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Treatment and Operating Cost Analysis of Textile Wastewater by Electro-coagulation Using Mild Steel Electrodes

Kalpataru Paul*, Shaikh Ashik-Un-Noor and M. A. Jalil

Bangladesh University of Engineering and Technology, Dhaka (10 00), Bangladesh

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Corresponding Author

Kalpataru Paul

e-mail: kolpo.ce.buet@gmail.com

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Abstract

Conventional treatment of industrial wastewater is often ineffective in removing color, especially from highly colored textile wastewater. This research was undertaken to investigate the removal of color and COD from textile effluent using electro-coagulation process. The effects of applied current flow, different types of electrodes, age of wastewater, EC time and initial pH on the removal of color and COD were studied. Cost estimation was also been assessed. Aluminium, mild steel and stainless steel plates were used as electrodes and comparison among these plates regarding the removal efficiencies assessed. Wastewater from two different textile industries were collected four times and treated in the laboratory. Under the experimental conditions**,** color removal up to 98%, COD removal up to 67% and turbidity removal up to 71.5% were achieved. The results suggest that electrocoagulation process is very effective for removal of color. It was observed that slightly low pH than initial would be effective for color and COD removal and low electricity cost. Considering economical and effectiveness of the treatment process the initial pH should be lowered about 1.6-2 than the raw sample. It was also observed that the removal of color was more effective when the experimental run using fresh sample rather than old sample. As metal decomposes in this process; mild steel was found to be more economical than aluminium. The operating cost includes the energy cost of EC and the material cost. Operating cost as 0.53 US \$ m^{-3} at 5 ampere and 15 min EC time was evaluated.

Keywords: Textile wastewater, electro-coagulation, electrode consumption, COD removal

1. Introduction

In textile industries, dyeing and finishing are the two most important process operations, which generates considerable amount of wastewater containing strong color, suspended particles and high COD and BOD. The color content is not only aesthetic pollutants, but may also interfere with light penetration in the receiving bodies of water, thereby disturbing biological processes. Furthermore, textile industry effluent contains a variety of dye-assisting chemicals which are in some cases bio-inhibitory, creating an additional ecotoxicological impact in receiving water bodies and thus will affect the sustainability of agriculture and fisheries. The textile effluent is hard to be treated by chemical methods as these techniques generate considerable amount of sludge. While the biological methods are relatively cheap, they are not efficient in removing color from highly colored textile effluents. On the other hand, the advanced

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techniques such as reverse osmosis have the disadvantage of high cost. Electrocoagulation process has attracted a great deal of attention in treating various wastewaters because of its environmental compatibility, protection, sustainability and integrated bioresource management. The EC process has such advantages as simple equipment, easy operation, shortened retention time and decreased amount of precipitate, which sediments rapidly.

Electro-chemical technology has been adopted successfully to treat various types of wastewater, such as textile wastewater (Can et al., 2003); heavy metal laden wastewater (Lai et al., 2003); landfill leachate (Tsai et al., 1997); salina wastewater (Lin et al., 1998); carwash wastewater (Moulood et al., 2019); surface water (Fuente et al., 2019). It has also been used for defluoridation (Zhu et al., 2007), arsenic removal (Mroczek et al., 2019), sewage sludge disintegration (Yildiz et al., 2018), removal of nitrate (Koparal et al., 2002), removal of dissolved organic carbon (Jiang et al., 2002), and removal of oil and grease (Chen et al., 2000). EC has three main processes as electrolytic reaction at the surface of electrodes, formation of coagulants in the aqueous phase and adsorption of soluble or colloidal pollutants on coagulants and removal by sedimentation or floatation (Kobya et al., 2003). This process produces corresponding metal hydroxides and poly-hydroxides which work like coagulants to remove the pollutants. (Daneshvar et al., 2006, Ammar et al., 2018). When iron and aluminum electrodes are used, the generated Fe^{2+} or Al^{3+} ions will immediately undergo further spontaneous reactions to produce corresponding hydroxides and poly-hydroxides.

