Journal of Technology Research (JTR)
Volume 4, Issue 2, (2026), pp 201-207, ISSN 3005-639X

Treatment of Pond Water by Electrocoagulation Process Using Iron Electrodes

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Received: 19-10-2026 | Accepted: 22-10-2026 | Available online: 08-11-2026 | DOI:10.26629/jtr.2026.16

ABSTRACT

The electrocoagulation (EC) process is an electrochemical treatment that can be used for the removal of contaminants from wastewater. The primary objective of this study is to investigate the effectiveness of EC for pond water treatment. Batch experiments were conducted using iron electrodes and an 800 ml working volume. The effects of reaction time, applied voltage, electrode area, and solution temperature on the removal of contaminants from pond water. These contaminants including total dissolved solids (TDS), calcium (Ca), sodium (Na), and turbidity. The reaction time was varied between 30 and 90 min, applied voltage between 10 and 30 V, electrode area between 5 × 3 and 10 × 6 cm2, and temperature between 30 and 70 °C. The results showed that the removal of TDS and Ca has been improved by increasing reaction time, while removal of Na showed small change between 30 and 90 min. At 90 min, the efficiency of TDS removal was 49.09%, the efficiency of Na removal was 35.19%, the efficiency of Ca removal was 79.25%, and the efficiency of turbidity removal was 95.95%. In addition, the removal of contaminant was improved by increasing the applied voltage. The highest efficiency was reported at 30 V with a value of 46.00% for TDS, 41.67% for Na, 45.28% for Ca, and 96.61% for turbidity. Also, the removal efficiencies was increased by increasing solution temperature from 30 to 70 °C. The highest values was reported at 70 °C, the highest removal efficiencies were reported at values of 29.27%, 47.22%, 69.81%, and 98.34% for TDS, Na, Ca, and turbidity respectively. The results demonstrates that the EC process using iron electrodes can effectively reduce the measured contaminants and turbidity under the investigated operating conditions.

Keywords: Electrocoagulation (EC); pond water; contaminants; iron electrodes; water treatment.

معالجة مياه البرك باستخدام التخثير الكهربائي بأقطاب الحديد

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ملخـــــص البحـــــث

تُعد عملية التخثير الكهربائي إحدى تقنيات المعالجة الكهروكيميائية التي يمكن استخدامها لإزالة الملوثات من مياه الصرف الصحي .تهدف هذه الدراسة بصورة أساسية إلى تقييم كفاءة عملية التخثير الكهربائي في معالجة مياه البرك .وقد أُجريت التجارب بنظام الدفعات باستخدام أقطاب الحديد، وبحجم تشغيلي للمياه بلغ **800** مل. وتمت دراسة تأثير كلٍّ من زمن التفاعل، والجهد الكهربائي، ومساحة الأقطاب الكهربائية، ودرجة حرارة المحلول في إزالة الملوثات من مياه البرك .وشملت الملوثات المدروسة المواد الصلبة الذائبة الكلية، والكالسيوم، والصوديوم، والعكارة. تراوح زمن التفاعل بين **30**و90 دقيقة، والجهد الكهربائي المطبق بين **10** و30 فولت، ومساحة الأقطاب الكهربائية بين (5×3) و (10×6) سم²، في حين تراوحت درجة حرارة المحلول بين **30**و70 درجة مئوية. أظهرت النتائج أن كفاءة إزالة المواد الصلبة الذائبة الكلية والكالسيوم تحسنت مع زيادة زمن التفاعل، في حين شهدت كفاءة إزالة الصوديوم تغيرًا طفيفًا خلال الفترة الممتدة من **30** إلى **90** دقيقة. وعند زمن تفاعل بلغ **90** دقيقة، بلغت كفاءة إزالة المواد الصلبة الذائبة الكلية **49.09%**، والصوديوم **35.19%**، والكالسيوم **79.25%**، والعكارة .**95.95%**. إضافةً إلى ذلك، تحسنت كفاءة إزالة الملوثات مع زيادة الجهد الكهربائي المطبق. وقد سُجلت أعلى كفاءة عند جهد كهربائي بلغ **30** فولت، حيث بلغت كفاءة الإزالة **46.00%** للمواد الصلبة الذائبة الكلية، و41.67**%** للصوديوم، و45.28**%** للكالسيوم، و96.61**%** للعكارة. كذلك، ازدادت كفاءة إزالة الملوثات مع ارتفاع درجة حرارة المحلول من **30** إلى **70** درجة مئوية. وسُجلت أعلى كفاءات الإزالة عند درجة حرارة **70** درجة مئوية، إذ بلغت **29.27%** للمواد الصلبة الذائبة الكلية، و47.22**%** للصوديوم، و69.81**%** للكالسيوم، و98.34**%** للعكارة. وتشير النتائج إلى أن عملية التخثير الكهربائي باستخدام أقطاب الحديد يمكن أن تسهم بفاعلية في خفض تراكيز الملوثات المقاسة وتقليل العكارة، وذلك ضمن ظروف التشغيل التي خضعت للدراسة.

