



## Full Length Research Article

### FLUORIDE IN GROUNDWATER: EVALUATION OF REMOVAL METHODS

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#### ABSTRACT

In the wake of widespread fluoride occurrence in groundwater, the incidence of endemic fluorosis across the country is alarming. In the year 2009, the Central Ground Water Board and Rajiv Gandhi National Drinking Water Mission reported 218 and 229 districts to be affected with high fluoride content in groundwater, particularly in the states of Assam, Andhra Pradesh, Gujarat and Rajasthan with over 50% districts affected. This has of late become a critical hazard giving rise to both dental and skeletal fluorosis, such as mottled teeth (brown / yellow stained, discolored and chalky white patches on teeth), sporadic pain on joints, osteosclerosis of pelvis and vertebral spine, crippling deformities, etc. The removal of excess fluoride is cumbersome and an expensive process. At present, methods being generally used to treat or remove fluorides include chemical precipitation with alum and lime, activated alumina, ion exchange process, electro-dialysis and reverse osmosis. In view of the above, the Paper highlights the various methods of treatment and their advantages and disadvantages in detail, and recommends suitable treatment technologies for fluoride removal from groundwater to bring down the fluoride level to less than 1.0 mg/L desirable limit and 1.5 mg/L permissible limit prescribed by IS 10500:2012, the WHO recommended permissible limit of 1.5 mg/L of fluoride concentration in drinking water.

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#### INTRODUCTION

The natural concentration of fluorides in groundwater depends upon the physical, chemical and geological characteristics of the aquifer, the porosity and acidity of the soil and rocks, the action of other chemicals and depth of the aquifer. When surface water percolates into the ground water aquifers through the strata, the fluoride is picked up from fluoride rich rocks, such as fluorspar ( $\text{CaF}_2$ ), cryolite ( $\text{Na}_3\text{AlF}_6$ ) and fluorapatite [ $3\text{Ca}_3(\text{PO}_4)_2 \cdot \text{Ca}(\text{FCl})_2$ ] which have 49%, 13.5 – 26% and 6.8% of fluoride respectively (Larsen *et al.*, 1950). Because of large number of variables, the fluoride concentration in ground water varies from place to place and ranges from 1 mg/L to 48 mg/L. It was evident that excess fluoride was present in ground water in many parts of the country by mid-1980 and even early. In 1987, RGNDWM estimated that about 25 million people in 8700 villages were drinking water with excess fluoride (Susheela, 2009).

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<sup>1</sup>As per 1999 data of UNICEF, this figure has been quoted as 66.62 million people in 19 states. From the trends of data available in 2009 and 2012, the affected areas are only increasing and people suffering would be higher. (Saxena and Sewak, 2012) reported that 218 and 229 districts were affected with high fluoride as per CGWB<sup>2</sup> and RGNDWM data in the year 2009. The number of districts suffering from endemic fluorosis increased to 267 as per MoWR<sup>3</sup> in 2012 (Sethi, 2012). The people suffering are about 70 million in 20 states of India and Union Territories<sup>2</sup>. The most affected states are Assam, Andhra Pradesh, Gujarat and Rajasthan which have more than 50% districts affected. High value of fluorides in drinking water has become a critical hazard as it induces teeth mottling, dental fluorosis, skeletal fluorosis and non-skeletal fluorosis and lack of fluoride in water causes dental caries where there is no alternate source of fluoride in the food chain and practice of excessive sweet or chocolate consumption. Removal of excess fluoride from water is difficult and expensive process. The current methods of removal of

<sup>1</sup> Rajiv Gandhi National Drinking Water Mission

<sup>2</sup>Central Ground Water Board

<sup>3</sup>Ministry of Water Resources

fluorides are chemical precipitation with alum and lime, activated alumina, ion exchange process, electro-dialysis and reverse osmosis. In view of the above, it was thought worthwhile to discuss the various methods of treatment and their advantages and disadvantages and to suggest suitable treatment technologies for fluoride removal from ground water to bring down the fluoride level to less than 1.0 mg/L desirable limit and 1.5 mg/L permissible limit prescribed by IS 10500:1991. The WHO recommended permissible limit of 1.5 mg/L of fluoride concentration in drinking water.

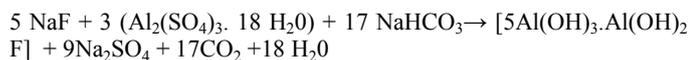
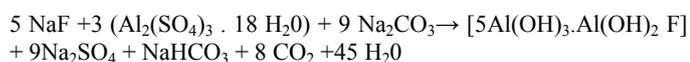
## Methods of Treatment

### Nalgonda Process

This method was developed by National Environmental Engineering Research Institute (NEERI), Nagpur in 1975. It involves addition of alum and lime to the raw water with proper mixing. The fluoride reacts with alum and forms complexes of aluminum salts and settles. Whenever the alkalinity is less in the groundwater, the lime is also added for proper flock formation. The flocks are allowed to settle and supernatant water / filtered water is free from fluoride. The bleaching powder is recommended for disinfection. The method has been successfully demonstrated and utilized at domestic and community level in India. The domestic defluoridation unit is shown in Figure 1. NEERI had designed community water de-fluoridation unit which had been installed at many places under RGNDWM. It is economical and is appropriate for developing countries like India. The main limitation of the Nalgonda Technique is the daily addition of chemicals (alum, lime and bleaching powder) depending upon the chemical characteristics of water and large volume of sludge produced. The technique is not effective for water having high total solids and hardness as it does not reduce these contaminants from groundwater. The aluminum concentration in the treated water is more than the desirable limit prescribed by the IS 10500:1991 of 0.03 mg/L. Selvapathy and Arjuman<sup>16</sup> have reported that the treated water from Nalgonda technique has residual aluminum in the range of 2.1 to 6.8 mg/L under various operating conditions.

### Chemistry of the Process

Alum reacts with fluoride and forms the following reaction:



The flocks formed are combination of poly hydro oxy aluminum species complex with fluorides and their adsorption on polymeric alumino hydro oxides. (Nawlakhe *et al.*, 1974) reported that dosage of chemicals necessary for various concentration of fluoride at different alkalinity levels are given in Table 1. The addition of lime becomes essential when the raw water has low alkalinity. It is generally 5% of the alum required. Bleaching powder at the dose of 3 mg/L is added for disinfection. The selection of aluminum salt either as aluminum sulphate or aluminum chloride or a combination of

both depends on sulphate and fluoride content of the raw water. The water having fluoride content of 5 mg/L or above, the sulphate may increase beyond 400 mg/L in the treated water and this violates IS 10500: 1991.

