

9.6.1 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 surface waters occasionally. Iron and Manganese are 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 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 very sparingly soluble.

Iron forms complexes of hydroxides and other inorganic complexes in solution with substantial amounts of bicarbonate, sulphate, phosphate, cyanide, or halides. 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 determination of organic iron or manganese.

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

9.6.2 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. Use of zeolites as well as catalytic oxidation also serve the purpose.

9.6.2.1 Precipitation

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 ferrous iron to ferric hydroxide as indicated below.



$$1 \text{ mg Fe}^{2+} \equiv 0.14 \text{ mg O}_2$$

The rate of oxidation of ferrous iron by aeration is slow under conditions of low pH, increasing 100% for every unit rise of pH. Increased aeration time would be necessary for stripping the carbon dioxide, hydrogen sulphide etc. 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 which accelerate the oxidation of iron.

The contact beds for deferrisation are normally 2 to 3 m deep operating at a surface loading of 40 to 70 m³/d/m² 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 75 cm depth of sand or sand and anthracite. Filter rates are usually of 6 to 9 m³/h/m².

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

By 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. 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 washing varies and depends on the initial turbidity and iron content. Experience indicates a closer interval of one week for turbidity around 40 mg/l and 1-2 months for waters with low turbidities (less than 10 mg/l). Washing of filter medium involves removal of top 5 to 10 cms 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 at the high pH value reached in municipal softening plants using lime.

Manganese removal requires a pH adjustment upto 9.4 to 9.6. 0.29 mg of oxygen is needed to convert 1 mg manganese





Prechlorination to free residual values upto 0.7 to 1.0 mg/l will effect the oxidation and precipitation of manganese.

9.6.2.2 Contact Beds

The purpose of contact beds is to facilitate 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 9.6 m/h is preferred, but a lower rate may be used. 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 led -aerator constructed to facilitate 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 about 1.63 kg manganese per cubic meter of zeolite per cycle. Re-oxidation or regeneration of all material in each cycle is secured 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, a water with a content of 1 mg/l manganese will contain 1 kg/m³. Then a contact bed with a volume of say, 4 m³ would treat 4 x 1.63 x 1.0 = 6.52 m³ 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: $(3.26/10) \times 4 = 1.3$.

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

9.6.2.3 Zeolite

The method is applicable if the iron is present in the reduced state and in a soluble form in the 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 10 mg/l of iron or manganese.

The process consists of 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 deposition of colloidal oxides on the ion exchange material. Therefore, air lifts, open tanks or pneumatic tanks should not be used preceding the ion exchanger. If the water is to be softened also, then the zeolite process offers a very simple method of iron and manganese removal as it can be carried out under pressure and therefore usually obviates the necessity for double pumping such as is required in most other processes. In fact, 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 salt solution.

9.6.2.4 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 the 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 for the rather smaller plants, it may be used with waters containing upto 10 mg/l 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 $21 \text{ m}^3/\text{h}/\text{m}^2$. When the bed loses its capacity for oxidation of iron and manganese, it can be regenerated by treatment with potassium permanganate solution.

9.6.3 SIMPLE TECHNIQUES FOR IRON REMOVAL IN RURAL AREAS FOR 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 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 rural water supply scheme to treat raw water containing free carbon dioxide and dissolved iron, the units include, hand-pumps, tray-aerators, sedimentation basin 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 hand pump is used, a tray type aerator with two trays operated at an aeration rate of $1.26 \text{ m}^3/\text{m}^2/\text{hr}$ 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 and its uniformity coefficient 2-3. Sand is cleaned by manual scraping. Provision could also be made for adding sodium carbonate wherever essential. Reference may be made to the type design for iron removal plant given in Appendix 9.2

9.6.3.1 Package Iron Removal Plants For Hand Pump

NEERI has designed package iron removal plants having different capacities of $0.5 \text{ m}^3/\text{hr}$, $1.0 \text{ m}^3/\text{hr}$, $1.5 \text{ m}^3/\text{hr}$ and $2 \text{ m}^3/\text{hr}$ depending upon requirement of treated water and discharge of hand pump. The plants are designed in rectangular/circular shapes having aeration chamber, collection chamber, settling chamber and filter. The settling chamber is provided with plate settling device to enhance settling and reduce the detention time thereby reducing the dimension of settling chamber. The aeration chamber contains media of size 2.0-5.0 cm gravel/ stone chips to increase the surface area of air-water interface. The iron contaminated water trickles over aeration media through spraying device. The aerated water flows through pores over baffle plate to collection chamber to settling chamber to filter. The filter bed of 20 cm depth contains sand media of size 0.8-1.4 mm, supported by 5 cm depth gravel of size 0.8-1.0 cm. The treated water is taken out from tap attached to it. The sedimentation chamber having a detention period of one hour and is provided with two plate settlers at 45° angles as shown in drawing of $1 \text{ m}^3/\text{hr}$ plant (Fig. 9.1). The filter is cleaned by making backwash connection with hand pump, scraping sand bed manually and opening the sludge scouring valve. The hand pump is operated with possible high speed till clean water has accumulated over the sand bed.

9.6.4 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 corrosions of mains and pipes. The means by which iron, free carbon dioxide and other toxic substances are removed from water in community systems consists 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 addition of lime. The community water supply scheme makes provision to meet these requirements and comprises raw water storage tank, cascade tray aerators, chemical dosers, sedimentation basin, filtration and disinfection.

