Civil and Environmental Research
ISSN 2224-5790 (Paper) ISSN 2225-0514 (Online)
Vol.3, No.13, 2013

Combination of Electrocoagulation and Electro-Oxidation Processes of Textile Wastewaters Treatment

Ahmed Samir Naje (Corresponding author)
Faculty of Civil Engineering, University Teknologi Malaysia
University Teknologi Malaysia
Tel: 01128826273 E-mail ahmednamesamir@yahoo.com

Saad A. Abbas
Razak School of Engineering and Advanced Technology, Universiti Teknologi Malaysia
Tel: +0123199241 E-mail: saad@ic.utm.my

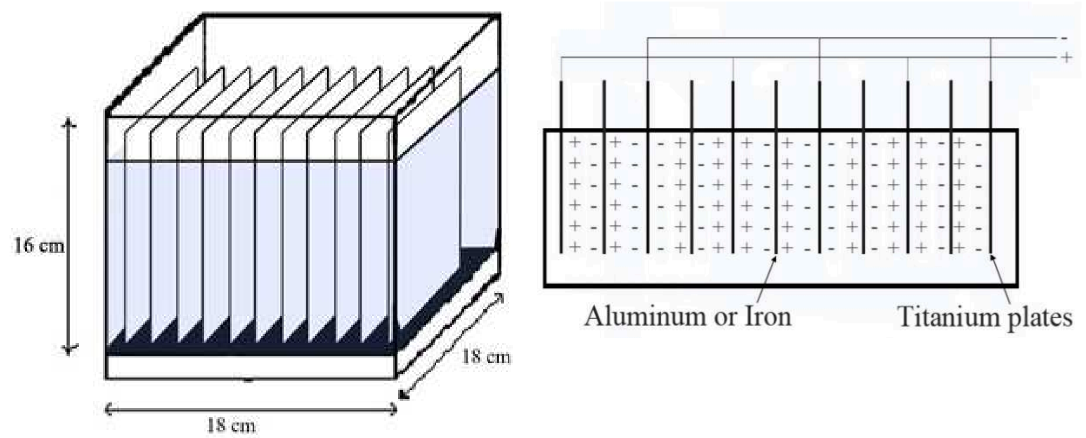
Abstract

The present paper investigates the electrocoagulation-electrooxidation (EC-EO) process for the treatment of high-strength wastewater textile industry located in Babylon governance -Iraq. This EC-EO process evaluated the efficiency of electrocoagulation in treating contaminants.Textile wastewater such as BOD, COD, TDS, TSS, turbidity, nitrates, sulfate, total phosphates, electrical conductivity, oil and grease and the total phenols by using either Aluminum or (Iron) electrodes set in a bipolar structure or Titanium coated with iridium oxide Ti/IrO2 electrodes arranged in a monopolar outline in the same electrolytic cell. The first set of analyses that examined the best performance of textile wastewater was achieved by using Aluminum and Titanium coated with iridium oxide plates alternated in the electrode pack and operated at a current of 0.6 A during 90 min of treatment with pH adjusted to approximately 6.0. Further analysis showed that, 95% of oil and greases (O&G) were removed, however chemical oxygen demand (COD) and biological oxygen demand (BOD) removal reached 90% and 87%, respectively. Another important finding was that, more than 96 % of soluble phosphate was removed, and the process was effective in removing turbidity (98%) and suspended solids (98%). A total cost of treated textile effluent process under the best conditions involved using an EC - EO process including chemical electrode consumption, and energy was 2.03 USD/m3.

Keywords: Electrocoagulation, Electro-oxidation, Titanium electrode, Textile wastewater, Aluminum electrode.

1. Introduction

The textile industry is one of the major water-intensive chemical processes. It generates a huge amount of wastewater and creates significanteconomicand environmental problems (Belkacem et al. 2010).In recent years, have seen increasingly rapid advances in the field of wastewaters treatment Investigations have been focused on the using of electrocoagulation (EC) Compared with traditional flocculation and coagulation, EC has in theory, the advantage of removing the smallest colloidal particles. The smallest charged particles have a greater probability of being coagulated because of the electric field that sets the minmovement. In addition it has also the advantage of producing a relatively low amount of sludge. Electrocoagulation has the advantage of removing the smallest colloidal particles compared with traditional flocculation–coagulation,such charged particles have a greater probability of being coagulated and destabilized because of the electric field that sets them in motion. In addition, electrocoagulation-flotation is capable of reducing waste production from wastewater treatment and also reduces the time necessary for treatment (Djedidi et al. 2009). The Electro Oxidation is defined as electro-chemical techniques that are applied to supplant the dissolved pollutants from the waters. The pollutant can be oxidized in two ways, directly and indirectly (Linares- Hernandez et al. 2010), the difference between them, is the direct oxidation used to remove the pollutant from the surface of the electrode, and the indirect aondic oxidation is allowing the in situ of oxidants (H2O2, O3, HClO and HBrO) (Linares- Hernandez et al. 2010). Zaviska et al. (2009) suggested that the production of the electrolytic of chlorine is considered as one of the industrial electrochemical reactions. In the solution, the ions of the chloride can be oxidized at the anode and form the hypochlorous acid (HClO).Treatment was obtained by using either Aluminum or Iron electrodes fixed in a bipolar structure and Titanium electrodes arranged in a monopolar outline in the same electrolytic cell. Titanium coated with iridium oxide (Ti/IrO2) was used as the cathode, the electrodes were horizontally installed in the electrolytic cell and each anode was immediately followed by a cathode. The primary objective of this study is to develop a hybrid process combining the electrocoagulation and electro-oxidation processes, and to evaluate its performance in treating TWW Using. This process should be capable of removing color and clarifying effluents. At the same time, it should remove inorganic pollutants (such as phosphate) by co-precipitation, and simultaneously remove both dissolved and suspended organic pollutants.