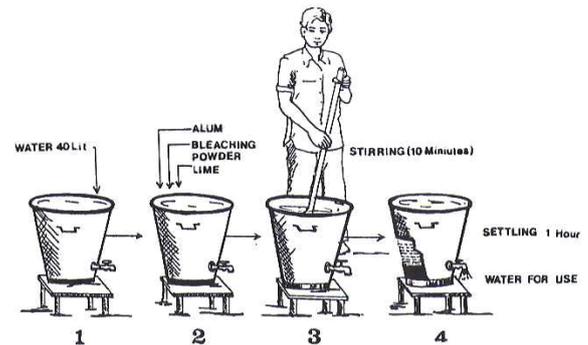


Figure 1. Domestic Defluoridation Unit

Table 1. Alum Dose to attain Permissible Fluoride Limit in Water at various Alkalinity and Fluoride Levels

Raw Water Fluoride (mg/L)	Alum Dose (mg/L)							
	Raw Water Alkalinity as CaCO <sub>3</sub> (mg/L)							
	125	200	300	400	500	600	800	1000
2	145	220	275	310	350	405	470	520
3	220	300	350	405	510	520	585	765
4	*	400	415	470	560	600	690	935
5	*	*	510	600	690	715	885	1010
6	*	*	610	715	780	935	1065	1210
8	*	*	*	*	990	1120	1300	1430
10	*	*	*	*	*	*	1510	1690

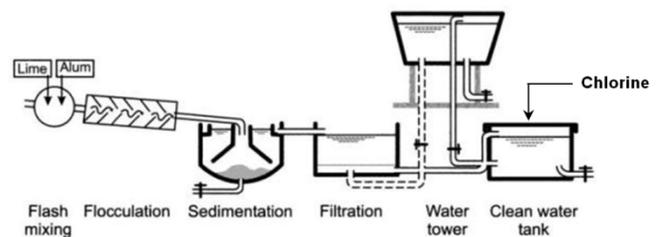


Figure 2. The Flow Sheet of Nalgonda Process (Anne Marie Helmenstine, 2008)

### Mechanism of Defluoridation

The treatment flow sheet of Nalgonda process is given in Figure 2. It consists of rapid mixing of chemicals, flocculation, sedimentation, filtration, disinfection and sludge disposal.

**Rapid Mixing:** The chemicals alum and lime are added to the water and water is stirred rapidly for some time. If the raw water has low alkalinity and /or hardness, lime is added first but if the alkalinity is adequate, the lime is added later for better settling of alum flocs and improved supernatant quality.

**Flocculation:** The chemical added water is gently agitated for 20 minutes at 20 rpm before entry into the sedimentation tank.

**Sedimentation:** The flocculated water is allowed to settle to separate the flocs loaded with fluorides, turbidity and suspended solids for about 1 to 2 hours.

**Filtration:** The clear water after sedimentation is sent to the filtration unit and the filtration is carried out on rapid gravity filters to remove unsettled gelatinous floc. The residual fluoride and bacteria are further removed by this process.

**Disinfection:** The filtered water is chlorinated and sent to storage tanks before distribution.

**Sludge disposal:** The sludge is collected from the bottom of the sedimentation tank and treated on sludge drying beds or filter press to dewater it before sending it to sanitary land fill because the sludge has high concentration of aluminum as well as fluoride. It is recommended that the sludge is disposed of in polythene bags so that leachate does not harm shallow aquifers.

**Pilot Plant Studies:** Bulusuet *et al.*<sup>3</sup> reported the performance of full scale defluoridation unit of 2372 cum/day at Kadari township in AP in 1980. The average fluoride concentration in the raw water was 4.2 to 4.8 mg/L and it was 0.70 to 1 mg/L in treated water. The alum dose was on an average 494 mg/L.

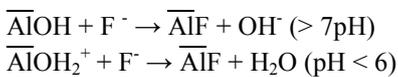
**Limitation of Nalgonda Technology:** It needs high dose of chemicals and their daily weighing is difficult at rural installations to match the requirement as the lime and alum dose is dependent upon the fluoride content of the raw water which requires special skills in field testing.

#### Activated Alumina Process

Gamma aluminum oxide ( $\gamma$   $\overline{\text{Al}_2\text{O}_3}$ ) is the common name of activated alumina. This is prepared by slow dehydration of hydrous aluminum oxide at 300 – 700°C temperature. Upon hydration, hydroxo group develops at the alumina surface  $\overline{\text{AlOH}}$ . These groups have iso-electric pH of about 9.5 and amphoteric in nature, that is, they can react with both acid and alkali and can exist as positive, neutral and negative surface hydroxo group depending on pH.



Fluoride exchange takes place when activated alumina surface is in the form of  $\overline{\text{Al OH}_2^+}$  and  $\overline{\text{Al OH}}$  as per the following equation:

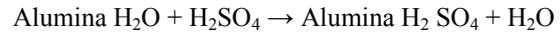


*The over bar on  $\overline{\text{Al}}$  indicates Activated Alumina Solid Surface:*

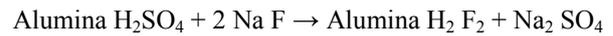
It removes anions below pH 9.5 and cations above this pH. The affinity of alumina for anions seems to be inversely proportional to the solubility of its aluminum salt. Therefore when treated with dilute acid, alumina behaves like anion exchange. Affinity of activated alumina for fluoride is very high. Adsorption of anions can be represented in descending order as hydroxide > phosphate > fluoride > bicarbonate > sulphate and > chloride<sup>17</sup>. Fluoride uptake capacity of alumina is affected by the particle size of activated alumina, raw water fluoride concentration, pH and alkalinity and ratio of adsorbate to adsorbent. A typical adsorption, regeneration cycle for the

removal of fluoride may be represented as follows (Clifford *et al.*, 1978):

**Acidification:** When neutral activated alumina is treated with sulphuric acid (0.1 N), acidic alumina is formed and the following reaction takes place.



