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CHAPTER 10: SPECIFIC TREATMENT PROCESSES

10.1 Introduction

Water treatment involves removal of physical, chemical, and biological contaminants to transform raw water into potable water. The treatment process used in any specific instance depend upon the quality and nature of the raw water. Quality requirements for industrial uses are often more specific than for domestic supplies. Additional treatment may be required by the industry like demineralization of boiler feed water to prevent scale deposits.

Water treatment processes may be simple like sedimentation or may involve complex, physio-chemical changes, such as with coagulation. The specific treatment processes include control of algae, control of taste and odor in water, removal of color, softening, removal of iron and manganese, Arsenic, Nitrate, de-fluoridation of water, demineralization of water, and desalination of water.

10.2 Control of Algae

10.2.1 General

Algae give rise to a variety of troubles in water supplies. They impart color, odors and tastes to the water. Algae like Synura cause a perceptible odor; while Asterionella, Meridion, and Tabellaria produce aromatic odor, and Dinobryon, Peridinium, Uroglenopsis, Asterionella, and Tabellaria produce fishy odor. Grassy odor is caused by Aphanizomenon, Anabaena, Gomphosphaeria, Cylindro-spermum, and Rivularia. Septic odor is caused by Cladophora, Hydrodictyon, Ceratium, Aphanizomenon, Anabaena, and Cylindrospermum. When algae like Microcystis, Anabaena, and Aphanizomenon die *en masse* and decay, they produce foul odors.

Some algae impart sweet or bitter or sour tastes to water. Algae like Nitella, Geratium, and Synura give rise to a bitter taste, while algae such as Chara, Euglena, Aphanizomenon, Microcystis, Cryptomonas, and Gomphosphaeria impart a sweet taste to water.

Algae interfere in the process of flocculation and sedimentation. Algae like Asterionella and Synedra prevent floc formation. Water containing Gomphosphaeria and Anabaena needs to be agitated for proper floc formation. They buoy up the flocs and carry them into the filters. They choke the filters and as a result, reduce the filter runs. Algae associated with filter clogging are Asterionella, Fragilaria, Navicula, Synedra, Cymbella, Diatom, Oscilatoria, Rivularia, Trachelomonas, and Closterium. Algae like Synedra and Oscillatoria can pass through a rapid sand filter. Algae such as Euglena, Phacus, Navicula, Nitzschia, and Trachelomonas get through a slow sand filter. These algae cause biological corrosionin the distribution system.

Lyngbya, Anabaena, Cylindrospermum, Nodularia, and Microcystis are some of the common toxic algae associated with fish mortality. Hay fever is caused by Anacystis and LyngbyaContorta. The gastrointestinal disturbances are also said to be due to algal toxicity.

Algae can be killed by treating the water with suitable chemicals. However, allowing the algae to grow and then adopting algicidal measures has many disadvantages, viz. (i) the dose of chemical required is greater than that needed if the treatment is adopted at the initial stages of growth (ii) the dead algae decay and produce acute odor problems (iii) the dead algae provide a pabulum for a second crop which are generally more prolific than the first and also more resistant to the action of algicides. It is, therefore, preferable to take all possible measures to prevent the growth of algae and to reserve the use of algicidesonly as last resort.

10.2.2 Causative Factors for Algal Growth

Algal growth is influenced by several factors such as nutrients in the water, the availability of sunlight, the character of the reservoir, and temperature.

10.2.3 Nutrients in Water

Nutrients like nitrogen and phosphorus favour growth of algae. Swamp water or water in contact with decaying vegetation as well as water polluted by sewage contains prolific organic matter favouring growth of certain types of algae.. Among the various mineral compounds, nitrogen and phosphorus are particularly favourable to algae and are generally brought in by agricultural return waters and some industrial wastes. Algicidal treatments have limited value when the water is rich in such nutrients because the conditions become more favourable for the growth of succeeding crops of algae.

10.2.4 Eutrophication

Eutrophication is the process whereby lakes become enriched with nutrients that make the water undesirable for human use, both for water supplies and recreation. Limnologists categorize lakes according to their biological productivity. Oligotrophic lakes are nutrient-poor. Typical examples are a cold-water mountain lake and a sand-bottomed, spring-fed lake characterized by transparent water, very limited plant growth, and low fish production. A slight increase in nutrients results in a mesotrophic lake with some aquatic plant growth, greenish water, and moderate production of fish. Eutrophic lakes are nutrient-rich favouring high plant growth in the form of microscopic algae and rooted aquatic weeds making the water quality totally undesirable for body-contact and non-body contact recreation.

10.2.5 Effects of Eutrophication

The process of eutrophication is directly related to the aquatic food chain. Algae use carbon dioxide, inorganic nitrogen, and orthophosphate and trace nutrients for growth and reproduction. These plants serve as food for microscopic animals (Zooplankton). Small fishes feed on Zooplankton and large fishes consume small ones. Abundant nutrients destabilize the normal succession and promote blooms of blue-green algae that are not easily utilized as food by Zooplankton. Thus, the water becomes turbid. Floating masses of algae are windblown to the shore where they decompose producing mal-odours. Decaying algae also settle to the bottom, reducing dissolved oxygen.

Even a relatively mild algal bloom can result in the accumulation of substantial decaying scum along the windward shoreline because of the lake’s vast surface area. The most damaging aspect of eutrophication is that the process is difficult to slow down once started. Once a lake has become eutrophic it remains so, for a very long time, even if nutrients from point sources are reduced.

10.2.6 Sunlight

Algae require sunlight for their life processes and hence the growths are profuse in seasons of intense sunlight. Clear waters favor the growth of algae because they permit penetration of sunlight to greater depths.

10.2.7 Characteristics of Reservoirs

Shallow reservoirs offer more favorable conditions than deep reservoirs because their dissolved nutrients closer to the surface may stimulate algal growth. Irregular margins and shallow areas encourage the growth of aquatic weeds which offer anchorage for the algae.

10.2.8 Temperature Effects

Temperature has a considerable influence on algal growth. The blue-green and the green algae make their presence felt when the water temperatures reach 20-30°C.

10.2.9 Remedial Measures

10.2.9.1 PREVENTIVE MEASURES

Preventive measures should, therefore, be based on control of those factors such as reduction of nutrient supply, change of the environment, or exclusion of sunlight though these are not always practicable. Clear water reservoirs, service reservoirs, and wells may be covered to exclude sunlight, but such a remedy is inapplicable in the case of large reservoirs of raw waters. Turbid water prevents light penetration and thereby reduces the algal population. Activated carbon (10.5 to 24.5 kg/hectare) reduces the algal population by excluding sunlight but the disappearance of activated carbon from the water may start algal growth again. To a limited extent, the environmental conditions for the growth of algae may be made unfavorable by proper care in the construction and operation of reservoirs, as explained in 4.9.2 (f) of Chapter 4: Planning and Development of Water Sources of Part A of this Manual.

10.2.9.2 CONTROL MEASURES-ALGICIDAL TREATMENT

Algicidal measures may be adopted to control algae in reservoirs. As has been mentioned earlier, it is preferable to initiate the treatment in the early stages of algal growth.

(a) Microscopic Examination

To decide on the best time at which the water should be treated, it would be necessary to have a regular schedule of microscopic examinations of the water. Such examination is especially necessary during the season in which algal invasions may be expected.

(b) Time of Treatment

Generally, the practice has been to apply algicides when the total count reaches or exceeds 300 areal (measure of the Algal strength/growth rate) units. Areal growth rate is the new biomass per area per time. This is usually used to express growth in a pond or lake. (mass per area time, g/m^2s). Algae which are known to be particularly troublesome should be eradicated even though the total count is much less than 300 areal units. For example, algicidal treatment is indicated as soon as Synura, a type that causes severe odour troubles is encountered, irrespective of the total count.

(c) Type of Algicides

A large variety of algicides are available and many new algicides are being synthesized. Many of these are complex organic compounds and are credited with specific actions against particular species. Chemicals such as ketones, aldehydes, organic acids, quaternary ammonium compounds, silver nitrate, ClO_2, and rosin amines have also been tried as algicides. However, these are costly and have not come into general use. The most widely used algicides are copper salts and chlorine and potassium permanganate in small-scale water supplies. The chemical to be used as an algicide should be species selective, non-toxic to aquatic life, particularly fish, harmless to human beings, have no adverse effect on water quality, as well as in expensive and easy to apply.

i. Copper Salts

The most common algicide is copper sulphate. Its action is due to the copper ion which acts as a direct protoplasmic poison. The reaction is a function of the concentration of the chemical and the time of exposure of the algal cells to the action of the copper.

ii. Copper Sulphate

The copper sulphate reacts with the bicarbonates in the water to form a basic copper carbonate which further decomposes to form copper hydrate. The basic copper carbonate is somewhat soluble especially if the water is not very hard and if it contains carbon dioxide. The copper hydrate is almost insoluble in water. It remains in a colloidal form for some time before it precipitates out. This reaction is retarded by low temperature and organic matter in the water, while temperature and suspended matter accelerate it. It was thus, observed that the efficacy of copper sulphate as an algicide is influenced by the temperature of the water, its hardness, and its content of organic matter and suspended matter.

The added copper sulphate is rendered inactive in a short while. This is both an advantage and a disadvantage. It is an advantage because the content of the copper in the water rapidly gets reduced to levels below those at which copper is toxic to human beings by mere efflux of time and without the need for any elaborate treatment for removal of the excess copper. The tendency of copper to get out of the solution is a disadvantage because the algicidal effect is rendered purely temporary. With the disappearance of the copper from the field of action, another crop of algae can come up necessitating a repetition of the treatment.

The following are the reasons for which Copper Sulphate practice is discontinued in India.

1. **It doesn’t treat the *causes* of algae in water body**. When applied to an infected body of water, it can only treat the visible symptoms of algae. It only attacks the algae itself, rather than the nutrients that allow it to grow in the first place.
2. **It is toxic to humans.** Copper sulphate, when used to control algae blooms in water, can be hazardous to humans. Because copper sulphate is easily absorbed via the skin, individuals who administer it must exercise extraordinary caution to avoid even minor skin contact with it. If contact occurs, it can cause itching and permanent yellow discoloration of the skin. Furthermore, if consumed (through inhalation of the powder or drinking it), copper sulphate can cause acute vomiting, as well as unconsciousness, searing pain, nausea, diarrhoea, headache, shock, and unconsciousness. The EPA has recognised these concerns by classifying copper sulphate as a class 1-highly hazardous chemical, requiring a poison warning to be put on all labels. The risks to human health outweigh the benefits of using itfor treatingalgal blooms.
3. **It is more likely to contribute to rebound blooms.** When put to water, it swiftly sinks, accumulating as a heavy metal precipitate. This accumulation of copper sulphate and decaying algae causes the release of toxins, which can cause the accumulated mass to resurface or "rebound" to levels comparable to or higher than the original bloom. It also quickens the recycling of phosphorus, which can

encourage algae blooms. As a result, usngcopper sulphate will result in more of the problem in the end.

4. **It does not biodegrade.** When copper sulphate is added to water, it forms a heavy metal precipitate, as mentioned previously. As it does not biodegrade, Copper sulphate buildup can result in a sterile water bottom, which can reduce and kill beneficial microbes. It is not natural and cannot be removed without using other chemicals or treatments.
5. **It is detrimental to the plant and aquatic life.** The accumulation of copper sulphate after application can result in a sterile water bottom that kills off critical microorganisms that fish and other aquatic life require. Copper sulphate can disrupt the aquatic food chain by killing off weaker fish that rely on nutrients to thrive, resulting in short-term overpopulation of some species (until they too die off because they are without a food source). It also produces over-oxygenated water, which can kill plants. Finally, animals that drink from this water may become sick or die.
6. **It is expensive to dispose of.** When copper sulphate accumulates, it may be considered hazardous waste. When its disposal is required, the hazardous waste status might increase the cost of disposal due to the need for skilled cleanup.
7. **It can make runoff water hazardous.** Copper sulphate is known to accumulate after use, making runoff water potentially dangerous to individuals who come into contact with it. Copper sulphate-contaminated water can be detrimental to crops, animals, and humans.
8. **Public Health officials are concerned about the safety of copper sulphate use.** Concerns regarding the impact of copper sulphate on human and animal health have made Public Health officials to stop its use as algicide.
9. **It is highly corrosive.** Another disadvantage of copper sulphate is that it is extremely corrosive to steel, iron, and galvanised pipelines. It may only be used withstainless steel, Monel, or plastic and cannot be stored in metal containers. Because of its corrosive nature, copper sulphate is incompatible with cost-effective storage methods,.

iii. Other Compounds

Attempts have been made to develop compounds of copper that can persist for longer periods. Treatment with copper citrate which can stay in solution for longer periods has been practiced but this chemical is much costlier than copper sulphate.

By using a complex of copper with ammonia in conjunction with the chlorine-cupri-chloramine process, the algicidal effect of copper is reinforced. The use of more persistent compounds of copper necessitatesmore rigid control over the treatment to ensure that the water is not supplied to the public until the copper content is madewell below toxic limits.

iv. Chlorine

Chlorine is normally a bactericide butis also used as an algicide. Chlorine has a specific toxic effect and causes the death and disintegration of some species of algae. The essential oils present in the algae are thus liberated and may cause taste and odor problem. Occasionally these essential oils as well as the organic matter of the dead algae may combine with chlorine to form new or intensified odors and tastes. Such intensification of odors makes the control of algae by chlorine a problem that challenges the professional skills of the operator.

(a) Dosage

The lethal doses of chlorine for the more common types of algae are given in Table 10.1

Table 10.1: Amount of Chlorine Required to destroy Microscopic Algae

Algae	Chlorine Dose mg/L
Aphanizomenon	0.85
Cyclotella	1.00
Melosira	2.00
Dinobryon	0.5
Uroglenopsis	0.5
Synura	0.3

(b) Methods of Application

Chlorine may be applied either as a slurry of bleaching powder or preferably as a strong solution of chlorine from a chlorinator..

Small reservoirs may be treated by applying a slurry of bleaching powder at the influent end or by towing bags containing the bleaching powder in the water. Chlorination to prevent algal growth is more commonly adopted in the pretreatment part of the water works. The point of application is generally at the entry of raw water into the treatment plant or just before the coagulant feed. Algal growths in raw water conduits can be removed by heavy doses of chlorine. The addition of chlorine along with coagulant is also practiced sometimes

v. **Surface Aeration of Lakes or ponds to control Algae growth**

Algal blooms are more common during hot, calm, sunny weather (Figure10.1). Agitation at the surface eliminating stagnant pockets reduces the preferred sites for algae to thrive (Figure 10.2). Simply moving the water will assist to reduce the amount of algae in the pond.. Surface agitation in a pond or body of water can be induced by aeration. This is advantageous in several ways. It aids in the elimination of still stagnant water patches (stratification) and simulates natural breeze.

Surface agitation is also advantageous since it aids in the mixing of algae that are already present in the water column. Algae cannot stay at the water's surface and absorb the sunshine needed for photosynthesis, and it cannot survive without much sunlight. The agitation also helps to de-stratify the pond by mixing up the water and lowering the general pond temperature, making the environment less favourable to algae.

Aeration can cause a shift in the carbon dioxide, thereby pH levels within the pond., , allowing beneficial plants to outgrow the unwanted algae

Finally, the agitation serves to refract some of the sunlight that strikes the water's surface. The amount of sunlight that can enter the water column is thus limited. Algae and other aquatic plants struggle to grow as sunlight diminishes throughout the water column limiting their numbers.

Aeration should not be considered as the only panacea, but rather as one of many strategies that is used in conjunction with other ways of algae control. Aeration is always useful, and most of the time there will be some additional water quality advantage from added oxygen, including the increased oxygen levels that are beneficial for fish growth, reduction in odor problems, and general improvement in water body ecosystem health.

Figure 10.1: Algal Sludge

Figure 10.2: Surface agitation can be achieved by Aerators or by Pumps/ blowers

10.2.10 Control of Algae at Water Treatment Plants

Algae in water treatment plants may be removed by the application of chlorine, ozone, chlorine dioxide, or activated carbon. Pre-chlorination will help in killing the algae and facilitate their settling. It will prevent the growth of algae on basin walls and will aid in the removal of algae by coagulation and sedimentation because the dead cells of these organisms are more readily coagulated. The chlorine in the settled waters will also destroy slime organisms on the filter sand prolonging filter runs and facilitate filter washing. Doses required for this purpose may have to be upto 5.0 mg/L to meet the chlorine demand of water, oxidize free ammonia, etc., however, the water may have to be de-chlorinated in case of higher residual chlorine, so as to leave 0.2 to 0.5 mg/L free residual chlorine in the settled water.

The most cost-effective approach involves utilizing pre-chlorination for initial disinfection using free residual chlorine, followed by post-chlorination using chlorine dioxide, which yields the most economical results.

Ozone is effective in the destruction of algae and gives more consistent results, since it is an active oxidizing agent. Ozone is only slightly soluble in water and hence persists in the treated water for only about 30 minutes. Control is through the use of special equipment indicating the concentration of ozone in the treated water, or by the *Orthotolidine* test. The latter indicates, the presence of 0.1 mg/l ozone when the reagent color is equivalent to 0.15 mg/L of residual chlorine.

Chlorine di-oxide along with chlorine is effective in pre-oxidation. It reduces the potential for the formation of DBP (Disinfectionby Products). The chlorine dose needs to be just enough to immobilize or kill algae cells. An excessive chlorine dose is likely to rupture the cell structure and bring out intra-cellular compounds and toxins (cell lyses) which further complicates the treatment. The combination of coagulation with Aluminium/Ferric salts and polyelectrolyte with effective slow mixing and flocculation should ensure the settlement of “intact” dead algae mass from the clarifier. Excessive coagulant dosages during a low turbidity period (raw water) ensure “sweep flocculation” to trap the microscopic algal particles.

Micro-strainer

A special process known as micro-straining is being used in some water treatment plants. The micro-strainer is an open drum. Water is passed through a finely woven fabric of stainless steel. The size of the openings in the mesh determines the size of the algae to be removed from the water.

10.3 Control of Taste and ODOR in Water

10.3.1 General

Normally in summers the water level depletes below the Maximum Drawdown Level (MDDL) in the dam. In such a situation, the water supply utility even consumes the water in the dead storage and therefore the color, taste and odor problem come to the fore. color, taste and odor are caused due to decay of inundated vegetation at the bottom of the dam/ impounding reservoir. The utility engineer should be vigilant of this situation and in such situations, should sample water from dead storage and apply jar test to determine the required Alum dose. Taste and odor in water are subjective phenomena and are difficult to quantify exactly. The problems of taste and odor (one co-exists with the other) are more intensive and more frequent in surface water sources as these are more subject to contamination by natural and manmade wastes. Taste and odor are caused by dissolved gases like hydrogen sulphide, mercaptans, methane, organic matter derived from certain dead or living micro-organisms (blue and green algae), decomposing organic matter, industrial wastes containing phenols, cresols, ammonia, agricultural chemicals, high residual chlorine, and chloro-phenols. It is possible that some of the dissolved gases may be found in groundwater also. odor can be classified as aromatic, earthy, swampy, septic, or chemical.

Biological organisms are among the most common causes of taste and odor in water. Diatomacae with Asterionella and Synedra, actinomycetes, and free-swimming nematodes are the principal offenders causing earthy or musty odor. Apart from algae, decomposing leaves, weeds or grasses also cause odor. Vegetation that grows in the low-water areas in the reservoir subsequently gets submerged and decomposes resulting in odor. Chemical and refinery effluents have the greatest potential for odor, followed by domestic sewage. odor tests indicate that only a small quantity (in mg/l) of these materials is enough to produce perceptable odor.

In short, taste and odor producing materials in water are chemical compounds of many varieties with different physical and chemical characteristics, present in water because of direct pollution or biological activity. Most of these compounds are in solution and some exist in the form of particulate and colloidal compounds. Those in solution are comparatively more difficult to remove.

10.3.2 Control of Taste and odor

Preventive and corrective treatment of raw and processed water is necessary for the control and elimination of taste and odor problems. Wherever possible, preventive steps like control of microorganisms are to be undertaken where the source of raw water is from rivers, reservoirs, or lakes and there is control on effluent discharges. Special treatment is given to water in the treatment plant for the removal of odors by aeration, oxidation by chemicals, or adsorption by activated carbon.

10.3.3 Corrective Measures

Odours can be removed by mechanical aeration, oxidation by chemicals like chlorine or its compounds, ozone, permanganates, and adsorption of odor by agents such as activated carbon, floc, and clays.

For removing dissolved gases like hydrogen sulphide and volatile matter, aeration can be practiced at the start of water treatment. Free available residual chlorination at pre chlorination or post chlorination stage can bring about complete elimination of taste and odour. Inadequate chlorination will only intensify the odor of water containing phenolic compounds, tannin, and lignin imparting a medicinal taste. Even with breakpoint chlorination, it may not be possible to remove taste and odor from water in certain cases. Such causative compounds can be removed by super-chlorination. Super-chlorination is normally done at the lake outlet or the plant inlet to maximize both chlorine concentration and its contact time together to effect complete oxidation of problem compounds. This should invariably be followed by dechlorination using sulphur dioxide or sodium sulphate to reduce the residual chlorine to acceptable limits. Using ammonia with chlorine in combined residual chlorination can partly mask or delay chlorophenol tastes in water.

Chlorine Dioxide which is 2.5 times more powerful than chlorine as an oxidizing agent has been found extensively efficient and the general dosage values range from 0.2 to 2.0 mg/l. This is a specialized form of chlorine treatment used for taste and odor control where large doses of chlorine are to be avoided. Chlorine dioxide gas is released in water on site by the inter-action of a solution of sodium chlorite ($NaClO_2$) with a strong chlorine solution of 6000-7500 mg/L.

$$2NaClO_2 + Cl_2 \rightarrow 2ClO_2 + 2NaCl \qquad (10.1)$$

Though the theoretical ratio of chlorine to sodium chlorite is 1:2.6, values between 1:2 and 1:1 are employed in practice. Chlorine dioxide is more expensive and is used for taste and odor control only. It is applied at the first stages of the treatment plant. Thereafter, the final desirable residual chlorine may be adjusted by simple chlorination after filtration. Ozone at dosages of 1.0 mg/L has also produced good results. Chloramination is useful in the removal of phenol tastes.

The preferred method of treatment for taste and odor removal is activated carbon. Activated carbon is made from hydrocarbon or carbohydrate sources, the principal requirement being that the carbon residue left after destructive distillation has a porous structure. odor producing substances that cannot be removed by oxidation are physically adsorbed onto the surface. This treatment is usually applied before filtration. The contact time varies from 10 to 60 minutes. Activated carbon performs well at lower pH values. A bed of carbon or suspension kept in circulation could be used. The active surface must be preserved from the coating by other chemicals. Application of carbon can be made before sedimentation if the taste and odor are severe and frequent and in certain cases after sedimentation. The approximate dosage for routine, continuous application as the suspension is 2 to 8 mg/l, for emergency treatment 20 to 100 mg/l.

Activated Carbon (AC) beds are generally 1.5 to 3 m deep with the sizes 0.2-0.4 mm with loadings of about 4.8 $m^3/hr/m^2$ of bed. Filtration rates range from 7.2 to 15 $m^3/hr/m^2$ with expected efficiencies of about 90%. As many variables are involved, pilot plant tests are necessary. AC can also be used as a polishing agent to remove residual odors after other treatments.

Variables such as pH, temperature, quantity, and type of organic matter in the influent water and detention time have a marked effect on the efficiency of removal of odorous substances.

10.4 Removal of color

10.4.1 Causes of color

Colour in water may be due to natural causes or as a result of human activity. Waters occurring in peaty soils acquire color due of the presence of colloidal organic matter. color is also due to mineral matter in solutions, as a colloid, or in suspensions as in the case of groundwater in certain areas. Waters containing oxidized iron and manganese impart characteristic reddish or black color. Heavy growths of algae may also impart color to the water. Discharge of industrial wastes or heavy sewage pollution may also bring in color. The constituents in colored water can consist of Natural Organic matter (NOM) or Synthetic Organic Matter (SOM). NOM mostly consists of Fumic and Fulvic acids having a low molecular weight.

10.4.2 Colour Due to Iron and Manganese

Colour due to iron and manganese may be removed by specific treatment for the removal of these constituents as discussed in para 10.6.

10.4.3 Colour due to Algae

Water that is colored because of the growth of algae has to be treated to eliminate the source by control of the algae as discussed in para 10.2 or by processes such as micro-straining. Micro strainers are cylindrical drums with stainless steel screens having openings of 0.025 mm. The proprietary units have sizes varying from 0.75 m dia x 0.6 m long to 3 m dia x 3 m long. The latter size will handle 10-30 lpm of water with a power consumption of about 3 kW. The head loss is only about 150 mm with unit capacities of 7.2 to 12 $m^3/hr/m^2$ of the strainer, the capacity determined by the concentration of microorganisms in the raw water. The coatings of microorganisms are continuously washed down by a jet of water, with the volume of wash water varying from 1 to 3% of the volume of water strained.

10.4.4 Colour due to Colloidal Organic Matter

Coagulation at a low pH range by chemicals such as alum or ferric salts and polyelectrolytes (sweep flocculation) are used for removing color due to colloidal organic matter(Natural Organic Matter, NOM). Ferric coagulants are generally superior to alum. After removal of the color colloids, the pH of the water will have to be corrected by treatment with lime. The color colloids are often stabilized at a high pH value and hence the addition of lime to aid coagulation is fraught with danger in the case of waters that are colored. It is essential that laboratory tests should be conducted to determine the most suitable chemical and its optimum dosage in the given conditions.

10.4.5 Colour due to Industrial Wastes

Colour due to industrial wastes may be removed by the use of bleaching powder or chlorine or by activated carbon. Since removals are more efficient when the concentrations are high, it is advisable to treat the effluents for color at the factory site itself before discharge into the water bodies.

10.4.6 Colour Removal

The appropriate treatment for the removal of color from water has to be determined for each case with the consideration of the causative factors and on the basis of local trials.

10.4.7 Oxidation of color

In some cases, color is not removed by coagulants and it will be necessary to oxidize the coloring matter. The application of heavy doses of chlorine is one of the methods commonly adopted. When the color is not destroyed by such treatment, the water may have to be treated with strong oxidizing agents like chlorine dioxide. Refer to para 10.3.3.

10.4.8 Treatment by Activated Carbon

Treatment with activated carbon is effective against most problems of color in waters. Carbon removes the coloring matter by adsorption. Application has been discussed in para 10.3.3.

10.5 SOFTENING

10.5.1 General

Water is said to be hard when it does not form lather readily with soap. The hardness of water is due to the presence of calcium and magnesium ions in most cases.

Bicarbonates, sulphates, and chlorides are the anions associated with the hardness. The purpose of softening is to remove these salts from the hard water, reduce the soap consuming properties, ensure longer life to washed fabrics, mitigate its scale forming tendencies, and improve palatability.

Usually, a total hardness of 75 to 100 mg/L (as $CaCO_3$), would meet these requirements. The magnesium hardness should not exceed 40 mg/L to minimize the possibility of magnesium hydroxide scale in domestic water heaters. Calcium and magnesium associated with bicarbonates are responsible for carbonate hardness and that with sulphates, chlorides and nitrates contribute to non-carbonate hardness.

Normally, the alkalinity measures the carbonate hardness unless it contains sodium alkalinity. The non-carbonate hardness is measured by the difference between the total hardness and the carbonate hardness. Carbonates and bicarbonates of sodium are described as negative carbonate hardness.

A summary of the more common salts and the problems they cause in water are presented below in Table 10.2:

Table 10.2: Common Salts and the Problems They Cause

Alkaline causing		**Saline (neutral causing)**		**Acidity causing**
Na and K Alkalinity only	CO_3 Hardness	Non CO_3 Hardness	Salinity only	
$KHCO_3$	$Ca(HCO_3)_2$	$CaSO_4$	K_2SO_4	Mineral acids and acid salts
K_2CO_3	$CaCO_3$	$CaCl_2$	KCl	

$NaHCO_3$	$Mg(HCO_3)_2$	$MgSO_4$	KNO_3	are restricted to acid mine wastes and rare mineral water
Na_2CO_3	$MgCO_3$	$MgCl_2$	Na_2SO_4	
			NaCl	
			$NaNO_3$	$FeSO_4$

Water is classified with regard to its hardness is given in the following Table 10.3:

Table 10.3: Water Hardness Classification

Classification	Total hardness as mg/L of $CaCO_3$
Soft	<50
Moderately Hard	50-150
Hard	150-300
Very Hard	>300

When hardness is less than 150 mg/L, softening for domestic purposes is not usually required.

10.5.2 Method of Softening

The two methods ordinarily used are lime and lime-soda softening and ion-exchange softening.

10.5.2.1 Lime and Lime-Soda Softening

This process is seldom employed in India, however, wherever water characteristics and other limitations exist then this can be used with precautions. More often, it is used for industrial use where the water has to be fed to boilers and also reduce colloidal silica. Softening with these chemicals is used particularly for water with high initial hardness (greater than 600 mg/L) and suitable for waters containing turbidity, color, 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 zero-hardness water.

(a) Lime Soda

(i) Chemical Reactions

When lime and soda are added to water containing calcium and magnesium salts, the following reactions take place.

$CaO + H_2O \rightarrow Ca(OH)_2$ (10.2)
(Quicklime Slaking)

$Ca(OH)_2 \leftrightharpoons Ca^{++} + 2OH^-$ (10.3)

$CO_2 + OH^- \leftrightharpoons HCO_3^-$ (10.4)
(Removal of CO_2)

$HCO_3^- + OH^- \leftrightharpoons {CO_3}^{2-} + H_2O$ (10.5)

$Ca^{++} + CO_3^- \leftrightharpoons CaCO_3$ (10.6)
Solid (Removal of Calcium hardness)

$Mg^{++} + 2OH^- \leftrightharpoons Mg(OH)_2$ (10.7)
Solid (Removal of Magnesium hardness)

Reactions (10.4), (10.5), and (10.6) indicate that carbon dioxide, which is present in water, is converted by hydroxyl ions in lime to ${CO_3}^{2-}$ which combines with Ca^{++} to form relatively insoluble $CaCO_3$. The alkalinity present as bicarbonate furnishes the necessary ${CO_3}^{2-}$ by reaction with added OH^- (equation 10.5) for the reaction (equation 10.6) to be completed. Magnesium ions will have to be removed as $Mg(OH)_2$, according to equation (10.7) since, $MgCO_3$, is fairly soluble. The removal of Mg^{++} is effective around pH ranges of 10 to 10.5 for which additional OH^-ions in the form of lime have to be made available. No reduction of hardness takes place by removal of magnesium by the addition of lime since an equivalent amount of Ca^{++} ion is put back into the solution from the lime added. When all the alkalinity is used by OH^- to form ${CO_3}^{2-}$ any further ${CO_3}^{2-}$ needed, has to be added to the water. This is the case when non-carbonate hardness is present in the water and the needed CO_3^{2-}; can be added in the form Na_2CO_3 (Soda ash).

For calculating the theoretical amount of lime and soda required for softening an analysis of the following constituents is necessary, viz., free CO_2, bicarbonate (usually the total) alkalinity, total hardness, and magnesium. Appendix 10.1 gives an illustrative example to compute the chemical dosage required in water softening using the lime-soda process. Chemical requirements (mg/L) are computed by the sum of the following factors.