(a)

(b)

Figure 1. Schematic view of experimental setup: (a) the EC-EO cell; (b) the configuration of Iron (or Aluminum) and Titanium coated with iridium oxide plates.

2. Materials and Methods

2.1Sampling and Description of the Textile Wastewater

The sampling procedures were adopted from the Standard Methods for the Examination of Water and Wastewater (APHA 2000). In this study the samples were collected from the wastewater textile industry located in Babylon governance in Iraq. The effluent was sampled twice and prepared eight times. The main characteristics of TWW are presented in Table 1.

Table1. Characteristics of Textile wastewater

Parameter	**Value**
Electrical conductivity (µS/cm)	240
Turbidity (NTU)	390
Total suspension solid TSS (mg/L)	3285
Total dissolved solid TDS (mg/L)	1241
PH	4.52
Chlorides Cl− (mg/L)	42.8
Sulfate (mg/L)	672
Phosphate (mg/L)	6.9
Nitrates/nitrites (mg/L)	9
Phenols (mg/L)	345
O&G (mg/L)	2
BOD (mg/L)	110.8
COD (mg/L)	985

2.2 Experimental Unit

The treatment of textile wastewater was carried out in a batch electrolytic cell made of Plexiglas [18 cm (width) × 18 cm (length) × 16 cm (height)] [Figure. 1 (a)].The electrode sets consisted of five Aluminum (or Iron) plate electrodes and six Titanium plates, each having a surface area of 144 cm2 (12 cm width × 12 cm height) with an interelectrode distance of 1.4 cm. Iron (or Aluminum) and Titanium coated with iridium oxide (Ti/IrO2) plates alternated in the electrode pack and were submerged in the effluent. Only Titanium plates were connected to the power supply (anode and cathode). The Iron (or Aluminum) electrodes situated between two Titanium electrodes were not electrically connected to the power supply [Fig. 1(b)]. The five inner Iron (or Aluminum) electrodes were operated as bipolar and sacrificial electrodes. They function as bipolar electrodes owing to the mobility of ions in solution, each ion transporting a fraction of the current intensity imposed. The thickness of Titanium plate is 0.1 cm and the Aluminum (or Iron) electrodes is 0.2 cm. The electrodes were vertically installed on a perforated Plexiglas plate placed at 3.0 cm from the bottom of the cell. Mixing in the cell was achieved by a magnetic stirrer at a rotating velocity of 500 rpm (HP-3000) installed at bottom of the cell. For all tests, a total volume of 3 L of effluent was used. Between two tests, the electrolytic cell (including the electrodes) was cleaned with 5% (v/v) hydrochloric acid solution for at least 10 min and then rubbed with a sponge and rinsed with tap water. The anode and cathode sets were connected to the positive and negative outlets, respectively, of a DC power supply (ATTEN DC power supply type APR 3002A of 0-30V). The current was kept invariant in each test by a rheostat (Wheatstone Type 2755-Japan) and measured by an ammeter (Aswar DT830D, China).

2.3 Experimental Procedure

The initial set of testing the operating parameters such as electrode materials such as Aluminum or Iron, treatment times from 30 to 90 minutes, current at 0.2 to 0.8 A, initial pH (4 to 8), and concentration of electrolytes NaCl and Na2SO4 (10 to 110 mg/L).Adjusting the value of the initial PH was done by 0.5 M NaOH. The sample was allowed to settle for 60 min after treatment so that the flocs were formed during the process may settle ,after settling, about 100 ml supernatant sample was collected for laboratory analysis. At the end of each test, 30 ml sample was taken to measure the residual metal concentration. The effectiveness of the EC-EO process was evaluated by measuring simultaneously chemical oxygen demand for COD, BOD, O&G, TSS, TDS, phenols, and turbidity of the liquid fraction. The pH and the conductivity also were measured in the liquid fraction. Once the appropriate values of these parameters were determined, the optimal conditions were repeated in triplicate to verify the effectiveness and the reproducibility of the EC-EO process. The same parameters were measured in each of the replicate samples.

2.4 Sludge Compaction Study

The TWW sludge was submitted to 60 minute sedimentation to increase consolidated of the sludge. The cationic polymer with two concentrations (10 and 40 mg/L) was tested. The volume occupied by the solid (in mL) was observed at regular intervals. The solid fraction (wet residue) was measured and dried for 24 h at 100°C to determine total residual solids. Specific resistance to filtration (SRF) and cake dry solid were measured to characterize the dewater ability of the sludge. The formula of the SRF (m/kg) as follow (Nazih el at. 2008).

$$RF(SRF) = (2 \cdot Kb \cdot P \cdot A2) / \mu \cdot a \quad (1)$$

Kb = plot slope (V versus t/V); A = filter area; P = pressure applied during the sludge filtration; μ = viscosity of filtrate; and a = weight of solid per unit volume of filtrate. Measuring the cake of the solid concentration was done using the following formula:

$$\text{Sludge dryness } (\%) = 100 \times [(m3 - m1) / (m2 - m1)] \quad (2)$$

Wherem2 and m1 = mass of the cup containing the membrane before and after filtration, respectively; and m3 = mass of the cup containing the membrane after drying at 100°C for 24h.

