The Effects of Initial Boron Concentration on Energy Consumption in Boron Removal by Electrocoagulation

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Abstract: In this study, it was investigated initial boron concentration affecting energy consumption in boron removal from boron containing wastewaters prepared synthetically, via electrocoagulation method. Initial boron concentration of solution was selected as experimental parameter affecting energy consumption. The other parameters such as solution pH, current density and temperature of solution were kept constant during reaction time. Experiments were carried out with different initial boron concentrations ranging from 100, 250, 500 and 1000mg/L. Increasing initial boron concentration caused to increase specific conductivity of solution. Specific conductivity of solution was a important parameter on energy consumption of electrocoagulation system. The higher specific conductivity of solution caused to the lower energy consumption values. While energy consumption value was 49,87 kW-h/m^3 for 100 mg/L initial boron concentration, this value was decreased to 14, 3 kW-h/m^3 for 1000 mg/L initial boron concentration under 3.0 mA/cm^2 of current density, pH 8.0, 293 K of solution temperature and 150 rpm of stirring speed.

Keywords: Electrocoagulation, energy consumption aluminum electrode, boron removal

1. Introduction

High levels of boron are obtained in groundwater in some Mediterranean countries, such as Turkey, which has the largest boron reserves in the world. Boron pollution is a severe problem for Turkey. Wastes from the boron mines and boric acid plants are the main sources of the pollution. In addition to this, geothermal waters contain high levels of boron concentration in west Anatolia in Turkey. The recent European Union (EU) drinking water directive defines an upper limit of 1mg B/L. A minimum of boron in irrigation water is required for certain metabolic activities, but at only slightly higher concentration, plant growth will exhibit effects of boron poisoning, which are yellowish spots on the leaves and fruits, accelerated decay, and ultimately plant expiration[1]. Boron is a naturally occurring element throughout the environment. Boron has a number of minerals, in nature mostly calcium and/or sodium borates, such as colemanite

($2CaO.3B_2O_3.5\ H_2O$), ulexite ($Na_2O.2CaO.5B_2O_3.16H_2O$), tincal ($Na_2O.2B_2O_3.10H_2O$), etc. The main boron-bearing end products in the industry are insulation and textile- grade fiber, borosilicate glass, fire retardants, enamels, glazes and agricultural products [2]. Boron is an essential element for plant growth however, and if present in a larger amount, it is necessary to remove from effluents due to its toxic effectivity [3]. A minimum boron concentration in irrigation water is required for some metabolic activities of plants, such as cellular multiplication, the metabolism of nucleic acids. Deficiency in boron level will result in poor budding, excessive branching, and in general, inhibits plant growth. On the other hand, boron concentration in irrigation water which is only slightly higher than the minimum will be negative for plant growth and will exhibit signs of "boron poisoning" yellowish spots on the leaves and the fruit, accelerated decay, and ultimately plant expiration [4]. Boron is important in the metabolism and utilization of calcium in humans. Other benefits of boron include improvement of brain function, psychomotor response, and the response to estrogen ingestion in postmenopausal women. In humans, the sign of acute toxicity include nausea, vomiting, diarrhoea, dermatitis and lethargy [5.Therefore, removal of boron from water and wastewater is a crucial problem for environmental control. There are several methods suggested for boron removal from aqueous solutions. Several methods have been investigated for removal of boron, including ion exchange [6-7], adsorption[8-9], electrocoagulation[10-11], membran techniques like, nanofiltration and reverse osmosis [12-13], electrodialysis[14-15].

EC (electrocoagulation) is an emerging water treatment technology and could be good choice to remove boron from water: the amount of required chemicals is much lower, a smaller amount of sludge is produced, no mixing of chemical is required, coagulant dosing as well required overpotantials can be easily calculated and controlled, operating costs are much lower when compared with most of the conventional technologies [16]. During the last two decades, a special research field, environmental electrochemistry has been developed.

