Application Notes on IISc method of defluoridation

The IISc method relies on magnesium oxide based, precipitation-sedimentation-filtration technique to reduce fluoride concentrations in water to permissible levels (< 1.5 ppm). It uses a domestic defluoridation unit (DDU) to implement the chemical treatment procedure. The magnesium oxide method for fluoride removal has several advantages. Magnesium oxide has very limited solubility in water and therefore does not add to total dissolved salinity. All chemicals used in the process are non-toxic. Alkaline pH of the magnesium oxide treated water is easily neutralized by addition of sodium bisulfate solution. The method does not involve any recharge process and thus avoids generation of corrosive and toxic wastes. The method is designed to treat fluoride-contaminated groundwater with varied ionic composition. Technology for re-use of sludge into stabilized mud blocks has been developed.

Principle of the method

The designed method treats fluoride-contaminated groundwater with fluoride ion concentrations ranging from 1.5 to 7 mg/L. Fluoride ions are removed by magnesium oxide through chemisorption mechanism. On addition to water samples, magnesium oxide hydrates to brucite [$Mg(OH)_2$] as:

$$MgO + H_2O \rightarrow Mg(OH)_2 \qquad (1)$$

During brucite formation, fluoride ions (F^-) in the contaminated water samples are incorporated into the brucite lattice by isomorphous substitution of hydroxyl ions by fluoride ions. The isomorphous substitution reaction leads to the formation of the $Mg(OH)_{2-y}.F_y$ phase. In addition to magnesium oxide, calcium chloride solution, sodium bisulfate solution and calcium hydroxide (as solids) are added to the raw water. Addition of magnesium oxide increases the pH of water between 10.1 and 10.3. Sodium bisulfate solution reduces the pH of magnesium oxide treated water within potable water limits (6.5 to 8.5) by the reaction:

$$HSO_4^- + OH^- \Rightarrow SO_4^{2-} + H_2O \qquad (2)$$

Bicarbonates ions present in the fluoride-bearing water samples convert to carbonate ions in the alkaline pH created by magnesium oxide addition according to the reaction;

$$HCO_3^- + OH^- \Rightarrow CO_3^{2-} + H_2O \qquad (3)$$

The carbonate ions formed in reaction 3, in turn consume additional sodium bisulfate as:

$$CO_3^{2-} + HSO_4^- \Rightarrow HCO_3^- + SO_4^{2-} \qquad (4)$$

Calcium hydroxide (hydrated lime) and calcium chloride solution reduce interference of bicarbonate ions towards sodium bisulfate consumption by transformation of soluble bicarbonates to insoluble calcium carbonates as:

$$HCO_3^- + Ca^{2+} + OH^- \Rightarrow CaCO_3 + H_2O \qquad (5)$$

Chemical treatment procedure

Known weights of magnesium oxide-calcium hydroxide mix + known volume of 7.5 % calcium chloride solution (see Table 1) are added to fixed volume (15 or 100 liters) of fluoride-contaminated water. Efficient contact between added chemicals and fluoride (in water) is achieved by stirring the fluoride-contaminated water for 3-5 minutes using electrical (Figures 1 and 2) or hand-operated stirrer (Figure 3). The water is allowed to settle for 16 hours at the end of which the magnesium oxide sludge settles to the bottom of the container. The clear water is filtered into a separate container and water-soluble sodium bisulfate is added for pH adjustment and the water is fit for human consumption. The magnesium oxide sludge is carefully stored in a 100 liter container till further use (Figure 1).

