Electrocoagulation in batch mode for the removal of the chemical oxygen demand of an effluent from slaughterhouse wastewater in Lima Peru: Fe and Al electrodes

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ABSTRACT

In order to study the treatment of wastewater from a meat plant in a batch reactor, the electrocoagulation (EC) process with aluminum and iron electrodes was applied. Foams formed with iron electrodes show brown, greenish, and reddish colors, and foams formed with aluminum electrodes mainly show a whitish color. The effects of the applied voltages (6, 8, and 10 V) were analyzed over time on parameters such as current density (A/m²), pH, temperature, removal percentage of ionic conductivity (μS/cm), turbidity (nephelometric turbidity units), chemical oxygen demand (COD), thermotolerant coliforms, and oil–grease. The removal efficiencies for turbidity and COD in meat industry wastewater-slaughterhouse wastewater that were obtained were 99%, and 53%–59%, for aluminum, and 81.5%–88.5%, and 59%–60% for iron electrodes and 25 min EC time respectively. At 6 V the energy consumption per unit volume of treated effluent (kg/m³) and per kg COD removed (kwh/kg COD) with Al and Fe electrodes were (3.07 and 0.84) and (2.99 and 0.90), respectively. The EC process with Al and Fe electrodes proved to be a technique that removes contaminants from slaughterhouse wastewater with good yields.

Keywords: Electrocoagulation; Fe/Al electrodes; COD; Slaughterhouse; Esmeralda Corp S.A.C.

1. Introduction

Water is vital for life, as well as for sustaining life on our planet. For these reasons, we are compelled to use it responsibly. Water is the greenest substance imaginable [1] essential for life [1,2], and totally recyclable [1]. Manufacturing and other kinds of industries use water during their production process for either creating their products or for cooling equipment used in creating their products [3].

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Water pollution is adding something to the water by humans that alter its chemical composition, temperature [4,5], or microbial composition to such an extent that harm occurs to resident organisms or to humans [4]. Water pollution occurs when unwanted materials enter into the water, changes the quality of water [6,7], and alters its chemical composition, temperature [4,5], or microbial composition to such an extent that harm occurs to resident organisms [4], human health [4,8] and environment [8]. There are strict laws in all countries for pollution control which must be complied with. Modern management are of the opinion that it is better to improve the working and process efficiency of the chemical plants so that the generation of effluents can be minimized if not discharged altogether [9]. Wastewater of a meat plant is full of insoluble and soluble organic contaminants [10], such as fats, carbohydrates, proteins, organic acids [11], and inorganic and organic solids [10,12]. Untreated wastewater from meat processing typically contains high levels of oxygen demand substances (like blood, fat, urine, and feces) [13,14] total suspended solids [13,15], ammonia, nitrogen, phosphorus, oil and grease, fecal bacteria, and pathogens [13,16,17]. Blood, one of the major dissolved pollutants in abattoir wastewater, has the highest chemical oxygen demand (COD) of any effluent from abattoir operations [15]. In several works, a value of 375,000 mg/L is mentioned for COD [10,18–21]. When released into waterways in large quantities and high concentrations, these pollutants can cause extensive damage to waterways [13,17]. They drive excess algae growth [13,15], create low oxygen dead zones that suffocate fish and other aquatic life, and turn waterways into bacteria-laden public health hazards [13]. Effluent discharge from slaughterhouses has caused rivers to deoxygenate [19,20,22], and has caused groundwater to contaminate [20,23]. The conventional wastewater treatment plant (WWTP) processes are designed primarily for the removal of organic matter, nitrogen, phosphorus, and pathogens [24]. Electrocoagulation technology reduces contaminant levels by passing an electrical current through water, which generates coagulant precursors by electrolytic oxidation of sacrificial anode material usually aluminum or iron [24,25]. During the EC process, amorphous insoluble polymeric metal hydroxides and oxides are formed, which adsorb (particulate and dissolved) pollutants during precipitation, making them easily separable [24,26], by either complexation or electrostatic attraction followed by coagulation [27]. For example in surface complexation mode, the pollutant acts as a ligand (L) to chemically bind to hydrous iron [Eq. (1)] [28]:

$$L-H(aq)+(OH)OFe(s) \rightarrow L-OFe(s)+H_2O(l) \quad (1)$$
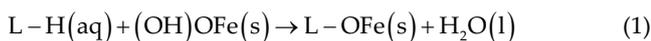
In the case of aluminum electrodes, soluble and insoluble pollutants can be coagulated by aluminum hydrates and hydroxides and then effectively removed from effluent due to the existence of monomeric and polymeric species over a wide pH range [27,29]. In the case of Al, the contaminant also acts as a ligand (L) to chemically bind to aluminum hydrous [30]:

$$L-H(aq)+(OH)(OH)_2 Al(s) \rightarrow L-(OH)_2 Al(s)+H_2O(l) \quad (2)$$
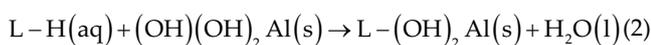
The calculation of ionic conductivity (μS/cm), turbidity (nephelometric turbidity units, NTU), and COD removal percentage after EC process were performed using the following formula [Eq. (3)].

$$XR(\%) = \frac{X_0 - X_t}{X_0} \times 100 \quad (3)$$

where X_0 is the initial value of the parameter to analyze, and X_t is the value of the parameter after an EC processing time. Energy consumption (kwh) and energy consumption per unit volume (kwh/m³) were evaluated with the following formulas:

$$Energy(kwh) = 0.001V \times I \times t \quad (4)$$

$$Energy(kwh/m^3) = 0.001V \times I \times t / V_t \quad (5)$$

where V (volt), I (current, A), t (time, h), and V_t (treated volume).

The main objective of this research was to analyze the electrocoagulation process as a primary treatment, analyzing the removal of organic matter from wastewater from a cattle, poultry, and pig slaughterhouse using Al and Fe electrodes.

2. Materials and methods

In this study, we worked with the effluent generated at the Esmeralda Corp., S.A.C. company, located in the district of San Juan de Miraflores (SJM), Province of Lima, Department of Lima, Peru. The tributary is generated due to the various activities that are developed in the Meat Business Unit involved in the slaughter of cattle, pigs, and other kinds of animals. Blood, fats, and ruminal material are incorporated into the water, along with the washing waters of the equipment and process facilities containing detergents and surfactants which are discharged into the wastewater. These waters with high organic and microbiological content make up line 3 of the tributary of the wastewater treatment plant (WWTP) with an approximate flow of 130 m³/d. Fig. 1 shows the homogenizer tank with a capacity of 170 m³ from which the water samples for this research were obtained. It is important to mention that, according to law, the effluent produced in this WWTP cannot be discharged into the sewage system; and it is delivered in donation to the municipalities of the districts of San Juan de Miraflores and Villa María del Triunfo in the southern zone of Lima for the irrigation of parks and gardens.

