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LEAD Removal from Industrial Wastewater by Electrocoagulation process

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Abstract

This investigation was carried out to study the treatment and recycling of wastewater in the Battery industry for an effluent containing lead ion. The reuse of such effluent can only be made possible by appropriate treatment method such as electro coagulation.

The electrochemical process, which uses a cell comprised aluminum electrode as anode and stainless steel electrode as cathode was applied to simulated wastewater containing lead ion in concentration 30 – 120 mg/l, at different operational conditions such as current density 0.4-1.2 mA/cm2, pH 6 -10 , and time 10 - 180 minute.

The results showed that the best operating conditions for complete lead removal (100%) at maximum concentration 120 mg/l was found to be 1.2 mA/cm2 current density, in alkaline media pH = 10 , and at 120 minute.

Key wards; lead removal, electrocoagulation, and wastewater

Introduction

The increased water use and wastewater discharge particularly industrial wastewater have added impurities to water which overload natural cleaning processes [1].

Heavy metal species are some of the most common pollutants that are found in industrial wastewaters. Because of their toxicity, these species can have a serious impact if released into their environment as a result of bioaccumulation, and they may be extremely toxic even in trace quantities.

There are many problems associated with the presence of the trace metal in drinking water. Metal ions such as Cd2, pb+2 and Hg+2 are serious health hazards, while Zn+2, Cu+2 are associated with taste and staining problems. Due to pollution or natural cause, water sources exceed metal levees standards set by Environmental Protection Agencies [2].

Since growing populations result in significant increases in wastewater volume, there is an urgent need to develop innovative, effective and inexpensive technologies to treat wastewater. To address this problem, technologies such as ion exchange, ultrafiltration, reverse osmosis and chemical precipitation have been developed. Each treatment method has advantages and disadvantages. Ion exchange, for example, while highly effective in removal of certain charged contaminants, requires resin regeneration or replacement at a high cost. Ultrafiltration and reverse osmosis are clean processes, but can be prohibitively expensive. While chemical precipitation is a simple process, it does generate a high volume of sludge. An effective technology that meets the requirements of process cleanliness, ease of manipulation, and low operational and investment costs is electro coagulation. This technology is essentially electrolytic processes that involve the destabilization of suspended, emulsified or dissolved pollutants in an aqueous medium, by the application of an electric current. In electro coagulation (a process similar to chemical coagulation), there is a reduction of the net surface charge to a point where the colloidal particles can approach closely enough for Van der Waal's forces to hold them together and allow aggregation to take place. The surface charge reduction is a consequence of the decrease of the repulsive potential of the electrical double layer by the presence of an electrolyte having an opposite charge. This mechanism corresponds to the destabilization of colloidal particles [3].

During electro coagulation, the coagulant is generated in situ by electrolytic oxidation of an anode of appropriate material. Charged ionic species are removed from wastewater by allowing ions to react with oppositely charged ions, or with flocs of metallic hydroxides generated within the effluent [4].

In electro coagulation, sacrificial electrodes are used and the passage of an electric current through the water from electrodes causes the metal to go into solutions as ions via the anode reaction.

A current is passed through a metal electrode, oxidizing the metal (M) to its cation (Mn+) at the anode.

$$M \rightarrow M^{n+} + ne^- \quad (1)$$

Simultaneously, water is reduced to hydrogen gas and the hydroxyl ion (OH-) at the cathode.

$$2H_2O + 2e^- \rightarrow 2OH^- + H_2 \quad (2)$$

Electro coagulation thus introduces metal cations in situ, electrochemically, using sacrificial anodes, (usually aluminum or iron) inside a processing tank.

The cation hydrolyzes in water forming a hydroxyl with the dominate species determined by solution pH.

The metal ions combine with OH- ions from the water to from highly charged coagulation which adsorb pollutants form insoluble floc particles; so that AL(III) reacts with H2O to form Al(OH)3.

Electro coagulation has proven its viability by removing a wide range of pollutants. The approach to reactor design has been haphazard, however, with little or no reference to previous designs or underlying principles [5].

$$Al^{3+} + 3OH^- \rightarrow Al(OH)_3 \quad (3)$$

Electro coagulation cleans most wastewater streams better, with less operating cost, producing less sludge, with the sludge being a better quality than chemical precipitation. The reuse opportunities for the water is increased because dissolved solids are not added to the waste water stream, and usable products are harvested because the metal oxides pass leachability tests, allowing the sludge to be utilized as a soil additive [6].

Vik et al. 1984 studied the efficacy of electrocoagulation in removal of humic acid from potable water [7].