Electrocoagulation involves the generation of coagulants in situ by dissolving electrically either aluminum or iron ions from respectively aluminum or iron electrodes. The metal ion generation takes place at the anode; hydrogen gas is released from the cathode. Also, the hydrogen gas would help to float the flocculated particles out of the water. This process sometimes is called electroflocculation. The electrodes can be arranged in a mono-polar or bi-polar mode. The materials can be aluminum or iron in plate form or packed form of scraps such as steel turnings, millings, etc. The most widely used electrode materials in electrocoagulation process are aluminum and iron. I
When aluminum used as electrode materials, the chemical reactions are as follows;

- At the cathode:
  $3H_2O\ +\ 3e^-\ \rightarrow\ 3/2H_{2(g)} + 3OH_{(aq)}^-$
- At the anode:
  $Al_{(s)}\ \rightarrow\ Al_{(aq)}^{3+}\ +\ 3e^-$
- In the solution:

  $Al_{(aq)}^{3+} + 3H_2O \rightarrow Al(OH)_{3(s)} + 3H_{(aq)}^{+}$

The H_2 produced as a result of the redox reaction may remove dissolved organics or any suspended materials by flotation

The purpose of the present study is too asseses the performance of EC on the treatment of boron, by exploring the effects of parameter such energy consumption on boron removal efficiency.

2. Experimental

Wastewater samples used in the experiments were prepared synthetically using $Na_2B_4O_7$ having 99.99 of purity from Merck. The solution with boron concentration of 100 mg/L was prepared by dissolved 459.1 mg borax dried at 105 ◦C in distilled water and completed with distilled water to 1 L. The same operations were repeated for the solutions with boron concentrations of 100, 250, 500 and 1000 mg/L with different $Na_2B_4O_7$ weights. The pH of the solution was adjusted by adding either sodium hydroxide or nitric acid.

A laboratory-scale reactor (16 cm × 8cm × 8 cm), made of plexiglass, was used in all experiments (Fig. 1).Two groups of alternating electrodes being cathodes and anodes (by eight plates of each type) made of aluminum were arranged vertically. The net spacing between the aluminum electrodes was 5 mm. They were connected to terminals of a direct current power supply characterized by the ranges 2–10A for current and 0–30V for voltage. At the beginning of each run the solution of boron of the desired concentration fed into the reactor. Each run was timed starting with the dc power supply switching on.

The analytical determination of boron was done potentiometrically by means of mannitol, which forms a complex compound with boric acid. For this purpose, boron analyses were carried out following: Solution pH was adjusted to 7.60 after sample was filtered. Then, 5 g mannitol was added to solution. The solution was titrated with 0.5N KOH until solution pH became 7.60. Boron amount was calculated from KOH consumption. 1ml 0.5N KOH is equal to 17.41 mg B_2O_3[17]. This method was selected in order to prevent aluminum interference in boron detection done by spectrophotometric methods such as Carmin, Azomethine-H and Curcumin methods [18]

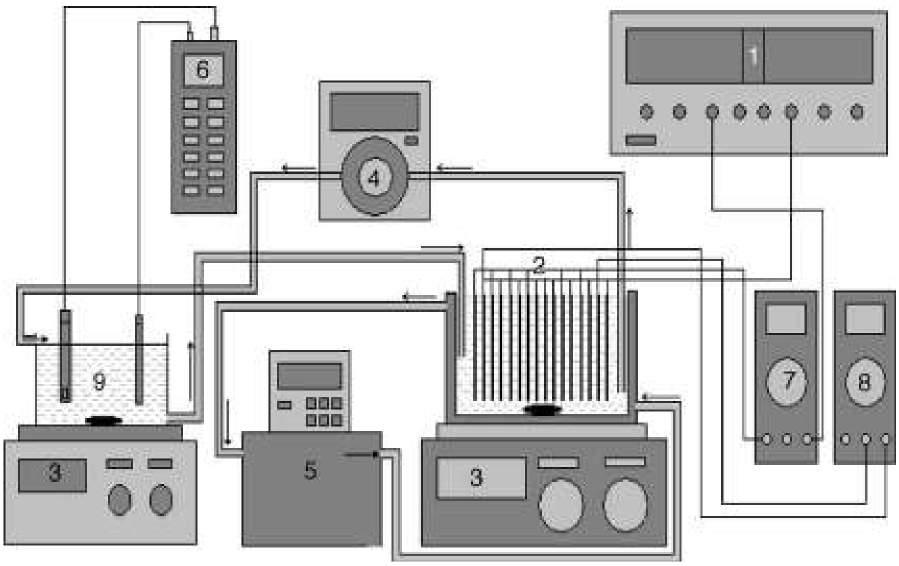

Figure 1. Schematic view of the experimental system ((1) dc power supply, (2) electrocoagulation cell, (3) magnetic stirrer, (4) pump, (5) circulator, (6) pH and conductivity meter, (7) ampermeter, (8) voltmeter and (9) pH control unit)

3. Result and discussions

The effect of initial boron concentration on the boron removal was examined with solutions including boron of 100, 250, 500 and1000 mg/L. Current density of 2, 4, 6, 8 and 10 A, optimum pH of 8.0 and stirring speed of 150 rpm were kept constant in the experiments. Boron removal efficiency decreased with increasing boron concentration. This can be explained as following; although the same amount Al^{+3} passed to solution at the same current density for all boron concentration, Al^{+3} was insufficient for solutions including higher boron concentration. The results obtained were shown graphically in Figure 2.

