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Short Communication

Investigation of Different Electrode Connections in Electrocoagulation of Textile Wastewater Treatment

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This paper presents the results of the treatment of a real textile wastewater by electrocoagulation (EC) process. The textile effluent used in the experiments was obtained from a textile industry in Malatya/Turkey. The effluent was wastewater taken from dying process of the industry. Aluminum electrodes were connected to an EC reactor in three different types: monopolar-parallel (MP-P), monopolar-serial (MP-S), and bipolar-parallel (BP-P). Color and turbidity removals were selected as performance criteria. Moreover, the financial cost of the total treatment has been considered as important as removal efficiencies. Electrical and sacrificial electrode costs have been used in the calculation of the total cost. The results show that MP-P mode is the most cost effective for both electrode connection types. All connection types show similar results in reducing color and turbidity, MP-P is preferred as a low cost treatment. In addition, iron and aluminum electrode materials have been investigated in the MP-P EC reactor. The results show that, according to electrical and sacrificial electrode costs, iron is superior to aluminum but aluminum electrode leads to high turbidity, color and COD removal efficiencies.

Keywords: Electrocoagulation, Electrochemical treatment, Textile wastewater treatment, Operating cost, Electrode connection.

1. INTRODUCTION

The textile industry consumes considerable amount of water in the manufacturing process. The wastewater includes various chemicals and some other undesirable constituents as a results of the manufacturing process. The wastewater has to be purified before the final discharge. Textile wastewater has also high turbidity due to its strong color and high dissolved solid components. It is

crucial to remove these properties of the textile industry wastewater as it affects the ecological system of nature [1].

During the textile dyeing processing, frequent changes of dyestuff employed in the process cause considerable variation in the wastewater characteristics such as pH, color and wastewater chemical oxygen demand (COD) concentration. Conventional purification methods have been becoming insufficient during the composition of textile wastewater. One of the promising methods for purification of the textile wastewater is known as electrochemical treatment based on electrocoagulation [2-3]. Electrocoagulation process has attracted a great deal of attention for treatments of industrial wastewaters from olive mills [4], petroleum refineries [5], pulp and paper mills [6], tanneries [7], metal cutting [8], paint manufacturing [9] and textile wastewaters [10-11] because of the versatility and the environmental compatibility it provides.

Electrocoagulation uses an electrical current and produces several metal ions in electrolyte solution to purify the wastewater. As a matter of fact, the electrocoagulation system is very effective in removing suspended solids, dissolve metals, tannin and dyes. In an electrocoagulation system, when metal ions are neutralized with ions of opposite electric charges, they become unstable and precipitate in a form that is usually very stable. The hydrogen gas bubbles carry the colloidal pollutants to the top of the solution. These particles can be more easily concentrated, collected and removed from the top of the solution. In the electrocoagulation process, during the evolution of H_2, the metallic ions react with the OH^- ions, which are produced at the cathode As a result, the insoluble hydroxides absorb the pollutants out of the solution. In addition, it contributes to coagulation by neutralizing any negatively charged colloidal particles that have been reported to be more compact than the sludge obtained by chemical methods [12].

In this work, we present a successful electrochemical coagulation process to remove pollution from textile wastewater. The roles of different electrode connections and operating times on the process performance have been explored and reported. Three criteria have been selected for this purpose. These are turbidity, color removal and operating cost. For calculating the operating cost, electrode consumptions and voltage changes for the energy consumptions have been examined. In addition, Fe and Al electrodes have been investigated in the EC reactor that yields the best electrode connections.

2. EXPERIMENTAL

2.1. Materials

The textile effluent used in the experiments was obtained from a textile industry in Malatya/Turkey. The effluent was wastewater taken from dyeing process of the industry. The characteristics of the effluent are presented in Table 1.

