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Performance Evaluation of Solar Power Based Electrolytic Defluoridation Plants in India

Subhash Andey, Pawan Kumar Labhasetwar, Gajanan Khadse,
Poonam Gwala, Prashant Pal and Prashant Deshmukh

CSIR-National Environmental Engineering Research Institute,
(CSIR-NEERI), Nagpur- 440020 (India)

Abstract: Higher concentrations of fluoride in groundwater are a global problem, occurring in at least 25 countries across the globe and affecting millions of people. Excessive intake of fluoride causes fluorosis, a disease affecting the multiple tissues, organs and systems in the body. It is a threat to millions in the country as it ultimately leads to crippled and vegetative life. National Environmental Engineering research Institute (CSIR-NEERI), India has developed Electrolytic Defluoridation (EDF) technique for the treatment of excessive fluoride in water sources. The process is based on the principle of electrolysis by passing Direct Current (DC) obtained from solar photovoltaic cells through aluminium plate electrodes placed in fluoride containing water. During the process aluminium plate connected to anode dissolves and form polyhydroxy aluminium species which remove fluoride in water by complex formation followed by adsorption and removal by settling. EDF technology provides a technically sound, cost-effective and reliable community drinking water defluoridation system for supplying safe drinking water, which meets the guideline value (1 mg/L) of the World Health Organization (WHO) for fluoride. Solar power based electrolytic defluoridation demonstration units were successfully installed at 4 places in India in the fluoride affected villages during the period of 2008 to 2011. Performance evaluation of these plants is being undertaken. It was found that EDF plants produce the treated water with fluoride less than 1 mg/L and 90 - 99% reduction in bacterial load from the raw water with the fluoride in the range 2 - 5 mg/L and total coliform and fecal coliform counts in the range 120–630 CFU/100 ml and 70-100 CFU/100 ml respectively in raw water. Reduction in hardness and nitrate is also observed in treated water. The recurring cost for the treatment worked out for electrolytic defluoridation demonstration plant is $ 0.4 / m^3 of treated water which is much more less than the treatment cost by any other defluoridation system available in the market. The capital cost of the plant is about $ 12000.

Key words: Electrolytic Defluoridation · Dongargaon and Usarvara villages · Fluoride in groundwater and fluorosis problem

INTRODUCTION

Throughout history, people around the world have used groundwater as a source of drinking water and even today, more than half of the world's population depends on it for survival. Groundwater quality may be impaired by many natural constituents such as fluoride, arsenic, iron, nitrate and salinity of which fluoride stands first as a pollutant of geogenic origin in many countries. Fluoride concentration in groundwater is reported from as many as 40 countries including India.

It is estimated that in India, 80% of domestic needs in rural areas and 50% in urban areas are met by ground water and is under threat from problems due to excess fluoride, arsenic, iron, nitrate and salinity. Problem of fluoride contamination above permissible limit in groundwater has come to stay as major toxicological and geo-environmental problem reported in 19 states of India [1]. A recent study conducted by UNICEF on the extent and magnitude of fluorosis problem tentatively indicates that 213 district with affected 25 million people and at risk as 66 million population1. The overall concentration of

Corresponding Author: Subhash Andey, CSIR-National Environmental Engineering Research Institute, (CSIR-NEERI), Nagpur- 440020 India. E-mail: sp_andey@neeri.res.in or subhash.andey@gmail.com.

fluoride in ground water varies from 0.2 to 29 mg/L with maximum sources found in the range of 3-5 mg/L. Since 1986, measures, both remedial and preventive, are organized and intensified by the Government of India for control of excess fluoride and include three pronged strategy comprising provision of fluoride free alternative source for public water supply schemes, defluoridation of drinking water supplies wherever essential and preventive measures.

