Electrocoagulation and chemical coagulation for treatment of Al-Kut textile wastewater: A comparative study

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ABSTRACT

In this study, two processes were utilized to achieve the most capable treatment for the effluent of Al-Kut textile factory, Iraq. The processes are electrocoagulation and chemical coagulation. The investigation was paid attention into operation factors; such as time, pH and electrical conductivity; and pollution parameters like turbidity and TDS. Different voltages of 10, 20 and 30 V with various electrical currents of 1, 2 and 3 A were adopted. Aluminum electro-generated amount is used initially in adding to the chemical coagulation with jar test. The results showed a reduction in the pollution contents in which depend on the amount of Al^{+3} ions resulted by electrodissolution of aluminum anode. It was found that at voltage 20 and current 2, the effective turbidity removal was 96.4% at pH 6.2, EC 990 µS/cm and TDS 501 mg/L. While higher removal of turbidity in chemical coagulation was 75.4% at 0.02 mg/L dose, pH 8.3, EC 1788 µS/m and TDS 1514 mg/L. The electrocoagulation was more effective to eliminate TDS and presented higher removal of turbidity compared to chemical coagulation. Based on the analysis, the electrocoagulation is more efficient that the textile effluent treated can be reused or rejected without risk in the environment.

Keywords: Textile effluent, coagulation, aluminum electrodes, removal, operation cost.

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1. Introduction

Among all industrial sectors the textile factories are one of the most polluting industries. The textile wastewater makes an issue in environment related to its liquid waste and chemical composition. High amount of suspended solids, chemical oxygen demand, high toxicity and low biodegradable chemicals contains in the textile wastewater [1]. This industry consumes large capacities of fresh water. It can be benefited from the textile wastewater for recycling programs. There are so many techniques to remove the dyes of the textile wastewater using traditional treatment technologies such as chemical oxidation, advanced oxidation, coagulation, biological and adsorption processes [2,3]. In other words, the coagulation process has advantage in an effective approach for insoluble dyes removal like disperse dyes. However, this approach not convenient for soluble dyes and the sludge is created considered as a pollutant itself. Thus, an appropriate solution for effective pollutants removal is the application of combined treatment processes [4]. Several studies are performed in the real and synthetic textile wastewater using different inorganic chemicals such as ferric chloride, ferric sulfate, alum, lime and others like components of biological origin like chitosan. The most suitable and attractive methods for the wastewater treatment and water containing oil wastes and dye compounds are: electrochemical and electrocoagulation [5]. The electrochemical treatment use coagulants for the removal of pollutants. While, the electrocoagulation is considered an approach in which dissolve electrically either iron or aluminum ions from iron or aluminum electrodes and used it as coagulants in the generation of ions [6]. Generation of metal ions occurs at the anode and hydrogen gas is emitted from the cathode. The pollutant is carried by the hydrogen gas bubble at the upper of the solution, then it can be readily collected and taken away [7]. Several reactions occur in the electrocoagulation process. Different pollutants existing in textile effluents can be removed by enhancing some essential aspects concerning the impact of electrical potential, coagulant dose, dose of adsorbent and reaction time on the pollutants from real textile effluent [8]. The electrocoagulation is considered to be simple, reliable, and cost-effective method for the treatment of effluents without any need of additional chemicals. The reduction of the amount of sludge is achieved in which needs to be disposed. In the electrocoagulation process, the need for additional chemicals and sludge production reduced significantly in compared to chemical coagulation [9]. The aim of present study is to investigate the performance of electrocoagulation process and chemical coagulation for treatment of Al-Kut textile wastewater. It is examined the influence of the aluminum ions on the removal of some pollution parameters such as turbidity and TDS, and EC to make the synergistic effects and get the optimum conditions to complete pollutants removal for the purpose of water recovery and reuse.

2. Materials and methods

2.1 Textile wastewater

The wastewater samples were collected from a local textile factory situated in Al-Kut city, Iraq. In Table 1 the characteristics of the textile wastewater are presented. The effluent has been sampled at the same times during the study, so the initial characteristics varied with time. The methods for wastewater treatment are the chemical coagulation and electrocoagulation. Figure 1 illustrates the flow chart which is used in this study.