Table 1. Characteristics of wastewater used

Parameter	Units	Value
pH	-	9.14
Conductivity	mS/cm	2.30
Turbidity	FTU	100
Color	CU	398
Chemical oxygen demand (COD)	mg/L	5855

2.2. Apparatus and instruments

The experimental setup is schematically shown in Fig. 1. The electrocoagulation unit consisted of a 1L electrochemical reactor with aluminum or iron anode and cathode. The electrochemical reactor was made of plexiglass. There were four mono-polar electrodes, two anodes and two cathodes of the same dimensions. All cathodes and anodes were made from plates with dimensions of 60 mm × 60 mm × 3 mm. Total effective electrode surface area was 96 cm^2 and the distance between electrodes was 0.8 cm in all experiments. The current density was maintained constant by means of a precision DC power supply (MAY11-PS Constant Current Power Supply). The following electrode connection modes have been considered.

Monopolar electrodes in parallel connections (MP-P): As shown in Fig. 1(a); anodes and cathodes are in parallel connection, the current is divided between all the electrodes in relation to the resistance of the individual cells. The parallel connection needs a lower potential difference compared with serial connections [13].

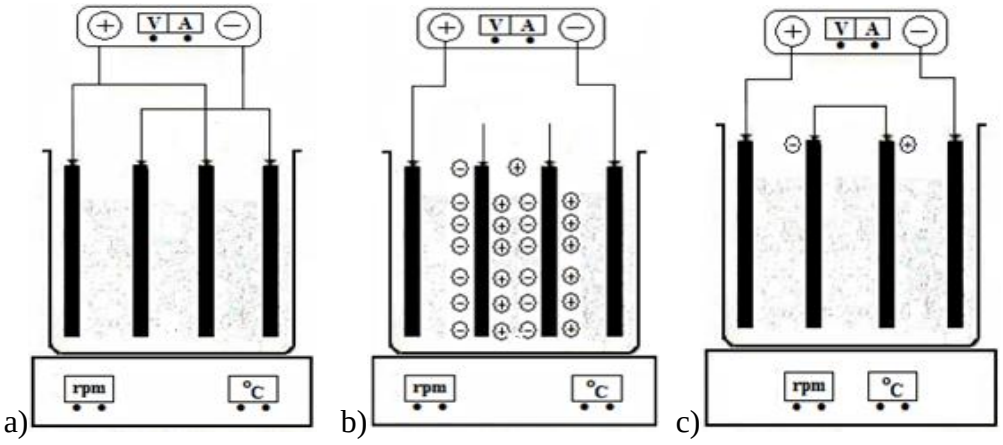

Figure 1. Schematic view of the EC reactors: a) MP-P, b) BP-P, c) MP-S.

Bipolar electrode in parallel connections (BP-P): As shown in Fig. 1(b); the sacrificial electrodes are placed between the two parallel electrodes without any electrical connection. Only the two monopolar electrodes are connected to the electric power source with no interconnections between

the sacrificial electrodes. When an electric current is passed through the two electrodes, the neutral sides of the conductive plate will be transformed to charged sides, which have opposite charge compared to the parallel side beside it [14].

Monopolar electrodes in serial connections (MP-S): As shown in Fig. 1(c); each pair of sacrificial electrodes is internally connected with each other, because the cell voltages sum up, a higher potential difference is required for a given current [15].

2.3. Procedure

For high removal efficiency, the wastewater of reactor was stirring at a constant value of 200 rpm with a stirrer (MS-3020 Lab. Stirrer). In each run, 1L of wastewater was placed into the electrolytic reactor. Probes were put into a bunker connected with a pipe to the electrochemical rector to prevent the possible false measurements that could be affected by the system current.

At the end of the experimental runs, all samples were allowed to settle for 1 day in a tube before any analysis. Neither centrifuging nor filtration was performed. The electrodes were washed thoroughly with distilled water to remove any solid residues on the surfaces. COD, color and turbidity values were determined using a water analysis system (Orbeco-Hellige Model 975-MP).

The removal efficiency (Re %) was calculated using the following equation:

$$\text{Re (\%)} = \frac{Y_0 - Y}{Y_0} \times 100$$

where, Y_0 and Y represent, respectively, the initial and final COD, color or turbidity.

2.4. Cost analysis

Total operating cost includes direct cost items such as power and electrode consumption costs during the electrolysis. Economic data used for the evaluation of the total operating cost are given for December 2014, Turkey, in Table 2.

