
UNIT 3 PURIFICATION AND TREATMENT OF WATER

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3.1 INTRODUCTION

The basic purpose of water treatment system is to provide wholesome water that is aesthetically attractive, hygienically safe and palatable. The extent of treatment of raw water depends on the characteristics of water. There are various methods such as screening, sedimentation, coagulation, filtration, aeration, disinfection and softening, etc. for treating raw water independently or in combination depending on the quality of raw water, desired water quality standard and cost involved in various alternative treatment units. The present unit describes the various types of treatment that are commonly employed for bringing raw water to desired standards of quality.

Objectives

After studying this unit, you should be able to

- develop an overview of the important processes that are employed in treatment of water,

- define pre-treatment and list various treatments that are included in it, and
- describe various treatment processes such as sedimentation, coagulation filtration, disinfection and softening, etc.

3.2 TYPES OF TREATMENT OF WATER

Treatment process of water can be classified into three categories, i.e. physical, chemical and biological, based on their principle of operation and prevailing quality characteristics of water.

3.2.1 Physical Treatment Processes

Characteristics such as size, density, viscosity, solubility are of importance in physical treatment operations. The chemical nature of the impurities and whether they are living organisms or inanimate objects are not relevant in physical treatment.

Treatments, which are physical in nature, include :

- screening and straining,
- sedimentation,
- flocculation, and
- filtration.

3.2.2 Chemical Treatment Processes

These processes depend on the chemical properties of the impurities. Chemical reagents are added to remove the impurities. They include :

- adsorption,
- coagulation,
- ion exchange, and
- precipitation.

3.2.3 Biological Treatment

Biological treatment utilizes biological activity to stabilize or remove impurities and they are particularly useful for the removal of organic impurities. Biological processes may be aerobic, anaerobic or facultative and are mostly done to purify waste water but not commonly used for treatment of water.

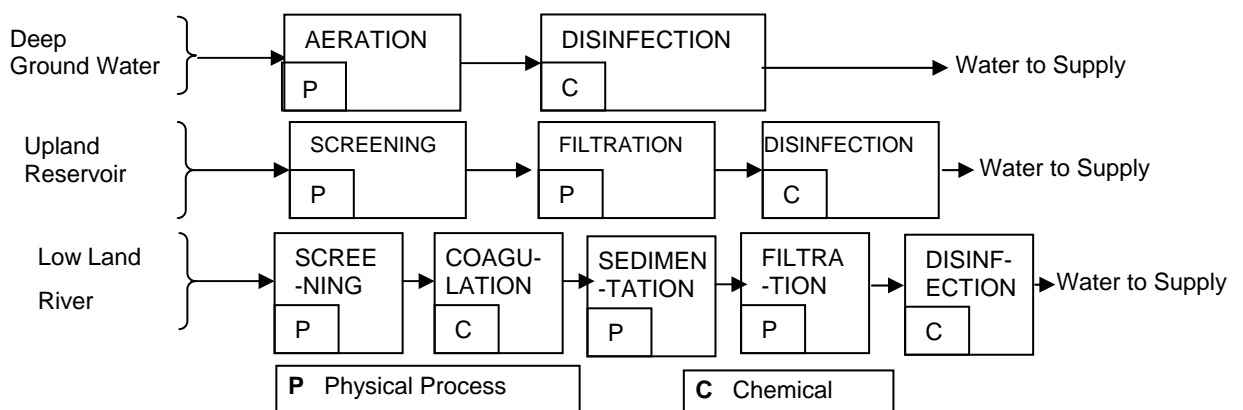


Figure 3.1 : Typical Water Treatment Processes

In practice, there are several processes which combine various modes of operation although one may predominate. For example, in the filtration of water through a bed of sand, the processes involved include physical straining, sedimentation, chemical and molecular attraction reactions, and some biological activity.

In many cases of water treatment, it is necessary to use several processes in sequence to achieve the desired natural quality. Physical processes like screening and straining often form first stage of the treatment chain and these are frequently followed by further physical or chemical processes for water treatment. Figure 3.1 shows some typical process chains for a number of situations.

3.3 PRE-TREATMENT

To reduce the load on main purification units such as sedimentation tanks, filter etc., raw water from river or streams is not pumped directly but sent to such units after pre-treatment. There are some intermediate processes, which collectively are called pre-treatment. These include :

- (a) Screening
- (b) Raw water storage
- (c) Pre-chlorination
- (d) Aeration
- (e) Algal control
- (f) Preliminary settling

Each processes perform a specialized function which may be employed independently or in combination as per the need of the situation.

3.3.1 Screens

Screens are provided in front of river/stream intakes so as to remove large size floating material from raw water. There are mainly two types of screen, i.e.

(i) coarse screens (trash racks) and (ii) fine screens.

Coarse screens are provided at river/stream intakes to prevent floating material of fairly large size entering into the intake. The bars of steel forming screen are normally of about 25mm diameter and are spaced 100 mm apart. The screen is placed at a slight inclination from the vertical to facilitate raking. Sometimes, bars in the form of frames are placed in duplicate so that one of the frames may be lifted for cleaning or repair when required without hampering the process. The bars in the frame are placed such that velocity of water through the screen opening should not exceed 0.5 m/sec.

Fine screens remove the fine suspended particles, which get pass through coarse screen. This is made up of fine wire or perforated metal with opening less than 10 mm wide. These are normally fitted immediately after the coarse screens.

3.3.2 Raw Water Storage

This is regarded as a first stage in treatment as it involves a complex combination of physical, chemical and biological changes. Raw water storage has been regarded as an almost essential “first line of defense” against the transmission of water-borne disease. When water is stored in a reservoir, there is usually a great decrease in the number of bacteria of intestinal origin and the specific organisms of typhoid and other water-borne disease also disappear. To some extent, this

effect is due to sedimentation but the bactericidal action of ultra-violet radiation and of light is of major importance near the surface and there are numerous biotic agencies, which play a major role in reducing the pollution of enteric micro-organisms. But prolonged storage of raw water sometimes causes growth in large numbers of various forms of algae, which increases difficulties in treatment.

The minimum water depth may be kept around 1.5 m as very shallow depth encourages weed growth and should be avoided. Storage normally provided purely to improve quality should atleast be equivalent to 7-15 days of average water demand. This is sufficient to reduce pathogenic bacteria and river algae. The beneficial effect of storage on water of low quality is shown in Table 3.1.

