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Electrocoagulation using zinc electrodes for dairy industry wastewater treatment

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ABSTRACT

The aim of this research was to test the use of a new material for the construction of electrodes, zinc, as an alternative in the treatment of wastewater of a small dairy industry using electrocoagulation in real conditions. We performed the electrocoagulation tests in a batch, in a 150 mm diameter glass reactor with four zinc plates (100 mm × 130 mm × 15 mm). The connection was in parallel and monopolar, and constant direct current was applied. We collected samples of wastewater from a dairy industry for the application of treatment by electrocoagulation. The operational variables were electrolysis time, pH, and electrical current density. A central composite design (CCD) with three factors, electrical current density (j), electrolysis time (t), and initial pH with the two-level complete factorial using α = 1.6818 was composed of eight cubic points, six central points, and six axial points. The levels of operating parameters j, t, and initial pH used were 50.0 and 116.7 A m^{-2}, 26.2 and 73.8 min; 4.2 and 7.8, respectively. We tested the treatment for final chemical oxygen demand (COD), total solids and their fractions, and turbidity. The conditions for treating dairy wastewater was electric current density 82.6 A m^{-2}, electrolysis time around 10 min, and initial sample pH of approximately 3.0. This operating condition allowed a difference with reduction value of 50.4% in COD, 99.8% in turbidity, 24.2% in total fixed solids (TFS), 9.6% in volatile dissolved solids, 73.4% in total suspended solids, and 79.9% in volatile suspended solids. The negative effects of the zinc electrode were that the TFS in 17.7%, fixed dissolved solids in 64.6%.

Keywords: Electrolysis; Electrofloculation; Electroflotation

1. Introduction

Water in the dairy industry is used at various stages of processing such as cleaning, sanitizing, heating, and cooling. Dairy industries are associated with the generation of large volumes of wastewater, and this effluent contains milk and dairy products with wash water [1,2]. The liquid effluent from the dairy industry has high biochemical oxygen demand (BOD) and high chemical oxygen demand (COD), and nutrient levels are very high [3]. The volume of wastewater generated by the activity can vary from one to five times the volume of processed milk, depending on the final product and the technological level of the dairy industry. Based on the organic load, it can be inferred that large impacts can be generated if not properly treated and disposed of in the environment [4].

In the treatment of dairy industry effluents, biological treatments such as activated sludge, aerated ponds,

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biological filters, upflow anaerobic sludge blanket (UASB) reactor, anaerobic filter, etc., are used [5]. Aerobic biological processes have high energy consumption, and effluents treated by anaerobic biological processes often require additional treatment. Regarding the physicochemical processes, the most cost-effective ones are coagulation–flocculation [6,7]. The treatment of liquid effluents by electrocoagulation (EC) is considered an advanced type of treatment, that presents high efficiency and compact reactors that are easy to control and operate [8–11].

Kobya et al. [12] studied the technical and economic evaluation of the electrocoagulation process in the wastewater treatment of the textile industry using different types of electrode connections. They concluded that the parallel monopolar connection has the best cost-efficiency ratio for both evaluated electrodes, iron, and aluminum.

Hakizimana et al. [13] review the studies of the electrocoagulation process (EC). They found that EC has been the subject of several reviews in the last decade and is still an active area of research. Most published works deal with applications for the treatment of drinking water and urban, industrial, or agricultural wastewaters to enhance the simultaneous abatement of soluble and colloidal pollution using iron and aluminum how materials. Industrial application is not yet considered as an established wastewater technology because of the lack of systematic models for reactor scale-up.

In an electrolytic cell during electrolysis, the potential difference required is the sum of several terms. These various terms are: the anode's reversible equilibrium potential (E_a); the activation potential on the anode (η_{Aa}), which is a function of electrical current density; diffusion overvoltage the anode (η_{Da}), which is the difference in the concentration of a species between the anode and the solution, because of diffusion phenomena; the ohmic resistance of solution, which converts part of the electrical energy into heat by Joule effect; the diffusion overvoltage in the cathode (η_{Dc}) generated by the concentration gradient near the cathode; activation overvoltage (η_{Ac}), the electrochemical reaction that occurs in the cathode; to reversible cathode equilibrium potential (E_c). It describes the relationship between different components of the equation in several ways by several authors [14–18].

