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Assessment of Electrocoagulation for Groundwater Purification

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Abstract. The performance of a batch electrocoagulation system in the removal of Cr (VI) from brackish groundwater was experimentally investigated. The effect of electrode types, applied current density, initial pH, initial chromium concentration, conductivity and temperature were investigated. The experimental results indicated that the utilization of iron electrodes as anode and cathode was the most efficient arrangement in the removal of chromium from groundwater. The performance of EC was found to be largely affected by the conductivity, applied current density and initial chromium concentration. The results proved that electrocoagulation is a reliable technique for the purification of groundwater.

Keywords: electrocoagulation**,** hexavalent chromium**,** groundwater

1. Introduction*:*

In most parts of the world, the main water sources such as groundwater are being constantly polluted by the accumulation of hazardous contaminants and dangerous heavy metals, such as chromium. The occurrence of chromium in aqueous systems, especially groundwater, is often attributed to indiscriminate discharge of industrial effluents such as chrome plating, dyes and pigments and leather tanning [1] [2] or natural sources, specifically the weathering of chromium-containing aquifer minerals. Chromium usually exists in two forms that are characterized by different chemical behaviours and toxicity. Hexavalent chromium Cr(VI) is one of these forms that is known to be highly toxic and carcinogenic and has a high solubility in aqueous medium [3] [4]. On the other hand, trivalent chromium Cr (III) is much less toxic and has low solubility in aqueous solutions. Therefore, chromium reduction is the main phenomenon to eliminate it from polluted aqueous medium [3].

Electrocoagulation (EC) is a wastewater treatment technique that works through destabilizing suspended or dissolved contaminants in an aqueous medium by introducing a current into the medium and generating coagulant in-situ by electrolytic oxidation of an appropriate anode material. EC system is wildly used to eliminate or reduce a wide range of water pollutants, such as: oil and organic contaminants [5] [6], dyes in textile wastewater [8] [9], chemical oxygen demand (COD) [10], and heavy metal such as Cr, Ni and Cu [11] [12]. The most important advantage of using EC is avoiding the use of chemical substances at high concentrations and hence reducing the possibility of secondary pollution, compared to the conventional chemical techniques [5] [13] [12].

In this study, the potential of utilizing EC for the removal of Cr (VI) for brackish groundwater has been evaluated. The aim is to optimize the electrocoagulation reactor to reduce Cr (VI) concentration to be within the acceptable limit of 0.05 ppm.

The electrochemical reactions with a metal (M) as "sacrificial electrode" can be generally shown as the following [13-14]:

At the cathode:

$$2H_2O_{(l)} + 2e^- \rightarrow 2H_{2(g)} + 2OH^- \quad (1)$$

At anode:

$$M_{(s)} \rightarrow M_{(aq)}{}^{n+} + ne^- \quad (2)$$

$$2H_2O_{(l)} \rightarrow 4H_{(aq)}^{+} + O_{2(g)} + 4e^{-} \quad (3)$$

2. Materials and Methods

2.1. Characterization of Groundwater

The groundwater used in this study was collected from - farm wells (350 m in depth) located in Al-Ain, UAE. The groundwater characterization of pH, conductivity, TDS, different elements (Ca, Na, and K) and chromium concentration is presented in Table 1. The groundwater samples were classified as moderately saline.

To raise the chromium concentration in the groundwater samples, a potassium dichromate was used to prepare different initial concentrations of chromium. The conductivity and TDS measurements of the samples were measured using JENWAY 4510 conductive meter. The pH of the solutions was measured by pH meter (Checker by HANNA). Samples were withdrawn from the reactor at different time intervals, filtered using Whatman filter paper (Grade 40), and then sent for analysis of the total chromium using ICP Optical Emission spectrometer. The effect of applied current density, electrodes type, initial pH, initial chromium concentration and electrolysis time were investigated.

Table 1: Characteristics of Groundwater

characteristic	Cr	Ca	Na	K	Conductivity	TDS	pH
Value	0.2 ppm	323.5 ppm	711.9 ppm	37.42 ppm	5,930 µs /cm	3,570 ppm	8

2.2. Electrocoagulation Procedure

The electrocoagulation experiments were conducted in a batch Plexiglas cylindrical reactor (ID = 150 mm; H = 150 mm) with a total volume of 2,651 ml. The total volume of groundwater treated in each experiment was 1000 ml; two types of rectangular metal electrodes (Fe and/or Al) were used with dimensions of 63 mm X 50 mm X 2 mm and a total anode surface area of 6300 mm^2 (63 cm^2). The metal electrodes were placed in the middle of the reactor and connected to a DC power supply (Popular PE-23005).