On a 100% purity basis, the dosage of lime as CaO required for softening as obtained from the chemical equations is as follows:

1.	For every gram of CO_2 to be removed	1.27 g
2.	For every gram of CO_3 hardness as $CaCO_3$to be removed	0.56 g
3.	For every gram of Mg as Mg to be removed	2.33 g
4.	Additional lime as required for raising the pH to the range of 10 to 10.5 for precipitation of $Mg(OH)_2$	30-50 mg/L
5.	Soda ash requirements as Na_2CO_3 to remove one gram of non-carbonate hardness as $CaCO_3$	1.06 g
6.	Additional soda as required to neutralize every gm of excess lime	1.89 g

Plant conditions like temperature, time of detention, and agitation influence the completion of reactions, and the dosages of chemicals may have to be increased to provide for any inadequacies and impurities.

Alternatively, caustic soda can be used instead of lime. The reactions are:

$$NaOH \leftrightharpoons Na^{+} + OH^{-}$$

$$OH^{-} + HCO_3 \leftrightharpoons CO_3^{2-} + H_2O$$

$$Ca^{++} + CO_3^{2-} \leftrightharpoons CaCO_3$$

$$Mg^{++} + 2OH^{-} \leftrightharpoons Mg(OH)_2$$

Liquid caustic soda can be used since it can be handled and fed easily. The amount of calcium carbonate sludge formed in this case is theoretically half that formed by the use of lime. However, caustic soda is costlier than soda ash, which in turn is more expensive than lime.

Waters higher in carbonate than in non-carbonate hardness will require relatively more lime than soda ash for their treatment. The sludge settling out carries with it a large portion of the turbidity, iron, manganese, silica, color producing matter, and microorganisms in the water. The softened water may have a higher pH due to the neutralization of CO_2 with lime, thus reducing its corrosive nature.

(b) Process Equipment

Lime soda softening plants include chemical feeders, rapid mix, flocculation, sedimentation basins, and rapid sand filters. The process design must ensure the promotion of the chemical reactions necessary to remove the hardness from water by converting them into insoluble precipitates and then settling these precipitates and filtering the partially clarified water.

(i) Chemical Feeders

The solubility of calcium hydroxide (slaked lime) is low being of the order of 1600 to 1800 mg/L in cold water. It is common practice, therefore, to feed a 5% slurry of lime so that unusually large solution tanks are avoided. Soda ash is also added in solution form. Types of chemical feeders used are discussed in para 7.4.

(ii) Rapid Mix and Flocculating Basins

Rapid mixing ensures thorough mixing of the slaked lime (lime slurry) and soda ash with the water. A mixing period of 5 to 10 minutes is necessary due to the low solubility of lime. Peripheral speeds of paddles for rapid mixing basins should be 45 to 60 cm/sec with water velocities of 15 to 30 cm/sec. The addition of lime and soda ash results in a supersaturated solution of calcium carbonate and magnesium hydroxide, and some precipitation of the two compounds starts immediately after the rapid mixing. These are kept in suspension to further the growth of these precipitates. Some of the settled sludge deposited, from the settling basin is often recirculated to the rapid mix basin for aiding in flocculation. This may ensure the promotion of chemical reactions with the previously precipitated solids and the formation of more readily settleable precipitates.

The removal of the post-reaction products takes place by precipitation on the surface of the previously formed particles which enhances the reaction rate. The flocculation time required
varies from 40 to 60 minutes. Mechanical flocculators are preferred to ‘baffled’ ones. A tapered flocculator is generally preferable. The precipitates are formed on the paddles in rapid mixing and flocculation basins, which may require periodic cleaning.

(iii) Sedimentation Basins

They may be circular or rectangular and the detention time varies from 2 to 3 hours depending on the size of the flocs. The limiting horizontal velocity is usually about 0.3 m/min. A large volume of sludge is produced since every unit (mg/l) of hardness produces approximately 2 mg/l of dry sludge and, therefore, adequate extra basin capacity must be provided. Continuous mechanical sludge collection and removal are almost always required.

Another type of softener is the sludge blanket type which is used for flows greater than 2 MLD and where compactness is an essential requirement. The treated water is passed and sieved upward through a suspended sludge blanket composed of previously formed precipitates. Some of the hydrated lime in suspension may be carried down by sludge. In this type, the upward flow or sieving through the blanket offers full scope for a complete solution and utilization of the added lime. The intimate contact of the treated water with a large mass of solids that serve as nuclei prevents supersaturation and hence overcomes problems after precipitation. The need for separate filtration can also be dispensed with. The upflow velocity at the sludge blanket zone should be equal to one-half the settling velocity of the floc to have a good blanket of flocs. Overflow rates of 50 to 100 m3/d/m2 could be used. Experience has shown that the use of precipitated calcium carbonate granules or other suitable catalysts of 0.3 to 0.6 mm grain size in these sludge blanket units could reduce the detention times to one-quarter that of the regular units, without any loss of efficiency.

(3)Sludge Disposal

Disposal of sludge is usually done by lagooning it in sludge drying beds. Large land area is required as the sludge does not dry up rapidly. Lime can be reclaimed from the sludge and it has to be free from magnesium if it is to be reused. One of the common methods (Hoover Process) is to precipitate the calcium sludge in the first stage by adding just enough chemicals and then precipitating the magnesium sludge in the second stage. The sludge from the first stage, which is devoid of magnesium, is dried and calcined. The resulting calcium oxide is reused for softening and the carbon dioxide is utilized for re-carbonation. Another method (Lykken-Estabrook Process) is to apply the total chemicals required for the precipitation of calcium of about 12% of the water and precipitate the calcium and magnesium sludge that is wasted. The water from this portion carrying excess chemicals is then mixed with the rest precipitating only calcium sludge which can be calcined and reused. The reclamation processes also reduce the quantity of sludge to be handled.

(4) Filters

(a) Conventional softening units are followed by rapid sand filters but incrustation of filter sand due to precipitation of super-saturated calcium carbonate has to be guarded against. The application of 0.5 mg/l or more of polyphosphate or metal phosphate has been found to prevent effectively not only the sand incrustation but also, coatings of calcium carbonate on the filter walls and wash water troughs. Surface wash devices are used to remove loose deposits. Another method of checking after precipitation is to adjust the pH value of the softened water to about 8.3 by re-carbonation. Carbon Dioxide is applied to the effluent from the settling tank. The gas can be obtained by burning coke, oil, or gas in presence of excess air and then scrubbed to remove the other gases. In small plants, dry ice or liquid CO_2 can be used. The carbonation tank must provide 15 to 30 minutes of retention time with a depth of water equal to 3 to 4.5 m and the whole plant should be well ventilated.

(b) Excess Lime Treatment

Plain lime or lime soda treatment is used when the bulk of hardness is due to calcium and magnesium is not significant. However, when the water contains more than 40 mg/L of magnesium warranting its removal, excess lime treatment has to be resorted to, since magnesium has to be removed as magnesium hydroxide whose solubility decreases with increasing pH values. The water treated thus is highly caustic and has to be neutralized following precipitation. This is done either by re-carbonation or by split treatment. In the latter case, the total flow is divided into two parts, one part being treated with excess lime and the settled effluent mixed with unsoftened water. The final residual hardness in the water will depend upon the percentage of flow bypassed and the levels of hardness in both the portions.

(c) Hot Lime-Soda Process

The hot lime-soda process is used for boiler feed water treatment. This is similar to the cold process except that the raw water is heated to about 95° to 100°C before it is taken to the reaction tank. The reactions take place rapidly, resulting in decreased viscosity, hastening the settling of the precipitates. A greater degree of softening is accomplished than that in the conventional cold processes.

10.5.2.2 Ion Exchange Softening

The ion exchange process is the reversible interchange of ions between an exchange medium and a solution and this process is used extensively in water softening. The hardness-producing ions preferentially replace the cations in the exchangers and hence this process is also known as Base Exchange softening. The ion exchange can produce water of zero hardness. There is only a temporary change in the structure of the exchange material which can be restored by regeneration. The ion exchanger can work on the hydrogen or sodium cycle, the hydrogen ions being released into the water in the former case and the sodium ions in the latter. The regenerant agents are an acid and sodium chloride respectively. In general, the ion exchange materials used in softening, also called zeolites, are hydrated silicates of sodium and aluminium having the formula $xNa_2O.yAl_2O_3.zSiO_2$. The reaction can be depicted as follows.

$$Na_2Z + \frac{Ca^{++}}{Mg^{++}} + 2A^- \leftrightarrow \frac{Ca}{MgZ} + 2Na^+ + 2A^- \qquad (10.8)$$

Where A^-represents the relevant anions of bicarbonates, sulphates, or chlorides and Z represents the anionic part of the zeolite.

Treatment with zeolite thus increases the dissolved solids in the ratio of 46:40 of the hardness removed. The reverse equation operates during the regeneration resulting in a strong solution of calcium and magnesium salts, which is run to waste.

(a) Inorganic Zeolites

The two common inorganic zeolites are the natural and synthetic types. The natural zeolite is available as green sand while the synthetic or gel type is obtained by the reaction of either sodium or aluminium sulphate with sodium silicate which, after drying is graded to suitable sizes by screening. A cubic metre of green sand weighs 1600 kg with a specific gravity of 2.1 to 2.4 and for regeneration it requires 3.5 to 7 kg of salt for every kg of hardness removed. The synthetic inorganic zeolite weighs 900 to 1100 kg per cubic metre. The relevant exchange capacities and regenerant requirements are given in para 10.5.2.2 (d).

(b) Organic Zeolites

These are lighter than the inorganic zeolites weighing 500 to 800 kg/m^3. These consist of sulphonated carbonaceous material and sulphonated styrene type resins which have excellent cation exchange properties, requiring for regenerating 2-4 kg of salt for every kg of hardness removed. These are resistant to attack by acid solutions and hence can be regenerated with acid also. They can be used for waters with a wide pH range. The loss due to attrition is negligible compared to the synthetic inorganic zeolites.

(c) Raw Water characteristics

For application to ion exchangers, the raw water should be relatively free from turbidity, as otherwise, the exchange material gets a coating that affects the exchange capacity of the bed. The desirability of using filters before zeolite beds or resorting to more frequent regeneration would depend upon the level of turbidity. Metal ions like iron and manganese, if present are likely to be oxidized and can coat the zeolites, thus deteriorating the exchange capacity steadily since the regenerant cannot remove these coatings. Oxidizing chemicals like chlorine and carbon dioxide, as well as low pH in the water, will tend to attack the exchange material, particularly the inorganic types, the effect being more pronounced on the synthetic inorganic zeolites. Waters low in silica content are likely to pick up silica from synthetic inorganic zeolites, which has to be avoided in boiler feed water. The organic zeolites operating on the brine regeneration cycle do not add any silica to the water and consequently are ideally suited for boiler feed water.

(d) Design Criteria

The design criteria for a softening system are based upon (i) the required flow rate, (ii) the influent water quality, (iii) desired effluent water quality, (iv) exchange capacity and hydraulic characteristics of the exchanger, (v) period between regenerations, (vi) type of operation, (vii) number of units required, (vii) rate, time of contact, uniformity, and concentration of brine application. (ix) Rate and volume of rinse and (x) quality of regenerant. A softening unit is similar to a rapid sand filter unit for the hydraulics and equipment concerned.

The volume of exchange material to be used in cubic metres (E) is calculated by the formula:

$$E = \frac{QH}{1000G} \qquad (10.9)$$

Where;
Q = Volume of water to be treated between regeneration, in m^3
H =Hardness of water in mg/L
G = Exchange capacity of the material kg/m^3

Generally, ion exchange beds are encased in shells - shell diameter, and bed depth being adjusted to maintain a rinse rate of flow in the range of 0.15 to 0.30 m/min. The vertical units are 2 to 3 metres in diameter while the horizontal ones are 3 m in diameter and 8 to 9 m long. The ion exchange bed has a depth of 0.6 m usually and is placed over supporting gravel (size depending upon the composition of the exchange material but with similar specifications as those for rapid gravity sand filters) of 0.30 to 0.45 m depth with an underdrain system at the bottom for collecting softened water. After the softening cycle, the softener should be backwashed for 3 to 5 minutes to loosen the exchange resin and remove particulate matter. The rate of backwash should ensure at least 50% bed expansion. Then regeneration of the bed is carried out with brine solution. The brine distribution manifold is placed immediately above the softener bed.

Exchange capacities and the common salt requirements of cation exchangers are presented in Table 10.4

Table 10.4: Exchange Capacities and Common Salt Requirements of Cation Exchangers

Cation Exchanger	**Capacity Kg/m^3**	**Common Salt kg/kg exchanged**
Green sand	7 - 14	3.5 – 7
Synthetic Siliceous Zeolite (inorganic)	14 - 37	2.5 - 3.5
Synthetic Organic	-	-
Sulphonated Coal	12 - 70	2 – 4
Resin, Polystyrene	25 - 100	2 – 4

The optimum concentration of brine for restoration of maximum exchange capacity in any resin is about 10 to 15% and the contact time for regeneration varies from 20 to 45 minutes. A dosage of salt of 15 kg/min/m^3 of resin using 10% brine solution is usually applied at a rate of about 150 lpm/m^3 of the exchanger. For sea water, about 200 to 400 lpm/m^3 of the exchanger is necessary.

The total rinse water requirement is 3 to 10 m^3/ m^3 of material and applied at a rate of 9 to 18 m^3/h/m^3 in the slow and 30 m^3/h/m^{3}of material in the fast types. The rinse water is introduced through the brine distribution network or by simply flooding the unit through a hose.

The salt or brine storage tank should provide for a capacity of 24 hours or 3 successive regenerations, whichever is greater.

(e) Disposal of Spent Brine

The total waste flow from a softening unit may vary depending upon the capacity of the exchanger and the hardness removed in each cycle. The waste flow consists of a mixture of salts of sodium, calcium, and magnesium with concentrations as high as 9,000 to 12,000 mg/l. The disposal of spent salt or spent brine poses a problem. Methods like controlled dilution, evaporation ponds, and disposal at sea or brine wells can be adopted.

10.5.2.3 Combination of Lime and Zeolite Softening

For waters that contain large carbonate hardness, a combination of lime and zeolite softening can be practiced. The lime treatment, which is applied first, removes by precipitation a large part of the carbonate hardness, simultaneously decreasing the amount of dissolved solids in the water. After leaving the lime reaction tank, the water is settled and filtered and then passed through the zeolite softeners which by base exchange remove the residual carbonate hardness and all the non-carbonate hardness.

The combination of lime and zeolite offers the following advantages:

(a) It gives water a lower hardness than can be obtained by lime and soda ash treatment.
(b) It reduces the amount of total dissolved solids which the zeolite treatment alone would not do.
(c) It has a lower cost of chemicals than with lime and soda ash and possibly lower than with zeolite alone, depending on the relative costs of salt and lime.

Surveys carried out in other countries have brought out the fact that the benefits of savings of soap alone justify the expenses of softening on a municipal scale. Other benefits like good public relations add to the attractiveness of the proposition. The practice has not, however, is not the trend even in those countries. With greater demands for higher quality water, water softening may have to be carried out on a municipal scale also.

10.6 Removal of Iron and Manganese

Appreciable amounts of iron and manganese in water impart a bitter characteristic, metallic taste, and the oxidized precipitates can cause the coloration of water which may be yellowish brown to black and renders the water objectionable or unsuitable for domestic and many industrial processes. In addition, staining of plumbing fixtures and laundry can also result. The carrying capacity of pipelines in the distribution system is reduced due to the deposition of iron oxide and bacterial slimes as a result of the growth of microorganisms (iron bacteria) in iron-bearing water. The concentration of iron in excess of 0.2 to 0.3 mg/L may cause nuisance and become aesthetically non-acceptable, even though its presence does not affect the hygienic quality of water. Iron is present mostly in ground waters and its occurrence is as shown in Figure10.3.

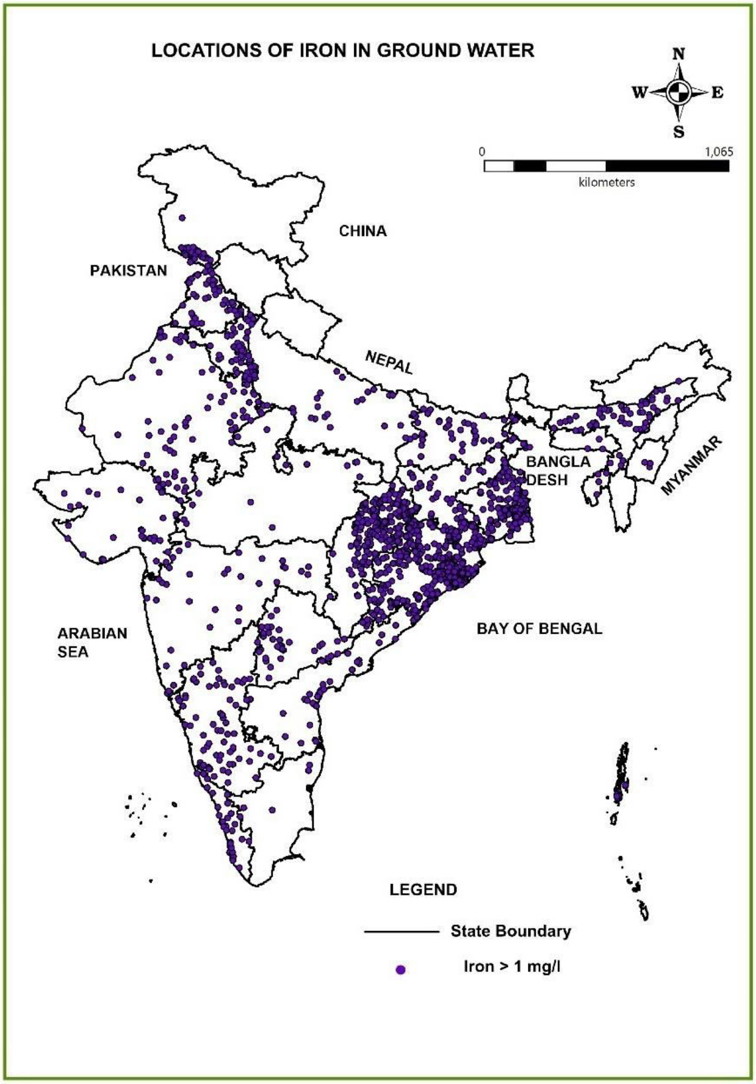


Figure 10.3: Location of Iron in Ground Water*(Source: CGWB)*

10.6.1 Sources and Nature

Iron and manganese occur in certain underground waters and springs, alone or in association with organic matter, iron being generally predominant when they are together. They could also be found in solution in water derived near the bottom of deep lakes, where reducing conditions develop. These are usually seasonal. The presence of iron can also result due to the discharge of certain industrial wastes or mine drainage.

Iron and manganese in ground waters are attributed to the solution of rocks and minerals chiefly oxides, sulphides, carbonates, and silicates of these metals. This dissolution is enhanced by the presence of dissolved carbon dioxide present in groundwater.

Iron exists in water in two levels of oxidation (i) as the bivalent, ferrous iron (Fe^{++}) and (ii) as the trivalent, ferric iron (Fe^{+++}), the latter occurring generally in the precipitated form. Therefore, in clear ground waters, the iron, if present, is all ferrous iron. Manganese is also found in water naturally in two oxidation states, bivalent and quadrivalent, the latter being quite less soluble.

Iron forms complexes of hydroxides and other inorganic complexes in solution with substantial amounts of bicarbonate, sulphate, phosphate, cyanide, or halides. The presence of organic substances induces the formation of organic complexes and chelates which increase the solubility of iron and manganese.

The terminology of organic iron and manganese is used when difficulties in oxidation are encountered. There are no analytical techniques for the determination of organic iron or manganese.

Waters of high alkalinity have lower iron and manganese contents than waters of low alkalinity. If the water contains significant amounts of hydrogen sulphide, little or no iron or manganese is found in the solution as most of it is precipitated.

10.6.2 Removal Methods

Chemical analysis of water alone may not always provide a clue to the removal method to be adopted. Hence, it is advisable that laboratory and pilot plant studies are made before any particular method is used. Oxidation by aeration or use of chemicals like chlorine, chlorine dioxide, or potassium permanganate followed by filtration alone or by settling and filtration can bring about the precipitation of iron and manganese and their removal. The use of zeolites, as well as catalytic oxidation, also serves the purpose.

10.6.2.1 PRECIPITATION OF OXIDES

Iron or manganese in water in reduced form is converted to soluble ferric and manganic compounds by oxidation and these are removed by filtration alone or by sedimentation and filtration. The reaction period is about 5 minutes or less at a pH of 7 to 7.5 and 0.14 mg of oxygen is needed to convert 1 mg of ferrous iron to ferric hydroxide as indicated below.

$$4\,Fe^{2+} + O_2 + 10H_2O \Rightarrow 4Fe(OH)_2 \downarrow + 8H^+ \qquad (10.10)$$

$$4 \times 56\,mgFe^{2+} = 2 \times 16\,mgO_2$$

$$1\,mg\,Fe^{2+} \equiv 0.14\,mg\,O_2$$

The rate of oxidation of ferrous iron by aeration is slow under conditions of low pH and increases 100% for every unit rise of pH. Increased aeration time would be necessary for stripping the carbon dioxide, hydrogen sulphide, etc. The addition of lime can also remove the carbon dioxide or in case where there is mineral acidity, it can accomplish the raising of pH. Rates of precipitation and flocculation are accelerated in practice by contact and catalysis. Water is allowed to trickle over coke or crushed stone. The deposition of hydrated oxides of iron and manganese and bacteria on the contact media is believed to act as catalysts that accelerate the oxidation of iron.

The contact beds for deferrization are normally 2 to 3 m deep operating at a surface loading of 40 to 70 $m^3/d/m^2$ with the contact medium of sizes 50 to 150 mm. Accumulation of iron and manganese are flushed out by rapid drainage after filling the bed to near overflow level. Sedimentation before filtration will be necessary when the iron content exceeds 10 mg/L. A settling period of two to three hours is adequate. The water has to pass through filters (gravity or pressure type) with a 75 cm depth of sand or sand and anthracite. Filter rates are usually 6 to 9 $m^3/h/m^2$.

Oxidation of iron can be inhibited possibly due to the binding of ferrous iron by organic substances and ammonia which behave like tannic, gallic, or ascorbic acids. All the organic material has to be oxidized before any perceptible oxidation of iron can be affected. Chlorination of many iron-bearing waters can bring about the oxidation of organic matter and other reducing agents facilitating the oxidation of ferrous iron. Deeper filter beds upto 2 to 2.5 m with a sand size of 0.6 mm have also been used with good results. In many waters, especially containing organics, pre-chlorination ahead of coagulation, sedimentation, and, filtration at pH values between 6.7 and 8.4 usually will ensure iron removal to acceptable limits.

By the addition of lime to raw or pre-aerated waters, carbon dioxide content can be brought down to zero and the resulting high pH value will promote the flocculation of iron and manganese. The plants will require washing of filter medium. The necessity of washing is ascertained as and when there is overflow through the overflow pipe provided in the filter compartment of the units. The interval between successive washings varies and depends on the initial turbidity and iron content. Experience indicates a closer interval of one week for high turbidity with an iron content of around 40 mg/l and 1-2 months for waters with low turbidities with an iron content of less than 10 mg/l. Washing of filter medium involves removal of top 5 to 10 cm filter medium and washing it manually with water to free it from sediment and replace the same in position. The coke medium needs washing/replacement once in 6 to 24 months depending on the iron content in raw water.

Iron removal is also concomitant with the high pH value reached in municipal softening plants using lime.

Manganese removal requires a pH adjustment upto 10.4 to 10.6, and0.29 mg of oxygen is needed to convert 1 mg of manganese.

$$6Mn^{2+} + O_2 + 6H_2O \leftrightharpoons 2Mn_3O_4 + 12H^+$$

$$2Mn_3O_4 + 2O_2 \leftrightharpoons 6MnO_2\ (black)$$

$$6Mn^{2+} + 3O_2 + 6H_2O \leftrightharpoons 6MnO_2 + 12H^+$$

$$1\ mg\ Mn^{2+} \equiv 0.29\ mg\ O_2$$

Pre chlorination to free residual values upto 0.7 to 1.0 mg/L will affect the oxidation and precipitation of manganese.

10.6.2.2 CONTACT BEDS

The purpose of contact beds is to facilitate the oxidation of iron or manganese through the catalytic action of previously precipitated oxides of these minerals on the gravel or ore. Superior results are claimed for the manganese ore, pyrolusite, which is an oxide of manganese. Usually, upward flow at rates upto 10.6 m/h is preferred, but a lower rate may be used based on laboratory and pilot plant studies. Bed depth should be 1.8 m or any greater depth found necessary by pilot-plant studies. Provision must be made for the rapid draining of the beds, so as to wash excess oxides from the gravel or ore, and for the use of a hose stream for periodic cleansing of the gravel or ore. The beds are regenerated by backwashing with potassium permanganate solution when permanganate is not applied continuously to the raw water.

Contact beds of pyrolusite ore, for manganese removal without lime or potassium permanganate treatment, must be in closed structures to prevent the entrance of air. Upward flow, at rates established by pilot-plant tests, should be provided. A trial rate of 4.8 m/h with a bed depth of 1.8 m is suggested giving a contact period of 9 minutes, with a usual void volume of 40%. The effluent from such beds should be aerated in a downward flow contact bed-aerator constructed to facilitate the passage of air. Final filtration is needed as discussed further.

Manganese zeolite, formed by treating sodium zeolite with a solution of potassium permanganate, is an effective contact material that will remove by oxidation of about 1.63 kg manganese per cubic meter of zeolite per cycle. Re-oxidation or regeneration of all material in each cycle is ensured by backwashing with a solution of potassium permanganate containing about 3.26 kg of this chemical for each cubic meter of zeolite. Incomplete re-oxidation will result in the passage of manganese through the contact bed. The need to regenerate may be anticipated by computing the volume of the raw water which contains 1.63 kg manganese per cubic metre of zeolite. For example, water with a content of 1 mg/L manganese will contain 1 kg/m^3. Then a contact bed with a volume of say, 4 m^3 would treat 4 x 1.63 x 1.0 = 6.52 m^3 of this water before regeneration is necessary. A solution of potassium permanganate such as 10 kg/ m^3, would be used to re-oxidize the bed. Then 1.3 m^3 of this solution would be needed per cycle: (3.26/ 10) x 4 = 1.3.

Chlorine dioxide and potassium permanganate which are strong oxidants are employed chiefly for manganese-bearing waters. The pH range at which manganese dioxide ~~si~~ is oxidized rapidly is quite broad.

10.6.2.3 ZEOLITE

The method is applicable if the iron is present in a reduced state and in a soluble form in raw water. Such waters are encountered from the bottom strata of deep reservoirs or ground waters. It is usual to limit the application of this process to water having not more than 1 mg of iron or manganese for every 30 mg of hardness upto a maximum of 10mg/L of iron or manganese.

The process consists of the percolation of the water through the bed of the zeolite which takes up the iron and manganese by a process of ion exchange. The base exchanger may be of the siliceous, carbonaceous, or synthetic resin type. Air should be excluded from the system to prevent the deposition of colloidal oxides on the ion exchange material. Therefore, airlifts, open tanks, or pneumatic tanks should not be used preceding the ion exchanger. If the water is to be softened, then also the zeolite process offers a very simple method of iron and manganese removal as it can be carried out under pressure; therefore, usually obviates the necessity for double pumping, as required in most other processes. Many zeolite plants have been installed principally for iron and manganese removal, the softening being of secondary importance. The removal of iron and manganese is almost complete, the exhausted bed of ion exchange material being regenerated with a salt solution.

10.6.2.4 CATALYTIC METHOD

This method is of limited application; but is of value, if the content of iron and manganese is low and if it is desirable to treat the water under pressure. It is applicable in the case of clear deep well waters, where the iron is held in solution by carbon dioxide. In municipal use, it is usual practice to restrict the use of this method to waters, whose content of iron or manganese is not greater than 1 mg/l. For household use or the rather smaller plants, it may be used with waters containing upto 10 mg/l of iron or manganese. The removal of iron and manganese is accomplished without affecting the hardness of the water as this process is entirely one of oxidation and filtration and does not involve Base Exchange. The method consists of percolating the water through suitable contact materials which oxidize the iron and the manganese. These contact materials, which are sold under various names, are made by treating a siliceous base exchange material successively with solutions of manganese chloride and potassium permanganate. They may be housed in a separate filter or a layer of this material may be sandwiched in the sand bed of a pressure filter. By percolation through this bed, iron and manganese are oxidized and also filtered out. At intervals, the filter has to be backwashed to remove the deposits. The backwash rates are generally of the order of 21 $m^3/h/m^2$. When the bed loses its capacity for oxidation of iron and manganese, it can be regenerated by treatment with potassium permanganate solution.

10.6.3 Simple Techniques for Iron Removal in Small Communities

For small communities in rural areas, where the density of population is low, piped distribution is costly, and trained personnel for the operation and maintenance are not available; a simple and inexpensive treatment unit for the removal of iron is suggested so that the difficulties of operation and maintenance can also be minimized. In a small water supply scheme to treat raw water containing free carbon dioxide and dissolved iron, the units include, hand-pumps, tray-aerators, sedimentation basins, and sand filters.

Where the source is a well or a sump and the water consumption rate is in the order of 40 lpcd and where a hand pump is used, a tray type aerator with two trays operated at an aeration rate of 1.26 $m^3/m^2/hr$. are employed and the water aerated. Then the water is settled in a sedimentation basin having a detention period of 3 hours and the clarified water passed through a rapid sand filter having a depth of 0.3 m supported by gravel 3-6 mm in size and 0.1 m deep. The effective size of sand is 0.30-0.45 mm with a uniformity coefficient of 2-3. Sand is cleaned by manual scraping. A provision could also be made for adding sodium carbonate wherever essential. Reference may be made to the type design for the iron removal plant given in Appendix 10.2.

10.6.4 Iron Removal Plants for Large Communities

When the question of iron removal is under consideration for community water supply, it is important to decide and cover what other treatment of the water, if any, is necessary or desirable. Considerable free carbon dioxide and toxic substances are usually present in ferruginous waters. Hence, it is not advisable to remove iron alone leaving the free carbon dioxide which may cause corrosion of mains and pipes. The means by which iron, free carbon dioxide, and other toxic substances are removed from water in community systems consist substantially of their oxidation and removal of free carbon dioxide, followed by precipitation and its separation by sedimentation and/or filtration. Aeration may suffice for the preliminary precipitation but may not be adequate when concentrations are high and pH correction may be required by the addition of lime. The community water supply scheme makes provisions to meet such requirements and comprises raw water storage tank, cascade tray aerators, chemical dosers, sedimentation basin, filtration, and disinfection.

Tray aerators are commonly used for aerating the water. The trays are designed for an aeration rate of 1.26 $m^3/m^2/hr$. and spaced at intervals of 1 m. Then the water is settled in a sedimentation basin having a detention period of 2.5 hours. The clarified water is filtered through a rapid sand filter having sand of effective size 0.6-0.8 mm and uniformity coefficient 1.3 with an effective depth of 1.2 m. The head of water above the sand is 1.35 m and the rate of filtration is 5 m^3/m^2/hr. The minimum backwash rate is 35 m^3/m^2/hr. and the total head required for filter wash is 12 m.

Type designs for iron removal plants for 5, 10, and 15 m^3/hr. of flow are given in Appendix 10.3 along with drawings.

WHERE IS THE CONTINUITY?