**Ion Exchange (Loading):** When the activated alumina is in contact with fluoride ions, it displaces the sulphate with fluoride.



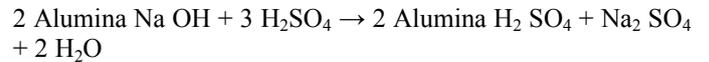
**Backwashing:** The backwashing is carried out with clean water to remove the suspended solids from the activated alumina particles and break up any tendency towards wall effect and channelizing.

**Regeneration:** This is carried out with dilute sodium hydroxide (1% caustic soda solution) as the most preferred ion.



**Rinsing:** This is necessary to remove excess regenerant from the alumina bed before neutralization.

**Neutralization:** Alumina NaOH is regenerated with dilute sulphuric acid (0.1 N).



The acidic alumina is now ready for another absorption cycle.

- The studies indicated that the rate of adsorption was dependent upon the particle size of the adsorbent. The particle size greater than 0.3 mm and lesser than 1.0 mm is recommended for use.
- The contact time is between 5 minutes is to be maintained for fluoride adsorption by activated alumina when adsorption is carried out at pH 5.5 to 6.0. As raw water with higher pH and alkalinity is used, the contact time is increased to 15 – 20 minutes as the rate of adsorption decreases.
- The adsorption of fluoride from water is relatively more rapid at low fluoride concentration.
- Rate of adsorption of fluoride increases with decrease in the pH of water. The optimum pH is between 5.5 and 6.5.
- Defluoridation capacity of activated alumina is reciprocally dependent upon the alkalinity of water. Higher the alkalinity, lesser the absorption.

The fluoride removal capacity of activated alumina in mg/kg is higher for elevated fluoride concentration in the feed water and was found to be 1500 mg/kg for fluoride concentration of 3 - 4 mg/L and 1925 mg/kg for 10 mg/L in the feed water (Iyengar and Venkobachar, 1997).

### Pilot Plant Studies

A cylindrical vessel of 0.5 m diameter and 1.5 m height containing 110 kg of activated alumina of particle size 0.3 to 0.8 mm was installed at Makkur village Unnao District, UP<sup>5,6</sup>. A sample flow sheet for Activated Alumina Plant is shown in Figure 3.

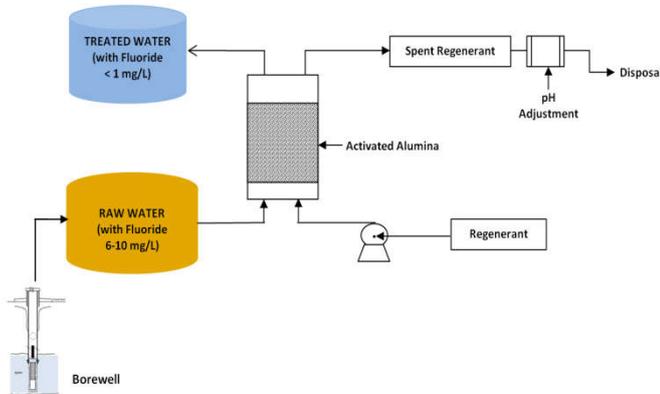


Figure 3. Flow Sheet for Activated Alumina Plant

The bed depth was around 55 cm. The fluoride concentration in groundwater was 5 – 6 mg/L. Average yield of treated water with less than 1.5 mg/L fluoride per cycle was around 25,000 L. Regeneration was carried out in-situ using sodium hydroxide (NaOH) and sulphuric acid (H<sub>2</sub>SO<sub>4</sub>). 17 defluoridation cycles were carried out in the span of six years. The unit was operated from 1993 to 1998 by IIT, Kanpur. It was discontinued once piped water supplies were made available to the village. Activated Alumina-based domestic fluoridation plant is shown in Figure 4.

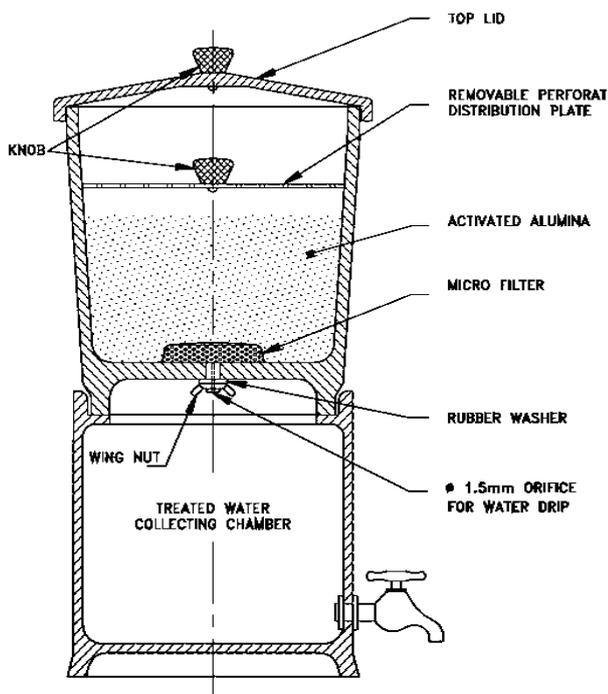


Figure 4. Activated Alumina-based Domestic Defluoridation Plant

### Disposal of spent regenerated waste water

There are two alternative methods of regeneration of activated alumina. One is in-situ regeneration and the other option is by removing activated alumina from the unit and transporting it to the site of regeneration. Regeneration of activated alumina is carried out leads to 6 to 8 bed volumes of waste water. The exhausted 4 kg activated alumina is kept in a bag and is dipped in 10 L of 1% of NaOH for 8 hours with intermittent mixing. After washing with raw water to remove excess alkali, the bag with activated alumina is dipped in 10 L of 0.4 N H<sub>2</sub>SO<sub>4</sub> for 8 hours with intermittent mixing. This was followed by washing with raw water to raise the pH to 6. The regenerated activated alumina is ready for next cycle. The alkaline regenerated waste water is mixed with the acidic waste water and settled in a pond with tiles lining. The pH of the treated water is adjusted between 6.5 and 8.5 before discharging it in common drains. The sludge is disposed in the sanitary landfill after packing it in polythene bags.