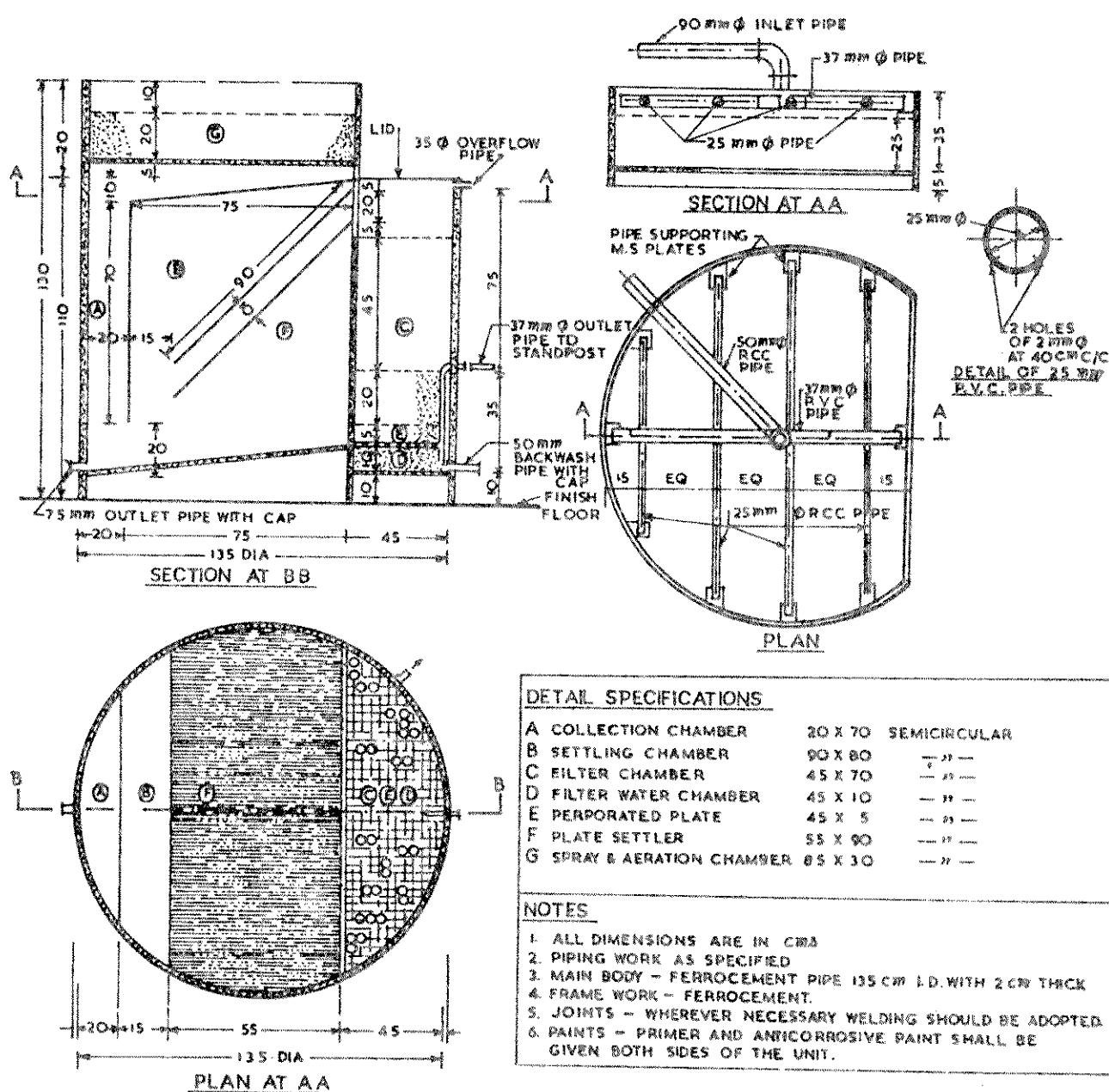


FIG. 9.1 IRON REMOVAL PLANT FOR 1 M³/HY

Tray aerators are commonly used for aerating water. The trays are designed for an aeration rate of $1.26 \text{ m}^3/\text{m}^2/\text{hr}$ 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 sand is 1.35 m and the rate of filtration $5 \text{ m}^3/\text{m}^2/\text{h}$. The minimum backwash rate is $35 \text{ m}^3/\text{m}^2/\text{h}$ and the total head required for filter wash is 12 m.

Type designs for iron removal plants for 5, 10 and $15 \text{ m}^3/\text{hr}$ of flow are given in Appendix 9.3 along with drawings.

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

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

Power shut-downs are frequent and rarely more than two hours supply is available in the morning and evening in rural areas. Hence 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 additional over-head 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 time schedule as for pumping raw water. Backwashing of the sand filter would be carried out by using raw water from the overhead tank.

9.7 DEFLUORIDATION OF WATER

Excessive fluorides 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 increases when the fluoride levels exceed 1.0 mg/l . With higher levels, skeletal or bone fluorosis with its crippling effects are 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 and Tamil Nadu in the country. While majority of values range from 1.5 to 6 mg/l some values as high as 16 to 18 mg/l and in one solitary instance, even 36 mg/l have been reported.

9.7.1 REMOVAL METHODS

The removal of excessive fluorides from public water supplies or individual water supplies is justifiable solely on public health grounds. This is a problem particularly in rural areas and hence the accent has to be on simplicity of operation, cheapness and applicability to small water supplies. The methods use fluoride exchangers like tricalcium phosphate or bone meal, anion exchangers, activated carbon, magnesium salts or aluminium salts.

9.7.1.1 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 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 a 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 capacity of 0.7 kg of fluoride/m³. The spent material is regenerated by treatment with 1% alkali solution and rinsed with dilute hydrochloric acid.

9.7.1.2 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.

9.7.1.3 Activated Carbon

Activated carbons have also been known to have the capacity for removal of fluorides. An activated carbon for fluoride removal has been developed in India by carbonising 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/m³ 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 replacement of two bed volumes. A flow rate of 4.8 m³/ m²/hr of bed area is adopted. The rinse water requirements after regeneration are 9-12 m³/ m²/hr for a maximum duration of 10 minutes. The medium has a life of three years.

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 down by 30% when hydroxyl alkalinity becomes 25 mg/l.

Treatment cost using Defluoron-2 varies from Rs. 1.0 to Rs. 5.0 per 1000 litres of water treated, depending upon the initial fluoride concentration and the alkalinity of water.