2.1. Batch mode

Fig. 2 shows the system for the removal of pollutants in batch mode. It was designed to treat 5 L of water, in the form of a parallelepiped whose internal dimensions are 0.13 m × 0.20 m × 0.25 m of transparent Plexiglas material, whose thickness was 0.009 m. The separation between the anode and cathode was 0.03 m. The dimensions of the electrodes were 0.15 m × 0.133 m × 1/16″. The reactor has a

Fig. 1. Storage of the meat effluent in the equalizing tank after pretreatment (screening and sedimentation).
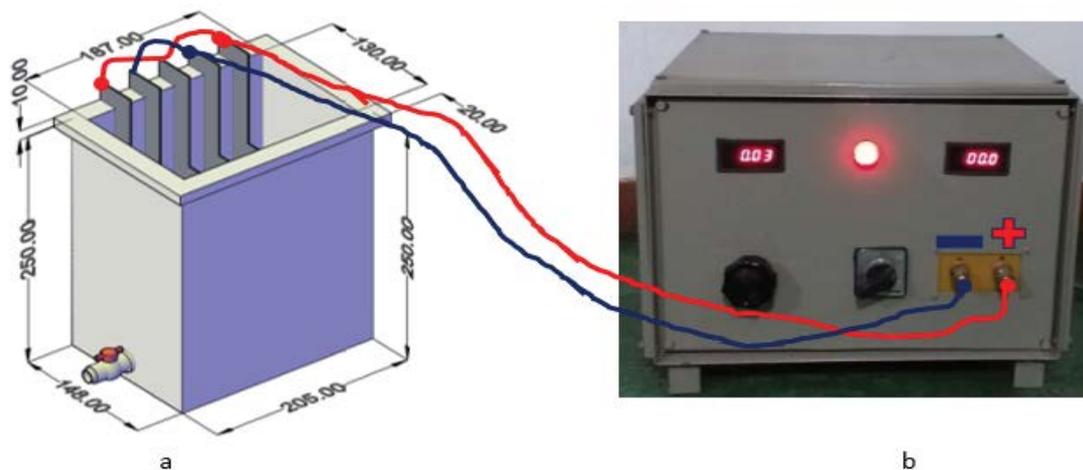
Fig. 2. System batch mode: electrolytic cell (3 anodes and 2 cathodes), power source (0–20 V and 0–100 A).

1/2″ ball valve for the discharge of the treated effluent. We worked with three voltages: 6.0, 8.0, and 10.0 V corresponding to current densities in the range of 47–103 A/m². The initial voltage of 6.0 V was experimentally selected where the process is sustained over time and changes are notorious in gas production, formation of flocs as well as change in water color. The characteristics of the power source were voltage variation range of 0–30 V and amperage of 0–100 A. Samples for analysis of the different parameters of the effluent treated by electrocoagulation were collected at 10, 25, 45, and 60 min. The experimental development was organized to analyze the effect of the voltage applied over time on the parameters: current density, pH, temperature, removal of ionic conductivity, turbidity (NTU), COD, and fecal coliform bacteria.

Temperatures were measured using a multi-thermometer-91000–050/F. A combo pH and EC-HI 98129 Hanna Instruments instrument were used to measure pH and conductivity. A 2100AN-turbidimeter Hach model was used to measure turbidity. A HI 83980 COD reactor-Hanna Instruments thermoreactor and a HI 83224 WTP-Hanna Instruments multiparameter photometer were used to measure COD. Hanna Instruments and Hach are headquartered in Woonsocket, Rhode Island and Loveland, Colorado in United States, respectively. The equipment was purchased in Peru from the EQUINLAB S.A.C Company, representative and authorized distributor of both companies in Peru.

3. Results and discussion

3.1. Electroflotation of pollutants

Electroflotation is a unitary operation to separate a solid phase from a liquid phase [31]; floating pollutants to the water surfaces [32], using the generated gas *in situ* consisting of hydrogen and oxygen produced by water electrolysis. Fig. 3 shows the reactor working in batch mode with Fe (a and b) and Al (c and d) electrodes and the differences
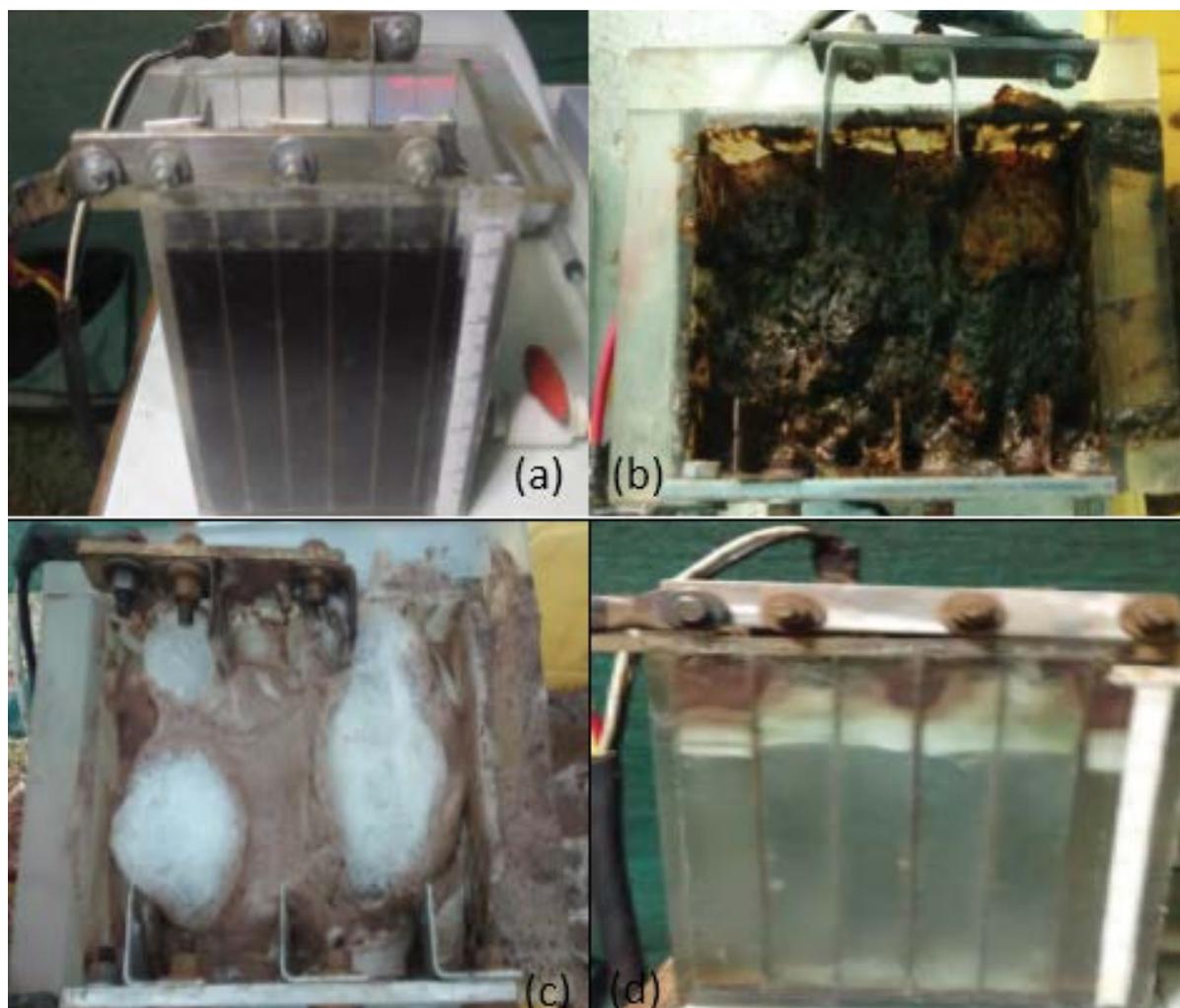
Fig. 3. (a) Batch reactor with the effluent, (b) EC process with 3 Fe anodes and 2 Fe cathodes at 8 V and 25 min, (c) EC process with 3 Al anodes and 2 Al cathodes at 8 V and 25 min, and (d) effluent at the end of the EC process.