The sludge volume index (SVI) was used to determine the settling characteristics of the sludge suspensions. SVI (mL/g) is the volume in milliliters occupied by 1 g of a suspension after 30 min settling [4].

$$SVI = VD30/TSS \quad (3)$$

WhereVD30 = volume of settled sludge after 30 min (mL/L);

TSS = concentration of total suspension solids (g/L).

2.5 Measurements Techniques

The measurements techniques are done by standard meters; where the pH meter (pH meter-pHM84) were used to measure pH, the conductor-meter HANNA HI-99301 used to measure the Ionic conductivity and for the Turbidity (HACH 2100P). Table 2 presents characteristics of the Textile Wastewaterwere determined using standard meters.

Table 2: Measurement tools for the TWW Parameters

Parameter	**Meter**
pH	pH meter-pHM84
Ionic conductivity	HANNA HI-99301
Turbidity	HACH 2100P
COD	Closed Reflex, Titrimetric Method
BOD	DO-meter
O&G	Solvent Extraction
TSS,TDS,Phenols	Gravimetric
Phosphate, Sulfate, Nitrates	Spectrophotometer
residual metallic sluge	Whatman 934AH filter

2.5 Cost Analysis

Operating cost calculations have been made to this treatment process included cost of chemicals and electrodes, energy consumption, and sludge disposal. Calculations typically include the cost of chemicals, electrodes and energy consumption. It should be noted that the price of materials and energy changes over the course of time and therefore, operating costs are only rough estimates. Cost calculations do not typically include investment costs, which may be significant, including, for example, power supplies, electrochemical cell vessels and sludge separation systems. In this research the operational cost at optimum condition. Electrode consumption, energy consumption and operating cost were 0.30 kg ⁄m3, 5.66kwh ⁄m3and 2.03USD ⁄m3, respectively. Overall the treatment efficiency forAluminumsheet was better compared with Iron but it was more expensive (2.5 USD/kg) versus (2.25 USD/kg).While, the cost of the electrolytes (NaCl and Na2SO4) was calculated at 0.05 USD/kg and 0.4 USD/kg, respectively. The sodium hydroxide (NaOH) was valued on the basis of a solid unit cost of 500 USD/T. The cost of polymer was estimated at 5.5USD/kg. The energy consumed was estimated at a cost of electricity price 0.077USD/kW.h. The disposal residual sludge for, excluding drying costs including transportation were evaluated at 70USD/T. The total cost was evaluated in terms of U.S. dollars spent per cubic meter of treated effluent (USD/kg).

3. Findings and Discussions

3.1 The production of Oxidant Agent and Coagulant

The main objective of the study is to evaluate the efficacy of the electrolytic cell to produce a coagulating and oxidant agent (HClO for oxidant agent and coagulating agent (Fe2+/Fe+3) or (Al3+). The Active chlorinewasdetermined from the sum of ClO-, HClO and Cl2, which is initially measured in mol/L and later changed to mg/L based on the atomic weight of Cl (35.45 g/mol). The kinetics of chlorine production was determined as a function of the imposed current by using a concentration of chloride ions of 30 mg/L and a treatment time period of 60 min (Figure. 2).

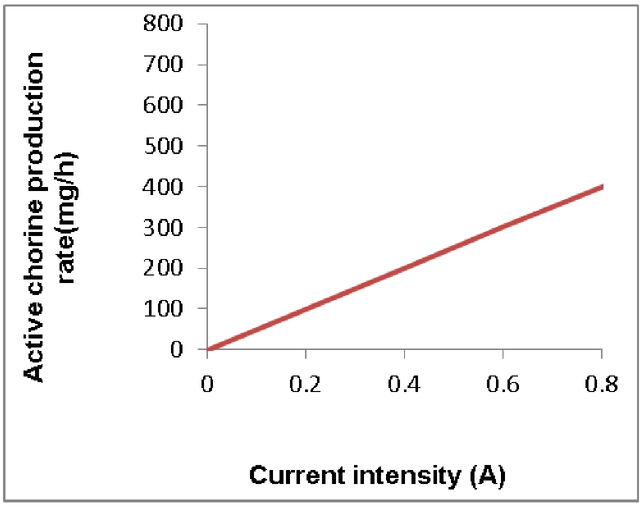


Figure 2. Influence of the current intensity on active chlorine production

The chlorine production rate increased linearly with increasing current from 0.2A to0.8A. The slope of the curve represented a production rate of 500 mg ⁄A.h. The performance chlorine production was evaluated by Faraday efficiency (η) versus imposed current for a retention time of 60 min (Figure. 3).

The following equation was used to determine η:

η= (ne FCi V)/(I tMi) (4)

For 60 minutes of retention time, firstly the Faraday efficiency increased rapidly from 0.2 A to 0.6 A, and then decreased slowly. The maximum value of the Faradiac efficiency (η =60%) was recorded at 0.6 A. The oxidation of chloride to chlorine process was produced at the Ti/IrO2 surface anode, compared to Szpyrkowicz et al. (2005) where he used several materials (graphite, Ti/Pt, and Ti/Pt – Ir) as anode electrode (Muthukumar et al. 2007).