9.7.1.4 Magnesium Salts

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

$$\text{Fluoride reduction} = 7\% \text{ initial fluoride conc.} \times \sqrt{\text{magnesium removed}} \quad (9.1)$$

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

Magnesia and calcinated magnetite have also been used for removal of fluoride from water. The study established the following empirical relationships for amounts of MgO which are required to obtain 1 or 2 mg F/l in treated water.

- (a) MgO required to obtain 1 mg F/l in treated water ($F_0 > 2 \text{ mg F/l}$)

$$= 1.71(13.33) \left(1 - \frac{1}{F_0} \right)^2 + 160 \times \text{basicity of raw water (me/l)} \quad (9.2)$$

- (b) MgO required to obtain 2 mg F/l in treated water ($F_0 > 3 \text{ mg F/l}$)

$$= 1.71(13.33) \left(1 - \frac{1}{F_0} \right)^2 + 120 \times \text{basicity of raw water (me/l)} \quad (9.3)$$

F_0 represents 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.

9.7.1.5 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 extract of Avaram bark and formaldehyde when soaked in alum solution has been found to have good fluoride removal capacity (800 mg/kg).

Calcinated or activated alumina in granular form can be used for fluoride removal and the spent material regenerated with alkali, acid or by both alternately (removal efficiently 1.2 kg of fluoride/m³). A dilute solution of aluminium sulphate used as the regenerate for the spent material makes the alumina four times more efficient.

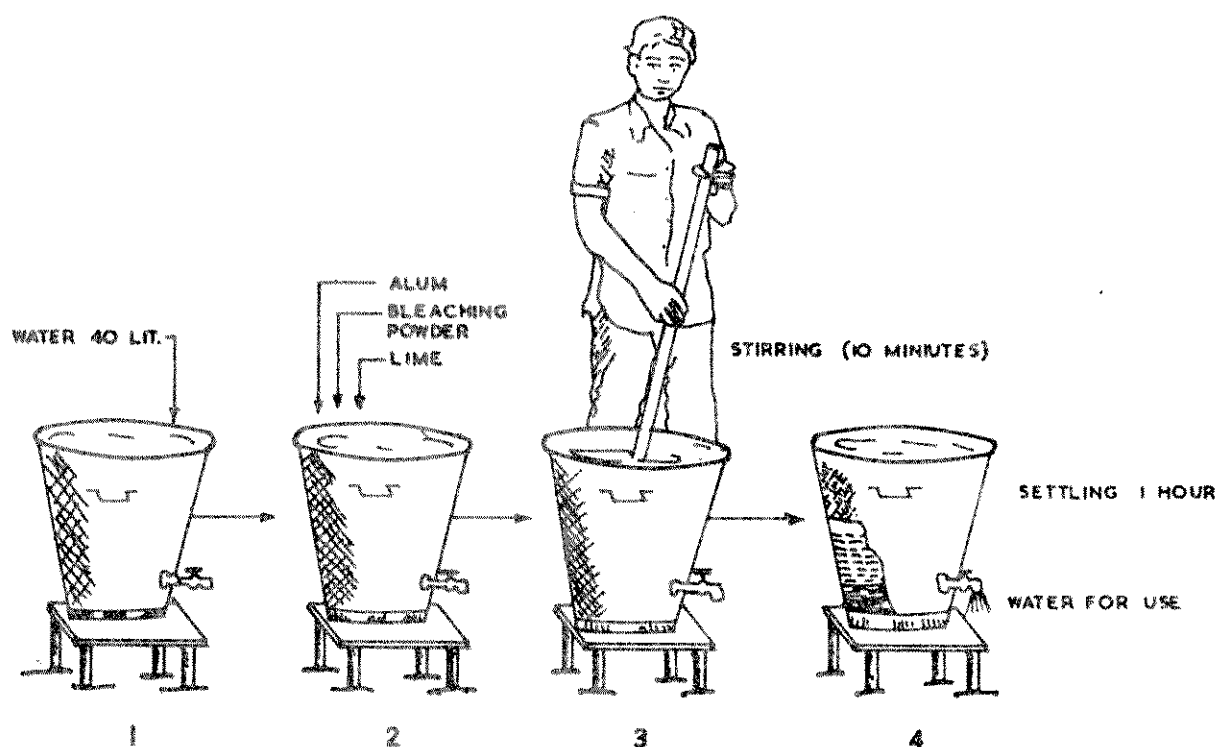


FIGURE 9.2: DEFLUORIDATION AT DOMESTIC LEVEL

9.7.2 SIMPLE METHOD OF DEFLUORIDATION

Defluoridation is achieved either by fixed bed media which could be regenerated or by the process of precipitation and formation of complexes. A simple method of defluoridation is employed in the Nalgonda Technique. It involves the use of aluminium salts for the removal of fluoride. The Nalgonda Technique employs either the sequence of precipitation, settling and filtration or precipitation, floatation and filtration and can be used for domestic as well as community water supply schemes.

(i) Domestic Treatment-Precipitation, Settling and Filtration

Treatment can be carried out in a container (bucket) of 40 l capacity with a tap 3-5 cm above the bottom of the container for the withdrawal of treated water after precipitation and settling (Fig. 9.2). The raw water taken in the container, is mixed with adequate amount of lime or sodium carbonate, bleaching powder and aluminium sulphate solution, depending upon its alkalinity and fluoride content. Lime or sodium carbonate solution is added first and mixed well with water.

Alum solution is then added and the water stirred slowly for 10 minutes and allowed to settle for nearly one hour. The supernatant which contains permissible amount of fluoride is withdrawn through the tap for consumption. The settled sludge is discarded. The amount of alum in ml to be added in 40 litres of water at various alkalinity and fluoride levels is given in Table 9.5.