The potential difference applied between the electrodes is:

$$U_{Ap} = E_c + \eta_{Aa} + \eta_{Da} + |\eta_{Dc}| + |\eta_{Ac}| + IR \quad (1)$$

$$U_{Ap} = E_{Eq} + \sum \eta + IR \quad (2)$$

where U_{Ap} is the measured electrical voltage (potential difference), E_{Eq} is the potential of equilibrium, $\Sigma\eta$ is the sum of anodic and cathodic overvoltage and IR is the resistance ohmic [20,21].

The potential difference (E_{Eq}) corresponding to the potential difference between the anode and cathode. This is the potential difference necessary for reactions to occur of redox. The sum of the overvoltages ($\Sigma\eta$) expresses the kinetic limitations of the electrode reactions. It characterizes the different stages of the electrochemical reaction [19]. Ohmic resistance, however, is characteristic of the composition of the solution and its conductivity. With flat electrodes, there are:

$$IR = \frac{j\,d}{k} \quad (3)$$

where d is the distance between the electrodes (cm), k the conductivity of the solution (S cm^{-1}), and j the electric current density (A m^{-2}) [20].

For solutions with low electrical conductivity, ohmic resistance is the major component of the applied potential difference. However, when the effluent has low ohmic resistance, contributions of $\Sigma\eta$ and E_{Eq} are important for U_{Ap}. The applied electrical voltage (U) contributes significantly to the cost process, as it affects the power applied to the reactor [19,20].

It makes the variables that affect the electrode reaction rate up of electrode-related variables (building materials, surface area, and condition surface), variables related to mass transfer, concentrations and adsorption, the concentration of electroactive species in the solution, variables electrical, and external variables such as temperature, pressure, and electrolysis time [20,21].

Regarding the type of material used in the construction of electrodes, mainly iron, and aluminum have been used [1–3,7,9,11]. Studies with liquid effluents from different industries had relevant differences in the cost of the electrode used in the electrocoagulation process, and the total process cost may vary from 50% to 80% when using iron or aluminum as a building material, observing a similar COD removal efficiency [1–3].

The key chemical reactions which occur at the anode and cathode when using Al and Fe electrodes are represented by Slavov [22]. In the researchers of Valente et al. [2,3] show that a higher electrical current density is necessary for aluminum electrodes when compared to iron electrodes in the treatment of dairy wastewater by electrocoagulation. This because of the greater oxidation potential of aluminum. Zinc is a metal that has the potential for oxidation between aluminum and iron. The efficiency of reducing wastewater from the aluminum electrode was greater when compared to the electrode made of iron, but the power applied was greater. Zinc is a material that can be more feasible technically and economically when compared to iron and aluminum. The equations for the zinc electrode:

At the anode:

$$Zn_{(s)} \rightarrow Zn^{2+}_{(aq)} + 2e^- \quad (4)$$

At the cathode:

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

The release of metal ions from the anode can be quantified by using Faraday's law [22]. However, Kuokkanen et al. [23] concluded that the theoretical amount of anode dissolution is often exceeded during EC operation due to pitting corrosion [24].

The objective of this study was to evaluate the use of zinc electrodes for the treatment of dairy wastewater in real conditions by EC.

2. Material and methods

Raw wastewater from a dairy industry (15,000 L d^{-1} milk) was used. The wash waters from the different sectors of the unit were collected in a passage box, which was selected as the sample collection site. Samples were collected using a flow proportional composite sampling methodology. Subsample collection (15 L) intervals of 1 h from 8:00 to 13:00. At the end of the collection period, and with the data, proportional volumes were used to form the sample composed of the volume necessary to perform all assays. The composite sample was homogenized for testing and characterization. The pH of the composite sample was measured. The parameters evaluated in this study were also used to characterize the wastewater (Total solids (TS), volatile total solids (VTS), total fixed solids (TFS), total suspended solids (TSS), volatile suspended solids (VSS), fixed suspended solids (FSS), total dissolved solids (TDS), volatile dissolved solids (VDS), fixed dissolved solids (FDS), turbidity and COD).

COD analysis was performed according to APHA colorimetric method 5220 [25]. The samples were digested in a heated MARCONI® DRY BLOCK MA 4004 digester block. The absorbance was read on a spectrophotometer GBC® model UV/VIS 911A at 600 nm.