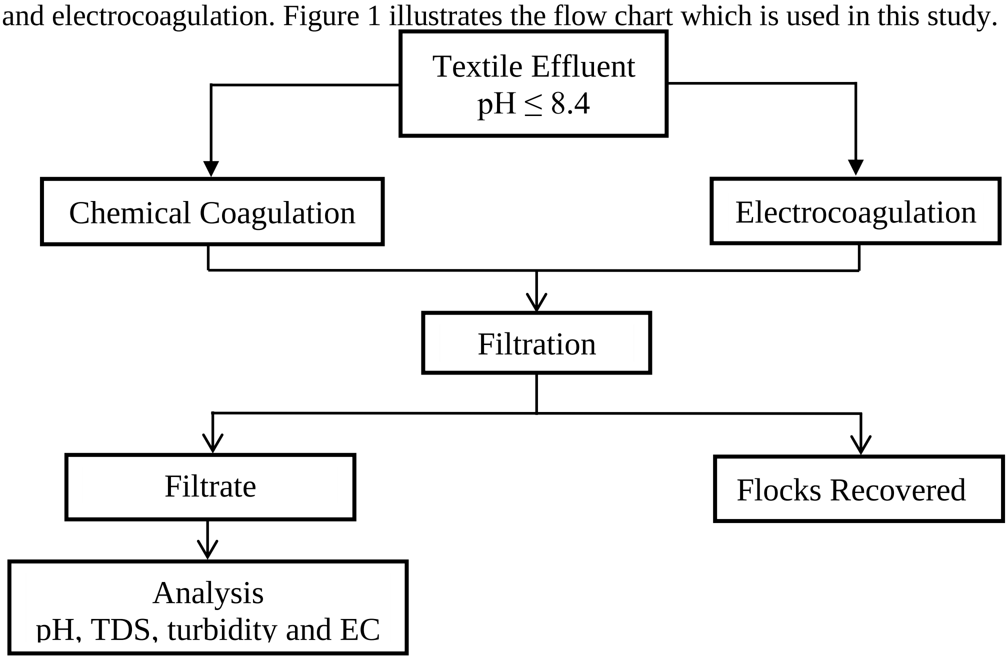

Figure 1. The treatment process procedure adopted in the present study

Table 1. The textile effluent characteristics used in the present study

Parameter	Amount
pH	≤ 8.4
Suspended solids, (mg/L)	150
Turbidity, (NTU).	≤ 28
Electrical conductivity, (µS/cm)	>1000
TDS, (mg/L)	≤712
BOD_5, (mg/L)	200
COD, (mg/L)	283
Sulphate, (mg/L)	488
Chlorides (Cl^-), (mg/L)	0.06
Phosphate, (mg/L)	0.75
Ferric, (mg/L)	0.26
Chromium, (mg/L)	0.06
Lead, (mg/L)	0.04

Parameter	Amount
Copper, (mg/L)	0.03
Cadmium, (mg/L)	0.042
Zinc, (mg/L)	0.46
Nitrates, (mg/L)	1.6

2.2. Electrochemical coagulation (electrocoagulation)

The experiments of electrocoagulation were carried out in a cylindrical reactor. The working volume of this reactor is 1L. A pair of aluminum electrodes with dimensions of 10cm× 4cm× 0.5cm procured in the local market was immersed in the solution of reactor to treat at a 5cm height. The electrodes connected to DC power supply. The electrodes were separated by a polyethylene grid of 0.5 cm thickness. The two aluminum plates (electrodes) in the electrochemical cell, one of them serve as anode the other as cathode as shown in the Figure 2. A 220V input and changing output of 0 to 60 V with a maximum current of 3 A were supplied from the power supply device. A 25 ml samples were withdrawn at 3 minutes' interval periods for maximum time of 30 minutes. The samples were measured at different interval time start with 0 minutes ending up to 30 minutes. The voltage was changed 10, 20, and 30 V and the electrical current was changed too to 1, 2, and 3 A. All the experiments were managed at a constant temperature of 22 ± 1 ºC. The analysis was performed to determine TDS, pH, turbidity, EC and removal efficiency. The magnetic stirrer was used to allow chemical precipitate to grow large enough for removal. The electrodes were rinsed with distilled water and finally weighed. Then, the electrodes were weighed again after each experiment in the changing of voltage and electrical current. The amount of aluminum electrogenerated based on the electrocoagulation process is utilized in the process of chemical coagulation. After this stage, the whole chemical coagulation process was achieved during approximately 10 minutes and analyzed.

As a result of imposed to the aluminum electrodes, the cations of polyvalent metal (Al^{+3}) is generated immediately in solution by dissolution of anode. The electrochemical reactions involve in the reactor can be expressed as [10-11]:

$$2H_2O + 2e^- \rightarrow H_2(g) + 2OH^- \qquad \textit{at the cathode}$$

$$Al \rightarrow Al^{+3} + 3e^- \qquad \textit{at the anode}$$

$$Al^{+3} + 3H_2O \rightarrow Al(OH)_3 \downarrow + 3H^+ \qquad \textit{in the solution}$$

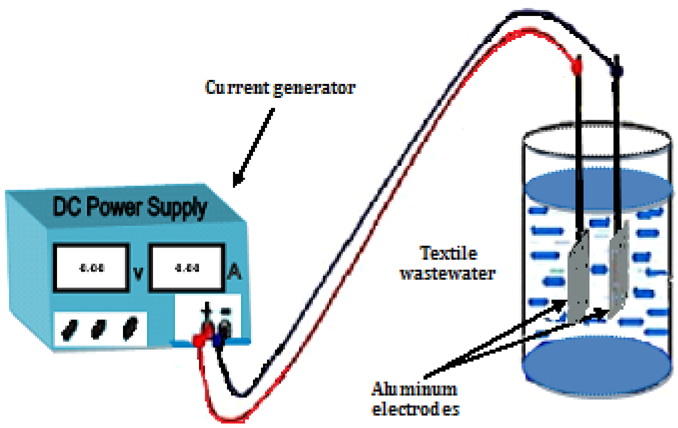

Figure 2. Electrochemical cell used in the present study to treat the textile wastewater.