TABLE 9.5

ALUM DOSE FOR DIFFERENT FLUORIDES AND ALKALINITY LEVELS

Test water Fluoride mg F/l	Test water Alkalinity, mg CaCO ₃ /l							
	125	200	300	400	500	600	800	1000
2	60	90	110	120	140	160	190	210
3	90	120	140	160	205	210	235	310
4		160	165	190	225	240	275	375
5			205	240	275	290	355	405
6			245	285	315	375	425	485
8					395	450	520	570
10							605	675

(ii) Fill and Draw Type for small community

This is also a batch method for communities upto 200 population. The plant comprises a hopper bottom cylindrical tank with a depth of 2 m equipped with a hand operated or power driven stirring mechanism (Fig. 9.3). Raw water is pumped or poured into the tank and the required amounts of bleaching powder, lime or sodium carbonate and alum added with stirring. The contents are stirred slowly for ten minute and allow to settle for two hours. The defluoridated supernatant water is withdrawn to be supplied through standposts and the settled sludge is discarded.

The notable features are:

- With a pump of adequate capacity the entire operation is completed in 2-3 hours and a number of batches of defluoridated water can be obtained in a day.
- The accessories needed are few and these are easily available (these include 16 l buckets for dissolving alum, preparation of lime slurry or sodium carbonate solution, bleaching powder and a weighing balance).
- The plant can be located in the open with precautions to cover the motor.
- Semi-skilled labour can perform the function independently.

(iii) Fill and draw type (electrically operated)

The Fill and Draw type vertical unit comprises cylindrical tank of 10 m³ capacity with dished bottom, inlet, outlet and sludge drain. The cylindrical tank will have sturdy railings, etc. Each tank is fitted with an agitator assembly consisting of (i) 5 HP drip proof electric motor; 3 phase; 50 Hz; 1440 RPM with 415 V $\pm 6\%$ voltage fluctuation, and (ii) gear box for 1440 RPM input speed with reduction ratio 60:1 to attain an output speed of 24 RPM,

complete with downward shift to hold the agitator paddles. The agitator is fixed to the bottom of the vessel by sturdy, suitable stainless steel supporting bushings.

The scheme comprises tanks of 10 m³ capacity each, a sump well and an overhead reservoir. Typical layout for system with two units in parallel for treating water for 1500 population at 40 lpcd is shown in Fig. 9.4. Raw water is pumped into the units and treated by Nalgonda Technique. The treated water collected in a sump is pumped to an overhead tank, from where the water is supplied through stand posts.

Approximate alum doses (mg/l) required to obtain permissible limit (1 mg F/l) of fluoride in water at various alkalinity and fluoride levels are given in Table 9.6.

TABLE 9.6
ALUM DOSE FOR DIFFERENT FLUORIDES AND ALKALINITY LEVELS

Test water Fluoride	Test water Alkalinity, mg CaCO ₃ /l							
mg F/l	125	200	300	400	500	600	800	1000
2	143	221	273	312	351	403	468	520
3	221	229	351	403	507	520	585	767
4		403	416	468	559	598	689	936
5			507	598	689	715	884	1010
6			611	715	780	936	1066	1209
8					988	1118	1300	1430
10							1508	1690

Note : *To be treated after increasing the alkalinity with lime or sodium carbonate.

(iv) Precipitation, Floatation and Filtration

Domestic treatment is achieved using a 100 l capacity batch type dissolved air floatation cell with hand operated pressure pump. The pump and cell form a compact dissolved air floatation defluoridation system.

Raw water in the cell is mixed with alkali and aluminium salts. A small quantity of air-water mix from the pressure pump is allowed into the cell. The precipitate with fluoride lifts to the top and floats. The treated water is collected in a bucket filtered through a sand filter. Using this cell, 100 l water is available for use in 20 minutes (Fig. 9.5.)

The same principle of floatation is extended to a 500 l capacity dissolved air floatation cell to obtain nearly 1 m³ treated water per hour for small communities.