Renk,R.R., 1989, stated that electrocoagulation has reduced contaminated water volume by 98% and lowered the treatment cost by 90% for bilge water containing heavy metals and oil emulsions. Although electrocoagulated water may vary because of the individual chemistry of process waters, a few examples of water treated by electrocoagulation include the reduction of heavy metals in water such as arsenic, cadmium, chromium, lead, nickel, and zinc are generally reduced by 95 to 99% [8].

Naomi et al. 1993 concluded that alternating current electrocoagulation treatment achieved approximately 66% removal of lead in the high metals runs, where as polymer treatment showed a slightly higher removal (71%), while electrocoagulation treatment of slurries with low concentrations of metals yielded the highest lead removal (96%) [2].

Rodnei et al. 1997 presented an electrolytic cell with a porous cathode of reticulated vitreous carbon (RVC) designed to remove metals from aqueous streams. The cell employed potential values in such away that the metals reduction reaction occurred under mass transport control, these potential are -0.3v for copper, -0.8v for lead and -1.35v for zinc, these applied to the cell from a potential mode, for two hours. The cell proved to be efficient in removing copper, zinc, and lead and it was able to reduce the levels of these metals from 50 mg/l to 0.1 mg/l [9].

Chen et al. 2000 used electrocoagulation technology for the removal of suspended solids, oil and fat in restaurant wastewater [10].

Escobar C. et al. 2006 optimized flow variables in the electro coagulation process to examine the effectiveness of the removal of copper, lead and cadmium. The electrochemical process, which uses electrodes of commercial laminate steel, was applied to simulated wastewater containing 12 mg dm-3 of copper, 4 mg dm-3 of lead and 4 mg dm-3 of cadmium. The optimum conditions for the process were identified as pH=7, flow rates 6.3 cm3 min-1 and current density between 31 and 54 A m-2, the copper removal reach a maximum value of 80% while reaching near 100% removal for lead and cadmium when the electrode distance was 2 cm [11].

Amuda et al. 2006 studied the effectiveness of polymer addition to coagulation process during treatment of beverage industrial wastewater to remove some of its trace metals content such as lead, cadmium, iron, chromium, nickel, and zinc. Experiments were conducted using the standard Jar test procedure to determine the performance of both ferric chloride and organic polymer. The dosage used for ferric chloride ranged from 0 to 500 mg/l whereas polymer dosage varied between 0 to 100 mg/l. Combination of 500 mg/l of ferric chloride and 65 mg/l for polymer achieved better removal efficiencies of the metals in the range of 84– 97 % [12].

Samarghandi et al. 2007 used photo catalysis / hydrogen peroxide process for removal of phenol, lead and cadmium by three different pH of 3.5, 7 and 11, and variable concentrations of reagent chemicals, but the time was kept constant (180 min). Results indicated that the optimum efficiencies of phenol and Cd removal were 76% and 97.7% at pH=11 respectively, and for lead it was 98.85 in all pH at UV irradiation with 3ml/l H2O2 and 0.8 g/l TiO2 [13].

Experimental Work

The object of this study is the evaluation of lead removal from industrial wastewater by electro coagulation process. For this study a glass tank 1.75 L volume was used . The cell comprised of two parallel plates (110 mm × 55 mm × 1 mm) with 30 mm distance between them and 70 cm2 used area. Aluminum electrode as anode and stainless steel electrode as cathode, connected to the positive and negative poles of DC stabilized power supply (W.Wrlenbach/Schwiez model IC. Triple). The electrical circuit was switched on as soon as the electrodes were immersed in the electrolyte and the desired current was achieved by altering the resistance of the electrical circuit. The schematic diagram of the system is shown in Figure, 1.

The standard solutions containing lead ions in different concentrations 30, 70, and 120 mg/l were prepared by dissolving lead nitrate Pb(NO3)2 in deionized water, 2-3 drops of Nitric acid (HNO3) must be added to the required amount of lead nitrate before adding the deionized water for complete mixing of lead nitrate with water.

The experiments were conducted by introducing 1.5 liter of synthetic wastewater into the electrochemical reactor. By the passage of the electrical current through the cell, the anodic dissolution occurred. Hydrogen gas was produced at the cathode along with localized pocket of the hydroxide ions and the cell will produce aluminum cation (Al+3) on the anode surface followed by their transfer to the bulk of the electrolytic solution, these cation will combine with OH- ions from the water to form highly charged coagulants which adsorb pollutants to form insoluble floc particles, these particles will rise to the surface of solution by gas bubbles which formed in electrolytic solution.

