Cadmium removal from real mine water by electrocoagulation

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Abstract

This study investigated Cd removal from real mine water by electrocoagulation and iron–stainless steel anode/cathode combinations as well as aluminum–stainless steel anode/cathode combinations. Parameters such as time, current density and the type of electrodes were investigated to optimize the electrocoagulation process. It was found that the current density has a direct effect on the cadmium removal. Specifically, Cd was removed better at 70 mA/cm^2 than at 10 mA/cm^2. In addition, the reaction time has a direct effect on the removal of Cd. By increasing the time, Cd was removed at higher removal rates compared to the beginning of the reaction.

On the other hand, it was understood that the type of electrodes has an influence on the removal of Cd. Specifically, Cd was removed much better by an iron–stainless steel anode/cathode combination than by an aluminum–stainless steel anode/cathode combination. The removal efficiency of the aluminum–stainless steel anode/cathode combination reached 82%, whereas the Cd removal efficiency by iron-stainless steel was 100% at 120 min of reaction and 70 mA/cm^2.

The best condition for Cd removal was therefore obtained by using an iron–stainless steel anode/cathode combination with a current density and reaction time of 70 mA/cm^2 and 120 min, respectively. Cd was removed by 100% with the aforementioned condition.

Key words: Electrocoagulation, Cd removal, real mine water

Introduction

Metal concentrations in water are considered hazardous as metals are not biodegradable (Vasudevan and Lakshmi, 2011). One of the hazardous metals in water courses is Cd (Vasudevan et al., 2010) as it is also considered as carcinogenic by the US Environmental Protection agency (Vasudevan and Lakshmi, 2011). It is released into water as a result of using phosphate fertilizers, pigments, alloys, welding and the pulp and mining industries (Vasudevan et al., 2010). The limitation for Cd in drinking water is set to 0.005 mgL^{-1} by the World Health Organization (WHO) (Vasudevan et al., 2010).

Cd in water can be removed by various methods, some of them being considered conventional such as electrochemical treatment, co-precipitation, reverse osmosis or coagulation (Vasudevan et al., 2010). Yet, physical and chemical treatment has several drawbacks. For example, chemical treatment of Cd is considered to be expensive and its sludge handling is problematic. On the other hand, physical methods are not always efficient and are expensive. Currently, electrocoagulation is known to be an effective method for removing Cd. It is a process which contains an anode and cathode, in which the anode dissolves in the water and water hydrolysis takes place (Vasudevan et al., 2010). One of the electrode combinations used in electrocoagulation are aluminum and iron, the latter being used as a sacrificial anode (Gatsios et al., 2015, Holt et al., 1999) and, in addition, it has been shown to be an effective treatment for reducing the chemical oxygen demand, oil and metal plating wastewater (Gatsios et al., 2015). Some of the advantages in electrocoagulation are its generally low cost, reduced sludge production and easy operate (Vasudevan et al., 2010).

The poly hydroxide and hydroxide complexes generated bond with the ions and deduce in coagulation (Vasudevan and Lakshmi, 2011). The following reactions display how electrocoagulation works on the anode and cathode (Liu et al., 2010).

Anode reaction:

$$M_{(s)} \rightarrow M_{(aq)}^{n+} + ne^- \quad (1)$$

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

Cathode reaction:

$$M_{(aq)}^{n+} + ne^- \rightarrow M_{(s)} \quad (3)$$

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

The objective of this study was to investigate Cd removal on a laboratory scale from real mine water of the Pyhäsalmi mine, which is currently the deepest metal mine in Europe (Enqvist et al., 2005). The effect of current density, reaction time and type of electrode regarding the Cd removal was investigated.

Methods

The inter electrode distance was set to 0.5 cm to minimize the voltage drop. A direct current (GW INSTEK psp-405) with 0–5 A and 0–40 V, was applied for the experiments. Iron and aluminum were used as anodes, whereas stainless steel was used as cathode with the electrodes having dimension of 70 × 50 mm. The beaker was filled 500 mL of mine water in each experiment and the current density in each experiment was set to a predefined values. The water was stirred with a constant speed of 200 rpm via a magnetic stirrer (Figure 1).

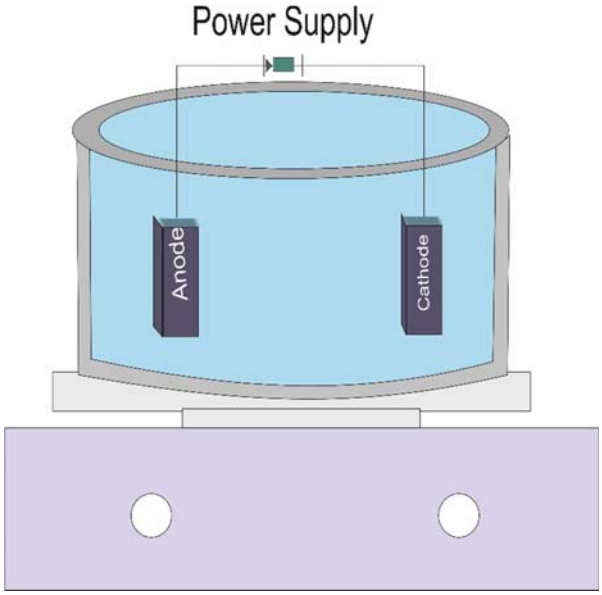

Figure 1. *Laboratory setup for electrocoagulation; monopolar electrode configuration, a stirrer and a DC electrical supply.*

