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Electrocoagulation of Drinking Water in Continuous Flow Mode for Fluoride Removal

Kruttika R. Apshankar[1+], Sudha Goel[1]

[1] Civil Engineering Department, IIT Kharagpur, Kharagpur 721 302

Abstract. The efficiency of electrocoagulation for the treatment of drinking water for fluoride removal has been evaluated in this study. Nine continuous flow experiments have been conducted for fluoride removal by varying different operating parameters. Ground water obtained from within the IIT campus was used in all the experiments. The best removal efficiency obtained so far has been 46.7 %. The pH increased in all experiments from a slightly acidic or neutral value to an alkaline value ranging from 8 to 10. The use of baffles was observed to increase the removal efficiency from a maximum of 22.5 % (in the experiments conducted without baffles) to a maximum of 46.7 %.

Keywords: groundwater, fluoride removal, iron electrodes

1. Introduction

Electrocoagulation is being explored as an alternative to conventional coagulation because of its advantages like higher efficiency, in-situ generation of coagulant ions, lower sludge production and no storage of chemicals. In conventional coagulation, pH of the water goes down requiring post-coagulation neutralization. On the other hand, in electrocoagulation, the pH of the water increases slightly or remains neutral. In electrocoagulation, a sacrificial anode dissolves to release ions of the coagulant metal such as iron or aluminum, which combine with the pollutants present in water and then can be removed by either flotation or by settling. Based on the published literature, fluoride removal has been studied in both, batch [1, 2] and continuous [3] modes. However, no studies with real water and in continuous-mode were found. Electrocoagulation for fluoride removal from drinking water has been practiced and reported by many researchers [4].

The objective of this study was to examine the effect of varying flow rate on fluoride removal from drinking water using continuous-flow electrocoagulation followed by filtration. Groundwater from the IIT campus was spiked with 10 ppm of fluoride and used as feed water. The reactor was run in continuous mode and mild steel electrodes were used. An applied voltage of 25 V was maintained throughout each experiment. Five different flow rates ranging from 0.25 L/h to 1.5 L/h were examined. The experiments were conducted for 6 to 36 hours. Fluoride, pH, current, turbidity, and conductivity were continuously monitored in each experiment.

2. Materials and Methods

2.1. Sample collection

Ground water samples were collected from the tubewell in Dandakaranya pump house in front of the VSR Complex, IIT Kharagpur. Fresh water samples were collected for each experiment and some were characterized for most water quality parameters. The depth of the groundwater is 250 feet.

2.2. Experimental procedure

+ Corresponding author. Tel.: +91 8436241631.
E-mail address: kruttika_ap@yahoo.co.in.

The experimental set-up comprised of an EC reactor, two peristaltic pumps (Miclins India, Model No PP 20 4C and Model No PP 20 EX-4C), a magnetic stirrer, a DC power supply (0 - 30 V and 0 – 3 A), and a filtration column filled with glass beads. A flow chart of the experimental set-up is shown in Figure 1.

