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Removal of lead and zinc from battery industry wastewater using electrocoagulation process: Influence of direct and alternating current by using iron and stainless steel rod electrodes

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ABSTRACT

In this study the efficiency of electrocoagulation by direct and alternating current in the removal of lead and zinc has been evaluated. Wastewater samples were taken from the battery building industry. In the electrochemical cell, metal iron and stainless steel rod electrodes were used and were connected together serially and monopolar to the power source. By using alternating current the removal of lead and zinc was done successfully with iron electrodes and in the current density of 6 mA/cm^2 which was respectively 96.7% and 95.2% and with stainless steel electrodes in current density of 8 mA/cm^2 was 93.8% and 93.3%. By using direct current the optimum removal of lead and zinc with iron electrodes was respectively with 97.2% and 95.5% in current density of 6 mA/cm^2 and with stainless steel electrodes was equal to 93.2% and 92.5% in current density of 8 mA/cm^2 was achieved. With alternating current the optimum energy was achieved by using iron electrodes and was 0.69 km h/m^3 and 0.72 kg/m^3 and with stainless steel electrodes were 0.98 km h/m^2 and 0.9 kg/m^3. In direct current the optimum amount of energy with iron and stainless steel electrodes wererespectively1.97 kW h/m^2 and 1.17 kg/m^3 and 2.53 kW h/m^3 and 1.42 kg/m^3. The maximum amount of sludge was made in alternating current with a 0.084 kg/m^3 current density and in direct current at 0.091 kg/m^3. According to the results this process can be used as a suitable method for a wide use of electrolyte reactors in the industrial scale and for removing lead and zinc from aqueous environments.

1. Introduction

Some industrial waste includes heavy metals such as cadmium, chromium, copper, nickel, mercury, lead and zinc which if drained directly into the environment are hazardous. Nowadays contamination with heavy metals is one of the most serious environmental disasters [1,2]. Drainage of heavy metal due to their dangerous side effects is a matter of concern in the environment. In contrast to organic pollutants, heavy metals are not biologically degradable, are highly solvable in water, have a tendency to accumulate in living organisms and many of their ions are toxic and carcinogenic. Lead and zinc are among the most toxic non necessary heavy metals in the environment and based on the severity of pollution are among the class one toxic pollutants [3,4]. Lead and zinc ions are high in waste water from different sources such as plating, lead batteries, phosphate fertilizers, mines, dyes, refineries, paper and pulp industries. Lead and zinc toxication leads to kidney failure, lung fibrosis and cancer, also these ions have negative effects on blood and bones. The permissible amount of lead and zinc in drinking water is respectively 0.01 mg/1 and 0.5 mg/l [5,6]. In order to prevent the negative effects of these metals on humans and the environment and also to follow the guidelines, it is necessary to remove these metals from wastewater before disposal. The routine methods for removing lead and zinc from water include ion exchange, reverse osmosis, floating, sequestration, coagulation, solvent extraction, chemical filtration, surface absorption and electrocoagulation. Each method has its own pros and cons. For example physical method such as ion exchange, reverse osmosis and electrodialysis for lead and zinc removal are expensive and inefficient. Chemical infiltration also has cons such as the high cost of maintenance, difficulty in transferring and disposing sludge and neutralizing the effluent, which it non-practical. Also removing lead and zinc from water by adsorption by different chemicals have

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been evaluated. The main cons of the experimented absorbents are their low efficiency and high cost [7–11]. From the different techniques mentioned above, one effective technology which fulfills the cleaning, applicability, investing costs, operation and environmental regulations is electro coagulation. This technology was used for the first time in the 19th century for the filtration of chips wastewater and recently is being used as a replacement for most popular filtration processes [12,13]. The electrocoagulation technologies are basically electrical processes and include unstabilizing suspending solids, emulsion or solved pollutants in aqueous solutions by using electrical currents [14,15]. Electrocoagulation (EC) is a process including hydro oxide metal flukes produced from wastewater by electrical dissolution of solvable anodes which are usually made from ferrous and aluminum. Due to electrochemical oxidation ferrous or aluminum is produced in the anode of metal cations, but in cathodes hydrogen production happens [16]. Despite this fact, it has to be considered that using Fe^{+3} as a coagulating factor in wastewater treatment has many advantages, because in comparison to the Al^{+3} ions which may have hazardous effects such as inducing Alzheimers disease, these ions are harmless [17]. Therefore in this study electrodes made from iron and stainless steel are used. In this process the main reactions that are used are as follows [18,19] Eqs. (1)–(4):