At the Anode;

$Al \rightarrow Al_{(aq)}^{3+} + 3e^-$

At the Cathode;

$3H_2O + 3e^- \rightarrow 1.5H_{2(g)} + 3OH^-$

In the solution;

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

When iron is used as an electrode material, the reactions are as follows:

At the Anode;

$Fe \rightarrow Fe_{(aq)}^{+2} + 2e^-$

At the Cathode;

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

In the solution;

$Fe_{(aq)}^{+2} + 2H_2O \rightarrow Fe(OH)_2 + 2H^+(aq)$

These insoluble metal hydroxides react with the suspended and/or colloid solids and precipitate. In this research, treatment of textile wastewater by EC process was investigated. A reactor was designed in which aluminum and iron electrodes were connected in parallel. The effect of electrode material, initial pH, current flow, EC time, removal efficiency of color, COD and turbidity, energy and electrode consumption were investigated.

2. Materials and Methods

2.1. Experimental setup

The laboratory electro-chemical treatment system used in the present study consists of two components. These are electro-chemical cell/reactor and DC power system. The reactor (12×7.5×4.8 inch) was produced from glass with double sides. Eight electrodes were used and the electrodes were placed as mono polar and parallel in the reactor. The spaces between the electrodes were adjusted as 25 mm, and the electrodes were immersed about 64.6 mm of the total length. Both aluminium and iron electrode materials were chosen as 172.72×88.9×2 mm with the 314 cm^2surface area. Aluminum plates consist of 99.1% Al and the iron plates are made of 98.7% Fe content.

A DC (Direct Current) power system was made using stepped down transformer and rectifier to supply DC at desired voltage to the reactor. The system converted the input Alternating Current (AC) into DC of desired voltage. There was also provision to change the current density. A digital multi-meter (DAZENG PS305D) of 0-5 Ampere and 0-30 Voltage range was used with the power system to measure the applied current density at different time intervals.

2.2. Wastewater sample

2.2.1. Textile wastewater

Textile wastewater used in this study has been provided from the A-One Polar Ltd. was collected on May 29, 2018 and Modele De Capital Industries Limited was collected on June 9, 2018 and both of them were collected from equalization tank. The wastewater which was collected from Modele De Capital had pH 7.4, color (Pt.Co unit) 1010, turbidity 115 NTU, COD 326 mgl^{-1} and DO 0.11 mgl^{-1}, whereas the wastewater from A-One Polar Ltd. had pH 8.8, color (Pt.Co unit) 1505, turbidity 172 NTU, COD 515 mgl^{-1} and DO 0.15 mgl^{-1}.

All the experiments were conducted with 1,500 ml wastewater. The electrodes were washed with tap water to remove the impurities before the tests were started. After each set of experiments, electrodes were washed for the removal of the residuals on the surface and weighed. The sampled wastewater was filtered in preparation for chemical analysis. COD, turbidity, pH and SS determinations were carried out as proposed by standard methods.

Wastewater from A-One Polar Ltd. was used to determine the effect of age of wastewater, effect of applied current flow, effect of EC time and selections of electrode materials.

Wastewater from Modele De Capital Limited was used to determine the effect of initial pH on color removal efficiency and COD removal efficiency and effect of initial pH on electricity cost. Three sets of tests were performed with different initial pH values in the range of 6 to 8.4 for three samples keeping the other parameters unchanged. NaOH was used to increase the pH and HNO_3 was used to lower the pH of the sample.

2.3. Analytical techniques

The COD of samples were analyzed using a HACH DR/2010 single beam spectrophotometer. The turbidity of samples was analyzed using an HACH 2100P turbidimeter. pH was measured by a pH meter (pHep, HANNA). Conductivity was determined by a conductivity meter (WTW MultiLine P4). The pH was adjusted to a desirable value using NaOH or HNO_3.