DDU construction and use

A simple to use 15 and 100 liters DDU is used to treat of fluoride-contaminated water using the IISc method (Figures 1 to 3). The 100 liters DDU comprises of 100 liters capacity PVC drum (Figure 1) and is equipped with heavy duty electrical stirrer (Figures 1 and 2). The 15 liters DDU comprises of 20 -25 liters capacity stainless steel drum (Figure 1to 3) and is equipped with light-duty electrical stirrer (Figures 1 and 2) or hand-operated mechanical stirrer (Figure 3). The units serve as a mixing cum sedimentation unit. Taps are fixed above the base of the containers to drain the sedimented water. To trap any escaping sludge particles from the unit, cotton cloth filter is tied to the tap of the upper unit (Figure 1). The cost of IISc method is provided in Table 2. The cost of treating

1 liter of fluoride-contaminated water by the IISc method is 17 to 27 paisa/liter. In comparison, the cost of treating fluoride contaminated groundwater by the activated alumina method is higher at 40 paisa per liter.

Field Implementation of IISc Method

Field worker was trained in using the IISc method and monitoring the field implementation in the selected households. The field worker was responsible for collecting chemicals from IISc distributing to selected households periodically; collecting raw and treated water samples from the households and bringing it to IISc for monitoring periodically. The households in Yellodu and Chakavellu villages (Kolar district, Karnataka) are supplied with magnesium oxide + calcium hydroxide packets containing specified dosages of chemicals to treat 15/100 liters of raw water and bottles containing specified volumes of 7.5 % calcium chloride solution and 5 % sodium bisulfate solution to treat 15/100 liters of water on a daily basis (Figure 4). At both villages in Kolar District, the IISc method is being successfully implemented at selected households over a prolonged period.

Environmentally Friendly Sludge Disposal

Treating 1 liter of fluoride contaminated water by IISc method approximately generates 2.5 grams of moist sludge (gravimetric water content is approximately 200 %). Sludge produced by the method can be disposed in an environment friendly manner by consuming it in the manufacture of sludge admixed stabilized mud blocks (SMB). The sludge is collected in 1000 liter container and at the end of the year is transformed into building material. Transformation of sludge is accomplished by using the air-dried sludge as a constituent of stabilized mud blocks (Figure 1). These stabilized mud blocks are an alternative to burnt bricks and are produced by cement stabilization of densely compacted soil mass. Experimental results indicate that incorporation of sludge as a constituent of stabilized mud blocks does not impact their compressive strength, linear expansion or durability. Furthermore, the fluoride-release potential is well within permissible limits during rigorous environmental tests conducted on sludge admixed stabilized mud blocks.

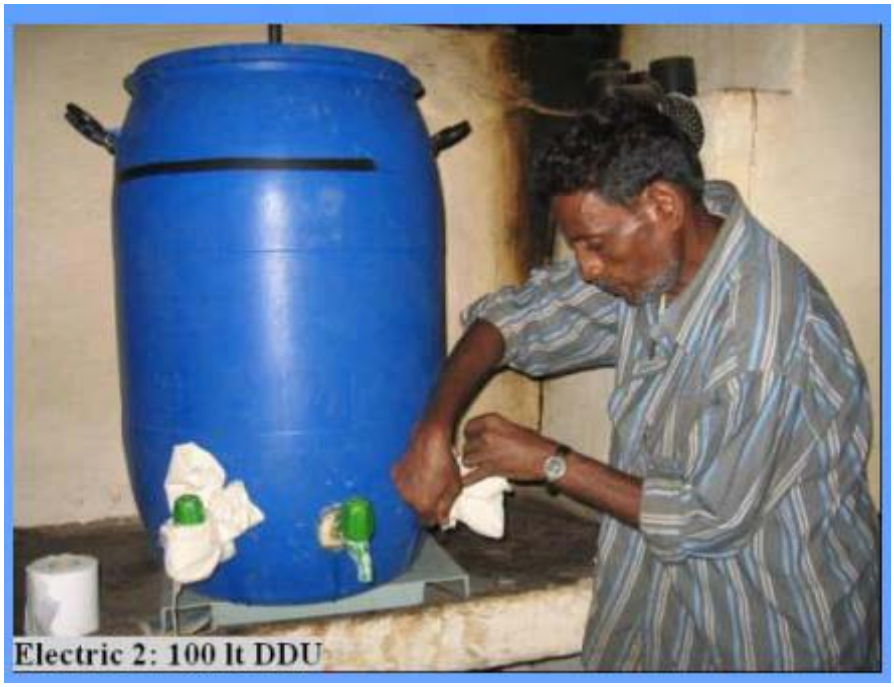
Table 1. Chemical dosages for IISc method

