

## Investigation of COD and color removal from medium density fiberboard wastewater by photo-electro-Fenton method

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### ABSTRACT

In this study, the effects of current density (10–50 A/m<sup>2</sup>), pH (2.5–5.0), H<sub>2</sub>O<sub>2</sub> concentration (100–1,500 mg/L), and the distance between electrodes (1.0–1.5 cm) on chemical oxygen demand (COD) and color removal from medium-density fiberboard (MDF) wastewater by the photo-electro-Fenton method were investigated. Under achieved optimum experimental conditions (pH: 3, current density: 10 A/m<sup>2</sup>, H<sub>2</sub>O<sub>2</sub> concentration: 750 mg/L, UV source: 16 W, the distance between electrodes: 1.0 cm, stirring rate: 250 rpm) a maximum COD removal of 98.17% (at 90 min) and maximum color removal of 95.28% (at 45 min) were obtained with 11.11 and 5.56 kWh/m<sup>3</sup> electrical energy consumptions, respectively. Under these conditions, H<sub>2</sub>O<sub>2</sub>/Fe<sup>2+</sup> molar ratios were calculated as 6.47 and 12.94 for the maximum COD and color removals, respectively. Also, while the total treatment cost for the maximum COD removal (electrical energy consumption + anode consumption + H<sub>2</sub>O<sub>2</sub> consumption) was 29.33 US\$/m<sup>3</sup>, the treatment cost per kilogram of COD was 5.45 US\$. The total treatment cost for the maximum color removal was found as 28.7 US\$/m<sup>3</sup>.

**Keywords:** Chemical oxygen demand; Color; Electricity consumption; Medium-density fiberboard; Photo-electro-Fenton

### 1. Introduction

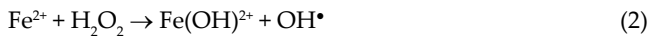
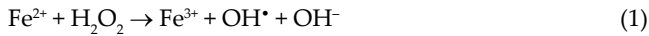
Medium-density fiberboard (MDF) is a wood product consisting of thin lignocellulosic fibers and is mostly used in the manufacture of products such as shelves, cabinets, and furniture [1]. Industrial processing of medium-density fiberboards (MDF or MDFB) requires large amounts of water consumption [2]. The production of MDF in the world and in Turkey in recent years has increased substantially [3]. Since the wastewaters of the MDF industry contain high concentrations of organic and inorganic pollution loads, color, suspended solids, and other toxic components, they must be treated before discharge into the receiving environment or sewage system [2]. Various

physico-chemical methods such as coagulation–flocculation, ozonation, and advanced oxidation processes (AOPs) are mostly used in the treatment of such wastewaters [4].

Hydroxyl radicals (OH•) with high oxidation capacities (redox potential = 2.8 V) produced with AOPs can convert toxic and permanent organic substances that can be found in wastewater into harmless products [5]. The most commonly used AOPs are UV radiation with hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) (H<sub>2</sub>O<sub>2</sub>/UV), ozonation (O<sub>3</sub>), UV radiation with ozone (O<sub>3</sub>/UV), Fenton (H<sub>2</sub>O<sub>2</sub>/Fe<sup>2+</sup>), photo-Fenton (UV/H<sub>2</sub>O<sub>2</sub>/Fe<sup>2+</sup>) [6].

The combination of electrochemical and photochemical processes from the AOPs with Fenton processes is known as photo-electro-Fenton (PEF) process:

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Eq. (1) shows the Fenton reaction. According to Eqs. (1–2), the reaction of  $\text{Fe}^{2+}$  and  $\text{H}_2\text{O}_2$  produces the  $\text{OH}^\bullet$ , while the  $\text{Fe}(\text{OH})^{2+}$  complexes, which can be formed depending on the wastewater pH, can be converted to  $\text{Fe}^{2+}$  and  $\text{OH}^\bullet$  radical with the effect of UV (Eq. (3)) [7]. In these processes, photochemical regeneration of  $\text{Fe}^{2+}$  ions and by photo-activation of complexes make PEF systems more efficient. It can be also directly formed 2 moles  $\text{OH}^\bullet$  by the reaction of UV with  $\text{H}_2\text{O}_2$  (Eq. (4)) [8]. Therefore, it is possible to create more  $\text{OH}^\bullet$  in the medium in the presence of UV. This increases the pollutant removal efficiency.

