Treatment of Industrial Oil and Soap Wastewater by Using the Application of Electrocoagulation Process

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Abstract

Electrocoagulation (EC) treatment of oily and soap industrial wastewater was studied in this paper. Operating parameters such as operating time, medium pH, voltage density, and electrode material and chemical oxygen demand (COD) are being investigated in oil and soap removal efficiencies. The maximum efficiency of COD removal is achieved using aluminum electrodes was 96.92%. The performance of EC using aluminum as the electrode exhibited better COD and oil-grease (O&G) removal than the iron electrode. EC is an extremely promising industrial wastewater treatment technique because it is simple, economic and less sludge production technology, especially for oil and soap wastewater. The optimum conditions to achieve high COD removal efficiency of about 96.92% in 30 min was found to be in using initial pH value range 2–3, and a voltage of 20 volts.

Keywords: Oil industrial; Electrocoagulation; COD; Aluminum; Iron; Electrode

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1. Introduction

The industrial growth combined with improvements in the processes of production has led to increased environmental wastewater volume and complexity. Many of the conventional methods have been changed and improved to prevent different chemicals from being released by industrial wastewater to drainage. Industrial effluents may also contain toxic contaminants to be reduced or eliminated to protect their production systems, the environment, public health, and treatment plants [1].

The major problems in discharges for industrial wastewater can be summed up as hydraulic overloads, extremes of temperature, excessive amounts of oil, fat, or grease; alkaline or acidic constituents; inorganic or organic suspended solids contents, volatile, odorous or flammable and explosive materials or corrosive gases. Recently, the use of electrochemical methods for extracting phosphate has been showing increasing interest [2,3] and boron [5] from water, arsenate [4], heavy metals [11,5,6,7,12] destroying harmful and bio-refractory organic contaminants which mostly industrial wastewater [10,15,17,13,14,25]. These methods use electrons for heterogeneous reactions as their main reagent. In the case of ionic components in industrial wastewater, a dissolved electrolyte is needed to raise ionic conductivity. The main benefit of this method is that temperature is not regulated as it depends on the room temperature. Electrochemical procedures are economical, working, eco-friendly, easy, and quick. Besides this pure water is suitable for drinking, colorless, odorless, and clear with low sludge production. Chances are that any secondary pollution will be zero through this technique [15].

Electro-chemical processes, such as electric reduction, electro flocculation, and direct electro-oxidation, electrical coagulation, electric flotation, and indirect electro-oxidation is known as electro-Fenton are techniques used for wastewater treatment. EC is a separation technique [34,35] involving both physical and chemical processes for the elimination of contaminants. [36,37] This method primarily destabilizes suspended, dissolved, or emulsified pollutants in the aqueous medium through supplying electricity. On-site EC is used by the iron or aluminum rod or both oxidized by the current applied. Simultaneously. The development of cathode hydrogen gas also helps to remove pollutants via flotation. For the destabilization, coagulation, and adsorption of dissolved toxins, a system is set up of hydroxides and coagulants. [8, 18]. Three steps are followed in the EC process [26].

a. Electrolytic oxidation of surface formation of coagulants.

b. Destability of contaminants, suspension of particulates, and the breakup of emulsions.

c. Formation of the flocs by collecting the disturbed particles. This provides the benefits of electrocoagulation because it is relatively cheap, high particle removal effective and does not need chemicals to be applied and output sludge volumes reduced. [15, 9]
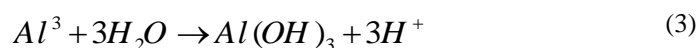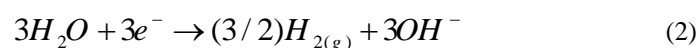
Oxidation – Reduction of electrochemical cell reactions are as follows:

In the case of aluminum:

Anodic (oxidation) reactions:

$$AL_{(s)} \rightarrow AL_{(aq)}^{+3} + 3e^- \tag{1}$$

Cathode:

$$3H_2O + 3e^- \rightarrow (3/2)H_{2(g)} + 3OH^- \tag{2}$$

$$Al^3 + 3H_2O \rightarrow Al(OH)_3 + 3H^+ \tag{3}$$

The freshly formed amorphous $Al(OH)_{3(S)}$ flocs have a wide surface area. Areas that are useful for the accelerated absorption of soluble organic compounds and the trapping of colloidal particles. These flocs, eventually, easily separated from the aqueous medium by sedimentation or flotation.