### Limitations of Activated Alumina Process

- Reactivated of exhausted alumina is cumbersome process and it can be done with the help of qualified persons (or trained persons) mostly not available in rural areas.
- The process also results in high residual aluminum in treated water ranging between 0.16 mg and 0.45 mg/L as against 0.03 mg/L desirable limit of IS-10500, as reported by (Iyengar and Venkobachar, 1997).
- Regeneration training of staff and reject water management has to be done carefully

### Bone Char Treatment Process

The use of bone charcoal or bone char (carbonized animal bone) was observed to be an effective means for the reduction of fluoride. Bone char has a carbon structure which supports a porous hydroxyapatite matrix (a calcium phosphate hydroxide in crystalline form). The dried bones are charred at about 1100 – 1600°C at controlled conditions. The organic char is made of 80% phosphate of calcium, 10% carbon and 10% calcium carbonate. The fluoride removal takes place due to adsorption and ion exchange on the calcium phosphate in the bone char. This replicates the process of fluoride affecting human health by attaching it to the bones of people ingesting fluoride rich water.

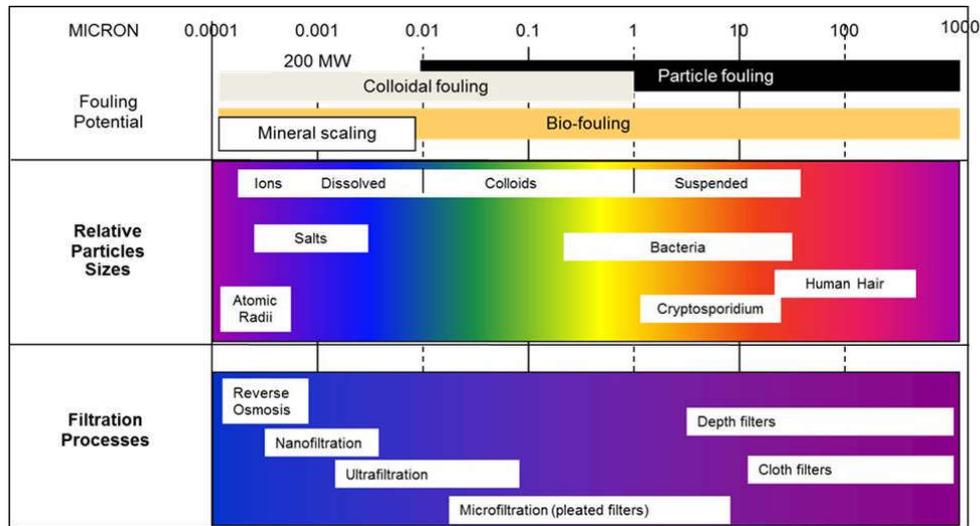
### Bone Char (Granular) Possible Designations

- Chemical Name: Tricalcium phosphate
- Chemical Formula: C=(~12%) CA<sub>3</sub>(PO<sub>4</sub>)<sub>2</sub>= (~ 88%)
- [Ca<sub>10</sub>(PO<sub>4</sub>)<sub>6</sub>(OH)<sub>2</sub>]

Bone char method is culturally not acceptable to most religions of South East Asia as their religious sentiments are affected in case the drinking water touches any animal bones or specifically that of cow/pigs. In order to overcome these religious taboos, pure hydroxyapatite is synthesized using calcium and phosphate salts, as reported by (Verwighenet al., 2007).

**Table 2. Fluoride Removal by Different Methods AA, Apatite, Bone Char and RO**

Media	Fluoride uptake mg/kg	Bulk Density kg/L	Fluoride uptake mg/L	Range of pH
Activated Alumina	1,550 – 1,925	0.67	2,300 – 2,900	5.5 – 6.5
Bone Char	600 – 1,000	0.64 – 0.72	930 – 1,560	< 6.5 pH to suppress competing ions impact <sup>10</sup>
Hydroxyapatite	9,827	0.34	28,900	Similar to Bone Char, being its synthetic version
Low Grade Hydroxyapatite	5,929	0.34	17,400	Similar to Bone Char, being its synthetic version
RO	80 – 90% Rejection	Not Applicable (NA)	NA	4 – 8.5 for Cellulose Acetate or cellulose triacetate (CA/CTA) <sup>19</sup>
RO	Up to 95% Rejection	NA	NA	3-11 for Thin Film Composite membrane <sup>19</sup>

**Figure 5. Filtration and Particle Spectrum**

### Low Grade Hydroxyapatite

MacDonald *et al.*, 2011 prepared a low grade hydroxyapatite by mixing 5 kg of lime (CaO) with 100 L of groundwater by hand while adding 85% - 90% phosphoric acid at a rate of approximately 50 ml per minute. The samples were dried at 250°C to form hard particles suitable for a filter bed, ranging in size from ~ 0.1 to 2 mm. The XRD analysis confirmed the formation of hydroxyapatite. When synthetic groundwater is passed on the filter bed consisting of this low grade hydroxyapatite, the first order model predicts that the adsorption of fluoride reaches equilibrium at about 6 min 37 seconds versus 4 min 15 seconds for active alumina. The breakthrough curve shows that the curve for the activated alumina is more or less same as of low grade hydroxyapatite. The fluoride binds to hydroxyapatite in greater amount than to activated alumina because activated alumina removes fluoride through surface adsorption while hydroxyapatite removes fluoride in three ways (1) surface adsorption (2) crystal substitution and (3) fluorite precipitation. The cost of activated alumina and low grade hydroxyapatite is Rs. 38,095 per kg and Rs. 5,800 respectively as per this paper. The relative uptake of fluoride ions is different for different media types and is also dependent on the competing ions present in the raw water and its pH. However, the range of fluoride pick up is given in Table 2.

### Reverse Osmosis Process

While the above four processes focus upon fluoride ion removal through precipitation or adsorption, the reverse osmosis membrane process works through removal of all dissolved solids along with fluoride ion.

In order to understand the membrane process, it is essential to understand the size of all the contaminants as well as sieve size of various mechanical filtration processes. The filtration spectrum and particle size distribution on a log scale is shown in the Figure 5 below:

The reverse osmosis membrane has a very fine pore size of less than 0.001 micro-meters which does not permit passage of microbial and dissolved contamination. A typical Reverse Osmosis Plant and its Treatment Steps are shown in Figures 6 and 7 respectively. Figure 8 shows the typical elements in an effective RO process flow sheet.

