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REVIEW

Water defluoridation: Field studies in India

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ABSTRACT:

Fluoride, a normal constituent of natural waters has dual significance. At optimum concentration it has a protective effect on teeth. At concentrations exceeding a certain limit, it acts as a cumulative toxin, adversely affecting every tissue and organ in the body. Since water is one of the major sources of fluoride for man, defluoridation of drinking water is one of the most important remedial measures to solve high fluoride problem. Over the years several defluoridation techniques have been developed and put to test, some at the laboratory level and others at the community level. This article attempts to review the procedure, pros and cons of some field studies on water defluoridation done in India.

Key words: ***Water, Fluoride, Defluoridation, Field studies, India***

Introduction:

Water is one of the most important elements for all forms of life and is indispensable to the maintenance of life on earth. Safe drinking water is the primary need of every human being. Pure water is scarce and is not easily available at all. Water may be contaminated by natural sources or industrial effluents. One such contaminant is fluoride.

Fluoride is a normal constituent of natural waters and its concentration varies depending on the water source. WHO standards and BIS: 105000, 1991 permit only 1.5 mg/dl as the upper permissible limit for fluoride in drinking water for the Indian context.[1]

Fluorides have certain physiological properties of great interest in relation to human health and well being. Fluoride has dual significance. If its content is less than optimum it may result in problems like dental caries. If it exceeds a certain limit it can act as an accumulative toxin. Excess fluoride in water affects not only bone and teeth, but every tissue and organ of the body. It not only affects the body of a person but also renders them socially and culturally crippled. It is a problem of public health importance.

Since majority of fluoride intake for human beings is through water, defluoridation of drinking water is one of the important remedial measures to solve high fluoride problem in drinking water.

Community Water Defluoridation:

It is defined as the downward adjustment of fluoride ion concentration in public drinking water supply so that the level of fluoride is maintained at the normal physiological limit of 1 ppm to prevent dental caries with minimum possibility of causing dental fluorosis.[2]

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Desirable characteristics of defluoridation process:[3]

1) Cost effective
2) Easy to handle or operate by the people.
3) Independent of input fluoride concentration alkalinity, pH, temperature.
4) Not affect taste of water.
5) Not add other undesirable substances (eg. Aluminium) to treated water.

Methods of water defluoridation:[4]

Based on the nature of processes:

1) Adsorption and ion exchange.
2) Precipitation
3) Electrochemical method
4) Membrane technique

Materials and Methods for water defluoridation:[4]

Adsorption	Ion Exchange	Precipitation	Others
Activated carbons, processed bone, natural or synthetic tricalcium phosphate, hydroxypatite, magnesia, activated aluminium wood, lignite, coal, petroleum residues, nut shells, paddy husk, auaram bark, coffee husk, teak waste jute waste, coconut shell, coir pitch, fly ash, krass, Bauxite, serpentine. Clay minerals, fish bone, calcite, biomass.	Anion exchange resins. Polystyrene resins. NCL polyanion resin. Tulsion A27 Lewatit MIH-59 Amberlite IRA-400 Deacedodite FF-IP Waso resin-14 Polystyrene Cation Exchange resins. Defluoron-1 Defluoron-2, Carbon	• Lime • Alum • Lime and alum (Nalgonda Tech) i) Fill and draw ii) Continuous flow Alum floc blanket method Polyaluminium chloride (PAC) Poly aluminum hydroxyl sulphate (PAHS).	Electrochemical (Aluminium electrode) Electrodialysis Reverse osmosis

1. PRECIPITATION METHOD OF WATER DEFLUORIDATION:

Nalgonda Technology:[2]

The methods are based on the addition of chemicals (coagulants and aids) and the subsequent formation of insoluble fluoride precipitates.

The first community defluoridation plant for removal of fluoride from drinking after was constructed in the district of **Nalgonda in Andhra Pradesh, in the town of Kathri**. The technology was developed by **National Environmental Engineering Research Institute (NEERI), Nagpur in 1961**.