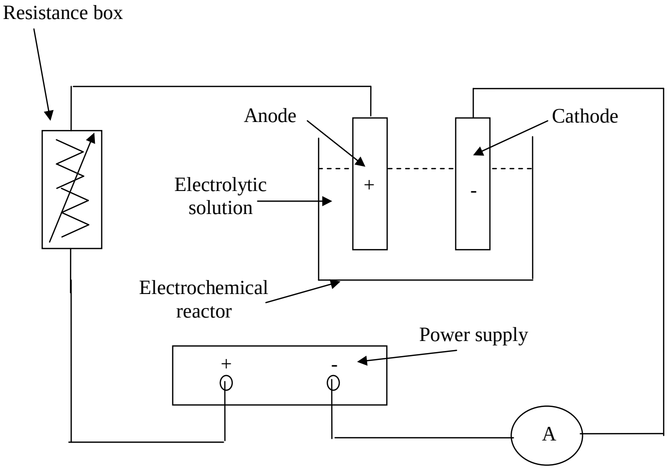

Fig. 1 Schematic diagram of the experimental apparatus

During each run, samples of the solution were taken at different times (10, 20, 30, 60, 120 and 180) minutes, then this solution was filtrated to remove floc particles, then the filtrated solution taken to be analyzed by Atomic absorption method (using Perkin - Elmer 5000 Atomic absorption spectrophotometer in the servicing laboratory-Chemistry Dept.- College of Sciences- Baghdad University), to measure the remaining concentration of lead ion in the treated solution.

The percent of lead ion removal was measured at pH 6, 8 and 10 and in current density of 0.4, 0.8 and 1.2 mA/cm2. The pH values of the standard solution were measured using a digital pH meter (Oakton pH 2100 series). While the current density was measured using digital multi-range ammeter (Type: WHN: 533638).

Results and Discussion

In the present study, electrocoagulation process has been evaluated as a treatment technology for lead removal from industrial effluents. Lead removal efficiency at different condition (pH, current density) in various times was evaluated. It has been established in previous studies [7, 10] that pH has a considerable effect on the efficiency of the Electrocoagulation process. In this study, the pH was varied in the range 6–10 in an attempt to investigate the influence of this parameter on the removal efficiencies of lead which shown is in Figures 2-4.

From these figures we can see that increasing pH of the solution will increase the removal efficiency of lead at constant current density. The same behavior can be achieved when changing the current density to other values. Vik [7] ascribed this increase to hydrogen evolution at cathodes. However, this was contested by Chen [10], who explained this increase by the release of CO2 from wastewater owing to H2 bubble disturbance. Indeed, at low pH, CO2 is over saturated in wastewater and can release during H2 evolution, causing a pH increase. The highest efficiency of lead removal observed in alkaline medium and the best value pH =10.

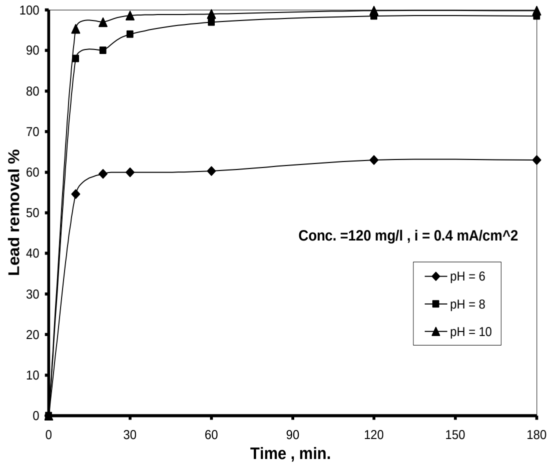

Fig. 2 The between time of treatment and lead removal efficiency for different pH values at constant concentration 120 mg/l, constant current density 0.4 mA/cm2

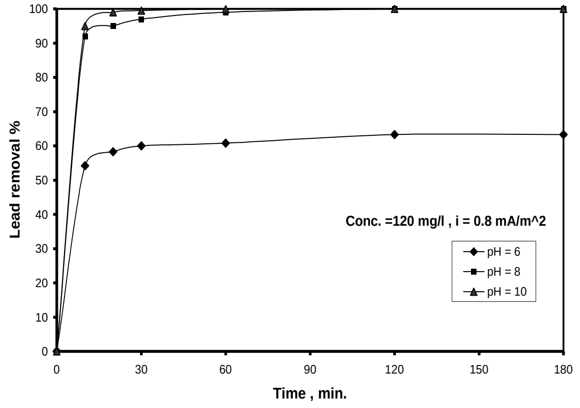

Fig. 3 The between time of treatment and lead removal efficiency for different pH values at constant concentration 120 mg/l, constant current density 0.8 mA/cm2