Thus, active chlorine production can be compared by using different electrolytic cells composed of different anode materials. In the present study, The values achieved were more than those stated by Kraft et al. (1999) while studying the kinetics of chlorine production (distilled water containing chloride ions at a concentration of 150 mg/L) in an electrolytic cell composed of iridium oxide electrodes with a current density ranging between 5 and 50 mA/cm2. They recorded a relatively low Faraday efficiency (41.5%).

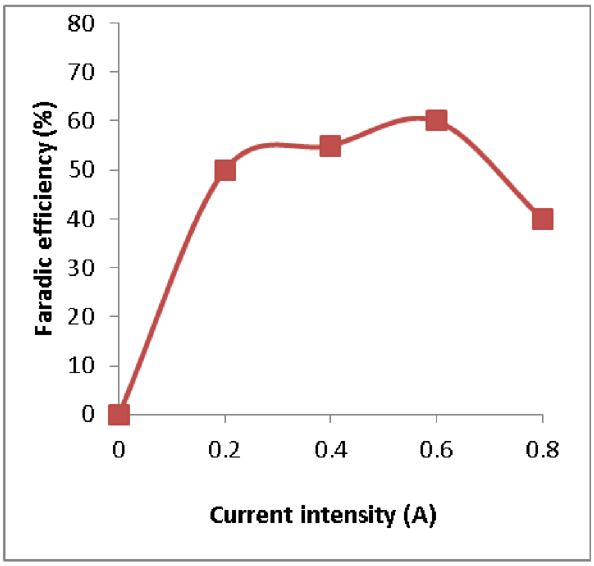


Figure. 3. The relationship between Faradiac efficiency and current intensity; t= 60 min; [Cl−]= 30 mg/L

Thes

e Values were much lower than the values derived from this study. The efficacy of the same EC-electrolytic cell to produce coagulant agent (Al or Fe) was then evaluated. Metallic hydroxide particles were produced up to a sufficient concentration to initiate polymerization reactions, inducing the formation of a green precipitate.The results in Table 3 show the increase of current induced an increase of the concentration of Aluminum or Iron in solution is lower. Relatively low faradaic efficiencies (7% to 67%) in terms of coagulant production have been measured. Parasitic reactions probably take place, such as water oxidation in oxygen. Golder et al. (2007) recorded relatively high faradaic efficiencies (64.5% to 91.7%),while imposing a current of 0.5 A during treatment periods of 20, 40, and 60 min. Numerous parameters, such as the nature of the electrolyte (NaCl, Na2SO4), the type of configuration of electrodes (bipolar or monopolar), the surface of the electrodes (smooth or rough), the conductivity of the electrodes, and the number of Aluminum (or Iron) electrodes can considerably influence the faradaic efficiency (Mameri et al. 1998; Meunier et al. 2006).

Table 3: Coagulant Agent Produced in the Electrolytic Cell EC-EO (t=60 min,V=3L)

Parameter	Test1	Test2	Test3	Test4
Bipolar electrode System	Al Ti/IrO2/ Al	Al Ti/IrO2/ Al	Fe Ti/IrO2/ Fe	Fe Ti/IrO2/ Fe
Current intensity (A)	0.2	0.6	0.2	0.6
Average voltage (V)	15.5	28.3	13.9	20.4
Initial pH	6.23	6.31	5.98	6.10
Final pH	6.91	7.02	6.57	6.78
Energy consumed (kW · h/m3)	1.03	5.66	0.92	4.08
Coagulant production				
Total Al (mg/L)	15	30	__	__
Total Fe (mg/L)	__	__	30	45
Theoretical Al or Fe (mg/L)	67	201	208	625
Faradaic efficiency (%)	67	44	14.4	7.2

4. EO-EC Treatment of Textile Wastewater

4.1 Electrode Materials

The bipolar configuration in the EC - EO treatment of TWW done by using (Aluminum and Iron Electrodes). The values of the COD removal for both Aluminum and Iron electrodes is presented in Table 4. The maximum COD removal value is 90.0% that was recorded by Aluminum electrodes, whereas 77.3% was obtained with Iron electrodes. Therefore the optimal results were recorded with Aluminum at COD Removal 90.0%. The applied current in the cell caused an anodic dissolution of Iron or Aluminumelectrodes into waste water.Aluminum (Al3+) or Iron (Fe2+/Fe3+) reacted with metallic hydroxides (OH−) in solution to produce Al(OH)3 or Fe(OH)2 [10]. Al(OH)3 or Fe(OH)2 have large surface areas that are beneficial for rapid adsorption of organic compounds and trapping of colloidal particles. The gas bubbles (H2 and O2) produced at the cathode and anode enhance the removal efficiency in EC processes (Asselin et al. 2008). For approximately the same electrical conductivity of the treated effluent (440 µS/cm using Aluminum and 450 µS/cm using Iron), and at the same imposed current (0.6 A).

