The Effect of Current Density and pH of Cadmium Removal by Electrochemical Processes

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Abstract : Removal of cadmium from synthetically prepared solution using electrochemical processes is studied in the present study. To determine the optimum operation conditions, the effect of several parameters such as current density and initial solution pH have been investigated. Iron electrode was used as electrode materials. Experiments were carried out with different current densities ranging from 0.25 to 1.25 A/m^2. It was observed that the removal of cadmium increases with increasing current densities. The distance of between electrodes was chosen as 5 mm. Initial cadmium concentrations was kept constant at 100 mg/L while other parameters such as current density and initial solution pH were investigated. Cadmium concentration in the solution was determined using Atomic absorption spectrophotometer. The experimentally obtained results were shown that electrochemical processes were achieved to cadmium removal (e.g. 99.99%) from synthetically prepared solution.

Key words: Cadmium, removal, electrocoagulation, electroreduction

1. Introduction

Heavy metals pose a significant hazard to environment and human health. Wastewater generated from cadmium processing is extremely toxic to environment and to humans. Due to their high toxicity, industrial wastewaters containing heavy metals are strictly regulated and must be treated before being discharged in the environment. Cadmium is a toxin of environmental concern. The impact for non-cancer causes includes kidney, liver, and lung damage [1]. It is also classified as a probable human carcinogen for lung cancer. The association of cadmium with hormone-related cancers such as prostate and breast cancers has being actively investigated since the initial implication [2-4]. There is no known function of cadmium in the human biological system. The presence of such foreign metal ion in the human is likely a result of various exposures. In addition to direct exposure from air and drinking water, another potential exposure is to result from crops grown in the contaminated water and soil environment, which transports the metal into food chain where cadmium is accumulated in various parts of crops [5]. Electroplating, nickel–cadmium battery production and disposal, fossil fuels, pigments, fertilizers, certain electronic components are all potential sources of contamination to water [6]. Various methods can be applied to remove toxic metals from industrial effluents [7,8]. These methods include precipitation, co-precipitation, electrodeposition, electrocoagulation, cementation, membrane separation, solvent extraction, ion-exchange,

adsorption and biosorption [9, 10]. Precipitation is most applicable among these techniques and considered to be the most economical. Among these methods, electrocoagulation is particularly interesting. The electrocoagulation has been successfully used to treat oil wastes, with a removal efficiencies as high as 99% [11,12]. A similar success was obtained when treating dye-containing solutions [13–14], potable water [15], urban and restaurant wastewater [16,17] and nitrate or fluoride containing waters [18,19]. In addition, a great deal of work performed in the last decades [20–21] has proved that electrocoagulation is an effective technology for the treatment of heavy metal containing solutions.

This technology delivers the coagulant in situ by anodic dissolution and produces subsequently, iron (or aluminium) hydroxides having a considerable sorption capacity, while the simultaneous cathodic reaction allows pollutant removal either by deposition on cathode electrode or by flotation (evolution of hydrogen at the cathode) [22]. Likewise, during electrocoagulation process, liquid is not enriched with anions and salts content does not increase, compared to chemical metal precipitation [23]. This contributes to production of metallic sludges which are compact using electrocoagulation compared to those generated by chemical precipitation [24,25]. Moreover, electrocoagulation requires simple equipment, small retention time and is easy to operate [26,27]. These characteristics contribute to reduction of operating cost for industrial applications.

In the present work, the efficiency of electrocoagulation in removing cadmium from synthetically solution was reported. The effect of initial pH and current density on the removal efficiency is explored and discussed to determine the optimum operational conditions. Aim of this study is to investigate the effects of initial pH and current density on cadmium removal from wastewater by electrocoagulation method using iron electrodes.