2.3. Chemical treatment (coagulation)

The chemicals used in this study to remove solids from textile wastewater are less expensive and active coagulant. Different amounts of alum of up to 0.1 mg/L was used. Jar test apparatus with four beakers of 1L capacity was used to perform the coagulation approach. Each beaker was contained 1L of textile wastewater. The amounts of alum (0.02, 0.03, 0.04 and 0.1 mg/L) were added into the beakers without pH adjustment. In the jar test, rapid mixing is performed at 150 rpm for 2 minutes and the slow mixing at 40 rpm for 20 minutes. The flocs were allowed to settle for 30 minutes and the supernatant was filtered through a filter paper before examine the parameters such as pH, turbidity, TDS and EC of treated wastewater. The experiments were done at room temperature. The turbidity measurement has been done using turbidity meter (TN100IR/EUTECH turbidity meter, Thailand). PH analysis is performed using pH-meter with electrolyte probe (Sensor professional Portable pH Meter for Aquarium, China). TDS and EC have analyzed using portable digital Temp, TDS and electrical conductivity meter water quality tester (TDS & EC meter, temperature ranges 0.1-80.0-degree C, India).

3. Results and discussion

3.1. Electrocoagulation

3.1.1. The correlation between turbidity and time

Figure 3 shows the relationship between turbidity and electrolysis time in which demonstrates an increasing in the removal efficiency with the increase of electrodes time with the voltage of 20 and current 2, the maximum removal at this voltage was 96.4% at time of 21 min. The best pH of solution for the removal of turbidity was equal to 6.2. At voltage 10 and current 1, the behavior of turbidity with time was fluctuated and the maximum removal percentage was 60.4% at time 24 min. While at voltage 30 and current 3 the turbidity was sharply fluctuated until reaching time 12 min then it was slightly fluctuated and decreased to 1.48 NTU, the maximum removal at this voltage was 94.2% at time 27 min at pH 8.3. In comparison between the turbidity values of voltage 20 V (current 2 A) and those at 30 V (current 3 A) for the time period of 12 min to 30 min, it can be noticed that the average turbidity values were 2.53 NTU and 2.51 NTU , respectively, which are very closest to each other. Thus, both voltage and current play an efficient role in the turbidity removal in electrocoagulation process. The quantity of Al^{+3} emitted from anode increased when the voltage increases, and therefore $Al(OH)_3$ particles increases, namely that at high voltages the anodic dissolution of aluminum increases and this will lead to a large amount of pollutants is precipitated and removed from solution.

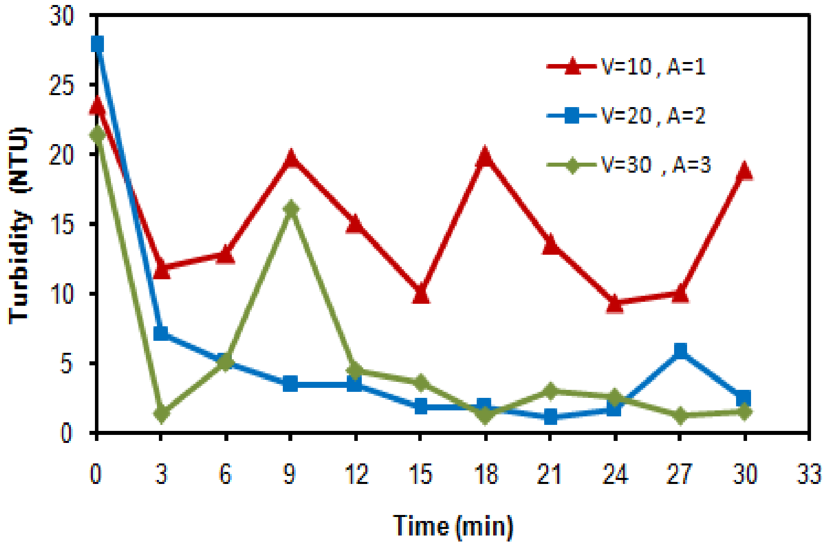

Figure 3. The correlation between turbidity and time at different voltages, for electrocoagulation process

3.2. The correlation between pH and time

In the electrocoagulation the pH plays an effective role in the performance of this process [9,12,13]. In general term, Figure 4 displays the relation between pH and electrolytes time. It shows that the pH at voltage 10 and 30 are remained approximately constant at some times and slightly changed at the other times. At voltage 20 the pH is varied from 12 to 6 at different electrolysis time, at the beginning of electrolysis time, the pH shows an increase which passes from 8 to 12, and this can be occurred because of the reduction of water at the cathode and formation of hydroxyl ion (OH^-). At both low and high pH values the removal was very poor, the reason was referred to the amphoteric feature of $Al(OH)_3$ which is not contributed at pH<2. While the solubility of $Al(OH)_3$ will increased at higher pH and this will leading to the production of dissolvable $Al(OH)_4$ that inhibit the treatment of water. [12,14].