Table 4. Experimental Conditions and COD Removal from Textile Wastewater using Bipolar Aluminum or Iron Electrodes and monopolarTi/IrO2 (I=0.6 A, t = 90 min)

Parameter	Raw effluent	Ti/IrO2/ BP-Al	Ti/IrO2/BP-Fe
Bipolar electrode	__	Al	Fe
Mean voltage (V)	__	28.3	20.4
Conductivity (µS/cm)	240	440	450
Final pH	4.52	7.62	7.29
Energy consumed (kW · h/m3)	__	5.66	4.08
Sludge production (kg/m3)	__	2.88	1.08
Electrode consumption (kg/m3)	__	0.30	0.93
Electrical energy cost (USD/m3)	__	0.43	0.31
Electrode consumption cost (USD/m3)	__	0.75	2.09
Sludge disposition cost (USD/m3)	__	0.20	0.07
Total operating cost (USD/m3)	__	2.03	3.12
Liquid fraction after sedimentation			
COD (mg/L)	985	98.5	223.5
COD removal(%)	__	90.0	77.3

During the treatment of effluent by Iron electrodes the sludge measured and it was 1.08 kg/m3, whereas for Aluminum electrodes was 2.88 kg/m3. This high amount of residual sludge measured with Aluminumelectrodes was probably attributable to the better electrical conductivity of the Aluminumelectrode compared to the Ironelectrode (Chen et al. 2000a). However, the amount of the Ironelectrode consumed (0.93 kg/m3) was higher than the amount determined for Aluminumelectrodes (0.30 kg/m3).

From the Faraday's law the electrode consumptions calculated to provide a theoretical amount for total Aluminum and Iron using the follow equation:

m = (I t M)/ (ne F) (5)

m = amount of Aluminum or Iron ions generated; ne = number of electrons transferred in the reaction at the electrode; M = molecular weight (g/mol); I = applied current (A); t = treatment time (min); and F = Faraday's constant (96500 C/mol).

According to Khemis et al. (2005) and Daneshvar et al. (2006) during the electrocoagulation process using Aluminum or Iron electrodes, the number of electrons transferred at the electrode surface is 2 (ne = 2) and 3 (ne=3) respectively. Based on Faraday's law, whenever one Faraday of charge passes through the circuit, 9.0g of Aluminum is dissolved at the anode electrode compared to 28.0 g of Irondissolved. Moreover, Faraday's law does not take into account the electrical conductivity of the electrode material and the state surface of the electrode (Khemis et al. 2005; Mameri et al. 1998). These explanations can be the reason for which the amount of metallic sludge using Al electrode was higher than that measured using Fe electrode. During the processes of the electrocoagulation, the conductivity of the electrode increases the energy consumption and the ohmic resistance decrease, this can result a high amount of metallic sludge (Meunier et al. 2006). The conclusion of that is clear that the Aluminum electrode is better than the Iron electrode for the present application. Consequently, all experiments were carried out with Aluminum electrodes.

4.2 Influence of Applied Current

The current is the most important factor that is influencing the treatment efficiency. In this study, the EC-EO process was investigated by applying different current intensities. Figure.4 shows during a treatment time of 90 min the turbidity, COD and TSS removal versus applied current. The maximum value of the COD removal was (90%) recorded at 0.6A current intensity. Choosing the optimal current should not consider only on the COD, but also the amount of Turbidity, the cost of the energy consumed and the TSS removal. The energy consumption increased from 5.66 kW • h/m3 to 43.20 kW • h/m3 affected by the intensity value from 0.2 to 0.8 A. The maximum removal value of the TSS was (98.0%) recorded at the current 0.6A and for the turbidity (98.5%) was recorded also at 0.2A and 0.4A current intensity.The results in figure 4 shows that the values of TSS, Turbidity and CODpercentages removal increased in the current 0.6 A compared with other current intensity values, where the effectiveness decreased with further increases in current. While increasing the current, the solid particles are not effectively separated from the liquid fraction during the sedimentation step. For that reason the optimum current was 0.6 A for the TWW treatment using the EC-EO process.

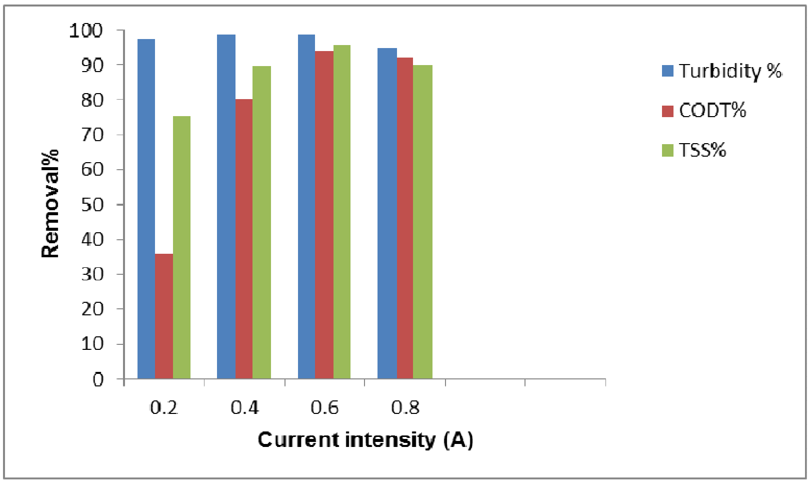


Figure 4. The Effect of current intensity on COD, turbidity, and TSS removal (MP –Ti/IrO2/BP –Al;I = 0.6 A; t = 90 min; pH = 6)

4.3 Influence of Electrolysis Time

The treatment efficiency of the EC-EO process can be influenced by the time which is the factor that helps to determine the rate of the production of active chlorine and Aluminum ions. Electrolysis time can influence the treatment efficiency of the electrochemical process.The relationship between the CODconcentrations.Electrolysis time and the metallic sludge production presented in (Figure 5). The minimum value of COD 98.5 mg/L was recorded at 80 minutes of the treatment and the maximum value of the metallic 2.88 kg/m3 were recorded at 90 minutes of the treatment.The COD concentration was stable between 20 and 40 min and then decreased after 60 minutes electrolysis to achieve a maximum removal of COD(90%) at 90 minutes of electrolysis. To produce a sufficient amount of Al13+ ions requires 60 minutes of electrolysis.