Table 3.1 : Change in Water Quality Due to Storage

	Raw River Water	Stored Water
Colour (Hazen)	30	5
Turbidity (NTU)	10	1.5
Chloride as Cl (mg/l)	54	54
Ammoniacal N (mg/l)	0.3	0.06
Nitrite N (mg/l)	0.1	0.01
Nitrate N (mg/l)	2.0	0.30
BOD (mg/l)	4.5	2.50
Total hardness (mg/l)	430	280
Iron (mg/l)	0.1	–
Presumptive Coli MPN per 100 ml	6500	20
E Coli, MPN per 100 ml	1700	10
Colony Counts (per 1 ml)		
3 days at 20°C	50,000	580
2 days at 37°C	15,000	140

3.3.3 Pre-chlorination

Pre-chlorination refers to the practice of injecting chlorine into the raw water when it is not so turbid but has a high bacteria count. Fairly high dose of chlorine (2-5 mg/l) is used. During the lengthy period spent by water in the settling basins, this oxidizes and precipitates iron and manganese if present in water. Pre-chlorination also kills algae and bacteria, reduces colour and slime formation and assists in settlement. If excessive silt is present in suspension, pre-chlorine is not so effective because silt absorbs chlorine without settling. Hence, in case of heavily turbid water, it is not very effective; in case of clear ground water with high ammonia content, it is effective.

3.3.4 Aeration

Aeration is the process of providing oxygen from the atmosphere to effect beneficial changes in the raw water. Due to aeration undesirable gases such as carbon dioxide and hydrogen sulphide is liberated. The absorption and release of gases in water is a slow process. Hence, water is agitated or a great water area is exposed to the atmosphere. This is done by splashing water over trays to break up the stream into countless droplets or by reversing the effect and blowing air bubbles through water.

3.3.5 Algae Control

Algae tend to float and are not easy to remove by means of settling basins. The best way to kill algae is by pre-chlorination before reaching the basins with a dose of 1 mg/l. Where organisms are more, a heavier dose of copper sulphate (2 mg/l) or chlorine (3-5 mg/l) may be necessary and again this high dose has to be removed before water is allowed to use. Strainers are widely used to remove algae either in the form of rapid sand filters running without coagulants or as micro-strainers. Micro-strainers are also effective if water is silt free and have been found to reduce the algae problems to the extent of 80% to 90%.

3.3.6 Pre-settlement Basins

They are included in the treatment system to reduce the silt load on basins. The pre-settlement basins are required in case water has suspended solids concentration more than 1000 mg/l by dry weight. Although 3 hours detention period is more than sufficient, pre-settlement basins with 1 hour detention period have been found to be effective.

SAQ 1



- (a) List the water treatment processes covered under pre-treatment.
- (b) State whether the following are true or false :
 - (i) Screens are provided to remove colloidal particles present in water.
 - (ii) Water storage improves water quality.
 - (iii) Due to aeration, gases such as carbon-dioxide and hydrogen sulphide is liberated from water.

3.4 SEDIMENTATION

Sedimentation is the separation of the suspended particles higher than water by gravity settling. This process is used to remove inorganic impurities from water prior to subsequent treatment process. Process of sedimentation is classified into two categories, i.e.

- (a) Plain sedimentation, and
- (b) Sedimentation with coagulation.

In plain sedimentation, impurities are separated from the suspended fluid by gravitational force and natural aggregation, whereas in sedimentation with coagulation, the addition of chemical substances known as coagulants increase the aggregation and finely divided suspended and colloidal matter are made to settle.

Sedimentation tanks are designed in such a way that water flows at very low velocity and inorganic impurities settle at the bottom of the tank and the lighter impurities such as colloidal particle, etc. float at the surface of the water. The

settled impurities are removed from the bottom of the tank. The quantum of impurities removal in sedimentation tank depends on several factors :

- (a) Size, shape, density and nature (discrete or flocculant) of the particles.
- (b) Viscosity, density and temperature of water.
- (c) Surface overflow rate.
- (d) Velocity of flow.
- (e) Inlet and outlet arrangements.
- (f) Detention period.
- (g) Effective depth of settling zone.

However, it has been estimated that plain sedimentation tank removes about 60% of suspended and 70% of bacterial load from water.

Sedimentation tank are classified as :

- fill and draw type (also known as batch process), and
- continuous flow type.

Continuous types are most popular. Depending on their shape, they are classified as :

- circular,
- rectangular, and
- square.

Depending on the direction of flow, sedimentation tanks are classified as :

- horizontal flow – longitudinal or radial flow, and
- vertical flow – circular (upward flow).

Figure 3.2 depicts cross-section of typical horizontal flow sedimentation tank.

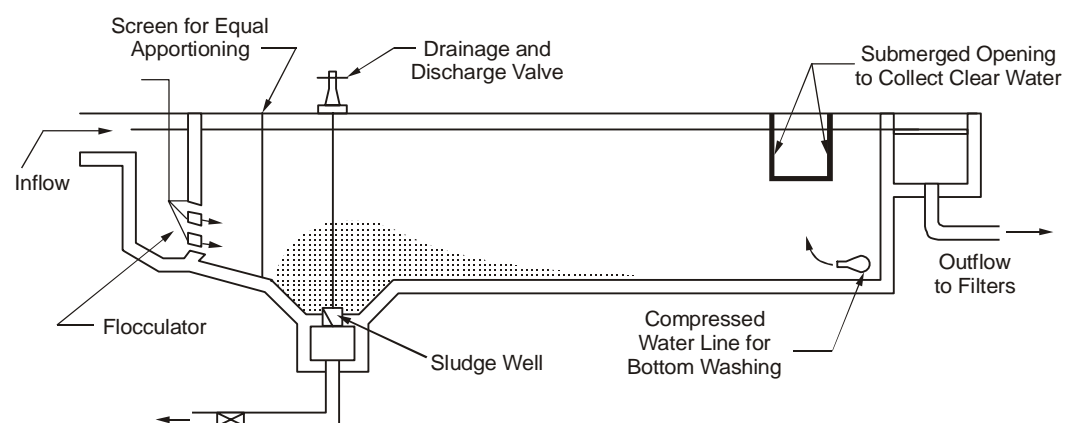


Figure 3.2 : Cross-section of Typical Horizontal Flow Sedimentation Tank

3.4.1 Common Design Criteria for Sedimentation Tank

While designing a sedimentation tank, following guidelines should be observed for its satisfactory performance.

Velocity of Flow

Velocity of flow of water in sedimentation tank should be sufficiently low to cause settling of suspended impurities. It should be uniform throughout the tank. Normally, velocity of flow should not be greater than 30 cm/min.

Tank Dimensions $L : B$ should be 3 to 5 : 1

Generally, length provided is 30 m and in extreme case, it may be taken as 100 m. Breadth should be between 6 m to 10 m. Circular tank : Diameter not greater than 60 m. Common size is 20 m to 40 m.

Depth of the Tank varies from 2.5 m to 5.0 m (3 m, typical).

Detention Period

This is the theoretical time for which the water is detained in a settling basin. It is evaluated as the volume of the tank divided by the rate of flow and is denoted as $D_t = V/Q$. Thus, it is that time which would be required by the flow of water to fill the tank if there was no outflow.

Detention period t for a rectangular tank

$$\begin{aligned} &= \frac{\text{Volume of the Tank}}{\text{Rate of Flow}} = \frac{V}{Q} \\ &= \frac{BLH}{Q} \end{aligned}$$

And detention period for a circular tank

$$= \frac{D^2(0.11D + 0.78H)}{Q}$$

where, D = diameter of the tank,

H = vertical depth at wall or side water depth, and

B and L = width and length of the rectangular tank respectively.