Since it is known that, the excess fluoride in drinking water causes fluorosis, many methods have been suggested for treatment of water with excessive fluoride. Boruff [2] was the first to investigate variety of materials including activated alumina and alum for fluoride removal [2]. NEERI initiated the defluoridation studies in 1961 and materials like clay minerals, ion exchange resin, activated carbon; sulphonated coals, serpentine mineral, activated alumina and alum were evaluated for removal of fluoride. The review of these methods is reported in base paper on Control of Fluoride in drinking water [3]. Out of all these technologies activated alumina and alum treatment (Nalgonda Technique) are extensively studied and field tested [4-7]. Aluminium compounds play a very important role in removal of fluoride. The extensively studied and field tested technologies based on adsorption (activated alumina) and co-precipitation (Nalgonda Technique) are dependent on aluminium salt. The Electro-coagulation process has been utilized for the treatment of contaminated water [8-10]. Electrolytic defluoridation is one of it and found effective for excess fluoride removal [10-11]. This paper includes the laboratory and pilot plant studies carried out on electrolytic defluoridation.

Electrolytic Defluoridation: The electrocoagulation (EC) is the process utilizing “sacrificed” anodes to form active coagulant which is used to remove pollutant by precipitation and flotation in situ. Compared with traditional chemical coagulation (CC), EC process requires less space and does not require chemical storage, dilution and pH adjustment. It is proven to be effective in water treatment such as drinking water supply for small or medium sized community.

Electrolytic defluoridation offers a new device of in-situ generating aluminum species without chemical addition. It involves the anodic dissolution of aluminum by passing DC in fluoride bearing water. The quantity of water treated per unit weight of introduced metal is higher in electro coagulation than in chemical coagulation [12-14]. During dissolution of aluminium anode, the partially hydrolysed complexes of aluminium are formed and produce insoluble compound with impurities present in the water. The reactive intermediate hydroxy species formed during the reaction further interact to form hydroxide of disordered structure which intensifies the fluoride removal [15-16].

MATERIALS AND METHODS

Based on laboratory studies, solar power based electrolytic defluoridation demonstration units were successfully installed at 4 places in India in the fluoride affected villages during the period of 2008 to 2011. Location of EDF plants are depicted in Figure 1. First EDF plant was installed at Dongargaon fluorite mine of Chandrapur district in Maharashtra state in 2008. The other three EDF plants are installed in Usarwara village and Malegaon village in Chattisgarh State and Sargapur village in Madhya Pradesh State (Plate 1 to 4). Public Health Engineering Departments (PHED) of these states are responsible for operation and maintenance of the plants.

Plate 1: Electrolytic Defluoridation Plant at Dongargaon.

Plate 2: Electrolytic Defluoridation Plant at Sargapur.