2. Materials and methods

2.1 Materials
Wastewater sample used in the experiments were prepared synthetically using $CdCl_2H_2O$ having 99.99 of purity from Merck. The solution with cadmium concentration of 100 mg/L was prepared by dissolved 0,1796 mg in distilled water and completed with distilled water to 1 L. The electrolyte was synthetically prepared by using analytical reagents and distilled water. A stock solution of cadmium chlorine, 100 mg/l was prepared. The pH of the solution was adjusted to the required value with $10^{-2}M$ nitric acid and $10^{-2}M$ sodium hydroxide. All measurements were carried out at ambient temperature approximately $(22 \pm 1 \ ^{o}C)$

2.2. Experimental setup and procedure

The experimental setup is schematically shown in Figure 1.The EC unit consists of six pair of electrodes made of plate iron with total area of approximately 1000 cm^2 and the gap between the electrodes is 5 mm. Electrodes were connected to a digital DC power supply (Good Will) in monopolar mode. Two digital multimeters (Brymen Bm 201) as ampermeter and voltmeter were used to measure the current passing through the circuit and the applied potential, respectively. The EC unit has been stirred at 150 rpm by a magnetic stirrer. (Heidolp MR 3004 S). The thermostated electrocoagulator is made of plexiglass with the volume of 900 mL. During the experiments, temperature, conductivity and pH of the solutions were measured by a multi-parameter (WTW Multiline P-4 F-Set-3). Reactor was operated in batch and galvanostatic mode. Figure 1.
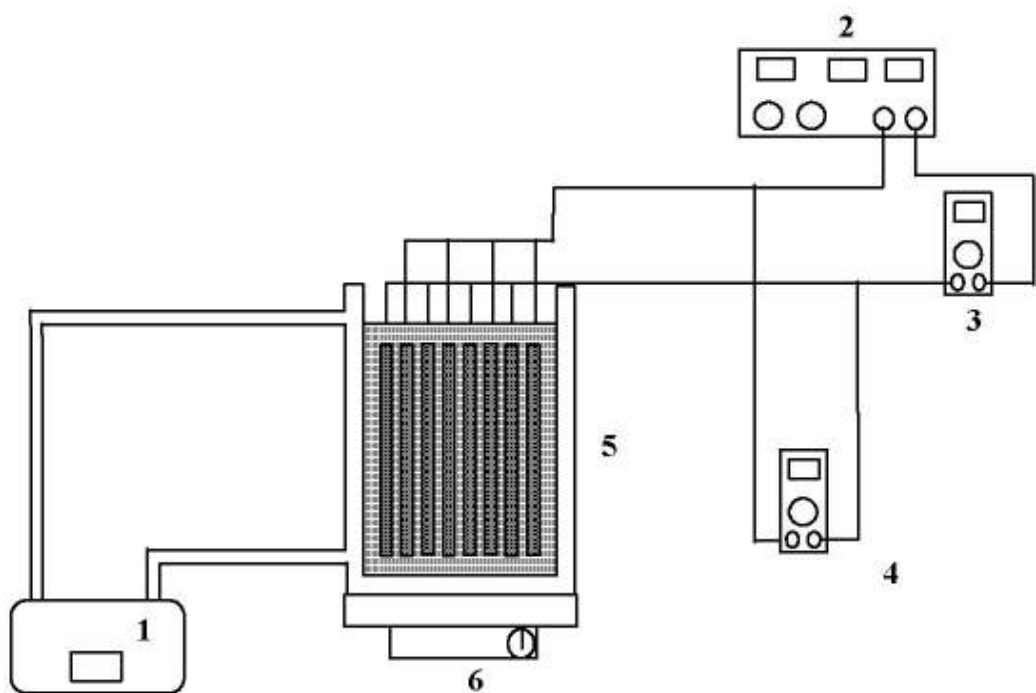
1.Water Cırculator   2.Digital D.C Power Supply   3.Digital Ampermeter
4.Digital Voltmeter   5.Electrochemcial Reactor   6.Digital Magnetic Stirrer

Figure 1. Schematic diagram of the experimental setup.

