes on increasing as more and more impurities get trapped into it.

A stage is finally reached when frictional resistance offered by filter media exceeds the static head of water above bed. Most of this resistance is offered by the top 10 to 15 cm sand layer. The bottom sand acts like a vacuum, and water is sucked through the filter media instead of getting filtered through it.

The negative pressure so developed, tends to release the dissolved air and other gases present in water. The formation of the bubbles takes place which stick to sand grains. This phenomenon is called the Air Binding, as the air binds the filter and stops its functioning.

To avoid such troubles, filters are cleaned as soon as the head loss exceeds the optimum allowable value.

d) Media Breakthrough

When media breakthrough occurs, the media starts appearing in the filter effluent or even in the distribution system. When media breakthrough occurs, filtration has to be stopped quickly.

e) Gravel Mounding

When this happens, the gravel is blown up and is mixed with the filter media. Mounding is often caused by hydraulic surges due to improper backwashing.

f) Media Boils

Media boils appear during backwash when there is uneven distribution. In filters with nozzle type underdrains, boils are often the result of nozzle failure.

Remedial measures

The following remedies adopted to overcome above problems:

- By mechanical rakes, the mud balls may be broken and the broken particles will be washed with water.
- Mud balls may be broken by using water stream. During back washing for 4 to 5 min. compressed air is used with manual surface raking will be able to remove mud balls.
- Removing, cleaning and replacing the damaged filter sand.

3.30 COMPARISON OF SLOW SAND AND RAPID GRAVITY FILTERS

Sl. No.	Item	Slow sand filter	Rapid sand filter
1.	Area	Need very large area	Needs small area
2.	Coagulation	Not required.	Required.
3.	Sand Media	Effective size 0.2 to 0.3 mm uniformity coefficient 2 to 3.	Effective size 0.35 to 0.7 nun uniformity coefficient 1.3 to 1.8.
4.	Rate of Filtration	100 to 200 litres per hour per m^2 of filter area.	5000 to 12000 litres per hour per m^2 of filter area.
5.	Under drainage system	Laid in order to receive filtered water.	Laid in order to receive filtered water and also to pass water from back washing at a very high rate.
6.	Loss of Head	15cm to 75cm	2.00 to 4.0m
7.	Supervision	No skilled supervision is required	Skilled supervision is required
8.	Cleaning of Filter	Scraping of 2-3cm sand from surface and replacing it with new sand. Long and laborious method.	Agitation and back washing with or without the help of compressed air. Short and speedy method.
9.	Period of cleaning	1 to 3 months.	2 to 3 days.
10.	Efficiency	Very efficient in removing bacteria (98 to 99%) but less efficient in removing colour.	Less efficient in removing bacteria (80 to 90%) but very efficient in removing colour.

3.31 PRESSURE FILTERS

A pressure filter is a small rapid gravity sand filter placed in a closed cylindrical vessel and through which the water to be treated is passed under pressure which is higher than atmospheric pressure. So it should be noticed that the filters located in air tight vessels. The raw water is generally pumped into the vessel by means of a pump. The pressure normally developed may 25 to 65 metre head of water.