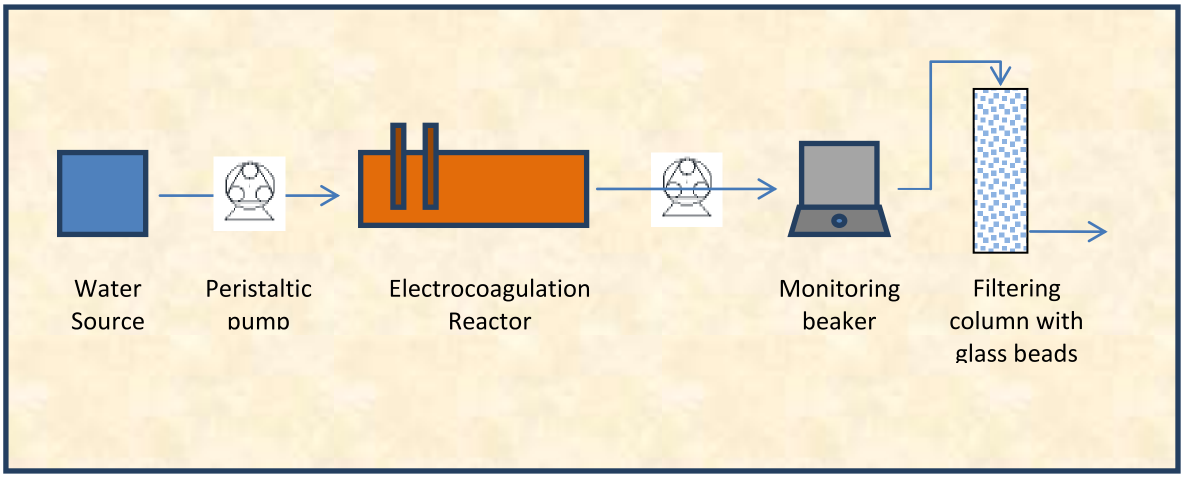

Fig. 1: Flow chart of the experimental set-up

The EC reactor was made from acrylic sheet with inner dimensions of 36 cm x 12 cm x 11.5 cm. Two MS steel electrodes with dimensions of 14.5 cm x 2.5 cm x 0.1 cm were used and the inter-electrode distance was 3 cm. These electrodes were connected to a DC power supply of capacity 0 to 30 volts and 0 to 3 Amperes.

The first peristaltic pump transferred the feed ground water from a bucket into the EC reactor. The supernatant from the EC reactor was collected in a 1 L glass beaker in which pH, temperature and DO probes were placed for continuous monitoring of their respective parameters. The beaker was placed on a magnetic stirrer to stir the water throughout the experiment. Samples were collected at intervals of 15 minutes during the first hour and every half hour after that. From the glass beaker, another peristaltic pump drew the water and transferred it to a column of approximately 3 cm diameter which was filled with glass beads (Loba, Chemie Company, India) for the purpose of filtering it. The filtered and unfiltered samples were collected at the same time intervals.

2.3. Experimental Conditions

Nine experiments were carried out to understand the effect of electrocoagulation on fluoride removal from drinking water under different operating conditions. Mild steel was used as the electrode material for all the nine experiments. The size of the glass beads used for filtration was 3.5-4.5 mm. pH, temperature, conductivity and the current was monitored continuously for all the experiments. The inter-electrode distance was 2 cm for all the experiments excepting the first one where it was 3 cm. The flow-rate was varied in the first five experiments over the range of 0.25 L/h to 1.5 L/h. Upon analyzing the results, it was seen that the best results were observed at 1 L/h. Hence, the 6th, 7th, 8th and 9th experiment was carried out at the same flow-rate, i.e. 1 L/h.

2.4. Analytical Methods

- pH, temperature and conductivity: These water quality parameters were measured using a multi parameter testing kit [Labquest, Vernier International, USA].The instrument was calibrated with a buffer solution of pH 7 [Merck India].

- Turbidity: Digital Turbidity meter [Model- 331, Electronics India] was used to measure turbidity.

- Ion concentrations: A 761 Compact IC (Metrohm) was used to determine the concentrations of cations and anions present in the filtered samples.

- Electrode Consumption: The mass of electrodes was determined before and after each experiment.

3. Results and Discussion

Out of the nine experiments that were performed, the results of only one experiment are discussed here and are representative of all experiments. The results of the other experiments are tabulated after the results and discussion of the 6th experiment.

3.1. Experiment 6

This experiment was conducted at 1 L/h after observing and analyzing the results of the previous five experiments. The experiment was conducted for 6 hours at 25 V. One baffle was placed immediately after the inlet pipe due to which the water entered the reactor with a low velocity in laminar flow. The reactor dimensions were 36 cm x 8.3 cm x 17.8 cm and the electrode dimensions were 17.6 cm x 2.5 cm x 0.1 cm. The submerged depth of the electrode was 7.5 cm which made the effective submerged area 0.0039 m^2. The electrodes were placed in the middle of the reactor. pH, conductivity, turbidity and temperature were continuously monitored for this experiment.

Maximum fluoride removal efficiency of 46.7 % was observed in this experiment and is the highest achieved in all the experiments conducted so far. Concentration and removal efficiency throughout the experiment are shown in Figure 2.