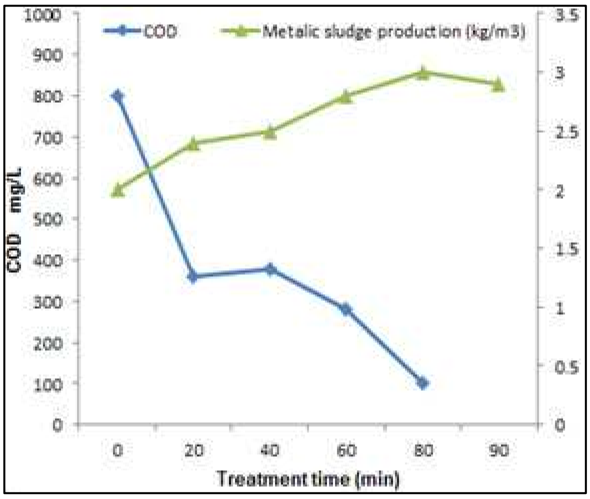


Figure 5. The effect of electrolysis time on COD and metallic residues for textile wastewater

Dispersed organic particles were destabilized by neutralizing charged particles. For that reason, the gas bubbles (H_2) produced at the cathode electrodes allows for pollutant removal by flotation as showing in the following equation:

$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-$ (6)

In addition, the chloride ions in TWWcan be oxidized in situ at the anode electrodes and form hypochlorous acid (HClO) in solution (Eq. 7 and 8). Zaviska et al. (2009) and Kobya et al. (2003) mentioned that the HClO is a powerful oxidant capable of modifying and oxidizing the structure of organic particles.

$2Cl^- \rightarrow Cl_2 + 2e^-$ (7)

$Cl_2 + H_2O \rightarrow HClO + H^+ + Cl^-$ (8)

4.4 Effect of Initial pH

One of the most important parameters that influences the electrochemical performance. According to Mollah et al. (2001) the initial PH affects the stability of the generated hydroxide species. It consequently influences the efficiencies of the removal (Jolivet 1994). In order to evaluate the effects of initial PH, TWW was adjusted by using sodium hydroxide. Figure 6 presents the effects of initial PH on the COD removal. From the results, the maximum value of COD removal was 90% at initial PH (6 and approximately 7).

A low increase in the final pH was recorded because pH values were measured in liquid fractions (after sedimentation of metallic sludge). During the process of the EC-EO, the increase in pH value was attributed to the increase of hydroxide ion concentrations (OH−) produced in solution from water reduction at the cathode (Eq.6). However, three of COD removal was decreased and reached a minimum value 76 % at an initial pH value of 4 and it increased at initial pH 5. The COD reached its highest value which was recorded at pH = 6. A slight drop in final pH value in alkaline medium (pH = 8 and (pH = 7.7) at initial pH 5 and 6 sequentially. Ionic forms of Al (OH)4- [Eq. (9)] Predominate and reduce the efficiency of the EC-EO process. The results clearly show that the typical pH value to ensure effective treatment of TWW is 6.0.

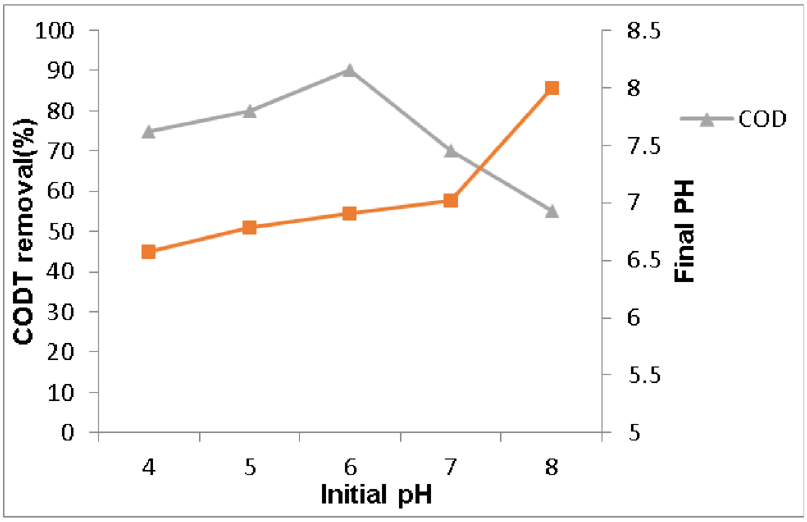


Figure 6. Influence of initial pH on COD removal;