This technique involves addition of aluminium salts, lime and bleaching powder followed by rapid mixing, flocculation sedimentation, filtration and disinfection. The dose of lime depends on the alkalinity of raw water. After the addition of lime, alum is added either as aluminium sulphate or aluminium chloride. Aluminium salt is responsible for removal of fluoride from water. The dose of lime is empirically 1/20th the dose of aluminium slats. The addition of lime ensures adequate alkalinity for effective hydrolysis of aluminium sulphate to aluminium hydroxide (floc formation). Bleaching powder is added to the raw water at 3 mg/l for disinfection. The process of floc formation and setting requires an hour.

In rural areas where people practice domestic defluoridation, stainless steel candle filters adopting Nalgonda technique are used. The equipment consists of filters fitted with candle and an additional mixing device. The advice is to mix the water with

lime and alum and leave it overnight so that the next morning, clear supernatant water is used for consumption.

In this technique, besides fluoride, turbidity, colour, odour, pesticides and organic substances are removed. Bacterial contamination is also reduced.

Cost of Defluoridation:

Annual cost (1991) of defluoridation of water at 40 litres / capita / day is Rs.20/- for domestic treatment. Rs.85/- for community treatment using fill and draw system based for 5000 population with F levels of 5 mg/l.

Domestic Defluoridaiton:

At domestic level defluoridation is carried out in a container of 60 liters capacity with a tap of 3.5 cm above the bottom of the container for withdrawal of water after precipitation and setting.

A fill and draw type defluoridation unit of 200 litre capacity was developed by NEERI. It consists of a cylindrical vessel of 1 m depth equipped with a hand operated stirring mechanism. The vessel in filled with raw water and similar defluoridation operation is performed as in bucket. The settled sludge is withdrawn through the value at the bottom of the unit. All unit operations of mixing, flocculation and sedimentation are performed in the same vessel.

Fill and Draw defluoridation plant for small community:

This is a batch method for communities upto 200 population. The plant has a hoper bottom cylindrical tank with a depth of 2 m equipped with a hand operated or power driven stirring mechanism.

Raw water is pumped or poured into the tank and the required amounts of alum, lime or sodium carbonate and bleaching powder added with stirring. The contents are stirred slowly for ten minutes and allowed to settle for 2 hours. The defluoridated supernatant water is withdrawn and supplied through stand posts. The settled sludge is discarded. **(Figure 1)**

Merits of Nalgonda Technique:

- It can be used at domestic and community level.
- The chemicals are the same as those used in municipal / urban water supply schemes.
- It is cost effective.
- There is considerable flexibility in design considerations; therefore, location specific alterations are possible.
- Defluoridated water meets the standards laid down by the Bureau of Indian standards.
- No regeneration of media.
- Simplicity of design, construction, operation and maintenance.
- Local skills can be readily employed.
- Highly efficient removal of fluoride from high levels of 1.5 to 20 mg/l to desirable levels.
- Little wastage of water and least disposal problems.
- Only muscle power is needed for domestic equipment.

Drawbacks:

- The daily operations require a trained and conscientious operator.
- The major cause for concern with the lime and alum technology in that if the dose of alum is not adhered to, thee is a possibility of excess aluminium contaminating the water The maximum concentration of aluminium permitted is 0.03 mg to 0.2 mg/litre of water according to BIS, as an excess is suspected to cause Alzheimer's disease.

2. DEFLUORIDATION BY ADSORPTION

Adsorption is the property of a solid substance to attract and hold to it's surface a gas, liquid or a substance in solution or suspension.

Activated Alumina (AA):

Prasanti Technology using Activated Alumina:[2]

This was the result of research and development activities carried out at the **Bio-Science Department of Satya Sai University for Higher learning in Prasanti Nilayam in Anantpur district, Andhra Pradesh.**

- Alumina (Al_2O_3) is practically insoluble in water. It is scarcely attacked by strong reagents.
- Alumina has to be activated for the defluoridation process.