الكلمات الدالة: التخثير الكهربائي، مياه البرك، الملوثات، أقطاب الحديد، معالجة المياه.

1. INTRODUCTION

Water is essential for various purposes, including domestic activities, agricultural production, and industrial processes. Pollution is the introduction of contaminants in to the natural environment that causes adverse change. Water pollution means contaminated water that is harmful for living being. The increasing of water demand has increased the need for effective wastewater treatment technologies [1]. Electrocoagulation (EC) technology is the one of the most widely used and practical technique for the removal of containments and colloidal solids from wastewater. The EC technology has been successfully applied for removing numerous contaminants from industrial, various agricultural, and urban wastewaters [2, 3, 4]. Additionally, the EC technology can be used to remove various types of pollutants, such as various anions, various organic compounds, heavy metals, and suspended oils [5]. Furthermore, the EC technology has many advantages, such as compactness and simplicity of the equipment required, high efficiency at low operating cost and simplicity of process control, leading to enhanced reliability [6, 7]. The EC, is also, integration with renewable energy systems has also been suggested due to it requires low electrical energy [8]. The electrochemical reactions occurring during EC process with iron electrodes include anodic iron and cathodic water. In iron electrodes, the cathodic reaction can be described by Equation whereas anodic iron dissolution is generally considered to produce Fe^{+2} ions [9].

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

Subsequently, Fe^{+2} can be oxidized to Fe^{+3} at the electrode surface or in the bulk solution by dissolved oxygen of pollutants [10], however, other reaction pathways have also be proposed [11], while water oxidation represents an additional possible anodic process [9].

$$2H_2O \longrightarrow O_{2\,(g)} + 4H^+_{(aq)} + 4e^- \quad (2)$$

Consequently, the objective of this study is to investigate the effectiveness of EC for pond water treatment, through batch experiments, as a function of various operating parameters including reaction time, applied voltage, electrode area, and solution temperature.

2. MATERIALS AND METHODS

In this study, pond water was selected as a case study and was collected from the dam of Wadi Kaam, Alkhoms City. The contaminant removal efficiency was investigated using batch experiments. The experimental work was conducted at the Instrument Laboratory, Chemical and petroleum Engineering Department, Elmergib University. First, samples were analyzed for contaminant concentrations at the Advanced Laboratory of Chemical Analysis, Tajoura. Second, turbidity measurements were performed at the Libyan Petroleum Institute (LPI). The materials used in this study include pond water, distilled water, and HCl solution. In addition, the equipment include iron electrodes, constant DC current, a laboratory model DC power supply, magnetic stirrer, hot plates/stirrer, stop watch, portable multi parameters, turbidity meter, and flame photometer.

3. THEORY AND CALCULATION

3.1 Preparation of Electrocoagulation Cell

The electrocoagulation unit was consisted of, as shown in Figure 1, of 1000 ml beaker and a direct-current power supply. Two iron electrodes, an anode and a cathode, were used in the electrocoagulation process with different dimensions since these dimensions were used as a parameter. The electrodes were immersed to a depth of 7 cm and a distance of 1.5 cm from each other. The electrocoagulation cell has a working volume of 800 ml. The voltage was regulated at 10V, 20V, and 30V. After each batch experiment run, the iron electrodes were cleaned by immersion in a dilute HCl solution (5%) to remove oxide layers and surface deposits, then reined by distilled water and dried before being placed in the EC cell.



Fig 1. Construction of the electrocoagulation cell.