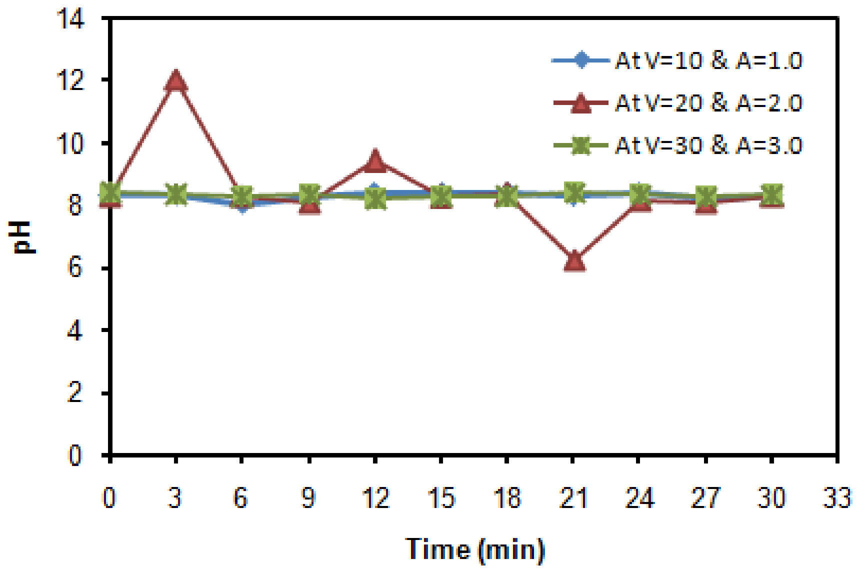

Figure 4. The change of pH with time at different voltages during electrocoagulation of the textile wastewater.

3.3. The correlation between TDS and time

The TDS is a measure of the dissolved combined content of all inorganic and organic substances in which to study the water quality for wastewater [15]. Figure 5 shows the correlation between total dissolved solid and the electrolytes time at different voltages. The value of TDS is varied from 300 up to 800 at voltage 10 and current 1. For both voltages 20, 30 with currents 2 and 3 respectively, the values of TDS is fluctuated until time 15 minutes and then the values are approximately closest to these of 10 V and 1 A until time 25 minutes. After that the behavior of the three cases were; slightly increasing in TDS at 30 V, sharply decreasing of TDS at 20 V, and fluctuation at 10 V. Decreasing in the TDS is related to the electrocoagulation process in which presented a decreasing in the amount of total dissolved solid with the voltage 20 and current 2. The amount of TDS is below 300 mg/L for drinking water and the maximum permissive limit is 600 mg/L [5]. The TDS level is 504 mg/L or below for voltage 20 and current 2 in which can be used for recovery uses.

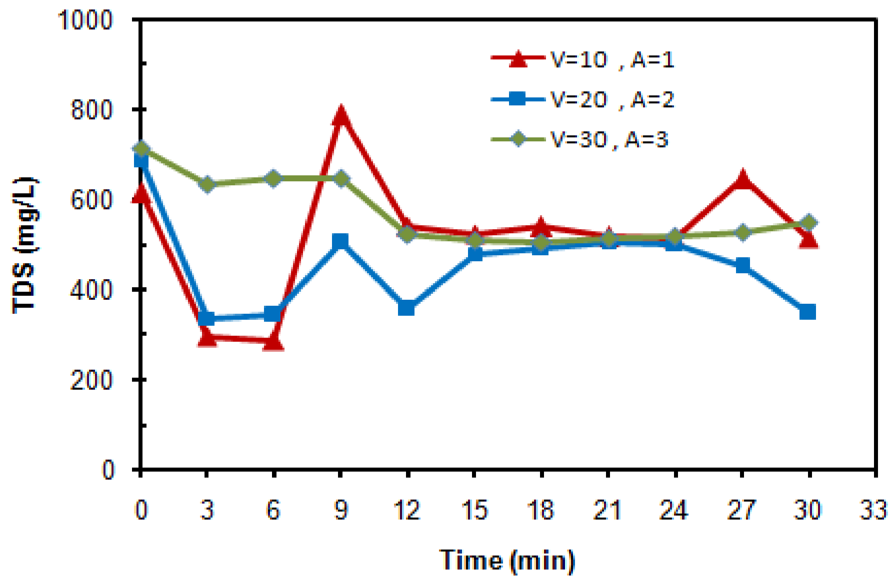

Figure 5. The effect of different voltages on the removal of TDS during electrocoagulation process.

