Original Article

Electrocoagulation Process Using Aluminum Electrodes for Treatment of Baker's Yeast Industry Wastewater

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Abstract

Background and Aims: Severe contamination with organic compounds and very high color is characteristic of yeast industry wastewater. Discharging this wastewater into the environment has adverse effects on the environment. The present study was conducted to determine the efficiency of the electrocoagulation (EC) using aluminum electrodes for the removal of color, turbidity, and chemical oxygen demand (COD) from the baker's yeast industry wastewater. **Materials and Methods:** In this experimental study, the effect of current densities (60, 80, 100, and 120 A/m^2) and reaction times (15, 30, 45, and 60 min) using aluminum electrode was investigated on removal efficiencies of COD, color, and turbidity. The pilot consisted of a reactor with a useful volume of 2.5 l of epoxy glass, a direct current power supply, and aluminum electrodes of 8 cm × 8 cm in diameter. **Results:** The highest removal efficiencies were obtained to be 83% for COD, 93% for color, and 96% for turbidity at density of 80 A/m^2 and 45-min contact time (pH = 7). Under these conditions, the power and electrode consumption was 16.89 kWh and 94.3 g/m^3, respectively, and the treatment cost of wastewater was estimated to be 1.5 $ per each cubic meter. **Conclusion:** The results showed that EC process using aluminum electrode is an appropriate and effective method for removing color, turbidity, and COD from baking industry wastewater.

Keywords: Aluminum electrode, baker's yeast wastewater, electrocoagulation, treatment

Introduction

Increased global demand for bread as a staple food in many countries, especially Iran, has turned yeast industry into an important and developing industry.[1] Throughout this industry, sugar beet molasses, which is a combination of sugar and nonsugar organic components, minerals, and water, is used as a main raw material.[2] During the fermentation process, the sugar in molasses is used as a carbon and energy source, but other compounds in molasses alongside the chemicals added during the process, the remaining yeast cells, and the materials resulting from yeast activity are introduced into the process wastewater.[3,4] These types of wastewaters conventionally contain high amounts of chemical oxygen demand (COD), biochemical oxygen demand (BOD), nitrogen and sulfate, unpleasant odor, and very dark brown color.[5] The dark brown color of this wastewater caused by a pigment called melanoidins is due to the compounds resistant to biodegradation and causes disturbance in natural process of photochemical reactions and delay in self-purification of surface water through disturbing sunlight absorption.[6] Because of numerous environmental problems, treating this wastewater prior to discharge into the environment is essential. To date, different approaches have been adopted to treat the wastewater of this industry.[6] Biological treatment, a combination of aerobic and anaerobic systems, decreases BOD to an acceptable level, but it is not efficient for removal of color and COD. In addition, anaerobic treatment process is very slow and requires a long period of commissioning.[7] Although oxidation methods cause a decrease in color, they have no notable contribution to removing COD;[8] and membrane processes are prone to fouling and clogging.[9] Furthermore, the application of reverse

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osmosis technology due to creating high salinity can cause problems for disposal.[10]

Although chemical coagulation and adsorption cause removal of color and COD, it has some problems such as the coagulant high dosage and adsorbent regeneration-related problems and requires high costs at full-scale operation.[11,12] In recent years, electrocoagulation (EC) has been widely used for strong industrial wastewater, because of unique advantages including no need for chemicals and production of low sludge, being environmentally friendly, easy operation and maintenance, shorter treatment time, low dependence on wastewater characteristics, and sustaining till power supply for electrodes.[13,14]

EC is the process of destabilizing suspended, colloidal, or dissolved pollutants, in an aqueous solution using an electric current in a solution, through which the particles overcome Van der Waals force between themselves by reducing the surface charge and produce flocs.[15] This technology is the integration of three basic techniques of electrochemistry, coagulation, and flotation.[16] The destabilization mechanism of the contaminants in EC process includes compression of the diffuse double layer around the charged species by the interactions of ions generated by oxidation of the sacrificial anode, and creation of hydroxyl ions by hydrolysis of metal ions and hydrogen gas production in cathode based on Faraday's law[17] (Equation 1).

$$M_{(s)} + (2+n)H_2O \rightarrow (2+n/2)H_{2(g)} + O_{2(g)} + n(OH^-) + M^{n+} \quad (1)$$