- Different grades of AA are available indigenously at nominal cost.
- The grade suitable for defluoridation depends on the porosity and surface area of the alumina.
- Using activated alumina technology, both community and domestic defluoridation can be carried out.
- 25 community defluoridation plants, each serving approximately 200-400 people at a cost of Rs.35, 000/plant have been installed.
- Around 500 domestic delfuoridation filters are also used by people living in endemic areas. Each SS domestic filter cost Rs.1300 to Rs.1700 depending on the number of containers (1, 2 or 3) in the filter system, and the volume of the container (6, 10, 18 or 27 liter). In the filter system, the unit which is sealed with AA is exchangeable for new one at a nominal charge.
- The quality of the output water meets the BIS standards.

Drawbacks of Activated Alumina Technology:

- Expensive process
- Reactivation of filter material is cumbersome and can be done only with the help of trained persons.
- Can result in high residual aluminium in output water ranging from 0.16 ppm to 0.45 ppm.

Domestic delfuoridation units using activated alumina:[4,5] (Figure 2)

- Launched by UNICEF in rural India.
- The unit has two chambers
- The upper chamber is fitted with a flow controlled device at the bottom
- Flow is 10 litres / hour
- The main component of the unit is PVC basket containing 3 Kg of activated alumina giving a bed depth of 17 cm.
- A peforated plate of either stainless steel or tin metal is placed on top of the AA bed to facilitate uniform distribution of raw water. The top chamber is covered with lid.
- Lower chamber collects the treated water. Fitted with a tap to draw treated water. About 10 liters of water can be collected in one hour.
- Exhausted AA can be regenerated by dip regeneration method.
- Casket containing exhausted alumina is placed in a bucket containing 8 litres of 1% NaOH for 4 hours.
- The casket is then transferred to a plastic bucket containing water and is rinsed by occasional lifting.
- The casket is then placed in a plastic bucket containing 8 litres of 0.20% H_2SO_4 for 4 hours. Wash with raw water till the pH rises above 7.0. Activated alumina bed is ready for next defluoridation cycle.

Experiences of UNICEF in India using House hold based defluoridation using activated alumina:[6]

UNICEF supported the research for development of technology along with water, environment. Sanitation section (WESS) by the Department of Chemistry, IIT Kanpur. Pilot projects were taken up in Andhra Pradesh and Rajasthan in 1996-2002.

Pilot Project in Andhra Pradesh:

- Kadiri Mandal of Ananthpur district is a chronic high fluoride area.
- Domestic defluoridation unit was installed in 98-99 with assistance from UNICEF and local NGO Mytry Social Service Society.

Project implemented in three phases.

Phase I: Carried out in 1998 in 6 villages. DDFUs with plastic containers using AA were used. 30 units supplied at the cost of Rs.410/unit. Regeneration of AA was done at Panchayat Raj Engineering Department in Kadiri.

Phase II: Carried out in 1999-2000 in 25 villages. 2000 DDFU made of stainless steel chambers distributed at unit cost of Rs.1000. Regeneration of AA carried out at Rural Sanitary Mart in kadiri. Given at Rs.250/unit to BPL families and Rs.400/unit to APL families.

Phase III: Expansion was carried out to 25 more villages at the same cost as in Phase II. 1800 units were

distributed in 2000-01 and 1000 units in 2001-02. Regeneration of AA was carried out at village level.

By June 2003, Mytry had 60 dealers in AP and 20 in Karnataka. About 60000 filters had been marketed.

Practical Problems:

- Disposal of effluents
- Long time required for the regeneration of activated alumina.

Pilot Project in Rajasthan:

Out of the 32 districts in Rajasthan 22 are fluoride affected. 16,560 villages are affected by high fluoride.

