



Evaluation of operating parameters with respect to charge loading on the removal efficiency of arsenic from potable water by electrocoagulation



M. Kobyas^{a,*}, E. Demirbas^b, F. Ulu^a

^a Department of Environmental Engineering, Gebze Technical University, 41400 Gebze, Turkey

^b Department of Chemistry, Gebze Technical University, 41400 Gebze, Turkey

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ABSTRACT

Charge loading is the most important parameter for controlling the reaction rate within electrocoagulation process (EC) which determines the coagulant production rate, and it may also serve as a design parameter for the process. In the present study, arsenic removal from potable water by a batch EC process using iron plate electrodes was investigated with respect to charge loading and effects of operating parameters such as current density, operating time, initial arsenic concentration, ratio of electrode surface area over volume (S/V), and electrode connection mode on removal efficiency of arsenic were evaluated. The results showed that arsenic concentration of $150 \mu\text{g/L}$ in monopolar series (MP-S) electrode connection mode during the EC process decreased the arsenic concentration to less than $6 \mu\text{g/L}$ corresponding to removal efficiency of 95.1% (under the limit set by the World Health Organization) at current density of 2.5 A/m^2 , charge loading of 50 C/L , S/V of $10 \text{ m}^2/\text{m}^3$ (ratio of electrode surface area over volume), EC time of 7.5 min. Arsenic removed capacity and charge dosage rate at the optimum operating conditions were $2.8 \mu\text{g As removed/C}$ and 4.00 C/L/min . The adsorption of arsenic over electrochemically produced hydroxides and metal oxide complexes followed pseudo second-order adsorption model ($r^2 > 0.94$). Operating costs were affected with current density, electrode connection mode, S/V and initial concentration of arsenic from potable water. The operating cost at MP-S connection mode was calculated as 0.00075 €/m^3 at $150 \mu\text{g/L}$, 0.05 A , 7.5 min and 30 C/L .

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1. Introduction

Arsenic contamination in natural water sources is one of the most challenging environmental problems today. Arsenic contaminated natural waters, including surface water and groundwater used to supply drinking water in many countries such as Argentina, Chile, Mexico, China and Hungary, and more recently in India-West Bengal, Bangladesh and Vietnam are a major public health problem threatening the lives of over 150 million people worldwide [1,2]. Arsenic is known to be toxic, mutagenic, and carcinogenic associated with long-term exposure to even very low concentrations. Chronic health effects of arsenic commonly include skin diseases (pigmentation, dermal hyperkeratosis, and skin cancer), many other cancer species such as cardiovascular, neurological, hematological, renal, and respiratory diseases, as well as lung, bladder, liver, kidney, and prostate [3,4]. Increased knowledge of

the cancer risk led the World Health Organization (WHO) to lower its recommended maximum limit of arsenic from $50 \mu\text{g/L}$ to $10 \mu\text{g/L}$ in drinking water [5]. The increased attention on arsenic toxicity has motivated considerable studies for developing of new methods for removing of arsenic from potable waters. Therefore, the removal of arsenic from water has attracted much attention from the research community in recent years. A variety of treatment processes has been developed including coagulation with aluminium and iron (III) salts, lime softening, reverse osmosis, electrodialysis, adsorption on activated alumina, activated carbon and granular ferric oxides, and so on [1,6–9]. These common conventional techniques for arsenic removal from waters have some advantages but they also have some drawbacks such as pH pre-adjustment, toxic and carcinogens by-products (trihalomethanes), interferences from other anions (silicate, phosphate, and sulphate), problems regarding regeneration, required of pre-oxidation of As(III) to As(V), high operation and capital cost, required of very high amount coagulant dose, and the generation of large volumes of backwash water and spent media or sludge [6–8]. Furthermore, it is still difficult to reduce arsenic to meet the

* Corresponding author. Fax: +90 262 6053005.

E-mail address: kobyas@gtu.edu.tr (M. Kobyas).

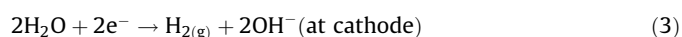
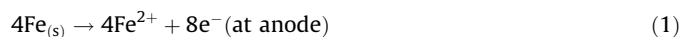
permissible World Health Organization (WHO) limit value by these techniques, especially at high initial arsenic concentrations. Due to these disadvantages, efforts are necessary to develop a simple, feasible, and cost-effective way to remove arsenic efficiently from water. At this point, EC process is promising due to many advantages over the other techniques such as small system size, ease of operation, low maintenance and cost, oxidization of As(III) to As(V) during the process, stable and less sludge produced, no chemical addition, and benefit of side reactions like electro-oxidation and electroflotation [10–12]. The removal efficiency of arsenic was obtained with the EC as high as 99% from industrial wastewaters, surface and groundwater [13–25]. Most investigations on arsenic removal by EC process have generally focused on effects of operating parameters such as initial pH of solution, current density, operating time, distance between electrodes and initial arsenic concentration. These researchers mostly considered current density as an important design variable for EC process. Additionally, charge dosage rate is proportional to the rate of anode dissolution into a unit volume of solution during the EC since charge dosage rate has significant effects on both arsenic removal capacity and operating time and is the appropriate parameter to maintain performance when scaling to different active areas and volumes. Therefore, the charge loading is the most important operational variables for treatment efficiency of arsenic from waters since the amount of adsorbent produced (coagulant dosage) in the EC process would be proportional to the charge loading (i.e., dissolution of electrode by Faraday's law is related to the charge loading (the total charge passed through solution by the current)) [26]. For that reason, it might be worthwhile to explore charge loading as a design parameter in the EC process.

