



PERFORMANCE EVALUATION OF ELECTRO-COAGULATION SYSTEM FOR WASTEWATER TREATMENT

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Abstract: In this study, the removal of some heavy metals ions such as cadmium [Cd⁺²], nickel [Ni⁺²] and lead [Pb⁺²] from a synthetic wastewater were investigated using a lab scale electro-coagulation [EC] system which was constructed for this purpose. Aluminum and iron were adopted as a selective electrodes in order to compare the results for which is the best efficiency. Operational circumstances parameters such as pH, current density, detention time and inner electrodes distance were tested in order to know the optimal operation values for the removal efficiency. The results showed that the optimal operation conditions for the max removal efficiencies occur at pH (7), current density (12.5 mA/cm²), inner electrode distance (1cm) for both aluminum and iron electrodes, and the detention time is (150 min) for aluminum, and (120 min) for iron electrodes. The experimental results indicates that the aluminum electrodes is better than iron electrodes.

Keywords: *Electro-coagulation, heavy metals removal, aluminum electrodes, iron electrodes.*

تقييم أداء نظام التختير الكهربائي لمعالجة مياه الصرف الصحي

الخلاصة: في هذه الدراسة، تم إزالة ايونات بعض العناصر الثقيلة كأيون الكاديوم، النيكل والرصاص من المياه المصنعة باستخدام نظام التختير الكهربائي الذي صمم لهذا الغرض. تم استخدام الألمنيوم والحديد كأقطاب موصلة للتيار الكهربائي وعمل مقارنة بينهما لمعرفة المعدن الأفضل في كفاءة الازالة. هناك عدة عوامل لها تأثير مباشر على كفاءة عمل النظام، وقد تم دراسة البعض منها لتحديد ظروف عمل النظام المثالية ومنها الرقم الهيدروجيني، شدة التيار الكهربائي، فترة التعرض و المسافة الداخلية بين الاقطاب. النتائج العملية بينت بأن الظروف المثالية لعمل المنظومة هي عند الرقم الهيدروجيني 7، شدة التيار الكهربائي عند 12.5 ملي أمبير/سم²، المسافة الداخلية بين الاقطاب عند 1سم، و فترة التعرض 150 دقيقة عند استخدام اقطاب الألمنيوم و 120 دقيقة عند استخدام اقطاب الحديد. النتائج العملية تشير الى ان اقطاب الألمنيوم هي الافضل لهذا النظام اكثر من اقطاب الحديد.

1. Introduction

Dissolved heavy metals in water and wastewater causes health and environmental problems because these inorganic pollutants cannot be biodegradable and may enter to the food chain and accumulate in living organisms. Heavy metals like lead [Pb], cadmium [Cd] and nickel [Ni] are resulted from many sources such as processing industries, fertilizers, pesticides, batteries and metal industries, [1].

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The electro-coagulation [EC] method is an effective process for the treatment of various types of wastewater containing sulfate, sulfite, sulfide, phosphate, algae and heavy metals ions such as; Fe, Ni, Cu, Cd, Pb and Zn, [2-6].

The electrocoagulation [EC] process has many advantages include relatively low cost (comparing with most other technologies such as ion exchange, reverse osmosis, electro dialysis and other physical techniques), high removal efficiency, a compact treatment facility and the possibility of complete automation, [7]. During the past few years, it is proposed that electro-coagulation [EC] is an effective process to treat several types of effluents such as wastewater charged with heavy metals, restaurant wastewater containing oil and fat, surface water, cigarette factory wastewater, black liquor from paper industry and suspended solids ,[8-12].

Although electro coagulation (figure 1) is not new technology, it has been known from 19th centuries and it was adopted especially for water treatment in industrial sector. Electro coagulation gain a recent interest in wastewater treatment due to the fact of the wide range of heavy metals type that can be removed using it, as well as it considered as an eco-friendly technology.

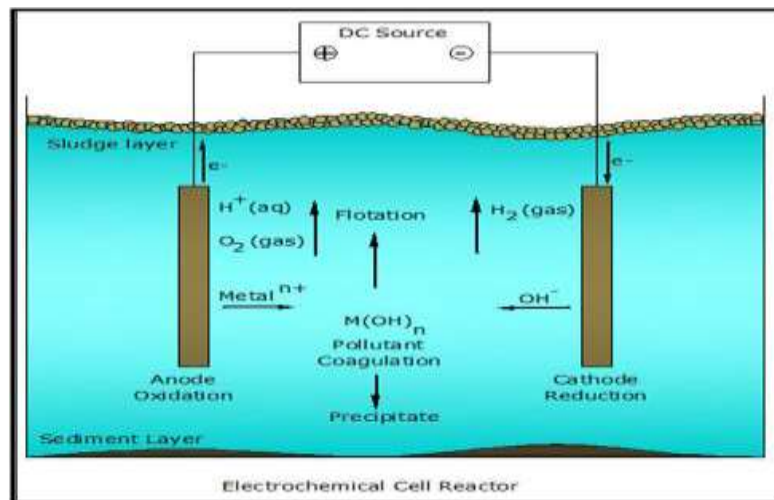


Figure 1: Schematic view of electro- Chemical reactions in a batch reactor, [13].