2.3. Brief description of electrocoagulation mechanism

Electrocoagulation is based on the in situ formation of the coagulant as the sacrificial anode corrodes due to an applied current, while the simultaneous evolution of hydrogen at the cathode allows for pollutant removal by flotation. This technique combines three main interdependent processes, operating synergistically to remove pollutants: electrochemistry, coagulation and hydrodynamics. An examination of the chemical reactions occurring in the electrocoagulation process shows that the main reactions occurring at the electrodes are:
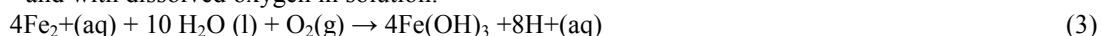When iron is used as electrode material, the reactions are as follows.
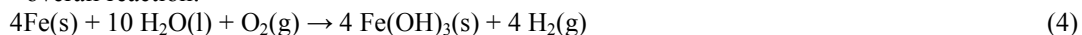• At the cathode:
$$3H_2O + 3e^- \rightarrow 3/2\ H_2(g) + 3OH^- \tag{1}$$
• At the anode:
$$4Fe(s) \rightarrow 4Fe_2+(aq) + 8e^- \tag{2}$$
• and with dissolved oxygen in solution:
$$4Fe_2+(aq) + 10\ H_2O\ (l) + O_2(g) \rightarrow 4Fe(OH)_3 + 8H+(aq) \tag{3}$$
• overall reaction:
$$4Fe(s) + 10\ H_2O(l) + O_2(g) \rightarrow 4\ Fe(OH)_3(s) + 4\ H_2(g) \tag{4}$$

2. Result and discussions

The effects of parameters: In the runs, it has been investigated the effects of parameters such as initial pH and current density under the conditions which the reaction time, temperature of solution and stirring speed hold in constant.

The effect of pH: It has been established that the pH has a considerable influence on the performance of electrocoagulation and reduction process. To evaluate this effect, a series of experiments were performed, using solution containing cadmium of 100 mg/L. The effect of pH on the cadmium removal was examined at 3.0, 4.0, 5.0 and 6.0 pH's. Solution temperature of 293 K and stirring speed of 100 rpm were kept constant in the experiments. The results of the experiments conducted to examine the effect of pH are shown in Figure 2.
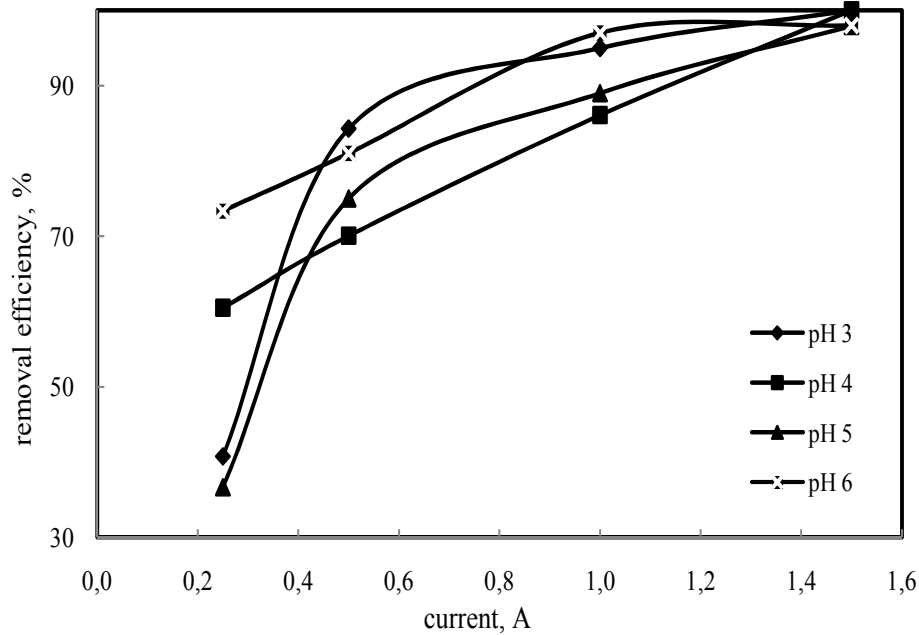
Figure 2. The effects of solution pH on cadmium removal (100 rpm of stirring speed, 293 K of solution temperature and 100 mg/L of initial cadmium removal)