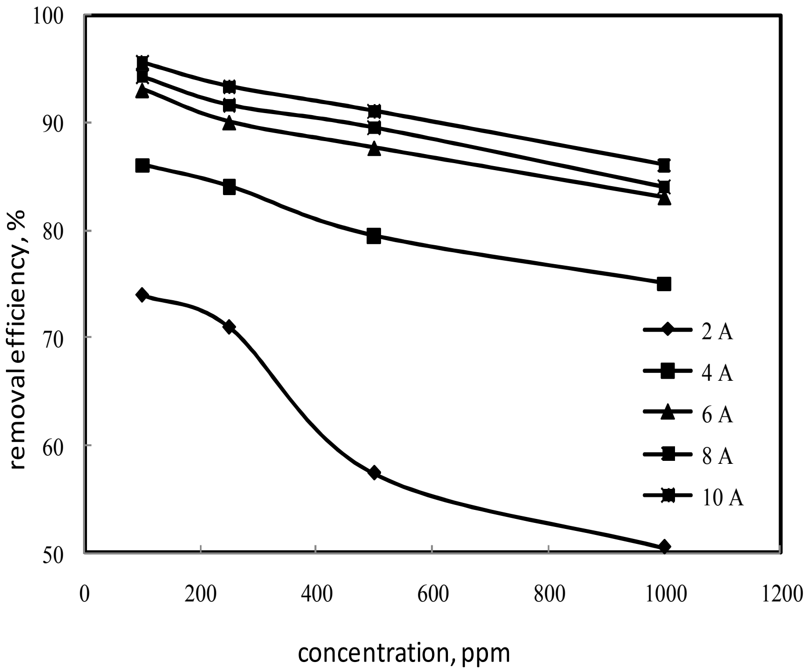

Figure 2. The effects of initial boron concentration on removal efficiency (pH 8.0, 293 K of solution temperature and 150 rpm stirring speed)

The effect of initial boron concentration on electrical energy consumption was examined with solutions including boron of 100, 250, 500 and 1000 mg/L. Current density of 2, 4, 6, 8 and 10 A, optimum pH of 8.0 and stirring speed of 150 rpm were kept constant in the experiments. Increasing initial boron concentration increased amount of ions in solution. As a result of this case, the solution conductivity increased with increasing boron concentration. Increasing of amount of ionized species in solution obtained more transmission for electric applied under constant current density.

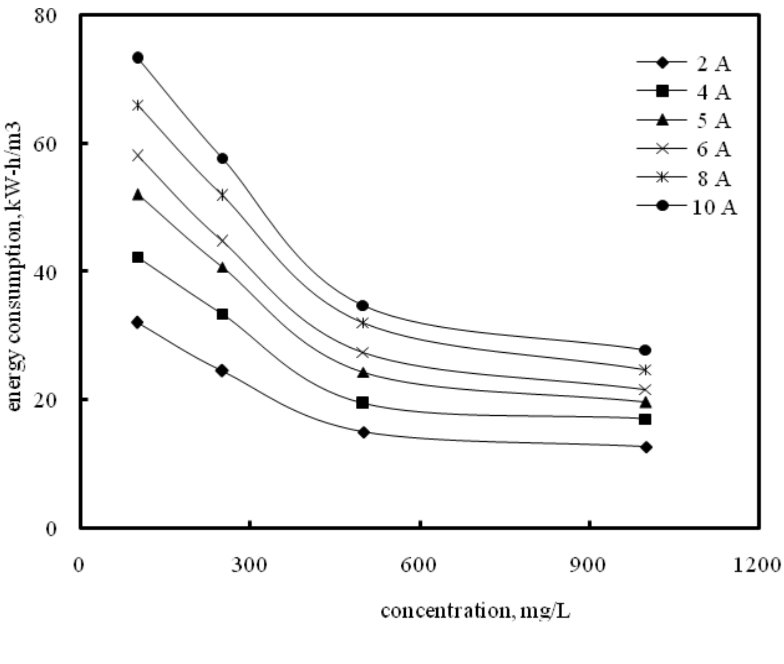

Figure 3. The effects of initial boron concentration on energy consumption (pH 8.0, 293 K of solution temperature and 150 rpm stirring speed)