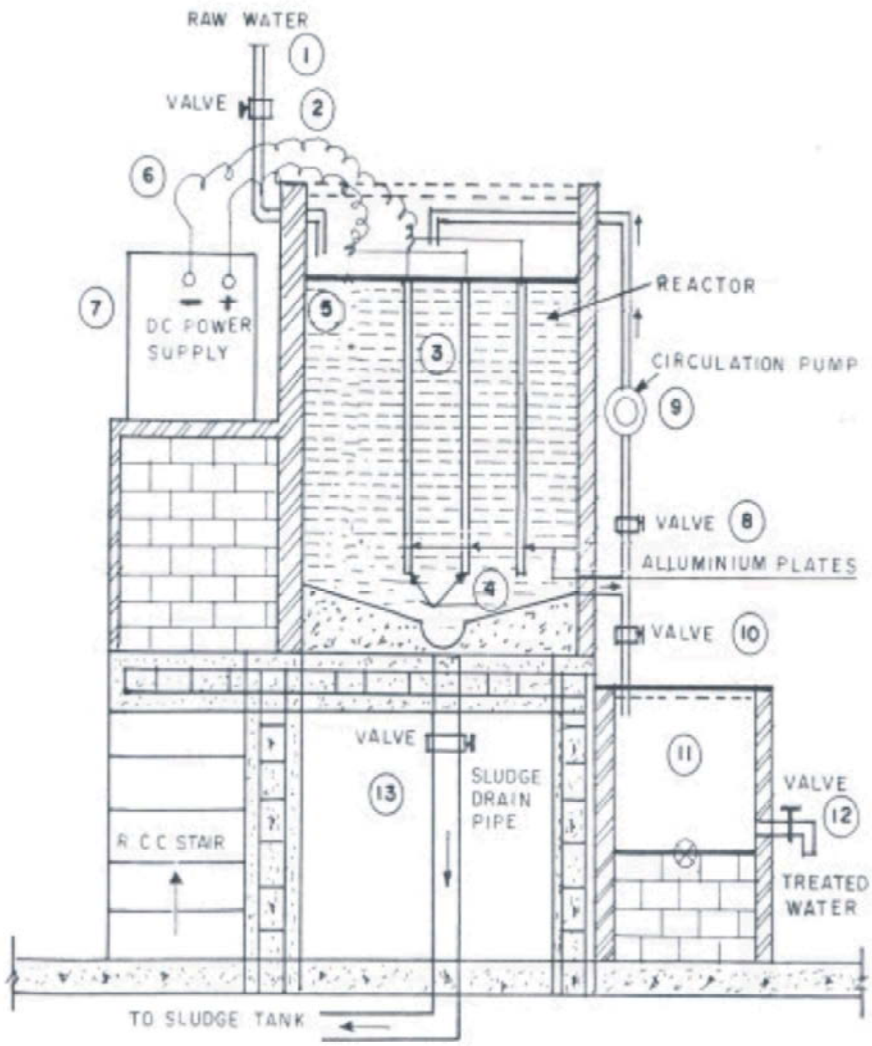
Plate 3: Electrolytic Defluoridation Plant at Usarvara.

Plate 4: Electrolytic Defluoridation Plant at Malgaon.

Fig. 1: Location of electrolytic defluoridation plants (EDF) in India

The evaluation of EDF plants was carried out for whole year in summer season, monsoon season and winter season for determining the performance efficiency. The studies were carried out to see defluoridation efficiency of the plants at varying current density with varying reaction period. The optimum current density and time required to bring down the fluoride below 1.0 mg/L in treated water was calculated. The consumption of aluminium was calculated from the Faradays law. Regular log books are maintained at the plants to keep the record of quantity of water treated. The residual soluble aluminium in the treated water was monitored. The treated water was analyzed for residual fluoride and other physico-chemical parameters.

Social and health surveys were conducted in the villages before and after installation of EDF plants to get the opinion of the community in villages about the EDF technology and to assess the impacts of providing defluoridated water on community health.



1	Raw water pipe	5	Insulating material for hanging the electrode plates	9	Circulation pump
2	Valve	6	Electrode connecting wires	10	Valve to carry the treated water to the tank
3	Hopper bottom reactor	7	DC Power supply	11	Treated water tank
4	Aluminium Plates (Electrodes)	8	Valve for inlet pipe of circulation pump	12	Valve to supply treated water
				13	Sludge drain valve

Fig. 2: The schematic of the EDF plant

Salient Features of Design of Electrolytic Defluoridation Plants: The EDF plants consist of two reactors and treated water storage tank which are constructed in RCC. Aluminum sheets have been used as electrodes and are suspended in the reactor. The raw water from the overhead tank is filled in the reactor and Direct Current (DC) is passed through the aluminum electrodes using DC power supply unit. The water in the reactor is recirculated by pump during the electrolysis to keep the aluminium flocks in suspension. Treated water is allowed to settle for 2 hours and the supernatant is transferred to treated water storage tank. This treated water is supplied to the mine workers for consumption. The sludge collected at the bottom of the treatment tank is discharged on sand bed outside the plant. The schematic of the EDF plant is presented in Figure 2.

RESULTS AND DISCUSSION

Seasonal Performance: The evaluation of solar energy based electrolytic defluoridation unit at Dongargaon was carried out for whole year in summer season, monsoon season and winter season to evaluate the performance efficiency.