The sand is supported over a gravel layer of depth 0.39 - 0.62 m, and it is arranged as per Table 10.5:

Table 10.5: Arrangement of Sand

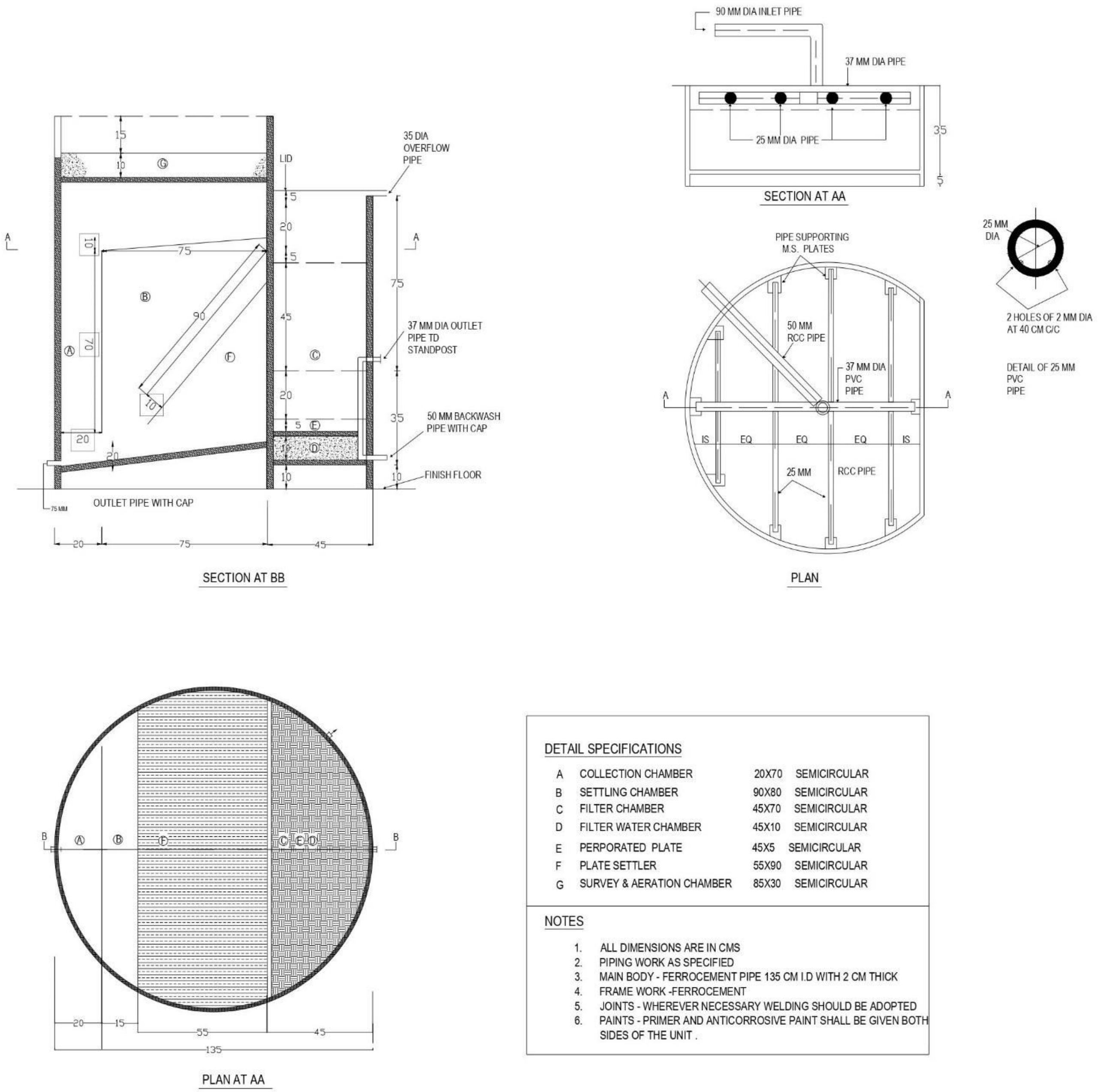
Size	Depth
65-38 mm	13-20 cm
38-20 mm	8-13 cm
20-12 mm	8-13 cm
12-5 mm	5-8 cm
5-2 mm	5-8 cm

In case, the power shut-downs are frequent and often only two hours of supply is available in the morning and evening. In such situation, the raw water pumping hours can be assumed to be 2 hours in the morning and 2 hours in the evening. During these 4 hours of pumping the total daily requirements of water are to be pumped to the raw water elevated storage tank. The treatment plant has therefore to be designed to operate under gravity from the raw water storage tank taking these facts into account. To avoid extra cost for an additional overhead tank for filtered water, the filtered water from the pump-well could be directly pumped for the distribution. The distribution of treated water would follow the same schedule as for pumping raw water. Backwashing of the sand filter would be carried out by using raw water from the overhead tank.

10.6.5 Packaged Iron Removal Plants

10.6.5.1 PACKAGED IRON REMOVAL PLANTS BY NEERI

NEERI has designed package iron removal plants having different capacities of 0.5 m^3/hr, 1.0 m^3/hr, 1.5 m^3/hr, and 2.0 m^3/hr depending upon the requirement of treated water. The plants are designed in rectangular/circular shapes having an aeration chamber, collection chamber, settling chamber, and filter. The settling chamber is provided with a plate settling device to enhance settling and reduce the detention time thereby reducing the dimension of the settling chamber. The aeration chamber contains media of size 2.0-5.0 cm gravel/ stone chips to increase the surface area of the air water interface. The iron contaminated water trickles over aeration media through a spraying device. The aerated water flows through pores over the baffle plate to the collection chamber to the settling chamber to filter. The filter bed of 20 cm depth contains sand media of size 0.8 - 1.4 mm, supported by a 5 cm deep gravel bed of size 0.8 - 1.0 cm. The treated water is taken out from the tap attached to it. The sedimentation chamber having a detention period of one hour is provided with two plate settlers at 45^o angles as shown in Figure10.4 of 1 m^3/hr. plant. The filter is cleaned by making a backwash connection with a hand pump, scraping the sand bed manually, and opening the sludge scouring valve.



DETAIL SPECIFICATIONS

A	COLLECTION CHAMBER	20X70	SEMICIRCULAR
B	SETTLING CHAMBER	90X80	SEMICIRCULAR
C	FILTER CHAMBER	45X70	SEMICIRCULAR
D	FILTER WATER CHAMBER	45X10	SEMICIRCULAR
E	PERPORATED PLATE	45X5	SEMICIRCULAR
F	PLATE SETTLER	55X90	SEMICIRCULAR
G	SURVEY & AERATION CHAMBER	85X30	SEMICIRCULAR

NOTES

1. ALL DIMENSIONS ARE IN CMS
2. PIPING WORK AS SPECIFIED
3. MAIN BODY - FERROCEMENT PIPE 135 CM I.D WITH 2 CM THICK
4. FRAME WORK -FERROCEMENT
5. JOINTS - WHEREVER NECESSARY WELDING SHOULD BE ADOPTED
6. PAINTS - PRIMER AND ANTICORROSIVE PAINT SHALL BE GIVEN BOTH SIDES OF THE UNIT .

Figure 10.4: Iron Removal Plant for 1M^3/HR

10.6.5.2 PACKAGED IRON REMOVAL PLANTS AVAILABLE

Many package iron removal plants have been installed by authorities in various parts of the country. The plants are predesigned for the specific requirements and are successfully being operated and maintained. There are various technologies recommended in "Handbook on Drinking Water Treatment Technologies" published by the Department of Drinking Water and Sanitation such as treatment units developed by NEERI, CMERI, CSIR-NEERI, IMMT, DRDO, CPERA, etc.

10.6.6 Iron Removal Plant (IRP) Technology

A non-RO-based cost-effective Iron, Fluoride, and Arsenic removal technology using Solar Renewable Energy, could prove its sustainability for over six years. Several such specially engineered IRP plants are installed across the Iron affected districts in Bihar under the initiative taken by PHED. These units are upgraded through automation and remote monitoring as the next step of innovation.

In the case of IRON removal technology of groundwater, Oxidation treatment is quite well known while from cost effective perspective is carried out in closed tanks where raw water to be treated is passed through especially treated and granulated media that enhances the process of oxidation. In this process, Iron free water is taken out of tanks while Iron precipitates (convert Fe++ to Fe+++). Ferrous in the dissolved stage is converted into Ferric oxide in the form of precipitate are gathered on the top of granulated media in the tank. The multiport valves fitted on the tank are used to remove these precipitates periodically. This is an essential and very critical task and traditionally it is done manually. Such plants of desired capacity (6KLPH/8KLPH/12KLPH/16KLPH) are engineered in a very cost-effective way requiring minimum O&M cost for dissolved Iron level in groundwater up to 10 ppm.

In case of excess level of dissolved Iron in groundwater is observed the provision of injecting additional oxygen of atmospheric air is provided by introducing specially designed air injectors rather than using traditional air blowers that are power consuming and thereby expensive process besides depending upon mechanical & rotating equipment needing constant attention and additional maintenance. The use of properly designed Air Injectors does this function very effectively. This technology was recognized as INNOVATION at the national level by Ministry of JAL SHAKTI, department of rural water supply Govt. of India in the year 2017.

As the number of such plants is increasing in numbers and rather than leaving this important removal of precipitate function to humans to assuring its repeatability & punctuality, automation has been introduces successfully. It further helps to rinse, clean & wash nontoxic granulated media periodically. With its further extension, even operational problems are overcome such as starting & stopping submersible pumps depending upon water levels in the storage tank, accessing online data at remote distances solving delays & accuracies in human communication and online functionality across the operational team (Figure 10.5).

Figure 10.5: IRP Plant with Auto Multiport Valve

10.7 De-Fluoridation of Water

Fluoride is one of the few substances that has been proved to have a substantial impact on human health when consumed through drinking water. Fluoride has good effects on teeth at low concentrations, but excessive fluoride exposure in drinking water, or in combination with fluoride exposure from other sources, can have a number of negative health effects.

Excessive fluoride in drinking water may cause mottling of teeth or dental fluorosis, a condition resulting in the discoloration of the enamel, with chipping of the teeth in severe cases, particularly in children. In Indian conditions where the temperatures are high, the occurrence and severity of mottling increase when the fluoride levels exceed 1.0 mg/l.

With higher levels, skeletal or bone fluorosis with its crippling effects is observed. The chief sources of fluorides in nature are (i) fluorapatite (phosphate rock), (ii) fluorspar, (iii) cryolite, and (iv) igneous rocks containing fluorosilicates. Fluorides are present mostly in ground waters and high concentrations have been found in parts of Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Assam, and Tamil Nadu in the country (Figure10.6). While the majority of values for Fluoride concentrations in Fluoride affected areas range from 1.5 to 6 mg/L some values are as high as 16 to 18 mg/l and in one solitary instance, even 36 mg/L have been reported. The permissible limit of fluoride in drinking water is 1.5 mg/L.

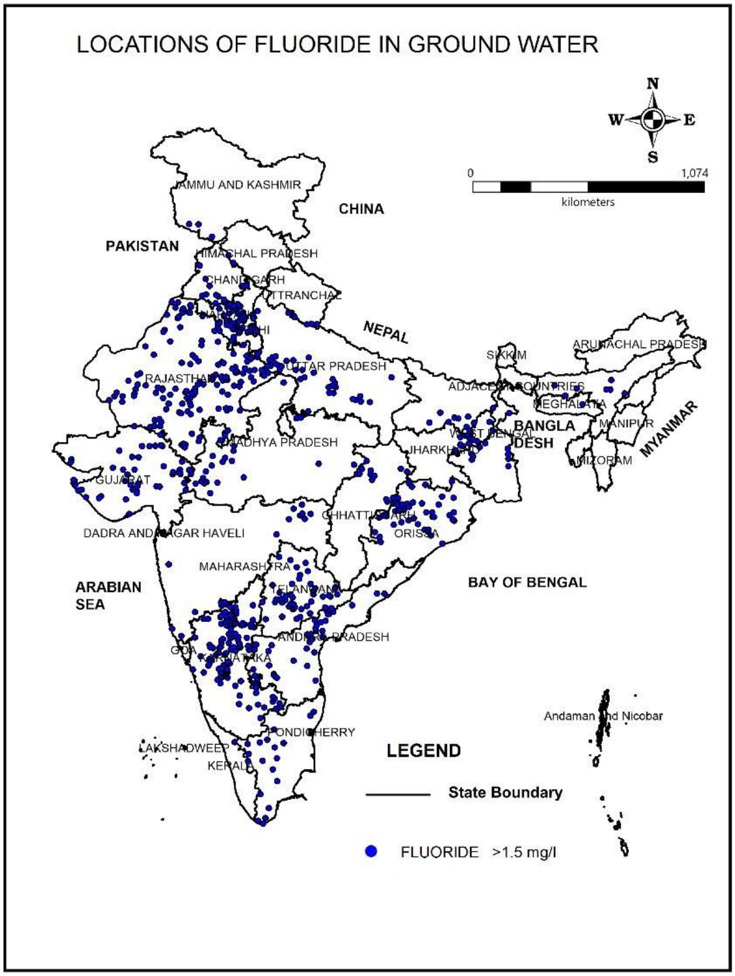


Figure 10.6: Occurrence of Fluoride in Ground Water*(Source: CGWB)*

10.7.1 Removal Methods

The removal of excessive fluoride from public water supplies or individual water supplies is necessary on public health grounds. This is a problem, particularly in rural/ peri-urban areas and hence the simplicity of operation, cheapness, and applicability to small water supplies are of main concern. The methods of removal use fluoride exchangers like tricalcium phosphate or bone meal, anion exchangers, activated carbon, magnesium salts, or aluminium salts. There are several de-fluoridation processes available and are in practice globally. The common methods used for the removal of fluoride from drinking water are categorized as under:

- Adsorption and Ion-Exchange
- Coagulation and Precipitation
- Membrane Filtration Processes

10.7.1.1 Fluoride Exchangers

Degreased and alkali-treated bones possess the ability to remove fluorides but have not been used on a plant scale. Bone charcoal prepared by controlled combustion of bones under a limited supply of air in the presence of catalysts when treated with alkali or phosphate has been found to be useful. One cubic metre of bone charcoal is capable of removing 1.1 kg of fluoride from water with fluoride content upto 6.0 mg/l. The spent material can be regenerated with mono or trisodium phosphate. Tricalcium phosphate in powdered form can also be used but it has a lesser removal capacity of 0.7 kg of fluoride/m^3. The spent material is regenerated by treatment with a 1% alkali solution and rinsed with dilute hydrochloric acid.

10.7.1.2 Anion Exchangers

Fluorides can also be removed by anion exchange resins-strongly basic formaldehyde resin quaternary ammonium type-in hydroxide or chloride form. But their efficiency is lowered in the presence of other anions like bicarbonates, hydroxides, and sulphates in the water.

10.7.1.3 Activated Carbon

Activated carbons have also been known to have the capacity for the removal of fluorides. Activated carbon for fluoride removal has been developed in India by carbonizing paddy husk or sawdust, digesting under pressure with alkali, and quenching it in a 2% alum solution. This could remove 320 mg of fluoride per kilogram of the dry material. The spent material could be regenerated by soaking it in a 2% alum solution for 14 hours. The attrition and hydraulic properties of the carbon are however poor.

A granular ion-exchange material Defluoron 2, which is a sulphonated coal operating on the aluminium cycle has been developed in the country. The capacity of the material is estimated to be 500 gm of fluorides/m^3 with test water containing 5 mg F/l and 150 mg/l alkalinity. The regeneration is carried out by means of a 2.5% alum solution, with the replacement of two-bed volumes. A flow rate of 4.8 m^3/m^2/hr. of bed area is adopted. The rinse water requirements after regeneration are 9-12 m^3/m^2/hr. for a maximum duration of 10 minutes. The medium has a life of three years.

The high alkalinity of the water considerably lowers the capacity as well as the efficiency of the bed. Hydroxyl alkalinity beyond 5 mg/L has a deleterious effect on the removal efficiency of the medium. The efficiency of the medium falls by 30% when hydroxyl alkalinity becomes 25 mg/L.

Treatment cost using Defluoron-2 varies from Rs. 1.0 to Rs. 5.0 per 100 litres of water treated, depending upon the initial fluoride concentration and the alkalinity of water.

10.7.1.4 Magnesium Salts

Excess lime treatment for softening affects the removal of fluoride due to its adsorption by the magnesium hydroxide floc. The fluoride reduction is given by the following expression:

$$\text{Fluoride reduction } = 7\% \text{ initial fluoride conc. } \times \sqrt{magnesium\ removed} \tag{10.11}$$

Sizable fluoride removals are possible only when magnesium is present in large quantities which may not always be the case and magnesium may have to be supplemented in the form of salts. The process is suitable only when the water is softened.

Magnesium and calcined magnesite have also been used for the removal of fluoride from water. Studies established the following empirical relationships for amounts of MgO which are required to obtain 1 or 2 mg/l in treated water.

MgO is required to obtain 1 mg F/l in treated water (F_o> 2 mg ~~F~~/l)

$$= 1.71(13.33)\left(1-\frac{1}{F_o}\right)^2 + 160\ \times basicity\ of\ raw\ water\ (me/l)$$

(10.12)

MgO is required to obtain 2 mg F/l in treated water (F_o> 3 mg~~F~~/l)

$$= 1.71(13.33)\left(1-\frac{1}{F_o}\right)^2 + 120\ \times basicity\ of\ raw\ water\ (me/l)$$

(10.13)

F_oRepresents the fluoride concentration in the raw water. The pH of the treated water was always beyond 10 and its correction by acidification was essential, adding to the complexity of operations and control.

10.7.1.5 Aluminium Salts

Aluminium salts like filter alum and activated aluminium and alum-treated cation exchangers have shown beneficial effects. Filter alum during coagulation brings about some removal of fluorides from water. The removal efficiency is improved when used along with a coagulant aid-like activated silica and clay. 300 to 500 mg/L of alum is required to bring down fluoride from 4.0 mg/l to 1.0 mg/l while with coagulant aid, the fluorides were reported to be reduced from 6.0 mg/l to 1.0 mg/L with alum dose of only 100 mg/l.

Alum-treated polystyrene cation exchangers and sulphonated coals have also been used successfully. A cation exchanger prepared from the extract of Avaram bark and formaldehyde when soaked in alum solution has been found to have a good fluoride removal capacity (800 mg/kg).

Calcined or activated alumina in granular form can be used for fluoride removal and the spent material regenerated with alkali, acid, or both alternately (removal efficiency 1.2 kg of fluoride/m^3). A diluted solution of aluminium sulphate used as the regenerant for the spent material makes the alumina four times more efficient.

10.7.1.6 Mechanism of De-fluoridation by Nalgonda Technique

The chemical reactions involving fluorides and aluminium species are complex. It is a combination of polyhydroxyaluminium species complexation with fluoride and their adsorption on polymeric alumino hydroxides flocs. Besides fluorides, turbidity, color, odor, pesticides, and organics are also removed. The bacterial load is also reduced significantly.

All these occur by adsorption on the floc surface. Lime or sodium carbonate ensures adequate alkalinity for effective hydrolysis of aluminium salts so that residual aluminium does not remain in the treated water. Simultaneously disinfection is achieved with bleaching powder and this keeps the systems free from undesirable biological growth. This technique has been used in the past only for small and remotely located plants and is not recommended for any new plants to be constructed.

10.7.1.7 Membrane Techniques

Membrane techniques for the removal of fluoride comprises of reverse osmosis, Nanofiltration, dialysis, electro-dialysis, etc.

Nano-filtration makes use of the same overall phenomenon as reverse osmosis. However, the membranes have slightly larger pores in nanofiltration than those used in reverse osmosis and offer less resistance to passage both of solvent and solutes. As a consequence, pressures required are much lower, energy requirements are less, removal of solutes is much less exhaustive and flows are faster.

In the dialysis process, the solutes are separated faster by the transport of solutes through the membrane rather than using the membrane to retain the solutes while water passes through it as in reverse osmosis and nanofiltration. The membrane pores are much less restrictive than those for nanofiltration, and the solutes can be driven through by either the Donnan effect or an applied electric field. In Electro-dialysis, the removal of ionic components from aqueous solutions is carried out through ion exchange membranes under the driving force of an electric field.

10.8 Removal of Arsenic

Arsenic is a metalloid that occurs naturally and is very mobile in the environment. Its mobility is heavily influenced by the type of mineral present in the environment, oxidation state, and mobilisation mechanisms. Arsenic exists in four oxidation states: arsenite (As^{3+}), arsenate (As^{5+}), arsenic (As^{0}), and arsenide (As^{-3}). The predominant arsenic species found in water are inorganic arsenite and arsenate.

Arsenic exposure in humans can occur through ingestion of contaminated food and water, inhalation, and absorption through the skin. If consumed in greater amounts than the permissible limits, arsenic can cause various health disorders in humans such as respiratory distress, cardiac problems, gastrointestinal effects, anemia and leucopenia, skin disorders leading to hyperkeratosis (warts or corns on the palms and soles), and areas of hyperpigmentation interspersed with small areas of hypopigmentation in the face, neck, and back. Chronic exposure to arsenic can result in neural injury, skin cancer, and lung cancer.

According to the Central Ground Water Board, arsenic levels greater than 10 µg/L (ppb) have been detected in groundwater samples from 153 districts in 21 Indian States/UTs (Figure 10.7). However, the middle, lower, and deltaic regions of the Ganga basin are the most affected. Arsenic is also found in several other regions in the recent past whose source has been related to phosphate fertilizers.

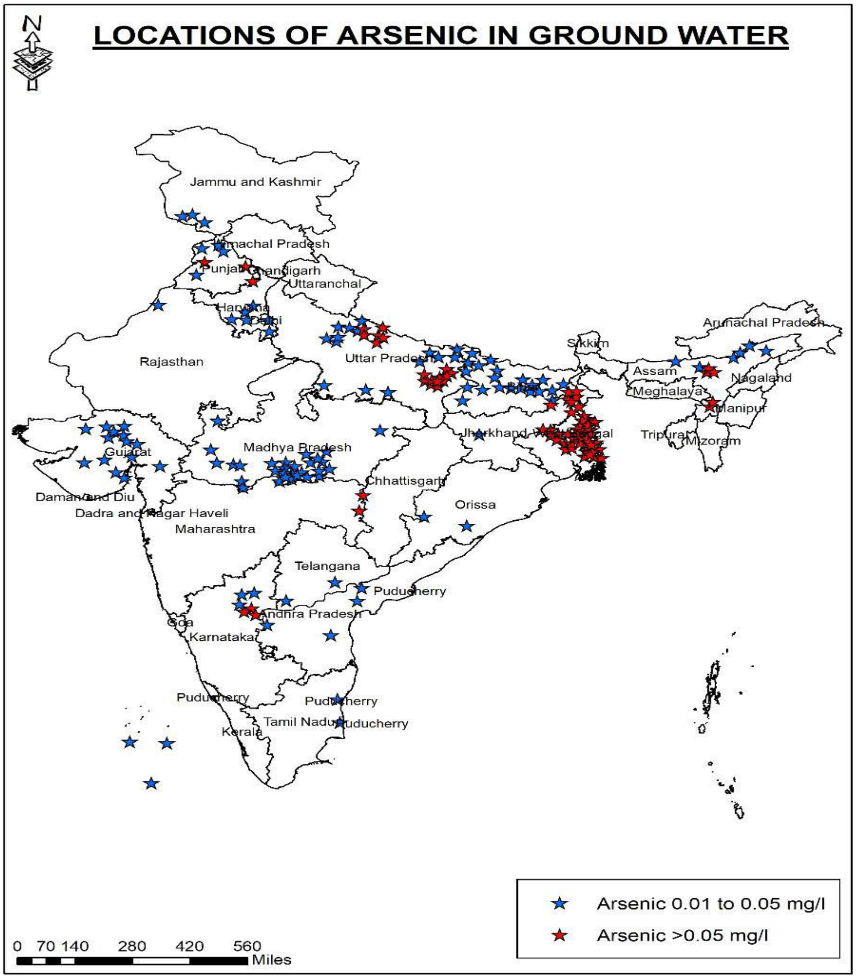


Figure 10.7: Occurence of Arsenic in Ground Water*(Source: CGWB)*

Arsenite is largely non-charged at pH below 10.2. This reduces the availability of the trivalent form of arsenic for precipitation, adsorption, or ion exchange. Hence, most available removal procedures are more efficient for arsenate. As a result, treatment technologies that use a two-step strategy consisting of early oxidation from arsenite to arsenate followed by an arsenate removal process are thought to be more effective. The approaches currently available for removing arsenic from water are summarised in Figure 10.8.

Figure 10.8: Arsenic remediation methods.

Sustainability of the processes can be enhanced by online monitoring and appropriate residue management and reuse.

10.8.1 Arsenic Removal Techniques:

10.8.1.1 Removal by Oxidation

The soluble arsenite is converted to arsenate by oxidation. As this does not remove arsenic from the solution; therefore, another removal process, such as adsorption, coagulation, or ion exchange, is also required. As arsenite is the predominant form of arsenic at near-neutral pH, especially when water is extracted from the ground, oxidation is a critical phase for anoxic groundwater. Many chemicals, ambient oxygen, as well as microbes, have already been employed to directly oxidize arsenite in water.

The most often utilised oxidants in developing countries are atmospheric oxygen, hypochlorite, and permanganate. Arsenite oxidation with oxygen is a very slow process that can take hours or weeks to complete. Chemicals, on the other hand, such as chlorine, ozone, and permanganate, can rapidly oxidise As^{3+} to As^{5+}. Despite this improved oxidation, interfering chemicals in water must be addressed when selecting the appropriate oxidant, as these substances can significantly alter and determine the kinetics of As^{3+} oxidation. Furthermore, this requires a sophisticated treatment that yields an arsenic containing residue that is difficult to dispose of. Thus, in order to effectively remove arsenic from a solution by oxidation, oxidants must be properly chosen.

10.8.1.2 Removal through Coagulation-Flocculation

Coagulation and flocculation are two of the most widely used and well-documented processes for removing arsenic from water. Positively charged coagulants (e.g., aluminium sulphate ($Al_2(SO_4)_3$), ferric chloride ($FeCl_3$)) lower the negative charge of colloids, causing them to collide and grow larger during coagulation. The addition of an anionic flocculant, on the other hand, produces bridging or charge neutralisation between the generated bigger particles, resulting in the development of flocs. During these processes, the chemicals convert dissolved arsenic into an insoluble solid, which then precipitates. Alternatively, soluble arsenic species can be co-precipitated by incorporating them into a metal hydroxide phase. In either case, solids can be removed later using sedimentation and/or filtration.

The efficacy of different coagulants in removing arsenic varies with pH. Under pH 7.6, $Al_2(SO_4)_3$ and $FeCl_3$ are both effective at removing arsenic from water. Most studies have found that arsenate is more efficiently eliminated than arsenite and that $FeCl_3$ is a superior coagulant than $Al_2(SO_4)_3$ at pH greater than 7.6. Despite their claimed decreased efficiency when compared to ferric chloride, aluminum-based coagulants were nevertheless capable of lowering arsenic concentrations below the acceptable maximum concentration level (MCL) of 10 µg/L.

The major drawback of coagulation-flocculation is the production of high amounts of arsenic-concentrated sludge. The management of this sludge is necessary to prevent the consequence of secondary pollution of the environment. Moreover, the treatment of sludge is costly. These limitations make this process less feasible, especially in field conditions.

10.8.1.3 Membrane Technologies

In terms of drinking water production, membrane filtration is a process for removing arsenic and other pollutants from water. Pressure-driven membrane filtration processes are broadly classified into two types: (i) low-pressure membrane processes such as microfiltration (MF) and ultrafiltration (UF); and (ii) high-pressure membrane processes such as reverse osmosis (RO) and nanofiltration (NF). Paragraph 10.14 goes into great depth about membrane technology.

MF alone cannot be used to remove dissolved arsenic species from arsenic-contaminated water. Therefore, the particle size of arsenic-bearing species must be increased prior to MF; the most popular processes for this are coagulation and flocculation. However, the pH of the water and the presence of other ions are important factors influencing the efficacy of arsenic immobilisation. This can be an issue when dealing with arsenite removal because it has a neutral charge in the pH range of 4–10. Arsenate can attach by surface complexation in this pH range because it is negatively charged. Thus, for this technique to be effective, complete oxidation of arsenite to arsenate is necessary.

Similar to MF, UF alone is not an effective technique for the treatment of arsenic-contaminated water due to large membrane pores. Surfactant-based separation methods such as micellar-enhanced ultrafiltration (MEUF) can be used for arsenic removal. Among the investigated surfactants, hexadecyl pyridinium chloride (CPC) demonstrated the best removal efficiency (96%). However, arsenic elimination has been shown to decrease when pH decreases. Furthermore, despite efficient arsenic removal, the surfactant concentration in the effluent is so high that it must be further treated with powdered activated carbon (PAC) before being discharged into the environment.

Both NF and RO are effective in removing dissolved chemicals with molecular weights greater than 300 g/mol from water. Given that the feed is free of suspended particulates and that the arsenic is predominantly available as arsenate, these approaches can dramatically lower the dissolved arsenic level in water. However, tests have indicated that As^{5+} removal efficiency exceeded by 85 percent for all tested NF membranes, whereas As^{3+} removal efficiency was far too low. Some other studies indicated that without oxidation of arsenite to arsenate, NF cannot comply with the maximum concentration level of arsenic in water. The same is the case for RO, as reported in several studies.

Although not technically a membrane system, Diatomaceous Earth (DE) filtration is a method that functions very similar to membrane filters. DE is a chalky sedimentary material containing fossil-like skeletons of microscopic organisms known as diatoms. The size of diatoms ranges from 5 to 100 micrometers and is characterized by a porous structure having small openings of about 0.1 micrometers in diameter. The combined effect of small pore sizes and high porosity makes DE one of the most effective filters used to remove small particles at high water filtration rates. Furthermore, this sort of filter is odorless, tasteless, and chemically inert, making it suitable for drinking water filtration. However, various disadvantages should be noted, including the necessity for pH adjustment, reagents, and a lengthy conditioning period.

10.8.1.4 Adsorption

Adsorption is a process that uses solids as a medium for the removal of substances from gaseous or liquid solutions. Substances are separated from one phase and accumulated on the surface of another. Van der Waals forces and electrostatic interactions between adsorbate molecules/ions and adsorbent surface drive this process. As a result, it is critical to initially characterize the adsorbent surface features (e.g., surface area, polarity) before using it for adsorption.

Activated carbon, coal, red mud, fly ash, chicken feathers, kaolinite, montmorillonite, goethite, zeolites, activated alumina, titanium dioxide, iron hydroxide, zero-valent iron, chitosan, and cation-exchange resins have all been explored in various field studies. Iron-based adsorption is a new approach for treating arsenic-contaminated water. This can be explained by the fact that inorganic arsenic species have a strong affinity for iron. Arsenic can be removed from water by iron serving as a sorbent, co-precipitant, or contaminant-immobilizing agent, or by functioning as a reductant.

Adsorption has been recognised as the most extensively used approach for arsenic removal due to various benefits such as relatively high arsenic removal efficiency, ease of operation and handling, cost-effectiveness, and no sludge creation. However, the adsorption of arsenic strongly depends on the system's concentration and pH. At low pH, arsenate adsorption is favored, whereas, for arsenite, maximum adsorption can be obtained between pH 4 and 10. Furthermore, contaminated water contains more than just arsenic; it is always accompanied by other ions, such as phosphate and silicate, which compete for adsorption sites. Aside from the system parameters, the type of adsorbent itself can reduce the effectiveness of adsorption in arsenic removal.