3.2 Parameters Affecting Experiment

The parameters affecting experiment include applied voltage, reaction time, solution temperature, and electrode area. The applied voltage was 10, 20, and 30V. Reaction times were investigated at 30, 60, and 90 min. Solution temperatures were investigated at 30, 50, and 70 °C. Electrode area were evaluated at areas of 5 × 3 cm^2 and 10 × 6 cm^2.

3.3 Analytical Measurements

Samples were analyzed for TDS, pH, electrical conductivity, sodium, calcium, and turbidity. The analytical measurements were conducted according to standard methods for the examination of water and wastewater. A turbidity meter was used to determine turbidity, portable multi parameters meters were used for water-quality parameters, a flame photometer was used for relevant ionic measurements.

4. RESULTS AND DISCUSSION

4.1 Initial Characteristics of Pond Water

The initial characteristics of the pond water were examined to establish a reference for evaluating the efficiency of the electrocoagulation (EC) technique. Table 1

shows the initial measured parameters including TDS, pH, concentrations of Na and Ca, and turbidity. Moreover, the EC technique performance was evaluated by comparing the measured parameters before and after EC under the operating conditions.

Table 1. Initial characteristics of pond water.

Parameter	TDS	PH	Na	Ca	Turbidity
Units	mg/l	-	mg/l	mg/l	NTU
Value	275	8.1	108	53	15.05

4.2 Effect of Applied Voltage

The effect of applied voltage on the process was investigated in the range of 10 – 30V. The obtained results are presented in Table 2. The measured concentrations of TDS, sodium, calcium, and turbidity were decreased with the increasing of applied voltage. Consequently, the removal efficiency has increased with applied voltage.

Table 2. Experimental results at different applied voltage.

Voltage	TDS	PH	E.CON	Na	Ca	Turbidity
10	179.4	8.76	328	93	35	2.18
20	168.7	8.6	309	75	33	1.24
30	148.5	8.71	273	63	29	0.51

Figure 2 shows that the removal efficiencies were 34.76% for TDS, 13.89% for Na, 33.96% for Ca, and 85.51% for turbidity at 10 V. In addition, at 20 V, the removal efficiencies were 38.65% for TDS, 30.56% for Na, 37.74% for Ca, and 91.76% for turbidity. At 30 V, the removal efficiencies were 46% for TDS, 41.67% for Na, 45.28% for Ca, and 96.61% for turbidity. The highest removal efficiencies were obtained at 30 V.

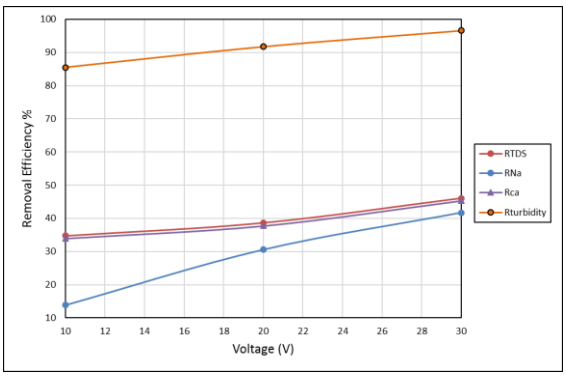


Fig 2. Effect of applied voltage on removal efficiency.

4.3 Effect of Reaction Time

The effect of reaction time was investigated at 30, 60, and 90 min. The obtained results are presented in Table 3. The removal efficiency has increased with increasing reaction time. However, we can noted that the removal efficiency of Na remained constant at 60 and 90 min whereas the improvement in removal efficiency of turbidity from 60 to 90 min was relativity small.

Table 3. Experimental results at different reaction times.

Time (min)	TDS	PH	E.CON	Na	Ca	Turbidity
30	168.7	8.6	309	75	33	1.24
60	159.7	8.71	293	70	16	0.7
90	140	10.27	257	70	11	0.61

Figure 3 shows that at 30 min, the removal efficiencies were 38.65% for TDS, 30.56% for Na, 37.74% for Ca, and 91.76% for turbidity. In addition, at 60 min, the removal efficiencies were 41.93% for TDS, 35.19% for Na, 69.81% for Ca, and 95.35% for turbidity. At 90 min, the removal efficiencies were 49.09% for TDS, 35.19% for Na, 79.25% for Ca, and 95.95% for turbidity. In conclusion, the highest removal efficiency in the reaction-time experiments were obtained at 90 min.

