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Operating parameters and costs assessments of a real dyehouse wastewater effluent treated by a continuous electrocoagulation process

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ABSTRACT

Treatment of a real dyehouse wastewater was studied with continuous flow electrocoagulation (CEC) process. Removal efficiencies of COD, TOC and turbidity were obtained as 85%, 76% and 95% for Fe electrode and 77%, 72% and 95% for Al electrode at current density of 65 A/m^2, inlet flow rate of 0.010 L/min, operating time of 80 min (hydraulic retention time of 350 min), and current density of 65 A/m^2 (the optimum operating conditions). The decrease in the inlet flow rate (0.20–0.010 L/min) led to an increase in removal efficiencies of COD (58–85% for Fe, 55–77% for Al), TOC (51–76% for Fe and 46–72% for Al) and turbidity (70–95% for Fe and 72–95% for Al). Operating costs for Fe and Al electrodes at the optimum operating conditions were calculated as 1.562 $/m^3 or 7.282 $/kg COD for Fe electrode and 1.851 $/m^3 or 14.257 $/kg COD for Al electrode. The results presented in this study revealed that the CEC process can be effectively used for the removals of color, COD, TOC and turbidity from textile wastewater.

1. Introduction

The textile industry utilizes about 10,000 dyes and pigments, and a high amount of these dyes can exist in effluents of dyeing processes [1]. Reactive dyes are very important class of textile dyes, whose losses through processing are particularly significant and difficult to treat. Under typical reactive dyeing conditions (pH: >10, temperature: >65 °C and salt: 60–100 g/L) as much as 20–50% of the initial mass of the reactive dye remains in the spent reactive dye bath in the hydrolyzed form which has no affinity for the fiber [2]. The dyeing and finishing are the two important processes generally applied in most of the textile manufacturing industries. In textile industries, substantial amounts of unfixed dyes are released into wastewater because of the low efficiency of dye fixing on textile fibers (60–90%) [3,4]. The direct discharge of textile wastewater into the water resources pollutes the water and affects the aquatic life (aquatic plants, microorganisms, fish and mammals). The direct discharge of this industrial effluent into sewage networks produces also disturbance in biological treatment processes. Textile wastewater is characterized by strong colors, high chemical oxygen demand (COD) and total organic carbon (TOC), low biodegradability and high-salt content [5,6]. There are many processes such as biodegradation, adsorption, precipitation, membrane filtration, chemical degradation, photodegradation and chemical coagulation to remove dyes from colored effluents [7–9]. However, these processes are quite expensive and involve several operational problems. For these reasons, there has been an increasing interest in the use of electrochemical methods [10]. Electrochemical methods have advantages due to no requirement of chemicals before and after treatment, producing of less sludge, requirement of small area and low investment cost. [11]. Moreover, the high electrolyte (e.g. NaCl, Na_2CO_3, Na_2SO_4 inorganic salts) concentration used in the textile dying process offers an inherent advantage for treating dying dyebath effluent with electrocoagulation (EC) [12].

In recent years, EC has been applied successfully to treat textile dyes containing solutions or wastewater samples [10–23]. However, most of these studies have involved with treatment of aqueous synthetic dye solutions. EC treatments of these samples have been conducted on a laboratory scale in batch and continuous EC reactors showing almost removal efficiencies of 85–100% for color and 40–80% for COD at various operating conditions. These processes are found to be very efficient in color removal with low-energy consumption. Treatment of textile wastewater by continuous EC process (CEC) has been less investigated for especially

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textile dyebath effluents [24–29]. Despite few scientific studies on treatment of actual textile wastewater by the CEC process using iron (Fe) and aluminium (Al) anodes, there have not been publications reported yet about technical and economical evaluation for treatment of actual exhausted textile dyebath effluents in the CEC process.

EC is an electrolytic process consisting of dissolution of sacrificial anodes (Fe or Al) upon application of a current between two electrodes for treatment of liquid wastewater containing inorganic or organic pollutants [29–39]. In the EC, the anodic reaction involves the dissolution of Al or Fe electrodes (Eqs. (1)–(3)), and the cathodic reaction (Eqs. (2) and (5)) involves the formation of hydrogen gas and hydroxide ions, then hydroxide ions formed at the cathode increase pH of the wastewater thereby inducing precipitation of metal ions as corresponding hydroxides and co-precipitation with iron hydroxides. The main anode and cathode reactions occurring at Al and Fe electrodes in EC process are as follows:

Anode and cathodes reactions for Al electrodes:

$$\text{Anode}: \ Al \rightarrow Al^{3+} + 3e^{-} \quad (1)$$

$$\text{Cathode}: \ 3H_2O + 3e^{-} \rightarrow 3/2H_{2(g)} + 3OH^{-} \quad (2)$$

Anode and cathodes reactions for Fe electrodes:

$$\text{Anode}: \ Fe \rightarrow Fe^{2+} + 2e^{-} \quad (3)$$

$$Fe^{2+} \rightarrow Fe^{3+} + e^{-} \quad (4)$$

$$\text{Cathode}: \ 2H_2O + 2e^{-} \rightarrow H_{2(g)} + 2OH^{-} \quad (5)$$

In the case of Fe electrodes, dissolved iron (i.e., Fe^{2+} or Fe^{3+}) hydrolyses by increasing pH to form precipitates as $Fe(OH)_{n(s)}$. The rate of the oxidation of Fe^{2+} depends on the availability of dissolved oxygen [28].

$$O_{2(g)} + 4Fe^{2+} + 2H_2O \rightarrow 4Fe^{3+} + 4OH^{-} \quad (6)$$

In the case of used aluminium electrodes in EC process, Al^{3+}/Fe^{3+} and OH^{-} ions generated by anode and cathode Reactions (1) and (2) to form various monomeric species depending on the pH of the aqueous medium. Consequently, the removal mechanism of pollutants from wastewater with both electrodes was related to forming of $Fe(OH)_{3(s)}$, $Al(OH)_{3(s)}$, monomeric and polymeric iron and aluminium species due to coagulation, precipitation, co-precipitation, and electrooxidation [11,28].

The objective of the present study was to investigate the influence of different operating parameters (current density of 20–85 A/m^2, operating time of 0–80 min, inlet flow rate of 0.01–0.20 L/min and COD or TOC concentration) on COD, TOC and turbidity removal efficiencies in the real dyehouse wastewater by the CEC process using sacrificial Fe and Al electrodes. Operating costs were also calculated in terms of energy and electrode consumptions.

2. Material and methods

2.1. Characterization of textile dyehouse wastewater

The dyehouse wastewater used in this study was obtained from a textile factory producing approximately 1000 m^3 of wastewater per day in Istanbul, Turkey. The textile wastewater contained real dyehouse effluents from both dyeing and rinsing baths of cotton, rayon, silk, wool and nylon. Reactive, dispersive and acidic dyes are the major types of dye used in this textile factory. The wastewater was collected from balancing (equalization) tank immediately after the dyeing and rinsing processes, and then directly stored at below 4 °C in a dark condition to avoid any change in physico-chemical characteristics before use. The relatively large suspended particles in the colloidal ranges were removed from the wastewater before conducting the experiments. Characterizations of the textile dyehouse wastewater from the balancing tank are shown in Table 1.

2.2. Continuous EC reactor and experimental procedure

The EC experiments were carried out in a continuous flow reactor made from Plexiglas with dimensions of 250 mm × 190 mm × 80 mm. A schematic of the experimental setup for the CEC reactor is shown in Fig. 1. Two anodes and two cathodes (Fe or Al) of rectangle electrodes with dimensions of 220 mm × 50 mm × 4 mm were placed in the reactor with monopolar parallel connection mode. The space between each electrode was 20 mm and their position within the reactor was in perpendicular order according to the wastewater flow. The total effective electrode area was 660 cm^2. The electrodes were connected to a digital dc power supply (Agilent 6675A model) operated at galvanostatic mode. The current was adjusted on the dc power supply. The initial pH of wastewater was adjusted to 5.5, and then the wastewater was fed into the reactor from the bottom using a peristaltic pump (Cole-Parmer 7553-75 model). Volume of the dyehouse wastewater in the CEC reactor was 3.5 L. The CEC experiments for Al or Fe electrodes were run up to 80 min depending on variations of the operating time and other operating parameters. Flow rate of the textile wastewater was varied at 0.010, 0.050, 0.10 and 0.20 L/min. Effluent samples from the reactor were taken at different times during the experiment and the experiment was continued until steady-state concentrations were achieved. Effluent from the reactor was passed through a filter column with diameter of 30 mm filled with 10 mm glass beads to remove suspended

Table 1
The characterizations of the textile dyehouse wastewater.

Parameters	Before the CEC process	Average values before the CEC	After the CEC process	
			Fe	Al
pH	6.5–7.1	6.8	8.4	8.2
COD (mg/L)	1940–2060	2000	300	460
TOC (mg/L)	520–450	485	116	136
Turbidity (NTU)	1850–2600	2225	111	111
Conductivity (mS/cm)	2.25–2.35	2.30	1.85	1.96
Total SS (mg/L)	210–250	230	10	15
Temperature (°C)	18–22	20	26	27
Fe (mg/L)	–	–	0.014	–
Al (mg/L)	–	–	–	0.018