The electro-coagulation is very important technique and has the ability to treated synthetic wastewater, as well as removal of color and turbidity from wastewater, [14]. By using electro-coagulation process, it was concluded that the removal efficiency of Cr(IV) from synthetic chromium solution was better with iron electrodes than aluminum electrodes at pH of 3 and electrolysis time between 20 and 60 minutes, [15]. Arsenic concentration reduced in the wastewater by 99% by using electro-coagulation [EC] process with iron and hybrid Al/Fe electrodes, as the current density increased from 0.0082 to 0.0816mA/cm², [16].

Electro-coagulation process was used for treating electroplating waste water. Results that the removal efficiency was 99.5% at pH of 4, electrolysis time of 15minutes and current density of 25 A/m², [17]. The objective of this study work is to evaluate the performance of the electro-Coagulation [EC] technology in reducing heavy metals ions

concentrations and the evaluation of different operational parameters on such performance, as well as, make a comparison between aluminum and iron electrodes.

2. Experimental Setup

2.1. Synthetic Wastewater Preparation

The synthetic samples are prepared by fermenting municipal solid waste for 10 days in 500 l storage tank containing 80% water and 20% solid waste, and then various concentrations of heavy metals ions as (Pb^{+2} , Ni^{+2} and Cd^{+2}) are dissolved in this water. The pH of the samples is adjusted using NaOH solution.

2.2. Lab Scale Electro-Coagulation Reactor Setup

In the laboratory experiments, electro-coagulation reactor is used with mono-polar electrodes connected in parallel. The volume of this reactor is 0.3m^3 (0.8 m length * 0.5m width * 0.75m depth), this reactor is made using fiber glass of 7mm thickness. Aluminum and iron metals are used as electrodes for the experiments. The dimensions of these electrodes are (10cm * 8cm) with a thickness of 0.5 mm. A power supply regulator device is used to control the power supply to the reactor [photo(1)] .



a. Front View



b. Top View

Photo 1. Laboratory Model.

2.3. Experimental Layout

Two sets of experiments are planned and conducted to study the performance of the lab scale model:

The first set of experiments is designed to study the ability of the treatment system with aluminum electrodes lead (Pb^{+2}), nickel (Ni^{+2}) and cadmium (Cd^{+2}) ions. The second set of experiments is designed to study the ability of the treatment system with iron electrodes for the treatment of the same parameters in the first set. The lead (Pb^{+2}), nickel (Ni^{+2}) and cadmium (Cd^{+2}) concentrations are carried out using Atomic Absorption Spectrophotometer shown in Photo (2), at different wave lengths.



Photo 2. Heavy metals meter.

2.4. Advantages and Disadvantages of Electrodes

Two types of electrodes may be used for the treatment process by electro-coagulation system are aluminum and iron electrodes. From experimental results, it was observed that each type of electrode has advantages and disadvantages are listed in Table (1) and show in Photos (3) and (4).

Table 1. Characteristics of aluminum and iron electrodes.

<i>Aluminum electrode</i>	<i>Iron electrode</i>
1-Higher cost than iron electrode.	1-Lower cost than aluminum electrode.
2-The amount of the generated hydroxides is lesser than those generated by iron electrode.	2-The amount of the generated hydroxides is higher than those generated by Al electrode.
3-Has a high operation life.	3-Has a lesser operation life.
4- Oxidized as a lower rate.	4- Can be oxidized easily.
5-Cannot form rust.	5-Can form rust easily.
6-Removal efficiency increases during the operation time.	6-During the operation time, the removal efficiency increases.



(a)



(b)

Photo 3. Aluminum plate: a)before the treatment. , b)after the treatment.

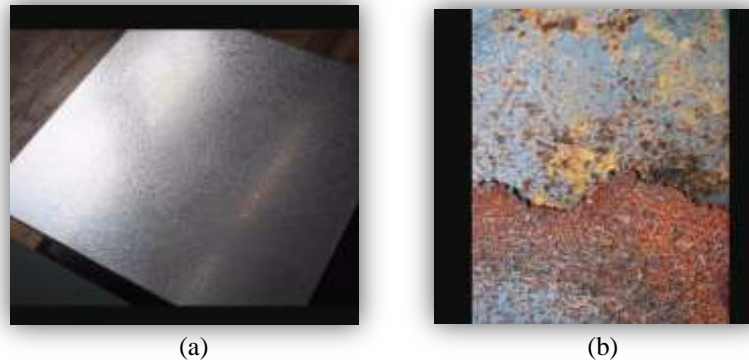


Photo 4. Iron plate: a) before the treatment. , b) after the treatment.

3. Results and Discussion

3.1. Effect of Initial pH

pH is one of the most effective operational parameters in the electro-coagulation technique. Effect of initial pH values are 4, 6, 7 and 9 on removal efficiency at best values of current and inner-electrode distance.