3.4. The correlation between electrical conductivity and time

The EC of solution depends on the ability for electrons or other charge. It measures the wastewater ability to conduct electricity due to the presence of certain ions [7]. It influences on the cell voltage, current efficiency and electrical energy consumption in electrolytic cells. Figure 6 demonstrates the behavior of electrical conductivity with time at different voltages. The EC was fluctuated for the three cases (10, 20 and 30 V) until time of 15 minutes, and then the behaviors of all cases were approximately convergent until time of 25 minutes. At voltage 30 V and time from 25 to 30 minutes the EC has been raised, while it was fluctuated at 10 and 20 V at the same range of time. In general, lower electrical conductivity was presented in the voltage 20 and current 2. The fluctuation was increased in the voltage 10 and current 1. However, at voltage 30 and current 3, a better conductor of electricity is presented. Moreover, better performance in the electrical conductivity for electrocoagulation process is shown with the voltage 20 with current 2. While, less performance in the electrical conductivity is displayed with the voltage 10 with currents 1. The EC measured the ability of water to pass an electrical current. The higher EC indicated that dissolved ions comes from aluminum sulfate as a dissolved salt as presented at voltage 20 with electrical current of 2. The higher concentration of ions in solution exists the higher conductivity presented. Based on this analysis, the present study is agreed with [16] and [15].

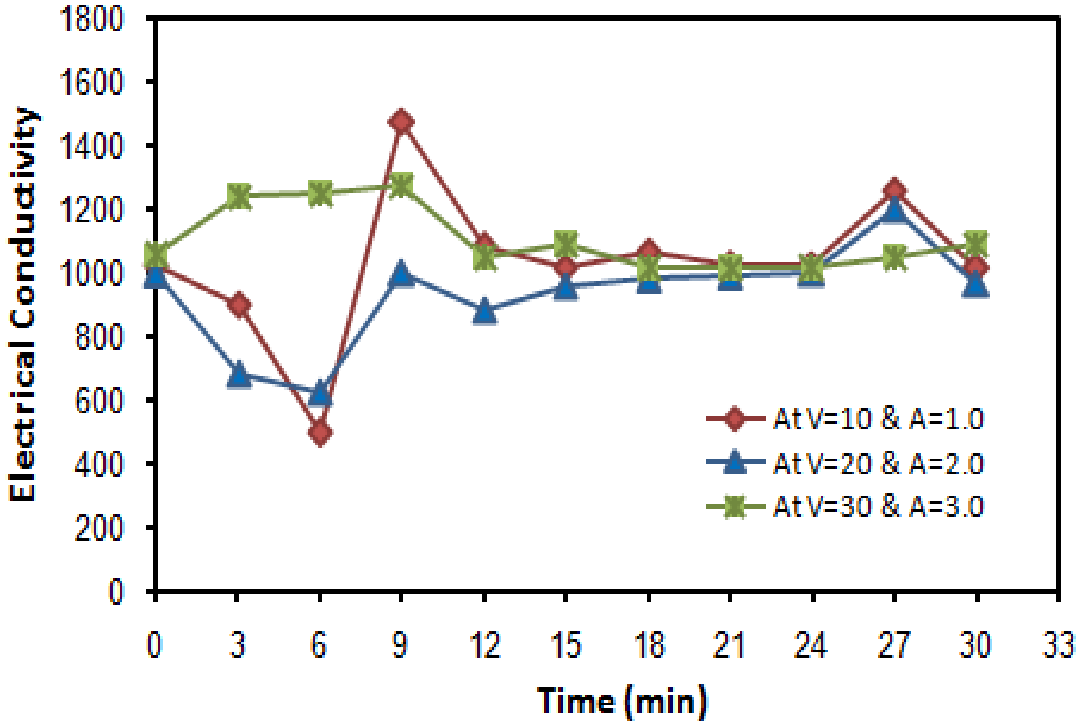

Figure 6. The change of electrical conductivity with time during electrocoagulation process

3.5. Chemical coagulation

From the results, the removal efficiency of turbidity varied by pH, alum dose, and initial turbidity of wastewater. The maximum concentration of aluminum generated during electrocoagulation process was found to be 0.1 mg/L. This value was adopted as a maximum dosage in chemical coagulation process.

3.5.1. Effect of pH

Turbidity and other pollutants removal is considerably affected by pH. The chemical coagulation is performed after completing the electrocoagulation treatment process in order to know the weight of aluminum in which is calculated before and after the electrolytes code, then the same quantity of aluminum was used in chemical coagulation process. Figure 7 depicted the relation between pH and aluminum dosages. The value of pH is increased from 5.7 to 8.31 with increasing dosage to 0.02 mg/L, then the value of pH is slightly fluctuated with increasing of the dosages of aluminum, it was between 8.31 at dosage 0.02 mg/L and 7.9 at 0.1 mg/L. The highest removal efficiency of turbidity was at higher pH 8.31.