3. Results and Discussion

This study is mainly focused on the treatment of textile wastewater for determining effects of the basic operating parameters on system performance. Therefore, color, COD, turbidity and operating cost (electrodes and energy consumption) were investigated in terms of selection of electrode material, initial pH, current flow, and EC time in order to determine the optimum operating conditions for maximum removal of color, COD and turbidity. Operating cost is one of the most important parameters in the EC process because it effects the application of any method of wastewater treatment. The operating cost includes material (mainly electrodes) cost, electrical energy cost, labor, maintenance, and other costs. The latter costs items are largely independent of the electrode material. Thus, in this study the operating cost was calculated with electrodes and electrical energy costs. So, both energy and electrode consumption costs are taken into account as major cost items. Calculation of operating cost is expressed as:

$$\text{Operating Cost} = P \times \text{Energy}_{consumption} + Q \times \text{Electrode}_{consumption} \quad (1)$$

Where $\text{Energy}_{consumption}$ and $\text{Electrode}_{consumption}$ are consumption quantities per m^3 of treated wastewater. Unit prices, *P* and *Q*, given for the Bangladesh Market, December 2018, are: electrical energy price 0.0114 US $/kWh, electrode material price 2.75 US $ kg^{-1} for aluminum and 0.52 US $ kg^{-1} for mild steel.

3.1. Selection of electrode material

The selection of electrode material is important. The most common electrode materials for EC are aluminium and iron. They are readily available and effective (Chen et al., 2000). Metal electrodes are dissolved during the EC process, which occurs with coagulant species and metal hydroxides. Metal anode dissolution is accompanied by hydrogen gas evolution at cathodes, the bubbles capturing and floating the suspended solids formed and thus removing contaminates (Lin et al., 1994).

The investigation of treatment efficiency for aluminium and iron electrodes was tested for removal efficiency of COD, turbidity and color. All experimental studies were carried out under same conditions, which was initial pH 8.2 (raw sample), current flow 4 amp, EC time was 15 minutes and wastewater was collected from A-One Polar Ltd. For iron electrodes both mild steel and stainless-steel plates were used separately. Figure 1 compares treatment efficiency for these two kinds of electrodes under same conditions. The EC process using aluminium electrodes was obtained to be more effective than for iron electrodes. The results for COD (65%), color (95%) and turbidity (98%) were removed by using aluminium electrodes. For mild steel electrodes COD (62%), color (93%) and turbidity (75%) were removed.

Figure 1: The comparison of electrode material on the treatment efficiency of the textile wastewater (pH8.2, current flow 4 amp and EC time 15 minutes)

The effect of stainless steel as electrodes was far less effective than both mild steel and aluminium electrodes. The experiment was conducted for 45 minutes. Figure 2 shows that the first 35 minutes the color removal efficiency was highly decreasing. After 45 minutes later only 34% color removal efficiency was achieved.

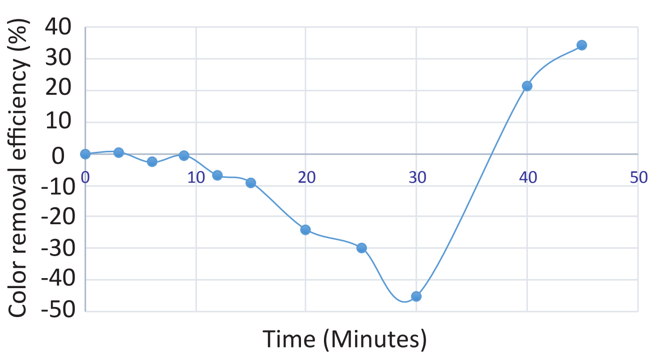

Figure 2: Color removal efficiency (%) with time (minutes) with stainless steel electrodes

The effluent treatment of aluminium electrodes was found to be clearer and more stable than mild steel electrodes. The effluent EC process using iron electrodes appeared greenish first and then turned yellow and turbid. The green and yellow color must have resulted from Fe^{2+} and Fe^{3+}. Fe^{2+} is the common ion generated in situ of electrolysis of iron electrode. It has relatively high solubility at acidic or neutral conditions and can be oxidized easily into Fe^{3+} by dissolved oxygen in water. Now, electrode consumption would determine which electrode is more economical than other.

$$Electrode_{consumption}: (I \times t \times M_w)/(z \times F \times v) \quad (2)$$