in color of the floated foams. The different colors observed in floated foams are explained by considering the different oxidation states of Fe and the compounds it forms [33]. The reddish-brown color (Fig. 3b) consists of three layers of iron oxide at different oxidation states [Eqs. (6–8)]: hydrous ferrous oxide $FeO \cdot nH_2O$ (or ferrous hydroxide $Fe(OH)_2$). $Fe(OH)_2$ is usually green, turns greenish-black (Fig. 3b) because of oxidation by air.

$$Fe^{2+}(aq) + 2OH^-(aq) \rightarrow Fe(OH)_2(s) \quad (6)$$

$$Fe(OH)_2(s) + (n-1)H_2O(l) \rightarrow FeO \cdot nH_2O \quad (7)$$
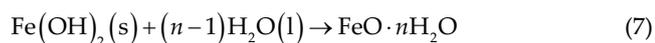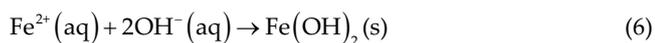
When the oxygen is dissolved in water or when the foam reaches the surface of the water, it converts the ferrous oxide into ferric oxide hydrated ($Fe_2O_3 \cdot H_2O$) or ferric hydroxide ($Fe(OH)_3(s)$). This oxide is orange to red–brown (observed) in color and most of it is ordinary rust, and it is explained with Eqs. (8) and (9) Mixtures of Fe(II)–Fe(III) hydroxides are also green.

$$4Fe(OH)_2(s) + O_2(g) \rightarrow 2Fe_2O_3 \cdot H_2O(s) \quad (8)$$

$$Fe^{3+}(aq) + 3OH^-(aq) \rightarrow Fe(OH)_3(s) \quad (9)$$
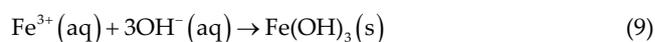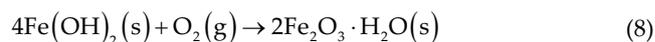
Aluminum hydroxide ($Al(OH)_3(s)$) forms white hydrogel foam on the surface of the water. The hydrogel foam may have a gray color [34] (Fig. 3c) that is produced by the excess of aluminum hydroxide that dissociated generates Al(s) [Eq. (10)] [34,35].

$$Al(s) + 3(OH)^-(aq) \rightarrow Al(OH)_3(aq) + 3e^- \quad (10)$$
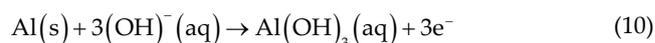
The chemical equations that explain the anodic and cathodic process of the formation of these gases are explained below [Eqs. (11–13)] [31,36]:
Anode reaction:

$$2H_2O(l) \rightarrow 4H^+(aq) + O_2(g) + 4e^- \quad (11)$$

Cathode reaction:

$$4H_2O(l) + 4e^- \rightarrow 4OH^-(aq) + 2H_2(g) \qquad (12)$$

Total reaction:

$$2H_2O \rightarrow 2H_2(g) + O_2(g) \qquad (13)$$
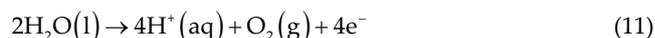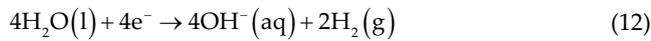
The gas bubbles which adhere to one phase (oil and grease) causes a decrease in the apparent density of that phase such that it will rise and float [31,37,38]. The coagulant species is formed by the electrolytic oxidation of the anode (M) and the process is as follows. Oxidation of the anode (M):

$$M \rightarrow M^{n+} + ne^- \qquad (14)$$

Here, we will not show the chemical equations of the different species that are formed by hydrolysis from the oxidized species M^{n+} formed of Fe or Al. These processes are explained extensively in several articles and books [14,39–44]. The applied current density determines the production speed of the coagulant, and the gas bubbles [44,45]; and the gas bubbles have a significant role in the controlling of the electroflotation process [46,47]. If the current density increases, the size of the bubbles decreases [48,49]. The size of the bubbles has a direct effect on the removal of oils and fats. It depends on several parameters: pH, current density, and electrode material [44]. In neutral and alkaline media the size of the hydrogen gas bubbles varied from 15 to 20 μm and the oxygen bubbles from 30 to 55 μm [49]. The smaller bubbles have more contact area and a greater probability of interacting with the flocs maintaining the stability of the formed flocs [50]. Hence hydrogen bubbles are more effective in the process of removal than oxygen bubbles. The removal mechanism could be via adsorption, charge neutralization, or sweep coagulation [51–53].