Anode:

$$Fe_{(s)} \rightarrow Fe^{2+}_{(aq)} + 2e^{-} \quad (1)$$

$$Fe^{2+}_{(aq)} + 2OH^{-}_{(aq)} \rightarrow Fe(OH)_{(2)}$$

Cathode:

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

Chemical reaction:

$$Fe^{2+}_{(aq)} + 2OH^{-}_{(aq)} \rightarrow Fe(OH)_{2(s)} \quad (3)$$

In total:

$$Fe_{(S)} + 2H_2O_{(l)} \rightarrow Fe(OH)_{2(s)} + H_{2(g)} \quad (4)$$

The electrochemical process includes many physical and chemical processes such as evacuation anode oxidation, cathode reduction, coagulation, electrophoresis migration and surface absorption. Also during the electrocoagulation process in comparison to chemical sedimentation the fluid does not enrich with anions and the salt content does not increase. This process is referred to the production of metal sludge which by using electrocoagulation is more condensed than chemical sedimentation. Also, electrocoagulation needs simple equipment, has a high removal efficiency, has condensed treatment facilities, relatively low cost and the capability of completely automating the retention time is low and also its operation is easy. This characteristic is referred to its low operation costs for industrial use [20,21]. Electro coagulation has been used successfully for treating wastewater including electroplating wastewater, textile wastewater, olive oil factory wastewater, laundry wastewater, tannery wastewater, paper industry and pulp wastewater, brewing and slaughtering wastewater [22–25].

In this study the efficiency of electrocoagulation with alternating and direct current (AC & DC) by using iron alloy and stainless steel in removing lead and zinc has been evaluated. The effect of current density, energy consumption, initial pH, electrode quality, space between electrodes and the mixing rate on the efficiency of removal has been studied, in order to determine the optimum condition for operation.

2. Materials and methods

2.1. Wastewater characteristics

The wastewater used in this study was taken from the battery making industry wastewater at the Kerman industrial town and its characteristics have been shown in Table 1. Before this wastewater was used in the study, its suspended particles were separated by a filter.

2.2. Electrochemical cell

An electrochemical cell was made from plexiglass with a $12 \times 10 \times 12$ cm diameter. The efficient volume of the reactor was 1 l. A figure of this cell has been shown in Fig. 1. In every experiment the total volume of the wastewater was 1 l. Thirty Iron and stainless steel rods with 50 mm length and 5 mm diameter were used. Electrodes were distance of 2 cm from the bottom of the reactor. The electrodes were connected to each other serially and to the main source monopolar (only the two outer electrodes were connected to the positive and negative poles and the middle electrodes were connected together). The direct and alternating current was provided by one source model (GW GPC-3060D) and with a current density range of 2, 4, 6, 8 and 10 mA/cm^2.

2.3. Experiments

The Wastewater samples were taken from the battery building industry and in less than 6 h were transferred to the laboratory. With samples were measured for lead and zinc by an atomic absorption model (UNICAM 924), electric conductivity with a conductivity meter (model 4071) and pH with a pH meter (model InoLab WTW), iron and sulfate by a spectrophotometer model AL800 based on the techniques mentioned in the book for standard techniques of water and wastewater experiment. Then the optimum pH for removing lead and zinc was determined and for keeping pH in the optimum range H_2SO_4 and NaOH, 0.1 N was used. The wastewater inside the reactor was mixed by a magnetic mixer. After each experiment, electrodes were washed with a brush and with diluted HCl. In order to watch the treatment progress, in time intervals of 10, 20, 30 and 40 min, 25 ml samples were taken from the middle of the reactor. Then the samples were passed through 0.45 μm filters in order to eliminate the floc. The filtered samples were stored at 4 °C and eventually were measured for lead and zinc by atomic absorption and according to the methods mention in the standard methods book for examining water and wastewater number 3111B. By the end of each study, the amount of producing sludge and the pH of the remaining solution were measured in order to find out about the amount of sediments and the changes in pH from this process. Also after each experiment, the electrodes were washed by diluting HCl solution and after washing again with distilled water, they were weighted accurately.

Table 1
The characteristic of the battery making industrial wastewater located at the Kerman Industrial Town.

Number	Wastewater characteristic	Amount
1	Lead (Pb)	9 mg/l
2	Zinc (Zn)	3.2 mg/l
3	Electrical conductivity	4.5 ms/cm
4	pH	2.8
5	Iron	2.3 mg/l
6	Sulfate	5 mg/l