UNICEF assisted two NGOs SKIACH and SARITA for pilot project in Dungarpur since 1996. The project has spread to 120 villages in Dungarpur and around 1800 DDUs were processed by UNICEF and distributed. By Mid 2003, 24000 DDUs had been distributed in 5 districts of Rajasthan through government agencies.

Major areas of Study:

Development of Hand Pump attached defluoridation units: **(Figure 3)**

- A cylindrical DFU was field tested in Makkur Unnao district in Uttar Pradesh, 1993.
- Drum was 0.5 m in diameter, 1.5 m in height and from mild steel sheet.
- 10 kg of AA, grade G-87, particle size 0.3 to 0.9 mm with a bed depth of 55 cm was used.
- The entire unit was maintained by IIT Kanpur.
- Raw water fluoride concentration ranged from .7 mg/l. Regeneration of AA was carried out in situ within the column and required 8-11 hours.
- Yield per cycle was 25,000 liters.

Advantages:

- No major maintenance problem
- No complaint from uses about the palatability of water or the design.

Disadvantages:

- Community involvement during regeneration was minimal. The unit was dismantled in 1998 as the village community got access to piped water supply.

Hand pump attached Defluoridation Units and Domestic Defluoridation Units (DDUs) for Rural Areas: Pros and Cons:[6]

Advantages:

- A low cost of treatment, as only a limited volume of water is required to be treated.
- The low requirement of treated water correspondingly lowers the need for chemicals and finally results in generation of lower volumes of sludge.

Disadvantages:

- Success depends on treatment reliability.
- Requires motivation of consumers to use only treated water for cooking and drinking.

Community defluoridation units are not encouraging because of,

- Lack of ownership by user communities.
- Reluctance to take over management responsibility.
- Lack of maintenance at local level by users.
- Lack of funding for maintenance.
- Degree of institutional willingness to relinquish control over installation.
- Activated alumina in a handpump unit has to be periodically regenerated.

KRASS Defluoridation Process:[7]

Fluoride contaminated water is passed through a bed of specially designed filter media to get defluoridated water. The process has been verified by CSIR and PHED of Rajasthan.

Advantages:

- Simple process and cost effective
- Very low traces of residual aluminum in outlet water.
- There is no limit on fluoride concentration in input water.
- Temperature, pH, alkalinity and total dissolved solids of input water do not affect this process.
- It is a practical approach for rural population.
- Easy to use for illiterate villagers.

- Minimal involvement of technical personnel.
- Once laid down, the only expenditure is that of recharging according to the capacity of the filter.
- The exhausted media bed can be easily recharged without replacing the material at least for 40 cycles.
- The process achieves better removal of suspended matter, better clarity and maintains taste of water.
- The treatment cost is around 0.6 — 0.8 paise / per litre at 10 ppm of fluoride.

3. DELFUORIDATION BASED ON ION EXCHANGE MECHANISMS

Carbion

- The resin has good durability
- Can be used both on sodium and hydrogen cycles.
- Fluoride removal capacity of 470 mg F/Kg carbion.

Pilot Plant:[2]

Using carbion and defluoron-1 in 8:1 proportion was installed at **Gangapur (Rajasthan).** Filter alum of 2, 3, 5, 6 and 10% were used to regenerate the mixed medium. The fluoride content of raw water was 4.8 mg/litre. Most of defluoron-1 was washed out in the first few cycles. Cost of treatment: Rs.0.3 / m^3 of water with 4.3 mg/liter fluoride.

Defluoron-2:[2]

- Developed in 1968
- It is a sulphonated coal and works on the aluminium cycles.
- Gives best results with one bed volume of 4% alum solution as regenerate.
- Life of medium is 2-4 years.
- Fluoride removal capacity 484 mg F/litre of defluoron-2.