Although COD and color removal studies are common using AOPs, there are limited studies on the treatment of wastewaters from MDF production. Kang et al. [9] used  $\text{Fe}^{2+}/\text{H}_2\text{O}_2/\text{UV}$  (pH: 4),  $\text{H}_2\text{O}_2/\text{UV}$  (pH: 4),  $\text{Fe}^{2+}/\text{H}_2\text{O}_2/\text{UV}$  (pH: 7), and  $\text{Fe}^{2+}/\text{H}_2\text{O}_2$  (pH: 4) processes to remove the color from textile wastewater, and achieved removal efficiencies of 93%, 82%, 73%, and 64%, respectively. Neamtu et al. [10] compared ozone, Fenton,  $\text{UV}/\text{H}_2\text{O}_2$ , and photo-Fenton processes for COD and color removal from dispersing red 354 azo dye, and they obtained 90% COD and 85% color removal at the end of 10 min treatment time with photo-Fenton method. Muruganandham and Swaminathan [11] applied photo-Fenton,  $\text{UV}/\text{TiO}_2$ , Fenton, and  $\text{UV}/\text{H}_2\text{O}_2$  advanced oxidation methods for color removal from reactive yellow 14 azo dye and achieved a maximum 96.8% color removal as a result of 60 min treatment only with photo-Fenton method. In the other study carried out by Asaithambi et al. [12], it was studied COD and color removal from leachate by PEF method (pH: 3, current density: 35 A/m<sup>2</sup>,  $\text{H}_2\text{O}_2$ : 300 mg/L, UV lamp: 32 W, the distance between electrodes: 0.75 cm), it was achieved a maximum of 97% COD and 100% color removal. Galehdar et al. [2] achieved 96% COD removal from MDF wastewater under their optimum conditions (pH: 6.50,  $\text{COD}_{\text{inlet}}$ : 4,000 mg/L,  $\text{Fe}^{2+}/\text{H}_2\text{O}_2$ : 0.11, and UV contact time: 70 min) with the photo-assisted Fenton oxidation method [2]. Canbolat et al. [3] obtained 58.8% COD and 81% color removal under optimum conditions ( $\text{pH}_{\text{input}}$ : 3,  $\text{H}_2\text{O}_2/\text{Fe}^{2+}$ : 2.5) in their study with Fenton method.

In this study, the effects of important operating parameters such as current density, pH,  $\text{H}_2\text{O}_2$  concentration, the distance between electrodes on COD, and color removal from a MDF wastewater with PEF method were investigated in detail and cost analysis was performed for the achieved optimum conditions. In these conditions (current density: 10 A/m<sup>2</sup>, pH: 3,  $\text{H}_2\text{O}_2$ : 750 mg/L, UV source: 16 W, the distance between electrodes: 1.0 cm, and stirring speed: 250 rpm), maximum 98.17% COD and 95.28% color removal efficiencies were achieved after 90 and 45 min of treatment, respectively. Also, total treatment cost was calculated taking into account the consumption of electrical energy (power supply plus UV source), anode, and  $\text{H}_2\text{O}_2$ . Unlike the other

studies, in this study, operating conditions were examined in a wide range and a detailed cost analysis was made. Also, it was revealed that higher COD and color removal efficiencies were obtained compared to a limited number of other studies.

## 2. Materials and methods

### 2.1. Wastewater characteristics

Wastewater was supplied from Çamsan MDF production facility in Ordu province. Laminated parquet and glue are produced in the facility with an annual production capacity of 200,000 m<sup>3</sup>. The facility, which is established on a total area of 159,000 m<sup>2</sup>, of which 42,000 m<sup>2</sup> is closed, consists of two MDF production facilities, three laminated coating facilities, laminated parquet facilities, chemical facilities, central biological and chemical waste treatment and evaluation facility. For the production of MDF in the facility, the wood is turned into thin fibers and then turned into pieces of the matchbox. After these chips are softened in a boiler at a steam pressure of 5–8 bar, they are compacted with a spiral and converted into fibers. At this stage, wastewater of the process is formed. These formed fibers are mixed with glue and sent to the press so that the MDF board is produced in the hot press in the desired thickness and size. Approximately 20 m<sup>3</sup>/h of wastewater is produced at the facility. The properties of the wastewater used in the experiments are shown in Table 1.

### 2.2. Photoreactor

All experiments were carried out in a cylindrical photoreactor made of plexiglass material with an inner diameter of 7.70 cm, an outer diameter of 8.25 cm, and a height of 48.5 cm. One 16 W power low-pressure mercury vapor lamp (UV-C, 254 nm) and 1 anode (iron) and 1 cathode (stainless steel) electrode were placed inside the photoreactor. The electrode dimensions were 4.6 cm × 29.6 cm × 0.2 cm (width × height × thickness) and the active anode surface area was 267.498 cm<sup>2</sup>. The electrodes were connected directly to the current power supply (GW GPC-3060D DC power supply – 30 V, 6 A) in monopolar parallel mode. The top view of the photoreactor used in the experiments is shown in Fig. 1 and the electrochemical system is shown in Fig. 2.

To remove the suspended solids that may affect the electrochemical process, the wastewater was subjected to a pre-filtration process using a sieve with a diameter of 0.063 mm [13]. In each experiment, the photoreactor was filled with 2.2 L of wastewater and operated in batch mode.

Table 1  
Characteristic of wastewater

Parameter	Level
pH	5.50–5.70
COD (mg/L)	5,100–5,450
Conductivity (mS/cm)	2.10–3.12
Color (Pt-Co)	3,885–3,977



Fig. 1. Top view of photoreactor.

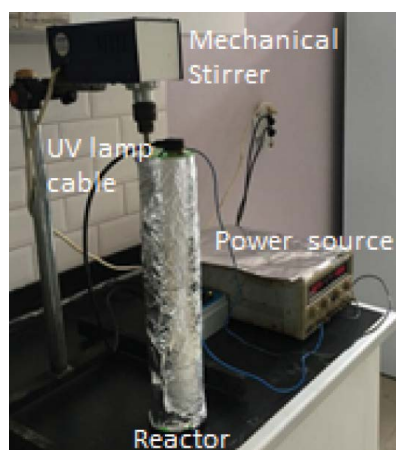


Fig. 2. Experimental set up of photo-electro-Fenton process.