3.2. Effect of applied voltage on current density

Fig. 4 shows the behavior of the current density with Al and Fe anodes during the EC process, with voltages of 6, 8, and 10 V. In both cases, after 25 min the current density has a more stable profile. In all cases, the current density with Al anodes is greater than the processes with Fe anodes. The average current densities for these voltages with Al electrodes were: 52.48 ± 2.51, 71.79 ± 5.21, and 95.21 ± 9.80 A/m², and with Fe electrodes were: 51.11 ± 1.90, 68.89 ± 5.09, and 87.01 ± 9.32 A/m². In all electrochemical process, the current density is the most important parameter for controlling the reaction rate within the EC reactor [54,55]. It determines the production rate of coagulant adjusts bubble production, and hence affects the growth of flocs [54,56].

Other studies for the removal of contaminants from wastewater from the food sector in batch mode show very varied current densities. Some examples with Fe electrodes are dairy wastewater (270 A/m², [57] and 60 A/m² [58]), and potato chips manufacturing (300 A/m², [59]). Some examples with Al electrodes are potato chips manufacturing (20 A/m², [59]), almond industry (50 A/m², [60]), and vegetable oil refinery (350 A/m², [61]).

3.3. Effect of applied voltage on pH

Fig. 5 shows the effect of the applied voltage on the pH. The initial pH of the effluent varies in a range of 7.8–8.16. In all cases, there is an increase in pH. For the same voltage, the greatest change in pH occurs with Fe anodes. These pH changes in 25 min with Fe and Al anodes were (1.00, 1.2, and 1.34) and (0.17, 0.24, and 0.12), respectively. These values in 60 min were (1.54, 1.96, and 1.92) and (0.06, 1.06, and 0.49), respectively. Hydroxyl ions are produced continuously in the cathode as shown in Eq. (7), and the increase in pH can be attributed to the imbalance between the production and consumption of hydroxyl ions to neutralize
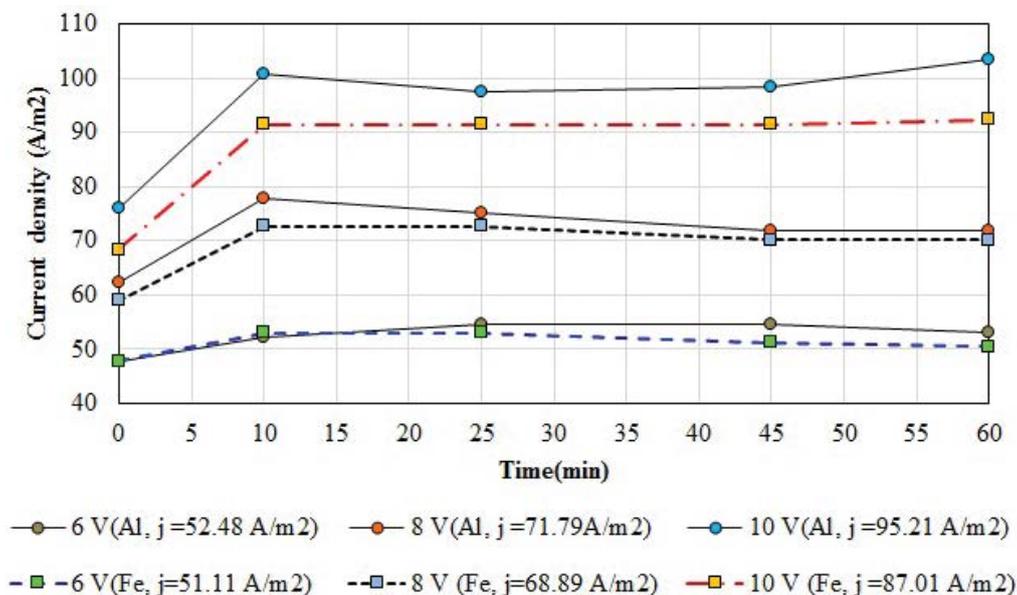
Fig. 4. Effect of voltage on current density with Al and Fe electrodes: 3 Al anodes and 3 Fe anodes.
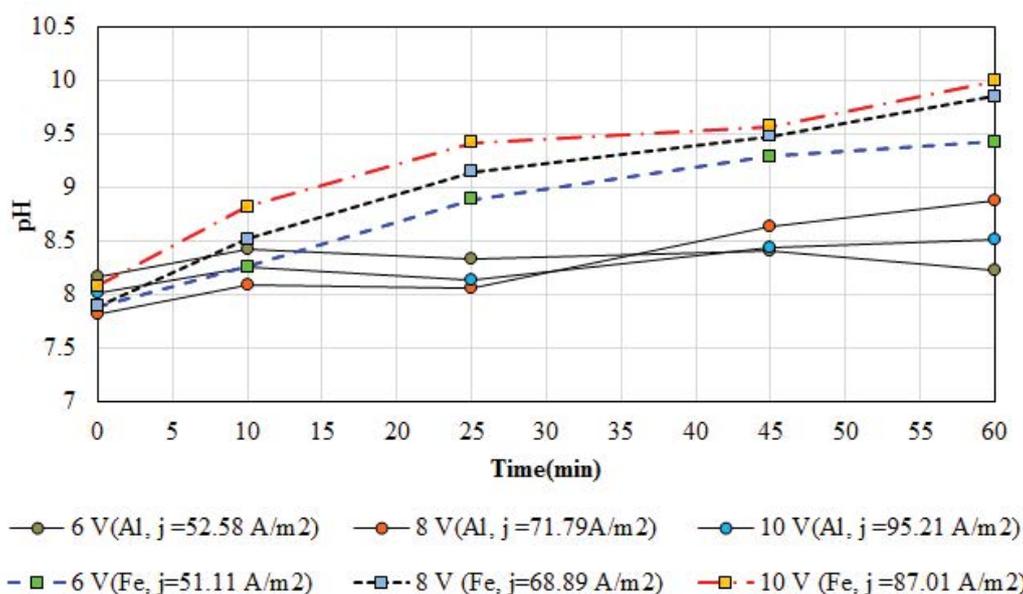
Fig. 5. Effect of voltage on pH with Al and Fe electrodes: 3 Al anodes and 3 Fe anodes.