Initial fluoride concentration, mg/L	**Volume of 7.5 % calcium chloride solution to be added, ml/L**	**Magnesium oxide dosage, g/L**	**Initial bi carbonate concentration, mg/L**	**Calcium hydroxide dosage, g/L**	**Volume of 5 % sodium bisulfate solution to be added to treated water, ml/L**
1.5 - 7	4	1-1.5	250 - 400	0.3	1-3
1.5 - 7	4	1-1.5	>400 - 500	0.4	1-3
1.5-7	4	1-1.5	> 500-700	0.50	3-6

Table 2: Costs for IISc technique for treating 100 liters of fluoride contaminated water (fluoride concentration 1.5 to 7 ppm)

Item of IISc method	Cost in Rupees	Cost of chemicals for treating 100 liters of contaminated water (Rupees)
Defluoridation unit 100 liter capacity with heavy duty electric stirrer (1 No.) Defluoridation unit 15 liter capacity with light duty electric stirrer (1 No.) Defluoridation unit 15 liter capacity with hand-operated mechanical stirrer (1 No.)	8000 2500 4500	----------
Light Magnesium oxide (Commercial grade) /kg	160	16-24
Lime (Commercial grade) /kg	20	0.6-1.0
Calcium chloride (commercial grade)	25	0.75
Sodium bisulfate (commercial grade)/kg	40	0.6-1.0
Total		8000[1] + 18-26.75*

*****Recurring cost of chemicals to treat 100 liters of water



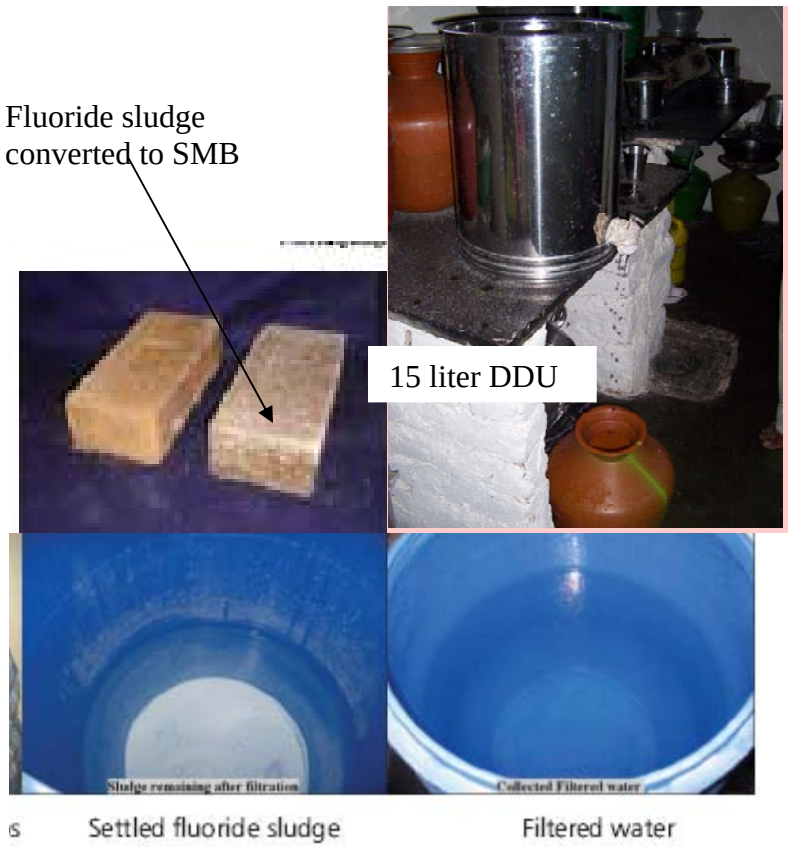


Fig. 1: 15 liter and 100 liter DDU used in Yellodu village. Fluoride sludge bearing stabilized mud block