The formula for circular tank is based on the fact that the volume of the shape of circular tank used for sedimentation, which is having a cone shaped bottom with slope 1:1 and its volume is $D^2(0.11D + 0.78H)$.

The detention time usually ranges between 4 to 8 hours for plain sedimentation and 2 to 4 hours when coagulants are used.

Surface loading or overflow rate or surface overflow rate (SOR) is defined as the quantity of water passing per hour per unit area of settling tank :

$$\text{SOR} = \frac{Q}{L \times B}$$

For the plain sedimentation for normal water 12,000 to 18,000 l/d/m² tank area is required and for thoroughly flocculated water 24,000 to 30,000 l/d/m² of tank area should be provided.

Slopes should be kept as 1% toward inlet of the circular tank. The total amount of flow from the tank within 24 hours, generally equals the maximum daily demand of water. For the efficient removal of sediment in the tank, the flow should be uniformly distributed throughout the cross-section of the tank. If current permits a substantial portion of the water to pass directly through the tank without being detained for the intended time, the flow is said to be short-circuited. To reduce the tendency of short-circuiting, proper design of

the inlets and outlets near the entrance and exit is necessary. It is to be kept in the mind that relatively narrow tank are less affected by the inlet and outlet disturbance.

3.5 COAGULATION

In the previous section, we have seen that coarse solids can be effectively removed by sedimentation process as their size enables them to settle them by gravity. Solids which are not coarse (such as fine or colloidal solids) pass on along with the effluents of settling basin. For settlement of such particles, aggregation is essential. The aggregation of such particle require :

- particle destabilization to permit attachment when contact occurs, and
- agglomeration of the established particles.

For this purpose, certain chemicals known as *coagulants* are added to the water, which on thorough mixing, form *floc*. The fine colloidal particles present in water get attracted and absorbed on these flocs, forming the bigger size flocs.

Coagulation, thus, results in reduction of surface charges of colloidal particles and formation of precipitate.

The **coagulation** process is practically instantaneous and the initial particles are usually of microscopic in size. These colloidal particles are then gathered to form settleable solids by the process of **flocculation**. Coagulation utilizes force of electrostatic or inter-ionic nature whereas flocculation occurs by chemical bridging of physical enmeshing mechanisms. For all practical purposes, however, the entire process of addition of chemical (coagulants) and mixing (flocculation) is usually referred to as coagulation. The coagulated water is finally made to pass through the sedimentation tank, where the flocculated particles settle down, and are, thus, removed.

Hydroxide [e.g. $\text{Al}(\text{OH})_3$, $\text{Fe}(\text{OH})_3$] is the desired end product of coagulation. It is insoluble, floc-forming and heavier than water and it carries the positive electric charge necessary to neutralize the negative charges of the colloidal particles. Further reason for the addition of some form of alkali are to establish the optimum pH value at which coagulation can take place and to raise the final pH value after treatment to reduce corrosiveness.

Where floc formation is poor, coagulants aids are added. By producing a heavier, faster setting floc, this allows smaller basins to be used and smaller doses of the main coagulant may also be possible. The experiment to find out optimum dose of coagulant is known as Jar Test.

3.5.1 Commonly Used Coagulants

The most commonly used water treatment coagulant is based primarily on Aluminium or Iron salts. Lime is used as secondary coagulants in drinking water treatment but as a primary coagulant in waste water treatment. In certain cases, polyelectrolytes are used as coagulant.

The reaction of coagulants in water and waste water are well-known in water chemistry and some of these are reproduced here for the ease of reference.

Aluminum Salts

Aluminum Sulphate ($\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$)

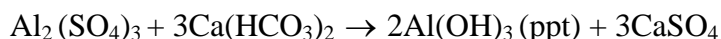
This is commonly known as filter alum or alum. When it is added to raw water, it reacts with bio-carbonate alkalinity present in raw water and forms gelatinous precipitate of aluminum hydroxide (floc). The

floc attracts under colloidal particles, grows in size and finally settles down. The chemical reaction involved is :

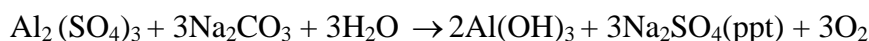


Likely Dosage

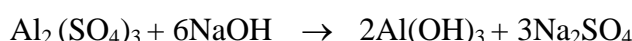
10 – 100 mg/l commercial product in water treatment is according to the quality of raw water; with lime added :



In water treatment, 1 part of $3\text{Ca}(\text{OH})_2$, 3 part of $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ (commercial aluminum sulphate) with soda ash added :



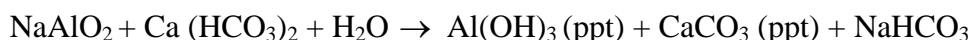
1 part of anhydrous sodium carbonate to 1 or 2 parts of $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ (commercial aluminum sulphate).



In water treatment, the requirement of NaOH is 36% of the dose of $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ (commercial aluminum sulphate).

Sodium Aluminates NaAlO_2

This white powdery compound of sodium hydroxide and aluminum oxide is usually used in conjunctions with commercial aluminum sulphate in drinking water treatment. The aluminate (5-10% of dosed alum) if added about 30 seconds before the alum, makes the flocs denser and the coagulation is effective over a wider pH range. Sodium aluminate reacts as follows



Iron Salts

Certain iron compounds such as ferric chloride can be used as coagulants and are normally cheaper, produce heavier flocs and operate over a wider pH range than sulphate of alumina. However, they are normally required to be used with lime and are a little more difficult to control. In this context, the following problem should be considered :

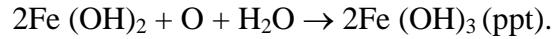
- (a) Special non-corrosive material may have to be used as liner for the storage containers.
- (b) Iron salts tend to form cake in humid conditions.
- (c) Iron salts are dirty to handle, causing staining.
- (d) Sludge is more difficult to dispose of without giving rise to aesthetic complaints.
- (e) Lime must be added, in advance.
- (f) While superior to alum in end results, bigger flocculation chambers may be required.

Ferric Sulphate

It can be used instead of ferric chloride, but is expensive. It should be used in special cases where decolourisation and clarification of water of low temporary but high permanent hardness is desired.



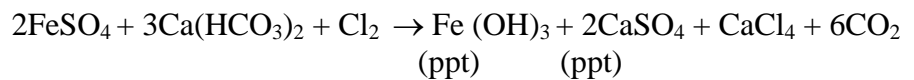
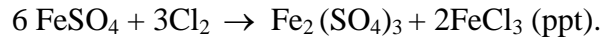
Ferrous Sulphate



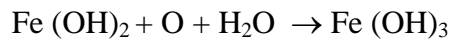
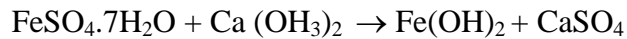
It should be used with sufficient lime or caustic soda to raise the pH to 8.5-10, more commonly used in industrial softening plants and industrial waste water treatment.