A variety of adsorbents, including those listed above, have already been investigated for the removal of arsenic from water. Most traditional adsorbents, on the other hand, have irregular pore architectures and poor specific surface areas, resulting in limited adsorption capabilities. Lack of selectivity, relatively weak interactions with metallic ions, and regeneration challenges can also limit these sorbents' capacity to reduce arsenic concentrations to levels below the maximum concentration threshold.

These limitations of traditional adsorbents have led to the development of new nanomaterials. See para 10.1.1.6 for more information.

10.8.1.5 ION EXCHANGE

Synthetic ion exchange resins can be used for arsenic removal. Generally, these resins have a base of cross-linked polymer matrices to which charged functional groups such as amine or quaternary ammonium are attached. Ion-exchange technologies are mostly used with water that have low TDS and where arsenic is the only significant contaminant. Their exchange capacity depends on the composition of the groundwater and the influence of interfering anions like sulphates, phosphates, silicates and nitrates. Hence, ion exchange can be performed after other treatment processes such as coagulation. Various ion exchange resins or arsenic removal are loaded with TiO_2, zirconium, iron, or MnO_2 as well. While ion exchange is useful, the contaminants must be in the ionic form and should be exchangeable with ions on the resin. This is not the case with neutral species. Resins loaded with iron oxides and oxihydroxides have also been used to remove such species.

10.8.1.6 APPLICATION OF NANOMATERIALS FOR THE REMOVAL OF ARSENIC FROM WATER

Advances in nanoscience and nanotechnology have paved the way for the development of various nanomaterials for the remediation of contaminated water. Due to their high specific surface area, high reactivity, and high specificity, nanoparticles have been given considerable environmental attention as novel adsorbents of contaminants, such as heavy metals and arsenic, from aqueous solutions. Carbon nanotubes and nanocomposites, titanium oxide-based nanoparticles, iron-based nanoparticles, and other metal-based nanoparticles are among the most commonly utilised and researched nanoparticles for arsenic-contaminated water treatment. Many of these materials have also been modified with other metal oxides such as zirconia to improve the adsorption capacity. Although the literature may refer to them as nanoparticles, the materials used in the field are nanostructured materials in the form of beads or millimeter scale particles.

Figure 10.9 A typical iron and arsenic removal community water treatment plant in Punjab. The installation was done by Hydro-materials Pvt. Ltd., an IIT Madras incubated company. The blue-colored unit, below the overhead tank, is the purification unit and the treated water is distributed to the village

One of the most notable nanoscale systems currently used in the efficient removal of arsenic is metastable two-line ferrihydrite, which adsorbs both arsenite and arsenate in natural pH conditions with excellent selectivity and in presence of the typical interfering ions present in natural waters. The technology is often referred to as AMRIT (Arsenic and Metal Removal through Indian Technology). The specific adsorbent used is confined metastable 2-line ferrihydrite (CM_2LF) in biopolymer cages.Its arsenic uptake capacity is about 25-30 mg g^{-1} in field conditions. Due to the large adsorbate capacity, the replacement of adsorption media is less frequent. The arsenic laden waste does not release arsenic in the ambient conditions and it can be disposed-off safely, following protocol. As a result of the lower cost, high efficiency of removal of arsenite and arsenate, safe disposal of the spent media and reduced maintenance cost, this method has been applied in various parts of the country. Besides, the media can be used for both domestic and community filtration. In cases where local sources are contaminated by other contaminants such as uranium, the method is found to be effective. Although a reactivation protocol exists to regenerate the arsenic-saturated CM2LF, in view of the high adsorption capacity, the frequency of adsorbate replacement is as long as 2-3 years. In addition, reactivation produces sludge and its management is a concern.

A block diagram of a nanotechnology-enabled water purification plant for arsenic and iron removal is shown in Figure 10.10. The input water after initial oxidation is passed through iron and arsenic removal units in succession. Any other contaminant present may be removed by a polisher unit. Post chlorination ensures the removal of microbes. The system may be fitted with sensors and devices at various locations for monitoring and control.

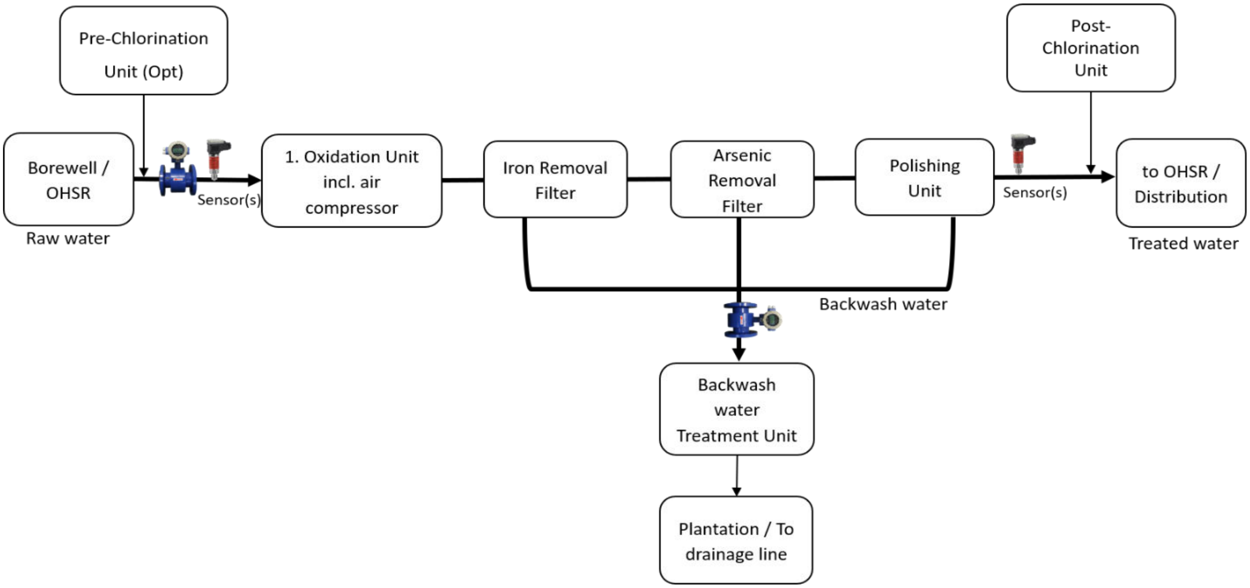


Figure 10.10: Block diagram of nanotechnology-enabled water purification plant for arsenic and iron removal

10.8.1.7 CAPACITIVE DEIONIZATION(CDI)

Capacitive deionization, where ions or polarizable species are electro-adsorbed on specific electrodes, typically made of carbon, and concentration of such species is reduced in product water. Although this is more common in the case of fluoride removal, the technology works for arsenic as well. The type of CDI used today is called membrane CDI, where an ion exchange resin is coated on the electrode. The technology can also wok in cases where other ions such as fluoride and nitrate coexist in the water.

Block diagram of a CDI water purification plant is shown below (Figure 10.11). The process involves passing brackish water to a CDI unit where ions are separated by a set of electrodes of opposite polarity, stacked alternately. Normally, CDI units are installed after appropriate pre-filtration.

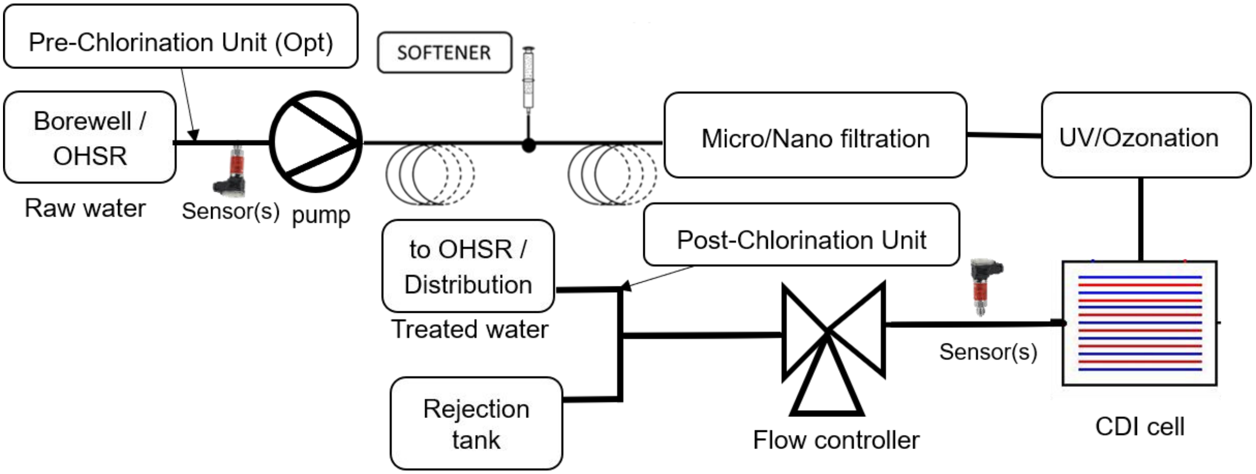


Figure 10.11: Block diagram of a CDI-enabled water purification plant

10.8.1.8 ARSENIC TEST KIT

Arsenic test kit: Arsenic in drinking water is difficult to detect. Arsenic field test kits work when inorganic arsenic compounds in the water sample are converted to Arsine (AsH_3) gas by the reaction of zinc dust and acid. Ferrous and nickel salts have been added to accelerate this reaction. The arsine gas converts mercuric bromide on the test strip to $AsH_2(HgBr)$ that appear with a color change from white to yellow or brown. Commercially available portable test kits come with color reference charts and a detection limit of roughly 10 micrograms/litre, according to the manufacturer. Previously, arsenic testing could only be done in a laboratory using atomic absorption or atomic emission spectroscopies. It is possible to do electrochemistry to detect arsenic at 10 micrograms/litre or lower, but the cost is substantial. However, there are new developments with improved electrodes at low costs, including biosensors which use arsenite species selective enzymes. There are other electrodes, including those with graphene. However, such products have not yet come into widespread use.

10.8.1.9 ADVANCED PLANTS WITH INTEGRATED SENSORS

Integration of sensors along with water purification devices and treatment plants can promote substantial advancement in environmental water monitoring and wastewater management. On-site and continuous monitoring of water quality can be performed using portable sensors, enabling adherence to effluent regulations and safety parameters as well as for the evaluation of efficiency of the treatment process. The entire plant can be Internet of Things (IoT)-enabled in terms of equipment automation and water analysis. Implementation of IoT-enabled plants can allow authorities to obtain real-time qualitative and quantitative information about the plant's operation over a long-time window. Such an advanced water treatment/purification plant will be beneficial for public awareness and establishing regulations for water quality. Figure 10.12 shows block diagram for such an advanced plant for arsenic removal.

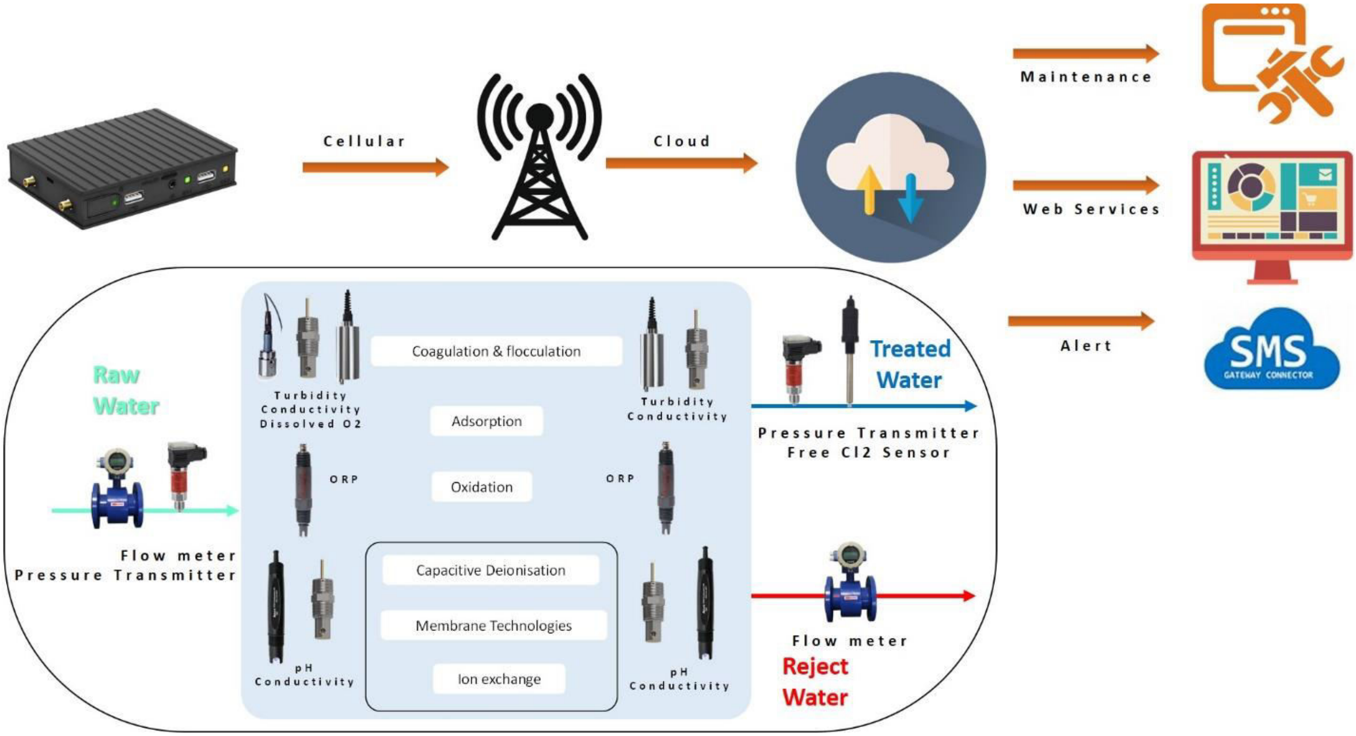


Figure 10.12: IOT based monitoring of various arsenic removal technologies

Such water quality data available online over a considerable period can be used to understand and predict the health of the population. A central command centre was put in place in Punjab to monitor the health of 97 treatment units and over 12000 household filters in 2021-22. Data from the treatment units such as the time duration of operation, water dispensed, voltage at the pumping station, current used by the pump and water quality in terms of total dissolved solids were collected and presented using a central dashboard. This ensured that all the treatment plants are used effectively and problems, if any, were addressed. Such problems may relate to the health of the motor, electrical supply, availability of the operator, clogging, efficiency of filtration, etc. More sensors and better controls can also be put in place and this has been implemented in select locations. The home units are monitored through SMS-based alerts through a call centre and the data are entered on a database. This allows the supply of parts, if any, at short notice so that downtime is minimum.

10.8.1.10 NEW DEVELOPMENTS

Hand-held, portable sensors: For water quality testing, miniature testing equipment connected to mobile phones can be implemented. The sensing method typically is electrochemistry, and this may be used today for many contaminants in water such as iron, chromium, manganese, lead, mercury, etc. Although it is not available for arsenic at present, many associated ions can be tested. Such devices cost under Rs. 8,000 and analysis involves limited consumables and testing can be done by even school children. As the data are available through mobiles, they can also be collected on the internet for crowdsourcing of information. Such a methodology can be used for effective education on water quality. Benefits of this method using low-cost hand-held instruments can be for collecting data from inaccessible areas, and also to carry out random quality checks. The testing methodology can also be spectroscopy. Such data can be used to develop water (and other) quality parameters for a society leading to hydro informatics..

Wastewater-based epidemiology: A related development is wastewater-based epidemiology (WBE) where wastewater is analyzed for specific microbial and chemical species. As everything humans consume finally ends up in wastewater, an analysis of wastewater can reveal everything about consumption wastes, which includes metallic, chemical, pharmaceutical and biological species. This analysis can relate the data to the extent of contamination in a community. For example, this can tell us about the presence of Covid-19 affected people in a population or the extent of drug abuse. The benefit of such an analysis is that it does not need every individual to be screened, simplifying analysis and at the same time, it avoids any stigma associated with personal identification. A similar methodology may also be used for drinking water quality. The data collected is related to the health of the population and can be used to provide health advisories. This advanced method of analysis will be of great value to the society.

10.8.1.11 REJECT/ RESIDUE MANAGEMENT OF ARSENIC, FLUORIDE, AND IRON REMOVAL PLANTS

In the preceding sections, various treatment techniques have been described for the removal of arsenic, fluoride, and iron from raw groundwater to produce potable water. These treatment methods generate hazardous liquid and solid residues/rejects containing high concentration of arsenic/fluoride/iron posing serious threat of contamination of groundwater/surface water /land if not properly and safely disposed of. The waste stream in arsenic, fluoride, and iron removal plants can be categorized as follows:

(i) Back wash wastewater stream
(ii) Sludge from treatment reactors
(iii) Spent adsorbents/ nanomaterial and replaceable catalysts

The above mentioned rejects/residue need to be treated and safely disposed of to prevent contamination of groundwater/surface water/land (please refer to NEERI’s O&M and Reject Management protocol for Arsenic, Fluoride, and Iron Treatment Units). The residue/rejects from Arsenic/Fluoride removal plants are more hazardous/toxic as compared to that of Iron removal plants, but IRPs produce more quantity of sludge.

The following residue/reject management practices should be employed:

- Back wash water generated from various techniques of Arsenic, Fluoride, and Iron removal plants shall be analyzed on a weekly basis.
- Back wash water shall be treated in sedimentation tanks.
- Sludge dewatering shall be carried out in sand drying beds, freeze assisted sand beds, vacuum assisted beds, solar drying beds, etc.

- Engineered landfills, if necessary, shall be designed and provided for Arsenic, Fluoride and Iron removal residues for a period of 15 years or the period decided as per the availability of land.
- Exhausted/spent media of Arsenic, Fluoride removal plants shall be tested for the toxicity characteristics leaching procedure (TCLP) prior to transport to the designated disposal facility.
- Supernatant after sedimentation and dewatering shall be tested before discharging into the environment.
- A sludge sedimentation tank and sludge storage facility shall be included as a mandatory part of the water treatment plant.

Management of Back Wash Water

A sedimentation tank for back wash water is designed based on total back wash water generated with the provision of sludge produced. The sedimentation tank may be rectangular or square type with a side water depth of 1.2-1.5 m with a free board of 0.3 m. The sludge storage facility is designed for 13-15 years or based on the availability of land having a regular shape. A geo-membrane liner etc. as per regulator specification shall be used to restrict the percolation of leachate in the ground.

Method for Supernatant of Sedimentation Tank and Sludge Disposal Facility

- **For Arsenic and Fluoride Removal Plants**

  The supernatant of sedimentation tanks shall satisfy the local effluent standards.

  The sludge can be directly disposed of in a secured landfill with pre-treatment with lime. The sludge may be used for making building construction materials like bricks, cement blocks, etc.
- **For Iron Removal Plants**

The supernatant of the sedimentation tank shall satisfy local effluent standards. The sludge can be directly disposed of in a secured landfill. As per MoEFCC (2016), the supernatant of the sedimentation tank shall satisfy effluent standards of maximum permissible limit (mg/L) as given in Table 10.6 below:

Table 10.6: Permissible Limit of As, F, and Fe (mg/L) for Supernatant of Sedimentation Tanks

Parameters	Into Inland Surface Water	On Land for Irrigation
Arsenic	0.2	Not permitted

Fluoride	2.0	2.0
Iron	3.0	3.0

The sludge shall satisfy standards for restricted landfills or will be used as construction material with the specified standards. The long-term solution is to recycle the sludge and use it for beneficial purposes. One of the techniques which is adopted to treat hazardous/toxic waste is to solidify it using cement etc., which results in stabilization of the components of waste.

10.9 Removal of Nitrate

Nitrates are inorganic nitrogen and oxygen compounds that occur both naturally and synthetically in the environment. Nitrates are found in the earth's atmosphere, in the soil, and water. They are easily biodegradable and highly soluble in water. Plant decay, animal waste, and agricultural byproducts all produce nitrates. Rainwater, floods, and soil erosion can contribute nitrates into groundwater supplies.

Water containing less than 45 mg/L of nitrate (as NO_3) is safe to consume. Long-term exposure to high nitrate concentrations can cause major health problems in children, such as methemoglobinemia, commonly known as blue baby syndrome, and stomach cancer in adults. A child with the blue baby syndrome will start displaying bluish or brownish colors around their lips and mouth, nose, and nail beds. It can also present flu-like symptoms, such as nausea, vomiting, and diarrhea.

Nitrates enter the water supply via agricultural runoff, industrial waste, fertilizer and herbicide use, leaking septic tanks, and broken sewage systems. Naturally occurring microorganisms in soil can also metabolize nitrogen, resulting in nitrate deposits in the ground. Manure from farmlands can be carried into streams and lakes by rainwater. Animal excrement is another source of nitrate contamination in water systems. Crop irrigation can deeply embed nitrates in the soil, and as precipitation percolates down through the earth, the nitrates can enter aquifers. Increased amounts of nitrates can also occur in underground water storage utilized for drinking water supply systems, Many districts in Andhra Pradesh, Bihar, Delhi, Haryana, Himachal Pradesh, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab, Tamil Nadu, Rajasthan, West Bengal, and Uttar Pradesh have high nitrate concentrations (greater than 45 mg/L) (Figure 10.13). The highest value was 3080 mg/L found in Bikaner, Rajasthan.

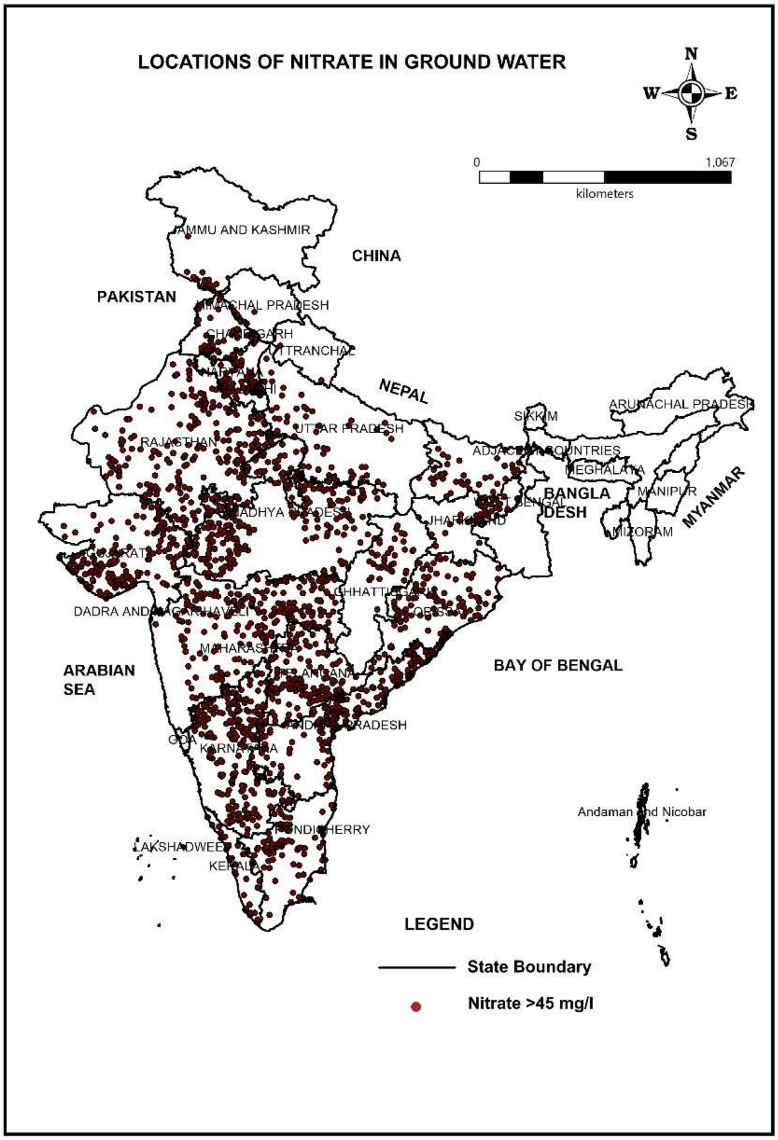


Figure 10.13: Occurrence of Nitrate in Ground Water

10.9.1 Techniques for Removal of Nitrates

Nitrates in water can be removed via reverse osmosis, distillation, or ion exchange resin. Nitrates are notoriously difficult pollutants to remove from water. Nitrates will not be removed by sediment filters, carbon filters, or ultrafiltration system's hollow fibre membrane. A typical ion exchange water softener also will neither reduce nor remove nitrates.

a) Reverse Osmosis

RO eliminates pollutants by pushing pressured water across a semi-permeable membrane with small pores. These pores operate as a sieve, separating pure water from the pollutants in the water. The membrane has such a fine micron rating that it can remove ions such as nitrates from the water. The clean, treated water flows through the membrane and accumulates in a tank. The remaining contaminants are rejected by the membrane and flushed down the drain in a brine solution. RO is one of the most effective techniques of domestic water filtering, capable of removing up to 98% of waterborne pollutants and it can remove anywhere from 83 - 92% of nitrates.

However, reverse osmosis does remove all traces of other minerals, while greatly reducing the nitrate levels present in water. As a result, doing a thorough water test is critical when selecting a water filtration system for making the water safe for consumption. It is important to note that reverse osmosis wastes lot of water. While early RO systems waste up to 90% of the water they treated, advances in technology and design have improved RO efficiency. For conserving the water, the installation of a system with a permeate pump to recover the maximum amount of reject water is recommended.

b) Ion exchange

Passing water through an ion exchange process is one of the most effective ways to remove nitrates. These nitrate removal devices, however, use chloride ions rather than the sodium ions normally used in traditional water softeners. When polluted water travels through the tank or cartridge, the resin beads capture the nitrate ions and replace them with innocuous chloride ions. Because both chloride and nitrate have a negative charge, this is known as anion exchange (making them anions). They will only be capable of processing a certain volume of water before all the chloride ions are exhausted and the media will either need to be regenerated or the cartridge replaced.

For backwashing the system, it will periodically need to flush the system with sodium chloride to regenerate the resin and flush out a brine solution. Because this brine solution contains nitrates, it should not be discharged into any natural water source or where animals could drink from it.

c) Water distillers

Water distillation is the third method for removing nitrates from water. Water distillers remove almost all waterborne pollutants by imitating the hydrologic cycle, the Earth's natural filtration mechanism. Water is placed in a chamber with a heating element, to boil until it is completely transformed to steam. This steam is then sent through a cooling coil and refrigerated until it returns to a liquid form. Although no nitrates can survive the distillation process, it is one of the most time-consuming and expensive ways of nitrate removal.

10.10 Demineralization of Water

Conventional methods of water treatment do not materially change the mineral content of water. Base Exchange softening merely converts the calcium and magnesium salts to the corresponding sodium salts. Lime softening causes a slight decrease in the contents of total solids but does not bring about any decrease in the content of sodium chloride or sulphate. Hence, these methods are not effective in converting brackish water into a potable one. For providing a potable supply in a brackish water area, the least mineralized water source could be identified and some method of treatment adopted to obtain potable water.

10.10.1 Distillation

Of all the processes of obtaining potable water from saline solutions, distillation is the oldest and in terms of established plants, the most productive. It differs from the other processes by its passage of water through the vapour phase. The plant design is directed to tapping the most economic source of heat energy and exploiting the most efficient processes of heat transfer.

Where relatively small quantities of water are to be distilled, straight or single-effect distillation is preferred because of the simplicity of operation and the lower capital cost of the installation. For larger outputs, improvement in efficiency acquires much greater importance because of the much higher rates of evaporation involved and the need for highly efficient heat transfer systems. Problems of scale formation also play a significant role.

The performance of an distillation plant is measured by the specific heat consumption, i.e., the number of kilocalories required to produce one kilogram of distillate. Distillation plants are generally better for lower values of specific heat consumption. The introduction of the flash evaporator has helped in better economics of heat recoveries and more efficient plants can be built more cheaply. It is only in such situations where natural gas or fuel is available cheaply that low thermal performance evaporators can be used with the resultant saving in capital cost.

10.10.2 Solar Stills

Solar energy can be harnessed with the help of system of mirrors following the path of the sun to focus the sunlight on sheets of water. In one of the popular methods, the saltwater trickles down to trays mounted on an inclined compartment provided with glass sides and a heat-insulated base that screens the condensing chamber from the sun. Since the focusing mirrors form an important element in the cost of the stills, the development of cheaper non-focusing types of mirrors and the use of inexpensive construction materials have been resorted to. In basin solar stills, a commonly used design, saltwater tanks, filled either by gravity or by stainless steel impeller pumps, feed the solar still whose cover is at a shallow angle of 10^o to 18^o with the glass panes tightly sealed to the holding frame and the joints between the still cover and the vertical walls perfectly sealed. The collecting troughs at the foot of the still cover must be built in such a way that water can freely drain to the pipe carrying the distillate to the freshwater tank while preventing any contaminated water from entering from the roof or ground on which it is built. In addition to the freshwater tank, it is a good practice to construct additional distilled water storage to balance out the fluctuations between production and demand.

The best situations for the use of solar distillation are the isolated areas and regions where fresh water is not available, solar intensities are high, fuel resources are meager and industrial development is poor.

10.11 Removal of Uranium

Uranium is a naturally occurring radioactive element that occurs in low concentrations in nature. It is present in certain types of soils and rocks, especially granites and metasedimentary rocks. Uranium concentrations in groundwater in shallow aquifers across the country range from 0 to 2876 µg/L, suggesting that groundwater uranium concentrations vary by several orders of magnitude. Punjab (where 24.2 % of groundwater samples have been detected to have Uranium concentrations greater than the limit prescribed in IS 10500), Haryana (19.6 % samples), Telangana (10.1 % samples), Delhi

(11.7 % samples), Rajasthan (7.2 % samples), Andhra Pradesh (4.9 % samples), and Uttar Pradesh (4 % samples) are the most affected States (Figure10.14).

Water with low levels of uranium is normally safe to drink. Because of the nature of uranium, it is unlikely to collect in groundwater, fish, or plants. Uranium that is absorbed and enters the human body is swiftly removed by urine and faeces.

The radioactivity of naturally occurring uranium is extremely low. The chemical properties of uranium in drinking water, however, are far more concerning than its radioactivity. A tiny amount is absorbed and transported through the bloodstream to numerous organs and bones. According to research, the presence of Uranium in drinking water promotes Nephritis (kidney damage).