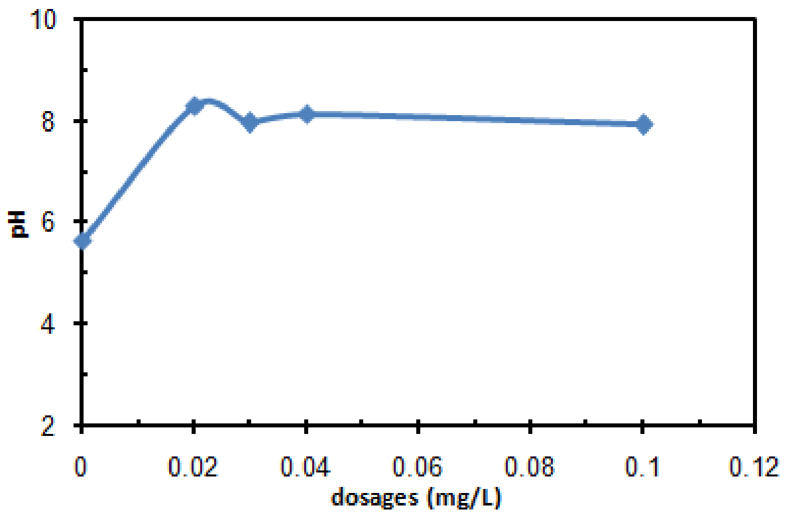

Figure 7. Variation of pH with aluminum dosages during chemical coagulation of the textile wastewater

3.5.2. Electrical conductivity effect

Figure 8 reveals the relation between EC and dosages. The amount of EC is varied and decreased with increasing the dosage of alum. At 0.04 mg/L of alum, the EC is reduced to 1290 µS/m. While at 0.1 mg/L of alum, the amount of electrical conductivity is increased to 1576 µS/m. Thus, the EC is varied based on the amount of alum in the chemical coagulation. The amount of alum electrogenerated is utilized in the chemical coagulation and the increasing the dose of alum led to an increase in EC to 1576 µS/m. The optimum value of EC is performed at the 0.04 mg/L concentration of alum. This is related to the lowest value of EC in which found at the 0.04 mg/L. This indicates that the material which is alum readily allows electric currents at the concentration of 0.04 mg/L.

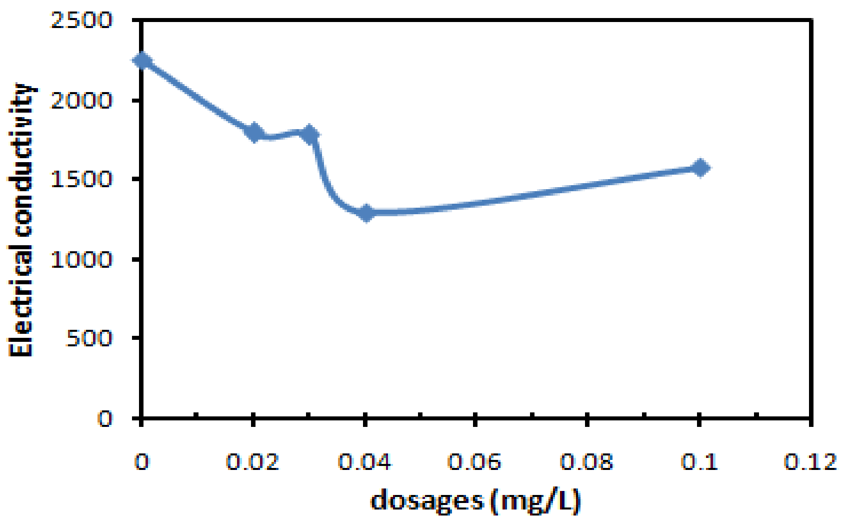

Figure 8. Variation of the electrical conductivity with aluminum dosages during chemical coagulation of the textile wastewater

3.5.3. TDS effect

Figure 9 shows the relation between TDS and time. The TDS concentration is varied between 1514 mg/L and 887 mg/L. Increasing TDS is presented with the increasing of alum dosages to 0.02 mg/L. When alum continued to add to the solution the TDS level was progressively decreased. Higher alum salt showed decreasing in TDS level. This is related to alum salt in which is not much acidic in nature. At the concentration of 0.03 mg/L, the TDS is decreased to 1072 mg/L. Moreover, at the dosage of 0.04 mg/L the TDS is decreased to 1049 mg/L, and at 0.1 mg/L alum dosage it is decreased to 887 mg/L. Thus, at the beginning without any addition of coagulant the TDS value is so lower than other values in which 692 mg/L. With addition of alum, the alkalinity reduced and TDS increased. Then, The TDS value decreases with increasing of coagulant dose. In order to raise TDS value, the coagulation involves charge neutralization (particle collisions).

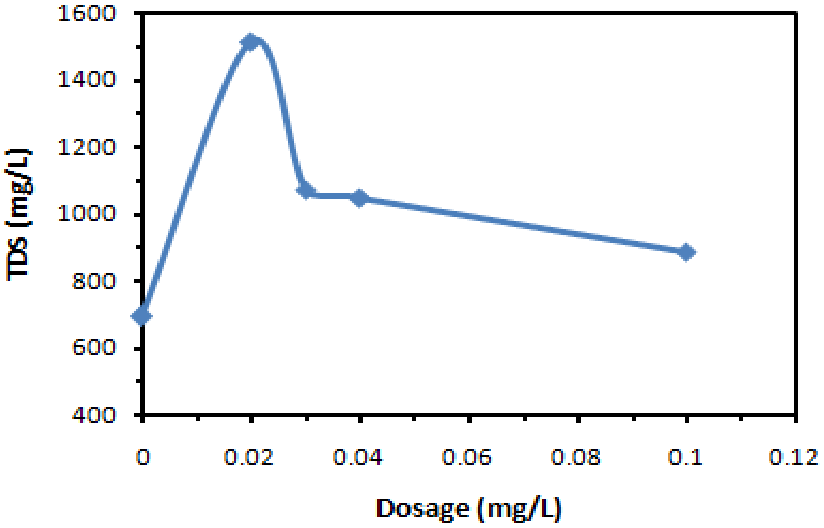

Figure 9. Variation of TDS with aluminum dosages during chemical coagulation of the textile wastewater