Charged pollutants are removed while they are influenced by the interaction of the ions produced by dissolution of neutral sacrificial electrode and/or their absorption by each other (i.e., coagulation). Furthermore, the hydrogen gas which is released in cathode electrode causes further removal of pollutants through floating some of the existing flocs in the solution.[18] Because of advantages such as containing insoluble hydroxides and cheapness, the electrode plates are mainly made up of iron and aluminum as compared with other metals with similar properties.[19]

A study of recent investigations indicates that EC process has been already used successfully for the treatment of food industries' wastewater, including dairy industry,[20,21] olive oil industry,[22] poultry slaughterhouse,[23] vegetable oil refinery,[24] and other food industries. Despite many studies on treatment of food industries' wastewater by EC, few studies have been conducted on this method with regard to treating baker's yeast industry wastewater. Regarding the abovementioned, the present study was conducted to determine the efficiency of the EC using aluminum electrodes for the removal of color, turbidity, and COD from the baker's yeast industry wastewater.

Materials and Methods

This experimental study was conducted in laboratory-scale batch reactor with full-factorial method design. Samples were collected from baker's yeast raw wastewater plant of Naghan located 80 km from Shahrekord, Iran. This plant produces 2500 tons of dry yeast for bakery per year and generates 600 m^3/d wastewater. The samples were stored at 4°C and transferred to the laboratory within at most 1 h. In this study, the efficiency of EC using aluminum electrodes for removal of turbidity, color, and COD was evaluated at contact times of 15, 30, 45, and 60 min and the current density of 60, 80, 100, and 120 A/m^2.

The pilot of EC used in this study was obtained from a 15 cm × 15 cm × 12 cm, epoxy glass reactor with useful capacity of 1250 ml. Four 8 cm × 7 cm, aluminum electrodes were placed in parallel at a 3-cm distance from each other in the tank that they were operated as dipolar. A magnetic mixer mixed the samples within the reactor uniformly at 150 rpm. The required power for the process was provided by a direct current supplier. Figure 1 depicts the scheme of the EC reactor used in this study.

At every step, 1250-ml wastewater was entered into the reactor, and after applying the current density in interval specified time, sampling was done at the abovementioned intervals, and after passing through 0.45-µm Whatman filter, the specified qualitative parameters were analyzed.

All the experiments were conducted at 20°C and in triplicate.

COD was tested by 5220B, color was measured by direct reading spectrophotometer (DR 2000), pH was tested with 4500-HB method (METTLER pH meter, Model Mp230), total suspended soilds (TSS) test was done based on 2540D and total dissolved solids (TDS) test per 2540C.[25]

It should be noted that before each round of testing, the grease on the electrode surface was washed by acetone, and the impurities on their surface were cleared by immersion in the solution containing 100-ml hydrochloric acid (HCl) 3.5% and 200-ml aqueous solution of hexamethylenediamine 2.8% for 5 min.

To measure the used electrodes, we placed the electrodes in HCl 2% solution after completion of the process and dried them

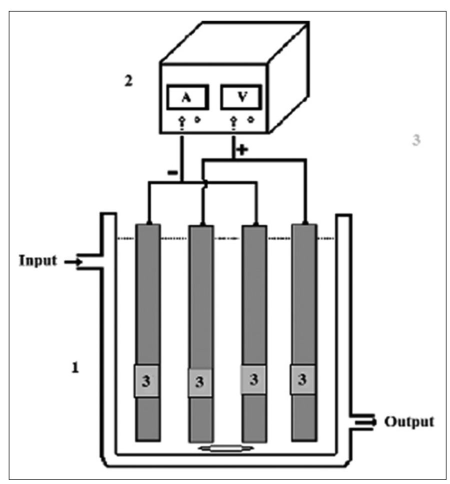

Figure 1: Scheme of the electrocoagulation reactor: 1: Electrocoagulation reactor, 2: Direct power supply (direct current), 3: Electrode position (bipolar connection)

in the oven after rinsing with water. Then, the electrodes were weighed by a digital weight scale.[26] The consumed power was measured using Equation 2:

$$E = \frac{UIt}{v} \quad (2)$$

Where: E: the consumed power (kWh/m^3 treated wastewater), U: voltage (Volt), I: current (A), t: reaction time (h), and V: volume of solution (l). The data were analyzed by Excel (office 2016) and SPPS$_{18}$.