The analysis of the solids concentration of the samples was performed according to the gravimetric method number. The pH measurements were performed by the potentiometric method using a DIGIMED® model DMPH-2 portable digital apparatus according to the American Public Health Association (APHA) method 4500 (H+) [25]. The turbidity measurement was performed according to the APHA method 2130 [25]. For turbidity measurement, a TECNOPON® model TB 1000 turbidimeter was used.

The experiment was performed using a central composite design (CCD) with three factors: current density (j), electrolysis time (t), and initial pH with two levels for each factor and five repetitions at the central point. The two-level complete factorial using α = 1.6818 was composed of eight cubic points, six central points, and six axial points. The factor levels were defined according to the researchers of Valente et al. [2,3,7] who evaluated the use of wastewater treatment by electrocoagulation with iron and aluminum electrodes from the same dairy industry. The levels of operating parameters j, t, and initial pH used were 50.0 and 116.7 A m^{-2}; 26.2 and 73.8 min; 4.2 and 7.8, respectively (Table 1).

To maintain constant current density (electric current/electrode area), the direct current source automatically adjusted the voltage. A parallel monopolar electrical connection was maintained between the electrodes for the direct current application. The effluent temperature at the time of conducting the electrocoagulation tests was maintained at 20°C ± 2°C, close to the average annual temperature (19°C) of the dairy industry facility site.

The electrocoagulation tests were performed in batch, in a 150 mm diameter glass reactor with zinc electrodes. The volume of wastewater in each assay was

Table 1
Electrical current density (j), electrolysis time (t), and initial effluent pH conditions used for electrocoagulation assays in central composite design using α = 1.6818

Assay	Encoded variables			Uncoded variables		
	Initial pH	t	j	Initial pH	t (min)	j (A m^{-2})
1	0	–1.6818	0	6.0	10.0	83.4
2	–1	–1	–1	4.2	26.2	50.0
3	1	1	–1	7.8	73.8	50.0
4	–1	1	–1	4.2	73.8	50.0
5	0	1.6818	0	6.0	90.0	83.4
6	0	0	1.6818	6.0	50.0	139.4
7	0	0	0	6.0	50.0	83.4
8	1	1	1	7.8	73.8	116.7
9	1	–1	–1	7.8	26.2	50.0
10	0	0	0	6.0	50.0	83.4
11	0	0	0	6.0	50.0	83.4
12	0	0	0	6.0	50.0	83.4
13	–1.6818	0	0	3.0	50.0	83.4
14	1	–1	1	7.8	26.2	116.7
15	0	0	0	6.0	50.0	83.4
16	0	0	0	6.0	50.0	83.4
17	–1	1	1	4.2	73.8	116.7
18	0	0	–1.6818	6.0	50.0	27.3
19	1.6818	0	0	9.0	50.0	83.4
20	–1	–1	1	4.2	26.2	116.7

1.5 L. The electrode was constructed with four zinc plates (100 mm × 130 mm × 15 mm) and the effective ratio of electrode area to effluent volume of 28.8 m^2 m^{-3} in each assay. The factor levels used in this study were based on Valente et al. [3], with the distance between the electrode plates being 6 mm. The connection was in parallel and monopolar, and the constant direct current was applied.

After each test, the polarity inversion of the electrodes was performed to avoid the formation of passivation films that reduce treatment efficiency. The sample pH was adjusted to the conditions stipulated in the experimental design, using NaOH (1 mol L^{-1}) or H_2SO_4 (0.05 mol L^{-1}) as appropriate.

The agitation of the system was promoted by the hydrogen gas produced by the cathodes during the assays. After the current application ceased, after 20 min, a sample was collected at the average depth of the reactor for the characterization analyses.

Second-order polynomial models were used to express dependent variables according to independent variables according to the equation model [Eq. (6)].

$$Y = \beta_0 + \sum_{i=1}^{3}\beta_i x_i + \sum_{i=1}^{3}\beta_{ii} x_i^2 + \sum_{j=1}^{3}\beta_{ij} x_i x_j + \varepsilon \quad (6)$$

where Y is the response variable. β_0, β_i, β_{ii}, and β_{ij} are offset term, linear coefficients, quadratic coefficients, interaction coefficients respectively. x_i and x_j are the independent variables.

3. Results and discussion

Experimental data (Table 2) were used to evaluate the polynomial, quadratic, and linear models to obtain the regression equations. Analysis of variance showed that models were significant for COD, final pH, turbidity, FSS, and TFS of treated wastewater. For all other efficiency parameters, neither factors were significant at a significance ANOVA level of 5% (α = 0.05). Table 3 summarizes the analysis of variance to adjust the polynomial regression models.

