Investigation of sludge production in an electrocoagulation process under different conditions

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Abstract
For the treatment of industrial wastewater, an electrocoagulation method is used. During the electrocoagulation process, a considerable amount of sludge is automatically produced. Sludge volume and sludge settling characteristics therefore are important parameters in the evaluation of the effectiveness of electrocoagulation treatment**.** In this study, the effect of pH, time, current density and distance between electrodes on Electrocoagulation Metal Hydroxide Sludge (EMHS) was investigated by electrocoagulation. The sludge produced was investigated using four different pH (1.45, 4.6, 6.2, 9.3), six current density conditions (0.5, 1, 1.5, 2, 2.5, 3A), and the inter-electrode distances (0.5, 1, 1.5, 2, 2.5cm). These characteristics were experimentally tested. The results show that there is linear relation between these parameters and EMHS such that EMHS increases with increasing current and time while decrease with more base pH.

Keywords: wastewater, sludge, electrocoagulation, EMHS

Introduction
Treatment of wastewater is significantly important in 21st century. There have been many techniques by which industrial wastewater can be treated among which electrocoagulation (EC) has been applied for years [1]. EC has been applied to remove many pollutants including arsenic, fluoride, nitrate, natural organic matter, and turbidity [2-4]. COD removal from industrial wastewater is also an interesting trend using the EC. Many authors have applied EC to investigate COD removal with focus on studying influencing parameters [5-7]. However, a very important issue associated with EC is the generated sludge which is semisolid and bulky [8]. In addition, this sludge is very complex as it contains organic and inorganic matter, oil and grease, toxic heavy metals and trace metals [9]. The dissolved metal hydroxides as the result of sacrificial anode used in EC process are yet another problematic portion of EC sludge [10]. The disposal of un-treated EC sludge is a concern both environmentally and economically [8]. Solidification of sludge is an evolving strategy to stabilize the industrial waste sludge whose physical properties have been also confirmed [11, 12]. Electrocoagulated

metal hydroxide sludge (EMHS) has been investigated and successfully approved for making different types of building materials [8, 13, 14]. There have been several studies to inspect the characteristics of sludge generated by EC operation [15-18]. Nevertheless, no study has focused on the effect of EC parameters including electrodes, density, time, pH, etc.
In this study, using both Al and Fe electrodes, the effect of pH, time, current density, and inter-electrode distance on the amount of EMSH has been investigated.

Experimental
Effluent
The wastewater was provided from leachate wastewater in Tabriz, Iran. The initial characteristics of the wastewater are stated in Table 1.

Table 1- initial characteristics of the experimental wastewater

parameter	value
COD (mg/l)	1928
TDS (g/l)	8.44
pH	7.94-8.34
color	Dark brown

EC Cells
EC cells each had a working volume of 250 millilitres agitated using a magnet stirrer at the bottom. Using a DC power source, Al electrodes worked at a constant current density of 250 $A.m^{-2}$, unless stated otherwise. All experiments were carried out for 10 min except the experiments in which the effect of time was to be investigated. The initial and final mass was evaluated gravimetrically at the start and end of experiments using a laboratory scale. Prior ro that the beakers were placed in an oven and kept overnight at 100◦C. The electrode area was 0.004 m^{-2}.
To investigate the effect of inter-electrode distances, experiments using both Al electrodes were carried out with inter-electrode distances of 0.5, 1, 1.5, 2, and 2.5 cm. To investigate the effect of current densities at both longer and shorter range of inter-electrode distances, electric currents of 0.2, 1, 1.5, 2, 2.5, and 3 were evaluated. In pH experiments, concentrated NaOH and HCl were used to set the pH values. pH set-points were decided based on the Pourbaix diagram of Al to investigate the speciation of Al. Thus, pH values of 1.45, 4.6, 6.2 and 9.3 were set for Al pH experiments. Finally, to investigate the effect of time, samples were taken continuously at the intervals of 3, 5, 10, 15, 30, 45, 60, and 90min. For each taken sample, equivalent volume was replaced with fresh wastewater to prevent any reduction of working volume.

Results and discussion
The effect of time
Figure 1 illustrates the results of sludge production versus EC duration. As the diagram shows, sludge production has excelled with EC duration.

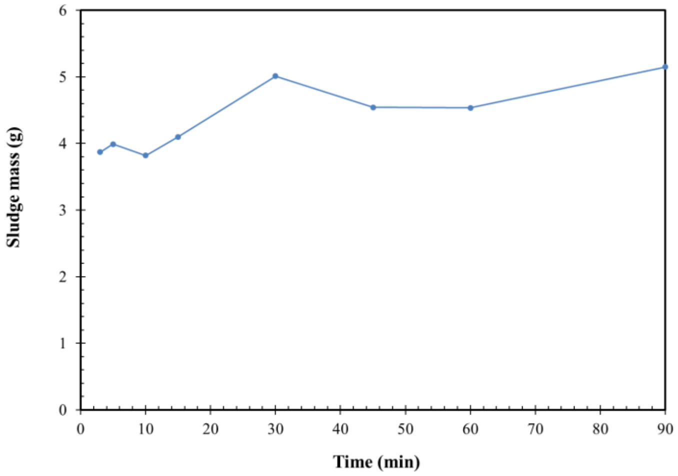

Figure 1-The effect of time o sludge mass during EC at current density of 250 $A.m^{-2}$ and electrode gap of 0.5cm