Results

Table 1 indicates the quantitative and qualitative characteristics of raw wastewater used in this study. Figure 2 illustrates the effect of EC operation time on the COD, color, and turbidity removal efficiencies in current density of 60 A/m^2.

The effect of EC operating times (15, 30, 45, and 60 min) on removal of COD, color, and turbidity is depicted in Figure 3. As illustrated in this figure with increasing in EC operating times and current density, the removal efficiencies increased.

With respect to effect of current density in EC operation, in the next stage of study, current density was elevated to 100 A/m^2 and 120 A/m^2. The result of influence of EC operating times on removal of COD, color, and turbidity in current density of 100 and 120 A/m^2 is illustrated in Figures 3 and 4, respectively.

In this study, after each experiment, aluminum electrodes were weighed and the consumed anode electrode was quantified. In addition, the amount of consumed power was measured in kWh/m^2. Table 2 demonstrates the effect of current density on the amount of consumed electrode and power in different reaction times. From this table, it can be concluded that as the reaction time and the applied current density increase, the quantity of electrode and power consumption increases, so that the highest weight loss in the anode electrode and maximum power consumption was seen at the current density of 120 A/m^2 and reaction time of 60 min and the least weight loss in the anode electrode and minimum power consumption at the current density of 60 A/m^2 and reaction time of 15 min. At optimal operating conditions, the rate of electrode consumption

Table 1: Characteristics of the raw wastewater that used as samples in the experiment

Parameter	Unit	Values
BOD_5	mg/L	7500
COD	mg/L	10,000
EC	mS/cm	17.22
TDS	mg/L	11,105
TSS	mg/L	1846
TP	mg/L	47.5
Total count	No/250 mL	160
Flow	m^3/d	600
Color	TCU	17,400
Turbidity	NTU	3200
pH	-	5.4-6.5

BOD: Biochemical oxygen demand, COD: Chemical oxygen demand, EC: Electrocoagulation, TDS: Total dissolved solids, TSS: Total suspended solids, TP: Total phosphorus

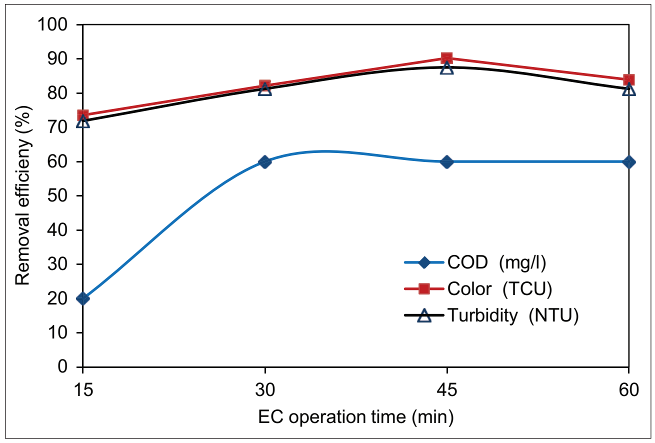

Figure 2: Effect of electrocoagulation operation time on the chemical oxygen demand, color, and turbidity removal efficiencies (pH = 6.5, current density = 60 A/m^2)

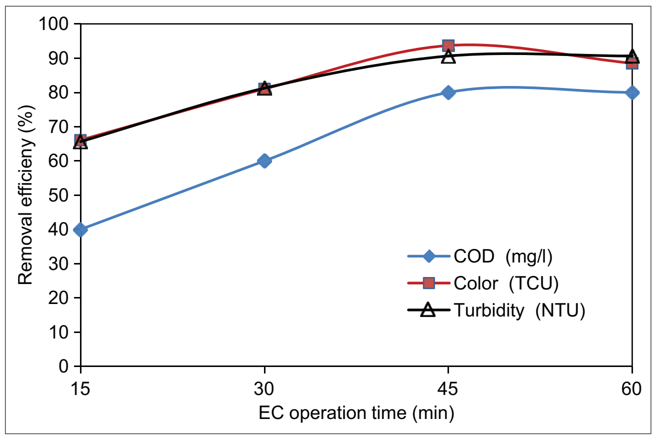

Figure 3: Effect of electrocoagulation operation time on the chemical oxygen demand, color, and turbidity removal efficiencies (pH = 6.5, current density = 80 A/m^2)