Fig. 2: Light duty (for 15 liter DDU) and heavy duty (for 100 liter DDU) electric stirrers used in Yellodu village

Fig. 3: DDU with mechanical (hand-operated) stirring devise used in Chakavellu village

Fig. 4: Chemicals distributed to households in Yellodu village

Field monitoring results

Figure 5 plots the data of fluoride concentration, in water samples treated by IISc method from a representative household in Yellodu village spanning the period of June 2006 to November 2007. Likewise, Figure 6 plots the corresponding data for a representative household in Chakavellu. Figures 5 and 6 show that fluoride concentrations in the treated water samples were always lower than the permissible limit of 1.5 ppm, implying that the IISc method was successful in reducing fluoride concentrations in the groundwater samples. More importantly it showed that the technology was successfully adopted by the rural user community.

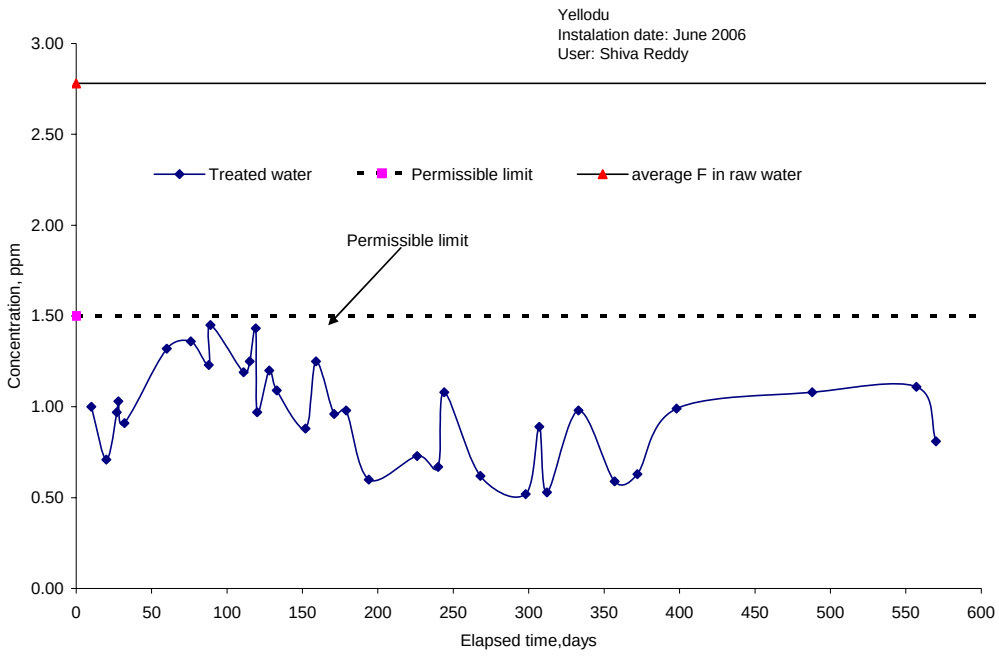


Fig. 5: Variation in fluoride concentration in treated water samples as function of treatment period: 15 liter DDU with electric stirrer