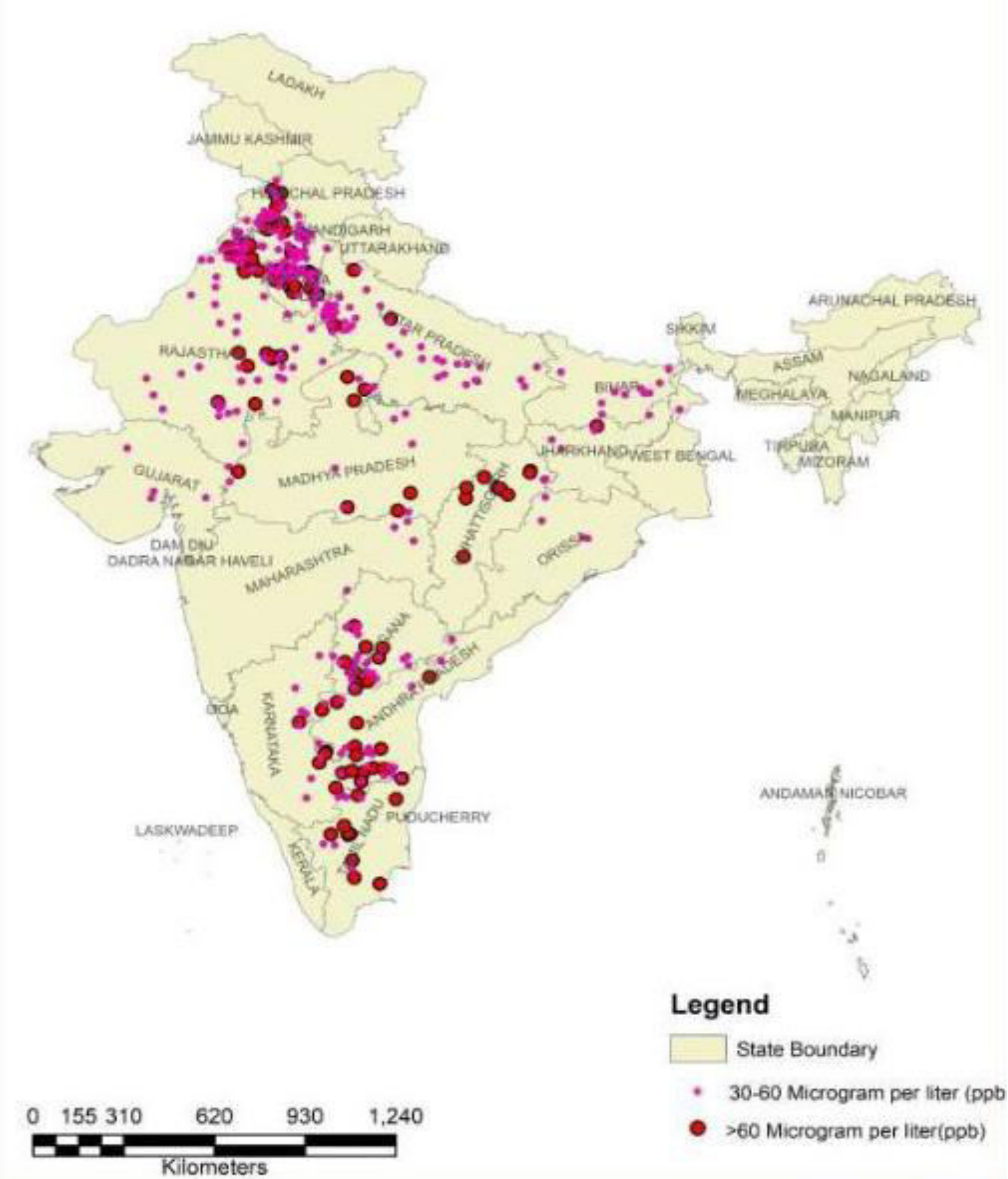


Figure 10.14: Occurrence of High Uranium in Groundwater (source: NDC CHQ Ajit Singh, 8/4/2020)

10.11.1 Remedial Measures

Ex-situ treatment of radioactive contaminants in ground water falls into the following categories:

1. Adsorption or ion exchange: The water-soluble contaminants are captured by sorption onto solid support that can be natural or synthetic material.
2. Reactive sorption: The process is based on the reaction of contaminants with a solid substrate. It is often applied in situ as a barrier wall through which the contaminant is forced through and trapped.
3. Precipitation: This process is mostly practiced above ground and involves the addition of alkali to raise the pH and precipitate the oxide or hydroxide.
4. Reverse osmosis: In this process, water is transported through a high-pressure gradient through a membrane essentially non-permeable to the contaminant.
5. Stripping: Only applicable to volatile contaminants like radon.

Remediation solutions based on in-situ chemical stabilisation are only as effective as the site's geochemistry allows. Such chemical technologies may be generally grouped according to the following paradigm.

1. Redox Technologies: These technologies attempt to manipulate oxidation-reduction conditions of the subsurface to reduce uranium to uranous (uranium IV) forms. The techniques include in-situ redox manipulation using sodium dithionite, zero-valent iron, microbial-induced reduction, and calcium polysulfide technologies. The common deficiency of technologies in this category is that the reduced environment and corresponding uranium precipitate are easily re-oxidized over time. Consequently, over time the “treated” uranium remobilizes in the system.
2. Co-precipitated Iron Oxy-hydroxide: This technology effects only temporary stabilization because the reaction is reversed as the precipitate ages.
3. Phosphate Precipitation Technologies: These techniques use and alter phosphate with uranyl (uranium VI) forms to remove soluble uranium and prevent additional uranium dissolution by sequestration, immobilization, or precipitation. The resulting reaction seeks to create a stable, long-lasting reaction that removes the source of ongoing uranium contamination in the groundwater. However, this group of technologies requires further development.

4. Flushing Technologies: This category of remediation procedures employs a variety of leaching solutions to dissolve solid-phase uranium and hydraulic extraction techniques to remove the dissolved Uranium. Because of subsurface stratigraphic heterogeneities, thorough treatment is difficult to achieve. Capture of the mobilized uranium can be problematic.

10.11.2 Pilot Study Cases

1. Bioremediation of uranium-contaminated groundwater: The addition of an acetate solution to groundwater can easily and effectively drive microbial reduction of soluble U(VI) to insoluble U(IV) via U(VI)-reducing capacity of Geobacter species that are naturally present in underground conditions. This precipitates uranium from the groundwater preventing its further mobility and concentrations of uranium dispersed in a large volume of groundwater into a discrete zone for subsequent removal.
2. Uranium removal from groundwater by natural zeolites: It is found that adsorption on clinoptilolite manganese oxide-coated zeolite (MOCZ) may be useful for uranium removal.
3. Permeable Reactive Barriers: Installation of Permeable reactive barriers (PRBs) like bone char phosphate, zero valent iron, or ferric iron across the path of the contaminant plume has consistently lowered the input U concentration in the pilot studies.
4. Ground water with a greater uranium percentage can be made potable using procedures like reverse osmosis (RO). Based on a field study carried out in Punjab, it was established that uranium content in RO treated water is below 0.1 micrograms per liter. However, disposal of reject water of RO is an issue to be taken care of.

10.12 Removal of Ammonia

Ammonia is utilized in the production of fertilizers and animal feed, as well as the production of fibers, plastics, explosives, paper, and rubber. It is used as a coolant, in metal processing, and as a starting product for many nitrogen-containing compounds. Ammonia and ammonium salts are used in cleansing agents and as food additives, and ammonium chloride is used as a diuretic.

On dissolution in water, ammonia forms the ammonium cation; hydroxyl ions are formed at the same time. Natural levels in ground waters are usually below 0.2 mg of ammonia per litre. Higher natural contents (up to 3 mg/L) are found in strata rich in humic substances or iron or in forests. Surface waters may contain up to 12 mg/L. Ammonia may be present in drinking water as a result of chloramine disinfection. Ammonia levels above geogenic levels are a major indicator of faecal pollution. If drinking water containing more than 0.2 mg of ammonia per litre is chlorinated, taste and odor problems, as well as lower disinfection efficacy, are to be expected, since up to 68 % of the chlorine may react with the ammonia and become unavailable for disinfection. Cement mortar used to coat the insides of water pipes may emit significant amounts of ammonia into drinking water, compromising chlorine disinfection. Because nitrification consumes too much oxygen, the presence of elevated ammonia levels in raw water may interfere with the operation of manganese-removal filters, resulting in mouldy, earthy-tasting water. Because of catalytic action or inadvertent colonisation of filters by ammonium-oxidizing bacteria, the presence of ammonium cation in raw water may result in drinking water containing nitrite.

Only when the intake exceeds the capacity to detoxify, ammonia become harmful to healthy persons. The effects of the anion must also be considered when administering ammonia in the form of its ammonium compounds. The acidotic effects of the chloride ion appear to be more important than the ammonium ion in ammonium chloride. Ammonium chloride impacts metabolism by altering the acid-base equilibrium, disrupting glucose tolerance, and lowering tissue sensitivity to insulin at doses greater than 100 mg/kg body weight per day (33.7 mg ammonium ion per kg body weight per day).

Excessive ammonium in drinking water can cause nitrification in the water distribution system, leading to many problems including corrosion, aesthetic issues, and lowering pH.

10.12.1 Remedial Measures

Remedial strategies that can be used are as follows in Figure10.15:

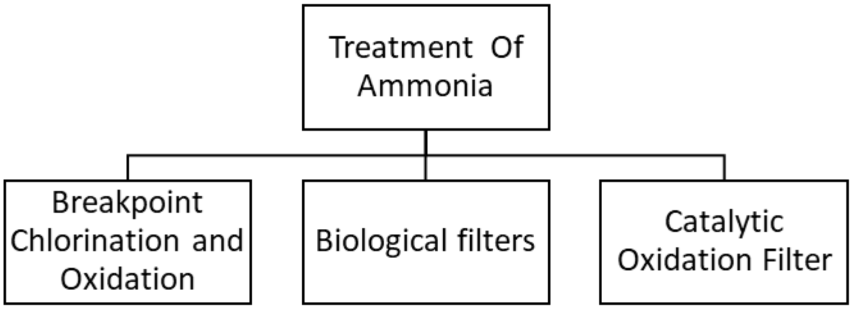


Figure 10.15: Remedial Strategies for treatment of Ammonia

1. Breakpoint chlorination is an effective way to remove ammonium from drinking water. It has low spatial requirement, non-sensitivity to temperature variations, and adaptability to existing facilities. However, it can result in excessive chlorine consumption and the development of harmful chlorination byproducts in drinking water.
2. To remove ammonium from drinking water, biological filters and catalytic oxidation are effective ways. However, removal activity in biological filtration is reduced at lower temperatures and due to a lack of some essential nutrients. There are two primary biofiltration mechanisms:
    a) Mass transfer from air to water film on the packing materials by adsorption or dissolution
    b) Biodegradation of adsorbed contaminants in the biofilm.
3. An alternative method to biofiltration would be the abiotic removal of ammonium, using catalytic oxidation technology. Iron–manganese co-oxide filter film (MeO) can remove ammonium from drinking water by chemical catalytic oxidation. Catalytic oxidation is a new way to remove high concentrations of ammonia from drinking water.
    a) Quartz sand coated with Metal oxide filter film (MeO) can remove ammonium from drinking water by chemical catalytic oxidation. (generally, Iron–manganese co-oxide Filter Film)
    b) It is more resistant to low temperatures and requires less time to start up than other biofiltration methods.
4. Various studies are also being carried out for the removal of higher concentrations of Ammonia from raw water for drinking water supply.

10.13 Osmosis

Certain natural and synthetic membranes have the property of permitting the solvent (water) to get through them but not the solute. Such semipermeable membranes permit the separation of solute from solvent. This phenomenon is known as Osmosis. Some of the osmosis processes which are widely used in India are explained in the subsequent sections

10.13.1 Reverse Osmosis (RO)

Reverse Osmosis is a membrane permeation process for separating relatively pure water (or other solvents) from a less pure solution. The solution is passed over the surface of an appropriate semi-permeable membrane at a pressure in excess of the effective osmotic pressure of the feed solution (Figure 10.16). The permeating liquid is collected as the product and the concentrated feed solution is generally discarded. The membrane must be highly permeable to water, highly impermeable to solutes, and capable of withstanding the applied pressure without failure. Because of its simplicity in concept and execution, reverse osmosis gained wide application in water and used water treatment.

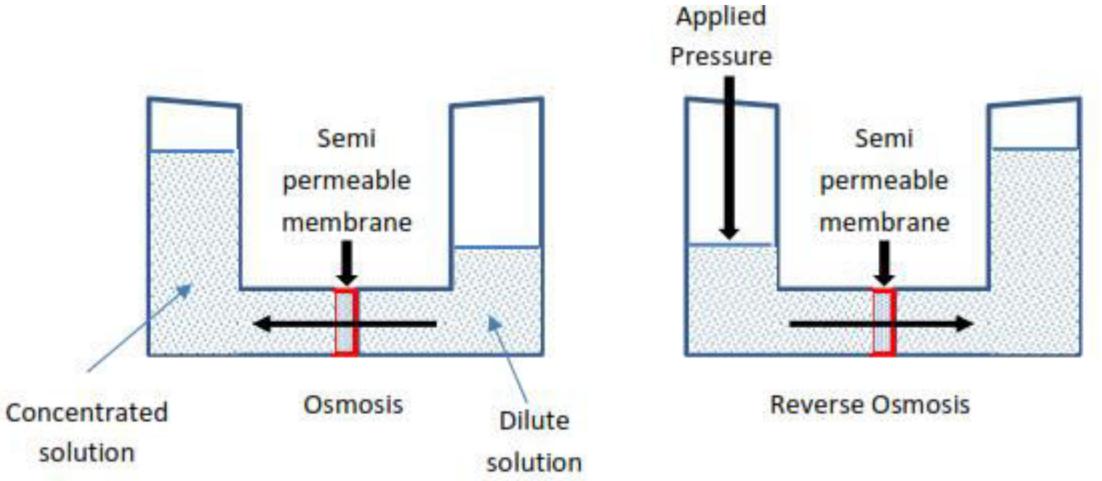


Figure 10.16: Reverse Osmosis(RO) Process

There are a variety of materials that are in use for manufacturing RO membranes, Cellulose Acetate being the first one to be introduced. Polysulfone coated with aromatic polyamides has become very popular in recent times. These are also referred to as Thin Film Composite (TFC) membranes.

10.13.1.1 TYPES OF RO MEMBRANES

RO membranes are the heart of Reverse Osmosis technology. Membranes along with Pressure housing, high-pressure pumps, cartridge filters, piping, skids, and auxiliary systems like dosing, instrumentation, and electrical control - form an entire RO system.

The performance of RO depends on the type and nature of membranes. The following types of membranes are widely used:

1) Tubular type membranes
2) Disc type membranes
3) Spiral type membranes

1) **Tubular type membranes**:

Tubular membrane modules are porous tube-like structures. Tubular modules use tangential crossflow to treat problematic feed streams like those with high dissolved solids, high suspended particles, and/or oil, grease, or fats. They typically contain 1/2" to 1" OD tubes that are individually packed into a long PVC housing and can be made of polymer or ceramic. Tubular modules are made up of at least two tubes: the inner tube, known as the membrane tube, and the outer tube, known as the shell tube. The feed stream flows across the membrane tube and is filtered out into the outer shell, while concentrate accumulates at the opposite end. They are frequently utilised in oily wastewater treatment, MBR, and other high solids processes.

2) Disc Type Membranes:

The disc membrane module used in water treatment differs significantly from traditional membrane modules. It employs a patented flow channel design with an open flow channel, allowing the feed liquid to enter the pressure vessel while the diversion flow exits. The liquid enters the deflector through a tube at the opposite end flange and runs across the filter membrane, reversing direction in a double "S" shaped path. This unique hydraulic design enhances transmission rate, self-cleaning functionality, and prevents membrane clogging and concentration polarization. The module is suitable for treating wastewater with high turbidity and sand content, and it can handle more severe water inlet conditions.

3) Spiral Wound type membranes:

Spiral-wound elements used in membrane filtration systems consist of membranes, feed spacers, permeate spacers, and a permeate tube. Membranes are folded and placed with feed spacers between them to enable water flow and ensure uniformity. Permeate spacers are attached to the permeate tube, and the membrane layers are wrapped in a spiral shape. During operation, feed flows tangentially, and the filtrate passes through the membrane surface into the permeate spacer and then into the permeate tube, while the remaining feed becomes concentrated. High-pressure spiral membranes which can take the pressure up to 118 atm are introduced.

10.13.2 Electro-dialysis (ED)

Unaided osmosis is a relatively slow process and hence attempts have been made to combine this with electrolysis. The application of an external electromotive force can draw the ions away from the salt solution towards the electrodes so that the solution is impoverished of its salt content. The reunion of the ions by diffusion can be prevented by using suitable membranes to separate the cathode and anode chambers and also by continuously removing the relatively concentrated solution of the electrolytes from the electrode chambers. To obtain purification of sufficient magnitude, several electrolytic cells have to be used in series. In essence, the apparatus would consist of several electrolytic cells each of which is composed of 3 compartments separated from each other by suitable membranes. The saline water circulates in series through the middle compartments of the cells and undergoes progressive purification. The number of cells and the rate of flow may be adjusted to give the degree of purification required. A direct current of 110 to 220 volts is employed. The electrodes are continuously washed with the treated water.

One of the main disadvantages of the electro-dialysis process is that the membranes get badly damaged as a result of corrosion and scale formation. Another disadvantage is that the cost goes up steeply as the total solids content of the finished water decreases. Power loss is minimized if the water is demineralized only partially to final concentrations of less than 500 mg/l in a multi-compartment cell. Average power requirements are 1 kWh/ m^3 of water/1000 mg/L of TDS removed for waters with initial TDS values of 10,000 mg/L and less. Since power requirements rise sharply with higher initial values in this method compared to distillation and freezing, this process is adopted only for waters containing less than 10,000 mg/L of dissolved solids.

10.13.3 Osmionic Process

This process is based on the principle of osmosis through ion-selective membranes which pass only anions or cations preventing the passage of the other ions. The concentration gradient between the solutions supplies the potential required to drive the ions through the ion-selective membranes unlike in the case of reverse osmosis where pressure is applied to force the water but not the salts through the membranes.

10.13.4 Ultra-Filtration

Ultrafiltration (UF) is a water treatment process that mechanically filters water containing very small particles. It is an effective way of lowering the silt density index of water and is frequently used to pretreat surface water, seawater, and biologically treated municipal water upstream of the reverse osmosis unit.

UF is a membrane filtering method that uses hydrostatic pressure to drive water through a semi-permeable membrane, comparable to reverse osmosis. UF is used to remove almost all colloidal particles (0.01 to 1.0 microns) and some of the biggest dissolved pollutants from water. The kind and size of pollutants removed are mostly determined by the pore size in a UF membrane. Membrane pores typically range in size from 0.005 to 0.1 micron.

These generate water with very high purity and low silt density by providing a pressure-driven barrier to suspended particles, bacteria, viruses, endotoxins, and other pathogens.. UF employs hollow fibres of membrane material, with feed water flowing either within the shell or through the fibre lumen. Suspended solids and high molecular weight solutes are trapped, whereas water and low molecular weight solutes pass through.

10.13.4.1 ULTRA-FILTRATION MEMBRANES

(a) Hollow fiber membranes (HF)

As the name suggests, HF membranes consist of thousands of hollow fibers, bunched together, and potted at both ends. Within the HF category, there are mainly two types – ‘Inside to out’ and ‘outside to in’ configuration. In the first case, feed water enters INTO the membrane and is filtered outside. In the latter case, the feed water is SUCKED or PUMPED from the outside to the inside of the membrane. Figure10.17 shows the ‘outside to in' type of membrane. In this case, the dirt or suspended solids remain outside the membrane and are relatively easy to drain off the membrane surface.

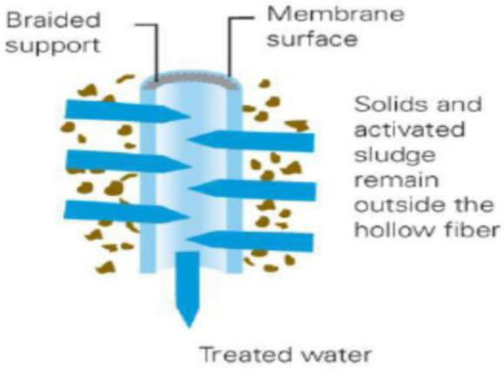


Figure 10.17: HF Membrane

These types of membranes are more popular since they can accept higher solids loading, require less pretreatment, and are less prone to plugging.

Figure 10.18 shows the 'inside to out' type of membrane configuration. In this case, the water containing suspended solids is pumped into the membranes, and solids are retained inside the membrane fiber. After a specific interval, the module is 'backwashed' to drain solids retained inside. Inside to out membranes typically operate with a high cross-flow velocity that scours the surface of the membrane fiber to prevent excessive build-up of solids that could plug the membrane fiber.

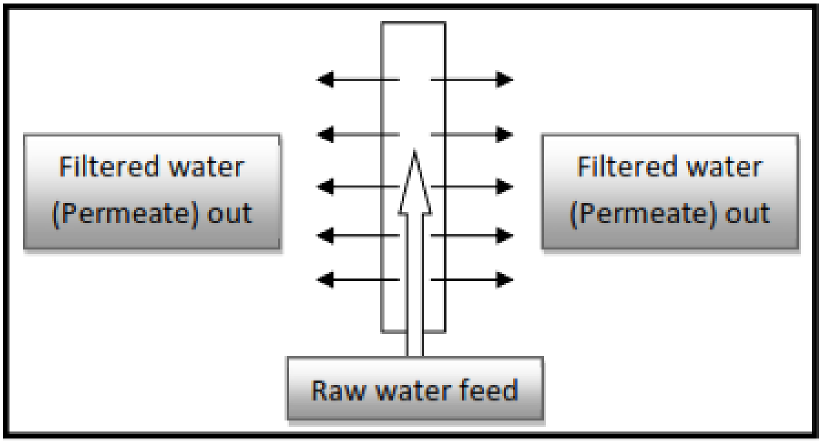


Figure 10.18: HF Flow Chart

(b) Flat Sheet membranes (FS)

FS membranes consist of square or rectangular sheets of membranes, with a spacer in between to allow filtered water to flow out (Figure 10.19). Thousands of sheets are put together in a 'cassette', and all such cassettes are connected by piping. All of the FS types of membranes are 'outside to in' types. FS membranes cannot be backwashed to remove solids. Instead, they use a combination of "resting" and air scour to keep from building up solids on the surface of the membranes. In addition, FS membranes cannot be integrity tested to verify pathogen removal. As a result, FS membranes are not typically used for drinking water applications.

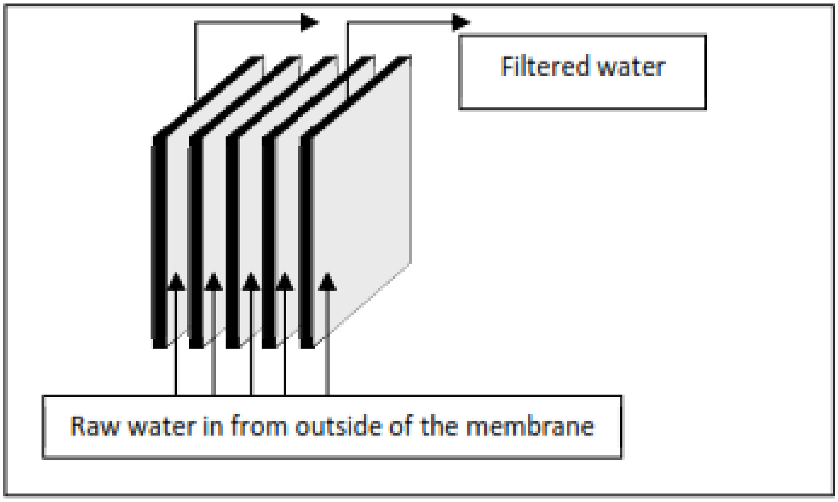


Figure 10.19: FS Membrane

10.13.4.2 CASE STUDY OF TERTIARY TREATMENT WITH ULTRAFILTRATION MEMBRANES AT HYDERABAD

Hyderabad Metro Development Authority (HMDA) operates many sewage treatment plants within Hyderabad city (Telangana State). One such plant is located on the periphery of Hussain Sagar Lake, a tourist attraction in Hyderabad.

In order to reduce (and subsequently eliminate) pollutants entering the lake, there are quite a few Sewage Treatment Plants (STPs) built around the said lake. Treated sewage from these STPs is let into the lake so that the replenishing is done with good quality treated water.

An ultrafiltration system was chosen as a final treatment step, prior to mixing the treated sewage into the lake.

The Following describes the said system in brief:

(a) UF Feed Tank

Secondary treated wastewater from STP is collected in a UF feed tank.

(b) UF Feed Pumps

Four Nos. (3W+1S) of UF feed pumps installed in the UF feed tank to feed secondary treated wastewater collected to the Ultrafiltration facility. Two Nos. of 150 Micron strainers are provided before the UF system for retaining the large size particles from entering the UF system.

(c) Ultra-Filtration Facility

The Ultrafiltration membrane facility is provided for the treatment of 20 MLD Wastewater inlet flow. The Ultra Filtration (UF) Membrane facility is comprised of 6 Nos. of UF Racks. Each UF Rack consists of 48 nos. of Ultrafiltration membrane modules (Figure 10.20).

The racks are equipped with a pressurized type of Ultra Filtration (UF) membranes ‘out to in’ type. The wastewater passes through the membranes, and ultrafiltration membranes filter the water and retain the suspended solids, colloidal matter, and certain species of bacteria and viruses. The treated wastewater is taken out of the system by permeate header and then transferred to the existing chlorine contact tank for final disinfection.

Table 10.7, Table 10.8, and Table 10.9 show the membrane details, flow and performance of the facility.

Figure 10.20: UF Feed Pumps

Table 10.7: Q-SEP 8012 Ultra Filtration Membrane Details

Particulars	UOM	Details
Membrane Model	-	Q-SEP 8012
Membrane Manufacturer	-	Qua
Membrane Type	-	Pressurized
Module Mounting	-	Vertical
Membrane Material	-	Hydrophilic PVDF
Membrane Housing Material	-	UPVC
Membrane Pore Size	micron	0.04
Membrane Surface Area	m^2	80
Nominal Module Length	mm	2116
Nominal Module Diameter	mm	225
pH Range	-	2 to 10
Recommended Flux Range	lmh	40-120
Trans-Membrane Pressure	bar	0.3 to 2 bar g
Design Recovery across the system	%	90-95
Operating Mode	-	Dead-End
Operating Configuration	-	Outside-In
Operating Temperature Range	°C	Up to 45

Table 10.8: Flow in the facility

Name / Capacity	Average (MLD)	Peak (MLD)
20 mld STP at Hussain Sagar	20 mld total 20 mld existing	20 mld total 20 mld existing

Table 10.9: Performance of the Facility

Parameter	Feed to UF System	Outlet of UF system
pH	6.8 – 7.8	6.8 – 7.8
BOD5	< 15 mg/L	< 2 mg/L
COD	< 70 mg/L	< 70 mg/L
Suspended Solids	< 20 mg/L	< 2 mg/L
Turbidity	< 10 NTU	< 2 NTU
Total Nitrogen as N	< 11 mg/L	< 10 mg/L

Total phosphorus (with coagulant addition)	< 1.0 mg/L	< 0.2 mg/L
Dissolved Oxygen	1.5 – 2 mg/L	> 3 mg/L
Total Coliform	-	< 100 MPN / 100 mL
Residual Chlorine		0.1 – 0.2 mg/L

10.13.5 Microfiltration

Microfiltration (MF) is a pressure-driven separation process that is commonly used to concentrate, purify, or separate macromolecules, colloids, and suspended particles from solution. Nominal pore diameters for MF membranes are typically in the range of 0.1–1.0 µm. Because of the vast range of pore size, MF membranes can be utilised in a variety of disciplines that need the separation of viruses, bacteria, aerosols, and other macromolecules from liquids. MF processing is widely used in the food industry, as a pretreatment filter before ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO) membrane-based processes, and for wastewater treatment and plasma separation from blood (Figure10.21).

Microfiltration can be performed in two modes: dead-end (inline) filtration and crossflow (tangential flow) filtration. The predominant flow direction in dead-end filtration is perpendicular to the membrane. The suspended particles are constantly drawn towards the membrane, where they settle on the surface or inside the membrane pores. Particle deposition results in a rising resistance to flow and, as a result, a decreased permeate flux rate. To decrease deposition, microfiltration is frequently performed in the crossflow mode (tangential flow), with the primary flow direction tangential to the membrane. The flow scours particles away from the membrane surface, limiting particle deposition.

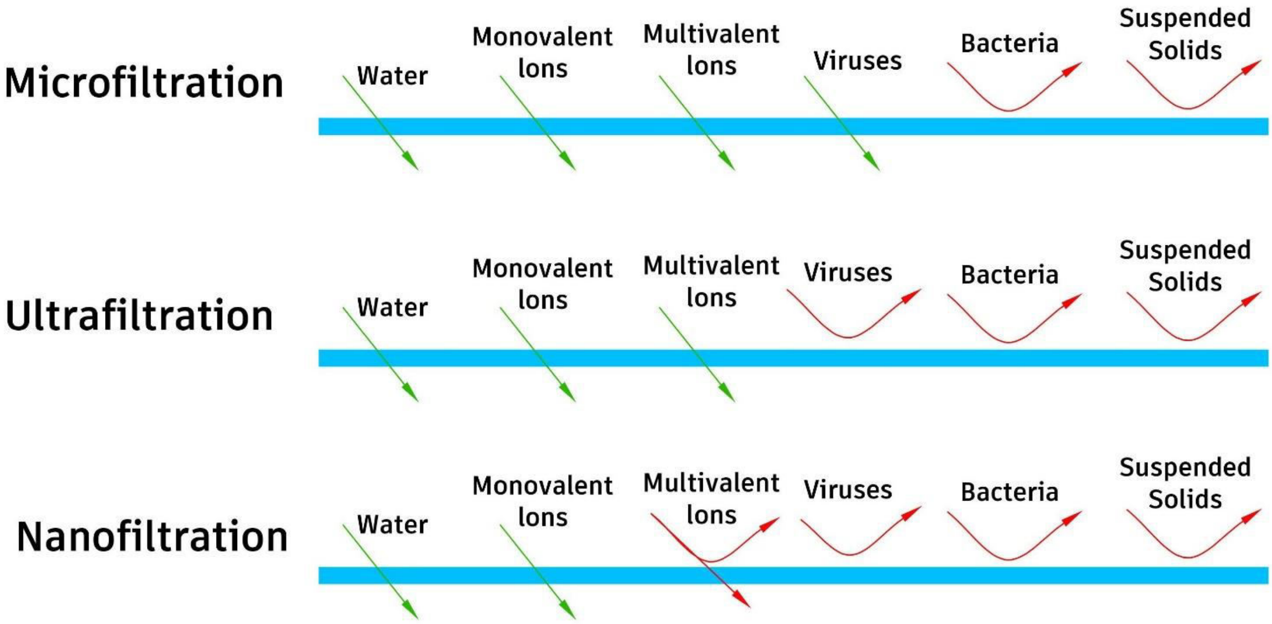


Figure 10.21: Membrane Process Characteristics

10.13.6 Availability of UF, and RO Filtration Membranes in India:

A wide range of membrane configurations and types to allow each and every system of UF, MF, NF& RO according to their specific separation application are available in the Indian market. The range includes a number of both polymeric and inorganic membranes.

10.13.6.1 CLASSIFICATIONS OF POLYMERIC MEMBRANES

a) **Spiral** – Spirals are good cost-effective solutions to high volume applications with limited or no suspended materials because of their compact layout and relatively significant amount of membrane area per element, with the principal advantage being both low capital investment and energy expenses. They are available for all filtration methods, including microfiltration and reverse osmosis.

b) **Tubular** – Tubular membranes, which are quite resistant to plugging, are often utilised when the feed stream has a high concentration of suspended particles or fibrous substances.

c) **Hollow Fiber Membrane** – Extremely high packing density and open channel design allows for backwashing from the permeate side, making it ideal for low solids liquid streams.

10.13.6.2 CLASSIFICATIONS OF INORGANIC MEMBRANES

a) **Ceramic** – Ideally used for value-added applications such as fractionation of proteins in milk, cell harvesting, etc., as well as separations of process streams at extreme pH and temperature conditions and presence of solvents.
b) **Stainless Steel** – Rugged design, especially effective for demanding applications with aggressive process conditions or feed streams with elevated particulate solids or viscosity.