opposite charges before these ions finally form iron or aluminum hydroxide. In addition, the pH may increase due to low water buffering capacity [62]. As can be observed for the process with Al anodes, the pH stabilizes faster with respect to the process with Fe anodes in a range of 8–9. This is due to the buffering effect of hydroxo-aluminum species that balance the quasi-static variation of the concentration of hydroxyl ions through the formation of monomeric and polymeric complexes of aluminum hydroxides. Several acid–base pairs can be formed in the medium that buffer the pH, the value is around 9 [63]. For a pH range between 4 and 9, adsorption occurs, Al^{3+} and OH^- ions generated by the electrodes react in order to form various monomeric species such as $Al(OH)_2^+$, $Al(OH)_2^{2+}$ etc., and polymeric species such as $Al_6(OH)_{15}^{3+}$, $Al_7(OH)_{17}^{4+}$, and $Al_{13}(OH)_{34}^{5+}$ that finally transforms into insoluble amorphous $Al(OH)_{3(s)}$ through complex polymerization/precipitation kinetics [59,64,65]. Ferric ions electrochemically generated may form monomeric ions, ferric hydroxo complexes with OH– ions, and polymeric species. These species/ions are: $FeOH^{2+}$, $Fe(OH)_2^+$, $Fe_2(OH)_2^{4+}$, $Fe(OH)_4^-$, $Fe(H_2O)_5 \cdot OH^{2+}$, $Fe(H_2O)_4 \cdot (OH)_2^+$, $Fe(H_2O)_8 \cdot (OH)_2^{4+}$, and $Fe_2(H_2O)_6 \cdot (OH)_2^{2+}$, which further react to form $Fe(OH)_3(s)$ [66,67]. The pH of the effluent changes slightly when the initial pH value is in the neutral range of 6–8 [27]. Moreover, hydrogen bubbles produced at the cathode are smallest and finest at neutral pH, providing sufficient surface area for gas–liquid–solid interfaces and mixing efficiency to favor the aggregation of tiny destabilized particles and colloids [27,68,69].

3.4. Effect of applied voltage on temperature

Fig. 6 shows the variation of the water temperature with the voltage applied during the EC process. An excellent linear relationship is obtained with both electrodes. For the same voltage, the variation in temperature (T/°C) over time (t/min) in all cases is always greater for Al:

For 6V:

Al: $T_{Al} = 0.175t + 18.621$, $R^2 = 0.988$, $dT_{Al}/dt = 0.175$
Fe: $T_{Fe} = 0.1341t + 19.526$, $R^2 = 0.993$, $dT_{Fe}/dt = 0.134$

For 8V:

Al: $T_{Al} = 0.3686t + 19.299$, $R^2 = 0.999$, $dT_{Al}/dt = 0.369$
Fe: $T_{Fe} = 0.2314t + 19.26$, $R^2 = 0.997$, $dT_{Fe}/dt = 0.231$

For 10V:

Al: $T_{Al} = 0.5463t + 18.963$, $R^2 = 0.991$, $dT_{Al}/dt = 0.546$
Fe: $T_{Fe} = 0.3795t + 18.694$, $R^2 = 0.991$, $dT_{Fe}/dt = 0.380$

From the data shown in the study conducted by [70], linear relationships are obtained between temperature and time with R^2 that vary in a range of 0.944–0.997.

3.5. Effect of applied voltage on ionic conductivity

Fig. 7 shows the behavior of water conductivity with the different voltages applied over time. Ionic conductivity is a very important parameter for electrochemical processes and has a relevant effect on current density, which could reduce energy consumption [71]. Usually, NaCl is added to water to improve ionic conductivity [39,55]. In our case, there was no need to add this salt. With Al electrodes for the three voltages applied, the removal levels of this parameter are practically equal, and show a linear trend that overlap. In 25 and 60 min of the EC process a low removal is reached of 7.5% and 11%, respectively, which favors the process. With Fe electrodes, there is also a clear linear trend in the removal of conductivity during the EC process. For each applied voltage, the removal levels are practically double with respect to the Al electrodes at 25 and 60 min, respectively.

For 6V:
Al: C_{Al} (removal %) = $0.1655t + 1.8256$, $R^2 = 0.898$, $dC/dt = 0.1655$
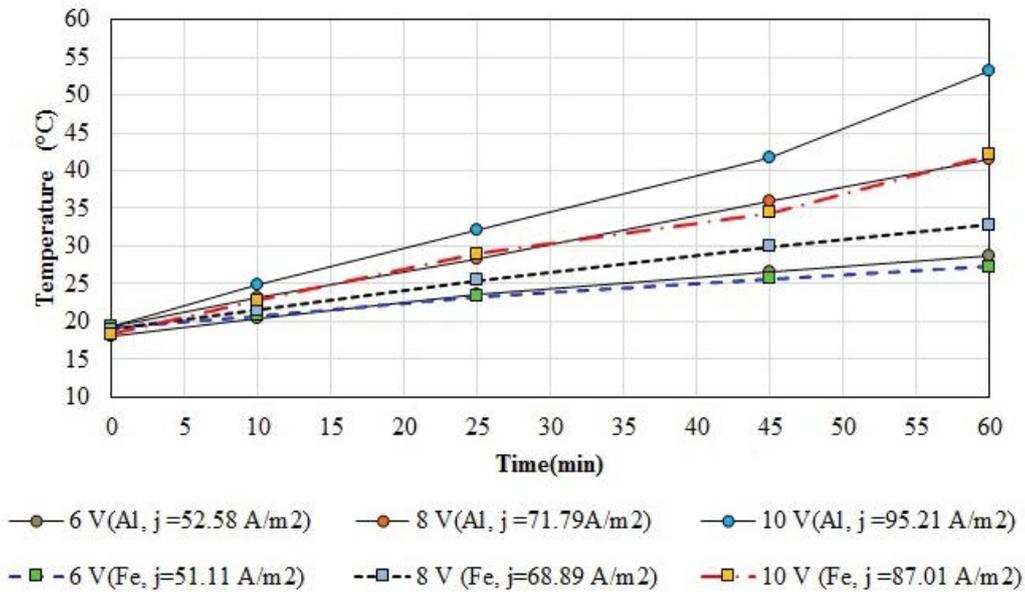
Fig. 6. Effect of voltage on temperature with Al and Fe electrodes: 3 Al anodes and 3 Fe anodes.
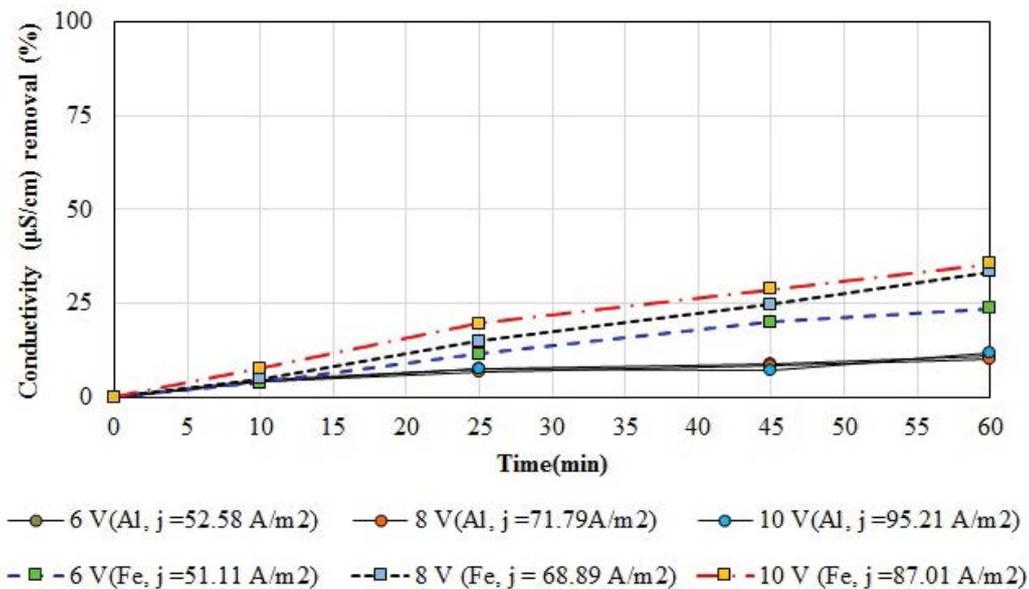
Fig. 7. Effect of voltage on conductivity (C) removal with Al and Fe electrodes: 3 Al anodes and 3 Fe anodes.