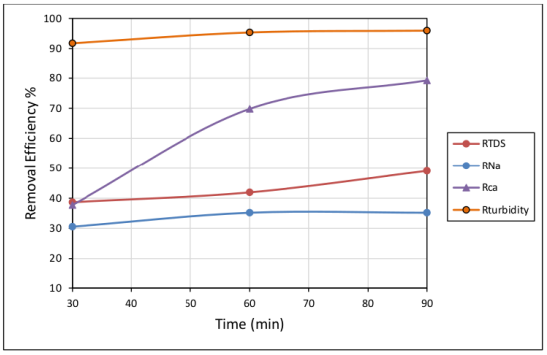


Fig 3. Effect of reaction time on removal efficiency.

4.4 Effect of Solution Temperature

The effect of solution temperature was investigated at 30, 50, and 70°C. The results of contaminates decreased with increasing solution temperature as shown in Table 4 below:

Table 4. Experimental results at different solution temperatures.

Temp (°C)	TDS	PH	E.CON	Na	Ca	Turbidity
30	212.4	7.72	388	83	36	0.86
50	208.4	7.77	381	64	32	0.77
70	194.5	7.78	355	57	16	0.25

Additionally, the improvements in removal efficiency can be explained by enhancing ion transfer and reduce solution viscosity, which can increase ion diffusivity.

Figure 4 shows that the removal efficiencies were 22.76% for TDS, 23.15% for Na, 32.08% for Ca, and 94.29% for turbidity at 30 °C. At 50 °C, the removal efficiencies were 24.22% for TDS, 40.74% for Na, 39.62% for Ca, 94.88% for turbidity. In addition, at 70 °C, the removal efficiencies were 29.27% for TDS, 47.22% for Na, 69.81% for Ca, and 98.34% for turbidity. The highest removal efficiencies were obtained at 70 °C.

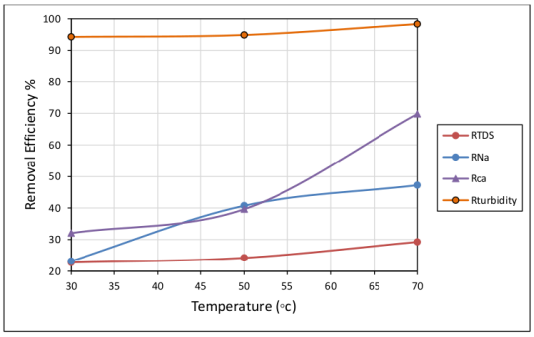


Fig 4. Effect of solution temperature on removal efficiency.

4.5 Effect of Electrode Area

The effect of electrode area was studied at variable values of the single electrode areas of 5 × 3 cm^2 and 10 × 6 cm^2. The obtained results are presented in Table 5.

Table 5. Experimental results at different electrode areas.

Electrode area. (cm^2)	TDS	PH	Na	Ca	Turbidity
(5×3)	162.1	8.18	93	36	1.38
(10×6)	168.7	8.6	75	33	1.24

The Figure 5 shows that the removal efficiencies increased with increase electrodes area. For an electrode area of 5 × 3 cm^2 , the removal efficiencies were 41.05% for TDS, 13.89% for Na, 32.08% for Ca, and 90.83% for turbidiry. In addition, for an electrode area of 10 × 6 cm^2, the obtained removal efficiencies were 38..65% for TDS, 30.56% for Na, 37.74% for Ca, and 91.76% for turbidity. It can be noted that the highest removal efficiences for Na, Ca, and turbidity were obtained at electrode area of 10 × 6 cm^2, whereas the highest removal efficiency for TDS was obtained at electrode area of 5 × 3 cm^2.

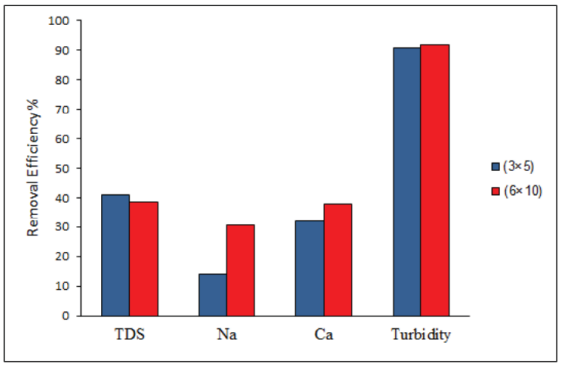


Fig 5. Effect of electrode area on removal efficiency.

