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Performance of Electrolytic Defluoridation Plants for Safe Drinking Water Supply in Fluoride Affected Habitations in Jharkhand State of India

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Abstract: Electrolytic defluoridation (EDF) technique worked on the process of electrocoagulation by passing direct current through aluminium electrodes immersed in fluoride containing water. In the process of electrocoagulation dissolution of aluminium electrode, connected to anode, takes place and form species of polyhydroxy aluminium, which reacts with fluoride in water to form the complex followed by adsorption and settling. Solar power based EDF plants were installed in fluoride affected habitations in Jharkhand state of India to remove excess fluoride from groundwater. Performance evaluation of these plants was undertaken for safe drinking water supply. The treated water meets the acceptable limit of fluoride (1 mg/l), as per IS-10500 standards. The treated water is also free from bacteriological contamination which is attributed to disinfection brought about by generation of chlorine during electrolysis of chloride in the water and also absorption of bacteria on flocs of poly-aluminium hydroxide species.

Keywords: Performance • Evaluation • Electrolytic • Defluoridation • Adsorption • Polyhydroxy • Aluminum O&M

INTRODUCTION

In rural water supply, fluoride in drinking water is one of the emerging problems and needs an effective and sustainable treatment solution. Fluoride in lesser amount is required for normal bone mineralization and dental enamel formation (Bell & Ludwig 1970). However, excess fluoride intake through drinking water may result in development of fluorosis. During past few years, studies have been conducted on several procedures and techniques for removal of fluoride from water. These procedures and techniques are based on the principle of adsorption (Raichur & Basu 2001), ion-exchange (Singh et al. 1999), precipitation and coagulation (Saha 1993; Reardon & Wang 2000), membrane filtration (Amer et al. 2001; Dieye et al. 1998), electrodialysis (Hichour et al. 1999; Hichour et al. 2000; Adhikari et al. 1989), electrolytic defluoridation (Mameri et al. 2001) etc.

Electrolytic defluoridation (EDF) is an electrocoagulation method for treatment of contaminated water whereby sacrificial electrodes dissolve to release active aluminium ions as precursors for coagulation (Pouet & Grasmick 1995; Mameri et al. 1998; Holt 2003).

In groundwater fluoride occurs in Garhwa and Palamu districts located in north-western side in Jharkhand state (Rahul Kumar 2016). Chronic fluoride intoxication in the form of dental and skeletal fluorosis is prevailed in villages of the Palamau and Garhwa districts, Jharkhand, India. Out of 238 sources of drinking water, mainly from groundwater, the majority had elevated fluoride concentrations capable of causing health risk to the community (Srikanth et al. 2008). Dietary intake of fluoride through food, however, was much less significant compared with drinking water. Among the children, 83% were diagnosed with dental fluorosis, and 47% of adults were afflicted with various stages of skeletal fluorosis. A level of 2.5 mg/L of fluoride was found to be a critical threshold for manifestations of crippling skeletal fluorosis. This area is having crystalline igneous rock formations and alkaline soils and semiarid climatic conditions and groundwater as a major source for drinking purpose.

The main source of fluoride in groundwater is considered to be fluoride-bearing minerals such as fluorspar (CaF_2), fluorapatite [$Ca_5(PO_4)_3F$], cryolite and hydroxylapetite in rocks (Farooqi et al. 2007). Fluoride in small amounts is an essential component of normal mineralization of bones and formation of dental enamel (Bell and Ludwing 1970). However, excessive intake of fluoride through water and food consumption can cause dental and skeletal fluorosis (Sorg 1978; Mahramanliglu et al. 2002). Due to its strong electronegativity , fluoride is attracted by positively charged calcium in teeth and bones (Susheela 1993). Palamu and Garhwa districts comprising the study area are located in the north western part of the Jharkhand state suffers due to high concentration of fluoride in groundwater (Pandey et al. 2012)

Drinking Water and Sanitation Department, Jharkhand have installed Electrolytic De-Fluoridation (EDF) plants in fluoride affected habitations in Garhwa and Palamu districts for safe drinking water supply. Performance evaluation of these EDF plants was undertaken in order to suggest suitable measures for better performance of the EDF plants with O&M measures for safe drinking water supply to the public on sustainable basis.