Plant Studies:

Two plants with a capacity to treat 20,000 gal per regeneration were installed at Municipal Corporation, Nalgonda and CTI, Hyderabad. The plant had a pressure shell, regeneration tank and a storage reservoir of 4-6 liters capacity. Water is passed through a bed of defluoron-2 medium contained in a cylindrical steel shell to which are attached pipe work and control values.

Fluoride Removal Technology Developed by Ion Exchange India:[8]

- Adopted for rural areas
- Reduces fluoride level at less than 1 ppm in a single stage.
- Simple and user friendly.

Available as

- Point of use for homes
- Hand pump attachments to cater to house holds that draw water from wells using hand pumps.
- Large community level systems.

Indion Domestic Defluoridation Unit:

The point-of-use unit has a three stage process of filtration and fluoride removal.

1) Filtration

Water is passed through a coarse washable filter pad to remove suspended particles.

2) Defluoridation

Water passes through a special activated alumina media which absorbs the fluoride son its surface. The large surface area and pore size of the media provides better diffusion.

3) Filtration

Fluoride free water passes through a filter dome. It retains the media in place and provides polishing filtration. Media can be regenerated several times.

Advantages:

- Stainless steel units are corrosion resistant.
- Easy to handle
- Does not require electricity to operate
- Filter media is reusable

- Operating and maintenance cost is low.
- Size of the filter is based on UNICEF guidelines. The quality management process has been audited by UNICEF.

Supplied to

- Methan, Mehasana district of Gujarat in 1997.
- Collaborative initiative between Ion Exchange India, Muniwar Abad Charitable Trust and the village community.
- Treats 30,000 litres/day drinking and cooking after at a treatment cost of 2 paise/ litre.

Indion Delfuoridation Hand pump Attachment:[9]

- Installed at Mangi Kolam site in Yavatmal district in Rural Maharashtra.
- The fluoride content of ground water reduced to 0.304 ppm from 8.73 ppm.
- Installed also at Nanded and Nagpur.
- Approved by Govt. Of Maharasthra.
- 67 defluoridation units have been installed at Yavatmal.

IISc Method of Defluoridation of water using magnesium oxide:[10]

The method uses **magnesium oxide, calcium hydroxide and sodium bisulfate.**

Magnesium oxide removes dissolved fluoride ions from water samples by;

$$MgO + H_2O \rightarrow Mg(OH)_2$$

$$2NaF + Mg(OH)_2 \rightarrow MgF_2 + 2\ NaOH$$

Fluoride ions precipitate as insoluble magnesium fluoride. Due to MgO the pH of treated water is 10 to 11. It is adjusted to desirable limits (6.5 to 8.5) by adding sodium bisulfate (0.15 to 0.2 g per litre). If bicarbonate ions are in excess of 200 ppm they interfere with sodium bisulfate used for lowering the pH. Hence, use of 0.3 g calcium oxide + 0.8 g magnesium is mixed / litre of fluoride water to overcome the bicarbonate interference to sodium bisulfite.

Fluoride Removal by IISc method at Kolar, Karnataka.

Spiked water samples

Fluoride level: 2 to 5 ppm

Dissolved salts: 260 to 940 ppm

Bicarbonates: 100 to 450 ppm

Natural water samples:

Fluoride level: 1.8 to 3.5 ppm

Dissolved salts: 390 to 775 ppm

Bicarbonates : 215 to 390 ppm

A simple to use domestic defluoridation unit is developed to treat 15 litres of fluoride contaminated water by IISc method.

Principles of the DDU:

The device has two units, each of 20 litres capacity. The upper unit has a mixing cum sedimentation unit. It is equipped with manually operated, geared mechanical stirring device for mixing of MgO and F water. The lower unit collects treated water. 15 litres of F water is poured in the upper unit. $Ca(OH)_2$ + MgO are added and manually stirred for five minutes.