Fe: C_{Fe} (removal %) = 0.4099t + 0.3735, R^2 = 0.988, dC/dt = 0.4099

For 8V:

Al: C_{Al} (removal %) = 0.1545t + 1.5861, R^2 = 0.911, dC/dt = 0.1545

Fe: C_{Fe} (removal %) = 0.5606t + 0.0278, R^2 = 0.998, dC/dt = 0.5606

For 10V:

Al: C_{Al} (removal %) = 0.1634t + 1.5675, R^2 = 0.851, dC/dt = 0.1634

Fe: C_{Fe} (removal %) = 0.5893t + 1.8687, R^2 = 0.982, dC/dt = 0.5893

3.6. Effect of applied voltage on turbidity removal

Fig. 8 shows the effect of the applied voltage on turbidity removal. This parameter with Al electrodes in 25 min of process reached a removal level of 99%, and remains constant after this time. With Fe electrodes in 25 min for the applied voltages, the removal varied from 81.5% to 88.5%, and in 60 min a range of 94%–97% was reached. Other studies also show a behavior similar to ours, increasing
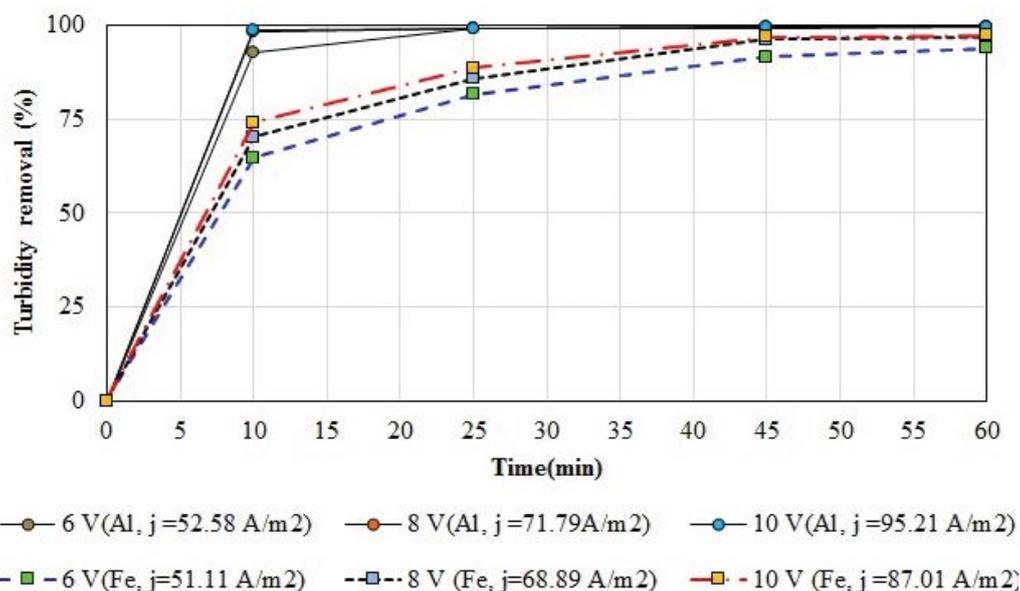
Fig. 8. Effect of applied voltage on turbidity (NTU) removal with Al and Fe electrodes: 3 Al anodes and 3 Fe anodes.

the removal of this parameter over time when the current density increases, with Al and Fe electrodes [72], with Al electrodes [73], and with Fe electrodes [74]. In the study conducted by [75], a 96% removal efficiency of this parameter with current densities of 25–125 A/m² is reported. Fig. 9 shows the turbidity removal at different times and it can be seen that this parameter is excellently removed as seen in Fig. 8.