Chlorinated Coppers

Ferrous Sulphate (Coppers) with chlorine is called chlorinated coppers, which is extremely effective in drinking water treatment over a wide range of pH. The relevant reaction follows:

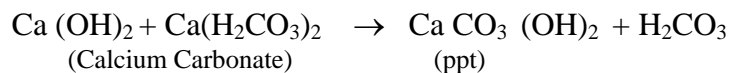
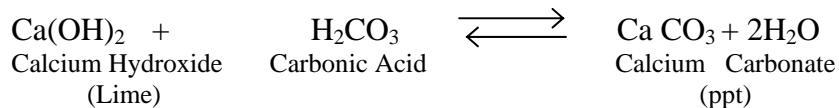


With hydrated lime, coppers reacts as follows :



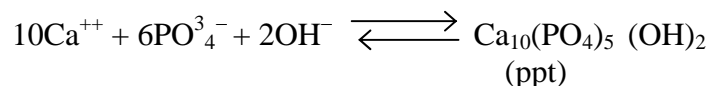
Lime

Lime is widely used with other coagulation in water treatment for raising pH and increasing alkalinity as indicated above. Lime is used alone as a precipitant to aid coagulant by iron salts. The reactions taking place is :



A sufficient quantity of lime must be added to combine with all the free carbonic acid and Calcium Bicarbonate, which act as a coagulant. Like all the other coagulants, the quantity of lime required for precipitation or coagulation need to be determined by the *JAR TEST*. Lime can be brought as CaO (quick lime) or Ca(OH)₂ (slaked or hydrated lime). The major problem in using lime as coagulant is the disposal of the large quantity of sludge produced. Lime is a unique coagulant in cases where phosphorous removal is desired and also in instances where it may be desired to remove ammonia by air stripping. For phosphorous removal, the operating equation is :

(pH above 9.5)



Polyelectrolytes

Polyelectrolytes are either derived from natural sources or are chemically synthesized. They may carry electrical charges and are classified as either cationic (positively charged) or anionic (negatively charged). Most naturally occurring polyelectrolytes are ampholytic. In water works conditions where alum is being used as primary coagulant, polyelectrolytes provide a powerful ancillary bridging and linking action to promote more rapid settlement. It is normally advantageous to put them into the water

after the alum. Easier treatment of sludge is claimed from the use of polyelectrolytes, but is still not proven.

SAQ 2



- (a) Define following in the context of sedimentation tank.
 - (i) Surface Loading
 - (ii) Detention Time
- (b) Calculate the diameter and depth of settling tank to treat a flow of $25,000 \text{ m}^3/\text{day}$. The maximum SOR is $15 \text{ m}^3/\text{m}^2\text{-d}$ and the detention period is 3 hours.
- (c) Differentiate between coagulation and flocculation.
- (d) Mention the chemical reactions using alum and chlorinated coppers as coagulants.

3.6 FILTRATION

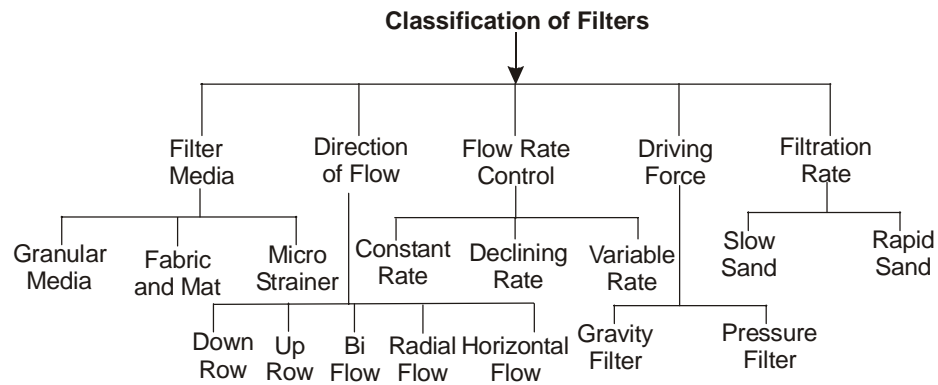
As you have seen that sedimentation process reduces large percentage of suspended and organic load of raw water, the process of coagulation further helps in the removal of impurities present in colloidal form. But still, resultant water may not be up to desired standards and may contain impurities in the form of very fine suspended particle and micro-organisms etc.

To reduce or remove remaining impurities further, the water is passed through bed(s) of porous medium/media such as sand etc. The process of removal of suspended or colloidal particle through passing the water through such medium/media is known as filtration.

The medium materials retain the impurities and allow the purified water to pass. The filtered water so obtained is relatively purer. Besides removing the turbidity filtration process is also helpful in the reduction or removal of other impurities such as colour, micro-organism, and odour etc. from the water.

The media used for filtration is mostly natural silica sand. In addition to this, crushed anthracite (hard) coal, diatomaceous earth, powdered or granular activated carbon, plastic spheres, rings and granules and metal fabrics are also used as filter media. In the lower portion of bed well washed gravel are used to support sand layer. Activated carbon is prepared from coal with a special manufacturing process to make it highly porous with high absorbing capacity. The supporting gravel layer permits the filtered water to move freely to the under-drains and allow the wash water to move uniformly upward.

The filters can be classified based on several criteria as shown below :



For treatment of community water supply, fifth type of classification is normally adopted. Accordingly filters under this category are classified as :

- the slow sand gravity filters, and
- the rapid sand gravity filters.

3.6.1 Slow Sand Filter

Slow sand filters are the original form of filtration used for potable water treatment and are becoming obsolete because of their large size and inability to deal with highly turbid water. However, for raw water with less than 30 NTU turbidity, they can provide a very effective form of treatment, which is particularly good at removing harmful micro-organisms. Much of the purification, which takes place in a slow filter is achieved in the surface layers of the bed and the biological activity, which produces a surface layer known as the *schemultzdeke*, contributes to the removal of fine particulate matter and also causes some removal of taste and odour forming organic compounds. Slow filters usually operate for several months before surface clogging grows to the point, where the flow rate can no longer be maintained. At this point surface scrapping, manually or by machine restores the flow and the bed can be kept back into service. To prevent disturbance of the bed surface, a depth about 1 m of water above the bed is used and this provides the head required for flow through the unit.