4.6 Energy Consumption

In this study, energy consumption was calculated, as a function of treatment time, using Equation 3:

$$E = V \times I \times t \quad (3)$$

Where: E is the electrical energy consumption (Wh); V is the applied voltage (volt); I is the current (A); and t is the operating time (h). Table 6 shows energy-consumption data. It can be noted that the energy consumption increased with reaction time due to increased electrodes polarization as the operation time increased. Additionally, a voltage of 20 V was selected as the optimum operating voltage because it provides high process efficiency while minimizing excessive electrical energy consumption.

Table 6. Energy – consumption data of electrogoagulation cell.

V(v)	I(A)	time (min)	Energy consumption (W.min)	time (h)	Energy consumption (kWh/L)
0	0	0	0	0	0
20	0.5	30	300	0.5	0.00625
20	0.5	60	600	1	0.0125
20	0.5	90	900	1.5	0.01875

Figure 6 illustrates that the power consumption was increased with increasing reaction time.This is because of increasing in polarization on the two electrodes.

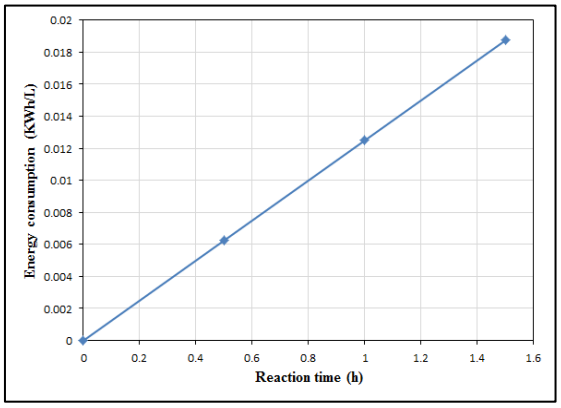


Fig 6. Energy Consumption of the EC treatment with respect to time.

5. CONCLUSIONS

In this study, the removal of contaminants from pond water by electrocogulation process using iron electrodes was investigated. Additionally, the effect of applied voltage, reaction time, solution temperature, and electrode area on the removal of TDS, Na, Ca, and turbidity were evaluated. The EC process can reduce the measured contaminants and turbidity from pond water by determining the removal efficiency of contaminants under the investigated conditions. The removal efficiencies were increased with increasing the applied voltage from 10 to 30 V with maximum values of 46.00% for TDS, 41.67% for Na, 45.28% for Ca, and 96.61% for turbidity at 30 V. Increasing reaction time from 30 to 90 min improved the efficiencies removal of TDS and Ca, while Na removal efficiency at 35.19% between 60 and 90 min. At 90 min, the removal efficiencies were 49.09% for TDS, 35.19% for Na, 79.25% for Ca, and 95.95% for turbidity. The removal efficiencies of TDS, Na, Ca, and turbidity were increased with increasing solution temperature from 30 to 70 °C. At 70 °C, the removal efficiencies were 29.27% for TDS, 47.22% for Na, 69.81% for Ca, and 98.34% for turbidity. In addition, the electrode area of 10 × 6 cm^2 produced the highest removal efficiencies for Na, Ca, and turbidity whereas the electrode area of 5 × 3 cm^2 produced the highest removal efficiency for TDS. Overall, the results showed that the iron-electrode electrocoagulation process is an effective technique for reducing the contaminants and turbidity in the pond water.

Based on the obtained results of this study, the proposed recommendations including: investigate the effectiveness of Aluminium-Aluminium electrodes and iron-Aluminium electrodes for wastewater treatment by electrocoagulation**.** Also, the effect of other operating variables such as stirring speed, electrode type and conductivity affecting the removal efficiency of the electrocoagulation process should be investigated. In addition, study the effect of sample PH and add salts during the electrocoagulation process on the removal efficiency. Furthermore, procedure further tests to find removal efficiency of heavy metals, COD, BOD and color for wastewater.

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