3. Results and discussion

The effectiveness of electrocoagulation for the removal of chromium is highly dependent on the conductivity of the groundwater. As it is shown in Table 1, the groundwater samples had high electrical conductivity of 5,930 µs/cm which played a key role in enhancing the current flow and consequently increased the removal efficiency of chromium a short time [15-16].

3.1. Effect of Electrodes type and Applied Current Density:

The effect of electrode type on the removal of chromium from groundwater was investigated using two electrode materials: iron (Fe) and aluminium (Al). Each experiment with 63 cm^2 electrode area was conducted at 0.5 A with three different electrodes arrangements: two Fe electrodes, two Al electrodes, and Fe anode and Al cathode.

The results, shown in Fig 1, indicate that the electrocoagulation process was very fast, especially for the iron electrode and that 100% chromium removal was achieved within the first minute of operation. During the same coagulation time the percentage removal of chromium by using aluminium cathode was slightly less, which may be attributed to the electrochemical reduction of hexavalent chromium at the cathode surface as it is shown in Eq (5), as well as the other electrochemical reduction by Fe^{2+} ions produced on the anode and reduce hexavalent chromium to trivalent chromium as it shown in Eq (4) and (6).

Anode reaction:
$$Fe_{(s)} \rightarrow Fe_{(aq)}^{2+} + 2e^{-} \quad (4)$$

Cathode reaction:
$$Cr_2O_7^{2-} + 6e^{-} + 7H_2O \rightarrow 2Cr^{3+} + 14OH^{-} \quad (5)$$

$$Cr_2O_7^{2-} + 6Fe^{2+} + 7H_2O \rightarrow 2Cr^{3+} + +6Fe^{3+} + 14OH^{-} \quad (6)$$

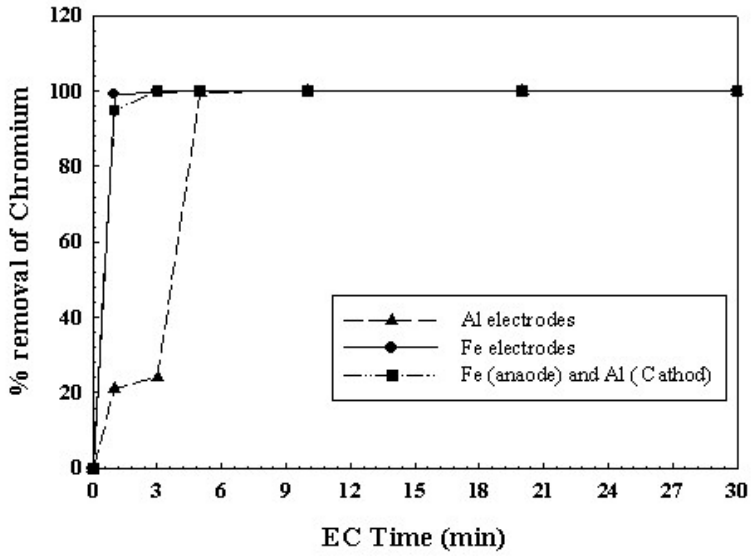

Fig 1. Effluence of types of electrodes in the removal of chromium from groundwater by EC at 0.5 A and initial chromium concentration 1ppm.

Applied current density is one of the main operating parameters that directly affect the process performance and operating cost. Therefore, a series of experiments were conducted in wide range of different current density varying from 1.587 mA/cm^2 to 5.873 mA/cm^2 at an average initial pH of 7.9. As it is show in Fig 2, the results indicated that increasing the applied current density from 1.58 to 7.9 mA/cm^2 enhanced the total chromium removal efficiency from 0.17 % to 98 % within the first minute of operation, but a further increase in the applied current density up to 15.87 mA/cm^2 did not show any further improvement. This behaviour can be explained according to Faraday's law (Eq.8), where increasing the applied current results in increasing the amount of iron and hydroxide ions, which increase the coagulant dosage by time [17-18].