Table 2. Economical data used in calculating of the operating cost

Item	Cost (€)
Electricity (€ kWh^{-1})	0.068
Fe electrode (€ kg^{-1})	1.02
Al electrode (€ kg^{-1})	3.06

3. RESULTS AND DISCUSSION

The effects of operating time, voltage change with time are presented separately for three different electrode connections, MP-P, MP-S and BP-S. Finally, according to the suitable EC reactor, different electrode materials are investigated for the EC treatment process.

3.1. Effect of Electrode Connection

To investigate the effect of electrode connection, turbidity and color removal efficiency were plotted versus electrocoagulation time starting from 1 min to 60 min (Figures 2-3) at 10.4 mA/cm^2 current density. No pH or conductivity adjustments have been applied to the real wastewater. The turbidity removal efficiency increased sharply during 40 minutes, beyond which no significant improvement was observed. For all electrode connection types, it is clear that turbidity and color removals show the same trend and agree with the observation made by Kobya et al. [16]. In our work, electrode connection modes that were used are MP-P, BP-P and MP-S whereas Kobya et al. compared the performances of three different electrode connection modes (MP-P, MP-S and BP-S) as a function of wastewater pH, current density and operating time [16].

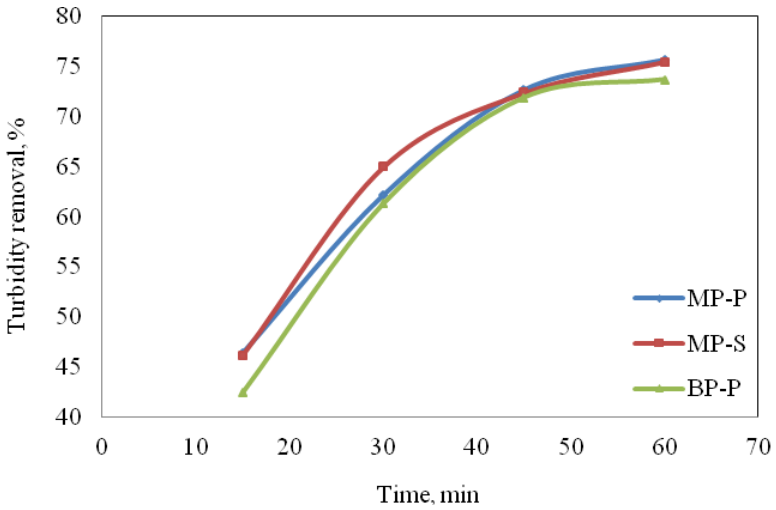

Figure 2. Effect of electrode connection on turbidity removal.

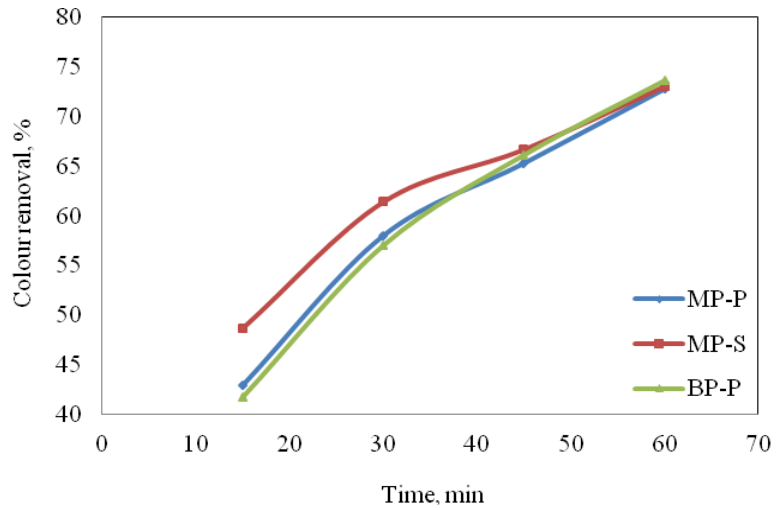

Figure 3. Effect of electrode connection on color removal.

3.2. Voltage Change with Time

For the different electrode connections, voltage changes with time during the electrolysis are given in Fig 4.