Where, F is Faraday's constant (96,485 C mol^{-1}), M_w is the molar mass of electrode material; for Aluminium 26.98 g mol^{-1} and for iron 55.85 g mol^{-1}, z is the number of electron transfer (z_{Al} :3 & z_{Fe}:2), t is EC time (s), I is current (Ampere) and v is volume of the treated textile wastewater (m^3) (Bayramoglu et al., 2004, Fuat et al., 2010). In both experiment the current, time and volume of treated waste water was 4 ampere, 15 minutes and 1.5 liter respectively. For aluminium and iron electrode consumption was 0.2237 kg m^{-3} and 0.6946 kg m^{-3}. Now considering market price of both metals; aluminium costs 0.62 \$ m^{-3} and iron costs 0.36 \$ m^{-3} roughly. So, for economical reason, mild steel electrodes are better than aluminium electrodes. Later consequently, all experiments were carried out with mild steel electrodes.

3.2. Effect of age of wastewater

On 9 June, 2018 the experiment was conducted on the collection day with initial pH and after 15 minutes later color removal efficiency was 75.8% was achieved. The wastewater was collected from the equalization tank of A-One Polar Ltd. The initial color was 1505 Pt.Co Unit.

The next day, another experiment was conducted. The initial color was 1050 Pt.Co Unit and after 15 minutes later color removal efficiency was 70.6% was achieved. On 15 June, the color removal efficiency was 62.6% where initial color was 740 Pt.Co Unit. Here, Color decreasing drastically with time if it is left untreated because of anaerobic actions of bacteria. All the experiments were conducted with 1.5L wastewater, 5 amp current and with mild steel as electrode.

The effect of age of wastewater was found to be effective in color removal efficiency. Fresh wastewater is effective in higher color removal efficiency.

3.3. Effect of initial pH on color removal efficiency and COD removal efficiency

On 9th June, 2018, three consecutive experiments were performed where wastewater volume, electrode material, EC time and electric current was constant and it were 1.5-litre , mild steel plates, 30 minutes and 5 amp respectively. Samples were collected at 3 minutes interval and voltage was recorded for calculating energy consumption.

Here, initial concentration was 1010 Pt-Co unit and color removal efficiency after 15 minutes for raw, acidic and basic sample was 75.8%, 91.4% and 49% respectively. Initial pH was 7.4, acidic sample and basic sample had pH at 6 and 8.5 respectively. The raw, acidic and basic sample had pH of 7.4, 6 and 8.4 respectively. Figure 3 and 4 show effect of different pH on color and COD removal efficiency respectively.

Initial concentration was 326 mg l^{-1} and COD removal efficiency

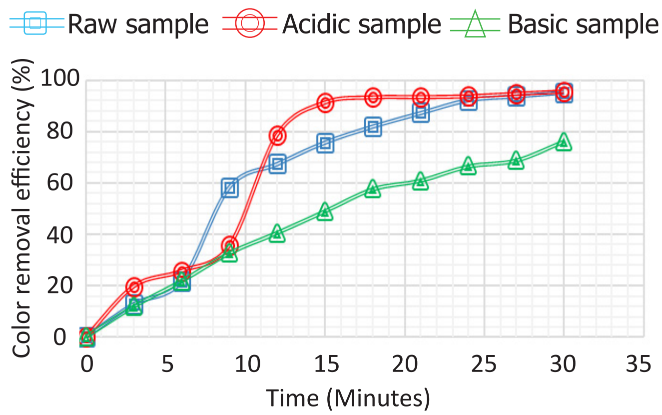

Figure 3: Effect of different initial pH conditions on color removal efficiency

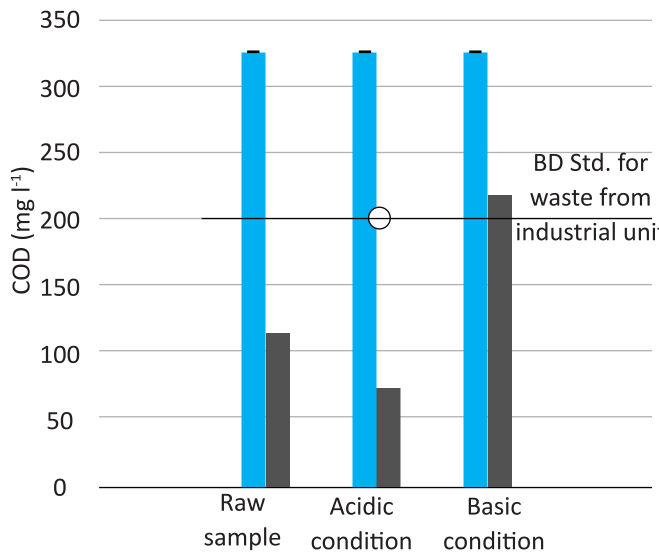

Figure 4: Effect of different pH in removal of COD

after 30 minutes for raw, acidic and basic sample was 64%, 77% and 32.8% respectively. Here both, raw and acidic condition meet the Bangladesh standard for waste from industrial unit.