**Figure 6. Reverse Osmosis Plant**



particles by adsorption and other taste and odor causing organic material. Additionally, carbon media is used to remove disinfectant byproducts (e.g. trihalomethane or haloacetic acid are formed when chlorine combines with organic matter). The operation of the Carbon Filter is exactly the same as the Sand. The mechanism of removal is different as the media is different. The impurities are captured within the carbon bead 'pockets'. Water flow is from the top to the bottom. During backwash, the water comes from the bottom and lifts the media, releasing the impurities and flushes them to drain. Backwash is set on a schedule versus on the differential pressure from inlet to outlet. It is sometimes more convenient to backwash on a schedule than to determine when it is required. The activated carbon media required to provide effective surface area for adsorption of impurities is determined by the flow rate and thereby the vessel holding the media.

### Micron filtration

Micron filter (two micron filters are recommended, first of 10 micron and second of 5 micron size) protects the RO membranes from relatively large particles should they somehow get through the system. It removes particles greater than 5 micron (typical size) by traditional depth filter media. Particles too small for the sand and carbon filter to withhold are caught in the micron filter. The micron filter further reduces turbidity and Silt Density Index (SDI). Micron filters are cartridge type filters constructed of a media on a core. Typical design is depth or pleated. Filtration in a depth cartridge takes place in depth rather than just on the surface. Filtration in a pleated cartridge is on the surface only; however, pleats provide very large surface area. As suspended particles become trapped within the depth cartridge or on the surface of a pleated cartridge, the available filter surface area is reduced and the pressure drop or differential pressure increases. If the pressure drops beyond the vendor's specification, this increases the potential for particles to break through to the membranes. Micron filters are replaced on a schedule or sooner if differential pressure  $> 1$  bar or there is a slimy films, or discoloration of micron filter.

### Anti-Scalant Dosing

Calcium (Ca) and Magnesium (Mg) will scale and deposit on the membranes as the water is purified. Anti-scalants are used to reduce the scaling and deposition potential on membranes. Anti-scalants are proprietary chemical blends that have special applications depending on levels and types of impurities in the raw water. Anti-scalant reduces the scaling potential by keeping the ions in solution.

### pH dosing

Water produced from the RO has a lower pH than incoming raw water. The dosing pump is installed to correct the pH of treated water from 6.5 – 8.5.

### Reverse Osmosis High Pressure Pump

High pressure is necessary to create osmotic pressure. This is created by using a high pressure multistage pump. The high

pressure pump is selected based on raw water characteristics and array of RO membranes being used in the treatment process.

### Reverse Osmosis Membrane

Reverse Osmosis (RO) reduces dissolved inorganic compounds such as sodium, chloride, sulphate, and nitrate. More importantly, RO has the capability of removing large organic molecules and organisms (bacteria, mold, viruses and waterborne pathogens) at efficiencies greater than 99%. Effective filtration is below 0.001 micrometer ( $\mu\text{m}$ ).

Osmosis is a natural process – a flow of low concentration to a higher concentration to achieve equilibrium. The concentrated solutions are separated by a semi-permeable membrane. A semi-permeable membrane allows water to pass, while rejecting some dissolved ions and organics, as shown in Figure 9. Reverse Osmosis uses a pump to overcome the natural process of osmosis and move the water across the semi-permeable membrane in the opposite direction. Essentially, clean water is extracted from the feed water stream, as shown in Figure 10.

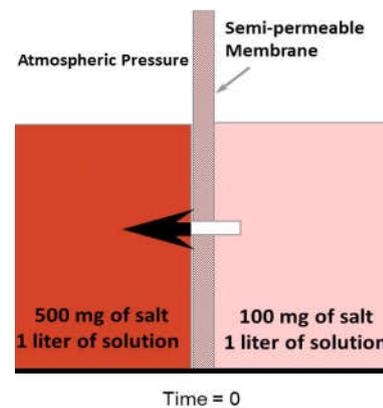


Figure 9. Osmosis

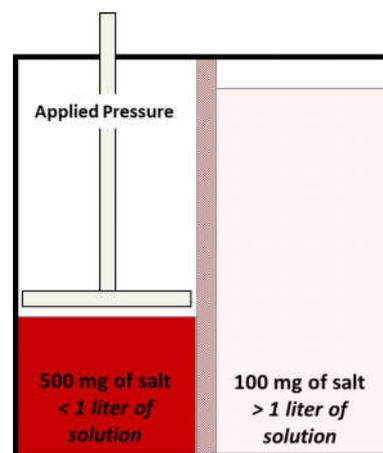


Figure 10. Reverse Osmosis

Flow is across the semi-permeable membrane through a feed channel spacer. This is commonly referred to as cross-flow filtration compared to dead-end filtration where the flow is through the filtering media (e.g. sand filter), as shown in Figure 11.