3.1.1. Using Aluminum Electrodes

Figures (2) to (4) show the optimum removal efficiencies of heavy metals. These results are obtained after 150 minutes detention time with pH of 7, current density of $12.5\text{mA}/\text{cm}^2$ and inner-electrode distance of 1cm. Also, Table (2) shows the percentage removal efficiency obtained from the previous mentioned figures for various values of pH.

Similarly, the best results for the removal of some heavy metals were obtained at pH value of 7, [18].

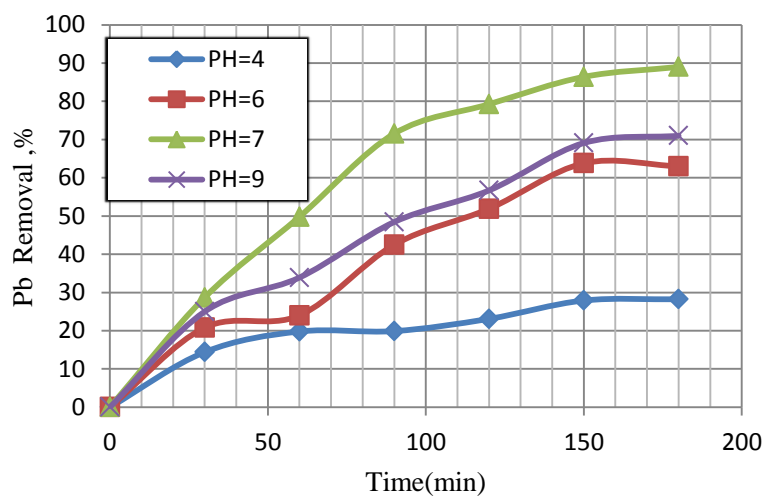


Figure 2. The removal of lead (Pb^{+2}) ions for different values of initial pH.

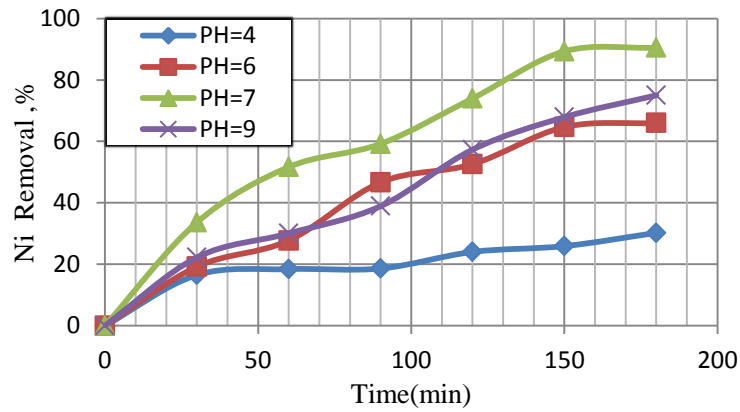


Figure 3. The removal of nickel (Ni⁺²) ions for different values of initial pH.

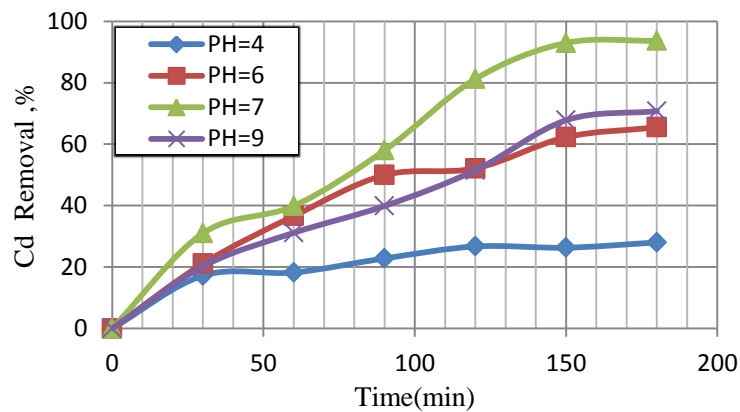


Figure 4. The removal of cadmium (Cd⁺²) ions for different values of initial pH.

Table 2. Removal efficiencies of heavy metals with various values of pH using aluminum electrodes.

Parameter	Removal Efficiency ,%			
	pH=4	pH=6	pH=7	pH=9
Lead ions(Pb ⁺²)	27.9	63.8	86.4	69.1
Nickel ions(Ni ⁺²)	25.9	64.66	89.33	67.89
Cadmium ions(Cd ⁺²)	26.3	62.26	92.98	67.8

3.1.2. Using Iron Electrodes.

Figures (5) to (7) show the optimum removal efficiencies of heavy metals. These results are obtained after 120 minutes detention time with pH of 7, current density of 12.5mA/cm² and inner-electrode distance of 1cm. Also, Table (3) shows the percentage removal efficiency obtained from the previous mentioned figures for various values of pH.