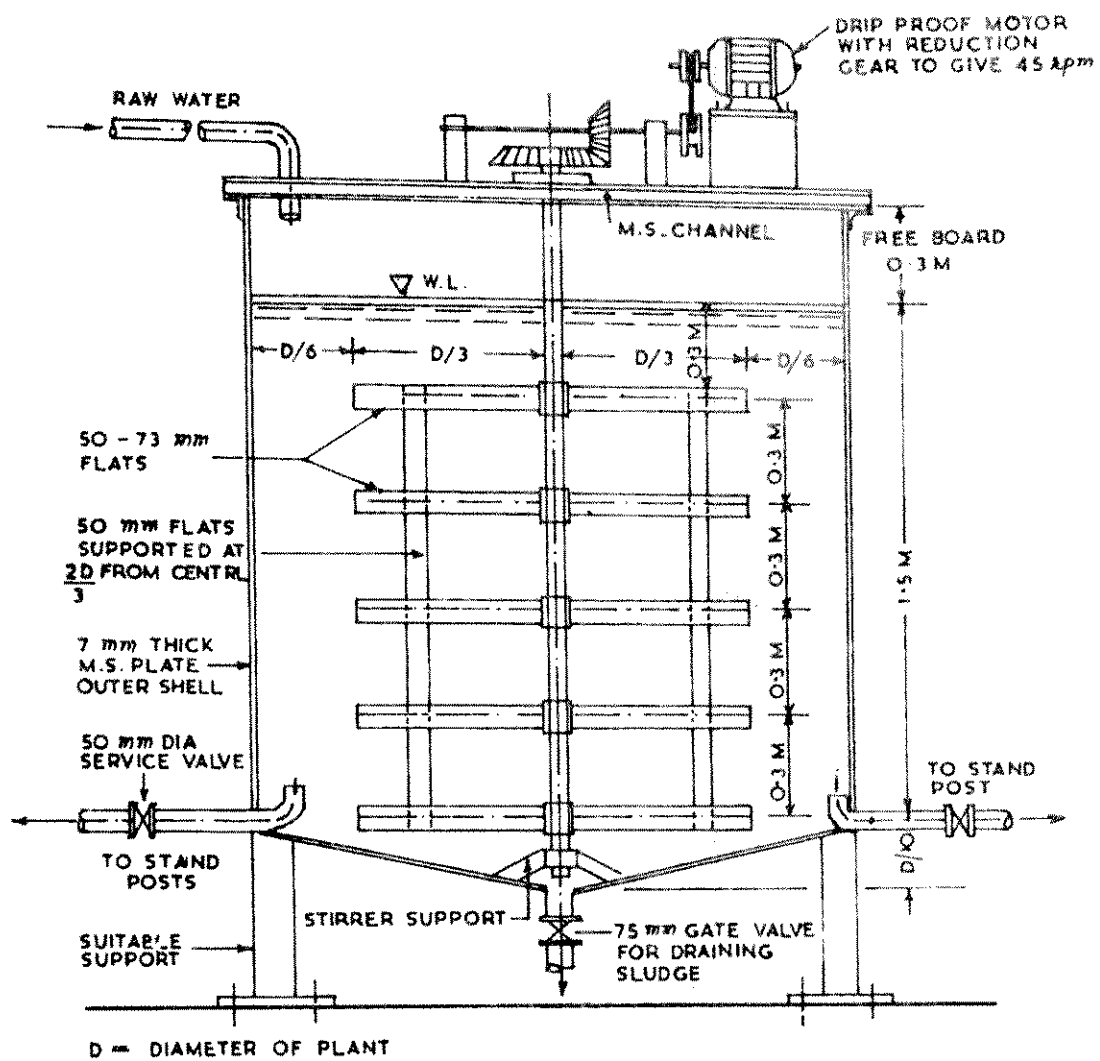


FIGURE 9.3: FILL AND DRAW TYPE DEFLUORIDATION PLANT FOR POPULATION UPTO 200 @ 40 lpcd

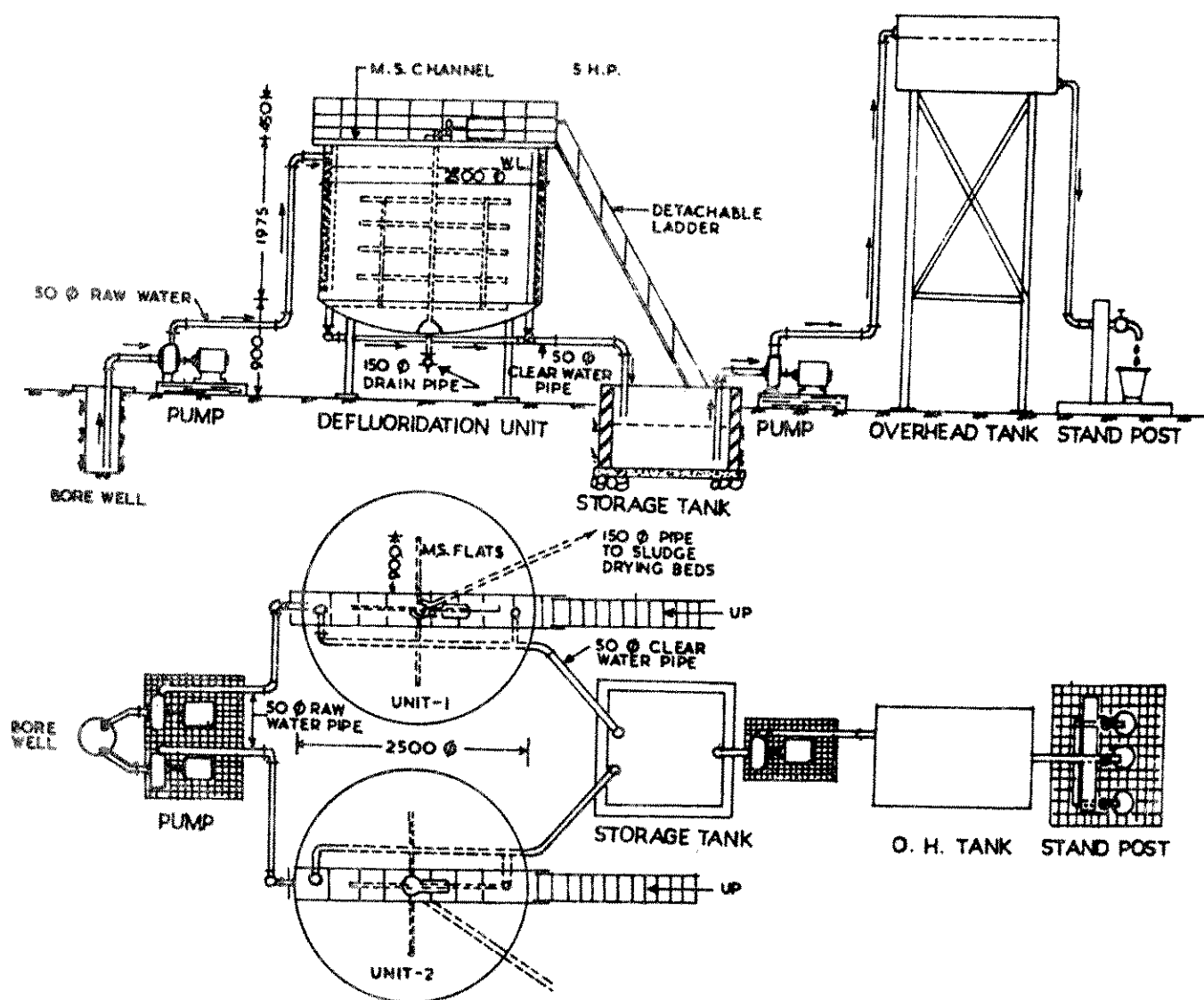


FIG. 9.4 FILL AND DRAW TYPE DEFLUORIDATION SYSTEM FOR RURAL WATER SUPPLY

9.7.2.1 Mechanism Of Defluoridation by Nalgond a Technique

The chemical reactions involving fluorides and aluminium species are complex. It is a combination of polyhydroxy aluminium species complexation with fluoride and their adsorption on polymeric alumino hydroxides flocs. Besides fluorides, turbidity, colour, odour, 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 insures 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.