Stirring was carried out mechanically at 250 rpm from the top of the reactor. While  $\text{Fe}^{2+}$  was produced from the iron anode in the reactor,  $\text{H}_2\text{O}_2$  was added externally. After each experiment, electrodes were washed with concentrated HCl for a few minutes to remove the microfilm layer formed on the electrode surfaces during the experiments and then rinsed sufficiently with distilled water. 1 M  $\text{H}_2\text{SO}_4$  (Merck, Darmstadt, Germany) and 1 M NaOH (Sigma, Spain) were used for pH adjustments in the experiments. pH measurements were made with Thermo Scientific Orion 4 (Beverly, USA) Star brand and model pH meter. After the pH value of the wastewater was brought to the desired value, initial COD, and color measurements were made in the raw wastewater before each experiment. Then, the wastewater was put into the photoreactor, and immediately after adding  $\text{H}_2\text{O}_2$  at the desired level, the voltage meter and UV lamp were operated simultaneously with the mechanical mixer. The samples were taken at periodic intervals (1, 3, 5, 10, 20, 30, 45, 60, 90, 120, and 150 min), centrifuged for 10 min at 9,000 rpm, and then COD and color measurements were performed using a spectrophotometer (Merck Spectroquant Nova 60A brand and model, Darmstadt, Germany).

### 2.3. Analytical system

All experiments were done according to Standard Methods book for water and wastewater treatment. COD measurements were performed according to the closed-reflux colorimetric method (5520-D) [14]. COD removal efficiencies were calculated using Eq. (5):

$$\text{Removal efficiency (\%)} = \frac{C_0 - C_t}{C_0} \times 100 \quad (5)$$

where  $C_0$  is the initial concentration of COD (mg/L);  $C_t$  is the concentration of COD corresponding time (mg/L).

Color measurements were made according to the Pt-Co method in the Standard Methods book. Absorbance of the samples was measured at 340 nm wavelength and color values were calculated by multiplying by the required multiplication factor [14].

## 3. Results and discussion

### 3.1. Effect of current density on COD and color removal

The current density is one of the important parameters that affect the reaction rate and the amount of  $\text{OH}^\bullet$  produced in electrochemical AOPs. Also, current density directly affects the electrical energy consumption and thus the cost of the treatment process [12]. To examine the effect of current density on COD and color removal, while the other experimental were kept constant (pH, 3,  $\text{H}_2\text{O}_2$ : 500 mg/L, UV source: 16 W, the distance between electrodes: 1.0 cm, and stirring rate: 250 rpm), current densities of 10, 20, 30, 40, and 50  $\text{A}/\text{m}^2$  were tried. Figs. 3 and 4 show the effects of current densities on COD and color removal, respectively. Maximum 98.10% COD and 78.50% color removal efficiencies were obtained at 10  $\text{A}/\text{m}^2$  and at 60 and 45 min, respectively. At the end of 60th and 45th min, when maximum COD and color removal was achieved, wastewater final pH values were measured as 3.88 and 3.54, respectively. The other COD removal efficiencies obtained for 20, 30, 40, and 50  $\text{A}/\text{m}^2$  were 74.16%, 74.16%, 58.82%, and 46.56%, while these were 63.44%, 60.72%, 55.14%, and 50.69% for color removal. By increasing the current density from 10 to 50  $\text{A}/\text{m}^2$ , COD removal efficiency decreased from 98.10% to 46.56%. When the applied current density is increased, the amount of  $\text{Fe}^{2+}$  ions dissolved from the sacrificial iron anodes increases (Eq. (6)). In this case, the decreases in the removal efficiencies can be explained by the increased current causing side reactions such as  $\text{OH}^\bullet$  degradation (Eq. (7)) [15,16]. Also, since a high level of  $\text{Fe}^{2+}$  in the reactor propagates to Fenton's reaction [16]:



A similar result was seen in the study by Zhang et al. [17]. It was reported that COD removal decreased from 89.2% to 79.3% by increasing the current from 250 to 300 mA in their study which was on COD removal from leachate. During the first 60 min COD removal efficiencies increased

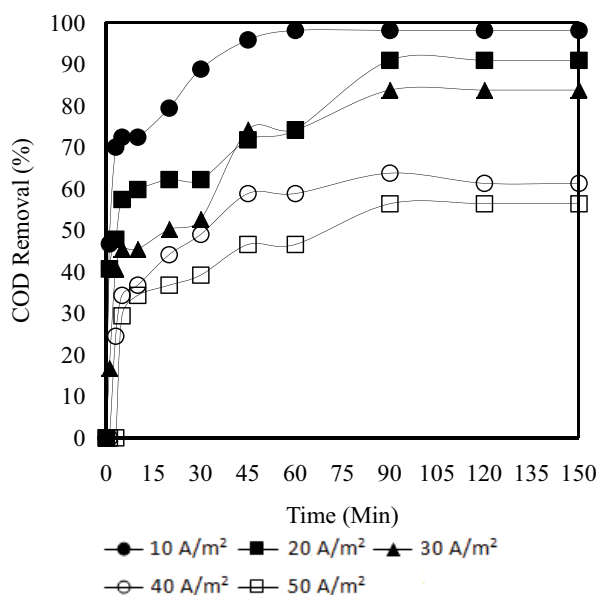


Fig. 3. Effect of current density on COD removal (conditions: anode: iron, cathode: steel, pH: 3,  $\text{H}_2\text{O}_2$ : 500 mg/L, UV source: 16 W, the distance between electrodes: 1.0 cm, and stirring speed: 250 rpm).