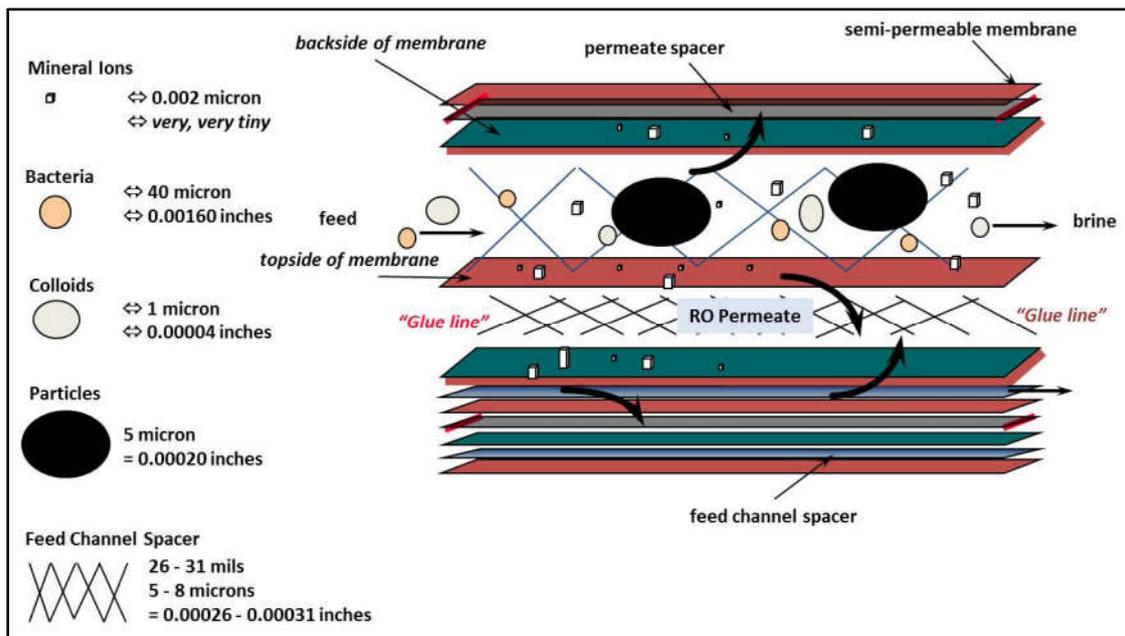


Figure 11. Cross-flow Filtration

A spiral wound element takes these flat sheets and rolls them around a tube called a permeate tube. The permeate water is captured in an envelope created by placing the two membranes back to back with a permeate channel spacer and glued on three sides. The open end of the envelope is attached to the permeate tube which has holes to collect the permeate, as shown in Figure 12.

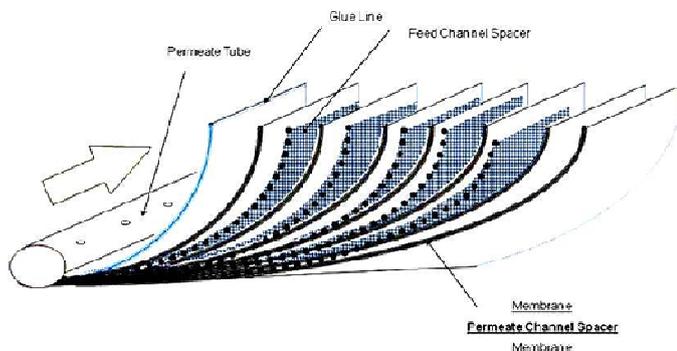


Figure 12. Use of Permeate Channel Spacer

Water flow is across the membrane through the feed channel spacer and product water gets into the permeate envelope via the high pressure supplied by the pump. The rolled-up membranes (known as spiral-wound membranes) are placed inside a membrane housing. The number of membranes and membrane housings depends on the overall design output and recovery, as shown in Figure 13. The amount of water produced from the 1<sup>st</sup> stage is typically 25% of the feed stream. The 2<sup>nd</sup> stage and recycle stream are design features to increase the recovery of the system, as shown in Figure 14.

### Recirculation

Recirculation of reject water is provided so that a part of the reject water can be recirculated through the RO membrane to reduce reject water. This is generally used where raw water total dissolved solids (TDS) and its scaling potential are low.

**Ultra Violet (UV) Treatment:** The water from RO is passed through the UV chamber to avoid any online contamination. This step can be avoided in light of residual chlorine dosing being provided in the treated water described below. UV is also provided after the treated water tank just before dispensing station if residual chlorine is not dosed.

### Residual Chlorine Dosing

To insure appropriate disinfection of the water and also to protect chance of recontamination, 0.2ppm chlorine is added to the treated water. It also protects contamination in storage tank, dispensing taps, water containers or even later when it is touched by slightly infected hands. Disinfectant, typically chlorine-base, breaks down and destroys microcell walls. Additional benefit is the disinfectant will oxidize metals and organics which can then be filtered. It is proportionally dosed into a storage tank or into the water stream via a metering pump. During start-up of the water system, the metering pump is set-up to deliver a dose (ml/min) based on daily water use, the concentration of disinfectant solution prepared, and the residence time required for proper disinfection. Primary reasons to adjust dosing (stroke speed of pump) is if there is a change in the overall design or an upset has occurred. The metering pump operates from the RO control panel. Operation on/off is dependent on water feeding the RO system.

**Storage Tank:** A 5000-litre food grade HDPE tank is generally used to store the treated water. The tank is kept within the treatment plant building, such that (1) water remains cool; and (2) no one can intentionally or unintentionally contaminate the water.

**Dispensing Station:** The dispensing taps have to be sized such that a 20-litre container can be filled in less than 60 seconds. It should also be able to operate with single twist of the lever rather than screw top version for ease of dispensing.