Adjusted models for COD, final pH, turbidity, FSS, and TFS of treated wastewater are in Eqs. (4)–(8):

$$\text{COD} = 5{,}036 - 61.2j + 0.370j^2 \quad (7)$$

$$\text{Final pH} = 10.70 + 0.097\,\text{pH} \quad (8)$$

$$T = 4{,}428 - 79.1j - 36.5t - 278\,\text{pH} + 0.285j^2 + 0.214t^2 + 0.256jt + 4.38j\,\text{pH} \quad (9)$$

$$\text{FSS} = -294 + 4.57j + 75\,\text{pH} - 0.912j\ \text{pH} \quad (10)$$

$$\text{TFS} = -460 + 8.62j + 153.9\,\text{pH} - 1.584j\ \text{pH} \quad (11)$$

where COD is chemical oxygen demand, T is the turbidity, FSS is fixed suspension solids, TFS is total fixed solids, j is current density, pH is the initial adjusted pH, and t is the electrolysis time.

From Eq. (7) and Fig. 1a, the minimum of COD was to the electrical current density of the 82.6 A m^{-2}. After treatment was possible to go to COD of 2,505.3 mg L^{-1}, a value of 50.4% of initial COD. With the increased electrical current density, íons Zn^{2+} is dissolved in the solution, but more ions OH^- is produced, the pH goes to bigger [Eq. (8) and Fig. 1b] and the species eletrolitics begin soluble. This theory is on the research of Lenzi et al. [26].

The minimum turbidity (Fig. 1c) occurs for the electrolysis time condition below 65 min and pH less than 5.3 for the electrical current density of the 82.6 A m^{-2}. From a level of initial pH less 5.3 more ions are produced and promote the removal of compost, but its necessary control of electrolysis time because a long time produced more ions of zinc and the turbidity begin to increase and electrolytes species more soluble according to the Pourbaix graph shown by Bennajah [20].

In Fig. 1d, it can be observed that minimum FSS, for a current density of 82.6 A m^{-2}, the initial pH is not important. The fraction of solids (FSS) is near the value original of wastewater. But current density and pH lower and current density and pH bigger its conditions that's go to down this fraction of solids.

Considering the fraction of solids (TFS) and the current density of 82.6 A m^{-2} (Fig. 1e) the initial pH should be between 4.7 and 5.6. It is possible to reduce this fraction using pH near 3 and a current density of 50 A m^{-2}, but this condition promotes an increase in COD of wastewater treated. The TFS goes up (Fig. 1f) if to increase the pH for condition of the current density of 86.2 A m^{-2}.

In Eq. (8), the pH after treatment by EC as a function of the initial pH of treatment. It is observed that pH was higher than 10.7 as a function of the initial pH of the wastewater. Lenzi et al. [26] researched the solubility of $Zn(OH)_2$ with pH variation.

The conditions of lower pH, bigger electrolysis time, and current density promote an increase in electrolytes species, but if occurred in excess, the pH increase (Fig. 1b), and more soluble species are produced [19].

The characteristics of wastewater and wastewater after EC, with better results for pH, turbidity, COD, TS, VTS, TFS, TDS, VDS, FDS, TSS, VSS, FSS, and SSed are in Table 4.

There was a predominance of dissolved organic material in wastewater, mainly volatile, and a low concentration of fixed dissolved solids, results that are in agreement with Valente et al. [3].

Tchamango et al. [27] experimented with synthetic dairy residues. They made the electrodes using an Al anode, a current of 43 A m^{-2} and a treatment time of 30 min; they achieved 81%, 89%, and 61% removal of N, P, and COD, respectively. Ghahremani et al. [28] compared the use of Al, Fe, and stainless steel anodes to treat raw samples of wastewater from a dairy. They got the best EC performance with Fe, which reduced the COD of the effluent of 82%.

Geraldino et al. [29] used Fe anodes in batch mode to complete a detailed study in which the factors pH, treatment time, and current were researched. These conditions removed over 90% of the turbidity and COD. Qasim and Mane [30] researched EC parameters for treating wastewater from milk and ice cream production. In their study, they reduced COD, turbidity, and hardness of wastewater.