The objective of this study is to investigate the performance of electrocoagulation (EC) for the removal of oil and soap generated by industrial wastewater approximately 750 m^3 of wastewater per day and also the Effects on operating variables including electrodes, working time, voltage density, electrode size, and initial pH; efficiency; will be studied and debated to determine the optimal methods for removal.

2. Materials and Methods

Industrial samples of wastewater were obtained from an exhaust oil-soap mixed tank solution at an oil and soap factory located at EL-Dakahlia Governorate, Egypt. Production of the composition of the wastewater is shown in Table 1. For further studies before using industrial wastewater, a screen filter was used to remove large suspended solids.

Table1: Characteristics of wastewater used

Parameter	Value
Chemical oxygen demand (COD) (mg/L)	19750 ± 487.92
Total suspended solids (TSS) (mg/l)	2753 ± 139.69
Conductivity (S/cm)	3800 ± 181.40
pH value	11.5 ± 0.45
Oil & Grease (mg/L)	978 ± 38.96

2.1. Setup of Experimental

The instrument of experimental is shown in Figure 1. EC is composed of a beaker of glass with the magnetic tumbling

electrochemical reactor, a D.C power supply (VARIABLE AUTO TRANSFORMER 25-volt, 6 Ampere). Two electrodes of the aluminum cathode and anode with dimensions of (4 cm × 14 cm × 0.1 cm). Each electrode plate's submerged surface area was 40 cm². They were positioned upright and submerged in a 500 ml solution. The distance of 2 cm between the electrodes (d). The electrodes were attached to an ammeter (PHYWE) and a voltmeter (G1002-500) digital DC power supply. Were used during the EC process to monitor current and voltage.
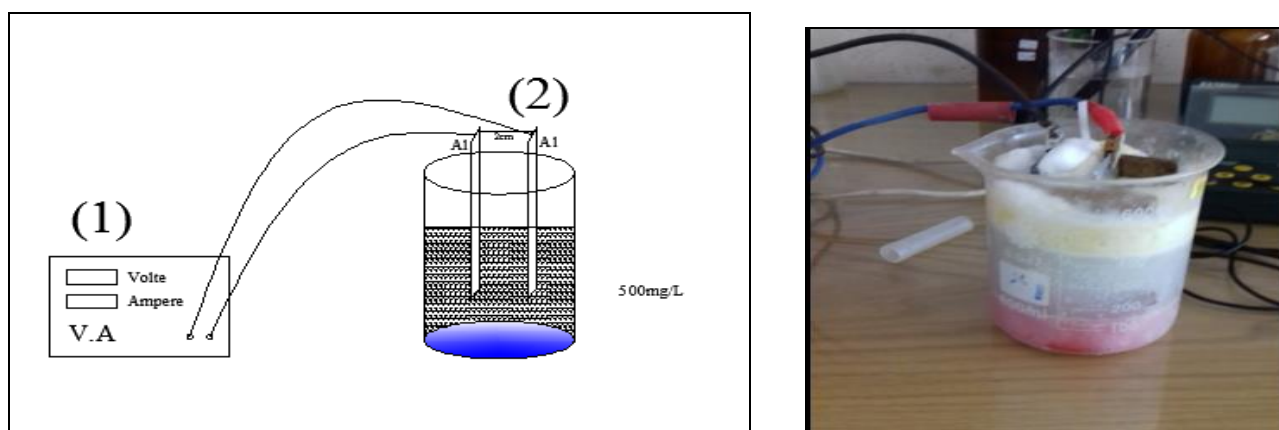
Figure 1: Experimental setup schematic diagram: (1) DC power supply (2) electrode cell

Before each stage, the electrodes were washed with acetone to eliminate any surface fat. Impurities were collected from iron or aluminum surfaces in a solution that is prepared for 6 minutes in combination with a 100 cm³ (HCL) solution.

During run time, COD and O&G were measured for 30 minutes and every 5 minutes at a constant temperature of 25 °C. It was washed well with water to remove any solid waste that has accumulated on the surfaces, dry it well, and measure it again.