3.4. Effect of initial pH on electricity cost

Calculation of energy consumption is expressed as

$$Energy_{consumption} = (V \times I \times t)/(1000 \times 3600 \times v) \quad (3)$$

Where $Energy_{consumption}$ is energy consumption (kWh/m^3), V is voltage (Volt) and t is 3 minute time interval (second). In the experiment the current was kept fix and voltage was malleable. So, energy consumption can be expressed as,

$$Energy_{consumption} = ((V_3+V_6+V_9+\ldots\ldots\ldots+V_{24}+V_{27}+V_{30}) \times I \times t)/(1000 \times 3600 \times v) \quad (4)$$

Where, V_6=Voltage reading after 6 minutes later

Here, I= 5 ampere, t=180 seconds. For acidic, basic and raw sample energy consumption was 0.023425, 0.03235 and 0.033175 kWh respectively. B.O.T (Board of Trade Unit) is a unit of energy equal to the work done by a power of 1000 watts operating for one hour. The average value of B.O.T unit in Bangladesh is 9.5 taka/ B.O.T. So, for acidic, basic and raw sample the electricity cost is 1.78, 2.45 and 2.52 \$ m^{-3} respectively. So, lowering the initial pH exerts less electricity cost.

3.5. *Effect of applied current flow*

The effect of current flow is another important parameter for pollutant removal in the electrocoagulation process that effects the metal hydroxide concentration formed during the process. High current density especially causes both decomposition of the electrode material and an increase in pollutant removal. The effect of current flow on the treatment of the textile wastewater shown in Figure 5 and 6 was investigated by varying the applied current to the wastewater in the same conditions (pH 8.5, EC time 10 min). The current flow was applied between the ranges of 2 to 5 Amp in order to assess the effect of different current flow on color and COD.

Charge loading is calculated by following equation

$$\text{Faraday } m^{-3} = (I \times t) / (F \times v) \quad (5)$$

Charge loading is increased from 8.3 to 20.72 Faradays m^{-3} under these conditions. The removal of pollutants increased rapidly from 21.5 to 45.7% COD and from 23.76 to 713% color

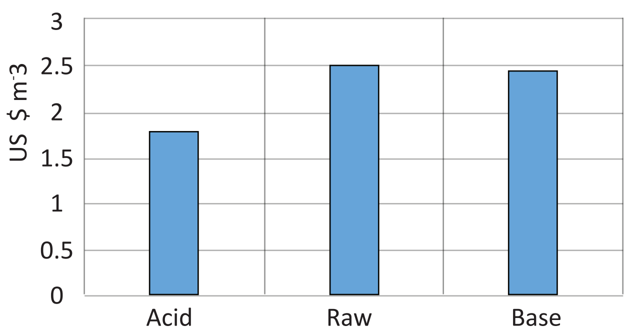

Figure 5: Electricity cost for different initial pH

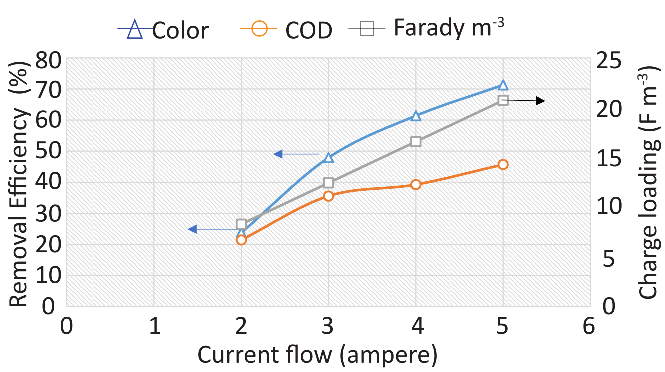

Figure 6: Effect of current flow on color and COD removal (pH initial 8.4, mild steel electrodes and EC time 10 min)

respectively.

