Study of laboratory scale Electrocoagulation for Defluoridation of water

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ABSTRACT:
Millions of people in several parts of the world are afflicted by water borne fluorosis. This is a non-curable disease and hence needs major attention. High volume sludge generation, residual Aluminium, generation of acid/alkali water are the problems associated with conventional treatment processes like Activated Alumina and Nalgonda process. Membrane processes have problem of poor selectivity, high cost and removal of beneficial contents of water. Therefore the need is to find an effective process which can overcome the mentioned drawbacks and remove fluoride efficiently. Process of electrocoagulation is emerging as a better treatment technique owing to lesser production of waste sludge and residual aluminium. In the present study, a laboratory scale electrocoagulation reactor has been designed and continuous flow experiments were conducted for defluoridation using aluminium electrodes. Sample to be treated was artificially prepared in the laboratory. The fluoride removal was investigated in terms of several operational parameters like flow rate (200-500 ml/min), applied voltage (10-18V), charge loading (0.47-1.87 F/m^3), initial fluoride concentration (3-6 mg/l) and residual aluminium. It was observed that with increase in flow rate the the fluoride concentration increases and with increase in voltage it decreases. By varying the charge loading, it was observed that increasing the charge loading decreases the fluoride concentration upto a critical level, beyond which the decrease is insignificant.

1. INTRODUCTION

Problem of fluorides in drinking water is of prime concern as it is affecting public health. Major health problems caused by fluorides are dental fluorosis and skeletal fluorosis. In human beings, effects on dental and skeletal tissues can occur in adolescents and young adults and even in children under 10 years of age among communities exposed to high levels of fluoride (Sharma et al., 2011). Skeletal deformation and weakening of joints are typical forms of fluoride at high levels of fluoride intake. Due to the adverse effects on human health various defluoridation techniques are gaining importance. The maximum acceptable concentration of fluoride in water is 1.5 mg/l (WHO, 2004).

Electrocoagulation (EC) has been demonstrated as an effective process for defluoridation by researchers (Hu et al., 2003; Emamjomeh & Sivakumar, 2006). Production of less waste sludge by the EC process might replace the conventional chemical coagulation (Emamjomeh et al., 2011). In this research, a monopolar EC system with two aluminium electrodes was set up and the study of operating parameters viz. flow rate, applied voltage, initial fluoride concentration, charge loading, and residual aluminium was carried out. Laboratory scale experiments were performed to understand the role of the above mentioned parameters in process of defluoridation by electrocoagulation.

In the EC process electrolytic dissolution of Al electrodes takes place by oxidation and the reactions are outlined below

Anodes: $Al(s) \rightarrow Al^{3+} + 3e^-$ (1)

Cathodes: $2H_2O + 2e^- \rightarrow H_2(g) + 2OH^-$ (2)

The H_2 bubbles float and hence drive the flotation process. The Al^{3+} ions further react to form a solid $Al(OH)_3$ precipitate:

$Al^{3+} + 3H_2O \leftrightarrow Al(OH)_3(s) + 3H^+$ (3)

The basic principle of the process is adsorption of fluoride at precipitated Al $Al(OH)_3$ as depicted in reaction (4) (Qianhai et al., 2008):

$$Al(OH)_3 + x F^- \leftrightarrow Al(OH)_{3-x} F_x + x OH^- \quad (4)$$

The above process is pH dependent. The fluoride complexes AlF^{2+}, AlF_2^+ and AlF_4^- dominate in the acidic solution till the pH of the solution reaches 6 and $Al(OH)_3$ precipitates (Emamjomeh et al., 2011). As the solution turns alkaline, $Al(OH)_4^-$ species are formed.Thus a pH range of 6-8 was considered to be suitable for an efficient defluoridation process.

2. MATERIALS AND METHODS

A continuous flow laboratory scale EC reactor was designed and constructed for fluoride removal as shown in Figure.1. Two aluminium electrodes in monopolar connection were used. The distance between electrodes was kept constant at 10 mm for all the runs. Sample to be treated was placed in an influent tank. pH of the sample was maintained 6 by using dilute HCl. Conductivity and pH were measured using a calibrated conductivity meter (Lutron CD 4302) and pH meter (Electronics India, deluxe 101) respectively. Sample was continuously fed into EC reactor at desired flow rate which was set using a peristaltic pump (Miclins PP- 20). Before each run electrodes were cleaned by acetone and HCl solution. Electrolysis was performed and samples were collected from the outlet of reactor. These samples were immediately filtered with Whatman No. 1 filter paper and the fluoride content was measured using fluoride ion meter (Thermo scientific Orion 5-star meter, 9609BNWP fluoride electrode). Digital power display (Testronix, 230 V DC regulated power supply) was used to maintain current. The samples for estimating aluminium concentration were collected from desired sets and then filtered with 0.45 µm filter paper. Aluminium concentration in the filtered samples was analyzed by Atomic Adsorption spectrophotometer of PG Instruments (model no. PG990) having graphite furnace at a wavelength of 309.3 nm. All the experiments were conducted at room temperature with water temperature varying in a close range of 25-27^{o}C.