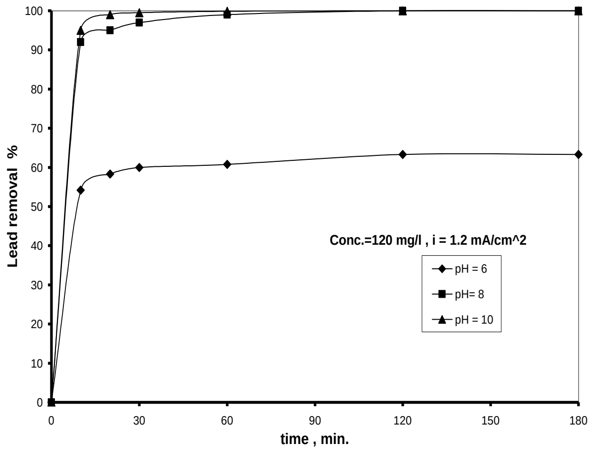

Fig. 4 The between time of treatment and lead removal efficiency for different pH values at constant concentration 120 mg/l, constant current density 1.2 mA/cm2

Figures 2 – 4 show also the effect of changing time of reaction on the concentration of lead in the treated solution, when changing pH and current density at maximum concentration of lead 120 mg/l, due to aluminum dosage through the process. According to these figures, the lead removal efficiency will increase by increasing the time of process, especially there is a sharp increase at the first few minutes. This effect occurs due to adsorbing aluminum hydroxide which is formed in electrolytic solution to the contaminants in wastewater and also due to effect of current density on time.

Preliminary laboratory testing of the electrolysis cell involved determining the effect of applied current density on the efficiency of lead removal which is shown in Figure 5. It is well-known that electrical current not only determines the coagulant dosage rate but also the bubble production rate and size and the flocs growth [14,15], which can influence the treatment efficiency of the electrocoagulation. Therefore, the effect of current density on the pollutants removal was investigated.

From figure 5 at pH=10 which is best value and at initial concentration 30mg/l where at low concentration the effect of current density can be noted clearly. As expected, it appears that for a given time, the removal efficiency increased significantly with increase of current density. The highest current density 1.2 mA/cm2 produced the quickest treatment reaching 93% lead removal after only 10 minute while for 0.4 mA/cm2 the removal efficiency for lead was only 50% and at 0.8 mA/cm2 89.7% removal after 10 minute.

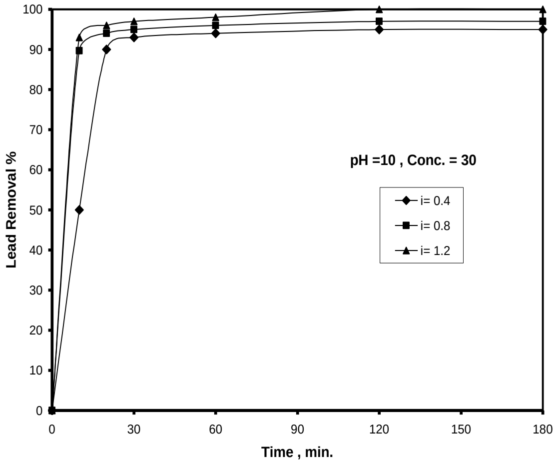

Fig. 5 The between time of treatment and lead removal efficiency for different current density values at constant pH 10, and constant concentration 30 mg/l

This is ascribed to the fact that at high current, the amount of aluminum oxidized increased, resulting in a greater amount of precipitate for the removal of pollutants. In addition, it was demonstrated that bubbles density increases and their size decreases with increasing current density, resulting in a greater upwards flux and a faster removal of pollutants and sludge flotation [16].

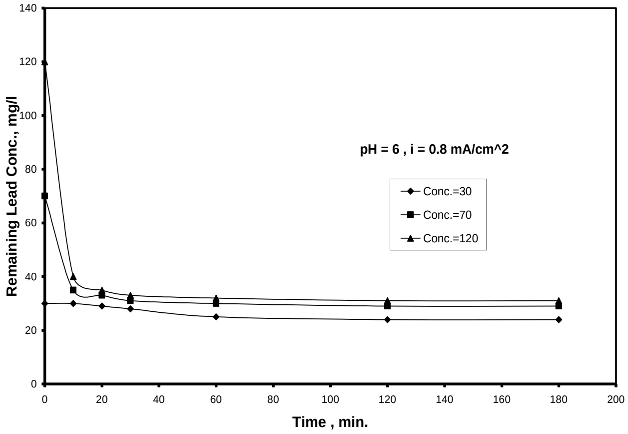

Fig. 6 The between time of treatment and remaining lead concentration for different lead initial concentration values at constant pH 6, and constant current density 0.8 mA/cm2