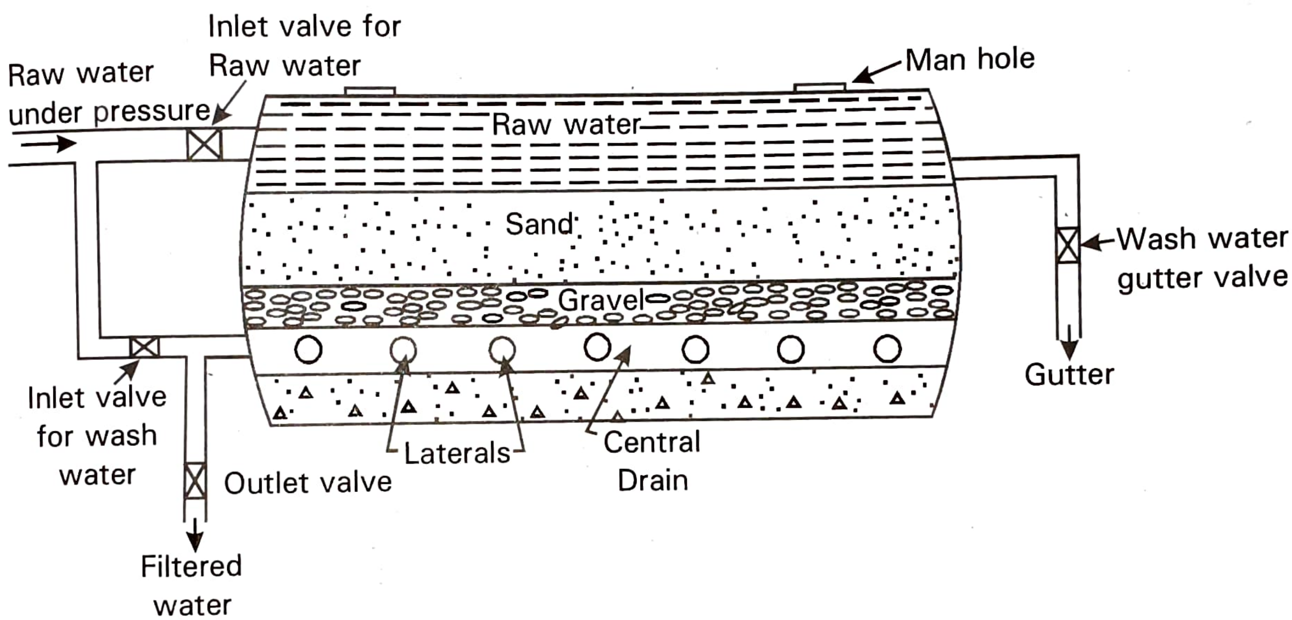


Fig. 3.33(a) : Horizontal pressure filter

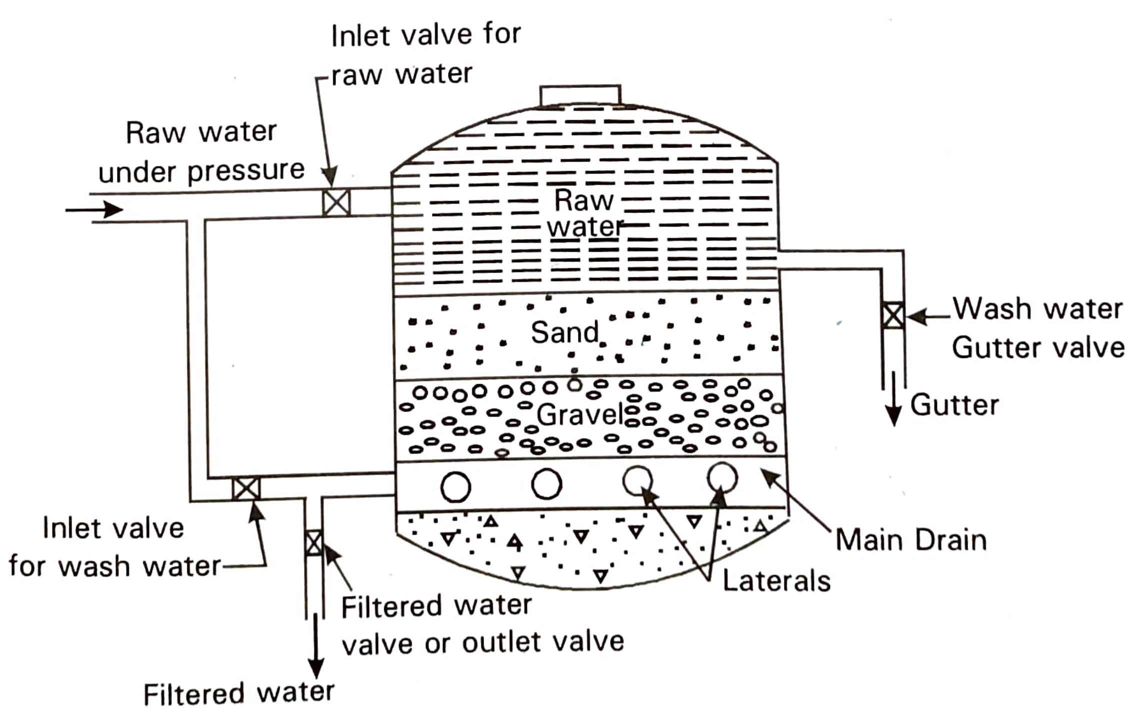


Fig. 3.33(b) : Vertical pressure filter

of filtration may be used for domestic, industrial supplies and the high rate is used for swimming pool recirculating supplies. Their rate of filtration normally ranges from 6000 to 15000litres per hour per sq.m of filter area.