3.6. *Effect of EC time*

The EC time is another significant parameter that is influential on the electrocoagulation process. Because the formation and concentrations of metal hydroxides play an important role on pollutant removal, this depends on operation time. The effect of EC time on treatment efficiency was carried out by varying the charge loading from 6.22 to 103.64 Faradays m^{-3}. In the EC process, anode produces metal ions during electrochemical reaction. Metal ions are a destabilization agent. If the charge loading were low, the metal ion dosage was not sufficient to destabilize all colloidal and suspended particles, so pollutant removal was not high. Figure 7 shows that the EC time has an important effect on pollutant removal efficiency. Here, the

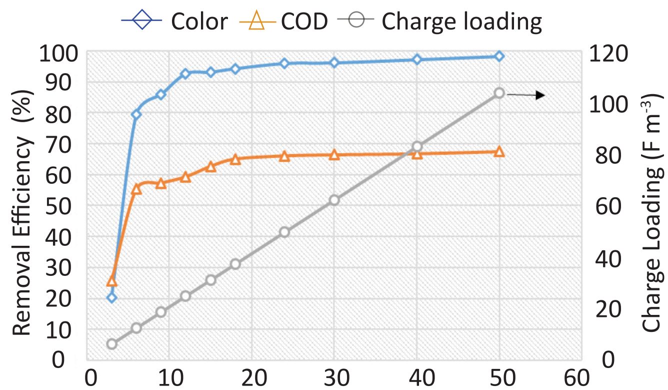

Figure 7: Effect of EC time on color and COD removal (pH 6.9 and current flow 5 amp)

initial pH was 8.8 and after adding HNO_3, it was 6.9. When EC time was changed from 3 to 50 min (similarly, charge loading was changed from 6.22 to 103.64 Faradays m^{-3}), the removal efficiencies of COD from 25.63 to 67.45% and color from 20.3 to 98.2%. Figure 8 showed that the EC time affected consumptions of energy and electrode. When the EC time was increased, both the energy and electrode consumption increased during the EC process were shown. The EC time increase from 3 to 50 min causes an increase in energy consumption from 0.88 to 15.58 kWh m^{-3}, and an increase in electrode consumption from 0.17 to 2.89 kg Fe m^{-3}. It is clear that EC time is an important parameter for the EC process because it affects the economic applicability in the treatment

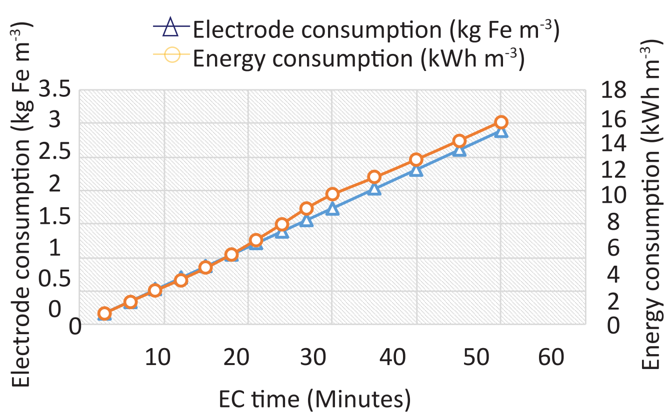

Figure 8: Effect of EC time on electrode and energy consumption (pH 6.9 and current flow 5 amp).

of the textile wastewater.

4. Conclusion

The EC process was found to be effective for the treatment of textile-wastewater. The removal efficiencies of color, COD and turbidity were about 98.2%, 67.4%, and 71.5% respectively using mild steel plates. Lowering initial pH (about 1.6-2 than raw sample) increases removal efficiency and decreases electricity cost. Operating cost as 0.08 US $ m^{-3} for electricity and 0.454 US $ m^{-3} for electrode consumption where the conditions were 5 amp, 15 minutes and initial pH 5.5 (raw sample pH 7.4).

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