### 2.2. Analytical procedures

The determinations of COD, oil-grease, Conductivity, pH, and TDS as suggested in Standard Methods for Examining Water and Wastewater were carried out [27]. COD reactor and spectrophotometer read directly (HI839800) were used to measure the COD. Hexane extraction of oil-grease was estimated. THE EXTECH341350A automated benchtop pH-meter and Lutron CD. The COD removal M210 model-level meter respectively has been calibrated for pH and conductivity with the desired value by [NaOH] or H₂SO4 and sodium chloride [NaCl]. The COD removal efficiency was determined as:

$$RE_{COD}(\%) = \frac{COD_0 - COD_t}{COD_0} \times 100\% \qquad (4)$$

Where COD_0 is the initial amount of COD (mgL^{-1}) and COD_t is amount of COD (mgL^{-1}) at the specific time.

2.3. Experimental work

The impact of the operating condition on EC performance was first investigated by changing the pH value from 2 to 11. Then the voltage changed from 5 to 25 volts and TDS from 3000 to 5000mg/l .The COD and O&G were measured every 5 minutes for 30minutes. The Sequential phases of the Electrocoagulation process are shown in Figure 2.
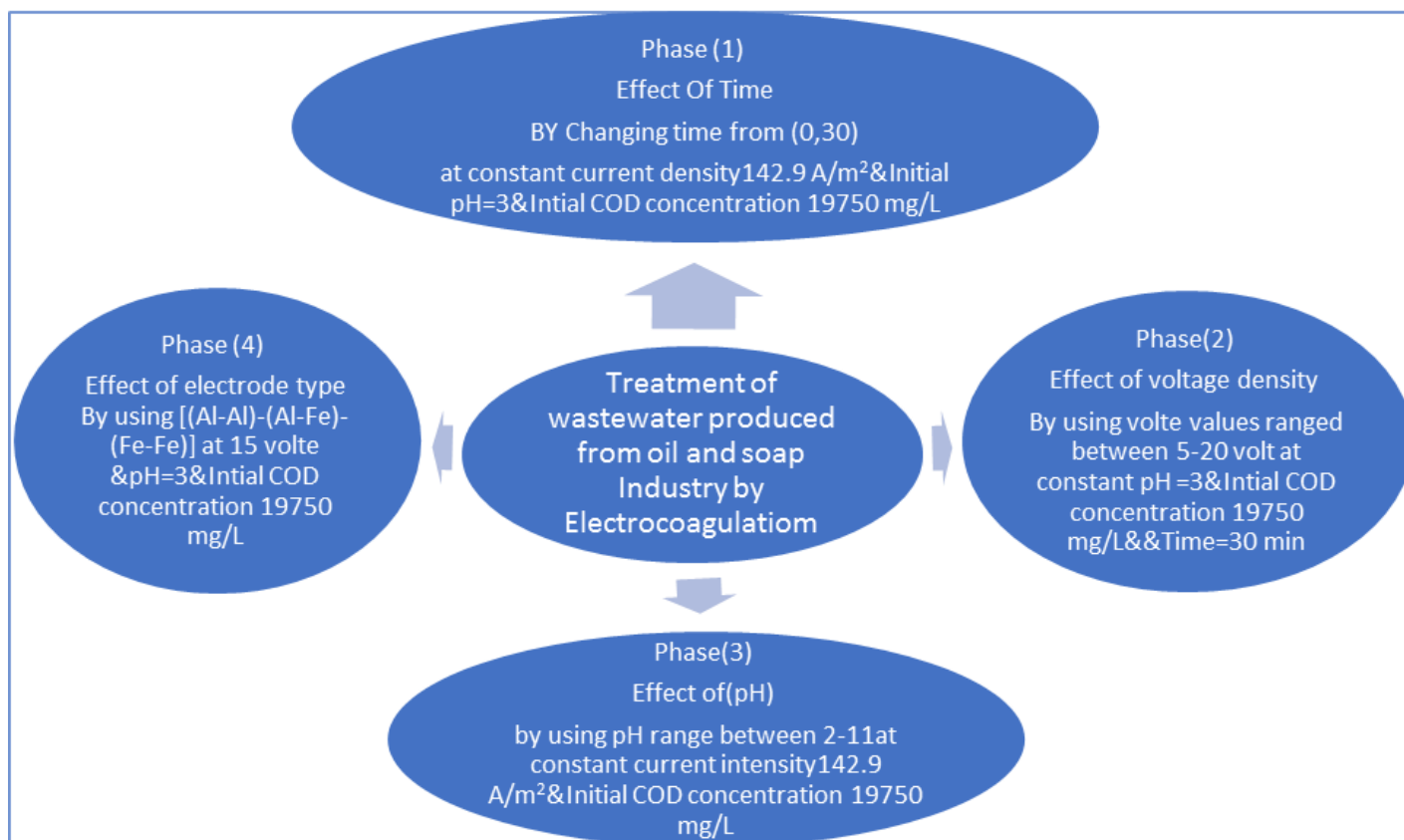