It consists of an open rectangular tank made of masonry or concrete. The bed slopes at around 1 in 100 towards the central drain provided for outlet of filtered water. Depth of tank varies around 2.5 to 3.5 m. The plan area of the tank varies from 100 to 2000 sq.m or more which depends on the quantity of water to be treated. The base material is gravel and the sand layer is supported on this gravel layer, which is 30 to 75 cm thick of different sizes placed in layers. The coarsest gravel is placed in the bottom most layers and the finest one on the top. The bottom most layer of the gravel is having size 40 to 65 mm, the intermediate layers varying from 20 to 40 mm to 6 to 20 mm (when two intermediate layers used) and the top most layer having size range of 3 to 6 mm. Size of sand varies from 0.2 mm to 0.4 mm averaging around 0.3 mm. The sand should be of the same grade in all parts of the same filter so that frictional resistance and hence, the rate of filtration shall be uniform. Chemical composition of sand is also an important factor. A sand containing considerable amount of lime will increase the hardness of filtered water. Presence of aluminous and calcareous materials increase the resistance to the flow of water. In designing a filter, it should be noted that the sand in fact forms the filtering medium, the gravel serves simply to collect the filtered water with little resistance to flow. The original depth of sand

must be sufficient to form an effective filteraction and to allow several scrapings without renewal of the sand. The original thickness of sand bed is kept around 90 cm.

Under-drainage system supports the sand bed and provides unobstructed passage for filtered water to leave the underside of the filter. This consists of a central drain connected with lateral drains as shown in Figure 3.3. The laterals are open jointed pipe drains placed 3 to 5 m apart at the floor stopping towards the main central drain. These laterals collect the filtered water and discharge it into the main drain which leads the water to the filtered water reservoir.

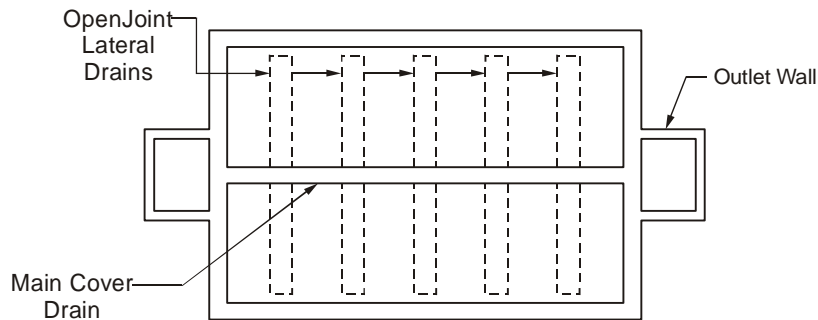


Figure 3.3 : Plan View of Under-drainage System

An inlet chamber is constructed for admitting the effluent from the sedimentation tank without disturbing the sand layers of the filter, and disturbing over the filter bed. At the outlet, the filtered water collecting unit is provided. Section view of a typical slow sand filter is shown in Figure 3.4.

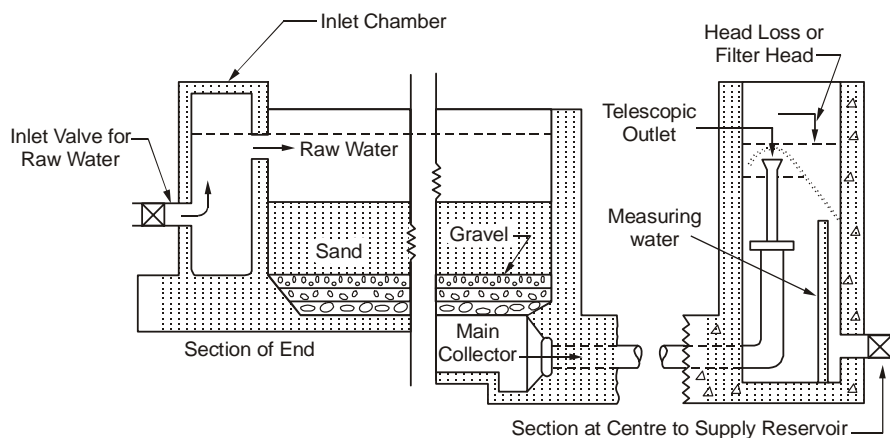


Figure 3.4 : Section of Slow Sand Filter

Important Features of Slow Sand Filter

Sl. No.	Item	Description
1.	Rate of Filtration	100-200 litres/hour/m ²
2.	Bacterial Load Removal	97 - 98% of raw water
3.	Colour Removal	About 20-25% of raw water
4.	Turbidity Removal	Up to 50 mg/litre

3.6.2 Rapid Gravity Filters

One of the drawbacks of the slow sand filter is its requirement of large area for installation. This makes it costly particularly for the places where cost of land is high. In order to reduce the requirement of the space, rate of filtration is to be increased, which could be achieved by increasing the size of filter media or

allowing the water to pass under pressure through filter media. The first principle is used in the construction of rapid gravity filter while later is achieved in pressure filters.

The rapid gravity sand filters are most commonly used nowadays. These are mostly operated with coagulants and often follow settling basins. They produce best result with incoming water having turbidity in the range of 10-20 JTU.

It is basically a bed of sand supported in a bed of gravel embedded in which there is a system of underdrains. The whole system is enclosed in an open concrete chamber. The sand layer has a thickness of around 0.45 to 0.75 m. The sand grains are fairly uniform in size lying between 0.4 mm and 1.2mm. About 10% of sand may pass an aperture of 0.45 mm and about 60% may pass an aperture of 0.65 mm. The co-efficient of uniformity should vary between 1.2 and 1.7 and the sand should be sharp, hard, clean and siliceous.

The supporting gravel beds are omitted if porous plate filter bottoms are provided. When gravel bed is provided, it should have a thickness of around 45 cm, making total thickness of the filter media around 1 m. The gravels should have size between 2 mm and 60 mm. The basic requirement for the filter bed is that it should consist of a large number of orifices, uniformly arranged to collect filtrate and deliver air and wash water to the filter bed. At the same time, they should preclude the passage of the filter media.

The filter has four valves to control inlet, outlet, wash water and the drain to waste. For air to be used with wash water, a fifth valve on the air pipe is provided.

Each filter has an area around 100 m^2 and depending upon amount of water to be filtered number of such units may be evaluated and installed.

The depth of water above a filter bed is kept around 2 m. The flow of water through sand is streamlined and the loss of head is proportional to the velocity.

Typical sketch of Rapid Gravity Filter is shown in Figure 3.5.

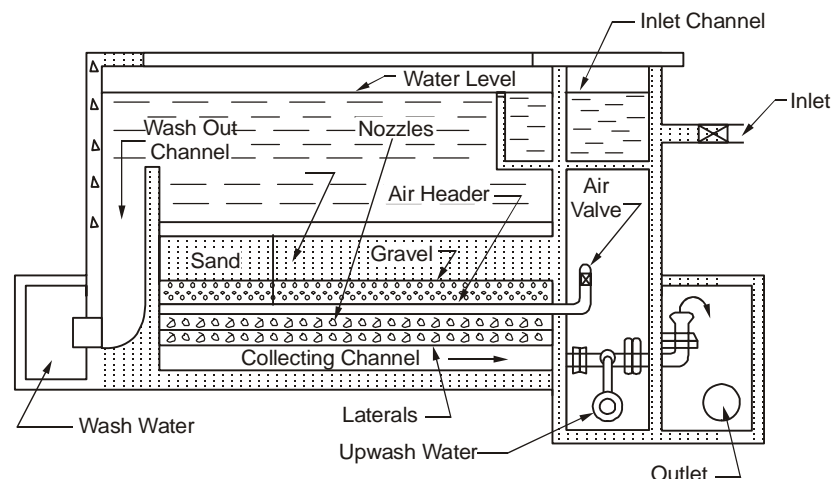


Figure 3.5 : Rapid Gravity Filter

For cleaning, the inlet and outlet valves are closed. The drain valve is opened to lower the level of water to the level of the weir wall that holds the sand bed in position. The air scour is operated for about 3 minutes. This operation forces air upwards through the sand at a rate of about $1 - 1.5 \text{ m/min/m}^2$ under a pressure of 0.42 kg/cm^2 . When water over the bed gets thoroughly agitated, up wash water is turned on at a rate of about $0.5 \text{ m}^3/\text{min/m}^2$ and allowed to run until the clean sand