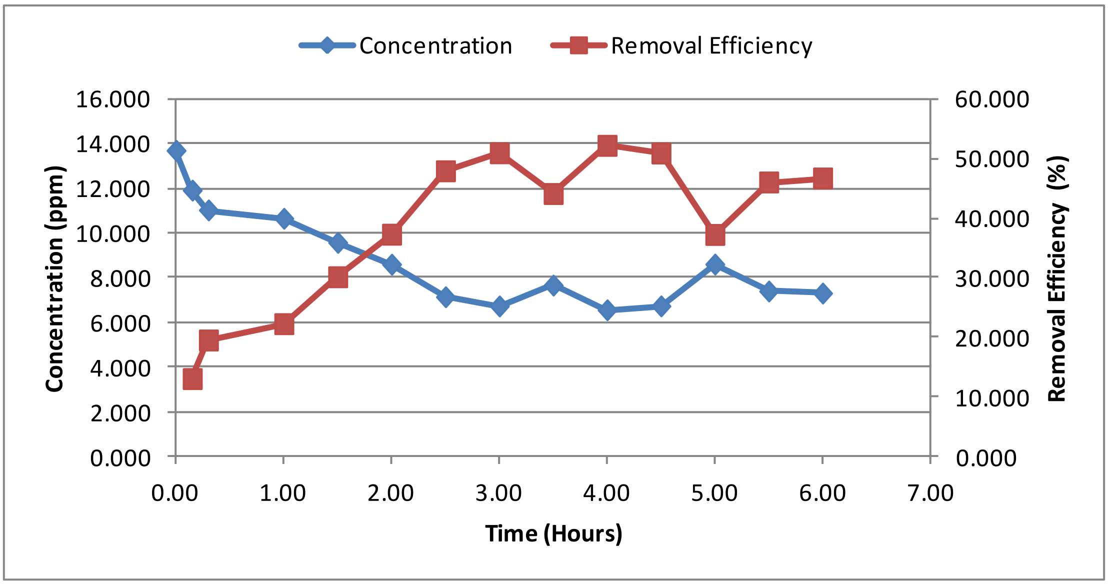

Fig. 2: Fluoride removal efficiency for the 6th experiment

The amount of fluoride removed per gram of iron consumed was 111 mg F/ g Fe for this experiment.

The conductivity observed throughout the experiment was more or less stable and ranged from 200 – 250 µS/cm. Initial pH was slightly acidic and increased up to 9.5 which is as reported in the literature [1]. The final pH was around 9. The turbidity levels observed were not satisfactory and the method of filtration or the reactor design will have to be modified.

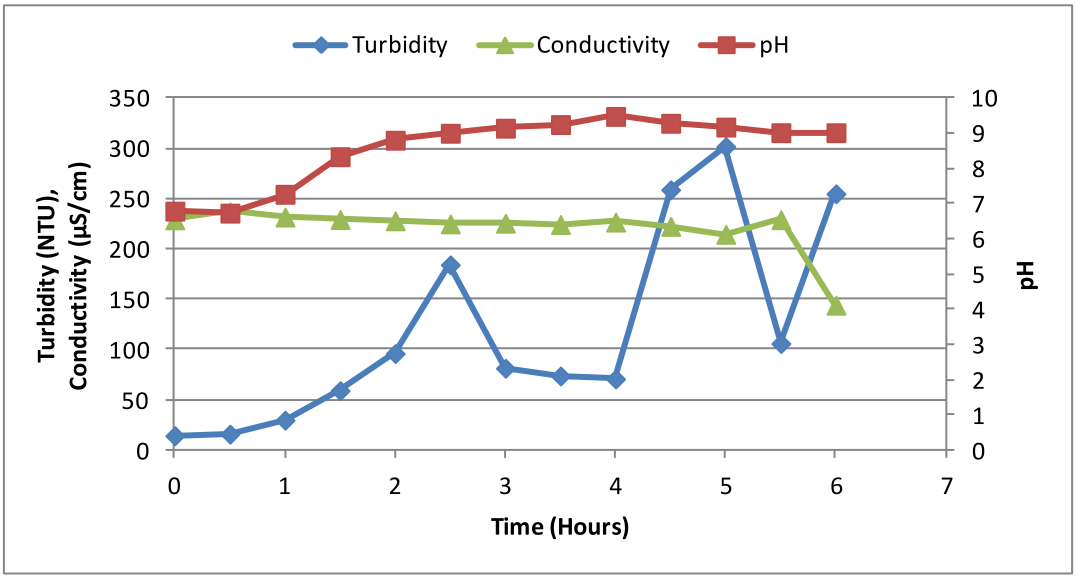

Fig. 3: pH, conductivity and turbidity

Average current observed throughout the experiment was 0.12 A. The total energy consumption of the experiment was 3 Wh/L while the current density was 30.8 A/m^2. Upon the commencement of the experiment; a coagulant layer was formed throughout the reactor as shown in Figure 3. This coagulant layer which must have formed due to the laminar conditions created in the reactor may be the primary cause of the highest fluoride removal. This layer was observed again in the 8th experiment where the removal efficiency was also good (42.97 %).