Figure 2: Summary of experimental work of Electrocoagulation process

3. Results and Discussion

3.1. Effect of electrolysis time on COD removal efficiency

The current density is maintained at 142.9 A / m^2 and the pH value of industrial wastewater adjusted to 3 to assess the effect of operating time. As shown in Figure 3, the removal of COD increases from 46.84% to 96.30% for aluminum by increasing the time from 5 to 30 minutes.

The removal of oil and grease, on the other hand, reached about 94.06% in 30 minutes. That's related to the efficiency of COD removal depends directly on the metal ion rates produced on the electrodes When the electrolysis period increases, the concentration of metal ions and their hydroxide flocs increases [29,30].
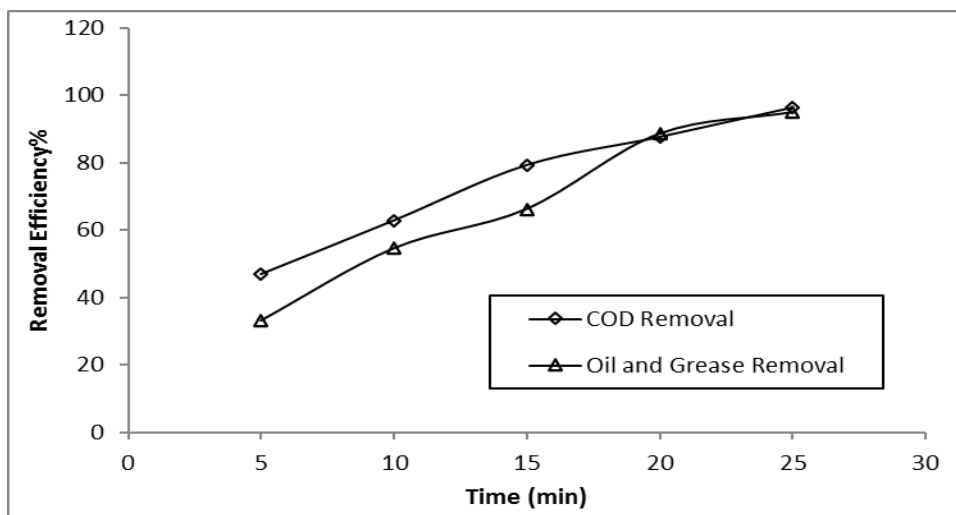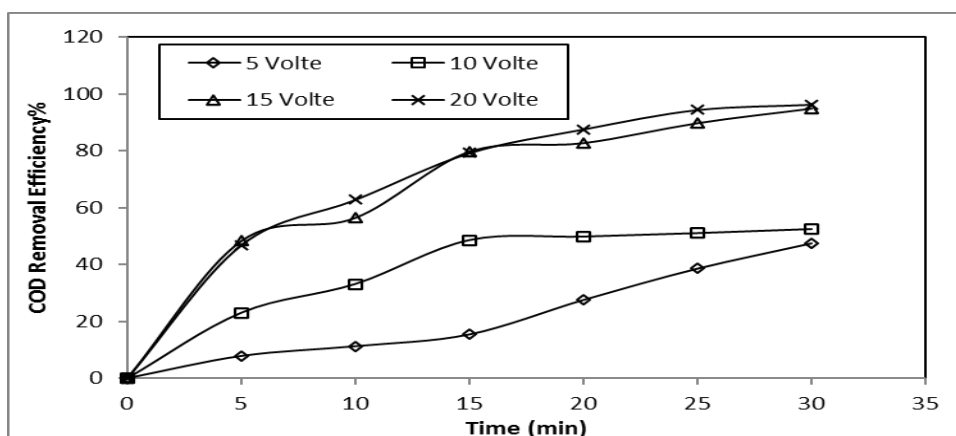
Figure 3: Effect of electrolysis time on the efficiency of COD removal; sodium chloride [NaCl] = 2 mole/l; initial pH value =3; current density=142.9 A/m^2 initial COD concentration=19750 mg/l.
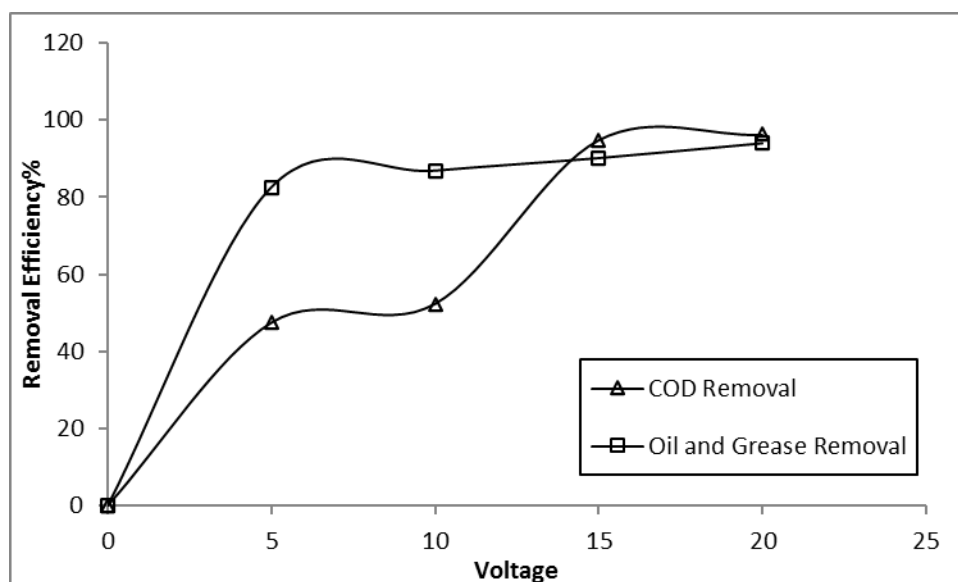
3.2. Effect of voltage density on the removal efficiency of COD