bed can be seen. Generally, in practice, it takes about 5 minutes during which time the wash water get falling over the cross-wall weir and escapes through the open drain valve. In some filters, air scour and water scour are applied simultaneously. When the filter gets washed the drain, upwash and air valves are closed and the inlet valve opened to recharge the filter. Normal service is returned by opening the outlet valve slowly to give the filter bed time to settle down and rid itself of any loose sediment stirred up during the washing process.

Comparison of important features of slow sand and rapid gravity flow sand filters are presented in Table 3.2

Table 3.2 : Technical Features of the Slow and Rapid Gravity Flow Sand Filters

Sl. No.	Item	Slow Sand Filters	Rapid Sand Filters
1	Rate of filtration	3m ³ /m ² /d	125 m ³ /m ² /d
2.	Size of bed	Large, 100 to 2000 m ²	Small, 100-400 m ²
3.	Depth of bed	0.3 m of gravel, 1.2 m of sand usually reduced to no less than 0.6 m by scraping.	0.5 m of gravel, 0.7 m of sand or less, not reduced by washing.
4.	Size of sand	Effective size 0.25 to 0.35 mm, uniformity coefficient 2 to 3	0.45 mm and higher uniformity co-eff. 1.5 and lower depending on underdrainage system.
5	Grain size distribution of sand in filter	Unstratified	Stratified with smallest or lightest grains at top and coarsest or heaviest at bottom.
6	Under-drainage system	Split tile laterals laid in coarse stone and discharging into tile or concrete main drain	1) Perforated pipe laterals discharging into pipe mains. 2) Porous plates above inlet box. 3) Porous blocks with included channels.
7	Loss of head	0.15 m initial to 1 m final	0.3 m initial to 2.5 m final
8	Length of run between cleanings	20 to 60 days	12 to 72 hours
9	Penetration of suspended matter	Superficial	Deep
10	Method of cleaning	1) Scrapping off surface layer of sand storing cleaned sand for periodic re-sanding of bed. 2) Washing surface sand in place by washer traveling over sand bed.	Dislodging and removing suspended matter by upward flow or backwashing which fluidizes the bed. Possible use of water or air jets or mechanical rakers to improve scour.
11	Amount of wash water used in cleaning sand	0.2 to 6% of water filtered	1 to 4 to 6% of water filtered
12	Preparatory treatment of water	Generally none	Coagulation, flocculation and sedimentation
13	Washwater rate (m/h)	-	10-40
14	Air scour rate m/h	-	20-40

15	Supplementary treatment of water	Disinfection	Disinfection
16	Cost of construction	Moderate to high	Relatively low
17	Cost of operation	Relatively low where sand is cleaned in place or labour cost is low	Relatively high
18	Depreciation	Relatively low	Relatively high

SAQ 3



- (a) With the help of a neat sketch describe the working of slow sand filter.
- (b) Compare slow sand filter and rapid gravity sand filter with reference to following :
 - (i) Filter media
 - (ii) Method of cleaning
 - (iii) Cost of construction and operation.
- (c) State whether the following are true or false :
 - (i) Water entering rapid sand filter has high turbidity as compared to slow sand filter.
 - (ii) Slow sand filters are not suited for places where cost of land is high.
 - (iii) Rate of filtration of slow sand filter is higher than rapid sand filter.

3.7 DISINFECTION

The various physiochemical treatment processes such as sedimentation, coagulation and filtration etc. mainly aim at providing aesthetically acceptable water. Although, these processes assist in removal of bacterial or micro-organism to varying degree, but may not produce safe water. Disinfection is aimed at inactivation or destruction of disease producing micro-organism such as bacteria, virus etc., which are considered to be mainly responsible for water-borne disease.

Disinfection can be distinguished from sterilization process. Sterilization is employed to completely kill all micro-organism through various physical processes such as boiling water for long time, while in disinfection reduction of harmful micro-organism is done such that they become inactive to cause any infection or disease.

Type of Disinfection

Broadly disinfection methods can be classified as :

Physical Disinfection

Such as boiling water for long time and use of ultrasonic radiation.

Chemical Disinfection

Using chemicals such as chlorine and its compound bromine, potassium permanganate, iodine, ozone, silver and hydrogen peroxide etc.

Chlorine and its compounds are most commonly used disinfectants. However, other disinfectants used in different situation are given in Table 3.3.

Table 3.3 : Type of Disinfectants

Sl. No.	Commonly Used Disinfectant	Purpose
1.	Ultraviolet radiation	Treating water of small public supplies, railway refreshment vehicles, restaurants etc.
2.	Silver	In-house water sterilisation.
3.	Iodine	Small scale use in emergencies
4.	Potassium permanganate	Pre-disinfection of water before other treatment.
5.	Boiling	Treating municipal water for in-house drinking purpose mostly in rainy seasons or in emergency.

3.7.1 Qualities of Good Disinfectant

For being a good disinfectant, any chemical or agent should :

- be effective in destroying harmful micro-organism within available contact time,
- not have toxic effect on water or make water un-potable,
- leave residual counter the possible re-contamination,
- not require skilled manpower and costly equipment for its application, and it should be amenable to detection by practical, rapid and simple analytical techniques in the small concentration ranges to permit the control of disinfection process,
- be such that its concentration in treated water could be measured easily, and
- be economical and easily available.

3.7.2 Factors Affecting Disinfection

Following factors affect the disinfection process :

Contact Time between Disinfectant and Micro-organism

The destruction of micro-organism increases with the increase in contact time available between disinfectant and micro-organism. In practice, contact time is limited by the design of plant and normally is not less than 30 minutes.

Type of Micro-organism Present

Among various micro-organism present in water it has been found that pathogens are less resistant than coliform group. Virus appear to be more

resistant than bacteria and cyst are extremely resistant, hence require longer period of contact as well as higher concentration of disinfectant.

Characteristic of Water

Various characteristic such as concentration of organic and suspended matter, presence of metallic and ammonia compounds, etc. in water reduces the rate of disinfection.

Concentration of Disinfectant

Higher the concentration of disinfectant, higher is the destruction of micro-organism.

Temperature of Water

Rates of chemical reactions are speeded up as the temperature of the reaction is increased. The higher the temperature, the more rapid is the destruction of organisms.