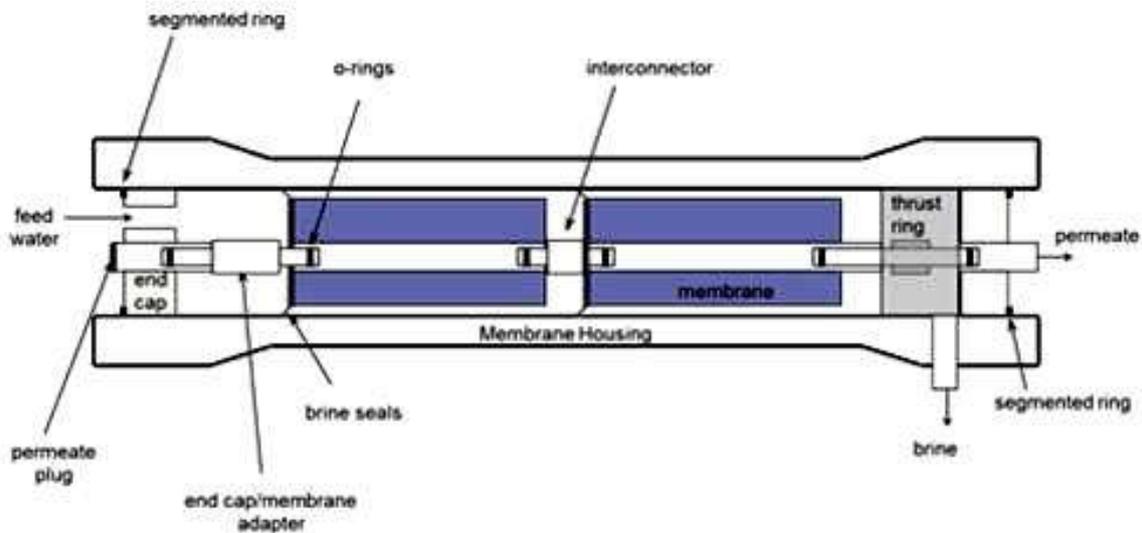


Figure 13. Spiral-wound Membranes

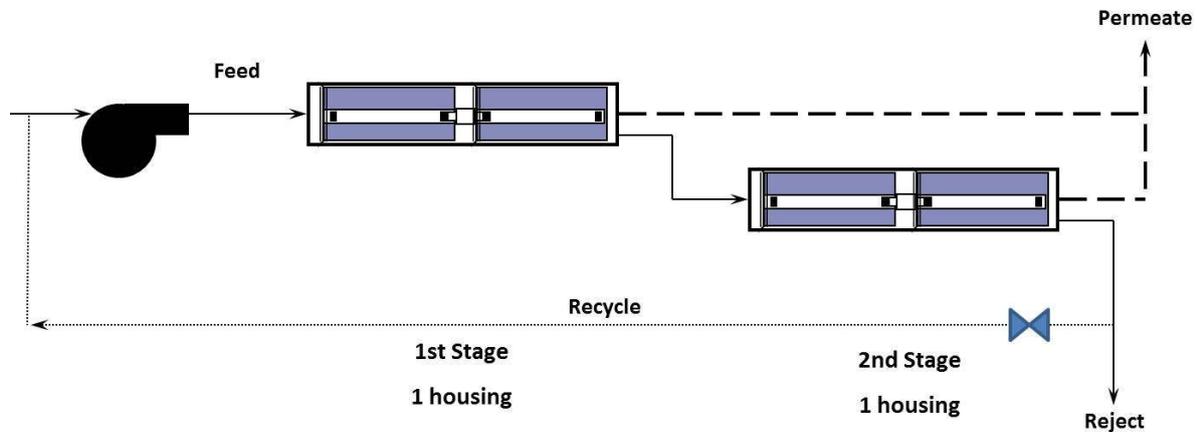


Figure 14. Two-stage RO System

Table 3. Performance Summary of Seven Reverse Osmosis Plants Installed at Warangal District in Telangana by Safe Water Network

S No	Test Parameter	Desirable Limit in IS 10500:1991	Permissible Limit in IS 10500:1991	Raw Water		Treated Water		Average		% Reduction
				Max	Min	Max	Min	RW	TW	
1	pH	6.5 to 8.5	6.5 to 8.5	8.3	7.4	8.1	6.3			
2	Color, Hazen Unit	5	Max 25	0.0	0.0	0.0	0.0	<5	<5	
3	Electrical Conductivity, $\mu\text{S}/\text{cm}$	--	--	4680.0	994.0	243.0	45.0	2220.6	118.0	95%
4	Turbidity, NTU	5	10 Max.	0.0	0.0	0.0	0.0	<1	<1	
5	Total Dissolved Solids, mg/L	500	2000 Max.	2900.0	646.0	158.0	30.0	1398.3	76.4	95%
6	Total Hardness as $\text{CaCO}_3$ , mg/L	300	600 Max.	1478.0	200.0	20.0	3.9	651.9	11.2	98%
7	Non Carbonate Hardness as $\text{CaCO}_3$ , mg/L	--	--	1056.0	100.0	0.6	0.6	Nil	Nil	
8	Calcium Hardness as $\text{CaCO}_3$ , mg/L	--	--	921.3	78.3	11.8	1.8	383.0	6.4	98%
9	Phenolphthalein Alkalinity as $\text{CaCO}_3$ , mg/L	--	--	26.6	19.0	0.0	0.0	22.8	Nil	100%
10	Methyl Orange Alkalinity as $\text{CaCO}_3$ , mg/L	--	--	543.0	319.0	30.4	11.4	401.5	22.0	95%
11	Calcium as Ca, mg/L	75	200 Max.	368.5	31.3	4.7	0.7	153.2	2.5	98%
12	Magnesium as Mg, mg/L	30	100 Max.	135.2	29.5	2.9	0.4	65.3	1.2	98%
13	Sodium as Na, mg/L	--	--	465.0	75.6	48.3	8.4	207.7	21.9	89%
14	Potassium as K, mg/L	--	--	7.4	1.2	1.4	0.1	3.5	0.5	87%
15	Silica as $\text{SiO}_2$ , mg/L	--	--	15.0	11.2	0.9	0.5	13.1	0.7	95%
16	Iron as Fe, mg/L	0.3	1.0 Max.	0.1	0.0	0.0	0.0	0.0	<0.005	
S No	Test Parameter	Desirable Limit in IS 10500:1991	Permissible Limit in IS 10500:1991	Raw Water		Treated Water		Average		% Reduction
				Max	Min	Max	Min	RW	TW	
17	Chloride as Cl, mg/L	250	1000 Max.	1025.0	53.2	48.5	3.9	356.5	17.9	95%
18	Sulphates as $\text{SO}_4^{2-}$ , mg/L	200	400 Max.	304.0	23.3	2.1	0.4	93.3	1.1	99%
19	Fluoride as F, mg/L	1	1.5 Max.	1.8	1.3	0.3	0.1	1.6	0.2	88%
20	Nitrates as $\text{NO}_3$ , mg/L	45	100 Max.	412.0	5.0	45.9	1.2	127.5	18.0	86%
21	Arsenic as AS, mg/L	0.01	0.05 Max.	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
22	Total Coliform / 100 ml	10 Max	10 Max	Absent	Absent	Absent	Absent	Absent	Absent	
23	Faecal Coliforms / 100 ml	Nil	Nil	Absent	Absent	Absent	Absent	Absent	Absent	
24	E. Coli / 100 ml	Nil	Nil	Absent	Absent	Absent	Absent	Absent	Absent	

Water samples collected from site by Safe Water Network’s trained staff, as per sampling protocol and sent for testing to M/s Bhagavathi Ana Labs Ltd, Hyderabad. The samples were analyzed as per IS: 3025 except Iron, Fluoride, Nitrate, Arsenic which were tested as per SM 3125, SM 4500 FD, SM 4500 NO3-B and SM 3125 respectively. The bacteriological samples were analyzed as per IS: 1622-1981.