One of the best control parameters in all electrocoagulation processes for the reaction rate is the voltage density. Figures. (4.1) and (4.2) reflect the voltage density effect for aluminum electrode materials on COD and O&G removal efficiencies, with 30 minutes operating time and pH value=3. In general, for aluminum electrode materials, greater voltage density is in favor of removal efficiency. Furthermore, higher than 20 volts, the performance of COD removal reaches a maximum of 96.3% value. Higher efficiencies are reached in the case of oil and grease removal of 94.06%. This is because, at a high rate, aluminum oxidation rises, which contributes to a higher precipitate standard for pollutant removal. Moreover, bubbles were seen to raise the density and decrease in size with a rising current density [31, 32], resulting in improved upstream flux and faster pollute and sludge flotation elimination.

In the meantime, greater voltage densities above 20 volts are not economically beneficial.

Figure 4.1: Effect of the voltage and electrolysis time on the efficiency of the COD removal: Initial COD concentration = 19750 mg/L, initial pH value=11.79 before adding sodium chloride [NaCl] to be pH value=3

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Figure 4-2: Voltage density effect on COD removal efficiency; [NaCl] = 2 mole/l; initial pH value =3; electrolysis time 30 min; initial COD concentration=19750 mg/l.
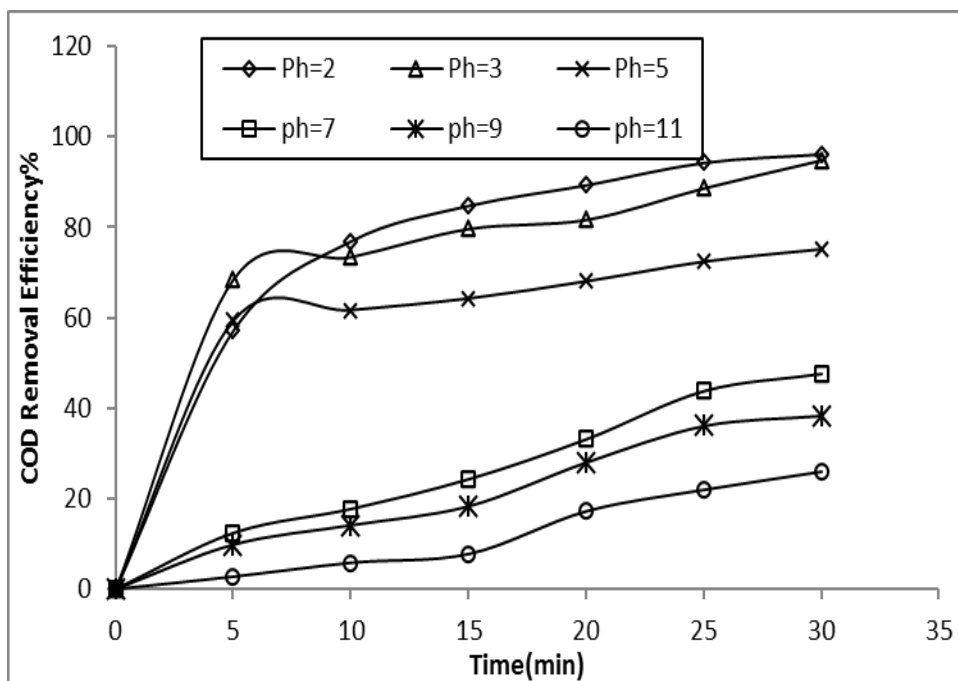
3.3. Initial pH effect on COD removal efficiency:

 The pH is important and essential to the success of EC. The initial pH was modified at 2 to 11 intervals to analyze the effects of the pH of the solution on COD and O&G removal. The pH effect on electrocoagulation is shown in Figure (5-1), Figure (5-2). The results indicate that the COD removal efficiency was optimal with the maximum pH in solutions of between 2 and 5 at pH value 2. There has been a substantial decline in the efficiency of COD removal in acidic and simple regions, for pH 9 and pH 11 respectively.

The highest removal efficiency was reported across pH value ranges from (2-5). The wide area of $Al(OH)_{3(s)}$ flocs is ideal for colloidal particulate trapping and heavy organic soluble adsorption [20]. It has been established [19] Al^{3+} and $Al(OH)^{2+}$ cationic soluble species are prevalent between 2 and 3 at low pH levels. Also, Different species of monomers and polymers are formed in pH ranges 4 and 9, using complex polymerization/precipitation kinetics, which are then transformed into insoluble amorphous $Al(OH)_{3(s)}$ [20]. Therefore, The soluble concentration of $Al(OH)^{4-}$ anion has increased to $Al(OH)_{3(s)}$ where the pH is greater than 9.according to the reaction:

$$Al(OH)_{3(s)} + OH^- \rightarrow Al(OH)^{4-} \qquad (5)$$
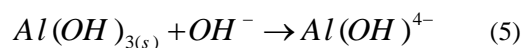
Besides, As shown in Figure(6), an activity-pH diagram in equilibrium