MATERIALS AND METHODS

Study area: The study area comprised of fluoride affected villages in Garhwa and Palamu districts in Jharkhand state of India. In these districts, groundwater is the main source of district of drinking water. Socioeconomic conditions are very poor and villager depend entirely on agriculture and allied activities suffering from various degree of malnutrition (Pandey et al. 2012). The location map of study area is given in Figure 1. The plants to be evaluated were visited as per the list provided by the DWSD and location details are provided in Table 1. **Error! Reference source not found.**The water samples from raw water

sources and treated water samples collected in storage tanks after treatment were collected and tested in the laboratory with standard methods (APHA, 2012)

Electrolytic Defluoridation Process: An electrolytic defluoridation unit primarily consists of electrolytic reactors with cathode and anode (Fig. 2). The electrocoagulation occurs by applying direct current (DC) through aluminium electrodes immersed in fluoride containing water. When a DC is transmitted across the electrodes, anode gets dissolved and release active aluminium ions whereas hydrogen gas is generated at cathode. Formation of polyhydroxy aluminium occurs during dissolution of aluminium electrode. This polyhydroxy aluminium reacts with the fluoride in water to form the complex by adsorption, which is settled consequently.

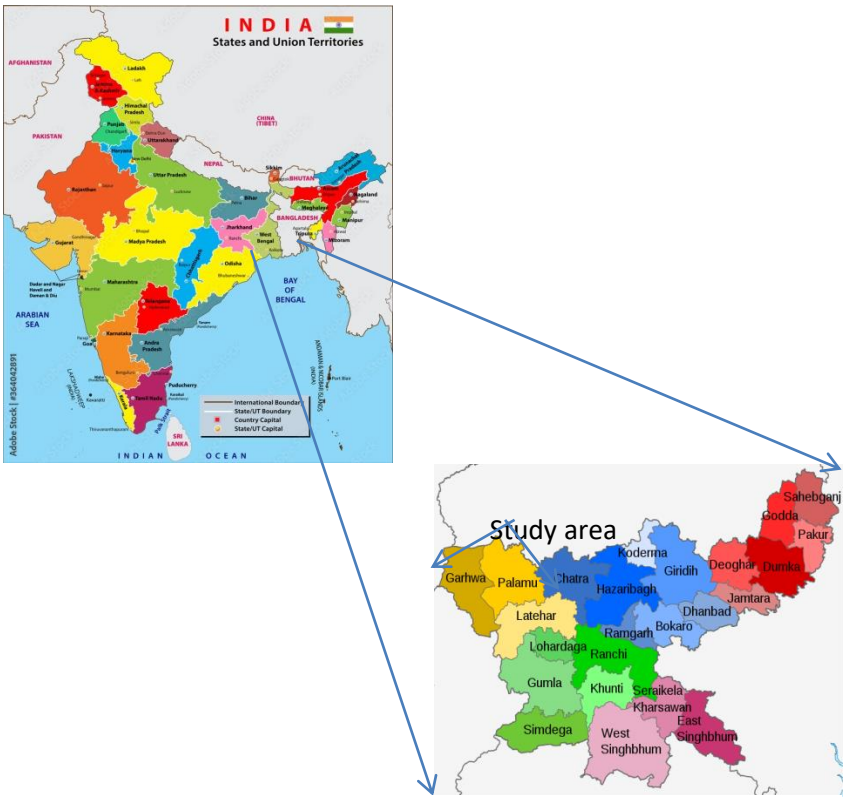

Fig.1. Study Area Map

Chemical reaction taking place during electrolytic defluoridation is as following:

Anode: $Al_{(s)} \longrightarrow Al^{3+} + 3e^-$

Cathode: $2H_2O + 2e^- \longrightarrow H_{2(gas)} + 2OH^-$

The Al^{3+} ions further react and form $Al(OH)_3$ flocs which adsorb fluoride ions available in water resulting in sludge formation.

$Al^{3+} + 3H_2O \longrightarrow Al(OH)_{3(sludge)} + 3H^+$

$Al(OH)_3 + nF^- \longrightarrow Al(OH)_{3-n}Fn + OH^-$ (sludge)

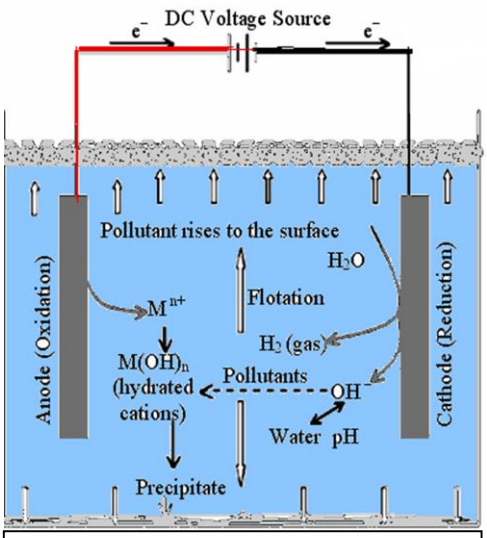

Fig. 2 Schematic diagram of EDF

In an electrolytic defluoridation process the 'in situ' generation of coagulating ions occurs in three consecutive stages viz. (i) electrolytic oxidation of anode resulting into formation of coagulants; (ii) destabilization of fluoride ions and (iii) aggregation of the destabilized phases resulting into floc formation. The destabilization of the fluoride ions takes place in following manner:

- Compaction of diffused double layer around charged species due to interactions of the ions generated during oxidation of anode
- Counter ions produced during electrocoagulation bring about charge neutralization of ions present in water. Thus the process results in zero net charge.
- Flocs formed during coagulation generate a blanket of sludge which entraps the colloidal particles left out in an aqueous phase.

Aluminium ions, generated from the sacrificial electrode (anode), hydrolyze to aluminum hydroxide. These aluminum hydroxides act as coagulants which offer an active surface for adsorption of fluoride ions present in water. The metal cations react with the negatively charged particles attracted towards anode by electrophoretic motion and coagulation takes place. Fluoride is aggregated by precipitation or adsorption on colloidal materials, and removed by sedimentation and filtration. Here, instead of adding coagulating agents, in situ generation of coagulating agents takes place.

Evaluation of EDF plants: The installed EDF plants were visited (**plate 1)** to collect the details such as location, habitats, design level of fluoride in water, plant capacity, approachability etc. Monitoring of drinking water quality was undertaken at various stages of treatment for performance evaluation of the EDF plants. Functioning of the plants was review with respect to fluoride removal efficiency and design parameters in order to suggest the measures for improvement in performance of the EDF plant. The water samples before (raw) and after the treatment were collected and tested in the laboratory for fluoride content, pH, and conductivity and also for other important water quality parameters. The water quality results are presented in **Table 1.**

Details of EDF systems installed and their specifications: The room (4m x 4m x 4 m) constructed for housing the EDF system. The bore well is fitted with solar pump (1 hp, 110 V DC) for pumping the raw water. Charge controller with 200AH batteries (1 X 200AH or 2 X 100 AH) is provided to supply Direct Current (DC) of required value to EDF electrodes (Plate 1). DC to AC inverter with 10-20 W pump is fitted to re-circulate the water in the EDF reaction tank. DC power regulator is of 30 A capacity. EDF reaction chamber is of 1000L capacity (Plate 2). Aluminium plate electrodes, containing 3 plates separated by 1-2 cm distance, are connected with Teflon nuts and bolts immersed in the reactor. 0.5 HP Pump is provided in order to pump the treated water through dual media filter and store in treated water tanks (Plate 3). Treated water tanks (HDPE) is of 1000L capacity (2 Nos.) with the 2-3 taps attached outside the EDF system room (Plate 4 and 5). Solar panels (12 nos.) of 100 Watt capacity each (9 panels for raw water pump and 3 panels for charging the battery for EDF process) are provided. Sludge collection tank (HDPE) with water overflow arrangement placed outside the EDF room below the ground level (Plate 6).

S. N.	Block	Habitation	Water quality parameters			
			pH	Conductivity (µS/cm)	Fluoride (mg/l)	BIS 10500:2012 limit of Fluoride
			……*Raw/Treated*……			*Acceptable/ Permissible*
1.	Garhwa	Mohnram Tola	6.8/6.7	447/420	6.9/0.5	
2.	Garhwa	Patsa	7.5/7.6	744/935	3.0/1.1	
3.	Nagar Untari	Hulhula Kala	7.0/7.3	667/535	3.2/0.6	

4.	Nagar Untari	Hulhula Khurd*	7.4/--	577/--	1.2/--	1.0/1.5
5.	Nagar Untari	Man Tola	7.3/7.3	658/827	3.5/1.2	
6.	Medininagar	Kauriya	7.1/7.2	1212/997	1.5/0.5	
7.	Patan	Khas	7.5/7.4	738/565	4.5/0.4	
8.	Tarhasi	Kasmar	6.6/6.9	375/349	3.2/1.0	
9.	Chainpur	Kosiyara*	7.2/--	506/--	3.5/--	
10.	Manatu	Chak	7.2/7.2	616/366	5.0/1.2	
11.	Satbarwa	Bari	7.2/7.2	522/592	3.9/0.6	

RESULTS AND DISCUSSIONS

The fluoride concentrations in untreated (raw) water samples range from 3.0 mg/l to 6.9 mg/l in nine EDF plants and in one plant fluoride concentration was 1.2 mg/l (Table 1). The fluoride content in untreated water was below the acceptable limit of 1.0 mg/l as per BIS standards (BIS 2012) in a plant located at Kauriya village in Medininagar block in Palamu district. Water samples did not show significant change in pH of untreated and treated water samples in all the plants. TDS content of water found to be within permissible limit for drinking water as per BIS standards. Out of 11 plants evaluated, fluoride content in treated water was below 1.0 mg/l in 5 plants. In 4 plants fluoride concentration was more than 1.0 mg/l, whereas in 2 plants treated water samples could not be collected as the plants were non-functional. Somewhat increase in conductivity of treated water was recorded in few EDF plants.