## Reject Water and its Management

An RO plant works essentially on the principles of the kidney, where solutes from the blood are filtered through a semi-permeable membrane using pressure in the blood capillaries. Treated water from a RO plant will allow the human kidneys to deal with metabolites – its natural function – rather than harmful chemical contaminants in drinking water. The reject water from an RO plant, therefore, will have nearly double the amount of total dissolved solids (TDS) if the volume of treated water is about half that of the incoming water. Similarly, the management of reject water from an RO plant will follow the principles of dilution with water which, in this case, could be rainwater. Small, community level RO plants generally reject 40 to 60% of incoming raw water which has double the incoming total dissolved solids (TDS) as RO treated water has very low TDS and in place of human kidneys filtering these minerals in their body, the filtration occurs in the RO plant<sup>4</sup>. However, handling reject water is a sensitive subject and needs careful planning so that it can either be diluted using rain water in the surface aquifers being used as a sink for reject water or used as irrigation water depending upon reject water TDS or fluoride concentration.

## Limitations

The RO technology has the following limitations:

- Energy intensive versus other processes.
- Power supply is must and investment into the solar power to run RO plant is higher than that of treatment system. Similarly, poor quality of power such as voltage fluctuations or absence / floating neutral or earth leads to equipment failure as well as safety risks.
- Reject water is high at about 50% of incoming raw water versus 5 to 10% in other processes.
- It requires highly technical service back up and support.
- It requires thorough plant operator training to conduct regular back washes, strict regimen of change of micron filters as well as dosing of anti-scalants is critical to the life of membrane.

In order to overcome these limitations, Safe Water Network and Mark & Space Telesystems Pvt Ltd have developed a remote monitoring system on the RO plant so that the service needs of the plant and advice are telephonically communicated to the local operator.

## Remote Monitoring System

Safe Water Network in collaboration with Mark & Space Telesystems (P) Ltd. has developed a remote sensing telemetry solution called “KARMA” for tracking Safe Water Station’s field operations and sales, and collect business analytics information through use of RFID Cards/Smart Cards issued to individual users with a unique identification code at the time of enrolment. The smart card system is capable of tracking information of 1500 users per location. Wireless data logging

is done through mobile network and provides information on a web based system with password protection. This has been developed as remote plants do not get similar attention or expert supervision and therefore stop functioning as intended due to lack of information flow or visibility. There are certain challenges observed in such remote operations time and again. Many a times, the data critical for providing feedback to the plant for smoother functioning is not readily available. In order to get data, someone needs to go personally, translate it into English and feed it into computer and then email. Service visits are often expensive and difficult to organize. Status of sales and consumer adoption rates also very opaque as all information are kept in registers, which cannot be mined for meaningful information. Equipment Protection is done through surge and overload protection. Remote Monitoring System is an answer to these bottlenecks.

Operations monitoring (as shown in Figure 8), and consumer profile and usage tracking are some of the integral features of the remote monitoring system. The system facilitates tracking of functioning of water treatment systems against the parameters of TDS, water recovery, pressure, water levels and energy use, tracking of daily sales information at all levels, of profiling of individual households, as well as need-based deactivation of system in the event of quality issues, including protection (automated operations) in case of erratic power supply, and alarm and alert system at appropriate level. It also provides the facility of tracking sales by user, such that pricing can be separately specified for each plant / Point-Of-Sale, enables monitoring of distribution performance and buyer behavior on consumption, logging of revenues, and location input basis Google map for lat/long coordinates. Other notable features include web visibility, automated report generation, global application and customization – hierarchical-, country-, state- and district-wise, flexible deployment, asset tracking and health status, and maintaining of historical records, among others. The data is reviewed at a Central Control Center where it is interpreted and decisions on rectification (if any) are made along with job allocation to appropriate local service providers.

## Plant Studies

Safe Water Network has installed RO plants in India in the states of Telangana, Uttar Pradesh and Maharashtra. The performance summary of a few Safe Water Station RO plants (as shown in Figure 15) are given in Table 3 for the villages of Nizampally, Pochampally, Katrapalle, Gangireinigudem, Wadlakonda and Pathipaka in the Warangal district of Telangana. An RO water treatment plant installed by Safe Water Network is shown in Figure 16. The pH of raw water and treated water varied from 7.4 to 8.3 and 6.3 to 8.1 indicating a fall in pH levels after RO treatment. The dosing pump has been installed in every RO Plant for pH correction which can be used in case of pH less than 6.5. The performance of the RO plant for the removal of turbidity and color could not be ascertained as the raw water had below detection limit concentration. TDS, total alkalinity, total hardness, chloride, and sulphate in raw water and treated water averaged at 1398 and 76 mg/L; 402 and 22 mg/L; 652 and 11 mg/L; 356 and 18 mg/L & 93 and 1 mg/L respectively. All these values show removal efficiency of 95% or above.

<sup>4</sup>Private Communication of Mr. Anil Sondhi, Head of Technical Operations & Supply Chain | NourishCo Beverages Ltd. & a Trustee of Safe Water Network India



**Figure 15. Safe Water Station, Village Nizampally, District Warangal, Telangana**



**Figure 16. RO Water Treatment Plant installed by Safe Water Network**

The fluoride and nitrate in the raw and treated water averaged at 1.6 and 0.2 mg/L, and 127 and 18 mg/L respectively showing percentage reduction above 85%. This removal efficiency is during the first year of operation of the RO plants. The iron and arsenic removal by RO system could not be concluded as concentration of both these ions was very low in the raw water. The raw water used in villages is from bore wells protected by well protection protocol with suitable apron to prevent contamination ingress in raw water even during the rainy season, owing to increased height of the apron above ground. The treated water is free from total coliforms, faecal coliforms and E. coli. As a precautionary measure, disinfection is done with chlorine and residual chlorine of 0.2 mg/L is maintained in the treated water reservoir. This reduces the chances of recontamination, if any.

### Conclusion

In light of the limitations and drawbacks the treatment technologies should be used only when other options of using fluoride free water from groundwater or surface water sources are not available. Selection also depends upon the community size, degree of fluoride contamination, existence of other contaminants, hours of availability and quality of power. While RO provides wide ranging protection and has high treatment efficacy, it requires high degree of skill to operate

and service. In fluoride adsorption or absorption technologies such as activated alumina, bone char, hydroxyapatite or commercial resins, pH management of raw water is critical factor in field deployment. These also require rigorous regeneration schedule and meticulous planning of regeneration reject disposal. Bone char may not find acceptance in India hence further work needs to be done to commercialize hydroxyapatite. The Nalgonda technology & Activated Alumina technology have associated risk of high aluminum in treated water, which might lead to other health challenges while mitigating fluorosis.

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