for all current density values. This can be explained by the increased  $\text{OH}^\bullet$  in the medium. The electricity consumptions resulting from the treatment for 60 min were 7.42, 7.79, 8.41, 8.94, and 10.03 kWh/m<sup>3</sup> for 10, 20, 30, 40, and 50 A/m<sup>2</sup>, respectively.

COD removal efficiencies did not change after 90 min. This can be explained by the exhaustion of  $\text{OH}^\bullet$  in the medium. Fig. 4 shows the effects of current densities on color removal. By increasing the current density from 10 to 50 A/m<sup>2</sup>, color removal efficiency decreased from 78.5% to 50.69% after 45 min of treatment time. This situation can be explained by the increase of the current density, and thus the increase of ferric and ferrous Fe ions that dissolve from the anode and coloring the water [16]. The electricity consumptions at the end of this period were 5.56, 5.84, 6.33, 6.74, and 7.61 kWh/m<sup>3</sup> for the current densities of 10, 20, 30, 40, and 50 A/m<sup>2</sup>, respectively. It was observed that the color removal efficiency decreased after 45 min. This can be explained by the decrease of  $\text{OH}^\bullet$  in the reactor.

The current density of 10 A/m<sup>2</sup>, where the maximum COD and color removal efficiencies were obtained with the lowest electrical energy consumption, was considered optimum for subsequent experiments.

### 3.2. Effect of pH on COD and color removal

Wastewater pH is a very important parameter that directly affects the efficiency of PEF systems [12]. PEF experiments were carried out at acidic pH. The reason for this is that  $\text{OH}^\bullet$  radicals predominant at acidic pHs have higher oxidation power than hydroperoxyl ( $\text{HO}_2^\bullet$ ) radicals predominant at alkaline pH [18]. To investigate the effect of pH on COD and color removal, provided that other

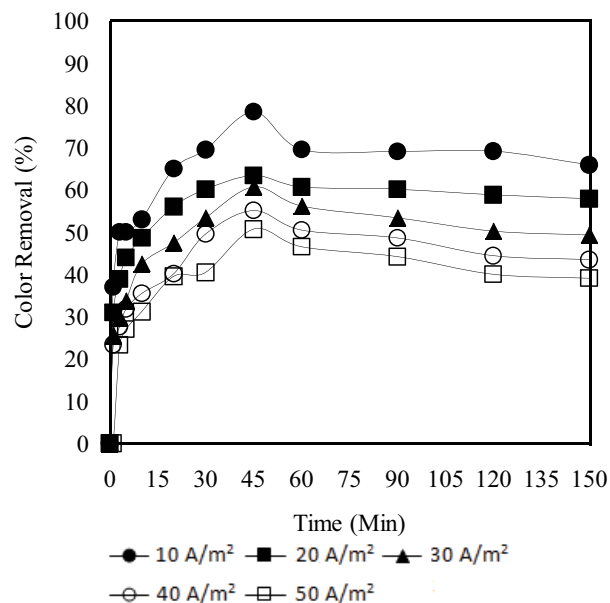


Fig. 4. Effect of current density on color removal (conditions: anode: iron, cathode: steel, pH: 3,  $\text{H}_2\text{O}_2$ : 500 mg/L, UV source: 16 W, the distance between electrodes: 1.0 cm, and stirring speed: 250 rpm).

conditions were kept constant (Current density: 10 A/m<sup>2</sup>,  $\text{H}_2\text{O}_2$ : 500 mg/L, UV lamp: 16 W, the distance between electrodes: 1.0 cm, and stirring speed: 250 rpm) different pH values (2.5, 3.0, 3.5, 4.0, 4.5, and 5.0) were studied. Fig. 5 shows the effect of pH on COD removal. A maximum COD removal of 98.13% and color removal of 78.5% were obtained at pH: 3 after 60 and 45 min of treatment, respectively. At the end of 60th and 45th min, when maximum COD and color removal was achieved, wastewater final pH values were measured as 3.88 and 3.54, respectively. By increasing the pH from 3 to 5, COD removal efficiency decreased from 98.13% to 58.41%. This can be explained as follows: dissolved iron ions begin to precipitate above pH: 3 as  $\text{Fe}^{3+}$ ,  $\text{Fe}(\text{OH})_2$ , and the formed  $\text{Fe}(\text{OH})_3$  not only reduces the dissolved  $\text{Fe}^{3+}$  concentration but also partially prevents  $\text{Fe}^{2+}$  regeneration by accumulating on the electrode surfaces [12]. While the maximum COD removal efficiencies obtained for pH values of 2.5, 3.0, 3.5, 4.0, 4.5, and 5.0 were 95.69%, 98.13%, 90.91%, 83.33%, 71.77%, and 58.41%, these efficiencies were 76.52%, 78.50%, 75.58%, 71.60%, 61.13%, and 51.65% for color. The electricity consumption after 60 min of treatment were 7.39, 7.42, 7.42, 7.44, 7.48, and 7.49 kWh/m<sup>3</sup> for pH values ranging from 2.5 to 5.0. Fig. 6 shows the effect of pH on color removal. During the first 45 min, the color removal efficiency increased for all pHs. This may be associated with increased  $\text{OH}^\bullet$  in the medium. The electrical energy consumptions at the end of 45 min, where the maximum color removal efficiency was achieved, were 5.54, 5.56, 5.57, 5.58, 5.61, and 5.62 kWh/m<sup>3</sup> for pH values ranging from 2.5 to 5.0. After 45 min, color removal efficiency decreased for all pHs. pH: 3, where the highest removal efficiencies of COD and color were obtained, was considered optimum for subsequent experiments.