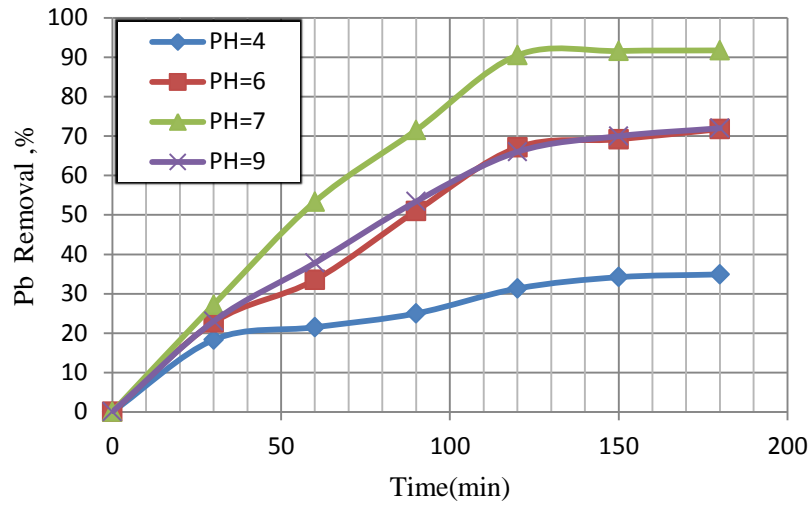


Figure 5. The removal of lead (Pb²⁺) ions for different values of initial pH.

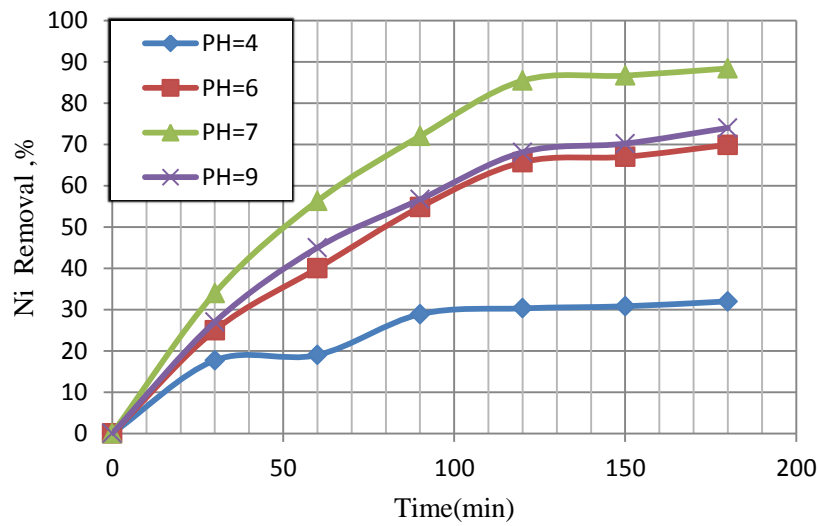


Figure 6. The removal of nickel (Ni²⁺) ions for different values of initial pH.

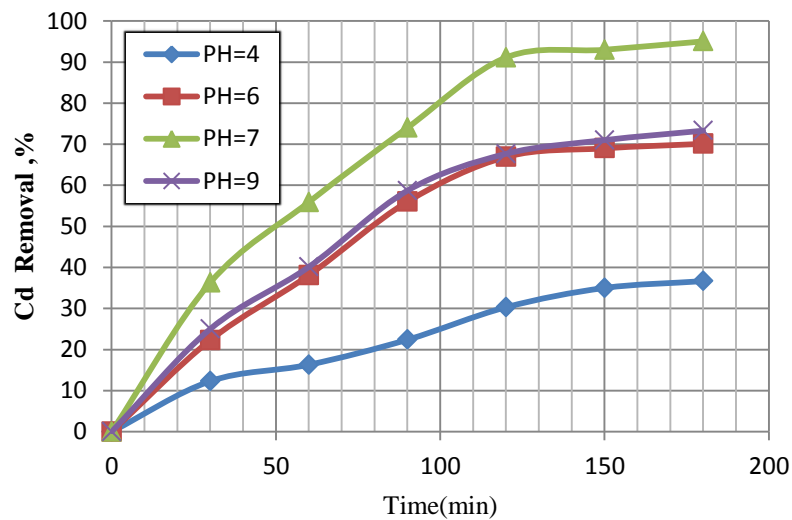


Figure 7. The removal of cadmium (Cd²⁺) ions for different values of initial pH.

Table 3. Removal efficiencies of heavy metals with various values of pH using iron electrodes.