As seen in Figure 2, while there had effects of pH variation on cadmium removal efficiency, the effects of pH variation were not important with increasing current density. At the lower current density, solution pH had effects on cadmium removal efficiency. When cadmium removal was investigated by electrochemical process, energy consumption values obtained in the system. Energy consumption values in the electrochemical reactor related to solution conductivity. The conductivity of an electrolyte solution is a key property. In an electrochemical process, the conductivity determines the cell resistance while the properties of solvent and electrolyte determine their interaction with the electroactive species and thereby influence the electrode reactions. The results obtained for energy consumption were shown graphically in Figure 3.
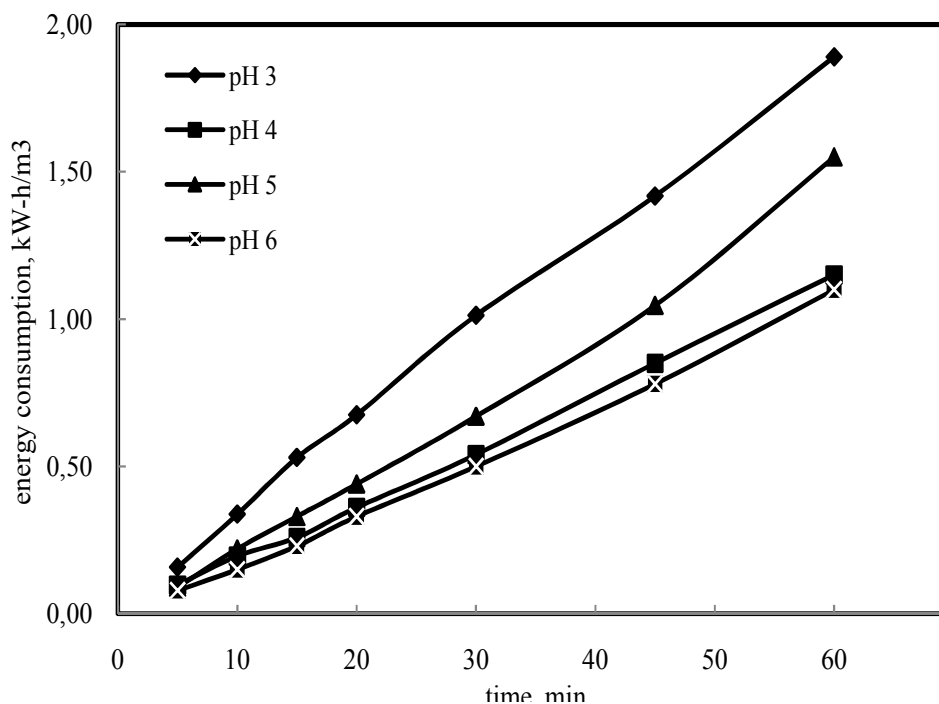

Figure 3. The effects of solution pH on energy consumption(100 rpm of stirring speed, 293 K of solution temperature, 0,5 A of current and 100 mg/L of initial cadmium removal)

The effect of current density: The effect of current density on cadmium removal by electrochemical process using iron plate electrodes was investigated using 100 mg/L Cd^{+2} and pH 5. Effects of current density on system parameters have been analyzed. Variation of cadmium removal efficiency versus time and variation of energy consumption versus time in various current densities with iron plate electrodes is shown in Figures 4-5.
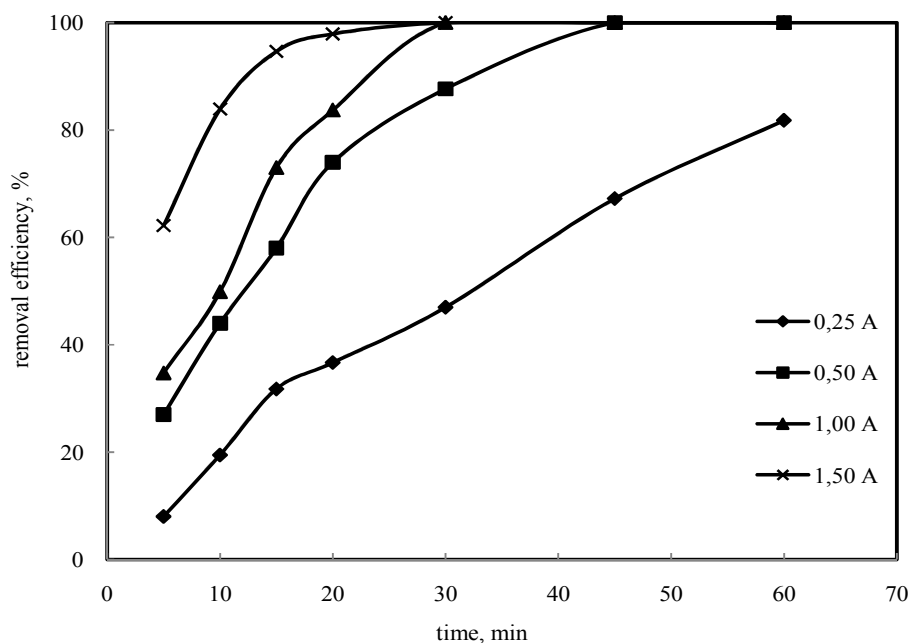