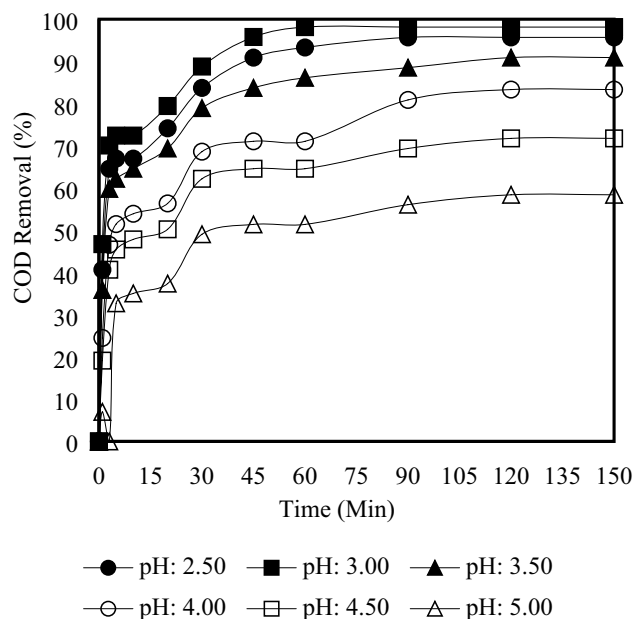


Fig. 5. Effect of pH on COD removal (conditions: anode: iron, cathode: steel, current density: 10 A/m<sup>2</sup>, H<sub>2</sub>O<sub>2</sub>: 500 mg/L, UV source: 16 W, the distance between electrodes: 1.0 cm, and stirring speed: 250 rpm).

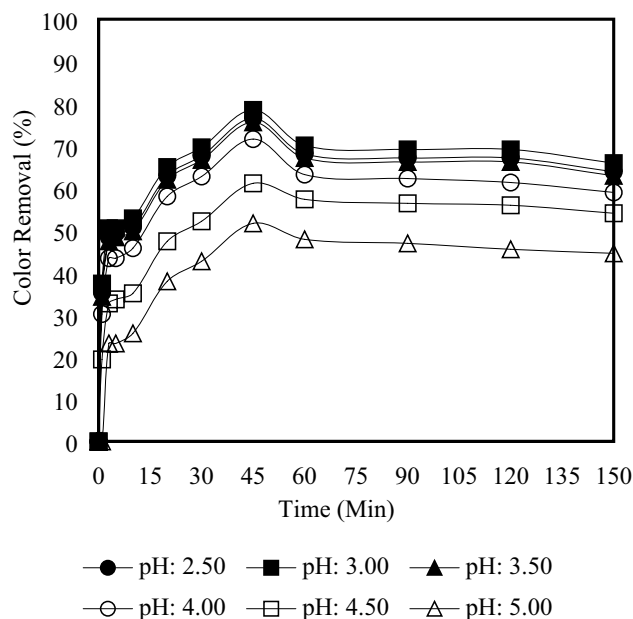


Fig. 6. Effect of pH on color removal (conditions: anode: iron, cathode: steel, current density: 10 A/m<sup>2</sup>, H<sub>2</sub>O<sub>2</sub>: 500 mg/L, UV source: 16 W, the distance between electrodes: 1.0 cm, and stirring time: 250 rpm).