The water was collected at the +500 m level in the Pyhäsalmi mine, which is located in Pyhäjärvi, Finland. All water samples were collected and stored in a freezer at a temperature of -20 °C and brought to ambient temperature immediately before each experiment. The redox-potential, electrical conductivity and pH were measured with Hach intelliCAL™ redox, electrical conductivity and pH

probes connected to a Hach HQ40d (Table 1). All electrodes were rinsed before each experiment with 0.2 M HCl.

Table 1. *Cd concentration and other relevant parameters of the Pyhäsalmi mine water.*

Parameter	Unit	Value
pH (field)	–	2.86
Cd	mg/L	2.1
Electrical conductivity (field)	µS/cm	6968
Redox (corrected, field)	mV	467
Temperature (field)	°C	16.70

Cd concentrations were measured by ICP-OES (iCAP 6300, Thermo Electron Corporation) and the water samples filtered with a 25 mm syringe filter (0.2 µm cellulose acetate membrane), before each measurement. The Cd removal in each experiment was calculated using the following equation:

$$\text{Removal efficiency}, \% = \frac{(C_0 - C_t)}{C_0} \times 100 \quad (1)$$

in which C_0 and C_t are the Cd concentration at 0 min and t min, subsequently.

It was shown that the current density has a direct effect on the Cd removal such that in increase in current density increases also the Cd removal. When the reaction time increases, the Cd removal efficiency also increases. This can be explained by the fact that with increasing time the release of the sacrificial anode as coagulant into water increases as well.

Cd removal was higher with the iron–stainless steel anode/cathode combination compared to the aluminum–stainless steel anode/cathode combination. It reached 46.6, 64.3 and 100% with the iron–stainless steel anode/cathode combination at 10, 40, 70 mA/cm^2, respectively. On the other hand, the aluminum–stainless steel anode/cathode combination removed 56.3, 61.2 and 82.4% Cd at 10, 40 and 70 mA/cm^2, respectively (Figure 2).

Cd removal reached its maximum at 70 mA/cm^2 and 120 min of reaction time with both aluminum and iron as anodes. It should be noted that the removal efficiency with an iron anode was better than with an aluminum anode.

The final Cd concentrations in the real mine water reached 1.85×10^{-5} mg/L and 0.01 mg/L with the iron–stainless steel anode/cathode combination and the aluminum-stainless steel anode/cathode combination, respectively. Therefore, Cd limits for drinking water can be met by using iron-stainless steel anode/cathode combinations.

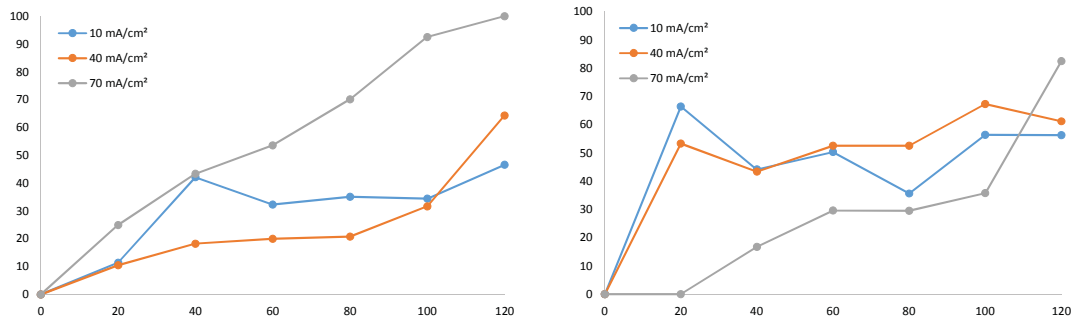

Figure 2. *Effect of reaction time and the current density on the Cd removal by various electrode pairs, (a) iron–stainless steel and (b) aluminum–stainless steel.*

Conclusions

The results showed that a removal efficiency of 100% can be achieved by an iron–stainless steel anode/cathode combination with a current density of 70 mA/cm^2 and a reaction time of 120 min. It was found out that with increasing current density and reaction time, the Cd removal increases as well.

The final Cd concentrations in the mine water after removal were 1.85×10^{-5} mg/L and 0.01 mg/L with an iron–stainless steel and aluminum–stainless steel anode/cathode combination, respectively. It indicates that at least the Cd concentration in mine water can meet the standards for drinking water.

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