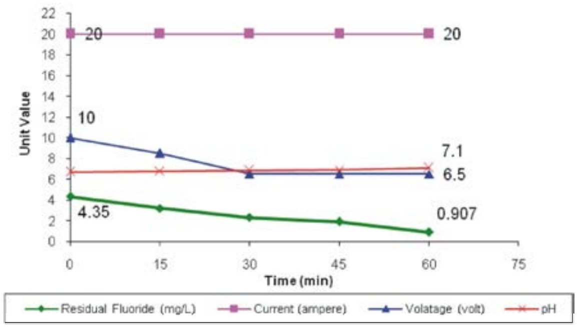


Fig. 3: Performance of solar EDF plant in summer season.

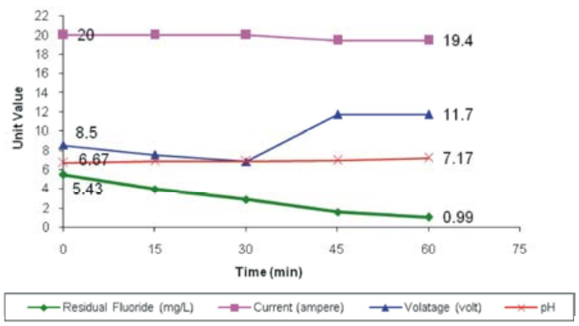


Fig. 4: Performance of solar EDF plant in winter season.

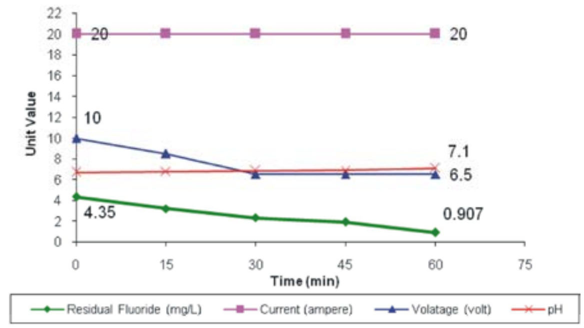


Fig. 5: Performance of solar EDF plant in rainy season - Batch 1

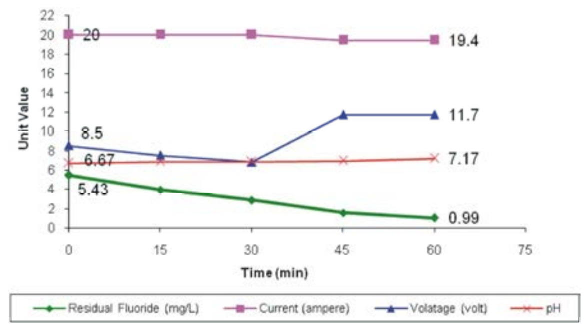


Fig. 6: Performance of solar EDF plant in rainy season - Batch 2

In summer season, the plant was operated on full charge battery supplying stable 20 ampere current throughout batch process. The results showed that the raw water fluoride concentration from 4.35 mg/L was reached to 0.9 mg/L within 60 min (Figure 3). In winter season, the plant was operated at DC supply of 19.4-20 A and the fluoride concentration of 0.99 mg/L in treated water was reached in 60 min from the raw water fluoride concentration of 5.43 mg/L (Figure 4). During rainy season due to cloudy sky, the intensity of sunlight was not sufficient to charge the battery fully using the solar photovoltaic system. It was observed that the solar charged battery was able to supply DC in the range of 16-20 ampere throughout batch process in monsoon season. The observed results of batch process showed that the raw water fluoride concentrations from 4.05-4.4 mg/L were reached in the range of 0.99-1.2 mg/L in 90 min. (Figures 5 and 6).