### 3.3. Effect of hydrogen peroxide on COD and color removal

Hydrogen peroxide is a very important parameter because it affects the OH<sup>•</sup> formation and cost that occur directly in PEF processes [12]. While the other conditions were kept constant (current density: 10 A/m<sup>2</sup>, pH: 3, UV source: 16 W, the distance between electrodes: 1.0 cm, and stirring time: 250 rpm) the effects of H<sub>2</sub>O<sub>2</sub> concentrations (100; 200; 300; 400; 500; 750; 1,000; 1,250; and 1,500 mg/L) on COD and color removal were examined. Fig. 7 shows the effect of H<sub>2</sub>O<sub>2</sub> concentrations on COD removal. A maximum COD removal of 98.17% and maximum color removal of 95.28% were obtained with H<sub>2</sub>O<sub>2</sub> concentrations of 750 mg/L after 90–45 min of treatment. At the end of 90th and 45th min, when maximum COD and color removal was achieved, wastewater final pH values were measured as 4.27 and 3.68, respectively. The other COD removal efficiencies for 100; 200; 300; 400; 500; 1,000; 1,250; and 1,500 mg/L were 60.75%, 73.06%, 81.34%, 88.52%, 98.13%, 91.12%, 85.78%, and 78.43%, while these values 50.47%, 55.41%, 64.65%, 71.37%, 78.50%, 90.61%, 79.14%, and 71.43%, for color. By increasing H<sub>2</sub>O<sub>2</sub> concentration from 100 to 750 mg/L, COD removal efficiency increased from 60.75 to 98.17% after 90 min. This situation can be associated with increased OH<sup>•</sup> with increasing H<sub>2</sub>O<sub>2</sub> concentration in the medium [12]. By increasing the H<sub>2</sub>O<sub>2</sub> concentration from 750 to 1,500 mg/L, COD removal efficiency decreased from 98.17% to 78.43% after 90 min. The reason for this is the recombination of OH<sup>•</sup> and the scavenging effect of H<sub>2</sub>O<sub>2</sub>. This situation is shown in Eqs. (8)–(10):

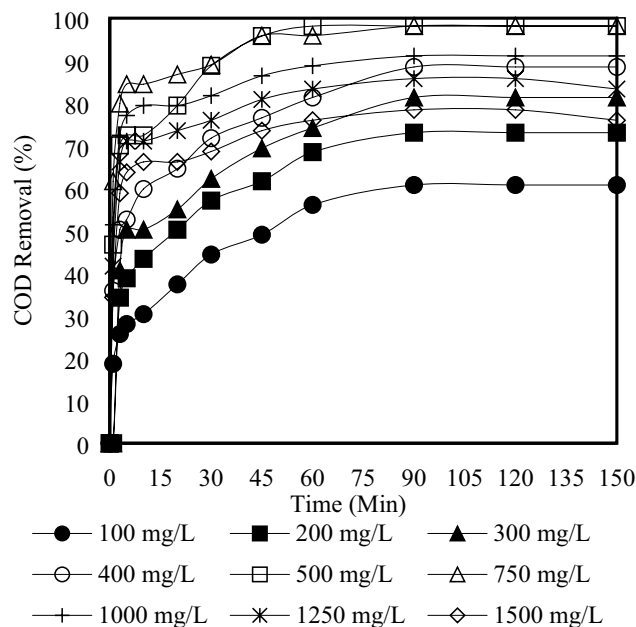
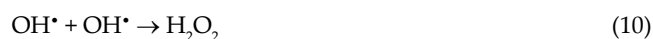


Fig. 7. Effect of H<sub>2</sub>O<sub>2</sub> concentration on COD removal (conditions: anode: iron, cathode: steel, current density: 10 A/m<sup>2</sup>, pH: 3, UV source: 16 W, the distance between electrodes: 1.0 cm, and stirring speed: 250 rpm).



As can be seen from Eqs. (8) to (10), other radicals ( $\text{HO}_2^*$ ,  $\text{O}_2^*$ ) are formed at high  $\text{H}_2\text{O}_2$  concentrations and their oxidation capacity are lower than that of  $\text{OH}^*$  [12]. A similar correlation was found by Asaithambi et al. [12] in COD removal from leachate by PEF method. By increasing the  $\text{H}_2\text{O}_2$  concentration from 75 to 300 mg/L, COD removal efficiency increased from 58.50% to 97%. By increasing the  $\text{H}_2\text{O}_2$  concentration from 300 to 450 mg/L, COD removal efficiency decreased from 97% to 80.50%. The electrical energy consumption for the concentration of 750 mg/L  $\text{H}_2\text{O}_2$ , where the highest COD removal efficiency (98.17%) was 11.11 kWh/m<sup>3</sup>. Fig. 8 shows the effect of different  $\text{H}_2\text{O}_2$  concentrations on color removal. At the end of 45 min, the highest color removal efficiency (95.28%) was obtained for 750 mg/L  $\text{H}_2\text{O}_2$  concentration. At the end of this minute, electrical energy consumption was found as 5.56 kWh/m<sup>3</sup>. The concentration of 750 mg/L  $\text{H}_2\text{O}_2$ , with the highest cod and color removals, was considered as optimum.

### 3.4. Effect of distance between electrodes on COD and color removal

Effects of the distance between electrodes (1.0, 1.5 cm) on COD and color removal at optimum experimental conditions (current density: 10 A/m<sup>2</sup>, pH: 3,  $\text{H}_2\text{O}_2$ : 750 mg/L, UV source: 16 W, and stirring speed: 250 rpm) were investigated. Figs. 9 and 10 show the effects of distances between electrodes on COD and color removal from wastewater, respectively. By increasing the distance between the electrodes from 1.0 to 1.5 cm, at the end of 90 min, COD removal efficiency decreased from 98.17% to 90.91%. As the distance between the electrodes increased, the removal efficiency decreased. As seen in Fig. 9, a short distance was more