9.7.2.2 Rural Water Supply Using Precipitation, Settling, Filtration
Scheme Of Nalgonda Technique-Continuous Operation

This scheme intends to treat the raw water for villages and includes channel mixer, pebble bed flocculation, sedimentation tank and constant rate sand filters. The designs of entire water facilities are available for 500, 1000, 2000 and 5000 populations. The scheme is gravity operated except the filling of the overhead tank and delivery from treated water sump. Channel mixer is provided for mixing lime slurry or sodium carbonate solution and aluminium salts with the raw water. Pebble bed flocculation is used in place of conventional flocculation in order to avoid the dependence on electric power supply. The scheme envisages power supply for 2 hours each during morning and evening for filling the over head tank and for supply of treated water. The basis of design of various units are given below:

(i)	Water consumption	70 lpcd
(ii)	Flash mixing-detention period, velocity to be maintained	30 secs.
(iii)	Pebble bed flocculator	
	detention period (considering 50 % voids)	30 minutes
	size of media	20-40mm
	depth of media	1.2m
	rate of backwash	0.5m/min
(iv)	Sedimentation	
	liquid depth	3m
	weir loading rate	< 300 m ³ /m/d
	surface overloading rate	< 20 m ³ / m ² /d
(v)	Sand gravity filter	
	depth of water over sand	2m
	rate of filtration	5 m ³ / m ² /h
	head required for backwashing filter	12m
	minimum backwash rate	36m/h
	gravel depth	0.45m
	effective size of sand	0.6mm to 0. 8mm

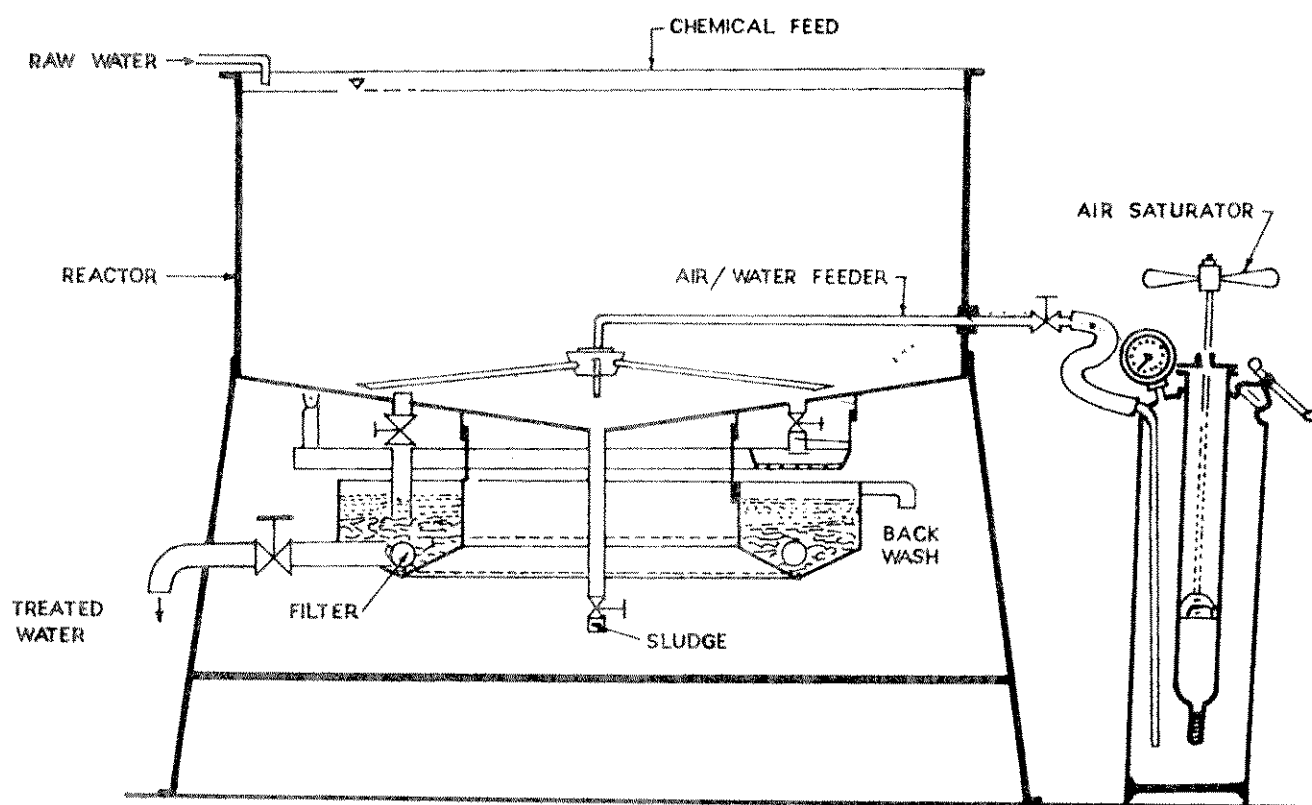


FIGURE 9.5: MUSCLE-POWER DISSOLVED AIR FLOATATION SYSTEM FOR WATER TREATMENT

The size of all units, viz., overhead tank, channel mixer, pebble bed flocculator, sedimentation tank, sand filter and underground treated water storage tank are based on these design considerations for populations 500,1000,2000 and 5000. Layout plan and sectional elevation for treatment plant of Nalgonda Technique are given in Fig. 9.6

Nalgonda Technique has several advantages over the fixed bed ion-exchange processes. It does not involve regeneration of media and employs chemicals which are readily available and easy to operate and maintain using local skills. Colour, odour, turbidity, bacteria and organic contaminants also get removed simultaneously. The sludge generated is convertible to alum for use in removal of excess turbidity of surface waters.