3.7. Effect of applied voltage on COD

Fig. 10 shows the effect of voltage on COD removal. In 25 min of the process with Al electrodes a removal level between 53% and 59% is obtained, and with Fe electrodes between 59% and 60%. After 1 h of process, the average removal of this parameter is 61%. Therefore, it is not advisable to work with times greater than 25 min. The COD load is also reduced, because dissolved organic substances may be adsorbed onto solids that are removed by flotation [76,77]. The electrochemical treatment of poultry slaughterhouse wastewater showed removal efficiencies of COD (76%–85%) applying current densities in a range of 30 to 150 A/m² [78]. In the study conducted by [75], the COD removal efficiency varied in a range of 40% to 61% with current densities of 25–125 A/m². It is also possible to improve ionic conductivity with a supporting electrolyte (NaCl) by adding 1.0–10.0 g/L, and improve the COD removal efficiency. With Fe electrodes, the increase was
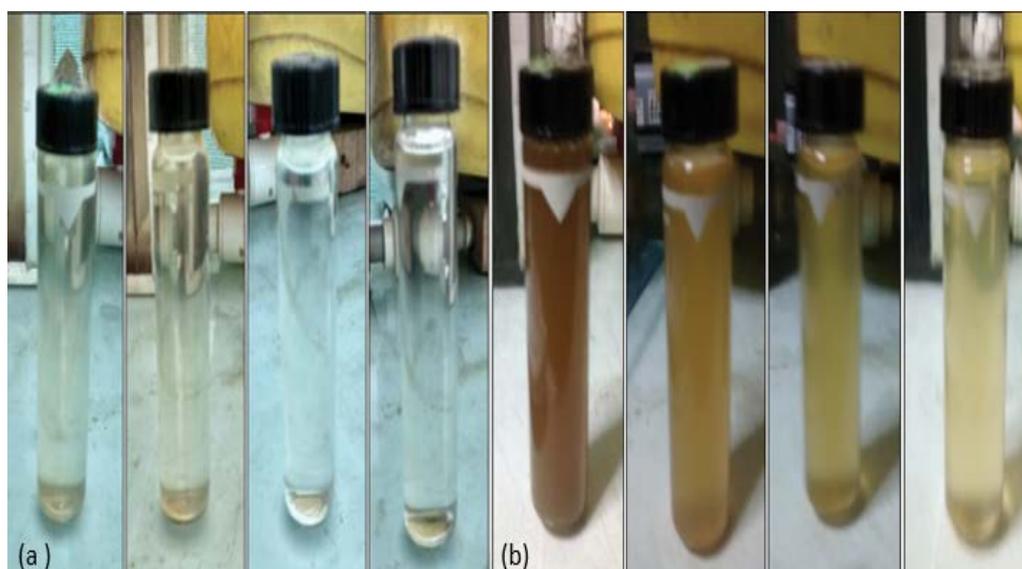
Fig. 9. Color and turbidity removals during batch EC at 8 V at times: 10, 25, 45, and 60 min with Al (a) and Fe (b) electrodes.
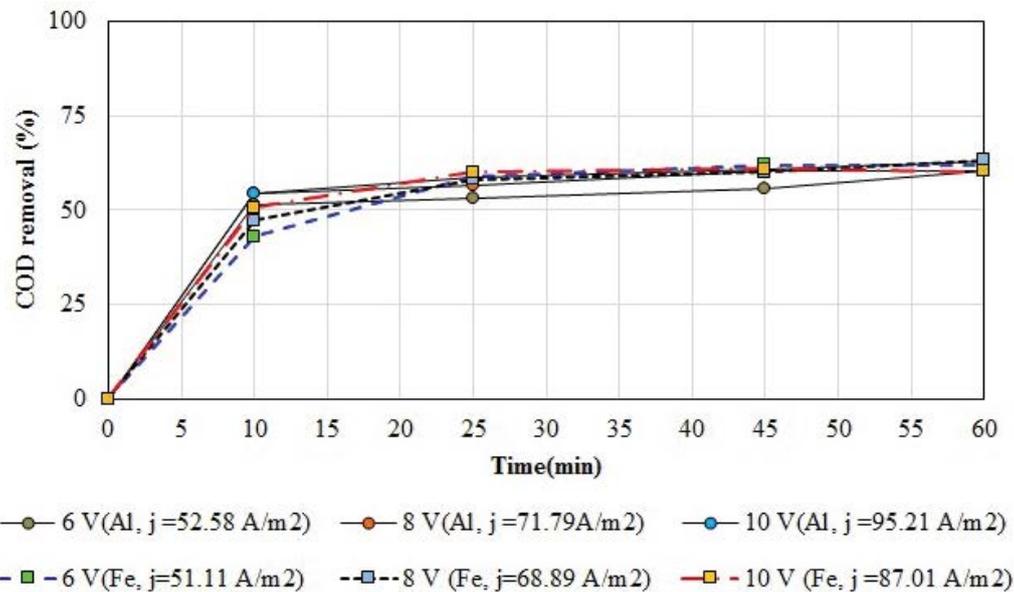
Fig. 10. Effect of applied voltage on chemical oxygen demand removal with Al and Fe electrodes: 3 Al anodes and 3 Fe anodes.

from 91.40% to 95.47%. The COD removal efficiency for the Al electrode increased from 89.69% to 94.60%. In both cases, the current density was 16.1 A/m^2 [79]. Chemical coagulation of slaughterhouse wastewater has also been studied by adding aluminum salts and polymer compounds, and a maximum COD removal efficiency of 45%–75% was reported [14,80].

3.8. Effect of applied voltage on thermotolerant coliforms and oil/grease removal

Table 1 shows the removal of thermotolerant coliforms with Fe electrodes and 8 V. Thermotolerant coliforms (fecal bacteria), and oils and grease are excellently removed in 10 min of EC process.

The study conducted by Yusoff et al. [81] also reports a superb level of removal of fat oil and grease (FOG). Using an Fe electrode at 8 V of applied voltage with 30 min of treatment time, the removal was 91%. In the same condition using Al electrodes the removal of FOG was 87%. Other studies also report an increase in the removal efficiency of bacterial indicators with increasing voltage. Maximum removal efficiency (>99.9%) was obtained in applied voltage 60 V [82]. The removal efficiencies for oil–grease in slaughterhouse wastewaters using Al and Fe electrodes were 94.7% and 92.8% at (pH 4, 100 A/m^2, and 20 min EC time for Al; pH 6, 100 A/m^2, and 20 min EC time for Fe) [83].

3.9. Energy consumption analysis

Table 2 shows the energy consumption per cubic meter of treated water with Al and Fe electrodes. At 6 V and 25 min of EC process, the energy consumed by each cubic meter of treated water has practically the same value. For the electrodes of Al and Fe the values are 3.07 and 2.99 kwh/m^3. For 8 and 10 V the power consumption kwh/m^3 is greater with the Fe electrodes at any time.

Fig. 11 shows the energy consumption behavior (kwh/m^3) and the COD removal level with both Al and Fe electrodes. With 6 V, 2.99 kwh/m^3, 25 min (Table 1), and Fe electrodes, a 58.8% removal are achieved. If the energy is doubled, the COD removal increases by less than 4%. Under the same conditions of voltage and time with the Al electrode a 53% removal is achieved.