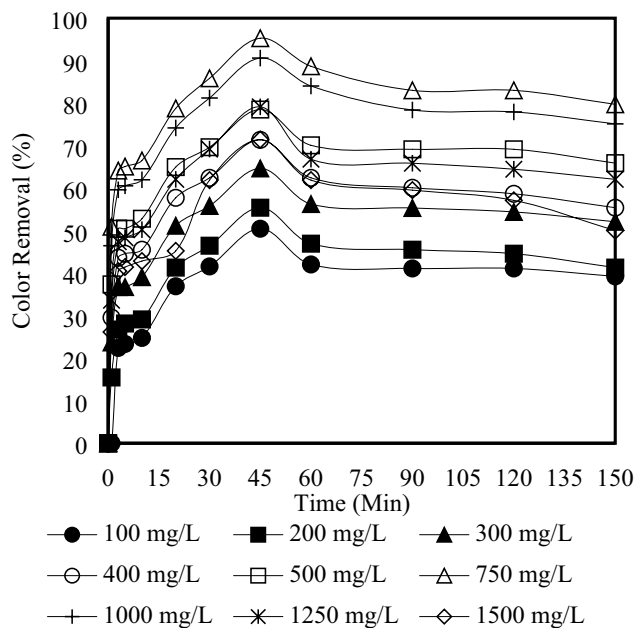


Fig. 8. Effect of  $\text{H}_2\text{O}_2$  concentration on color removal (conditions: anode: iron, cathode: steel, current density: 10 A/m<sup>2</sup>, pH: 3, UV source: 16 W, the distance between electrodes: 1.0 cm, and stirring speed: 250 rpm).

effective for COD removal. The maximum COD removal efficiency was found at the 90th min, and the electrical energy consumption was found to be 11.11, 11.15 kWh/m<sup>3</sup> for the distance between the electrodes of 1.0 and 1.5 cm, respectively. As the distance between the anode and cathode increases, electrical resistance increases which increases energy consumption [12]. As can be seen from Fig. 10, by increasing the distance between electrodes from 1.0 to 1.5 cm, color removal efficiency decreased from 95.28% to 89.57% after 45 min. The electrical energy consumption in this minute was found to be 5.56 and 5.58 kWh/m<sup>3</sup> for the distance between 1.0 and 1.5 cm electrodes, respectively.

By comparing the COD and color removals with the treatment times, it was seen that COD and color removals reached their maximum values after 90 and 45 min, respectively. At the end of 90th and 45th min when maximum COD and color removal was achieved, wastewater output pH values were measured as 4.84 and 3.77, respectively. This situation can be explained mainly by the fact that paint groups are only broken into by-products, while COD removal is provided by the further breaking of the intermediate and by-products formed. Therefore, this situation extends the COD removal period [19].

### 3.5. Cost analysis and calculations

The electrical energy consumption is calculated using Eq. (11) [20]. Anode consumption with the help of Eq. (12) [21]. Also, the electrical energy consumption of the UV power source has also been calculated:

$$E = \frac{U \times I \times t}{V} \quad (11)$$

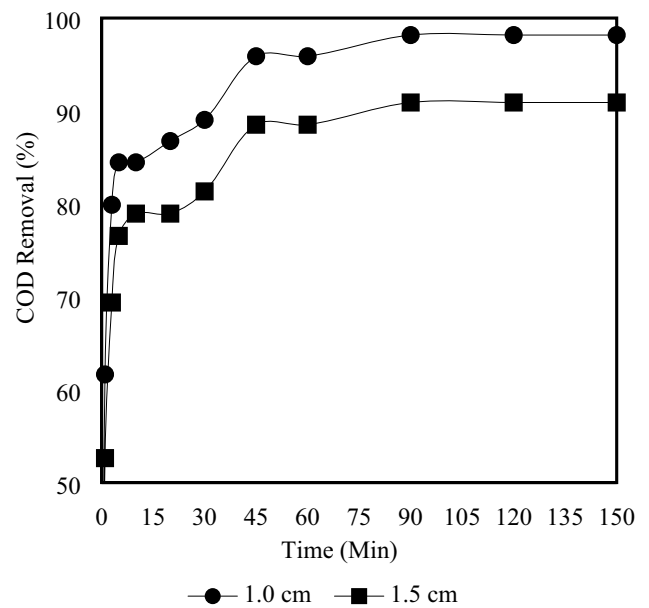


Fig. 9. Effect of distance between electrodes on COD removal (conditions: anode: iron, cathode: steel, current density: 10 A/m<sup>2</sup>, pH: 3,  $\text{H}_2\text{O}_2$ : 750 mg/L, UV source: 16 W, and stirring speed: 250 rpm).

where  $E$  is the electric energy consumption ( $\text{kWh/m}^3$ );  $U$  is the applied voltage (V);  $I$  is the applied current (A);  $t$  is the experimental time (s);  $V$  is the wastewater volume (L).

$$\Delta M = \frac{I \times t \times M}{z \times F \times V} \quad (12)$$

where  $\Delta M$  is the theoretically the amount of  $\text{Fe}^{2+}$  consumed ( $\text{g Fe}^{2+}/\text{m}^3$ );  $I$  is the applied current (A);  $t$  is the experimental time (s);  $M$  is the molecular weight of iron ( $\text{g/mol}$ );  $Z$  is the valence of iron (2);  $V$  is the wastewater volume (L).