3.7.3 Disinfection by Chlorine

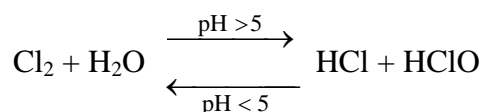
Chlorine and its compounds are most widely used as disinfectant due to their wide availability at economical rate. It also easily kills pathogens and leaves residual effect for future recontamination. However, if applied in excess it may not only make water unpalatable but also cause toxicity in water.

It is found in three forms, i.e.

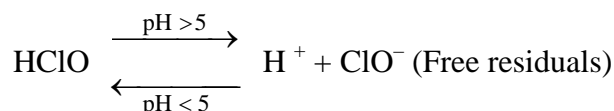
- (a) liquefied chlorine,
- (b) chlorine solution (NaOCl), and
- (c) powdered chlorine in the form of chlorinated lime (commonly known as bleaching powder).

The form in which chlorine should be applied in water treatment is governed by several factors such as the quantity of water to be treated, the cost and availability of chemicals, the equipment needed for its application and the skill required for operation and control.

It is a powerful oxidising agent, which when dissolved in water yields the following reaction:



which is followed by the secondary reaction.



Hypochlorous acid, HClO, is the more effective disinfectant, the chlorite ion, ClO^- , being far less effective. The dissociation of HClO is suppressed at acidic pH range, the residual being all HClO at pH 5 and below, about half HClO at pH 7.5 and all ClO^- at pH 9 (Figure 3.6).

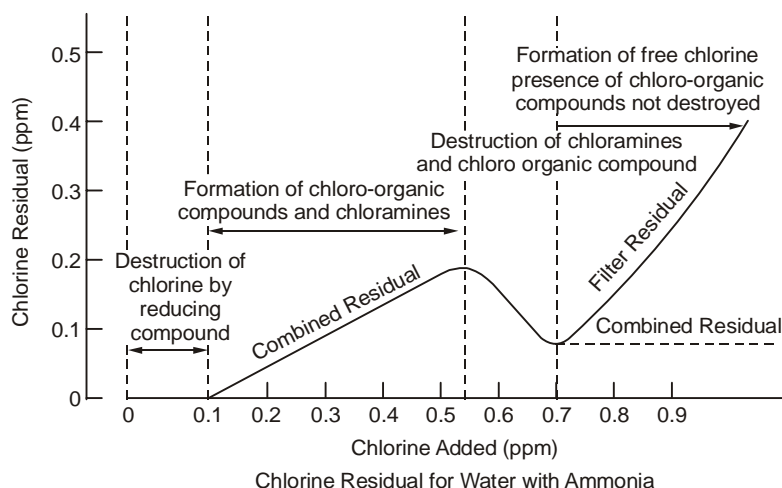
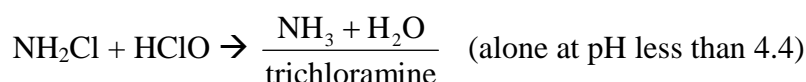
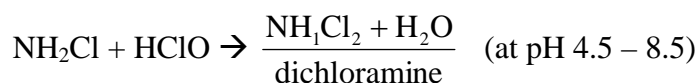
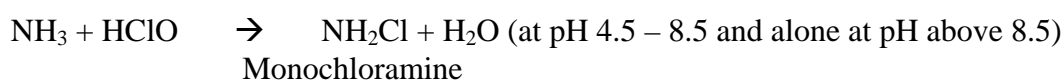


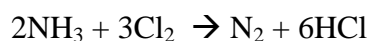
Figure 3.6 : Chlorine Reactions in Water

If ammonia is present in the water, the reaction is :



The chloroamines are the combined residuals. They are more stable than the free residuals but less effective as disinfectants. For a given kill rate with constant residual, the combined form required over hundred times the contact time required by the free residual. Alternatively for a given contact time, the combined residual concentration must be twenty five times the free residual concentration to give the desired killing.

Trace concentrations of ammonia are desirable in water destined for chlorination in order to ensure presence of residuals in the distribution system. In the presence of ammonia, the continued addition of chlorine produces the characteristic curve shown in Figure 3.6. Theoretically three moles of chlorine react with two moles of ammonia to give off nitrogen gas to reduce chlorine to the chloride ion as follows



Thus the breakpoint, which is the point at which the concentrations of the combined residuals have declined to a minimum should occur at chlorine to ammonia ratio 3 : 2, but in practice the ratio is nearer to 10 : 1 because of pH and other factors. Past the breakpoint, the free residual (HClO) is proportional to the dose. The actual chlorine demand is the difference between the applied chlorine dose and the residual concentration at the breakpoint.

Although the primary objective of chlorination of potable water is the destruction or inactivation of bacteria, there are several other important secondary functions achieved by chlorination. These include :

- (a) The oxidation of iron, manganese and hydrogen sulphide.
- (b) The destruction of some taste and odour producing compounds.
- (c) Control of algae and slime organisms in treatment plants.
- (d) As an aid to coagulation.

The requirements of effective chlorination are met when the chlorine dose is sufficient to meet excess or residual chlorine for disinfecting purposes in the water distribution system under the prevailing alkalinity and temperature of the water and also the contact time. In the developing countries like India a free chlorine residual of about 0.5 mg/l and a combined residual chlorine of about 1.5 mg/l is recommended for clear water having a pH of about 7 and a contact time of about 30 minutes is generally used.

3.8 SOFTENING

Water is considered to be hard if it does not form lather readily with the soap. Hardness of water is due to presence of calcium and magnesium salt. The greater the concentration of these salts in the water, the harder the water is. It is expressed in mg/l or meq/l as CaCO_3 . There are two types of hardness :

- (a) Temporary (Carbonate Hardness).
- (b) Permanent (Non-carbonate Hardness).

The temporary or carbonate hardness, which is caused by carbonates and bicarbonates of calcium and magnesium can be removed by boiling or by adding lime whereas the permanent or non-carbonate hardness, which is caused by the sulphates, chlorides and nitrates of calcium and magnesium are removed by special methods. The reduction or removal of hardness from water is known as water *softening*. The advantages of softening lies chiefly in the reduction of soap consumption, lowered cost in maintaining plumbing fixtures and improved taste of food preparations.

3.8.1 Water Softening Method

Normally following two methods are used for softening of the water :

- (a) Chemical precipitation.
- (b) Ion Exchange.

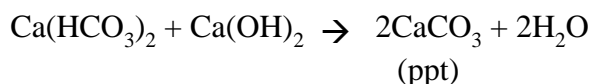
Chemical Precipitation

In chemical precipitation, lime ($\text{Ca}(\text{OH})_2$) and soda (Na_2CO_3) are added together or separately in water to reduce/remove the hardness. Lime and soda converts hardness causing compound (calcium and magnesium salts) to insoluble precipitates; which are settled out and supernatant liquid is filtered. This method of softening also achieves substantial removal of such constituents as iron and manganese, which may be present in high concentrations in ground water. This method is used particularly for water with initial hardness (greater than 500 mg/l) and suitable for waters containing turbidity, colour and iron salts because these have a tendency to inactivate the ion-exchange bed, by a coating on the granules. Lime-soda softening cannot, however, reduce the hardness to values less than 40 mg/l while ion-exchange softening can produce a zero-hardness water.