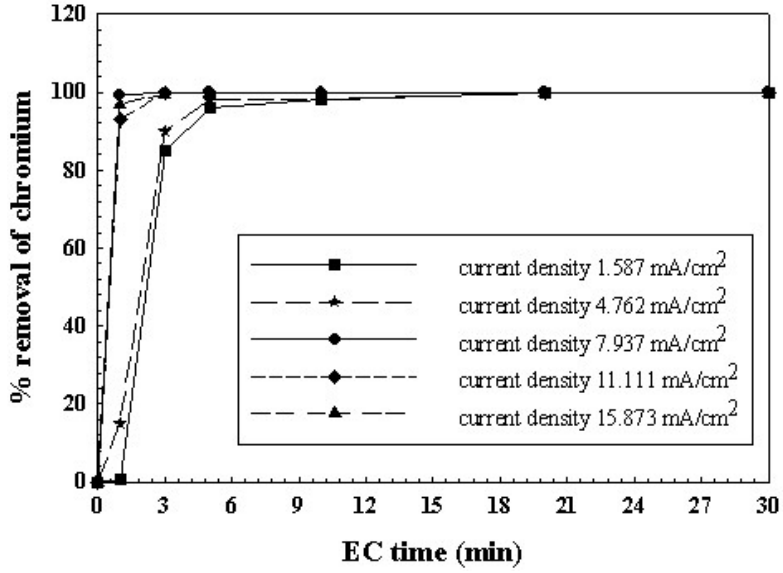

Fig. 2. Influence of different current density in the performance of EC removal of chromium from groundwater using iron electrodes at initial chromium concentration 1 ppm.

3.2. Effect of Initial Chromium Concentration

In order to evaluate the effect of initial Cr concentration on the performance of electrocoagulation, a wide range of initial concentrations, from 1 ppm to 20 ppm, were prepared. As the results in Fig.3 indicate, the percentage removal of chromium decreased with increasing the initial concentration. This can be again explained by Faraday's law; when applied current and time are constant, the same amount of Fe^{2+} is released from metal electrodes to the solution. As a results, at high initial concentration the Fe2+ ions will be insufficient to reduce Cr(VI) to Cr(III) [18].

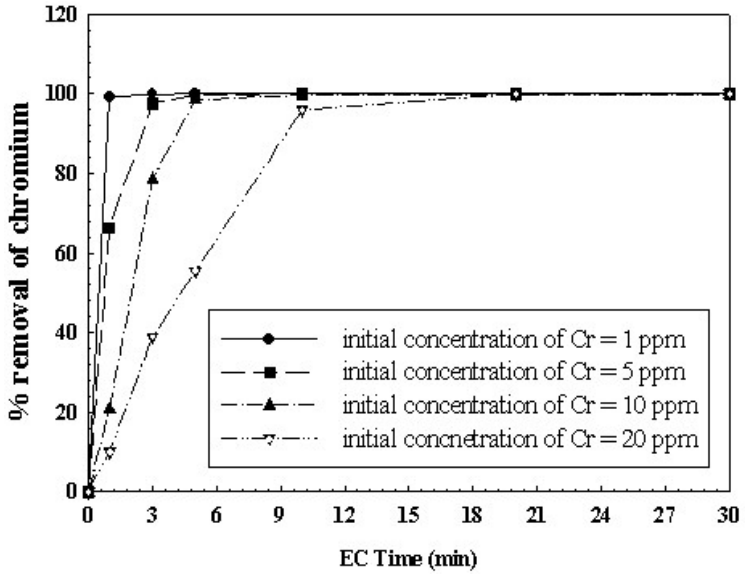

Fig. 3. Influence of different initial concentration in the performance of EC removal of chromium from groundwater using iron electrodes at applied current density 7.9 mA/cm2 and initial pH 8.

3.3. Conclusions

Electrocoagulation proved to be a promising treatment method for chromium removal in brackish groundwater. Groundwater samples, collected from farm wells located in Al-Ain, were treated in a batch electrocoagulation system using two types of electrodes: Aluminium and iron. The experimental results indicated that EC can reach 100 % removal of total chromium from brackish groundwater using iron electrodes arrangement. The experimental results proved that the performance of EC in removal of chromium is highly dependent on the applied current density, initial pH, and initial chromium concentration. Electrocoagulation could remove 100 % of chromium with 7.9 mA/cm^2 using iron electrodes with initial pH of 8 and initial chromium concentration of 1 ppm at room temperature and these conditions considered as the optimum conditions for the treatment of groundwater.

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