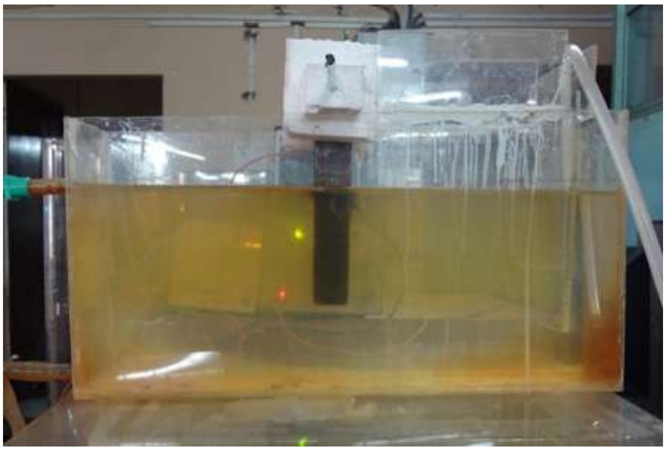

Fig. 3: Effect of baffles on coagulant layer formation

3.2 Summary of all EC experiments for fluoride removal

The removal efficiencies of all the other experiments are given in **Table 1**. The first five experiments were conducted with a reactor whose dimensions were 36.5 cm x 12 cm x 11.5 cm while the rest were conducted with a different reactor of dimensions 36 cm x 8.3 cm x 17.8 cm. A marked improvement in removal efficiency was seen upon implementing this new reactor. The liquid volume maintained in both reactors was the same, i.e., 4 L.

The 9th experiment was conducted for 36 hours but no exceptional increase in fluoride removal efficiency was observed. As current passes through the circuit, an oxide layer forms on the cathode which decreases the working efficiency of electrocoagulation. This phenomenon is called passivation [5]. No passivation point was observed within 36 hours for the 9th experiment and the maximum removal efficiency of the experiment was 41 %.

The average energy consumed per liter of water for all the experiments was 4.64 Wh/L and the average current density of all the experiments was 37.6 A/m^2. The results of removal efficiencies of various cations and anions for all the experiments are presented in Table 1.

Table 1: Removal efficiencies of anions and cations in each EC experiment

Experiment No.	1	2	3	4	5	6	7	8	9
Remarks	Flowrate varied				1 L/h				
	No baffles					1 baffle; coagulant layer observed	1 baffles; no coagulant layer observed	2 baffles; coagulant layer observed	2 baffles; no coagulant layer observed
Removal Efficiencies of Anions (%)									
	6 h ; 9 h	**6 h**	**6 h ; 9 h**	**6 h**	**6 h**	**6 h**	**6 h ; 15 h**	**6 h**	**6 h ; 36 h**
Fluoride	14.14 ; 12.2	0.8	13.3 ;11.5	21.1	22.5	46.7	29.7 ; 42.7	42.97	30.07 ; 22.7
Chloride	15.9 ; 15.3	14.8	22.4 ; 0	-	-	46.5	26 ; 30.43	29.13	1.4 ; 32.2
Nitrite	0 ; 0	9.7	10.6 ; 0	-	-	22.05	5.2 ; 0	0	81.1 ; X
Bromide	6 ; 8.4	3.7	5.31; 0	-	9.12	61.05	36.6, 45.6	61.66	0 ; 42
Nitrate	-	11.3	48.1; 0	19.5	-	67.4	55.7 ; 5.6	6.42	52.9 ; 68.7
Phosphate	-	-	6.7 ; 0	79.1	0.8	5.1	72.3 ; 70.3	0	61.8 ; 75.2
Sulphate	8.7 ; 8.1	0.1	48.6; 0	-	-	71.4	10.8 ; 1.6	46.09	0 ; 63.2
Removal Efficiencies of Cations (%)									
Sodium	5 ; 4.6	1.7	8.56 ; 0	-	-	0	0 ; 0	86.56	0 ; 0
Ammonium	-	-	-	-	ND	0	-	X	X ; X
Potassium	0 ; 13.6	1.13	10.37 ; 0	-	-	0	0 ; 0	0	0 ; 0
Manganese	0 ; 9.1	-	-	-	ND	0	-	X	X ; X
Calcium	6.01 ; 6.8	2.5	15.15 ; 11.8	-	-	30.5	0 ; 0	10.08	0 ; 0
Magnesium	6.9 ; 6.9	0.34	5.5 ; 0	-	-	12.9	0 ; 0	32.12	0 ; 0

4. Conclusion

The fluoride removal efficiencies indicate that electrocoagulation is a suitable method for removing fluoride from drinking water. The energy consumption is also low making it economical for small-scale treatment. Reactor design needs to be modified for enhancing turbidity removal as well as fluoride removal.

5. Acknowledgements

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