Considering the water quality this is not efficient than the rapid sand filter; in removing bacteria and turbidities. The quality of filter water is very poor considering for consumption of public supply.

These filters are not used for treating Municipal water supplies

The pressure filters are classified as:

- Vertical Pressure Filters. (fig. 3.33 (a))
- Horizontal Pressure Filters. (fig. 3.33 (b))

Advantages

1. It is a compact and automatic operation.
2. These are ideal for small estates and small water works.
3. These filters are very flexible, because the rate of filtration can be changed by change of compressed air pressure over the water.
4. These filters requires small area for installation.
5. Small number of fittings are required in these filters.
6. Filtered water comes out under pressure no further pumping is required.
7. No sedimentation and coagulant tanks are required with these units.

Disadvantages

1. Due to heavy cost on treatment, they cannot be used for treatment large quantity of water.
2. Proper quality control and inspection is not possible because of closed tank.
3. The efficiency of removal of bacteria & turbidity is poor.
4. Change of filter media, gravel and repair of drainage system is difficult.
5. They require additional pumps to pump the water in them.

3.32 OPTIMUM FILTER OPERATION

Getting the best from filter units depends on understanding the factors responsible for causing poor efficiency and keeping the system in a good working order. Here are some ways to achieve optimum performance.

- Checking the media cleanliness frequently by core sampling or visual inspection.
- Effective backwashing is very important in operating the filter efficiently and getting long filter runs. If the nature of the floc is sticky, it is advisable to have surface wash or air scouring to remove the sticky material from media grains during backwashing.
- Keeping the filter medium clean and maintaining the medium depth are essential.
- Aggressive backwash with air-water combination helps to wash the medium clean with low flow rates and less frequent back washings.

- Maintaining good records of water quality, filter run length, backwash frequency and any changes made helps to take appropriate action in time.

3.33 DESIGN AND PERFORMANCE PARAMETERS

i) Filtration Rate

The rate of filtration is defined as the flow per unit surface of the filter and is a measure of hydraulic loading rate.

$$\text{Filtration rate/velocity} = \frac{\text{Flow rate}}{\text{Filter surface}}$$

This equation is based on the principle of continuity. Thus, filtration rate basically indicates the velocity of the flow through the filter. It can be directly observed by noting the water drop rate after closing the influent valve. Keep in mind that it is not the velocity of water as it moves through the filter medium. The actual velocity would be significantly more as the open area is less as some space is occupied by the solids.

ii) Unit Filter Run Volume

Unit filter run volume (UFRV) is a measure of filter performance and is used to compare and evaluate filter runs. To find UFRV, divide the total volume of the water filtered between filter runs by the surface area of the filter. For majority of filters the UFRV falls in the range of 200–400 m^3/m^2 of the filter area.

iii) Flow Rate and Volume of Water Filtered

In the calculation of filtration rate, the flow rate must be known. The flow rate can be determined if the total volume of water filtered per filter run is known. Total flow volume produced divided by the length of the filter run (time) would yield the average flow rate during a filter operation. Flow rate can also be directly read from the flow meter.

Filtration rate can also be estimated by measuring the water drop in a filter when the influent valve to the filter is closed. Water drop rate is essentially the filtration rate.

The filtration rate calculated by measuring the drop rate corresponds to the time when the drop rate is observed. For a given filter, it may vary depending upon the operation time after the backwash cycle. It makes sense to expect higher values in the beginning and a drop towards the end of the filter run.

iv) Backwash Rate

Backwash rates can be calculated in a similar fashion as filtration rates. Filtration rate represents the drop rate. In a similar manner, backwash rate represents the rise rate. Backwash rates are 5–10 times that of filtration rates. In the evaluation of the filter performance, it is important to consider the volume of water used for backwashing. This figure is usually expressed as a percentage of the water filtered, and is typically in the range of 4–6%.

v) Selection of Filter Sand or Other Media

Media commonly available may be too coarse or too fine to meet the design specifications. By washing the fines and screening the course material, the required size and uniformity can be obtain. By performing sieve analysis on the stock material, coarse and fine fractions are based on P_{10} and P_{60} of the stock material.