Residual Aluminium Concentration in Treated Water: As per Indian Standards for drinking water quality, the permissible limit for aluminum in drinking water is 0.2 mg/L. Treated waters obtained in the various runs were analysed for residual aluminum concentration. The residual aluminum concentration in the treated water at various initial concentration of fluoride is presented in Table 1. It is observed that the aluminum concentrations in all the treated water (having fluoride concentration < 1 mg/L) is 0.002 - 0.028 mg/L which is well within the desirable limit of 0.3 mg/L. The effect of raw water pH variation on the residual aluminum concentration in the treated water was studied by changing the raw water pH using hydrochloric acid. The results are presented in Table 1.

It is observed that the raw water pH has significant impact on the residual aluminium concentration in the treated water. Concentration of Al is minimum at pH 8. When the pH of the water is less or more than 8, concentration of Al in the treated water was found to increase. Concentration of Al remains below the permissible limit of for drinking water, up to pH 6. Below pH 6, residual Al concentration in the treated water was found above the permissible limit.

Improvement in Water Quality: Water quality analysis of the raw water and treated waters from the EDF plants installed at Dongargaon and Usarvara villages is presented in Table 2. It is observed that electrolytic

Table 1: Residual aluminium concentration in treated water at initial fluoride concentration

Sr. No.	Initial Fluoride Conc. (mg/L)	Residual Aluminium Conc. (mg/L)
1	3.5	0.002-0.007
2	4.4	0.002-0.006
3	2.5	0.002-0.006
4	3.2	0.003-0.006

Table 2: Residual aluminium concentration in treated water at different pH and initial fluoride concentrations.

		Residual aluminium Conc. (mg/L)				
Sr. No.	Initial F Conc. (mg/L)	pH 5	pH 6	pH 7	pH 8	pH 9
1	2.5	0.48	0.169	0.018	0.004	0.024
2	3.5	0.462	0.178	0.022	0.006	0.028
3	4.4	0.443	0.181	0.026	0.005	0.032

Table 3: Bore well water quality at Dongargaon and Usarwara before and after treatment

		Bore Well at Dongargaon		Bore Well at Usarwara	
Sl. No.	Parameters	Raw	Treated Water	Raw	Treated Water
1.	pH	7.2 - 7.7	6.9 - 7.1	7.4 - 7.9	6.9-7.4
2.	Total Dissolved Solids	690 - 890	600 - 650	650 - 720	570-630
3	Total Hardness, $CaCO_3$	328 - 360	267 - 296	144-170	90-120
5.	Nitrate, NO_3^{-}	5.2 - 11	4.1 - 7.5	6 - 14	4 -7
6.	Sulphate, SO_4^{--}	310 - 375	310 - 370	42-90	40-88
7	Chloride, Cl^-	148 - 180	260 - 270	150 - 190	146-178
8	Fluoride, F^-	3.5 - 4.4	0.8 - 1.0	2.5 – 3.2	0.3-0.6
9	Bacteriological Quality (CFU/100ml)				
	Total coliform	120 - 430	10 - 12	220-630	2-5
	Fecal coliform	80-100	1-2	70-100	1-5
	All values except pH are in mg/L				

process reduces not only the fluoride but also the hardness and nitrate from the raw water. Increase in chloride concentration in treated water from Usarvara EDF plant is due to use of hydrochloric acid for adjustment of raw water pH to increase the efficiency of of EDF process. Improvement in bacteriological quality was observed during the electrolytic process. About 90-99% reduction in coliform and fecal coliform was observed in treated water. Improvement in bacteriological quality is attributed to the disinfection by chlorine generated due to electrolysis of chloride in the water and also the absorption of bacteria on poly-aluminium hydroxide flocs.

SUMMARY AND CONCLUSION

Electrolytic defluoridation technique is easy to operate with least maintenance problem. It increases the palatability of treated water and thus acceptability of the consumers for defluoridated water. From the whole year evaluation study, it was observed that the solar electrolytic deluoridation plants are working satisfactorily even in the critical rainy season when the sunlight is not bright due to cloudy sky. EDF plants produce the treated water with fluoride less than 1 mg/L and 90-99% reduction in bacterial load. Reduction in hardness and nitrate is also observed in treated water.

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