9.8 DEMINERALISATION 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 brackish water area, the least mineralized water source could be

prospected. When potable water is unavailable some method of treatment has to be adopted. Thus ships on the high seas as well as lifeboats are provided with stills for manufacturing distilled water. Distillation of seawater has also been adopted during the war in isolated atolls which had to be occupied.

9.8.1 DISTILLATION

Of the processes of removing 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,

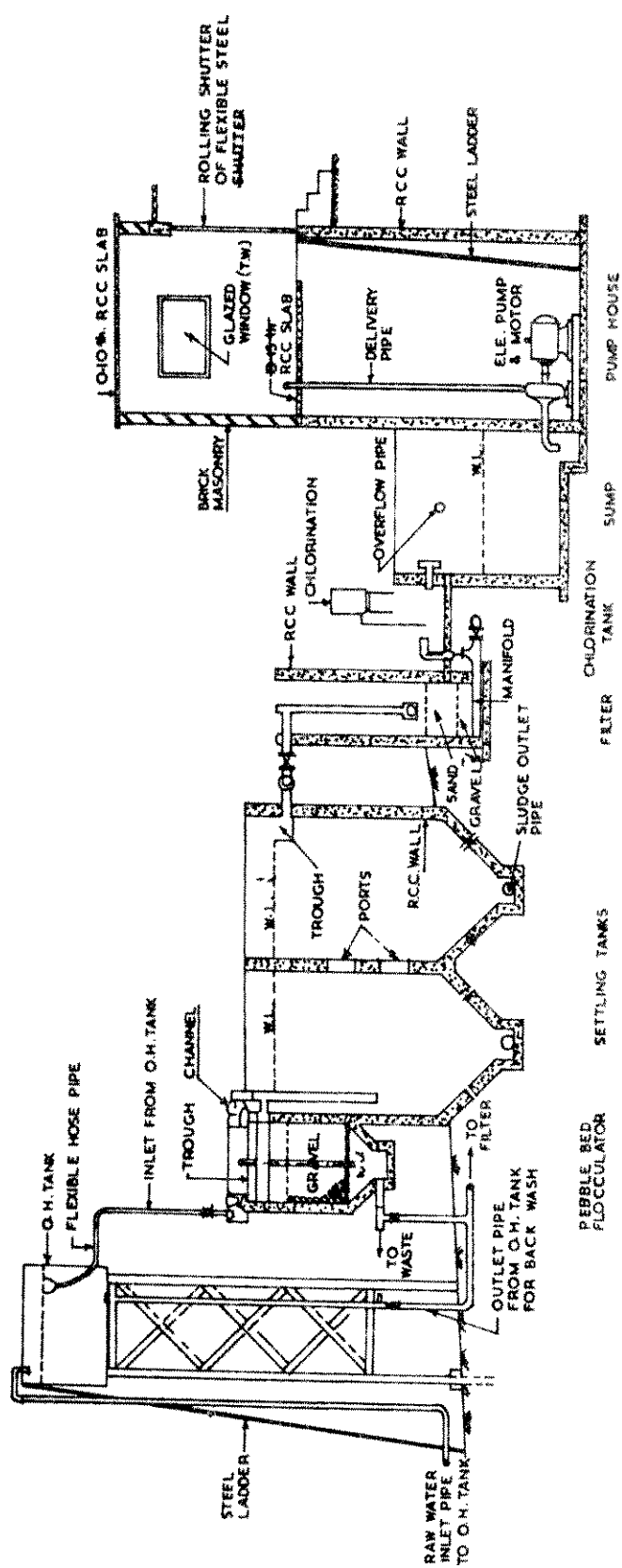
While relatively small quantities of water are to be distilled, straight or single-effect distillation is preferred because of the simplicity of operation and the lower capital cost of the installation. With larger outputs improvement in efficiency acquires much greater importance because of the much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

Performance of an evaporator 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.