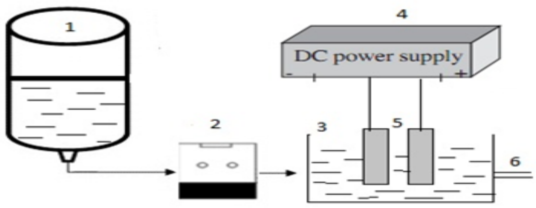

Figure 1. Schematic diagram of experimental set up for defluoridation by electrocoagulation (1) influent tank (2) peristaltic pump (3) electrocoagulation reactor (4) DC power supply (5) electrodes (6) outlet

2.1 Sample

Sample was prepared by mixing sodium fluoride in distilled water. Sodium chloride (2mM) was added to the aqueous solution to increase the conductivity. The chemical parameters are listed in Table 1.

Table 1. Chemical analysis of the water quality of the prepared sample

Chemical Parameters	*Concentration*
Alkalinity (total),ppm	10
Total dissolved solids, ppm	48
Conductivity, mS/cm	0.50-0.53
pH	5.96- 6.07

3. RESULTS AND DISCUSSIONS

3.1 Effect of flow rate on fluoride removal

The effect of flow rate on fluoride removal was studied by varying flow rates in range of 200-500 ml/min for initial fluoride concentration of 5 mg/l and applied voltage of 10V. The effect of flow rate has been depicted in Fig 2. It can be observed that, when the flow rates are increased the effluent fluoride concentration also increases. At 10V the effluent fluoride concentration increased from 0.4 mg/l to 3.13 mg/l, when flow rate is increased from 200 ml/min to 500 ml/min. It can hence be explained that for a fixed volume of reactor, the higher the flow rate the lower will be the detention time and hence lesser will be the removal.

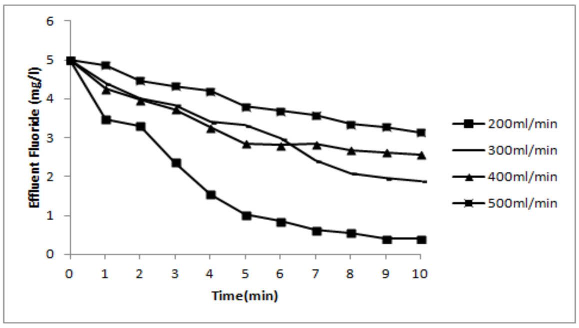

Figure 2. Effect of flow rate on effluent fluoride concentration (initial fluoride concentration= 5mg/l and applied voltage =10 V)

3.1 Effect of voltage on fluoride removal

The influence of applied voltage was studied on sample of fluoride concentration 5 mg/l. Varying voltage viz. 10V, 14V, 18V were applied on flow rate of 200 and 300 ml/min each. Results are shown in the Fig.3 & 4. It can be observed that on increasing the applied voltage, the effluent fluoride concentration decreases. At the flow rate of 200 ml/min the effluent fluoride reduces from 0.4 mg/l to 0.07 mg/l as the voltage was increased from 10V to 18 V and at 300 ml/min it reduces from 1.89 mg/l to 0.34 mg/l when the voltage was increased from 10V to 18 V.

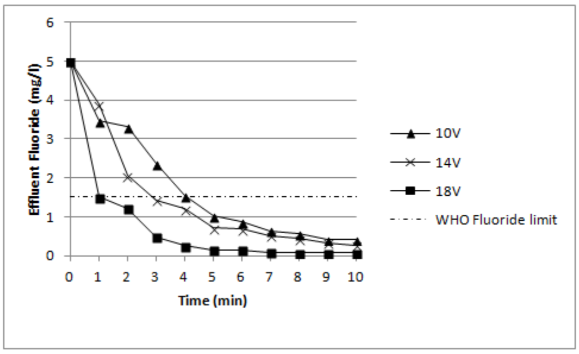

Figure 3. Influence of applied voltage on effluent fluoride at flow rate of 200 ml/min