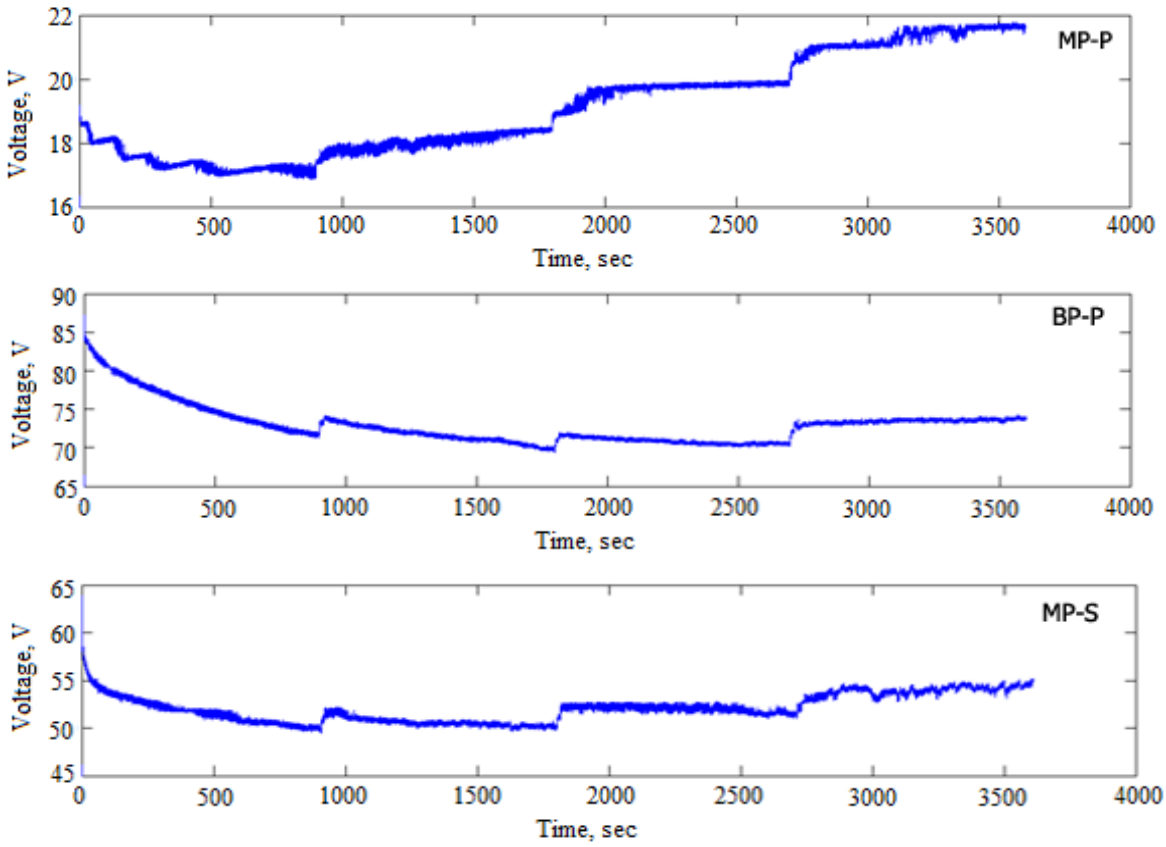

Figure 4. Voltage changes with time in MP-P, BP-P and MP-S EC reactors.

It is clear that voltage values strongly influence the decision about the type of electrode connections for given wastewater treatment power consumptions. BP-P EC reactor has the higher voltage values during the electrolysis. Thus, it has the higher power consumption cost. Kobya et al. reported that MP-P is the most cost effective mode for both aluminum and iron electrodes in a comparison where MP-P, BP-S and MP-S are compared with each other [16]. Our comparison is done using MP-P, BP-P and MP-S EC reactors. For all the electrode connection types, electrode consumption, power consumption and total operating costs are given in Table 3.

Table 3. Results of different electrode connections.