Figure 5-1: Initial pH effect and electrolyse time on the efficiency of COD removal: Initial COD concentration =19750 mg/l, volume of solution=500 mg/l, applied voltage=15 V
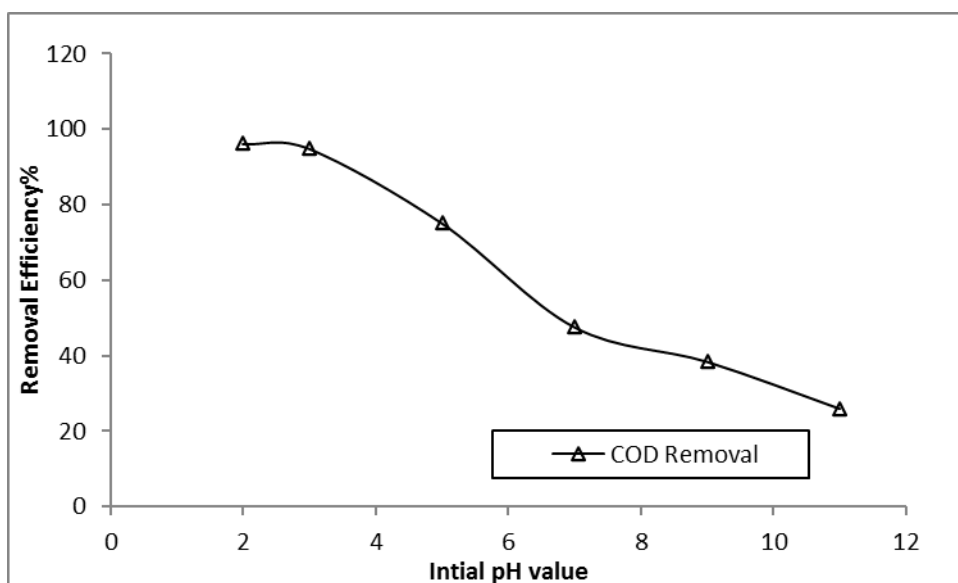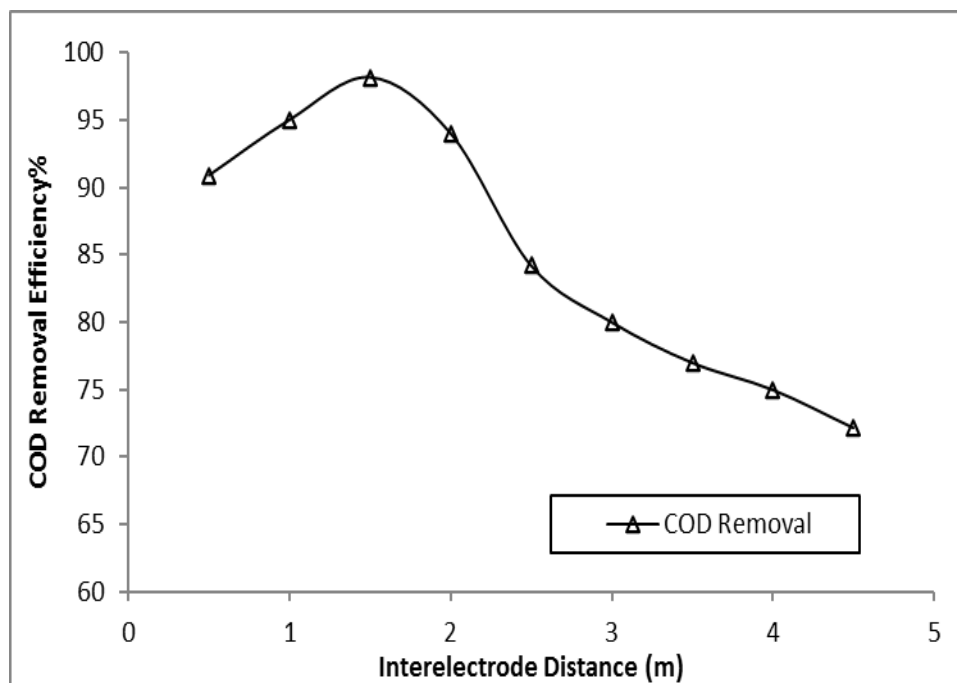

Figure 5-2: The initial pH effect on the efficiency of removal of COD; [NaCl] = 2 mole /l; current density=142.9 A /m^2; time for electrolysis=30 min; initial concentration of COD=19750 mg /l

3.4. Inter-electrode gap effect on the efficiency of COD removal

Figure 6. Shows the Effect of the distance between electrodes on pollutant removal efficiency. It is stated that the production of EC efficiency depends on electrode setup, contaminant nature, process Dynamic conditions, etc. as a

function of the interelectrode distance [18,21,22]. The effect of inter-electrode distance between 0.5 and 4.5 cm is investigated in our research. By reducing the gap between the electrodes, the best removal values are obtained, color removal increases slightly. The removal values increased from 90.89 % to 98.15 %, respectively, from 0.5 to 1.5 cm. An increase in the gap of electrons also led to a less effective removal. From the 4.5 cm gap between the electrodes, we obtain the lowest removal value of 70.10%. These findings agree with the results found in the Modirshahla et al report. [21]. Once the inter-electrode gap increases less electrode attachment, the movement of the produced aluminum polymers is slower and tends to be aggregated in flocs.

Figure 6: Effect on the efficiency of removal of COD by Interelectrode Distance: initial pH value= 3; current density= 142.9 A /m^2; initial Concentration of COD=19750 mg /l; [NaCl] = 2 mole /l; time of electrolysis= 30 min.