10.13.6.3 INDIAN MARKET

Currently, many international and national manufacturers are present in the Indian market supplying a wide range of membranes used in water and wastewater application.

10.13.7 Pretreatment Requirement for Pressurized Membranes

As we have now seen, membranes are fine filters, similar to gravity sand filters that provide a physical barrier for the removal of turbidity-causing particles and many water-borne pathogens. However, for the smooth and trouble-free running of membranes (specially pressurized ones),the feed water (to membranes) must be properly pretreated.

One such pretreatment for ‘Out to In’ type of membranes is either a standard sand filter or a 100 – 150 micron (self-cleaning or manual) filter. This ensures that feed water does not contain more than 5 – 10 mg/L of suspended solids.

For the ‘In to Out’ category of membranes, the pretreatment becomes even more important since the inside diameter of Lumen is quite small, and can get quickly choked, demanding frequent backwashing and cleaning.

Similar to Gravity sand filter choking, membrane filters also get choked (or clogged) after a certain time interval by the accumulation of particles on the surface of the membranes. The deposits need to be removed before membranes are again put into the filter service cycle. This operation of getting away the dirt (or suspended solids) is called Backwash or Back Pulsing. Like in the case of backwashing of sand filters, a small amount of filtered water is typically pushed in the opposite direction (to the filtration cycle). This way, the solids accumulated either on the membrane surface or inside the membranes are flushed out. The membrane backwash process occurs frequently (often every 30 to 40 minutes of operation) for a short duration (typically two to three minutes.

As membrane filtration systems operate, dissolved pollutants in the water may slowly precipitate on the membrane's surface, lowering the membrane's permeability and increasing the transmembrane pressure (TMP) required to filter the water. When the membrane TMP exceeds the normal operating limits for the system, the membranes require a recovery clean, also called a clean-in-place (CIP), to remove the precipitated contaminants and restore the membrane permeability.

10.13.8 Design Guidelines for RO Based System:

For designing an RO system, the following information is necessary:

1. Complete ionic analysis of feed water, including but not limited to:
    a. The concentration of cations like Ca, Mg, Na, K, Al, Fe, Mn, Boron, etc.
    b. The concentration of anions like Cl^-, SO_4^{--}, CO_3^{--}, HCO_3^-, NO_3^-, Colloidal and reactive silica, etc.
    c. Presence of organics (BOD / COD / TOC values)
    d. Overall Total Dissolved Solids (TDS)
    e. pH and temperature with all possible variations
    f. Expected recovery (and rejection) of ions
    g. Operating hours
2. The above analysis is to be fed into the “projection software” provided by the selected membrane manufacturer.
3. Any amount of excess anion/cation will be shown in ‘warnings’, i.e., the system may not function properly if the input is not properly adjusted.
4. More often than not, projection software also needs inputs regarding the type of water, viz. ground water / with pretreatment / UF treated, etc.
5. If all the parameters are within design guidelines by the particular manufacturer, select the number of membranes and hence the number of pressure tubes.
6. Projection software also indicates pump pressure required with a lot of other data.
7. There are variables available in the design/sizing of the RO system, such as:
    a. Use of 4” or 8” membranes (depending on flow to be handled)
    b. Recovery in %

   c. Feed pH (adjustable with addition of acid/alkali etc.)
   d. Variations in the number of membranes per pressure tube (usually varying from 2 to 7 membranes per tube) and different ‘arrays.’
   e. A variety of membranes that offer different performance

8. There is also a provision to insert an ‘energy recovery device’ in case the designer is interested to recover some energy from the rejects stream. The use of such devices is to be done in consultation with OEMs of energy recovery device manufacturers.

10.13.9 Performance of RO and ED Plants

Based on evaluation studies conducted by NEERI on the working of desalination plants employing Reverse Osmosis and Electro-dialysis principles, the following analysis emerges:

(a) The quality of product water in RO is consistent while it is generally not so in ED.
(b) Despite elaborate pre-treatment, operation and maintenance, the plants could not yield consistent quality of product water within permissible limits. Whenever such consistency in quality was attempted, the product water recovery decreased considerably, thereby raising the cost of treatment of desalinated water. The reject water quantity correspondingly increased.
(c) In the RO plants evaluated, the rated capacity of product water was rarely achieved. In the plants studied by NEERI, only one produced at 100% capacity, while others functioned at 30, 50, and 72% of the rated capacity, associated with problems during operation.
(d) Membrane life indicated by various firms for RO plants varied from 1 to 3 years. A membrane life of upto 5 years is claimed for ED. These claims, however, need validation as all evaluated plants operated on an average for 5-8 hours/day only and the frequency of membrane changes was higher. Membrane life depends on the degree of pretreatment.
(e) Pressure pump maintenance poses several problems during operation; the non-availability of spare parts at the site can seriously affect their maintenance.
(f) Due to the frequent deposition of salts on the membrane that needs to be acid washed more frequently, the maintenance of ED plants became more difficult.
(g) Scaling is a potential problem and large quantities of acid are used to prevent its formation. General practice has been to use the Langelier saturation Index of the

concentrate to calculate acid requirements. Stiff and Davis Stability Index is recommended which results in a significant reduction in acid use.

(h) Energy costs are typically 40-60% of the total operating costs of Reverse Osmosis. The production of 1 m^3 of water requires 4-6 kWh of energy, compared with 12-18 Kwh for the distillation process. However, the requirement can be reduced if energy recovery turbines are used, wherever feasible.

(i) During the life of a RO plant, membrane replacements are commonly projected to contribute for 25-35 percent of the operating costs. There is plenty of scope for reducing the frequency of membrane replacements.

10.13.10 Energy Efficiency of Reverse Osmosis (RO)

To recover fresh water from seawater, reverse osmosis (RO) technology consumes a significant amount of energy. Because of advancements in RO technology, seawater RO (SWRO) has become the primary form of large-scale desalination around the world. However, the specific energy consumption (SEC) of SWRO remains significantly greater than that of surface water treatment and indirect potable recycling, making SWRO less cost effective than other potable water production solutions. Furthermore, when nonrenewable energy sources are employed to meet SWRO energy demand, larger quantities of greenhouse gas are emitted than when lower energy alternatives are used.

The energy causes 60% of the total cost in Reverse Osmosis systems. Hence optimization of energy is essential to keep the overall cost optimum.

Following designs are used for efficient use of energy

1) Use of Energy recovery Devices
2) Selection of optimal flux
3) High efficiency of High Pressure Pumps
4) Use of VFDs
5) Use of high-efficiency drives
6) Prevention of biofouling in RO membranes

10.13.11 Recommendation to use RO membranes for treatment

It is recommended to use RO membranes for the treatment of

a) Brackish Water (BWRO)
b) Tertiary treatment of treated sewage (TTRO)

c) Seawater Desalination (SWRO)

Details of BWRO and SWRO are discussed in following sub-section. TTRO has been discussed as case studies later in this chapter.

10.13.11.1 BRACKISH WATER REVERSE OSMOSIS (BWRO) SYSTEMS

BWRO systems are typically designed with raw water Total Dissolved Solids (TDS) ranging from about 1,500 mg/L to 10,000 mg/L. Beyond this TDS level, Sea Water RO (SWRO) is required to be employed. For groundwater or surface water having TDS less than 1000 mg/L, RO treatment is not required or not desirable.

RO process itself is extremely versatile but needs the feed water to be treated with great care. Some of the limiting conditions (of feed water to BWRO) are:

- Total suspended solids : Below Detectable Limits (BDL)
- Silting Density Index (SDI) : Preferably below3.0, but less than 5.0
- Oxidizing chemicals : BDL
- Silica (colloidal) : BDL
- Other heavy metals : BDL
- Total Dissolved solids : Less than 10,000 mg/L
- Iron / Manganese : Less than 0.1 mg/L
- Bacterial load : Preferably NIL

To achieve these parameters, in most cases, some pretreatment is necessary. Unit operations and unit processes involved in such treatment depend on (raw water) source. The following block diagram indicates the combination of possible schemes (Figure10.22):

BWRO systems usually operate at low or moderate pressure (8 – 20 Bar). Feed pressure required (at membrane feed end) is usually 2 – 4 Bar and can have recoveries up to even 90%, depending on the array. If the feed water contains a large amount of heavy metals, silica, Boron, etc., more exhaustive pretreatment is called for.

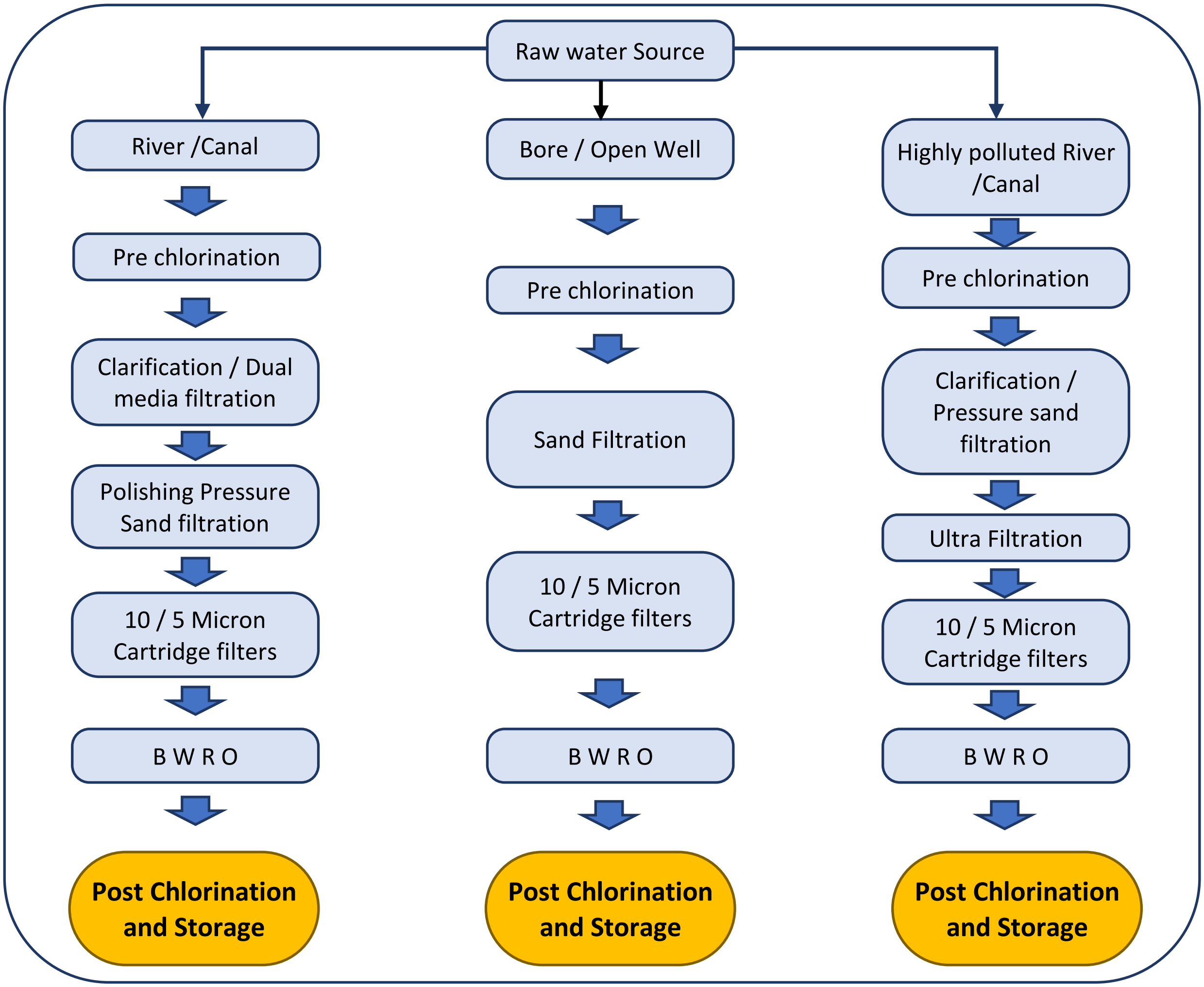


Figure 10.22: Combination of Possible Schemes

10.13.11.2 SEAWATER DESALINATION (SWRO)

Pressure-driven reverse osmosis (RO) has become the most preferred method to desalinate sea water across the world over the last 2 decades. Reverse Osmosis is a membrane-based separation process, where high pressure is applied to the influent water to overcome the osmotic pressure through a semipermeable membrane, to enable the separation of molecular/dissolved impurities from the water. This splits the feed into a reject stream rich in salt molecules and another stream lean in salts thus reducing the TDS of the water.

A Limitations of Conventional RO

Typically, SWRO (Sea Water Reverse Osmosis) process takes in feed water between 30 to 40,000 ppm TDS and can concentrate reject streams up to 70,000 ppm TDS. Concentration above this limit is capped by the prohibitive energy requirements. Thus, the ideal permeate recovery from the process is capped at ~ 40%.

Current desalination plants the world over, need to increase their intake (by up to 2.5 times) due to this recovery constraint to meet ever-growing permeate demands. Further, brine generated from the SWRO process is sent back to the sea as it cannot be treated further.

B Emergence of Counterflow Reverse Osmosis (CFRO)

CFRO system has been developed and scaled to take in existing brine streams (> = 70,000 ppm TDS) from SWRO process to

- Recover more water from brine streams and thereby increase recovery
- Considerably reduce final brine generation

CFRO is an advanced process innovation based on the conventional Reverse Osmosis process developed for brine handling needs and starts where conventional SWRO systems stop. CFRO systems extract high-quality permeate from saline water sources, including high salinity brine streams, at lower pressure, with less energy and lower capital and operating costs than alternative approaches.

With minimal intervention and maximized permeate extraction, CFROs enable quick project turn-around, be it brownfield expansion or end-to-end greenfield desalination needs.

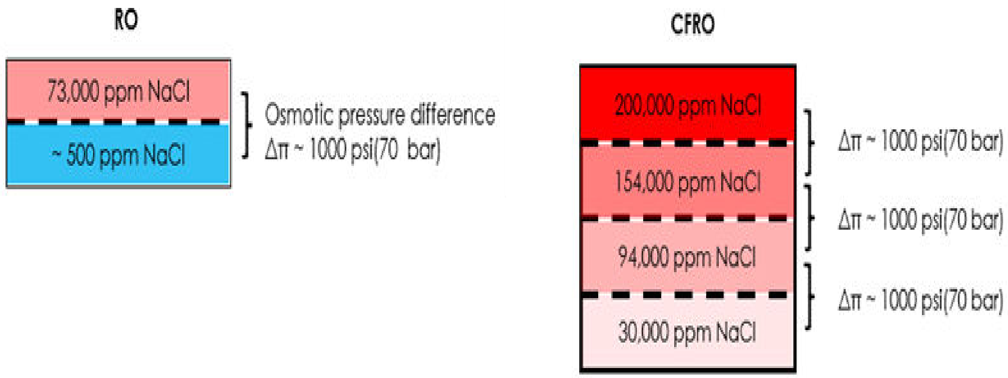


Figure 10.23: CFRO Working

The CFRO process works on the principle of osmotic assistance; diluted brine from succeeding stages is recirculated back into the system to decrease the relative osmotic pressure requirements and thus concentrate reject streams up to 200,000 ppm. This concentration level is comparable to thermal evaporators. Furthermore, the CFRO achieves the same with the standard spiral wound membrane architecture and similar operating pressures as conventional SWRO systems. Figure 10.23 shows CFRO Working and Figure 10.24 shows CFRO Configuration.

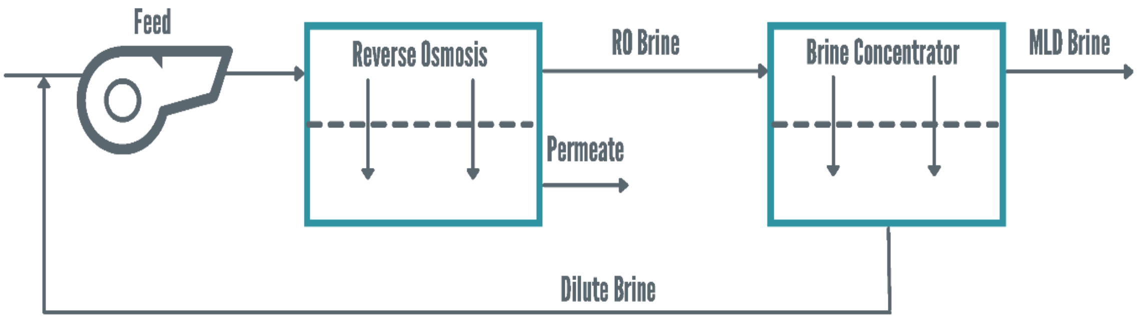


Figure 10.24: CFRO Configuration

The CFRO process works on the principle of osmotic assistance; diluted brine from succeeding stages is recirculated back into the system to decrease the relative osmotic pressure requirements and thus concentrate reject streams up to 200,000 ppm. This concentration level is comparable to thermal evaporators. Furthermore, the CFRO achieves the same with the standard spiral wound membrane architecture and similar operating pressures as conventional SWRO systems.

Novel advantages of CFRO for SWRO desalination;

- High recovery desalination solution up to 90%
- Minimize Intake/Outfall Structures required for desalination plants
- Quick SWRO project turn around to match expansion ambitions
- Meet future DM water quality demand with current desalination assets

10.13.12 Case Study on Tertiary Treatment RO (TTRO) Application at Koyambedu, Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB), Tamil Nadu

The TTRO of CMWSSB at Koyambedu has source water of secondary treated sewage from the Sewage Treatment Plant (Three plants totaling 217 MLD). The output capacity of TTRO is 45 MLD (further extendable by 15 MLD). Presently due to lack of demand, the plant is producing 15 MLD treated water. As reported the produced water cost is Rs.38 per cum. The treated water is supplied (pumped) to Industrial sector consumers (5 hubs) at the rate of Rs.80 per cum. The plant was designed and supplied by Wabag-IDE and is being maintained by Wabag since 2019 post commissioning.

TTRO plant receives good quality secondary treated sewage with maximum values of BOD: 20 mg/L, COD: 100 mg/L, and TSS: 30 mg/L. However, TDS is high in the range of 800-1000 mg/L.In order to feed the raw water at a uniform flow rate to the plant and for processes to function efficiently, there are two balancing tanks provided for the purpose. The detention time of each tank is two hours .

Before conveying raw water to Dual Media gravity filters (part of pre-treatment), it is dosed with Chlorine-di-Oxide to neutralize/reduce residual BOD, COD, Organic and bacteriological load. Eight numbers of dual media gravity filters are further provided to reduce the TSS and Turbidity to prepare feed water for UF membranes. The filters have Anthracite and Sand as media. They are backwashed with the filtered water from the Elevated Backwash tank. The treated water turbidity is reported as less than 2 NTU. The filtered water is stored in the Underground Reservoir.

The filtered water is further pumped to UF membrane skids. There are four skids working in parallel. The treated water from UF has a turbidity of less than 1 NTU. The TDS remains the same in the range of 800-1000 mg/L. By a combination of dosing of Chlorine-di-oxide and polishing off of all the suspended matter BOD & COD reach the Below Detection Limit

(BDL) level. The RO feed water is then injected with Sodium-Meta-Bisulphite for de-chlorination. Three-stage RO (Three passes) is provided with four RO skids each with membrane elements. The TDS is reduced to a range of 100-200 mg/L.

RO treated water is further passed through stripping towers to eliminate CO_2. This raises the PH from 5.7 to 7.5. It is further dosed with Ozone (on-site-generator) for complete disinfection. The treated water is stored in a storage tank for pumping to the consumer end (Industry). The waste filter backwash water and UF reject are recycled to STP. The reject from RO is disposed of with secondary treated sewage from STP.

On physically observing the filter media it is found to be of softer quality (akin to Bituminous coal). On visual observation, it was seen that the uniformity coefficient was high. There was coal powder content in the media too. This must be inducing rapid headloss (pressure drop) in filters. Hence frequent cleaning is required. Normally the percentage of backwash water should be 2-3% of total filtered water. If the plant is operated at rated capacity, then the Dual Media Filter efficiency is likely to get further affected. It is recommended to use imported Anthracite coal or Crushed coconut shell instead of bituminous coal.

It will be worth exploring whether to dose Ozone as a pre-oxidant/disinfectant and Chlorine –dioxide as a post-oxidant/disinfectant. This is for controlling the generation of DBPs (Disinfection by-products) and to maintain the residual chlorine in the distribution network.

UF Membranes and shell, Bituminous Coal, and High-Pressure RO feed Pump in TTRO Application at Koyambeduare shown in Figure10.21 and 10.22.

Figure 10.25: UF Membranes and shell, Bituminous Coal

Figure 10.26: High-Pressure RO feed Pump

(Source: Chennai Metropolitan Water Supply and Sewerage Board)

10.13.13 Design Criteria of Desalination Plant

The saline waters in India including the sea water, coastal and inland brackish waters having salinity more than the limits recommended for potable use require treatment through desalination plants. Typically, water with a TDS concentration higher than 500 mg/L and not higher than 15,000 mg/L is classified as brackish. Seawater is classified as natural water sources with TDS values greater than 15,000 mg/L, such as sea, bay, and ocean waters. This concentration can range up to 36,000 mg/L at various locations and depths along the seacoast.

There is no one ‘best’ method of desalination. Generally, Distillation and Reverse Osmosis are recommended for seawater desalination, while Reverse Osmosis and Electro-dialysis are used for brackish water desalination. However, the selection and use of these processes should be very site specific, they must be selected very carefully.

One of the major considerations in the selection of a desalination process should be its cost and maintenance. However, despite the substantial costs involved, the availability of desalinated water in arid zones can be a boon to that area. Where the water is salty, alternative water for consumption is often transported over long distances by truck or animal. When that water is sold, its unit price often exceeds that of desalinated water. Therefore, the economic conditions to support desalination already exist in many water-short areas.

Apart from this, the following criteria should be given due consideration for site selection and designing a desalination system of water supply:

Site selection is critical for desalination plant design, finance, building, and operation. The following criteria should be considered when choosing a site:

i. It should be suitably located in a marine environment where adequate quantity of feed water with a reasonable good, uniform, and steady quality of feed seawater is abstracted at a reasonable cost.
ii. The area extent and shape (topography and geometry) must be appropriate so that the marine intake head structures, the marine pipelines, the inland pit the, seawater pumping station, the inland pipelines, the main facility structures, the post-treatment system, the product delivery sub-system, and the power supply system (independent of national grid substation) are adequately accommodated and optimally located so that civil, electrical, piping interconnections and other works costs are minimized,
iii. It should be at a location where the brine, backwash wastewater, and other wastes are disposed of without environmental adverse effects,
iv. Geologically and oceanographically are suitable for the construction and erection of the various structures at reasonable costs,
v. Environmental, town planning, CRZ and rural planning regulations, law requirements, and restrictions are met,
vi. The desalination plant shall have the social acceptance of the neighboring communities and other authorities; and finally
vii. Must be located in a place where access and interconnections to the power supply grid, (or independent power production or alternate source of energy, especially renewable energy resources) and the water supply networks are technically and economically feasible,

10.13.14 Sea Intake

Site Condition:

Physical site parameters, as well as meteorological and oceanographic data, must be considered while evaluating a site for seawater intake. In addition, potential sources of contamination such as fouling by marine organisms, oil spills, or other pollution should be evaluated.

When considering the location of an intake structure, it is important to remember that the ocean is in constant motion and is constantly changing. Water levels vary on a daily basis as the tide level changes. In addition, forces caused by waves and currents are constantly at work modifying the shoreline and the profile of the sea floor near shore.

Water Quality:

The surf zone is the area in which waves approaching the shoreline break. Breaking waves create a great deal of turbulence. The churning motion of breaking waves suspends particles from the bottom, making the water in the surf zone more turbid and with higher amounts of suspended solids. For this reason, it is not advisable to take seawater directly from the surf zone. Further, wave forces on structures can be reduced by situating them at an appropriate depth below the water's surface.

Water temperature also varies with depth. It is important to keep water temperatures within a properly designed range for seawater intake. To reduce temperature fluctuations that can be experienced in stratified surface layers, it is preferred that seawater be obtained from a deeper layer.

One of the first considerations concerning the location of an intake for a desalination plant, is the proximity to the shore of a location deep enough to obtain cooler, less turbid water. Either a pipe or channel-type intake can then be selected, depending on seabed conditions, to bring the water to the plant. In alluvial soil formation on the shoreline, seawater may be collected through the construction of beach-well in coastal alluvial aquifers.

Seabed Conditions:

The seabed conditions will be one of the primary factors in determining the type of seawater intake structure for a particular location. If the intake is to draw water from the open coastline and not from a sheltered lagoon (which is a preferred location, if available and pollution free), the two most common types of intakes are the pipe and the channel intake.

Pipe-type intake:

In the pipe-type intake, a pipeline is run from the shoreline out past the surf zone (Figure 10.27& Figure 10.28). For sandy bottoms, a trench is usually dredged, the pipe laid, and the trench backfilled. For bottoms composed primarily of rock or coral, dredging and backfilling would be difficult and expensive. Pipelines are typically buried for anchorage and protection from wave forces and currents. Other methods of anchorage besides trenching and backfilling have been employed, including multi-helix anchors, concrete saddles, engineered backfill, and grouted neoprene impregnated nylon bags or pillows filled with grout. There are other problems associated with laying pipelines on a rocky bottom. Pipes laid on uneven terrain will only be supported at the high spots. This bridging between support points results in stresses that must be carried by the pipe. In addition, the danger of abrasion of the pipeline is increased with rock bottoms. For these reasons, rock bottoms are not conducive to the installation of a pipe-type intake.

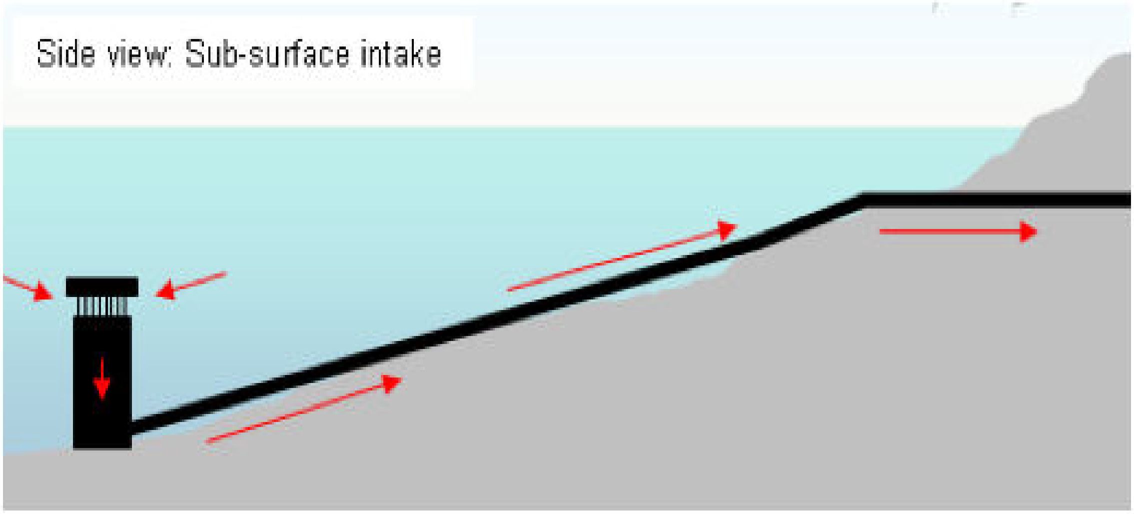


Figure 10.27: Side View of Sub Surface Intake

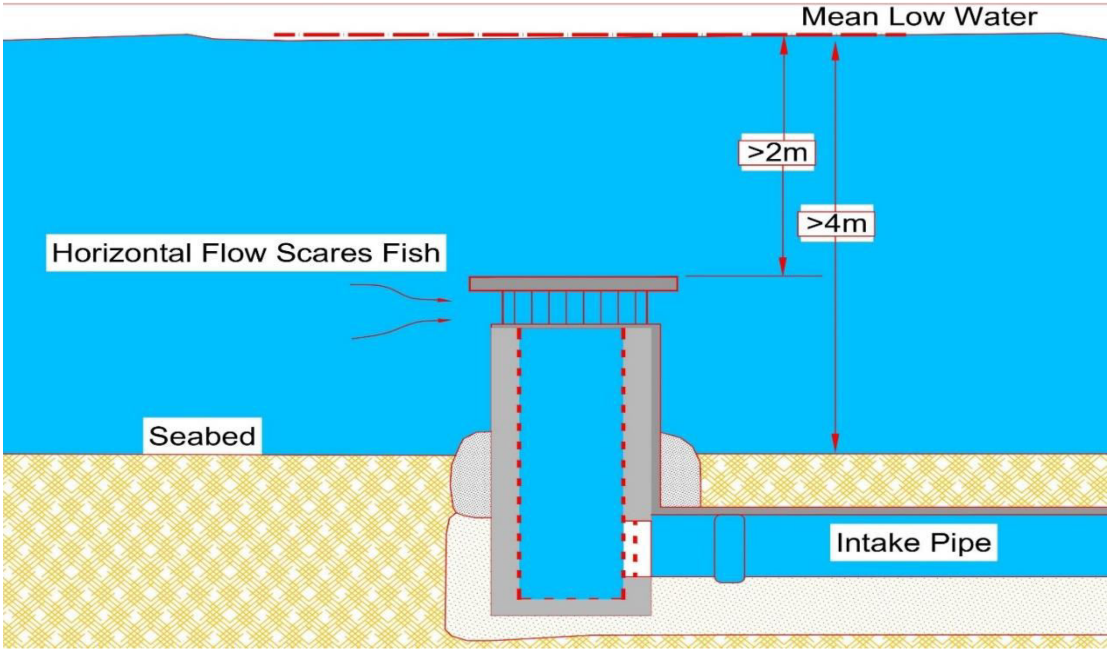


Figure 10.28: Pipe Type Intake

Channel type intake:

A channel type intake can be constructed either by installing rocks to form walls along each side of the channel or by dredging (Figure 10.29). In sandy bottoms, there is a tendency for the movement of sand due to littoral transport. This littoral transport can either act to erode sand from the channel walls or result in sand being deposited in the channel and could result in the channel requiring re-dredging to keep the channel open. In addition, wave action in the channel would result in sand and silt being placed in suspension causing higher turbidity. For rocky bottoms, the problems of littoral transport, erosion, and suspension of particles due to wave activity are not significant considerations in designing channel-type intakes. The design of a channel-type intake on rock bottoms would primarily be concerned with resisting wave forces and eliminating debris.

Thus, a sandy bottom favours the construction of a pipe-type intake system, whereas a rocky bottom favours the installation of a channel-type intake system.