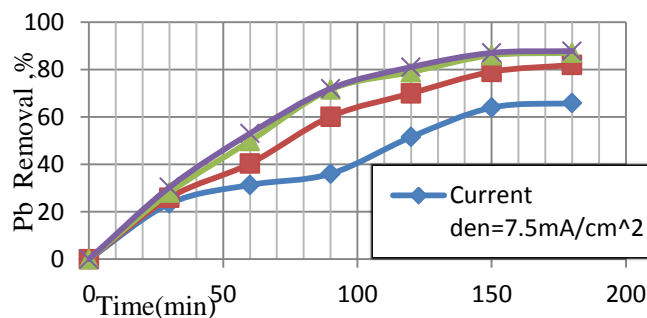
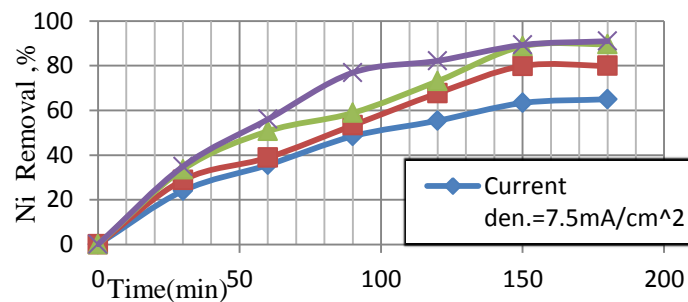
Parameter	Removal Efficiency, %			
	pH=4	pH=6	pH=7	pH=9
Lead ions(Pb^{+2})	31.33	67.1	90.5	66
Nickel ions(Ni^{+2})	30.3	65.7	85.44	68.1
Cadmium ions(Cd^{+2})	30.3	66.9	91.11	67.66

3.2. Effect of Current Density

The current density is an effective parameter that controls the reaction rate in the electro-coagulation system. Effective of current density values are 7.5, 10, 12.5 and 15mA/cm² at optimum values of pH and inner-electrode distance.

3.2.1. Using Aluminum Electrodes

Figures (8) to (10) show the optimum removal efficiencies of heavy metals. These results are obtained after 150 minutes detention time with pH of 7 current density of 12.5mA/cm² and inner-electrode distance of 1cm. Also, Table (4) shows the percentage removal efficiency obtained from the previous mentioned figures for various values of current density.

Figure 8. The removal of lead (Pb^{+2}) ions for different values of current density.Figure 9. The removal of nickel (Ni^{+2}) ions for different values of current density.

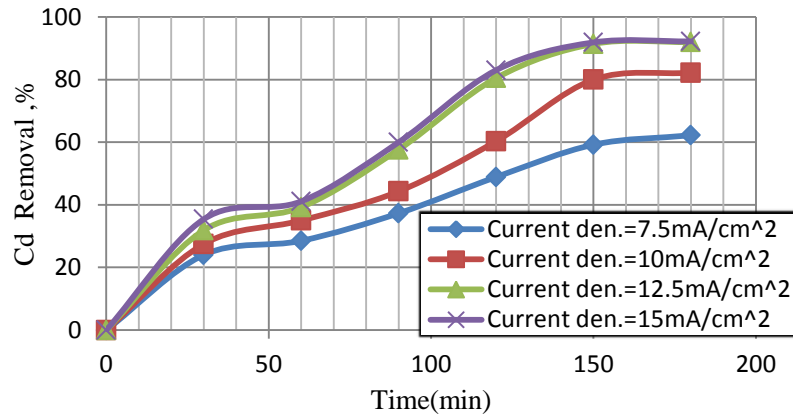


Figure 10. The removal of cadmium (Cd⁺²) ions for different values of current density.

Table 4. Removal efficiencies with various values of current density using aluminum electrodes.

Parameter	Removal Efficiency ,%			
	Current den.= 7.5mA/cm ²	Current den.= 10mA/cm ²	Current den.= 12.5mA/cm ²	Current den.= 15mA/cm ²
Lead ions(Pb ⁺²)	63.9	79	85.99	87
Nickel ions(Ni ⁺²)	63.33	79.9	88.7	89.3
Cadmium ions(Cd ⁺²)	59.2	79.99	91.4	91.88

3.2.2. Using Iron Electrodes

Figures (11) to (13) show the optimum removal efficiencies of heavy metals. These results are obtained after 120 minutes detention time with pH of 7 current density of 12.5mA/cm² and inner-electrode distance of 1cm. Also, Table (5) shows the percentage removal efficiency obtained from the previous mentioned figures for various values of current density.

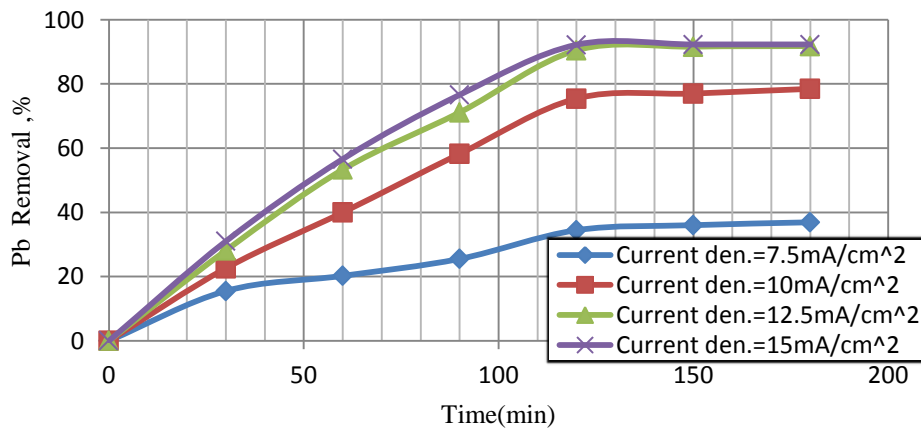


Figure 11. The removal of lead (Pb⁺²) ions for different values of current density.