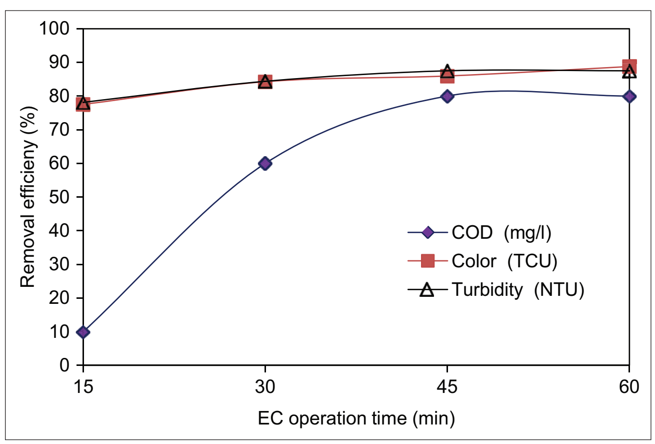

Figure 4: Effect of electrocoagulation operation time on the chemical oxygen demand, color, and turbidity removal efficiencies (pH = 6.5, current density = 100 A/m^2)

Table 2: Effect of current density on the amount of consumed electrode and power in different reaction times

Current density (A/m²)	Reaction time (min)			
	15	30	45	60
60				
Amount of electrode consumed (g/L)	0.0226	0.036	0.053	0.1048
Amount of energy consumed (kWh/m³)	3.12	6.49	10	14.44
80				
Amount of electrode consumed (g/L)	0.0426	0.0526	0.0943	0.1447
Amount of energy consumed (kWh/m³)	5.18	10.03	16.89	21.38
100				
Amount of electrode consumed (g/L)	0.071	0.1158	0.1573	0.1765
Amount of energy consumed (kWh/m³)	6.11	11.37	17.51	22.89
120				
Amount of electrode consumed (g/L)	0.1367	0.198	0.23	0.29
Amount of energy consumed (kWh/m³)	8.56	16.74	27.46	35.51

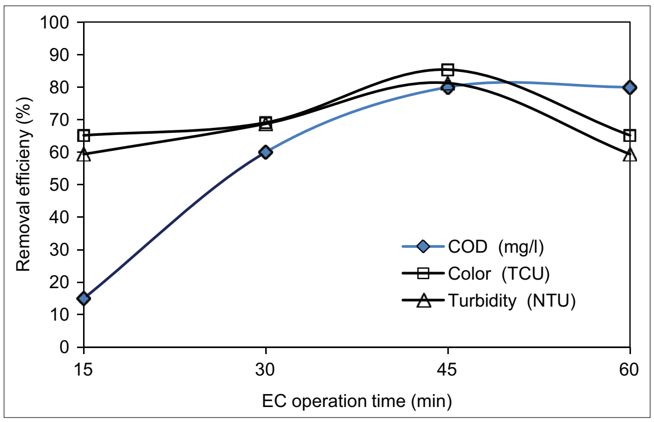

Figure 5: Effect of electrocoagulation operation time on the chemical oxygen demand, color, and turbidity removal efficiencies (pH = 6.5, current density = 120 A/m²)

was obtained to be 94.3 and the consumed power 16.89 kWh per each cubic meter of wastewater.

Discussion

Current density is a determinator of two factors affecting the efficiency of the process, including the amount of coagulant released from the anode electrode and the amount of the bubble generated in cathode electrode. Oxidation rate increases with increasing current density, and then, the efficiency of the formation of metal ion on the anode and cathode improves and consequently further aluminum hydroxide is precipitated.[27,28]

Increased production of flocs results in improved efficiency of pollutant removal.[29] The flocs formed as a result of coagulation form a sludge blanket that traps colloidal particles still in the aqueous medium.[30,31] Furthermore, at higher currents, the produced H2 bubbles in the cathode increase and their diameter decreases.[32,33] This creates a rapid upward current, and the contaminants will be removed more speedily through the sludge flotation.[27] The fact that the treatment efficiency increases with increasing current density has been demonstrated by other researchers, as well.