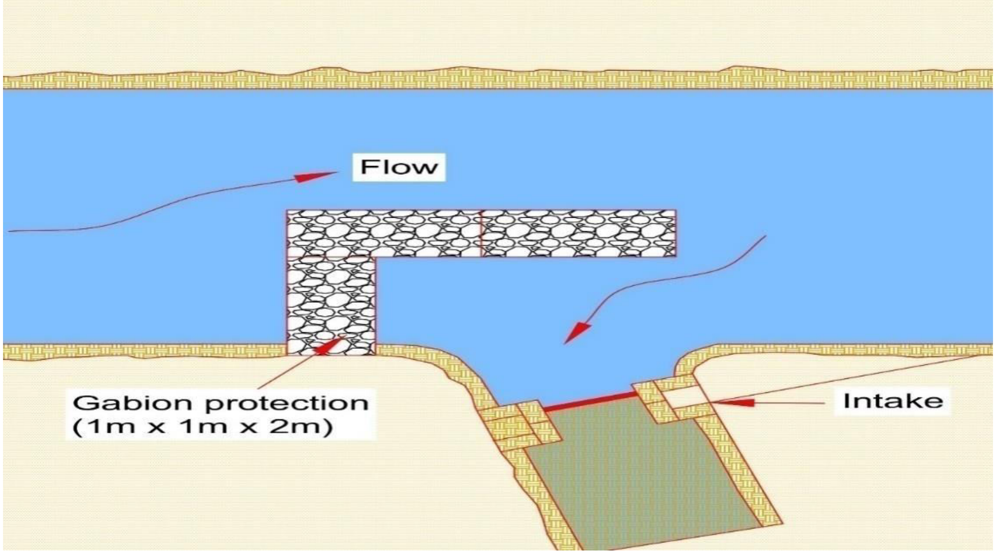


Figure 10.29: Channel Type Intake (Gabion Protection)

Non-surface intakes:

Non-surface intakes include beach wells, seabed filtration, and inflow galleries. These intakes are variations on the same basic approach of taking filtered seawater from below the surface near the shoreline (Figure 10.30). Each of these intakes has advantages, capabilities, suitability, and cost-effectiveness for different site conditions.

Due to natural filtration and underground detention, beach wells and galleries extracting groundwater of seawater quality can deliver a more consistent quantity and higher quality water than surface intakes. Although experience with similar beach wells and galleries as intakes for Seawater Reverse Osmosis (SWRO) plants is limited, non-surface intakes promise an opportunity for improved efficiency, reliability, cost effectiveness, and performance of desalination plants, particularly SWRO plants, due to their positive effects on feed-water quality.

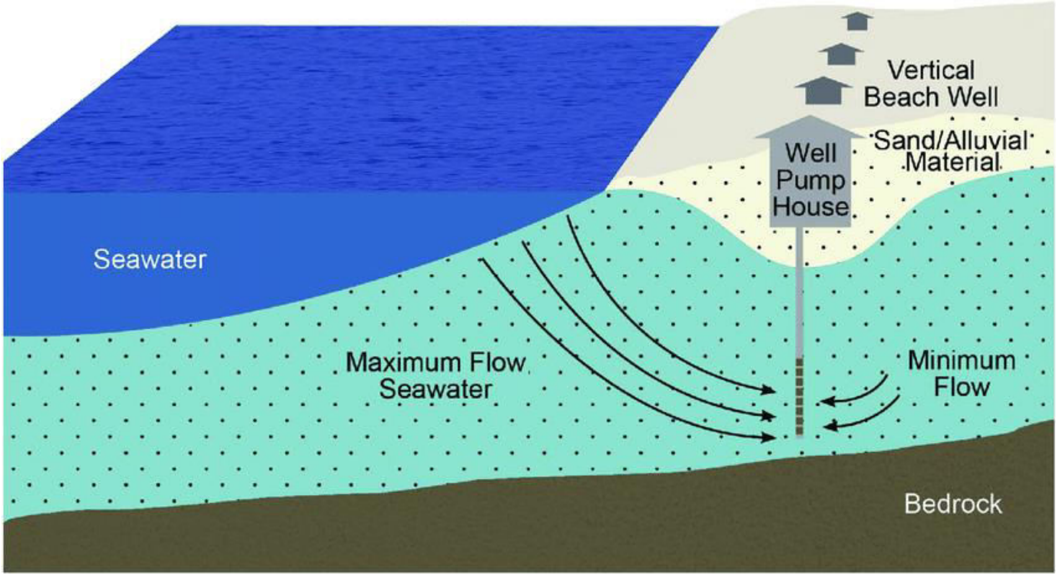


Figure 10.30: Non-Surface Intake

Other factors:
The oceans are extremely dynamic systems constantly in motion as a result of external forces, such as wind, and internal forces, such as temperature and salinity gradients. The rotation of the Earth results in oceanographic currents and wind forces cause waves and also affect the currents. Seismic forces may also result in disruptive waves in the form of tsunamis and seiches (standing waves oscillating in a sea water body).

Environmental Impact Assessment: A detailed environmental impact assessment of the SWRO project has to be carried out before taking final decision on the site selection and implementation of the project.

10.13.15 Design of Desalination Plant

The process of desalination can be classified into two basic methods. 1) Separating some water from dissolved salts, and 2) Removing dissolved salts from water. Sea and brackish water are typically desalinated using two general types of water treatment technologies: thermal evaporation (distillation) and reverse osmosis (RO) membrane separation. Aside from thermal distillation and RO membrane separation, two more popular desalination processes are electrodialysis (ED) and ion exchange (IX).

By evaporation, freshwater is removed from the saltwater source in thermal distillation. All thermal desalination technologies apply distillation (i.e., are based on heating the source water) to produce water vapour, which is then condensed into low-salinity water. Since the energy for water evaporation is practically not dependent on the source water salinity concentration, thermal evaporation is very suitable for desalination of high-salinity waters and brine.

In RO desalination, freshwater is produced from saline source water by pressure-driven transport through semipermeable membranes. The main driving force in RO desalination is pressure, which is needed to overcome the naturally occurring osmotic pressure that in turn, is proportional to the source water's salinity.

Electrodialysis is electrically driven desalination in which salt ions are removed out of the source water through exposure to a direct electric current. The main driving force for ED separation is an electric current, which is proportional to the salinity of the source water.

Ion exchange (IX) is the selective removal of salt ions from water by adsorption onto ion-selective resin media. The driving force in this desalination process is the ion charge of the IX resin, which can selectively attract and retain ions of the opposite charge contained in the saline source water.

Table 10.10 provides a general indication of the range of source water salinity for which distillation, RO separation, ED, and IX can be applied cost-effectively for desalination.

Table 10.10: Range of Source Water Salinity

Separation Process	**Range of Source Water TDS Concentration for Cost-Effective Application, mg/L**
Distillation	20,000–100,000
Reverse osmosis separation	50–46,000
Electrodialysis	200–3000
Ion exchange	1–800

For processes with overlapping salinity ranges, a life-cycle cost analysis for the site-specific conditions of a given desalination project is typically applied to determine the most suitable desalination technology for the project.

The Central Salt and Marine Chemical Research Institute at Bhavnagar, having its regional laboratory at Jodhpur, under CSIR is responsible for saline water conversion-related studies. The institute has installed a few desalination plants for this purpose.

10.13.2.1 Thermal Desalination

All thermal desalination plants have five key streams: source water (seawater, brackish water, or brine) used for desalination; steam needed for evaporation of the source water; cooling water to condense the freshwater vapour generated from the source water's evaporation; low salinity distilled water (distillate); and concentrate (brine), which contains the salts and other impurities separated from the source water.

Multi-Stage Flash Distillation (MSF), Multi-Effect Distillation (MED), and Vapour Compression (VC) are the three most popular types of thermal desalination technologies. Each of these classes of technology has evolved over the past 40 to 60 years toward improvements in efficiency and productivity. The three types of thermal technologies mainly differ by the temperature and pressure at which the source water is boiled to generate freshwater vapour.

a) Multistage Flash Distillation

In the multistage flash distillation (MSF) evaporator vessels (also referred to as flash stages or effects), the high-salinity source water is heated to a temperature of 90 to 115°C (194 to 239°F) in a vessel (the heating section) to create water vapour. The pressure in the first stage is maintained slightly below the saturation vapour pressure of the water. So, when the high-pressure vapour created in the heating section enters the first stage, its pressure is reduced to a level at which the vapour "flashes" into steam. Steam (waste heat) for the heating section is provided by the power plant co-located with the desalination plant. Each flash stage (effect) has a condenser to turn the steam into the distillate. The condensers are equipped with heat exchanger tubes, which are cooled by the source water that is fed to the condensers.

Entrainment separators (mist eliminators or demister pads) remove the high-salinity mist from the low-salinity rising steam. This steam condenses into pure water (distillate) on the heat exchanger tubes and is collected in distillate trays, from where it is conveyed to a product water tank. Distillate flows from stage to stage and is collected at the last stage. The concentrate (brine) is generated in each stage and after collection at the last stage, some of it typically is recycled to the source water stream to reduce the total volume of source water that must be collected by the intake for desalination. The recirculated brine flowing through the interior of the condenser tubes also removes the latent heat of condensation. As a result, the recirculated brine is also preheated close to maximum operating temperature, thereby recovering the energy of the condensing vapour and reducing the overall heating needs of the source water. This "brine recycle" feature has been adopted all of the most recent MSF facility designs and allows significant improvement of the overall cost competitiveness of MSF installations.

Each flash stage typically produces approximately 1 percent of the total volume of the desalination plant's condensate. Due to the fact that a typical MSF unit contains 19 to 28 effects, the overall MSF plant recovery (i.e., the volume of distillate expressed as a percentage of the total volume of processed source water) is normally 19 to 28 %. For comparison, RO seawater desalination plants have a recovery of 40 to 45 percent. The latest MSF technology has 45-stage units—i.e., can operate at 45 percent recovery. This feature allows it to compete with RO systems in terms of recovery.

Historically, MSF was the first commercially available thermal desalination technology applied to the production of potable water on a largescale, which explains its popularity. Over 80 percent of thermally desalinated water today is produced in MSF plants.

b) Multiple-Effect Distillation

In multiple-effect distillation (MED) systems, the saline source water is typically not heated; cold source water is sprayed via nozzles or perforated plates over bundles of heat exchanger tubes. This sprayed feed water boils, and the resulting vapour flows through mist eliminators, which remove brine particles from the vapours. The feed water that turned into vapour in the first stage (effect) is introduced into the heat exchanger tubes of the next effect. Because the next effect is maintained at slightly lower pressure, although the vapour is slightly cooler, it still condenses into freshwater at this lower temperature. This process of reducing the ambient pressure in each successive stage allows the feed water to undergo multiple successive boilings without the introduction of new heat. Steam flows through the exchanger tubes is condensed into pure water and collected from each effect. Heating steam (or vapour) introduced in the heat exchanger tubes of the first effect is provided from an outside source by a steam ejector.

The MED system is also equipped with a brine recycle system, which allows the introduction of warmer-than-ambient water in the first effects of the system, thereby reducing both the volume of feed water that must be collected by the plant intake system and the overall energy needs of the system.

The main difference between the MED and MSF processes is that while vapour is created in an MSF system through flashing, evaporation of feed water in MED is achieved through heat transfer from the steam in the condenser tubes into the source water sprayed onto these tubes. This heat transfer at the same time results in condensation of the vapour to freshwater. MED desalination systems typically operate at lower temperatures than MSF plants (maximum brine concentrate temperature of 62 to 75°C versus 115°C).

c) Vapour Compression

The heat source for vapour compression (VC) systems is compressed vapour produced by a mechanical compressor or a steam jet ejector rather than a direct exchange of heat from steam.

In VC systems the source water is evaporated and the vapour is conveyed to a compressor. The vapour is then compressed to increase its temperature to a point adequate to evaporate the source water sprayed over tube bundles through which the vapour is conveyed. As the compressed vapour exchanges its heat with the new source water being sprayed on the evaporation tubes, it is condensed into pure water. A feed water preheater (plate-type heat exchanger) is used to start the process and reach evaporation temperature.

VC and MED work based on similar principles. However, while in MED the steam produced by source water evaporation is introduced and condensed in a separate condenser located in the downstream effect, in VC the steam generated from the evaporation of new source water is sprayed on the outside surface of the heat exchanger tubes, is recirculated by the vapour compressor and introduced into the inner side of the same heat exchanger tubes in which it condenses to form distillate.

10.13.2.2 Membrane Desalination

Two general types of technologies currently used for membrane desalination are electrodialysis (ED) and RO.

Table 10.11 provides a comparison of the removal efficiencies of distillation, ED, and RO systems for key source water quality compounds.

Table 10.11: Contaminant Removal by Alternative Desalination Technologies

Contaminant	Distillation (%)	ED/EDR (%)	RO (%)
TDS	>91.9	50–90	90–91.5
Pesticides, Organics/VOCs	50–90	<5	5–50
Pathogens	>99	<5	>910.99
TOC	>95	<20	95–98
Radiological	>99	50–90	90–99
Nitrate	>99	60–69	90–94
Calcium	>99	45–50	95–97
Magnesium	>99	55–62	95–97
Bicarbonate	>99	45–47	95–97
Potassium	>99	55–58	90–92

One important observation from this table is that, as compared to distillation and RO separation, ED desalination only partially removes nutrients from the source water. This fact explains why EDR is often considered more attractive than RO or thermal desalination (which removes practically all minerals from the source water) if the planned use of the desalinated water is for agricultural purposes—i.e., generating fresh or reclaimed water for irrigation of crops.

Construction and equipment costs for brackish water reverse osmosis (BWRO) and EDR systems of equal freshwater production capacity are usually comparable, or EDR is less costly, depending on the RO membrane fouling capacity of the source water. However, since the amount of electricity consumed by EDR systems is directly proportional to the source water's salinity, at salinities of 2000 to 3000 mg/L the energy use of EDR systems usually exceeds that of BWRO or nanofiltration systems for source waters. As a result, EDR systems are not as widely employed as RO systems for BWRO desalination and are never used for Seawater Reverse Osmosis (SWRO). It should be pointed out, however, that salinity is not the only criterion for evaluating the cost competitiveness of EDR and

BWRO systems. Often, other compounds such as silica play a key role in the decision-making process.

Over the past two decades, RO membrane separation has evolved more rapidly than any other desalination technology, mainly because of its competitive energy consumption and water production costs. The all-inclusive energy consumption for freshwater production of thermal desalination plants is typically much higher than that for brackish or seawater RO desalination. BWRO desalination yields the lowest overall production costs of all the desalination technologies. It is also worth noting that the most recent Multi-effect Distillation (MED) projects undertaken in recent years have been finished at costs equivalent to those of comparable sized Sea Water Reverse Osmosis (SWRO) facilities. For the majority of medium and large projects, however, SWRO desalination usually is more cost competitive than thermal desalination technologies.

10.13.16 Brine Management

Brine (also known as membrane concentrate, reject brine, and wastewater) is a high-concentration salt (NaCl) solution in water (H_2O). Brine can refer to salt solutions with concentrations ranging from around 3.5 % to roughly 26 %. Brine is formed naturally from evaporation of ground saline water, but it is also produced during sodium chloride mining. It is also a by-product of many industrial processes, such as desalination, so it requires wastewater treatment for proper disposal or further utilization (fresh water recovery).

10.13.16.1 Disposal of Brine

Disposal of brine from desalination plants is of much significance both from economic and environmental standpoints. Improper surface disposal has the potential of polluting the groundwater resources that are used as feedwater for many of the desalination plants. The groundwater pollution is likely to result from high salinity and the presence of other harmful chemicals in the brine. For the disposal of rejected brine from inland desalination plants, the following should be examined:

i) Pumping into specially designed lined evaporation ponds,
ii) Deep-well injection,
iii) Disposal into surface water bodies,
iv) Disposal through pipelines to municipal sewers,
v) Concentration into solid salts, and

vi) Irrigation of plants tolerant to high salinity (halophytes).

Options at i) and vi) are seasonal, and therefore, a backup alternative is required to improve their reliability.

The following factors influence the selection of a disposal method: a) the volume or quantity of concentrate, b) the quality or constituents of concentrate, c) the physical or geographical location of the discharge point of the concentrate, d) the permissibility of the option, e) public acceptance, f) capital and operating costs, and g) the facility's ability to be expanded.

The main environmental issues for an appropriate location for brine discharge are, a) finding a region with no endangered species or stressed aquatic ecosystems, b) finding a location with a high underwater current to allow fast dissipation of high salinity discharge, c) avoiding areas with ship traffic to avoid damaging the brine discharge system and altering the mixing pattern, and d) identifying a discharge point near the shoreline or relatively shallow water to minimise construction, e) ensuring that discharged brine descends to the seabed and travels along the seabed thereafter, f) ensuring no dressing or alteration of the sand dunes, natural features including landscape changes for beautification, recreation, and other such purposes, and g) to meet the CPCB's water quality standards for coastal waters marine outfalls (Vide: EPA, 1986 - GSR 7, dated Dec. 22, 1998).

10.13.16.2 Importance of Brine reduction

Brine salts change the chemical and physical properties of soils. Brine has a deleterious impact on soils in a variety of ways due to the high concentrations of soluble salts (most notably sodium chloride, NaCl. Many biological species are poisoned by chloride levels in and around the spill location. Sodium is a natural dispersion, causing soils to inflate and spread.

The salts in brine reduce the plants ability to absorb water and nutrients. High salt concentrations in the soil limit the plant's ability to absorb water even when ample water is available in the soil, causing the plants to exhibit drought symptoms. This is due to an osmotic action, which causes water to migrate from low salt concentration locations, such as the roots, to high salt concentration areas, such as the soil.

Plant growth is reduced at damaged areas due to the effects of excessive salt concentrations on soil and vegetation. This is exacerbated by many seeds' incapacity to germinate.

10.13.16.3 Methods of Brine Reduction

Following methods are generally used for reduction of brine:

1. Membrane treatment system
2. Thermal Evaporation
3. Evaporation ponds

A Membrane Based System

Reverse osmosis (RO) is the membrane system most widely used to desalt brine waters. RO generates freshwater as well as more concentrated brine, which is referred to as RO brine, reject, or concentrate. This brine concentrate will typically include dissolved salts and chemical concentrations that are close to scaling limitations. If it is intended to use a thermal system to further concentrate the brine or generate solids, it must be treated it to reduce the scaling potential.

B Thermal Evaporation

When considering thermal evaporative systems, optimising freshwater recovery through lower cost membrane systems before adopting expensive thermal systems would result in the best project economics. Based on their residual outputs, thermal systems are classified into two types: (1) evaporators, which create concentrated, low volume brine but do not precipitate solids, and (2) crystallizers, which exceed salt saturation and produce solids.

C Evaporation Ponds

Evaporation ponds are an artificial solution to waste brine discharge from inland surface water. The water evaporates under the correct climatic circumstances, allowing more discharge more brine the ponds. One limitation of ponds is that they require large areas of land to increase the surface area where the water can evaporate and can represent a future environmental liability due to either animal entry or future decommissioning. If solids must be recovered for disposal or reuse, numerous evaporation ponds may be required to alternate between brine evaporation and solids extraction. Evaporation is also faster in hotter, arid areas.

10.13.17 Case Studies on Seawater RO (Reverse Osmosis) Applications

Such plants which are under operation in India are discussed in the section below and Annexure 10.4.

10.13.17.1 Nemmeli, Chennai Metro, Tamil Nadu

The SWRO plant of CMWSSB at Nemmeli receives the raw seawater from the Bay of Bengal located on the eastern side of India. The output capacity of SWRO is 100-110 MLD. Presently the plant is operated at 70-75 MLD capacity. As reported the produced water cost is Rs.32 per cum. The treated water is supplied (pumped) to the drinking water supply and distribution network of South Chennai at a heavily subsidized rate. The plant was designed and supplied by M/s Wabag-IDE and is being maintained by Wabag since 2013. Seawater has TDS in the range of 36,000-39,000 mg/L. It is designed for a maximum TDS value of 41,700 mg/L. The TSS in the fair-weather season is 20 mg/L. However, during monsoon, it goes as high as 300 mg/L. It also receives a moderate load of organics and seashells.

To produce 100 MLD of treated water, 240 MLD of raw seawater is required to be pumped into the pre-treatment system. The plant has a deep-sea submerged intake (15 m below water level). Raw seawater is conveyed by HDPE pipe buried under the sea bed to the plant's receiving well. The Receiving Well is provided with vertical travelling bar screens. Most of the sea shells and other coarse impurities are arrested and removed by the screens.

The raw water is then pumped from Receiving well to the pre-treatment plant consisting of Flash Mixers, Flocculators, and Lamella clarifiers. Pre-Chlorination is done at the Inlet Chamber. Ferric Chloride ($FeCl_3$) is dosed as a coagulant. The TSS of treated clarified water ranges from 10-15 mg/L. There are five parallel streams of Lamella Clarifiers preceded by flocculators. Lamella plates are made out of Polypropylene (PP). The clarified water is stored in an underground reservoir.

The clarified water is further pumped at 18 bar (183.55m H_2O) pressure to Disk Filters followed by UF membranes. The disk filters are self-cleansing and automated to have a cleaning cycle. There are twenty-two parallel chains of skids each comprises of four disk filter vessels. The disk filters produce water of quality less than 10 NTU.

It is further conveyed to UF membrane skids (Figure 10.31). The membrane flux has a design value of 85 lit/sqm/hr. The treated water from UF has a turbidity of less than 1 NTU. The feed water quality to RO (TSS, Turbidity, and Organics) is practically BDL (below detection level) due to the combination of Chlorine dosing and polishing off of all suspended particles by disc filters and UF.

The RO feed water is then injected with Sodium-Meta-Bisulphite for de-chlorination of residual chlorine since RO membranes are generally non-tolerant to Chlorine presence. The SDI (Silt Density Index) of RO feed water is achieved in the range of 2-3.

High-pressure pumps (72 bar) convey the water to RO skids (Figure 10.32). The total recovery rate is 40%. The RO treated water TDS is reduced to a range of 400-500 mg/L. The membranes are designed for flux values of 14-15 L/m^2/h. After the commissioning of the plant, the CIP (Clean-in-place) cycle was 60 days. After seven years of operation, it is 20 days.

For re-mineralization, part of RO treated water (30%, side stream) is injected with Carbon-Dioxide and then passe~~s~~ through columns of lime flakes. This raises the finished water PH above 7.5. It is further dosed with Chlorine (post-chlorination) for complete disinfection. The treated water is stored in the ground reservoir and then pumped to the consumer end (drinking water).

The waste, UF, and RO reject (TDS 70,000 mg/L) is disposed of in the sea. An elaborate diffuser arrangement is made at the disposal point so as not to disturb the marine life and environment due to shock loading.

The treated water is of excellent quality, of drinking water criteria mentioned as per the CPHEEO Manual and IS code. The plant is well designed including pipe and cable routing. It has a sound layout from a process, Operation and maintenance logistics points of view. The plant is automated, and manpower is trained and skilled.

During the initial construction of the project (Year 2010), pre-treatment consisting of Lamella clarifiers was not incorporated. However, to tackle the seasonal variations of TSS, it was required to be provided at a substantial additional cost later. As confirmed during the site visit and with the plant officials, pre-treatment of seawater is of utmost importance for plant performance. The degree of pre-treatment differs according to the quality of seawater. Seawater quality directly influences the overall project cost.

Figure 10.31: UF Membranes Skids

Figure 10.32: RO Membranes Skids

(Source: Chennai Metropolitan Water Supply and Sewerage Board)

10.14 Ion-Exchange Process

When a salt solution is percolated through a cation exchange resin treated with acids the effluent contains equivalent amounts of the corresponding acids as shown below:

$$H_2Zc + M^{++} + 2A^{-} \leftrightharpoons MZc + 2H^{+} + 2A^{-} \quad (10.14)$$

Where M^{++} is Ca^{++}or Mg^{++}. The same equation can also be written for monovalent ions like Na^{+}or K^{+}.

When this acidic effluent is passed through an anion exchange resin which has been treated with alkali so that it contains replaceable hydroxyl ions, the anions are exchanged forthe hydroxyl ion with the result that the effluent is rendered free from salts as illustrated as follows:

$$Z_AOH + H^{+} + A^{-} \rightarrow Z_AA + H_2O \quad (10.15)$$

Thus, it is possible to remove salts from brackish water by a process requiring no more technical skill than that involved in the use of percolation columns. The beds could be regenerated and used repeatedly, without appreciable loss in capacity.

High-capacity cation exchange materials have been discussed in 10.5.2.2. (b). the anion exchange materials have been prepared by condensing substituted aromatic amines with formaldehyde. These ion exchange resins have come to stay in the field of treatment of water for industries and especially in the production of makeup water for high pressure boilers. They have also a place in the treatment of brackish water for the production of potable water.

10.15 HORIZONTAL OR ROUGHENING FILTERS

The water quality of contaminated surface water can be improved significantly when filtered through gravel and sand layers. Therefore, favorable hydrogeological conditions allow polluted and turbid river water to be drawn as clear and safe groundwater from a shallow well located next to a river. These are useful for very small communities where alternative full-fledged treatment is not possible. Roughing filters are typically made up of different sized filter material that decreases in size in the direction of flow (Figure10.33& Figure10.34). The bulk of the solids are separated by the coarse filter medium located next to the filter inlet. The subsequent medium and fine filter media further reduce the suspended solids concentration. A roughing filter's filter media is made of moderately coarse (rough) material ranging in size from around 25 to 4 mm. Filtration velocity, synonymous with hydraulic load, usually ranges between 0.3 and 1.5 m/h. The accumulated solid matter is periodically flushed out of roughing filters by hydraulic filter cleaning. These filters need to be cleaned manually by excavating the filter material from the filter compartment, and washing and refilling it into the filter boxes. The approximate rate of filtration is given below in a study based in Maharashtra is given in Table 10.12 below.

Table 10.12: Approximate rate of filtration is given below from a study based in Maharashtra

Media size	No. of media boxes	Rate of filtration
12 mm to 20 mm	5	3 cum/sq.m
20 mm to 25 mm	5	4 cum/sq.m
25 mm to 40 mm	5	5 cum/sq.m
40 mm to 50 mm	5 to 7	7 cum/sq.m

Figure 10.33: Horizontal Flow Filters

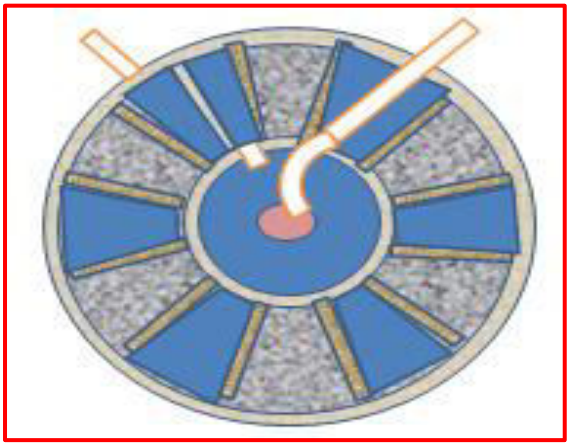


Figure 10.34: Well in well type Horizontal flow filters

The maintenance can be done by unskilled labour. It is essential to clean the filters before monsoon and after monsoon when they are used as the front pre-filter unit ahead of intake well. For the remaining period, it can be as required based on the observations, normally after 2 to 3 months. It can take any turbidity up to 2000 ppm.

10.16 Water Treatment Technologies for Different Climatic and Various Terrain Conditions

The problem of water treatment in extreme and different climates, high altitudes& difficult terrains are similar to many other engineering problems in those areas. The major problem is the extreme temperature which varies between (+) 50° C to (-) 40° C. Problems with transportation of equipment, construction and pipe materials are also there. Behaviour of materials becomes different in extreme climatic conditions. Materials tend to become brittle in extreme cold. The problem of extreme cold combined with lack of oxygen due to height exists in the Himalayas. There is a large variation in atmospheric pressure, which is very low at high altitudes.

10.16.1 Effect of Low Temperature

(a) **Physical:** At 4° C water is at its maximum density. It is in a more closely packed condition than at any other temperature. If a given quantity of water is heated from 4° C to say 100° C it will expand approximately to one-twenty-fourth of its volume. If the temperature of the same water is lowered, it will contract until it reaches a temperature of 4° C. Further reduction in temperature will result in the expansion of the sample of water and at 0° C it will solidify and turn to ice having expanded approximately one-twelfth of its volume. This is the reason why bursts in pipes take place by the expansion of water as it changes to ice.

The viscosity of water increases with falling temperature. Greater resistance is offered to the settling of particles in water. Waters at low temperatures are capable of carrying a greater load of suspended materials than is carried in tropical regions. Settling velocities decrease with temperature. It takes almost twice as much time for particles to settle at 4° C as it does for them to settle at 23.3° C which is very important in the design of sedimentation tanks.

(b) **Chemical:** In general, most chemicals react much slower at a temperature near freezing than they do at normal temperatures. Consequently, a longer reaction time is required for satisfactory performance in the treatment units. Coagulation, precipitation, oxidation, water softening reactions, solubility, etc. all are affected due to low temperature.

The chlorination process also poses difficulty at low temperatures. At temperatures between 1.1° C and 10.55° C, solid chlorine hydrate is formed by removing the chlorine from the solution. There is practically no chlorine at 0° C. Gaseous chlorine cylinders are heated up for chlorine apparatus to work properly.

10.16.2 Effect of High Altitude

Low Barometric Pressure: Low barometric pressure limits the pump suction head. To summarise, the effect of low temperature is to retard biological and chemical reactions and make the physical state of fluids, solids, and other materials appreciably different. Because low temperatures change most of the warm weather characteristics of water, the conventional methods of water collection, treatment, and distribution need modification for use in low-temperature regions.

10.16.3 Cold deserts

Cold deserts are primarily located in high altitudes in the Himalayan region of Arunachal Pradesh, Ladakh, Himachal Pradesh, Uttarakhand, etc. The primary source of water in these areas is Glacial melt, which is being impacted because of climate change. Further, the water gets frozen in the pipelines during winters disrupting the water supply. Solutions to improve and store run-off water in small tanks - a conventional water harvesting structure, i.e., zing - may be investigated. Furthermore, artificial glacial reservoirs can be built by redirecting run-off and allowing it to freeze and store as a glacier. During early spring, it will serve as both drinking water and irrigation source. Promoting the use of micro-irrigation can reduce the irrigation requirement and increase the drinking water security.

10.16.4 Hilly areas

In hilly areas, especially at higher altitudes, it is uneconomical to pump water from the valley for a very small number of houses. In these places, adopting spring-based sources, rainwater harvesting and standalone bore-well systems (if feasible) will be economical. Spring-based systems would require careful identification and delineation of springsheds, locating the aquifers contributing water to springs, and injection recharging them for sustaining them. Communities may be encouraged to adopt the traditional wisdom of rainwater harvesting (like bamboo-based ones in the NE States) for water security. In such areas, there is a need to focus on WQM&S.

10.16.5 Coastal areas

In coastal areas, augmentation of services can be done with energy-efficient small desalination plants with a high recovery ratio. Further, to avoid the ingress of sea water, sub-surface dykes can be constructed in rivers that can also improve the groundwater-based drinking water sources in the adjoining areas.

10.17 Emerging Contaminants

Chemicals that had not before been detected in the water supply are occasionally discovered. These chemicals are known as "emerging contaminants." Emerging contaminants (ECs) are significant because the dangers they pose to human health and the environment are not completely understood.

Because these contaminants were introduced or detected relatively recently, there is a knowledge gap in their fate, behaviours, and impacts, as well as treatment strategies for their efficient removal. Furthermore, despite the advances in treatment technologies, the design of existing treatment plants is not suited to remove these ECs. They may be industrial in origin or may originate from municipal (domestic), agricultural, hospital, or laboratory wastewater.