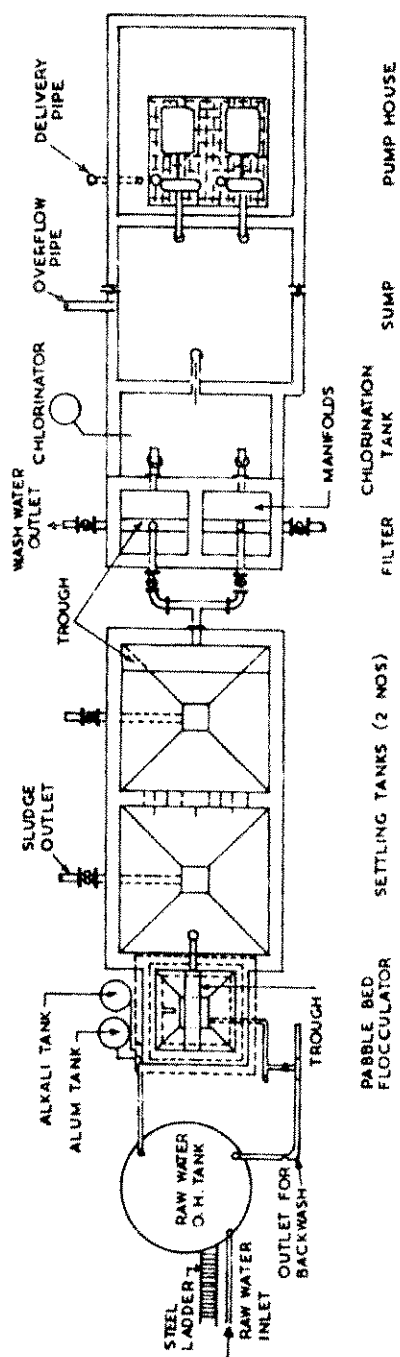
9.8.1.1 Solar Stills

Solar energy can be harnessed by the use of a system of mirrors following the path of the sun to focus the sunlight on sheets of water. In one of the popular methods, the salt water trickles down to trays mounted on an inclined compartment provided with glass sides and a heat insulated back which screens the condensing chamber from the sun. Since the focussing mirrors form an important element in the cost of the stills, the development of cheaper non-focussing types of mirrors and use of inexpensive materials of construction have been resorted to. In basin solar stills, a commonly used design, salt water tanks, filled either by gravity or by stainless steel impeller pumps, feed the solar still whose cover is at a shallow angle of 10° to 18° with the glass panes tightly sealed to the holding frame and the joints between the still cover and the vertical walls perfectly tight. The rate of feed to still should be such that for each 7.6 litres of salt water, 3.7 litres of fresh water is obtained and 3.7 litres of brine is discarded. The collecting troughs at the foot of the still cover must be constructed so that water will drain freely to the pipe which carries the distillate to the fresh water tank but preventing the entry of any contaminated water either from the roof or the ground in which it is constructed. In addition to the fresh water tank, it is good practice to construct additional distilled water storage so as to balance out the fluctuations between production and demand.

By their very nature, still covers are ideal for collection of run off of rain water and every advantage should be taken of the available rainfall by diverting in to the fresh water tank after disinfection. Such an addition can be substantial in areas, as for example, where annual rainfall is of the order of 30 cm and a still is so arranged as to recover 70% of it. The increase



SECTIONAL ELEVATION



LAYOUT PLAN

FIG. 9.6 DEFLUORIDATION PLANT USING NALGONDA TECHNIQUE

per square metre of still area is about 200 liters per year. The efficiency of a solar distiller is the condensed water actually produced divided by the water which could theoretically be evaporated by all the solar energy reaching the outer cover.

In general, wherever skies are generally clear, solar distillation is feasible upto 40° latitude, where 1000 kW/ m² of energy from the sun in each year can be available, the solar radiation being more important than the mean ambient temperatures and the wind factors being negligible except as they relate to stresses upon solar distillation structures. The production of water by still varies from month to month and even day to day depending upon the solar radiation available. The size of still is often to be designed on the basis of the least productive month. Yields of about 1 m³/ m²/year have been adopted for some of the bigger stills constructed and used successfully. The still area needed is given by the expression:

$$Q = 6.008 \times 10^{-3} \times S \quad (9.4)$$

Where

Q = Output per square metre of still area in lpd and

S = Insolation or solar radiation in calories/ cm²/day

Values typical for India for various latitudes are given in Appendix 9.4

The best situations for the use of solar distillation are the isolated areas and certain regions where fresh water is unobtainable, solar intensities are high, fuel resources are meager and industrial development is poor.

9.8.1.2 Single-Effect Distillation

The sea water is boiled in a vessel, using steam as the heating medium. The vapour is condensed by heat extraction to a cooling supply of sea water, part of which forms the feed to the plant.

It is not useful to install liquid/liquid heat exchangers to recover heat from the exit brine and exit distillate. The vapor produced has to be condensed. Any recovery of heat could only be used to heat the feed water, and if this were done, the circulating water supply to the condenser would need to be increased.

9.8.1.3 Multiple-Effect Evaporation

Each component unit of a multiple-effect evaporator is maintained in series at slightly lower pressure and temperature in order to permit the steam produced in one effect to serve as the source of heat in the next. Weight for weight, the amount of product water then approximates the number of effects. It has been computed that the quantity of water that can be evaporated by one kg of steam in single double and triple effect evaporations are in the ratio of 0.9, 1.7 and 2.5 respectively.

(a) Multi-Stage Flash Evaporation

This is also accomplished at successively lower pressure and temperatures. The multistage flash systems is logically related to the multiple effect system by extending the preheaters to full condensation duties and omitting all evaporation heating surface entirely, so that all

vapour is obtained by flashing. The incoming water is warmed by the heat of condensation and only a small amount of heat energy is required to flash the preheated water in the reduced-pressure stage into steam. Specific heat consumption values as high as 110 are possible.

(b) Low Temperature Flash Evaporation

This method has for its object, the exploration of the possibility of utilizing the energy in streams of warm water from power plant, oil refineries and industrial plants as well as from naturally occurring sources. The studies show that this method for warm saline waters is theoretically sound and technically feasible.

(c) Vapour Compression Process

This process relies on mechanical compression of the vapour to boost its temperature high enough to supply through its own condensation the heat necessary to evaporate the feed water. Once started, this process does not draw upon further heat energy but only upon mechanical energy.

Steam at 100° C is compressed so that its temperature is raised to about 105 °C and this compressed steam is used to raise the temperature of the feed water to the boiling point. Vapour compression distillation improves the efficiency of the reuse of the latent heat of steam. Heat is required only for the initial production of vapour. Thereafter the heat derived from the mechanical energy developed by the motor that drives the compressor may supply all the needs of energy. This method has been found to be remarkably efficient. Heat transfer coefficients can further be improved 4 to 6 times by making a thin film of the water pass rapidly over a rotating surface. The rotor surface showed no scale or corrosion and the mechanism appears to be self-cleaning.

Because of high cost of the compressor, the expected over-all benefit of vapour compression as far as cost is concerned is not good. However, there are many special applications, particularly in small capacity plants, where considerations other than cost determine that the vapour compression process is most suitable and convenient.

(d) Critical Pressure Distillation

The principle of this method is that by operating at pressures in excess of 250 kg/ m² and temperatures greater than 370°C, the density difference between the liquid and vapour phases is made relatively small so that the size of the vapour handling equipment can be greatly reduced. The main difficulties in this process are the rapid building up of scale and the need for developing materials of construction which can withstand these elevated temperatures and pressures.

(e) Vapour Reheat Distillation

This process is similar, in several respects, to multi-stage flash evaporation. In this system deaerated sea water enters the system and passes through a heat exchanger counter-current to hot fresh water. The temperature is then raised with heat from an external source (the prime energy supply). The hot sea water then cascades through a series of flash chambers counter current to a stream of fresh water flowing in open channels. In each stage, some sea water flashes to form steam, which condenses in the stream of fresh water. As a result, sea