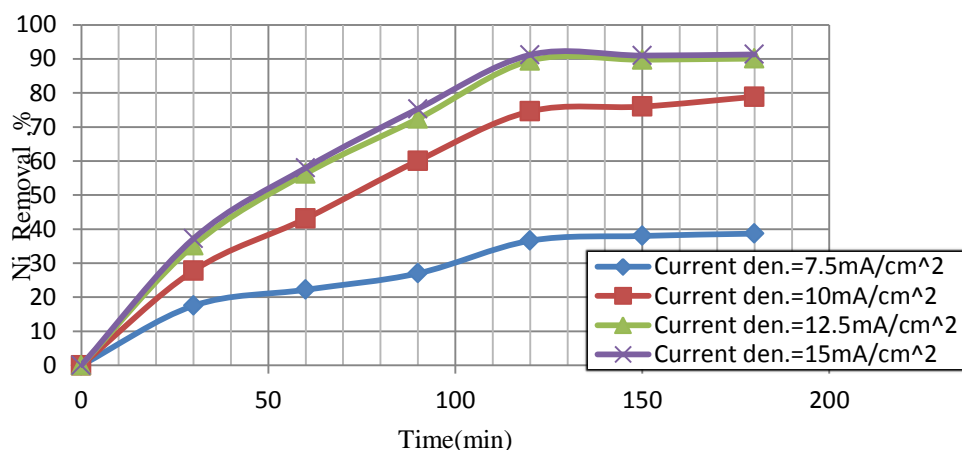


Figure 12. The removal of nickel (Ni^{+2}) ions for different current density.

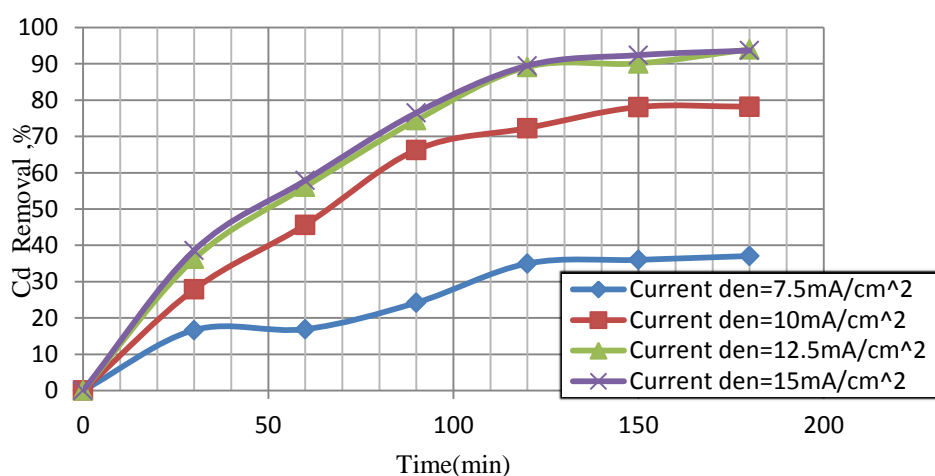


Figure 13. The removal of cadmium (Cd^{+2}) ions for different values of current density.

Table 5. Removal efficiencies with various values of current density using iron electrodes.

Parameter	Removal Efficiency, %			
	Current den.= 7.5mA/cm ²	Current den.= 10mA/cm ²	Current den.= 12.5mA/cm ²	Current den.= 15mA/cm ²
Lead ions(Pb^{+2})	34.44	75.45	90.465	92.2
Nickel ions(Ni^{+2})	36.6	74.6	89.5	91.2
Cadmium ions(Cd^{+2})	34.99	72.3	89.14	89.5

3.3. Effect of Inner-Electrode Distance

To study the effect of inter-electrode distance on the removal efficiencies of heavy metals and sanitary characteristics of waste water, several runs and tests are carried out for various inner-electrode distance of 1, 2, 3 and 4cm .When the inter-electrode distance is increased, the ohmic loss in relation to the anode and cathode over voltages

and the resistance to mass transfer become larger. Smaller amount of Al^{+3} cations at the anode leading to slower formation of coagulants in the middle, [19].

3.3.1. Using Aluminum Electrodes

Figures (14) to (16) show the optimum removal efficiencies of heavy metals. These results are obtained after 150 minutes detention time with pH of 7, current density of $12.5\text{mA}/\text{cm}^2$ and inner-electrode distance of 1cm. Also, Table (6) shows the percentage removal efficiency obtained from the previous mentioned figures for various values of inner electrode distance.