The linear relation between time and electrode mass can be explained by Faraday's law (Equation 1) [1]:

$$m = \frac{ItM}{nF} \qquad \text{Equation 1}$$

where m is the electrode metal mass (g), I is the current (A), t is the EC duration (s), M is the molecular mass of the electrode material ($g.mol^{-1}$), n is metal valence (2 for Fe and 3 for Al), and F is the Faraday constant (96500 $C.mol^{-1}$). Accordingly, as time increases more metal is dissolved into the medium, and therefore more metal hydroxide will be formed. Consequently, EMHS will rise. However, a slight drop at 10min and a sharp rise at 30min can be seen in Figure 1 which can be explained by restabilization and destabilization of colloids. At certain point, the concentration of coagulants surpasses colloid concentration, so that excessive adsorption occurs and restabilization takes place [19].

The effect of current

Figure 2 illustrates how current density influences the EMHS. It can be seen that increasing in current density has led to an increase in EMHS.

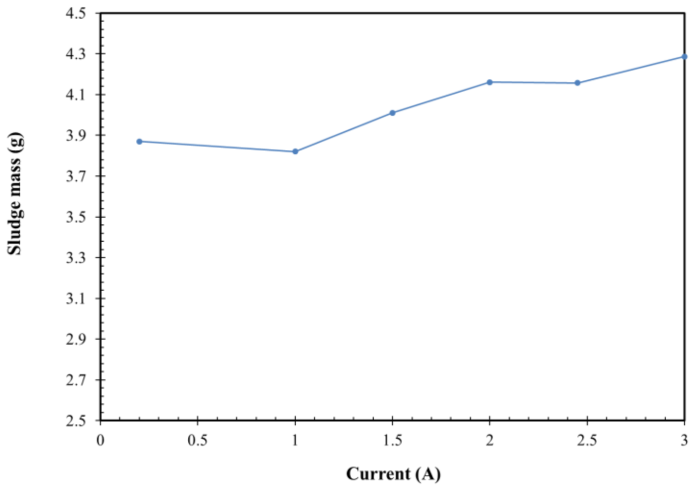

Figure 2-The effect of current on sludge mass during EC at 10min and electrode gap of 0.5cm

With reference to Equation 1, The higher the current goes, the more metal ions will be dissolved in the environment which will itself help both better neutralization of the colloidal charges and better metal hydroxides [20].

The effect of pH

The results of EMHS versus initial pH are illustrated in Figure 3. The results clearly state that the best values are obtained within the acidic pH for both Al electrodes. Within acidic pH predominant complexes of Al(OH)3 are produced, while within basic pH the complexes become more soluble. Since Al(OH)3 is the only insoluble species the best flocs must form around the pH of 5.2 and 8.8. Such results can be seen in Fig. 3 and similar studies [21, 22].

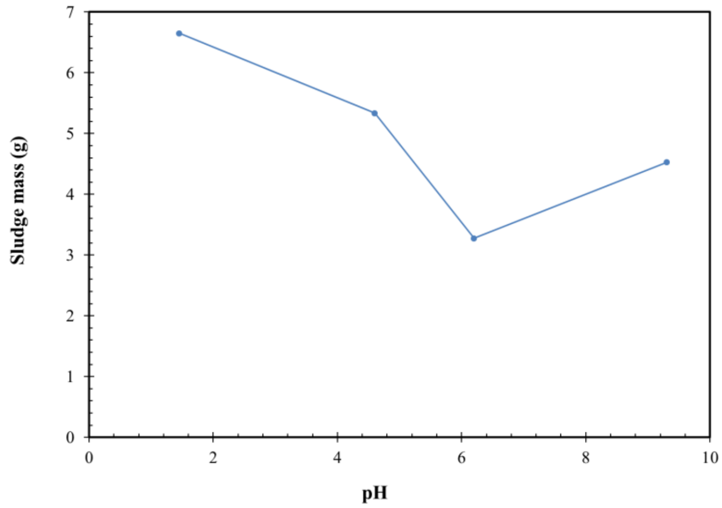

Figure 3-The effect of pH on sludge mass during EC at 10min, current density of 250 A.m-2 and electrode gap of 0.5cm

Conclusions

Electrocoagulation has been applied in wastewater treatment for many years. However, arguments still remain surrounding several issues on of which is the generated sludge after EC. Nevertheless, many studies have confirmed the successful application of electrocoagulation metal hydroxide slude in building materials. As a result, more accurate analysis seems necessary on the produced EMHS. In this study for the first time, a parametric evaluation of EC was performed to monitor how EMHS changes through various time, current, and pH. These results collectively give a better insight to how EMHS can be produced at higher amounts.

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