UV source electricity

$$\text{energy consumption (kWh/m}^3) = \frac{\text{Power (W)} \times \text{Time (h)}}{\text{Wastewater volume (m}^3)} \quad (13)$$

Under optimum conditions (current density: 10 A/ $\text{m}^2$ , pH: 3,  $\text{H}_2\text{O}_2$ : 750 mg/L, UV source: 16 W, distance between electrodes: 1.0 cm, and stirring speed: 250 rpm), for COD removal; electrical energy consumption, anode consumption, and  $\text{H}_2\text{O}_2$  consumption were 11.11 kWh/ $\text{m}^3$ , 213.8 g  $\text{Fe}^{2+}/\text{m}^3$ , and 1.90 L/ $\text{m}^3$ , respectively. Total treatment cost (electrical energy consumption + anode consumption +  $\text{H}_2\text{O}_2$  consumption) was found as 29.33 US\$/ $\text{m}^3$ . The treatment cost per kg COD is 5.45 US\$/kg COD). For color removal; electrical energy consumption, anode consumption,  $\text{H}_2\text{O}_2$  consumption were found as 5.56 kWh/ $\text{m}^3$ , 106.9 g  $\text{Fe}^{2+}/\text{m}^3$ , and 1.90 L/ $\text{m}^3$ , respectively. Total treatment cost (electrical energy consumption + anode consumption +  $\text{H}_2\text{O}_2$  consumption) was found as 28.7 US\$/ $\text{m}^3$ .

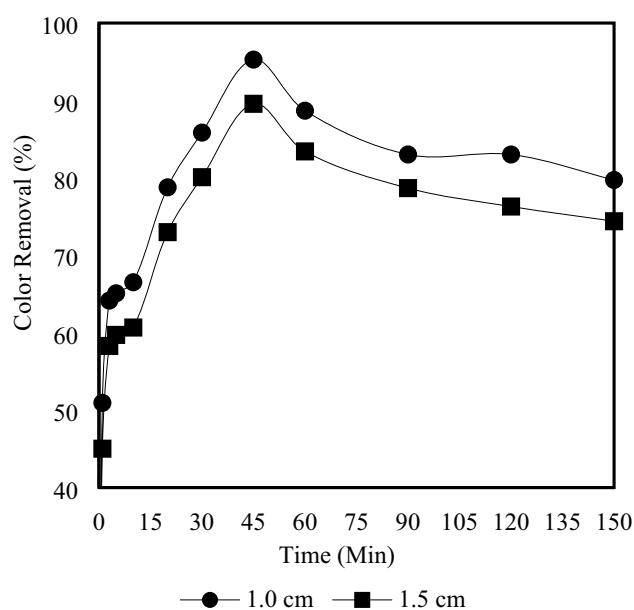


Fig. 10. Effect of distance between electrodes on color removal (conditions: anode: iron, cathode: steel, current density 10 A/ $\text{m}^2$ , pH: 3,  $\text{H}_2\text{O}_2$ : 750 mg/L, UV source: 16 W, and stirring speed: 250 rpm).

#### 4. Conclusion

In this study, the effects of various operating parameters (current density, pH,  $\text{H}_2\text{O}_2$  concentration, and the distance between the electrodes) on COD and color removal from MDF wastewater were investigated and cost analysis was performed. Under optimum experimental conditions (current density: 10 A/ $\text{m}^2$ , pH: 3,  $\text{H}_2\text{O}_2$ : 750 mg/L, UV source: 16 W, the distance between electrodes: 1.0 cm, and stirring speed: 250 rpm) a maximum of 98.17% COD after 90 min ( $\text{COD}_{\text{inlet}}$ : 5,475 mg/L,  $\text{COD}_{\text{outlet}}$ : 99.65 mg/L), and after 45 min a maximum of 95.28% color removal ( $\text{Color}_{\text{inlet}}$ : 3,922 Pt-Co,  $\text{Color}_{\text{outlet}}$ : 185.11 Pt-Co) was obtained. At the end of the 90 min treatment period, the color removal efficiency decreased to 83.02% since the color removed by the oxidation process is less than the color formed by the ferrous ions formed over time (color input: 3,922 Pt-Co, color output: 666 Pt-Co). This result showed that the COD and color parameter were not removed at the same time with high efficiencies. The maximum values of COD and color removal efficiencies were obtained with  $[\text{H}_2\text{O}_2]/[\text{Fe}^{2+}]$  molar ratios of 6.47 and 12.94, respectively. Unlike many other studies, COD removal efficiencies were higher than color removal in this study. On the other hand, the time required to efficiently remove the COD was twice that required for the color. While total cost for the maximum COD removal of 98.17% after 90 min (electrical energy consumption + anode consumption +  $\text{H}_2\text{O}_2$  consumption) was calculated as 29.33 US\$/ $\text{m}^3$ , this value was 28.7 US\$/ $\text{m}^3$  for the maximum color removal of 95.28% after 45 min. These results showed that the PEF method can be successfully applied for the treatment of MDF wastewaters containing COD and color, which are resistant to removal.

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