Following are the examples of removal of hardness by chemical precipitation :

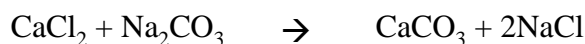
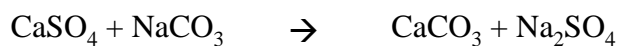
Lime Softening

The process is used for the removal of calcium (temporary) hardness. Lime is added to precipitate calcium carbonate, which has a solubility of about 25 mg/l at 20°C .



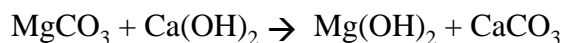
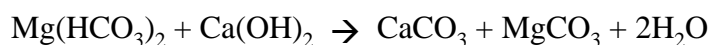
Lime-soda Softening

It is used for the removal of all forms of calcium hardness. Soda ash is added and the non-carbonate hardness is converted to the sparingly soluble calcium carbonate. In addition to the reaction above, following reactions take place :



Excess Lime-softening

In this process, lime is added in excess. Magnesium temporary hardness is removed when an equivalent amount of lime is added. Magnesium carbonate is produced, which does not precipitate in cold water. When pH is raised to 11 with excess lime, the insoluble magnesium hydroxide is produced, which has a solubility of about 10 mg/l.

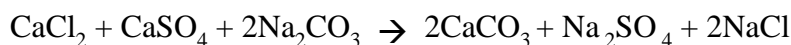
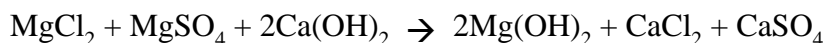


The high pH level produces good disinfection as a by-product and thus, chlorination may not be required after excess lime softening. Carbonation is necessary to remove the excess lime and reduce the pH after such softening.

Excess Lime-soda Softening

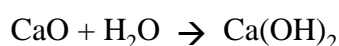
The process is used for the removal of all forms of magnesium hardness. Excess lime is added in order to precipitate the insoluble magnesium hydroxide.

To the calcium chloride and calcium sulphate produced, soda ash (Na_2CO_3) is added to convert these to calcium carbonates as in the removal of permanent calcium hardness as mentioned under Lime-soda softening.



Lime-soda treatment generally results in the reduction of total dissolved solids of treated water.

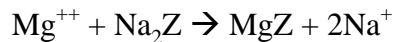
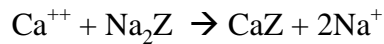
All forms of chemical precipitation softening produces considerable volumes of sludge. Sometimes lime is recovered by calcining the calcium carbonate sludge and slaking with water.



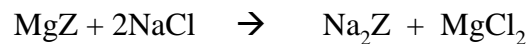
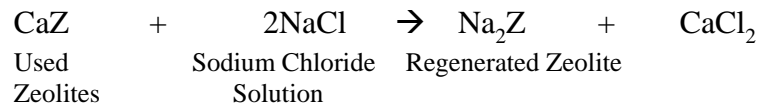
In most of the cases, hardness due to calcium is predominant in water. The addition of lime alone removes only the carbonate hardness portion of the calcium hardness. Soda ash is required to remove the non-carbonate hardness. Lime alone achieves sufficient reduction of hardness because in many cases greater portion of the hardness in water is temporary.

Ion Exchange

The ion exchange process is reversal interchange of ions between a solid in exchange medium and a solution. Since this method works on principle of base exchange, it is also known as base exchange process. In the process, ions of a given species are displaced from an insoluble exchange materials by ions of species from solution. The most commonly used exchange materials are zeolites, which are complex sodium alumino-silicates and green sands. When used for water softening, the hard water is passed through the bed of natural zeolites, which exchange their sodium ions for the calcium and magnesium ions in water, giving complete removal of hardness :



When the capacity for the exchanging ions has been depleted, a regenerating solution with a high concentration of the original ions is pumped through the bed. The process displaces the contaminant ions and rejuvenates the exchangers as given below :



The use of ion exchangers is not limited to water softening. Ion exchangers can be used for the removal of other ions such as ammonia, nitrate, chloride, fluoride etc. from water. A wide variety of ion exchangers are commercially available. The widest application of ion exchangers is in industrial water supply treatment rather than in domestic water supply treatment. The ion-exchange materials used is known as zeolites and are mainly processed green sand and synthetic zeolites made from sulphonated coals and condensation polymers.

SAQ 4



- (a) List the factors that affect disinfection process.
- (b) What is residual chlorine?
- (c) Discuss water softening process.

3.9 SUMMARY

In this unit, we have discussed the important treatment process which are commonly used in making raw water from river/stream safe, aesthetically attractive and potable. The impurities of raw water are removed in order of their sizes. The bigger one is removed first and finer in the last.

The important functions of various treatment processes discussed in this unit can be summarised as follows :

Treatment Process	Function (Removal)
Aeration	Colour, odour, taste
Coagulation	Suspended matter, a part of colloidal matter and bacterial
Disinfection	Pathogenic bacteria, organic matter and reducing substances
Filtration	Finer and colloidal dissolved matter, bacteria
Screening	Floating matter
Sedimentation	Suspended matter
Softening	Hardness

3.10 ANSWERS TO SAQs

SAQ 1

- (a) The intermediate processes which are collectively called pre-treatment include :
- Screens
 - Raw Water Storage
 - Pre-chlorination
 - Aeration
 - Algal control
 - Pre-settling basin
- (b) (i) False
(ii) True
(iii) True

SAQ 2

- (a) Please refer Section 3.4.1.
- (b) Detention time (T) = $\frac{\text{Depth of Tank}}{\text{Surface Over Flow Rate}}$

$$\text{Depth of tank} = \frac{3}{24} \times 15 = 1.875 \text{ meter}$$

$$\text{Surface area of settling tank} = \frac{\text{Rate of Flow}}{\text{Surface Over Flow Rate}} = \frac{25000}{15}$$

$$\frac{\pi}{4} (\text{Diameter})^2 = 1666.67 \text{ m}^2$$

$$\text{Diameter of settling tank} = 46 \text{ m.}$$

- (c) Please refer Section 3.5.
- (d) Please refer Section 3.5.1.

SAQ 3

- (a) Please refer Section 3.6.1.
- (b) Please refer Table 3.2.
- (c) (i) False

(ii) True

(ii) True

SAQ 4

- (a) Please refer Section 3.7.2.
- (b) For disinfecting drinking water, chlorine is used. There may be chances of infection during movement of water from treatment plant to distribution point. For safety against this some additional amount of chlorine is added to water so that after the disinfection to be completed after filtration there is some chlorine present in water and this residual amount of chlorine present in water is known as residual chlorine.
- (c) Please refer Section 3.8.