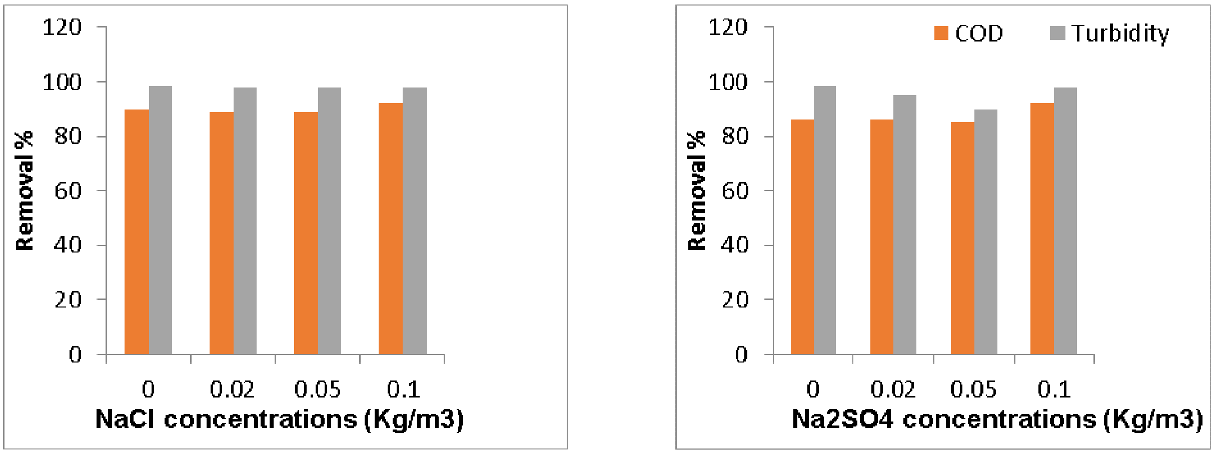
$Al(OH)_3 + OH^- \rightarrow Al(OH)_4$ (9)

4.5 Influence of Wastewater Conductivity

According to Daneshvar et al. (2006), the conductivity of the solution affects the current efficiency, the cell voltage, and the electrical energy consumed. The addition of an electrolyte such as Na_2SO_4 or NaCl in the solution can facilitate the passage of the electrical current and improve the conductivity of the effluent. In the present study NaCl and Na_2SO_4 (0.0, 0.02, 0.05, and 0.10 kg/m3) added to the TWW to evaluate the influence of the conductivity on the COD and turbidity removal.Figure 7 presents the effect of the conductivity on the COD and turbidity removal. In addition, adding NaCl and Na_2SO_4, the variation of the conductivity affects the consumption of the power. Power consumption changed from 5.66 kW · h/m3 to 4.32 kW · h/m3, and from 5.25 kW · h/m3 to 3.23 kW · h/m3 by using NaCl and $NaSO_4$, respectively. This discrepancy of energy consumption recorded between the assays carried out in the absence and in the presence of a supporting electrolyte was not very important. This can be compared with Bektas's study Chen (2004) by finding similar relationships. Further, the costs associated with sludge disposal would increase attributable to volume augmentation.

4.6 Effect of Compaction Sludge

In this study the compaction of the treated TWW was carried out with different concentrations of flocculating agents LPM 3135 (0.01 and 0.04 kg/m3) under optimal conditions (MP −Ti/IrO2/BP − Al;I = 0.6 A; t = 90 min; pH = 6). According to Asselin et al. (2008) [22], LPM 3135 was the most efficient



(a) **(b)**

Figure 7. The effect of conductivity on COD and turbidity removal at different NaCl and Na2SO4 concentrations (MP −Ti/IrO2/BP − Al;I = 0.6 A; t = 90 min; pH = 6)

flocculating agent.The results of these tests showed that the treatment efficiency of COD increases (from 68.6% to 82.3% use of 0.01 kg/m3 of LPM3135 without and with 0.01 kg/m3 LPM 3135, respectively), turbidity (from 34 NTU to 7 NTU without and with kg/m3 LPM 3135, respectively), and TSS (from 120 mg/L to 85 mg/L without and with 0.01 kg/m3 LPM 3135, respectively). Using 0.01 kg/m3 LPM 3135 after the EC-EO process, sludge dryness, SRF, and SVI were measured. The measurement of sludge dryness done after filtration of the fraction of sludge on membrane under vacuum. The value of sludge dryness measured was 7%, whereas 137 ml/g was recorded for SVI. The EC technique has been applied by Olmez (2009) using iron electrodes for treatment of contaminated industrial effluent by Cr (VI). The SVI value measured was 80mL/g. The nature of treated effluent and the experimental conditions could explain this discrepancy. In fact, the initial concentration of TSS used by Drogui et al. (2007) was 80 mg/L, whereas the initial concentration of TSS in TWW was 3285 mg/L. Furthermore, the EC process using iron electrodes was employed by drogue et al. (2007) to treat hexavalent chromium [Cr(VI)] from metal industry, whereas in this study an EC-EO process was used to treat TWW rich in suspensions particles. The value of SRF recorded in this study (7.7 × 1012 m/kg) is the same order of magnitude as that measured by Olmez (2009) (7.80 × 1012 m/kg).