Figure 4. The effects of current on removal efficiency (100 rpm of stirring speed, 293 K of solution temperature, pH 5 of solution and 100 mg/L of initial cadmium removal)

As seen in Figure 4, efficiencies of cadmium removal and removal rate have increased by increasing current density. The removal efficiency depends on the quantity of iron generated, which is related to the time and the current density. It is seen that system energy consumption has mainly increased over a specific current density, respectively.
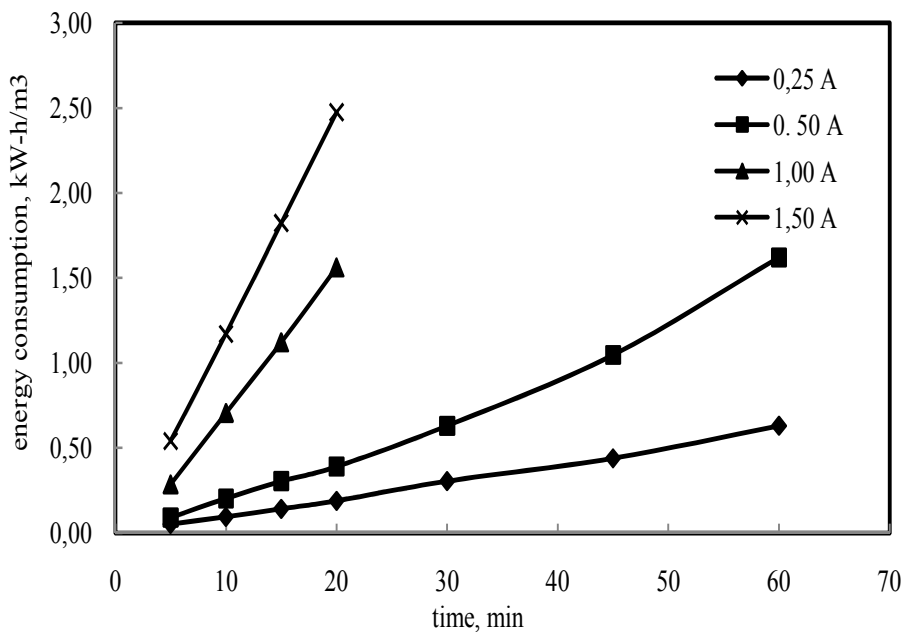

Figure 5. The effects of current on energy consumption (100 rpm of stirring speed, 293 K of solution temperature, pH 5 of solution and 100 mg/L of initial cadmium removal)

Since applied potential have increased by increasing current density, system energy consumption has increased. Although potential and current have linearly increased, energy consumption has exponentially increased. Thus, when it has been studied in high current, this state might be taken into consideration. Besides, when it is studied on high potential and current, electrode reactions have taken one's way to secondary reactions from major reactions. Thus, when optimal current density and potential are selected, either high removal rate or low energy consumption might be taken into account.

4. Conclusions

In this study, effects of solution pH and current density on cadmium removal by electrochemical process using iron plate electrodes were investigated and effects of these parameters on system parameters were analyzed. When lower current density was applied to electrochemical process, solution pH must taken into consideration. In the experiments, effects of current density on cadmium removal by electrochemical process were investigated. According to results obtained from the experiments, removal rates and removal efficiencies have increased by increasing current density using iron plate electrodes. But system energy consumptions have increased by increasing current density.

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