Suspension is allowed to stand for 16 hours. Fluoride bearing sludge settles at the bottom. The clear water is decanted into lower collection unit through flexible connecting pipe fitted with a fine filter to trap any escaping sludge. Water soluble sodium bisulfate is dissolved in the lower chamber and the water is ready for use. Sludge is stored in a concrete lined pit till further use. The cost of treating 1 litre of fluoride water with 2-5 ppm by IISc method is 7 paise/litre and the cost of DDU is ~ Rs.2000/unit.

The IISc method can be scaled up to treat fluoride contaminated water at community level (500-2000 litres/day).

Field trials of this method at individual house hold levels will soon commence in four villages of Kolar district, Karnataka.

CONCLUSIONS:

The community and household delfuoridation systems have pros and cons. The task is not just to experiment with more efficient methods of defluoridation; it is to develop workable strategies to provide safe drinking water. Simple, economical and effective procedures for water delfuoridation are needed. Demand driven and participatory approach are to be followed to successfully implement the fluorosis mitigation plan.

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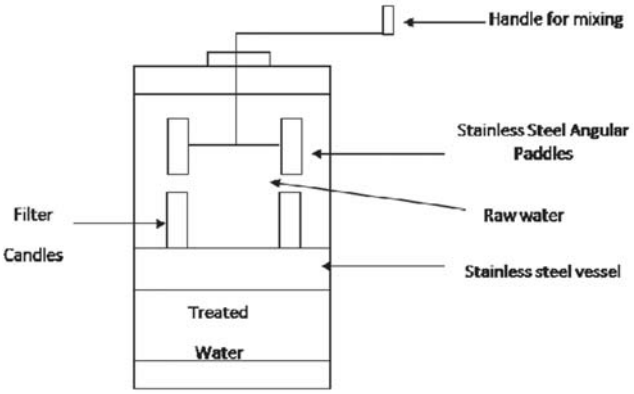

Figure 1: Fill and Draw Defluoridation Plant for a small Community

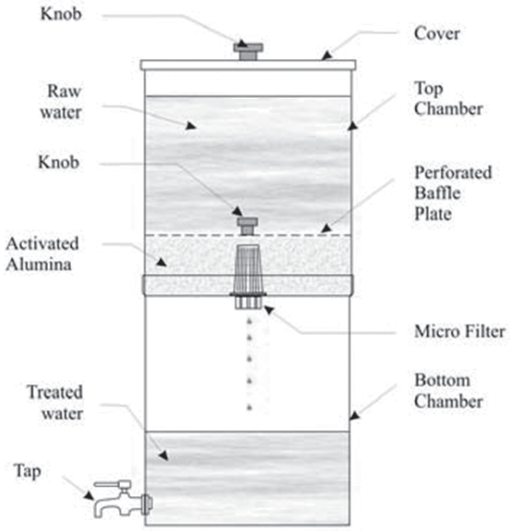

Figure 2: Household Level Activated Alumina Filter

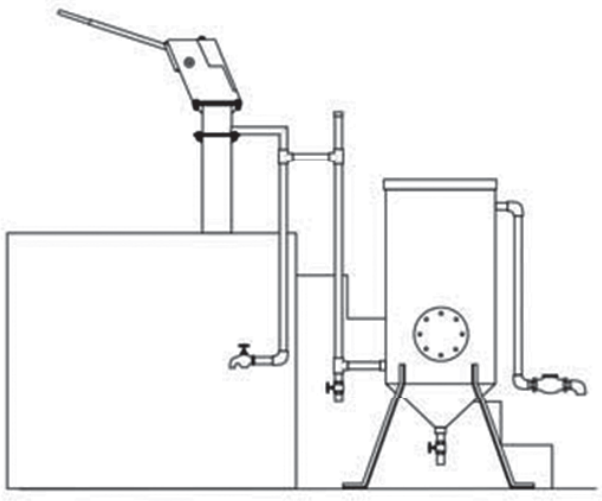

Figure 3: Hand Pump Attached Defluoridation Unit Developed By Iit Kanpu,1993