Electrode connections	MP-P	BP-P	MP-S
Electrode material	Al	Al	Al
Operating time, min	60	60	60
Turbidity removal, %	75.7	73.7	75.5

Color removal, %	72.8	73.6	73.1
Electrode consumption, g	0.551	0.843	0.769
Electrode consumption costs, €(10^{-3})	1.686	2.580	2.354
Power consumption costs, €(10^{-3})	1.299	4.961	3.542
Total operating cost, €/m^3	2.985	7.541	5.896

3.3. Effect of Electrode Material

To investigate the effect of electrode material; the operating time was selected as 120 min. The results are given in Fig. 5 for color and turbidity removals. In the use of aluminum, maximum COD removal is 69.3%, color removal is between 42.9 and 90.9% and turbidity removal is between 46.4 and 88.6%. It is clear that for the aluminum electrode, an operation time of 100 min is sufficient for both removals. In the use of iron electrode, no removal can be observed up to 40 min., maximum COD removal is 64.1%, color removal is 80.0% and turbidity removal is 84.1%. This result indicates that aluminum is more efficient than iron, for turbidity and color removal. Our results are in agreement with similar research papers in the literature. For example, Kobya et al. treated textile wastewater by electrocoagulation technique using iron and aluminum electrodes and reported that iron is superior to aluminum as sacrificial electrode material in terms of COD removal efficiency and energy consumption [3]. Similarly, Un et al. also indicate that iron electrodes are more effective in removing COD and turbidity [17].

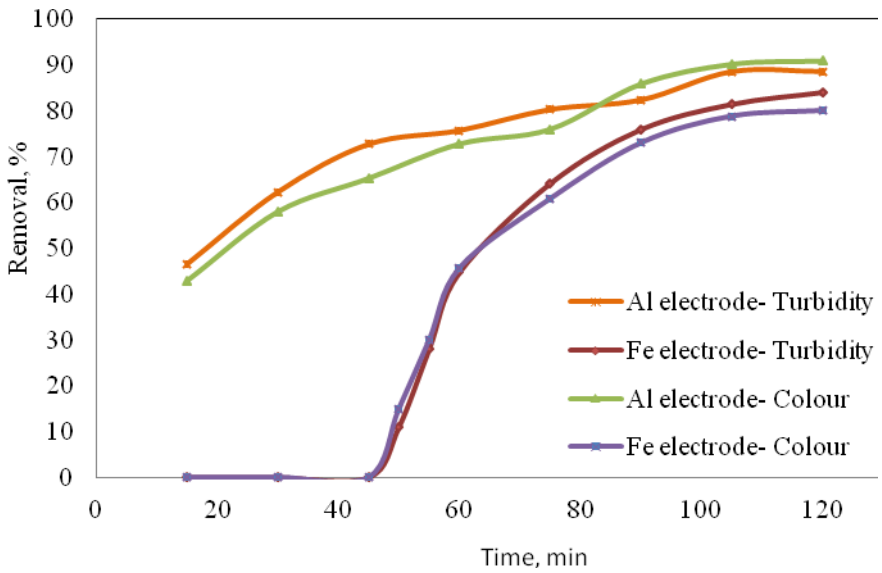

Figure 5. Effect of electrode material on color and turbidity removal.

The energy and electrode consumptions for aluminum and iron electrodes are shown in Table 4. It is clear that, for aluminum, the power consumption is higher and electrode consumption is lower. For the Al and Fe electrodes the experimental results are given in Table 4.

Table 4. Results of different electrode materials.

Electrode connections	Al	Fe
Operating time, min	120	120
Turbidity removal, %	88.6	84.1
Color removal, %	90.9	80.0
COD removal, %	69.3	64.1
Electrode consumption, g	1.095	2.445
Electrode consumption costs, €(10^{-3})	3.351	2.494
Power consumption, €(10^{-3})	3.088	2.238
Total operating cost, €/m^3	6.439	4.732

4. CONCLUSIONS

Electrocoagulation was assessed as a possible technique for the reduction of color and turbidity in textile wastewater. The results show that MP-P mode is the most cost effective for both electrode connection types. The experiments show that all connection types exhibit similar effects on the reduction of color and turbidity. Thus, MP-P is preferred for its low cost treatment. Moreover, according to electrical and sacrificial electrodes costs, iron is superior to aluminum but aluminum electrode leads to high turbidity, color and COD removal efficiencies.

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