3.5.4. Turbidity effect

In the Figure 10, it shows the relation between turbidity and dosages of alum. With increasing the dosages of alum to 0.02 mg/L, the turbidity is decreased to 6.3 NTU, and then it increased gradually with increasing alum dosage until reaching 18.23 NTU at 0.1 mg/L.
According to the results, turbidity parameter is increased with increasing the concentration of coagulant more than 0.02 mg/L. Based on the analysis, the removal of turbidity can be varied effectively from low to medium turbidity water at low level of aluminum sulfate. The turbidity removal depends on the coagulant dosage. The higher removal turbidity 75.4% is achieved at the dose of 0.02 mg/L. The decreasing in the alum dose demonstrated good performance in the turbidity removal from textile wastewater.

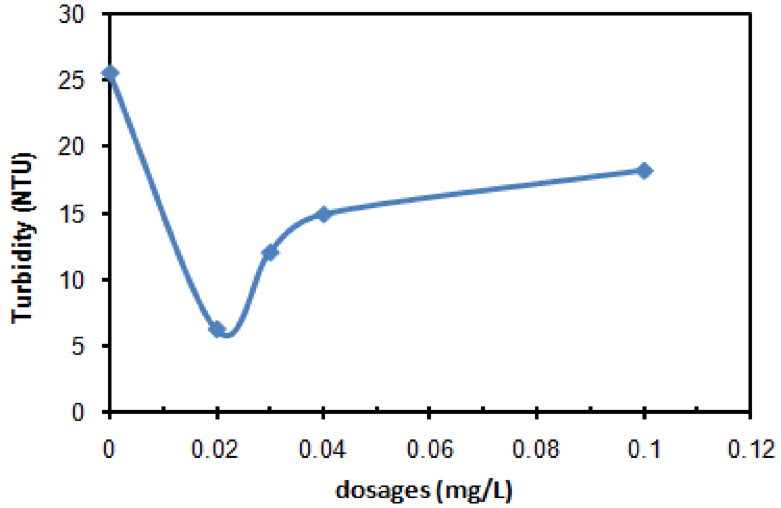

Figure 10. Variation of turbidity with aluminum dosages during chemical coagulation of the textile wastewater

4. Comparison between the results of electrocoagulation and chemical coagulation

The comparison between chemical coagulation and electrocoagulation based on the turbidity; it was found that the removal efficiency regarding electrocoagulation shows better performance than the chemical coagulation.

Based on the results analyses of the electrocoagulation process, an effective turbidity removal of 96.4% was obtained at the voltage of 20 and current 2, pH 6.2, EC 990 μS/m and TDS 501 mg/L. While the higher removal of turbidity in chemical coagulation was 75.4% at the dose of 0.02 mg/L, pH 8.3, EC 1788 μS/m and TDS 1514 mg/L. The high level of turbidity resulting from chemical coagulation means it needs to be treated again with flocculation/coagulation using different coagulants. It can be noticed that the electrocoagulation process is more effective to eliminate the TDS which can be reached to less than 500 mg/L, while in chemical coagulation TDS was increased more than the initial value of 692 mg/L depending upon amount of alum added in the process. The treated water from electrocoagulation process can be harmless on the environment; it can induce eutrophication of the rivers. The elimination of turbidity for both processes is not identical. The quantity of the reagents of recycling the treated effluent in the electrocoagulation process is more advantageous than chemical coagulation. Thus, the results depend on the quantity of the electro generated metal or the aluminum salt dissolved. The electrocoagulation process seems to be the recommended technique in which less expansive, does not induce secondary pollution, and produces treated effluent which can be recycled directly. The important operational parameter found to be an effective for textile wastewater treatment in process is the settling time. These results found to be go with [14] study in which the comparison between the electrocoagulation and chemical coagulation was made. They were presented that electrocoagulation is more efficient than chemical coagulation process. In fact, the textile effluent treated by this technology can be reused without risk in the environment.