A set of experiments was performed with different initial concentrations of lead to determine the time required for removal under various conditions of electrocoagulation process. The results obtained at different current density showed that initial concentration of lead can effect on efficiency removal and for higher concentration of lead, higher current density or more reaction time is needed. On the other hand, if the initial concentration increases, the time required of process should increase too. And, also it is clear from Figure 6 that the higher the concentration, is the greater the time needed for removal of lead, but that higher initial concentrations of lead were reduced significantly in relatively less time than lower concentrations. The time taken for reduction thus increases slowly with increases in concentration. So from Figure 6 we can see that at pH=6 and current density 0.8 mA/cm2, the concentration of lead reduced from initial values of 30, 70 and 120mg/l to 28, 33 and 35 mg/l respectively after 20 minute only.

This can be explained by the theory of dilute solution. In dilute solution, formation of the diffusion layer at the vicinity of the electrode causes a slower reaction rate, but in concentrated solution the diffusion layer has no effect on the rate of diffusion or migration of metal ions to the electrode surface [17].

According to Figure 7, The results obtained at best conditions (pH=10, and current density = 1.2 mA/cm2) showed that the removal efficiency for various concentrations of initial concentrations of lead (30,70 and 120) mg/l reach complete lead removal (100%) after 120 minutes almost.

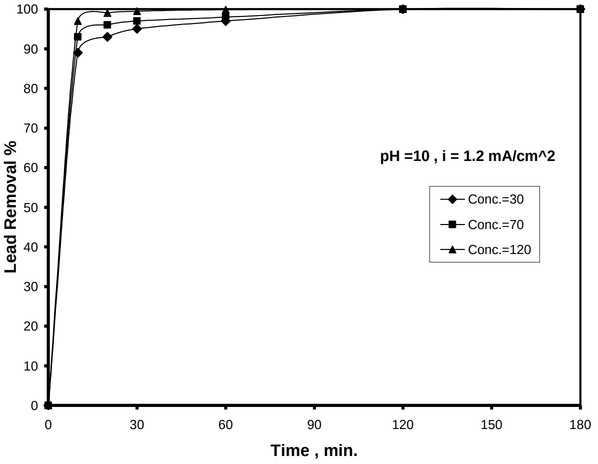

Fig. 7 The between time of treatment and lead removal efficiency for different lead initial concentration values at constant pH 10, and constant current density 1.2 mA/cm2

Conclusions

1. Electrocoagulation method followed by clarification was found to be highly efficient and relatively fast compared to conventional existing techniques.
2. By testing different values pH of synthetic wastewater. The highest efficiency of lead removal was in alkaline medium and best pH is 10.
3. The removal efficiency increased by increasing of current density and the best value is 1.2 mA/cm2.
4. Complete lead removal (100%) can be achieved for various initial concentrations 30, 70 and 120 mg/l after 120 minutes only.

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زالة الرصاص من مياه الصرف الصناعية بطريقة التلبيد الكهروكيمياوية

ابتهال كريم شاكر و بسمة إسماعيل حسين
قسم الهندسة الكمياوية–كلية الهندسة–جامعة بغداد

الخلاصة

في هذا البحث تم دراسة معالجة المياه وتدوير المياه الصناعية و بصورة خاصة في صناعة البطاريات, التي تحتوي المياه الخارجة منها على ايونات الرصاص.

إن عملية التلبيد الكهروكيمياوي تم تطبيقها على خلية متكونة من قطب أنود من الألمنيوم و الكاثود من الحديد المقاوم للصدأ لدراسة تأثير تغيير ظروف التشغيل على كفاءة عملية المعالجة لتراكيز مختلفة من ايون الرصاص في المياه الصناعية 30 – 120 مل غرام/لتر عند تغير كثافة التيار من 0.4 – 1.2 مل أمبير/سم2 , والدالة الحامضية من 6 – 10 , والزمن من 10 – 180 دقيقة.

بناءاً على نتائج الجانب العملي و التجارب المختبرية تم الحصول على إزالة تامة (100%) لايون الرصاص من المياه الملوثة بعد عملية المعالجة ولأعلى تركيز لايونه 120 مل غرام /لتر عند أفضل ظروف تشغيل 1.2 مل أمبير/سم2 وعند وسط قاعدي وأفضل دالة قاعدية تساوي 10 وبزمن 120 دقيقة.