The goals of this study were to assess effects of the operating parameters such as current density, operating time, initial arsenic concentration, electrode connection mode on removal efficiency of arsenic from potable water with respect to charge loading and electrochemically produced coagulant dose. The removal efficiency of arsenic was conducted in the batch EC reactor using Fe sacrificial electrodes to meet the WHO permissible concentration limit. Moreover, one of the important matters in design of the EC reactor for removal of arsenic is establishing of key scale-up parameters. In the EC process, ratio of electrode surface area over volume (S/V) could also be an important controlling EC variable due to being significant for scale-up parameters [27]. The effective electrode surface area influenced current density and rate of coagulant dosing as well as bubble production and bubble path length. Each of the above parameters affects operating time and cost in the EC process. Influence of S/V was studied for better removal efficiency. Operating costs based on energy and electrode consumptions were also calculated.

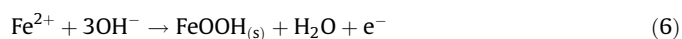
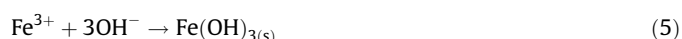
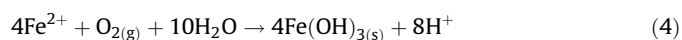
2. A brief arsenic removal by EC

Electrocoagulation is essentially an electrolytic process. When charge is applied through an external electrical power source, the generation of metallic cation monomeric and polymeric species

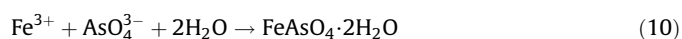
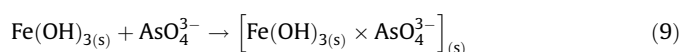
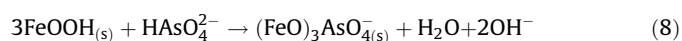
takes place at the sacrificial anodes, whereas typically a $H_{2(g)}$ production occurs together with OH^- release at the cathode [26]. In an EC process with Fe electrode; Fe^{2+} species are formed by the anodic dissolution of the electrode, and these are oxidized to Fe^{3+} species (i.e., $FeOOH$ and $Fe(OH)_3$) formed complexes with arsenates. The main anode (Eqs. (1) and (2)), cathode (Eq. (3)), solution and hydrolysis (Eqs. (4)–(6)), co-precipitation and adsorption reactions (Eqs. (7)–(10)) were shown in the following equations [13,14,22]:



When oxygen is introduced to the process, Fe^{2+} is oxidized rapidly [13,14,22].



In EC process, hydrous iron oxides (HFO), such as ferric hydroxides, ferrihydrite, goethite and lepidocrocite strongly adsorb inorganic arsenic species [21,23]. It was reported that arsenic removal occurs by ligand exchange, arsenate displaces a hydroxyl group of $FeOOH$ giving rise to an insoluble surface complex [19].



3. Materials and methods

3.1. Materials

1000 $\mu\text{g/L}$ of arsenic stock solution was prepared according to the EPA standard method by dissolving As_2O_3 in distilled water

Table 1
Specifications of the EC reactors used in these studies.

Specifications	EC Reactor I	EC Reactor II	EC Reactor III
Reactor dimensions ($W \times L \times H$, cm)	$8.1 \times 8.1 \times 12.6$	$18.7 \times 7.8 \times 24.5$	$28 \times 19 \times 31$
Electrode dimensions ($W \times L \times H$, cm)	$5.0 \times 7.3 \times 0.2$	$23 \times 4.8 \times 0.3$	$10 \times 27.6 \times 0.5$
Total effective electrode surface area (S , m^2)	0.0219	0.0660	0.1600
The distance between electrodes (cm)	1.3	3.5	4.8
Total number of electrodes	4	4	4
Volume of drinking water in EC reactor (V , m^3)	7.50×10^{-4}	3.50×10^{-3}	0.016
Ratio of electrode surface area over volume (S/V , m^2/m^3)	29.20	18.86	10.00

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