5. Economic evaluation for electrocoagulation process

This section explains the estimation of operating costs for electrocoagulation process and their relation to the treatment time. Equations (1) and (2) are used to calculate the electrode and energy consuming for the treatment of textile effluent [15].

$$C_{energy}\left(\frac{kWh}{m^3}\right) = \left(\frac{V \times i \times t}{V_w}\right) \quad (1)$$

$$C_{electrode}\left(\frac{Kg}{m^3}\right) = \left(\frac{MW \times i \times t}{F \times z \times V_w}\right) \quad (2)$$

where V : cell average voltage (V), i: applied current (A), V_w : wastewater volume (L), t : electrolysis time (h), MW: specific molecular weight of the aluminum electrode =26.98 g/mol, F : Faraday's constant = 96,485 ^{o}C/mol, z: electrons number (for aluminum, z =3).
Energy, electrodes and coagulant costs were determined in the estimation of the operating expenses. The other expenses such as maintenance, labor, sludge dewatering and sludge elimination; supposed fixed and not included in the estimation [15,17,18]. The equation used for calculated the operating expenses for the treatment of electrocoagulation textile wastewater is [14]:

$$Operating\ Cost = (a\ C_{energy}) + (b\ C_{electrode}) + (c\ C_{coagulant}) \quad (3)$$

where a : electricity unit cost (USD/kWh) , b : electrode substance price (USD/kg), c: coagulant cost (USD/kg). C_{energy}, $C_{electrode}$, $C_{coagulant}$ = consumed experimental quantities / m^3 of treated wastewater.
Table 2 presents the estimated values of energy and electrode consumption, and operating cost. The consumption of energy and electrodes are calculated using the equations (1) and (2), respectively. Moreover, equation (3) is used to calculate the operating cost for electrocoagulation process as a function of treatment time. The values of electricity unit (a), price of electrode material (b) and coagulant cost (c) which are adopted in equation 3 were 0.094 USD/kWh, 2.25 USD/kg and 0.53 USD/kg respectively. The operation cost was estimated at treatment time of 3, 9, 15, 21, 27- and 30-min. Figure 11 shows the relation between operating cost and treatment time at different voltages and electrical current. It is illustrated that the operating cost increases with increasing the treatment time, voltage and electrical current. The cost of maximum removal of turbidity (96.4%) at voltage 20 V and current 2A was 1.32 USD/m^3. Based on the analysis, the electrocoagulation treatment represents economically reasonable for textile effluent application from an energy consumption viewpoint. Thus, treatment of textile wastewater using electrocoagulation is preferred.

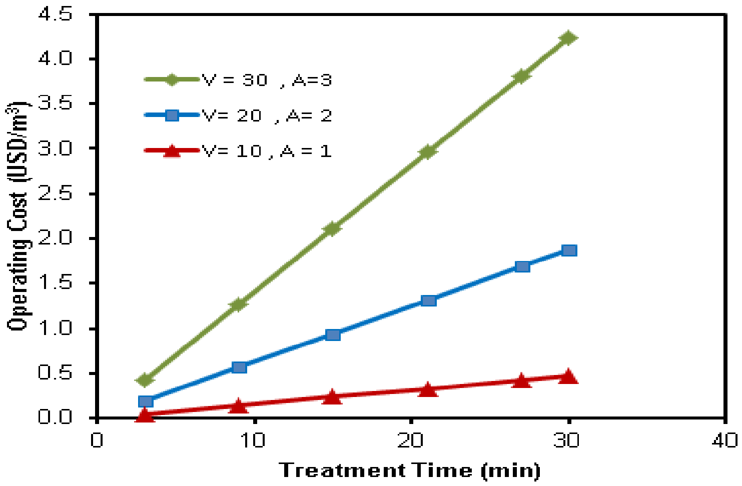

Figure 11. The operating cost for electrocoagulation process with treatment time.

Table 2. Estimated values of energy and electrode consumption, and operating cost.

Time (min)	V = 10, A = 1			V = 20, A = 2			V =30, A = 3		
	C_{energy} kWh/m³	$C_{electrode}$ kg/m³	Operating Cost (USD/m³)	C_{energy} kWh/m³	$C_{electrode}$ kg/m³	Operating Cost (USD/m³)	C_{energy} kWh/m³	$C_{electrode}$ kg/m³	Operating Cost (USD/m³)
3	0.5	4.66×10^{-6}	0.04717	2	9.32×10^{-6}	0.18818	4.5	1.40×10^{-5}	0.42319
9	1.5	1.40×10^{-5}	0.14119	6	2.80×10^{-5}	0.56422	13.5	4.19×10^{-5}	1.26925
15	2.5	2.33×10^{-5}	0.23521	10	4.65×10^{-5}	0.94026	22.5	6.99×10^{-5}	2.11532
21	3.5	3.26×10^{-5}	0.32923	14	6.51×10^{-5}	1.31618	31.5	9.78×10^{-5}	2.96138
27	4.5	4.19×10^{-5}	0.42325	18	8.37×10^{-5}	1.69235	40.5	1.26×10^{-4}	3.80744
30	5.0	4.66×10^{-5}	0.47026	20	9.30×10^{-5}	1.88037	45	1.40×10^{-4}	4.23047

6. Conclusion

The electrocoagulation and chemical coagulation were employed for the treatment of textile wastewater. Various parameters were investigated such as time, electrical voltage and current, TDS, electrical conductivity, and pH to determine the turbidity removal of the wastewater effluent. According to the results, with the voltage 20 and current 2.0, best turbidity removal was obtained. It can be concluded that the electrocoagulation technique was more effective than chemical coagulation, and this technology can utilize in the textile wastewater treatment because of the considerable improvement upon the conventional mode and chemical coagulation process.

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