Fig. 12 shows the effect of time on energy consumption (kWh) per kgCOD removed with both Al and Fe electrodes. For both electrodes, there is a linear trend for the three applied voltages. At 10 V a large energy consumption is required to remove a kg COD when Fe electrodes are used. For this same voltage, the Al electrodes require less energy

Table 1
Thermotolerant coliforms and oil and grease removal

Voltage (V)	Time (min)	Thermotolerant coliforms (MPN/100 mL)	Thermotolerant coliforms removal (%)	Oil and grease (mg/L)	Oil and grease removal (%)
	0	1.6×10^9	0.00	85.14	0.00
8	10	5.4×10^5	99.97	<0.5	99.41
	25	350	100.00	<0.5	99.41
	45	4.5	100.00	<0.5	99.41
	60	<1.8	100.00	<0.5	99.41

Table 2
Energy consumption per m³ of treated water, with Al and Fe electrodes

Voltage (V)	Time (min)	Amperes (A)	Energy (kWh)	kWh/m³	Amperes (A)	Energy (kWh)	kwh/m³
		3 Al anodes, 2 Al cathodes			3 Fe anodes, 2 Fe cathodes		
	0		0.0000	0.00		0.0000	0.00
	10		0.0061	1.23		0.0060	1.20
6	25	6.14	0.0154	3.07	5.98	0.0150	2.99
	45		0.0276	5.53		0.0269	5.38
	60		0.0368	7.37		0.0359	7.18
	0		0.0000	0.00		0.00	0.00
	10		0.0082	1.64		0.0107	2.15
8	25	8.4	0.0205	4.09	8.06	0.0269	5.37
	45		0.0368	7.37		0.0484	9.67
	60		0.0491	9.82		0.06	12.90
	0		0.0000	0.00		0.0000	0.00
	10		0.0102	2.05		0.0170	3.39
10	25	11.14	0.0256	5.12	10.18	0.0424	8.48
	45		0.0461	9.21		0.0764	15.27
	60		0.0614	12.28		0.1018	20.36
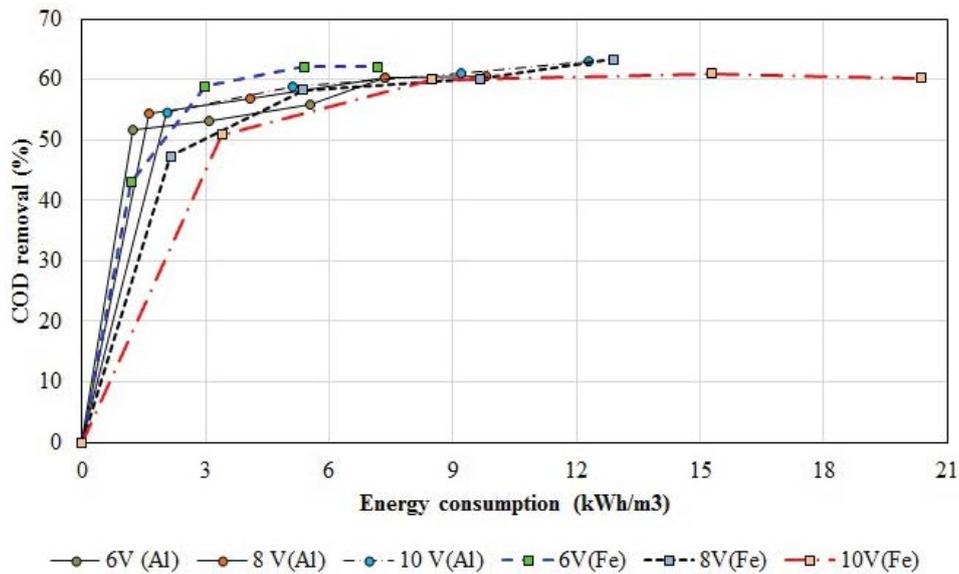
Fig. 11. Effect of energy consumption on COD removal.

for the same purpose. These linear behaviors are only shown at 6 V for both electrodes:

For:
Al electrode: Y_{Al} (kWh/Kg COD) = 0.0389t – 0.0642, $R^2 = 0.993$
Fe electrode: Y_{Fe} (kWh/Kg COD) = 0.0402t – 0.714, $R^2 = 0.997$

4. Conclusions

The batch EC processes studied were performed to evaluate the influence of voltage on several parameters already mentioned, with emphasis mainly on COD removal. The removal of pollutants from the wastewater is favored with the increase in the time of the EC process, generating greater energy consumption. At 6V, 51.11 A/m², using Fe electrodes and 3 kwh/m³, 59% COD removal was achieved in 25 min EC time, and 53% removal with Al electrodes at 52.58 A/m² at the same time. The increase in water temperature is always lower with Fe electrodes, which favors the energy efficiency kwh/m³. After 25 min of EC time, there is no significant increase in the level of COD removal. The results of this study show that EC as a primary treatment is a good alternative to remove contaminants from slaughterhouse wastewater. It remains to be investigated to what extent this primary treatment with
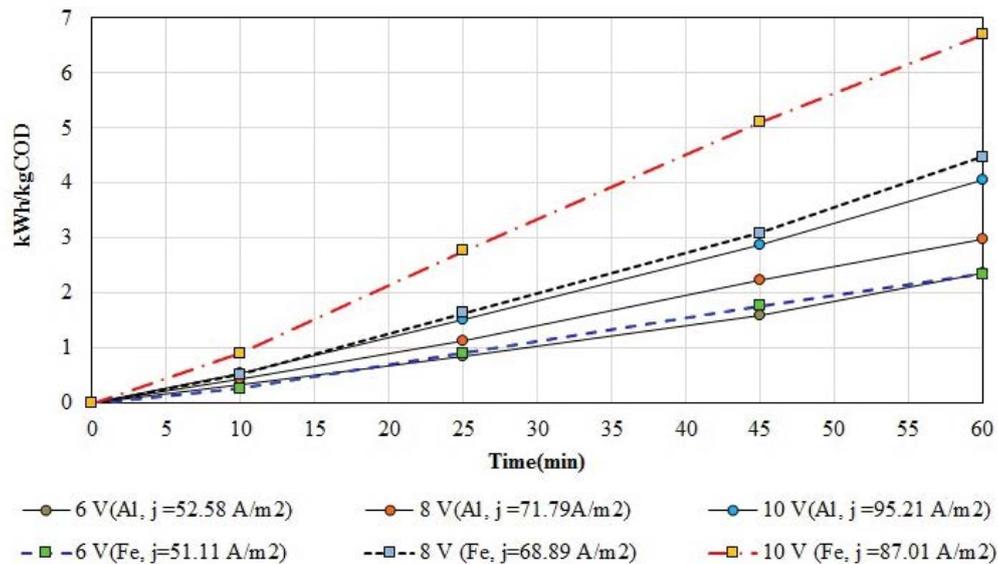
Fig. 12. Effect of time on energy consumption (kWh) per kg COD removed.

CD would help reduce costs of low-water treatments, which are necessary to apply to the effluent considering that this effluent cannot be discharged through the sewer system.

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