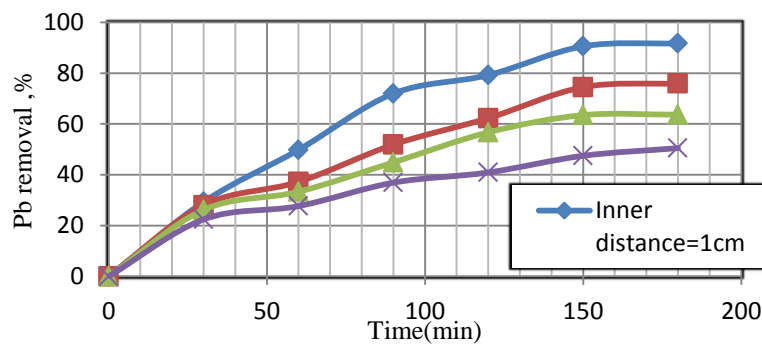


Figure 14. The removal of lead (Pb^{+2}) ions for different values of inner-electrode distance.

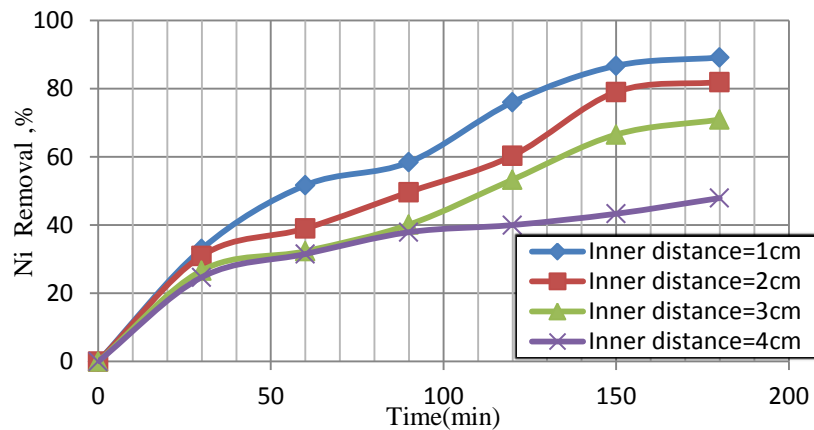


Figure 15. The removal of nickel (Ni^{+2}) ions for different values of inner-electrode distance.

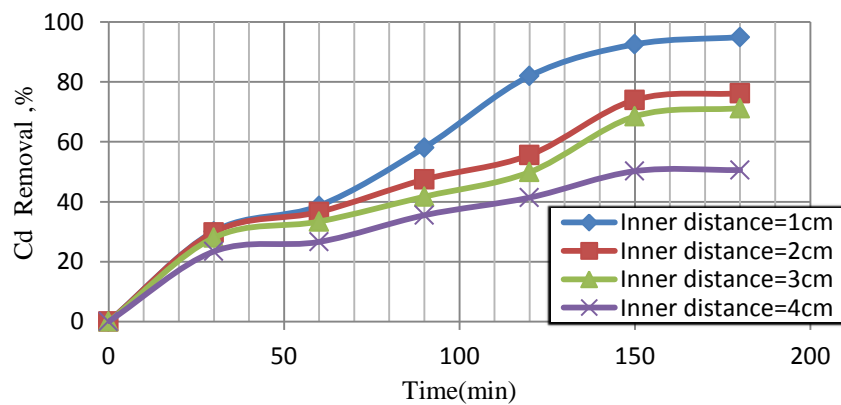


Figure 16. The removal of cadmium (Cd^{+2}) ions for different values of inner-electrode distance.

Table6. Removal efficiencies with various values of inner electrodes distance using aluminum electrodes.

Parameter	Removal Efficiency ,%			
	Inner dist.= 1cm	Inner dist.= 2cm	Inner dist.= 3cm	Inner dist.= 4cm
Lead ions(Pb ⁺²)	90.6	74.5	63.5	47.47
Nickel ions(Ni ⁺²)	86.66	79	66.5	43.3
Cadmium ions(Cd ⁺²)	92.56	74	68.5	50.22

3.3.2. Using Iron Electrodes

Figures (17) to (19) show the optimum removal efficiencies of heavy metals. These results are obtained after 120 minutes detention time with pH of 7, current density of 12.5mA/cm² and inner-electrode distance of 1cm. Also, Table (7) shows the percentage removal efficiency obtained from the previous mentioned figures for various values of inner electrode distance.

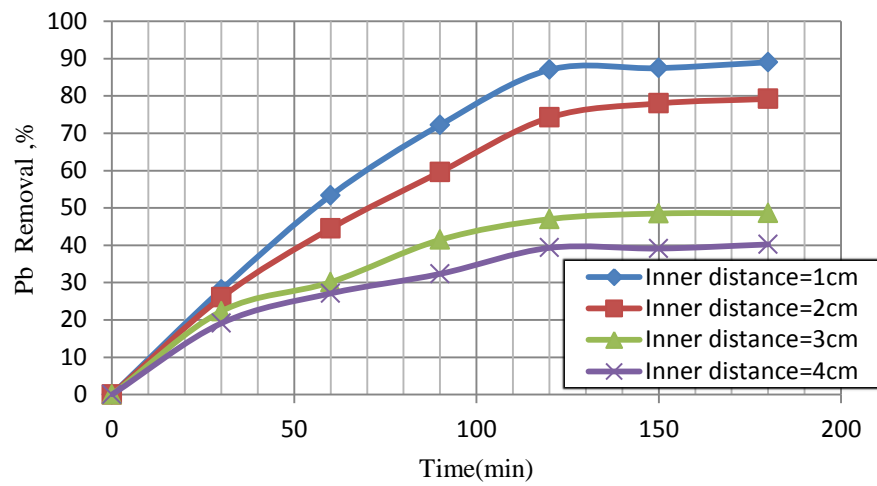


Figure 17. The removal of lead (Pb⁺²) ions for different values of inner-electrode distance.