Routine operations of EDF plants are handed over to the persons who are the owner of the land on which the plants are constructed. The agency who has commissioned the plants is paying some amount per month to these persons for operation of the plants. Fluoride testing kit was available at each EDF plant. Brochure indicating the plant SOP and day to day plant O&M was available at most of the plants. At every plant, there is a board indicating the details of the village, block, district, plant capacity etc.

CONCLUSION

Based on the findings it can be concluded that EDF technology provides a sound, economic and reliable defluoridation system for provision of safe drinking water to rural community in fluoride endemic areas. The treated water meets the acceptable limit of 1 mg/l, as per IS-10500 standards, for fluoride. The treated water is also free from bacteriological contamination which is attributed to the disinfection brought about by generation of chlorine during electrolysis of

chloride in the water and also the absorption of bacteria on flocs of poly-aluminium hydroxide species. EDF technology provides cost effective solution for provision of safe drinking water in fluoride affected areas with proper treatment, O&M and public participation.

RECOMMENDATIONS

In order to provide safe drinking water in fluoride affected areas, where EDF plants are installed, the following measures are to be undertaken.

- EDF plants should not be operated if fluoride concentration in raw water is below 1 mg/l.
- EDF plants should be operated at designed DC value for the required duration to bring down the fluoride content in the treated water below acceptable limit of 1 mg/l.
- Raw and treated water fluoride concentrations should be regularly monitored to change DC (if required) and duration of passing the DC to generate the fluoride safe water.
- Spare equipment/instruments should be available with the agency to replace the defective items immediately to avoid the non-functioning of the plant.
- Supernatant flowing out from the sludge storage tank should be monitored. Inventorisation of the sludge should be maintained and can be used for brick/road making once the quantity of sludge exceeds 100 kilogram.
- Residual aluminium in treated water should be monitored once in a month.
- Dust settled on the solar panels should be cleaned regularly in order to avoid the reduction in power supply generated by the solar panels.
- Names and mobile numbers of plant operator and the person responsible for the maintenance of the plant should be displayed on the plant.
- Schematic diagram of the electrical circuits, pipes and valves in the EDF system should be displayed on the board inside the plant.
- Training should be provided to the plant operators for day to day operation of the plant and periodic maintenance of plants including the minor repairs in case of emergency. Tools such as screw driver, pipe wrench, spare taps etc should be provided to the operator.
- Pictorial messages about the importance of the fluoride safe water and hazards of fluorosis may be painted on the wall of the plants which may help to generate the public awareness among the people.
- Public awareness camps should be organised in the villages to make them aware about the hazards of consuming water with high fluoride content.
- IEC should be undertaken through the support from the health and education department

Fig.1: Charge controller, battery inverter, DC regulator & battery (200 AH) inside EDF plant

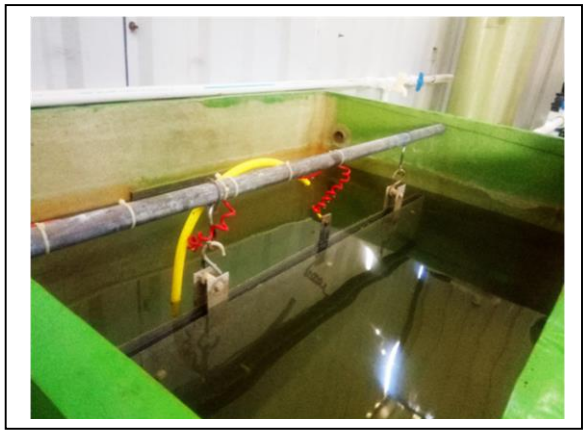

Fig. 2: Aluminium plate electrodes and EDF reaction chamber inside the EDF plant

Fig. 3: Dual media filter to remove the $Al(OH)_3$ flocs from treated water

Fig. 4: Treated water tanks inside the EDF plant

Fig. 5: Collection of safe water after treatment

Fig. 6: Sludge collection unit provided outside the EDF plant

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