3.5. Effect of electrode type on COD removal

As shown in Figure 7, that (Al) electrode was better than iron and a mix of aluminum and iron electrodes. The percentage of COD removal was more than 94.94% after about 30 min. The degradation of iron is one of the main problems when using iron. It is commonly noted that pH increases during an electrochemical process because the process leads to the formation of metal hydroxide according to previous equations [23]. Some researchers have stated that current density can influence electrochemical process treatment efficiency [24]. Three current densities have been used to analyze its impact. By using aluminum electrodes and for initial COD concentration of 19750 mg/l. After 30 min, the COD and O&G removal efficiencies improved from 47.54 % to 94.94 % and from 82.65 % to 90.20 % by increasing the voltage from 5 volts to 15 volts. When the applied voltage density was increased from 15 volt to 25 volts, the COD and O&G removal efficiencies improved from 94.94 % to 97.16 % and from 90.20% to 94.59 % using aluminum electrodes [33]. Electrocoagulation on aluminum surfaces has been greatly improved relative to stainless steel electrodes. This is attributed to the creation in situ of scattered aluminum – hydroxide complexes by aluminum ion hydrolysis, which is not present when electrodes are used.
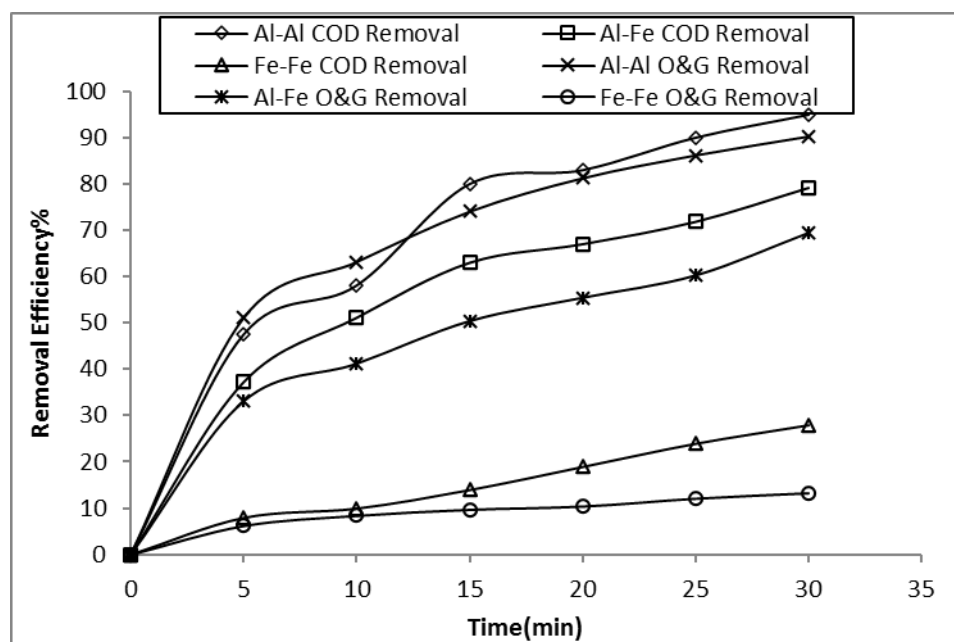
Figure.7: COD % removal with [(Al-Al), (Al-Fe), (Fe-Fe)] electrodes at constant voltage 15 Volt+1.1ampere and pH value=3 initial COD concentration=19750 mg/l; time of electrolysis=30 min.

4. Conclusions

It is demonstrated that EC is a sustainable tool for the treatment of industrial oil and soap wastewater. EC was identified as an effective technique for treatment and can be used for achieving high performance of COD and O&G removal. EC can act as primary treatment before the biological system. The COD and O&G removal efficiencies of the EC process using Aluminum electrodes are above 90%. The result shows that the optimal predicted conditions based on the highest removal efficiency for the COD and O&G were at a current density of 142.9 A m^{-2} and an EC time of 30 min and initial pH value in the range of 2 to 5. It's found that the optimal COD and O&G removal efficiency after 30 min was 94.94% and 90.20% respectively at 15volt using (Al/Al) system. The Aluminum electrode was much stronger than the Iron electrode and a mix of aluminum and the iron electrodes in reducing the COD. Increasing voltage density increase the removal efficiency of COD and O&G and increasing applied voltage decreases the operating time required for the removal.

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