5. Efficiency and Reproducibility of the EC-EOProcess Performance in Treating Textile Wastewater

The EC-EO process of the TWW was repeated three times to examine the application performance under optimal conditions : MP –Ti/IrO2/BP – Al , time in 90 minutes, current in 0.6 A, polymer LPM 3135 = 0.01 kg/m3 and initial adjustment PH = 6. Evaluating the system process done by measuring TSS, O&G, COD, sulfate,Iron and Aluminum in the fraction liquid. The effectiveness of the process (EC-EO) was evaluated by measuring simultaneously COD, BOD, O&G, TSS, turbidity, phosphor, sulfate, Iron, and Aluminum in the liquid fraction. The summary of the parameters results presented in Table 5.The EC-EO process produces a value of 90.0 % COD removal. At the end of the treatment process the BOD and O&G concentration values were14.4 mg/L and 0.1 mg/L, respectively, and in the raw effluent were110.8 mgBOD5/L and 2.0 mg O&G/L. The hydrophobic capacity of O&G ensures an excellent affinity with the H2 bubbles produced at the cathode. The (O&G)-H2 complex accumulates on the surface of the liquid, which can be easily skimmed (Asselin et al. 2008b). The results in the present study can be compared with the previous studies that done under other experimental conditions. As Hu and Li applied the combination of EC-EOfor the treatment of chemical thermo mechanical pulp (CTMP) effluent loaded with COD (33000 mg/L) and color (48000 CU) (Asselin et al. 2008b). Where they used the steel as anode and cathode was from graphite. The electro-coagulated effluent was successively treated with electro-oxidation. The COD was achieved in 90 minutes which was less than 10% of the required time using EO alone. Furthermore, the BOD and turbidity can be totally removed. The results obtained in the present study (COD removal of 90.0%) are similar to those recorded by Hu and Li (2009). The TSSremoval was98.0%. This result indicates low removal of dissolved solids. When the Turbidity reached 98.5% the effluent became clear and transparent. The EC-EO process removed the Phosphate, where the measured value before EC-EO was 6.9 mg/L and after the treatment decreased to 0.25 mg/L .During the process, the Aluminum electrode dissolution observed an increase in the total dissolved concentration from 1.44 mg/L to 7.5 mg/L. At the end of the treatment SRF, SVI and the sludge dryness were recorded 9.26 %, 7.70 × 1012 m/kg, and 70.6 mL/g, respectively. The total operating cost of EO-EC process was estimated to be 2.03 US$/m3.

Table 5. Effectiveness and Reproducibility of the Performance of EC-EO in Treating Textile Wastewater at Optimal Conditions (MP −Ti/IrO2/BP − Al;I = 0.6 A; t = 90 min)

Parameter	**Raw effluent**	**Treated effluent**	**Removal %**
Electrical conductivity (µS/cm)	240	440	—
Initial PH	4.52	6.0	—
Final pH	—	7.62	—
Energy consumption (kw h/m3)	—	5.66	—
Electrode consumption (kg/m3)	—	0.30	—
Sludge production (kg/m3)	—	2.88	—
Polymer consumption (kg/m3)	—	0.01	—
Hydroxide sodium consumption (kg/m3)		1.20	—
O&G (mg/L)	2	0.1	95
BOD5 (mg/L)	110.8	14.4	87.0
COD (mg/L)	985	98.5	90.0
TSS (mg/L)	3285	65.7	98.0
TDS(mg/L)	1241	170	86.3
Turbidity (NTU)	390	5.85	98.5
Sulfate (mg/L)	672	13.44	98.0
Phosphate (mg/L)	6.9	0.25	96.3
Nitrates/nitrites (mg/L)	9	0.88	90.0
Phenols	345	0.05	99.9
Aluminum (mg/L)	1.44	7.5	—
Sludge dryness (%)	—	9.26	—
SRF (kg)		7.70	—
SVI (mL/g)	146	70.6	—
Electrical energy cost (USD/m3)	—	0.43	—
Electrode consumption cost (USD/m3)	—	0.75	—
Sludge disposition cost (USD/m3)	—	0.20	—
Polymer cost (USD/m3)	—	0.05	—
Hydroxide sodium cost (USD/m3)	—	0.60	—
Total operating cost (USD/m3)	—	2.03	—

6. Conclusion

The EC-EO process is one of the most effective techniques to treat and flocculate contaminants in highly polluted industrial wastewater. The present study was designed to determine the effect of using Aluminum electrodes in removing pollutants from Textile wastewaters. The process is a feasible technology for the treatment of TWW characterized by COD, BOD, TSS , and turbidity concentrations. During the batch electrolytic cell, the active chlorine was recorded at (8.33 mg/A) and the Alumnium concentration was between 15 to 30 Al/L, Iron concentration was between 30 to 45 mg Fe/L, these results were electrochemically generated. The following findings can be concluded as follows:

- Aluminum electrodes were more effective in removing pollutants from the textile wastewaters compared to the Iron electrodes.
- By using a current of 0.6 A during 90 min of treatment with pH adjustment approximately 6.0, high removal of COD (90.0%), TSS (98.0%), and BOD (87.0%),O&G (95.0%) were recorded. Under these conditions, 98.5 % of turbidity were eliminated and more than 96.0% of phosphate were removed; and
- Electrochemical treatment costs of TWW (including only electrode consumption, chemical consumption, energy consumption, and sludge disposal) recorded in the best experimental conditions were estimated to be 2.03 USD/m3.

Acknowledgement

The authors would like to extend their sincere gratitude to the Universiti Teknologi Malaysia for supporting the project.

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Biography of Authors

MR. AHMED SAMIR NAJE

Mr.Naji is a Ph.D candidate at Civil engineering faculty , Universiti Teknologi Malaysia. His areas of interest's Electrocoagulation Technology In Wastewater Treatment, His email address is ahmednamesamir@yahoo.com

DR.SAAD BIN ABBAS

Dr.Saad is a doctor at Razak School of Engineering and Advanced Technology, Universiti Teknologi Malaysia. His fields of specialization are water Engineering, Process Chemical, Image Processing, Petroleum Engineering Mining Engineering,. He received his Ph.D from Universiti Putra Malaysia. He can be reached at saad@ic.utm.my.

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