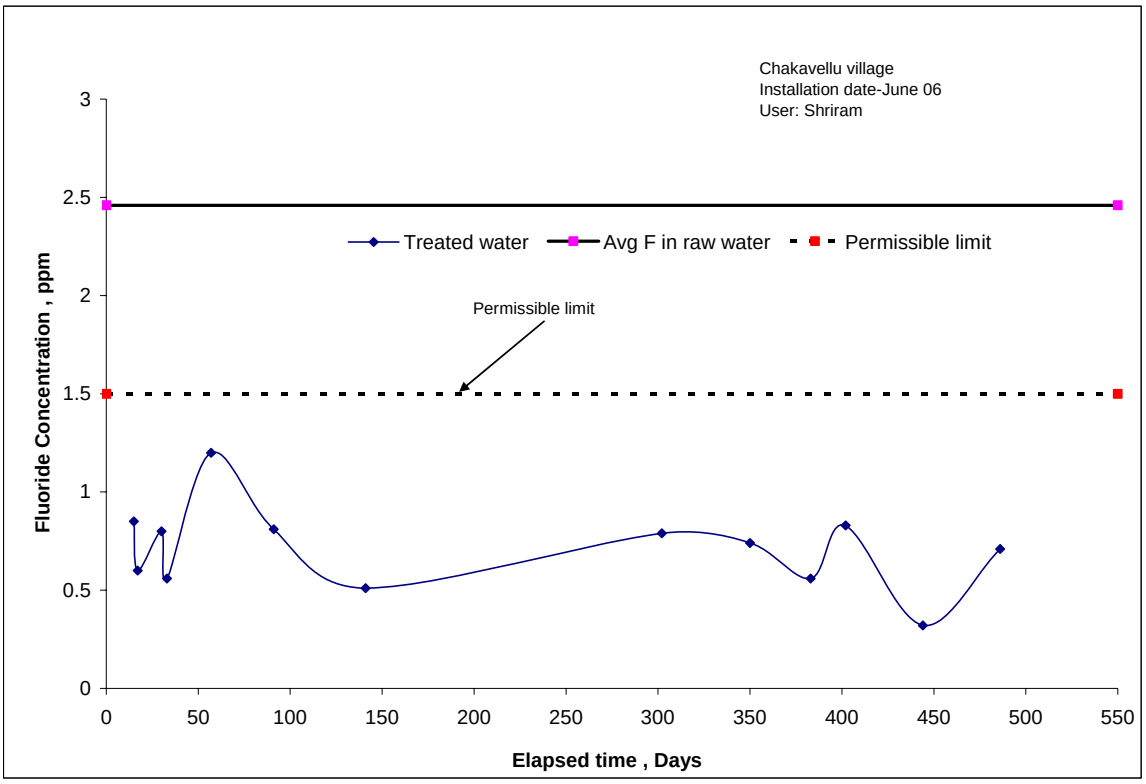


Fig. 6: Variation in fluoride concentration in treated water samples as function of treatment period: 15 liter DDU with electrical stirrer

Relevant references

1) Rao Sudhakar, M. and Mamatha, P., 2004. Water Quality in Sustainable Water Management, **Current Science**, 87, 942-947.

2) Rao Sudhakar M., Mamatha, P., Shantha, R. P. and Venkatarama Reddy, B. V. 2007. Encapsulation of fluoride sludge in stabilized mud blocks. **Waste and Resource Management**, 160 WR 4, 167-174.

3) http://dst.gov.in/about_us/ar06-07/st-socio-dev.htm

4) Rao, Sudhakar M., Monto, M. and Ravindranath, N. H. 2008. Advances in water quality and management, Research Publishing Services, Singapore (This edited book was sponsored by the Science & Society Division of DST).

Project Team

- Prof. Sudhakar M. Rao
- Mamatha. P (Research Student)
- Asha. K (Research Student)
- Soumita Kundu (Project Assistant)
- Mythri.D.J (Project Assistant)
- Prof.B.V.V.Reddy
- Manjunatha Reddy (Field worker)

Project Supported by

- Indian Institute of Science
- Department of Science & Technology
- Karnataka State Council for Science & Technology
- CAPART, New Delhi

Contact

Prof. Sudhakar M. Rao,
Dept of Civil Engineering /
Centre for Sustainable Technologies,
Indian Institute of science,
Bangalore-560012
India
Ph: 080-22932812
Email: msrao@civil.iisc.ernet.in