Pharmaceuticals and Personal Care Products (PPCPs) are increasingly being detected at low levels in surface water, and these compounds may be present inadvertently in various compartments of the aquatic environment (e.g., water, sediments, and biota) at concentrations capable of causing detrimental effects to aquatic organisms and their inherent ability to induce physiological effects in humans at low doses. This has become a major concern due to the widespread and rising use of PPCPs in human and veterinary medicine, resulting in their ongoing release into the environment (Figure10.35).The substances in question come from three broad categories: pharmaceuticals (PHACs), personal care products (PCPs), and endocrine disrupting compounds (EDCs). Up to 90% of all oral medications pass through the human body and end up in the water. Personal care goods (soaps, cosmetics, scents, and so on) also end up in our water. Endocrine disruptors are substances that can interfere with hormone function in the body. Trace quantities of these pollutants have been found in water in several nations. However, they are not limited to the above and may include nanomaterials (NMs), EC metabolites, illegal medications, and so forth.

PHACs are a class of emerging environmental pollutants that are increasingly being used in human and veterinary medicine. Antibiotics, legal and illegal pharmaceuticals, and other substances of environmental importance are among them.

PCPs are a new class of developing contaminants that include both prescribed and non-prescribed veterinary and human medications, as well as agile and inert components used for individual treatment. Cosmetics, tailored hormones, steroids, fragrances, shampoos, and other PCPs are examples.

EDCs are characterized as artificial chemicals that, when ingested into the body can either copy or obstruct hormones and affect the body's normal functioning.

ECs are generally not monitored in our environment and they are not regulated in our drinking water. The lack of pertinent data on the effects, fate, and concentration levels of developing toxins makes it difficult for governments to limit their use while also managing the amounts that are currently present in the environment.

Municipal wastewater is regarded as one of the primary discharge sources for the developing contaminants such as non-point and point sources, industry and stormwater, home wastewater, and water treatment facilities into the environment. Also, there is a growing concern about sludge management due to the high levels of ECs in them. The current design of WWTPs cannot remove the developing pollutants and their metabolites where they are released as sewage effluents into rivers or streams with high biodiversity. So far, considerable work has been done regarding the performance of wastewater technologies in the case of nutrient removal, while there is an absence of data on the ability to the removal of ECs, and additionally on the adverse eco-toxicological impacts of these compounds on surface water bodies.

Pharmaceutical compounds found in wastewater are from many groups of human and veterinary antibiotics, human prescription and non-prescription medications, and certain steroids and hormones. Personal care products (PCPs) include chemicals found in consumer products (e.g.,galaxolide, tonalide). Endocrine disrupting compounds (EDCs) can elicit adverse effects on endocrine systems as they have androgenic or estrogenic activities even at low concentrations. Concerns about the existence of these emerging pollutants in the environment include aberrant physiological processes and reproductive damage, higher cancer occurrences, the development of antibiotic-resistant microorganisms, and the possible enhanced toxicity of chemical combinations.

Thus, the presence of developing pollutants at trace levels in used waters, as well as their behaviour during wastewater treatment and drinking water production, are critical topics that need to be investigated further.

Per- and polyfluorinated alkyl substances (PFAS) are a class of nearly 4,000 man-made chemicals that have lately emerged as emerging pollutants with substantial deleterious effects on human health, even at low concentrations in the parts per trillion range. Nonstick cookware, upholstered furniture, clothing, food packaging, and firefighting foam used to extinguish petroleum fires are all products that contain PFAS. These compounds do not occur naturally in nature. They do not degrade readily and are exceedingly persistent in the environment, particularly in water, as well as in the human body. PFAS has been linked to health risks including developmental effects in fetuses and infants, various forms of cancer, and decreased liver, thyroid, and immune system function.

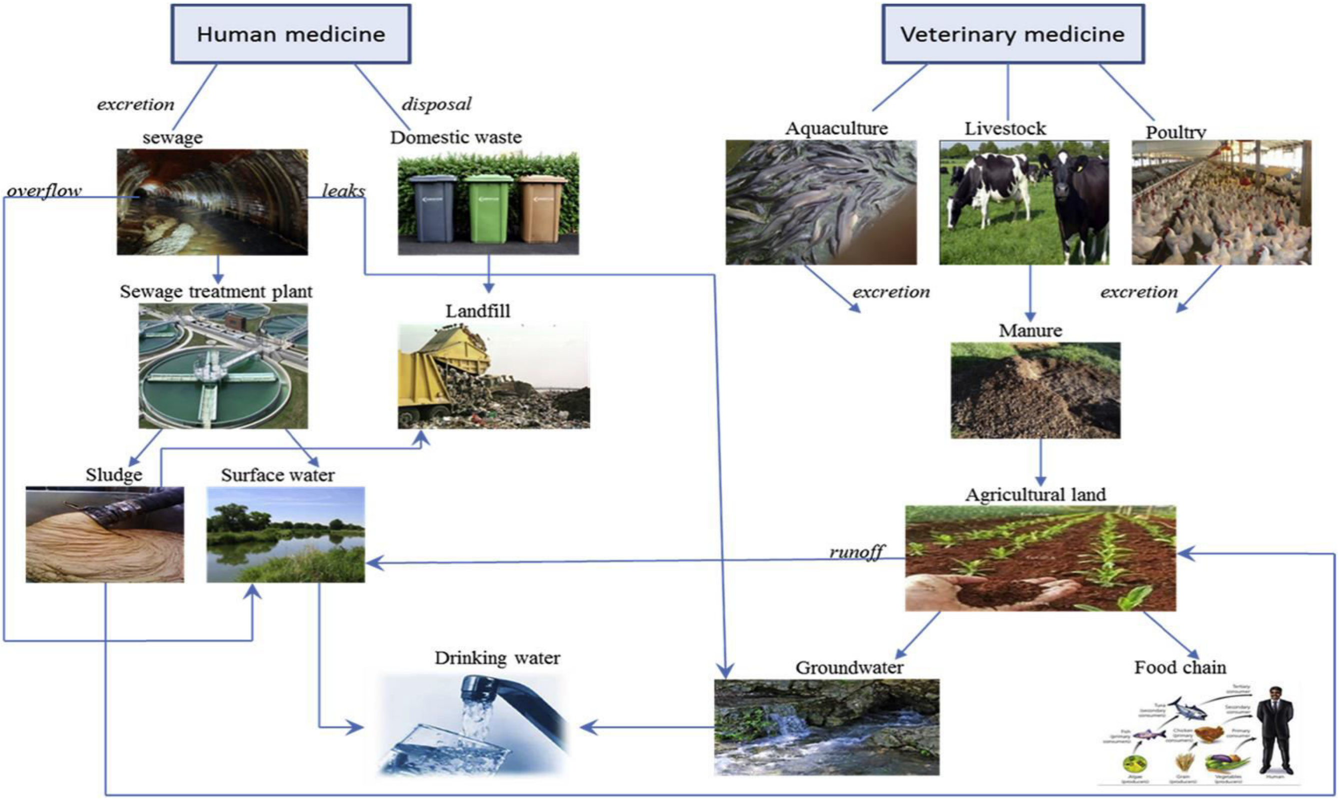


Figure 10.35: Sources of PPCP

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APPENDIX 10.1: Computation of Chemical Dosages in Water Softening Treatment Process Using Lime Soda Process

1. Problem Statement

The water with the following chemical constituents is to be softened using Lime Soda Process. Compute the quantities of chemicals required to treat 250 m^3/hr of water flow assuming practical units of removal for $CaCO_3$ to be 30 mg/L and for $Mg(OH)_2$ as 10 mg/1.

CO_2	= 10.9 mg/L	Alkalinity (CO_2)	= 175 mg/L
Ca^{++}	= 100 mg/L	SO_4^{2-}	= 107 mg/L
Mg^{++}	= 8.9 mg/L	Cl^-	= 17.8 mg/L
Na^+	= 11.5 mg/L		

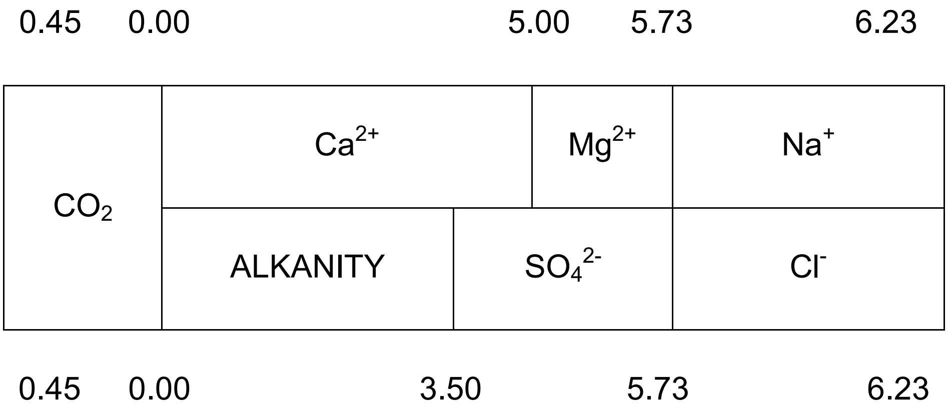
2. Solution

a) Compute mg/L of all components present in water.

S. No.	Component	Concentration mg/L	Equivalent Weight	Conc. me/l
1	CO_2	10.9	22.0	0.45
2	Ca^{+2}	100.0	20.0	5.00
3	Mg^{+2}	8.9	12.3	0.73
4	Na^+	1.5	23.0	0.50
5	Alkalinity	175.0	50.0	3.50
6	SO_4^{2-}	107.0	48.0	2.23
7	Cl^-	17.8	35.5	0.50

b) Prepare an mg/L bar graph of raw water with a hypothetical combination.

In preparing such a bar graph, the concentration of cations is usually arranged left to right starting with Ca^{2+} followed by. Mg^{2+}, $Na^{+,}$ etc. in that order. Similarly, below the cations, anions are arranged left to right commencing with alkalinity followed by SO_4^{2-}, Cl^- etc. The CO_2 being a molecule is conventionally shown to the left of the zero mark.



Graph

3. Compute the quantities of chemicals required.

a) Chemical reactions:

$CO_2 + Ca(OH)_2 \rightleftharpoons CaCO_3 + H_2O$ (1)
$Ca(HCO_3)_2 + Ca(OH)_2 \rightleftharpoons 2CaCO_3 + 2H_2O$ (2)
$MgSO_4 + Ca(OH)_2 \rightleftharpoons Mg(OH)_2 + CaSO_4$ (3)
$CaSO_4 + Na_2CO_3 \rightleftharpoons CaCO_3 + Na_2SO_4$ (4)

It may be noted that it is necessary to add excess lime, usually, a surplus of 35 mg/L as CaO or 1.25 mg/L above the stoichiometric requirement, to raise the pH for precipitation of Magnesium by reaction at (3)

No.	Components	Conc. me/l	Lime required me/l	Soda ash required me/l	Remarks

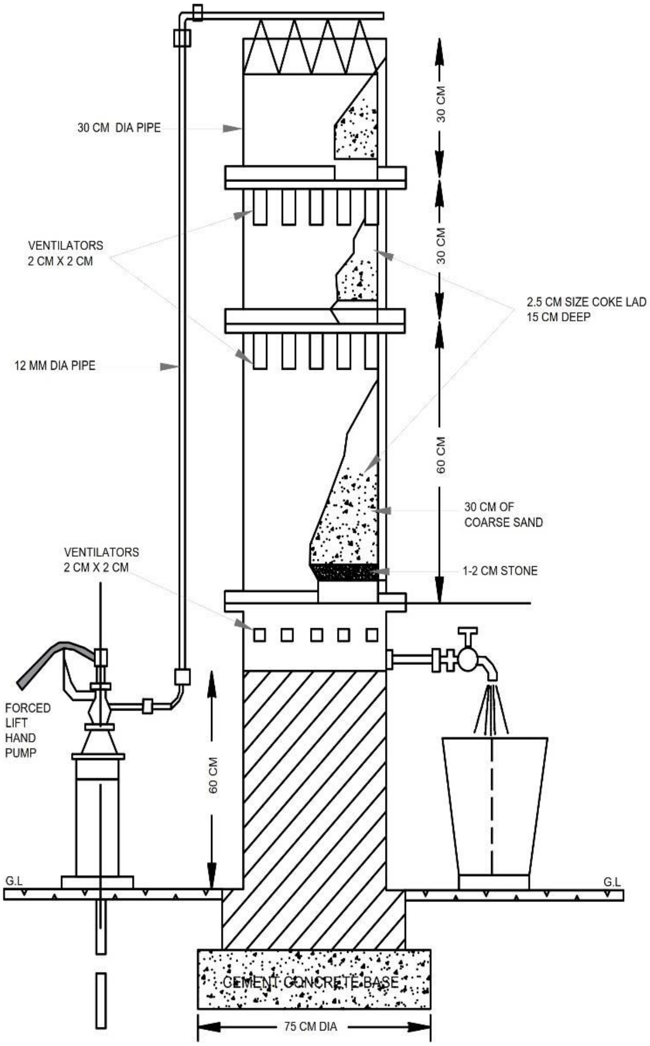
1	CO_2	0.45	0.45	-	Reaction (1)
2	$Ca(HCO_3)_2$	3.50	3.5	-	Reaction (2)
3	$CaSO_4$	1.50	-	1.5	Reaction (4)
4	$MgSO_4$	0.73	0.73	0.73	Reaction (3) & (4)
			4.68	2.23	

Lime required = Stoichiometric quantities + excess lime
= 4.68 + 1.25 = 5.93 mg/L
= 166.04 mg /l as CaO
= 2110.41 mg/L as $Ca(OH)_2$
Soda Ash required = 2.23 mg/L.
= 118.19 mg/L as Na_2C0_3

Annual consumption of lime as CaO
= $(166.04 \times 250 \times 24 \times 10^3 \times 365) / (10^6 \times 10^3)$
= **363.63** metric tons

Annual consumption of Soda ash as Na_2C0_3
= $(118.19 \times 250 \times 24 \times 10^3 \times 365) /(10^6 \times 10^3)$
= 258.84 metric tons

Appendix 10.2



TYPE DESIGN OF IRON REMOVAL PLANT

(CAPABLE OF GIVING 200 LITRES PER HOUR)

APPENDIX 10.3: Design of Iron Removal Units

Typical designs of iron removal units for 5,10 and 20 m^3 /h flow.

DESIGN CONSIDERATIONS

- Schemes have been designed for 5, 10, and 20 m^3/h flow and 10% extra water quantity to provide for sedimentation bleed losses and filter backwash requirements.
- Power shut-downs are frequent and rarely more than two hours of supply is available in the morning and evening. Accordingly, raw water pumping hours are assumed to be 2 hours in the morning and two hours in the evening. During these four hours pumping period, the total daily requirements of water are to be pumped to an elevated storage tank to draw water by gravity flow to the treatment units).
- To avoid extra cost for an additional overhead tank for filtered water, it is assumed that the filtered water from the sumpwell will be directly pumped for the distribution. The distribution of treated water would follow the same time schedule as contemplated for pumping raw water.
- Backwashing of the sand filter would be carried out by using raw water from the overhead tank.

DESIGN CRITERIA

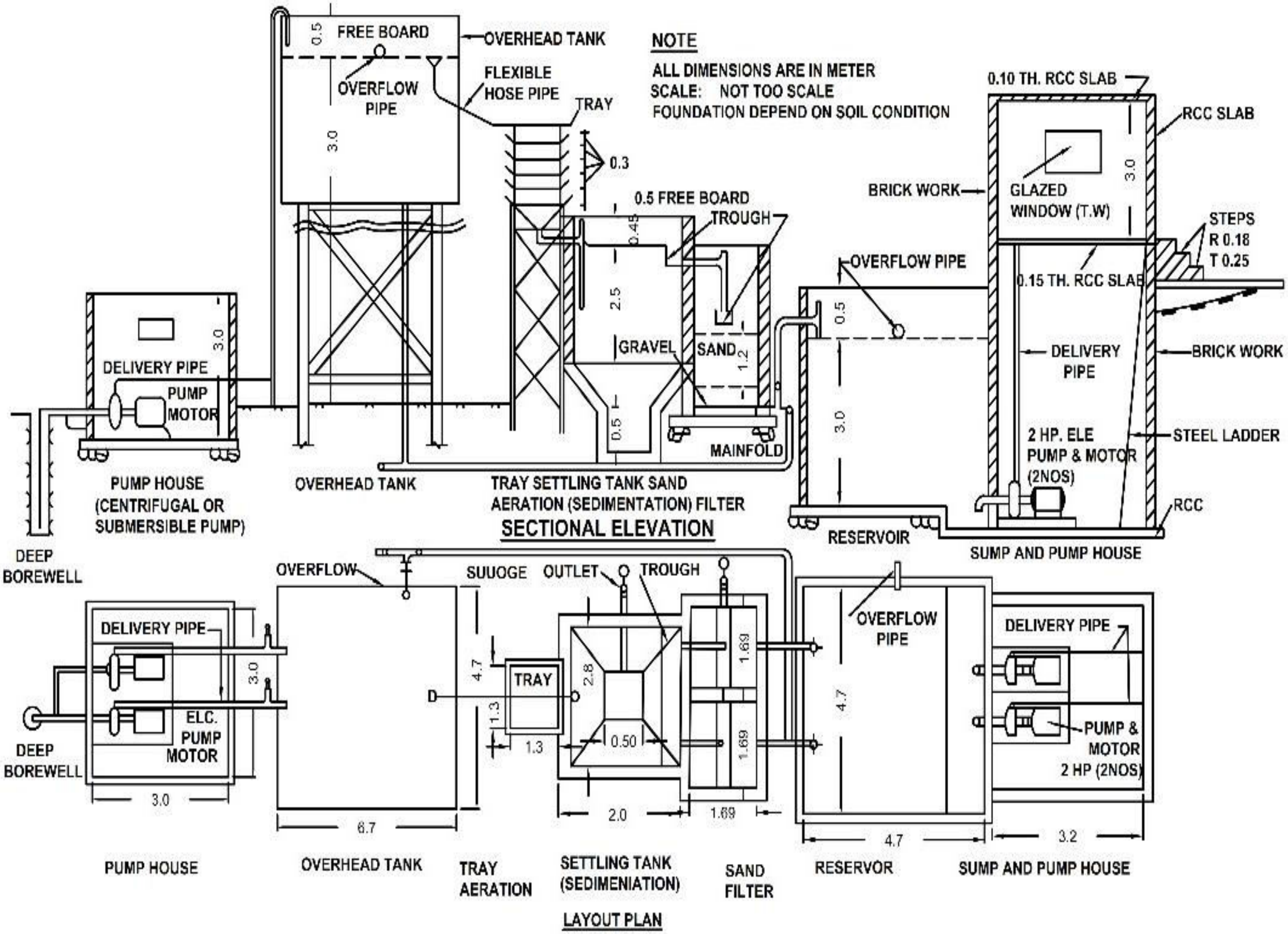
• Water consumption	40 lpcd
• Tray aerator	
Spacing of Trays	0.3 m
Aeration Rate	1.26 $m^3/m^2/h$
• Sedimentation Basin	
Detention Period	2.5 h
• Sand Filter	
Effective Size	0.6 - 0.8 mm
Uniformity Coefficient	1.3 to 1.7
Sand Depth	1.2 m
Total head above sand	1.35 m
Rate of Filtration	4.88 $m^3/m^2/h$
Minimum Backwash Rate	35 $m^3/m^2/h$
Total Head for Filter Wash	12 m
Gravel Depth	0.39 - 0.62 m

Gravel Size

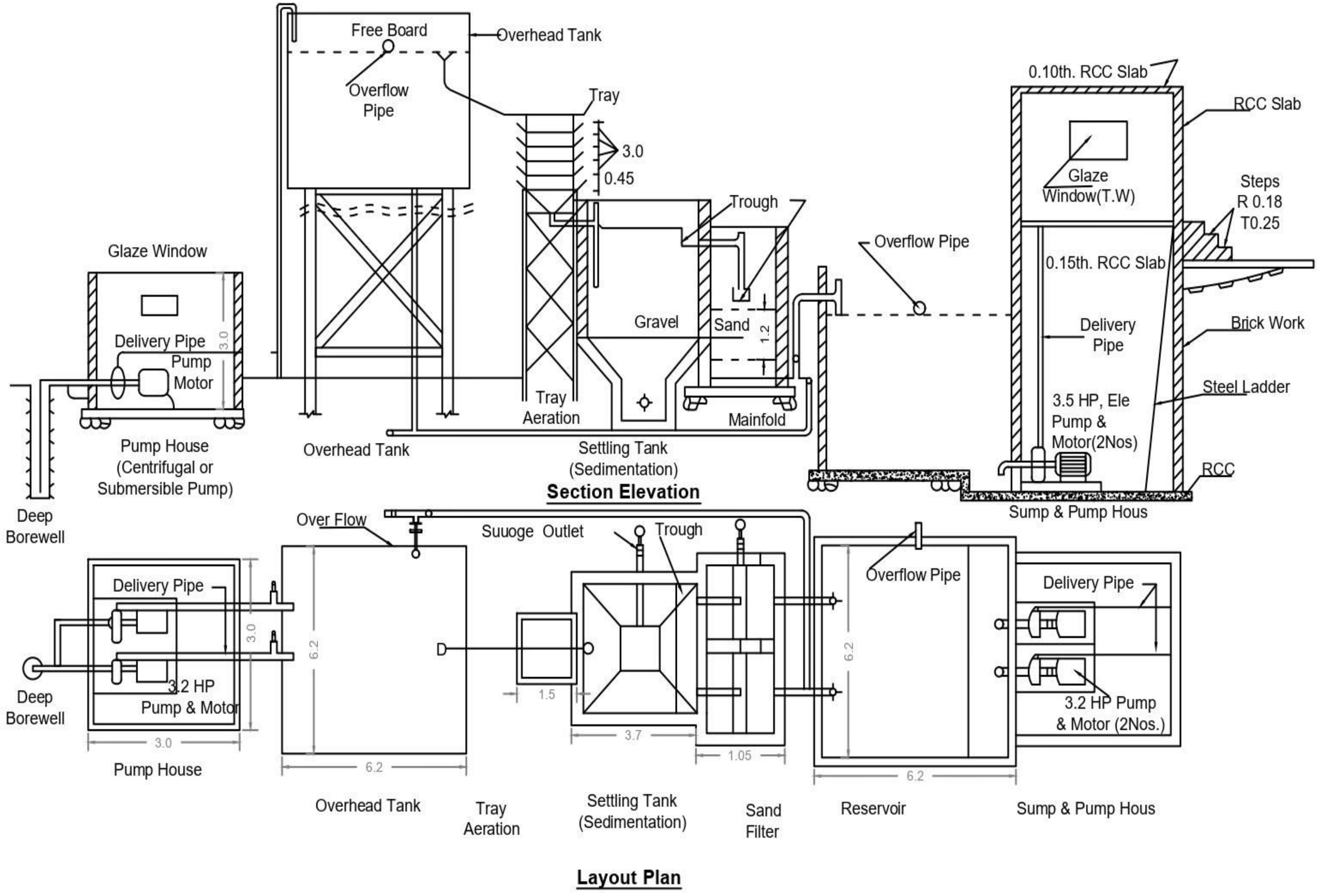
65 - 38 mm	13-20 cm
38 - 20 mm	8-13 cm
20 - 12 mm	8-13 cm
12 - 5 mm	5- 8 cm
5 - 2mm	5- 8 cm

Specifications of units are detailed in the following Table and the arrangements are as shown in:

Design Specifications for Continuous Iron Removal Unit for Community Water Supply			
Design Capacity, m^3/h	5	10	20
Raw water Pump, hp	2.0, 2 Nos.	3.4, 2 Nos.	7, 2 Nos.
Overhead Reservoir			
Capacity, m^3	66	132	264
Size	4.7m x 4.7m x 3m	6.2m x 6.2m x 3.5m	8.7m x 8.7m x 3.5m
Tray Aerators			
No. of Trays	4	5	6
Collection Trough	1	1	1
Tray Size	1.3m x 1.3m	1.6m x 1.6m	2.1m x 2.1m
Height of each Tray	0.3m	0.3m	0.3m
Sedimentation Tank			
Size	2.9m x 2.9m x 2.5m	3.7m x 3.7m x 3m	5.25m x 5.25m x 3m
Sand Filter			
Size	1.69m x 1.69m	1.85m x 1.85m, 2 Nos	2.6m x 2.6m, 2 Nos
Clear Water Storage Tank	4.7m x 4.7m x 3m	6.2m x 6.2m x 3.5m	8.7m x 8.7m x 3.5m

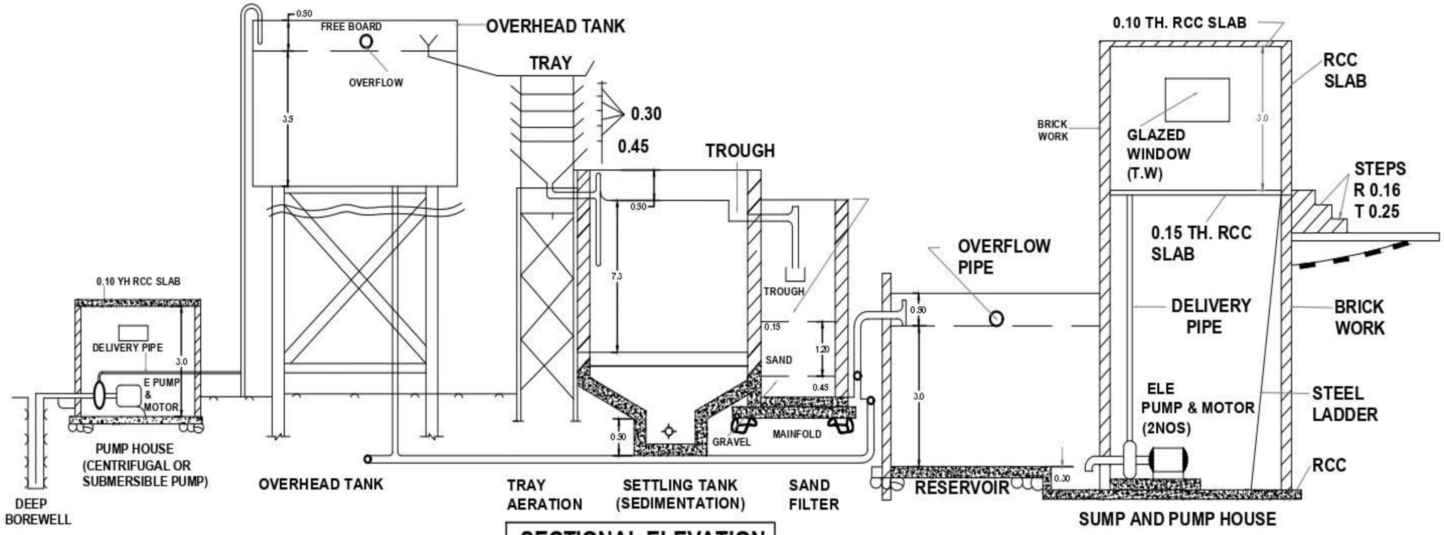


CONTINUOUS IRON REMOVAL FOR COMMUNITY WATER SUPPLY CAPACITY 5 m^3\h

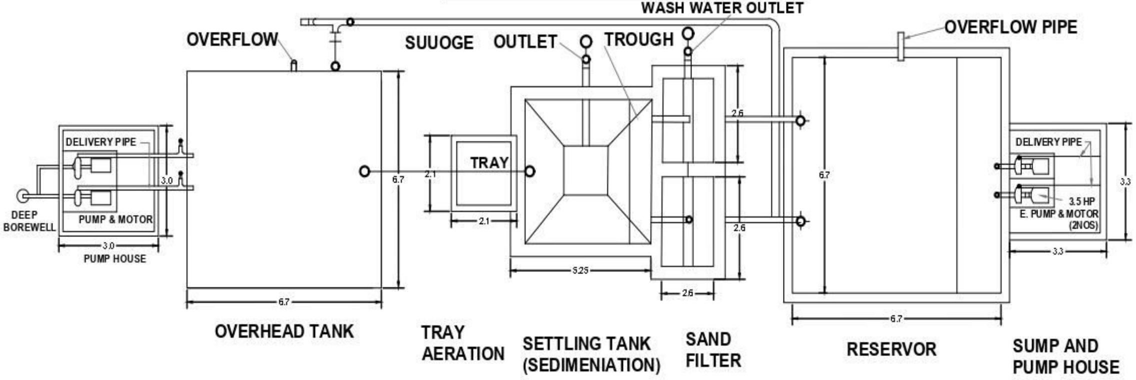


CONTINUOUS IRON REMOVAL FOR COMMUNITY WATER SUPPLY CAPACITY 10M³\h

Note:-All Dimension are in Meter
Not to Scale



SECTIONAL ELEVATION



LAYOUT PLAN

CONTINUOUS IRON REMOVAL FOR COMMUNITY WATER SUPPLY CAPACITY 20 m^3\h

NOTE
ALL DIMENSIONS ARE IN METER
SCALE: NOT TOO SCALE
FOUNDATION DEPEND ON SOIL CONDITION

ANNEXURE 10.4: Case Study on SWRO Plant of Nirma Industries, Bhavnagar, Gujarat (manufacturers of washing powder)

The SWRO plant of Nirma Industries receives raw seawater from a bi-directional creek on the Gulf of Khambat. Phase-1 of the plant completed in the year 2000 had an output capacity of seawater RO as 450 cum/hr. (11 MLD).This was then one of the largest SWRO plants in India. As reported the produced water cost was then Rs.45 to Rs.50 per cum. The treated water is supplied (pumped) to industrial applications and drinking water supply. The plant was designed and supplied by M/s Thermax Ltd. Seawater has TDS in the range of 40,000-42,000 mg/L. The seawater is pumped from a shore Intake well and is then conveyed through a series of storage lagoons. The TSS throughout the year is less than 20-25 mg/L. However, the raw water picks up organics and algae while passing through the lagoons. The raw water is received at the plant after passing through “a once through heat exchanger”. The temp of raw water varies from 38 to 42°C.

To produce 11 MLD of treated water, 25 MLD of raw seawater is required to be pumped into the pre-treatment system. The pre-treatment plant consists of a Rapid Mix Weir, and Mixing Channel. Flocculators and multiple hopper bottom tube settlers. Pre-Chlorination is done at the Inlet Chamber. Ferric Chloride ($FeCl_3$) and anionic polymer are dosed as a coagulant and coagulant-aid respectively. The TSS of treated clarified water ranges from 2-5 mg/L. There are two parallel streams of Clarifiers preceded by flocculators. Tubes are made of Rigid PVC, with size 50mm x 50mm and 600mm in length. The clarified water is stored in an over-ground reservoir.

The clarified water is then pumped through pressure sand filters followed by dual media filters (two-stage filtration). The rate of filtration for pressure sand filters is 7500 Lph/sqm and that for dual media filtration is 12,000 Lph/sqm. After cartridge filters, the SDI is reported to be 2 to 3. By the combination of dosing of Chlorine and polishing off of all the suspended matter by clarification and two-stage filtrations, the feed water quality to RO (TSS, Turbidity, and organics) is almost BDL (below detection level) level. The RO feed water is then injected with Sodium-Meta-Bisulphite for de-chlorination.

High-pressure pumps (60 bar) convey the water to RO skids. The total recovery rate is 40%. The RO treated water TDS is reduced to a range of 400-500 mg/L. The waste, RO reject (highly concentrated salt solution) is used as raw material in the industry. The plant is well designed including pipe and cable routing. It has a sound layout from a process, Operation and maintenance logistics point of view. The plant is automated and manpower is trained and skilled. Since the plant performance was found to be satisfactory, the Nirma Industries expanded the capacity further by 450 cum/hr. (11 MLD) in the year 2006 as Phase-2. The plant is working well when last reported.

Figure: Two stage Pressure Filtration and High-Pressure Pumps and RO Skids