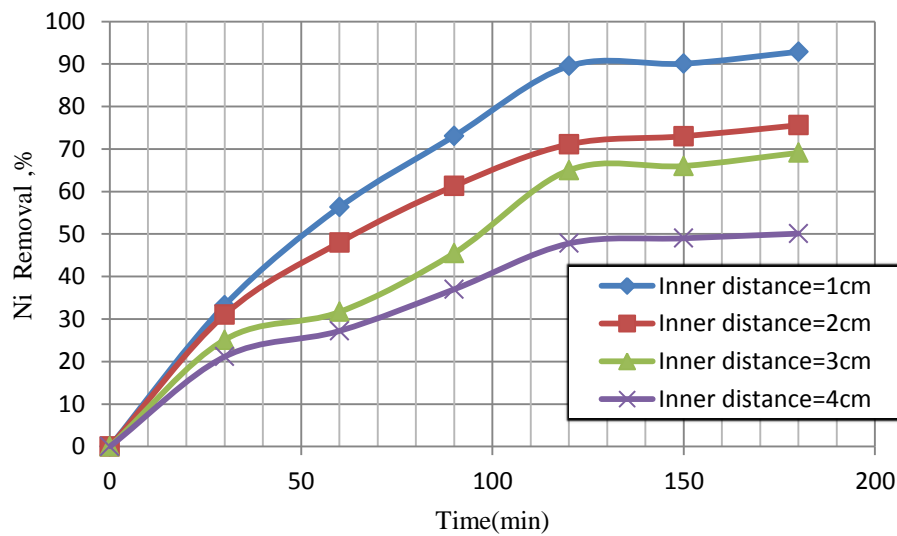


Figure 18. The removal of nickel (Ni⁺²) ions for different values of inner-electrode distance.

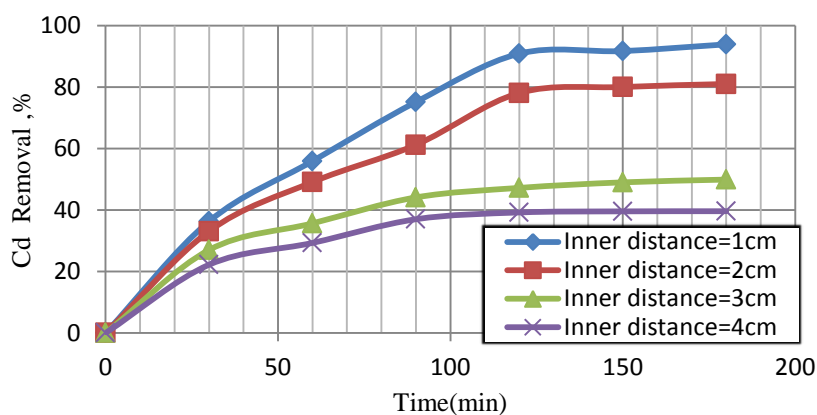


Figure 19. The removal of cadmium (Cd^{+2}) ions for different inner-electrode distance.

Table 7. Removal efficiencies with various values of inner- electrodes distance using iron electrodes.

Parameter	Removal Efficiency, %			
	Inner dist.= 1cm	Inner dist.= 2cm	Inner dist.= 3cm	Inner dist.= 4cm
Lead ions(Pb^{+2})	87	74.2	47	39.3
Nickel ions(Ni^{+2})	89.5	71.1	65	47.778
Cadmium ions(Cd^{+2})	90.88	78.1	47.2	39.2

3. Conclusions

Based on the results of the present work, it is concluded that:

- Electro-coagulation has lower cost and higher removal efficiency of heavy metals comparing with other technologies such as ion exchange, reverse osmosis, electro dialysis and other physical techniques.
- Expulsion of heavy metals is apparently sensitive on pH value for the feed wastewater. pH of 7 is found to be the best value in order to achieve best removal efficiency for both aluminum and iron electrodes.
- The removal of heavy metals increase with the increasing of current intensity, but it was observed that the best value appeared at 12.5 mA/cm^2 and above this value there is no significant increase in the removal efficiency for both aluminum and iron electrodes.
- The removal of heavy metals increase with the decreasing of inner electrodes distance, but it was observed that the best value appeared at 1cm for both aluminum and iron electrodes..
- The detention time is (150 min) for aluminum, and (120 min) for iron electrodes which indicates that the iron electrodes is faster than the aluminum electrodes in the treatment process.

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