In order word, this situation caused to decrease total resistance in electrocoagulation cell. Because of increasing boron concentration, potential applied to solution and energy consumption decreased. In Figure 4, the change of boron removal and energy consumption for 500 mg/L was demonstrated as a function of reaction time. As seen in Figure 3, energy consumption increased constantly with increasing boron removal during reaction time. Other initial boron concentrations had the same tendency. The results obtained were shown graphically in Figure 3. As seen in Figure 3, the lowest energy consumption curve was obtained in the experiments carried out with 1000 mg/L of initial boron concentration solution because it had the highest conductivity. When specific conductivity of solution with 1000 mg/L of initial boron concentration reached to 5245 mS/cm, specific conductivity of solution with 100 mg/L of initial boron concentration remained at 835 mS/cm. The solutions which are given conductivity values had pH 8. The effect of conductivity on electrical energy consumption could be explained with following equations:

$$W = \frac{V.I.t}{\vartheta} \quad (1)$$

where W is the electrical energy consumption (kW h/m^3), V the potential (V), I the current (A), t the time (h) and ϑ is the volume of solution (m^3). Applied potential could be explained with the equation:

$$V = I.R \quad (2)$$

where R is the resistance (Ω). From Eqs. (1) and (2), following equation could be obtained:

$$W = \frac{I^2.t}{\vartheta} \quad (3)$$

Electrical conductivity is a measure of how well a material accommodates the transport of electric charge. Electrical conduction is an electrical phenomenon in which a material (solid or otherwise) contains movable particles with electric charge, which can carry electricity. When a difference of electrical potential is applied to a conductor, an electric current appears. Conductivity stated as the inverse of electrical resistivity, is defined as the ratio of the current density to the electric field strength and has the SI units of Siemens per meter (S/m). Electrical conductivity caused to decrease energy consumption because there was a relationship between electrical conductivity and resistance. The decreasing initial boron concentration of solution caused to rise of electrical conductivity. Thus, high conductivity values of solution caused to low resistance values and low energy consumption.

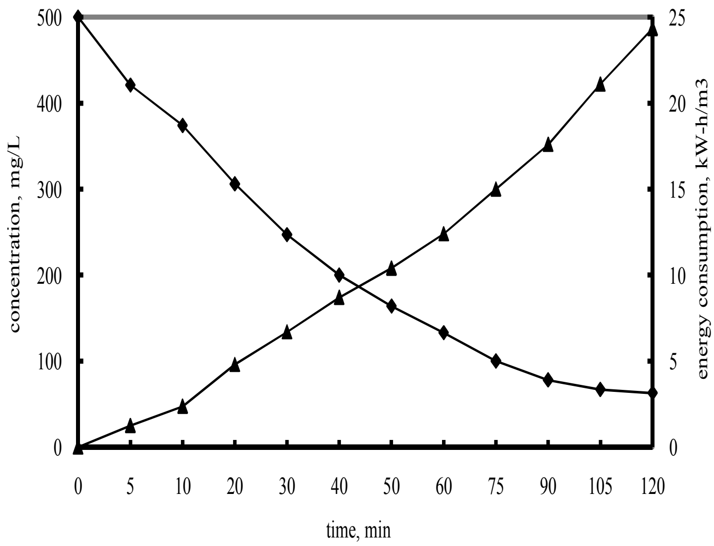

Figure 4. The change of boron removal and energy consumption for 500 mg/L as a function of reaction time

4. Conclusions

The present study clearly demonstrated the applicability of electrocoagulation process using the aluminum electrode for boron removal. The effects of operational parameters such as initial boron concentration on boron removal efficiency and energy consumption were studied in detail and explained as well. When effect of initial boron concentration on energy consumption was investigated, the obtained results shown that increasing boron concentration increased conductivity of solution. Thus, solution with higher boron concentration had more ions at the same volume. The higher conductivity values decreased energy consumption.

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