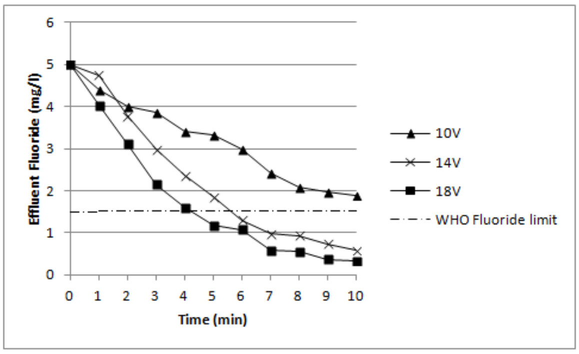

Figure 4. Influence of applied voltage on effluent fluoride at flow rate of 300 ml/min

3.1 Effect of charge loading on fluoride removal

Charge loading is defined as given in Eq 5

$$q = \frac{3600 \times i}{96500 \times Q} \quad (5)$$

where q is the charge loading in (Faraday/m^3), i is the current applied in (Ampere) and Q is the flow rate in (m^3/hr). The influence of charge loading and initial fluoride concentration is studied by varying charge loading in the range of 0.93 F/m^3 to 1.87 F/m^3 and initial fluoride concentration in the range of 3mg/l to 6 mg/l. Fig 3 shows the variation of the effluent fluoride concentration with varying charge loading for different initial fluoride concentration. At the same charge loading, the effluent fluoride concentration is increased when the influent fluoride concentration is increased. This is consistent with the results provided by Zuo et al, 2008. For initial fluoride concentration of 3 mg/l and charge loading of 0.93 F/m^3 the effluent fluoride concentration is 1.27 mg/l. On further increase in the charge loading from 1.4 to 1.87 F/m^3, the effluent fluoride concentration decreases from 0.99 mg/l to 0.93 mg/l. This observation also suggests that after a critical charge loading the decrease in effluent fluoride concentration is insignificant.

Also for same charge loading the effluent fluoride concentration increases with increase in initial fluoride concentration. At constant charge loading of 1.87 F/m^3, the effluent fluoride concentration is 0.93 mg/l for initial fluoride concentration 3mg/l, is 1.54mg/l for initial fluoride concentration 4mg/l, is 1.68 mg/l for initial fluoride concentration 5 mg/l, and is 2.0 mg/l for initial fluoride concentration 6 mg/l. Charge loading is directly proportional to the Al dosing. When the charge loading is low, Al dose in the reactor is less and hence the process of adsorption does not take place efficiently due to lesser amount of aluminium hydroxide.

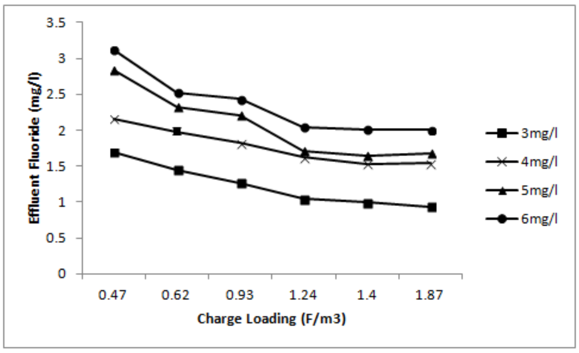

Figure 5. Influence of varying Charge Loading on effluent fluoride concentration (initial F^-conc.= 3, 4, 5, 6mg/l)

3.1 Residual aluminium

Samples collected from the outlet of an EC reactor for initial fluoride concentration 4 and 6 mg/l were analyzed for aluminium concentration. The residual aluminium concentration was in the range of 0.039 mg/l – 0.417 mg/l, which is less than the reported residual aluminium concentration in Activated Alumina process and Nalgonda technique, 0.16-0.45 ppm and 2.01-6.86 ppm respectively, and is a major drawback of these conventionally used techniques (George et al, 2010).

4. CONCLUSIONS

A monopolar continuous flow electrocoagulation reactor was studied for defluoridation. Results obtained from the experiments revealed that more the detention time, more is the fluoride removal. Also charge loading and effluent fluoride concentration does not hold a linear relationship. Charge loading was found to be a critical parameter in defluoridation experiments, as increase in charge loading initially decreases the fluoride concentration in the effluent but after a critical point the decrease in fluoride concentration is insignificant. Electrocoagulation process also combats with the major drawback of Nalgonda and Activated Alumina process as it renders lesser aluminium in the effluent.

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