For example, Drouiche *et al*., in a study of fluoride removal using aluminum electrodes, concluded that fluoride ions are removed more efficiently because of increased production of Al^{+3} with increase in the current.[34] Furthermore, Rahmani and Samarghandi study of efficiency of COD removal from wastewater using EC method found that with increasing current density, the removal efficiency increased.[19] In addition, increased current reduced the time required for treatment. In our study, the highest removal efficiency at current density of 80 A/m² and contact time of 45 min was obtained to be 83% for COD, 93% color, and 96% for turbidity.

Increase in the current density to more than 80 A/m² does not cause a significant change in the removal efficiency. This is due to the fact that at very high currents, metal ions are produced much more rapidly compared with the coagulation process, and therefore, pollutant removal efficiency decreases.[35] Too much increase in the current density leads to side effects such as heat production as well as increased production of sludge.[13]

According to obtained results of batch study experiments by Arbabi *et al*., optimum operating conditions of EC process for baker's yeast wastewater treatment were achieved using stainless steel electrode at current density of 120 A/m² and retention time of 45 min. Based on the results from optimum conditions, the removal efficiencies of COD, turbidity, and color were obtained around 55%, 45%, and 40%, respectively. Electrode corrosion and energy consumption rates were 0.086 g/L and 3.226 Watt/L, respectively.[3]

Jafarzade and Daneshvar also suggested current density of 100 A/m² as the optimal current density for treatment of textile industry wastewater.[28] Kobya and Delipinar, in a laboratory-scale study of baker's yeast industry wastewater treatment using EC, reported the highest efficiency removal of COD and total organic carbon as, respectively, 71.53% and 90% at pH of 6.5, current density of 70 A/m², and operating time of 50 min.[2] In another study in 2013, on baker's yeast wastewater treatment using EC by Gengec and Kobya, at current density of 80 A/m^2 and contact time of 20 min, they removed 86% and 43% of color and COD, respectively.[36]

As the time of reaction increased, the removal efficiency increased for all parameters of turbidity, color, and COD, as well. Since the removal efficiency of pollutants is directly correlated with the number of produced ions and according to Faraday's law, over time, the amount of produced ions increases with increasing the contact time, the pollutant removal efficiency increases, as well.[27,37] Hashemi *et al*.,[38] and Massoudinejad *et al*.,[39] also found that as the contact time increased, the efficiency removal increased, which is consistent with the present study.

In the present study, the highest removal efficiency was observed in the reaction time of 45 min. After 45 min, the slope of removal efficiency line was not significantly increased. In other words, after 45 min, removal efficiency did not increase remarkably and continuation of the process was not economical. In view of stable rate of removal for COD, color, and turbidity after 45 min, and for consumption of less energy throughout the EC process, the time of 45 min was regarded as the optimal retention time in the present study.

The cost of operating is one of the most important factors in choosing an approach to treating wastewater. During the EC, one of the most important parameters that affect the cost of operating is the cost of used electrodes and power.[40] Different studies have indicated that although the efficiency of pollutant removal increases with increase in current density throughout EC process, the consumption of electrodes and power goes up, as well.[41] The cost of treating one cubic meter of baker's yeast wastewater by EC at optimal operating conditions (current density of 80 A/m^2, time of 45 min, and pH of approximately 7) was estimated to be 1.5 $.

In this study, the COD concentration in baker's yeast wastewater reduced from 10000 mg/l to 2000 mg/l using EC process. EC process can significantly reduce the COD of this type of wastewater, but for further removal of COD, and achieving discharge standard, it still require to sufficient treatment.

Conclusion

In this study, the efficiency of EC for removal of color, turbidity, and COD was investigated. The results indicated that the efficiency of removal of all three mentioned parameters was directly correlated with increase in retention time and current density. Furthermore, the consumption rate of energy and electrode increased with increase in the current density. The highest efficiency of pollutant removal was obtained to be 83% for COD, 93% for color, and 96% for turbidity at density of 80 A/m^2 and 45-min contact time with no change in pH of the wastewater (approximately 7). Under these conditions, the power and electrode consumption was 16.89 kWh and 94.3 g/m^3, and the cost of treating 1 cubic meter of wastewater was estimated to be 1.5 $.

Finally, EC using aluminum electrodes could be a suitable approach to treating baker's yeast industry wastewater in view of some properties such as flexibility, low volume of produced sludge, user-friendly equipment, easy commissioning, and no need for chemicals.

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Conflicts of interest

There are no conflicts of interest.

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