Table 2
Experimental data for electrocoagulation tests for dairy industry wastewater treatment

Assay	TS (mg L^{-1})	TVS (mg L^{-1})	TFS (mg L^{-1})	TDS (mg L^{-1})	VDS (mg L^{-1})	FDS (mg L^{-1})	TSS (mg L^{-1})	VSS (mg L^{-1})	FSS (mg L^{-1})	pH	Turbidity (NTU)	COD (mg L^{-1})
1	3,024	2,627	401	2,768	2,382	386	258	232	14	11.3	327	2,957
2	2,886	2,545	345	2,616	2,322	294	272	211	50	11.5	428	2,722
3	2,741	1,945	801	2,440	1,934	506	302	9	292	12.2	80	2,605
4	2,850	2,555	299	2,566	2,272	294	286	268	4	11.3	82	2,112
5	2,679	2,401	281	2,462	2,214	248	218	177	32	11.6	928	4,271
6	2,599	2,333	269	2,590	2,326	264	10	6	4	10.9	1,573	4,037
7	2,665	2,291	377	2,360	2,132	228	306	150	148	11.0	38	2,558
8	2,810	2,399	416	2,408	2,048	360	404	332	54	11.1	1,581	2,112
9	2,852	2,453	403	2,408	2,040	368	446	391	34	11.3	50	2,464
10	2,816	2,514	306	2,698	2,438	260	120	71	45	11.2	50	2,370
11	2,697	2,441	259	2,438	2,190	248	260	237	10	11.2	329	2,511
12	2,757	2,456	304	2,664	2,410	254	94	43	49	10.9	53	2,346
13	2,769	2,373	399	2,492	2,260	232	278	106	166	10.8	52	3,614
14	2,669	2,323	349	2,492	2,162	330	178	152	18	11.5	650	2,440
15	2,838	2,557	285	2,438	2,228	210	402	311	74	11.2	52	2,159
16	2,910	2,541	373	2,546	2,276	270	366	251	102	11.6	70	2,018
17	3,042	2,439	608	2,768	2,268	500	276	161	106	11.1	443	3,285
18	3,030	2,595	440	2,488	2,256	232	545	321	206	11.2	791	4,318
19	2,914	2,413	506	2,758	2,342	416	158	66	88	11.6	517	2,135
20	2,792	2,439	357	2,432	2,208	224	362	218	132	11.2	65	2,792

Table 3
Summary of the analysis of variance (ANOVA) for the regression models

COD			Final pH			Turbidity			FSS			TFS		
Source	DF	*p*-value	Source	DF	*p*-value	Source	DF	*p*-value	Source	DF	*p*-value	Source	DF	*p*-value
Model	2	0.091	Model	1	0.045	Model	7	0.000	Model	3	0.085	Model	3	0.082
Linear	1	0.920	Linear	1	0.045	Linear	3	0.001	Linear	2	0.288	Linear	2	0.309
j	1	0.920	pH	1	0.045	*j*	1	0.001	*j*	1	0.121	*j*	1	0.353
Square	1	0.031				*t*	1	0.021	pH	1	0.921	pH	1	0.222
j^2	1	0.031				pH	1	0.016	Interaction	1	0.036	Interaction	1	0.032
						Square	2	0.000	*j* × pH	1	0.036	*j* × pH	1	0.032
						j^2	1	0.000						
						t^2	1	0.043						
						Interaction	2	0.002						
						j × *t*	1	0.016						
						j × pH	1	0.003						

The researchers [30] showed that by using Al electrodes, COD, turbidity, and hardness reduced in dairy wastewater by 39%, 51%, and 41%, respectively. Other researchers [11] have studied the incorporation of advanced oxidation processes in the EC treatment of dairy wastewater.

Torres-Sánchez et al. [30] electrodes were used with a periodic circuit polarity exchange. The addition of H_2O_2 in a 5:1 ratio (H_2O_2:Fe^{2+}) in combination with an ozone current of 250 mg h^{-1} could increase the COD removal to 70% compared to the 37.3% achieved by the electrocoagulation.

Researches on the use of electrocoagulation in the treatment of wastewater from dairy industries show variations in the reduction of COD, N, and P. For COD, the reduction varied from 37% to 98%. These results are in agreement with the research by Valente et al. [2], which shows that the efficiency of COD reduction depends on the solids present, the principal factor being the concentration of TDS.

The research by Şengil and Özacar [31] shows a 98% reduction in COD, however, the wastewater used in the

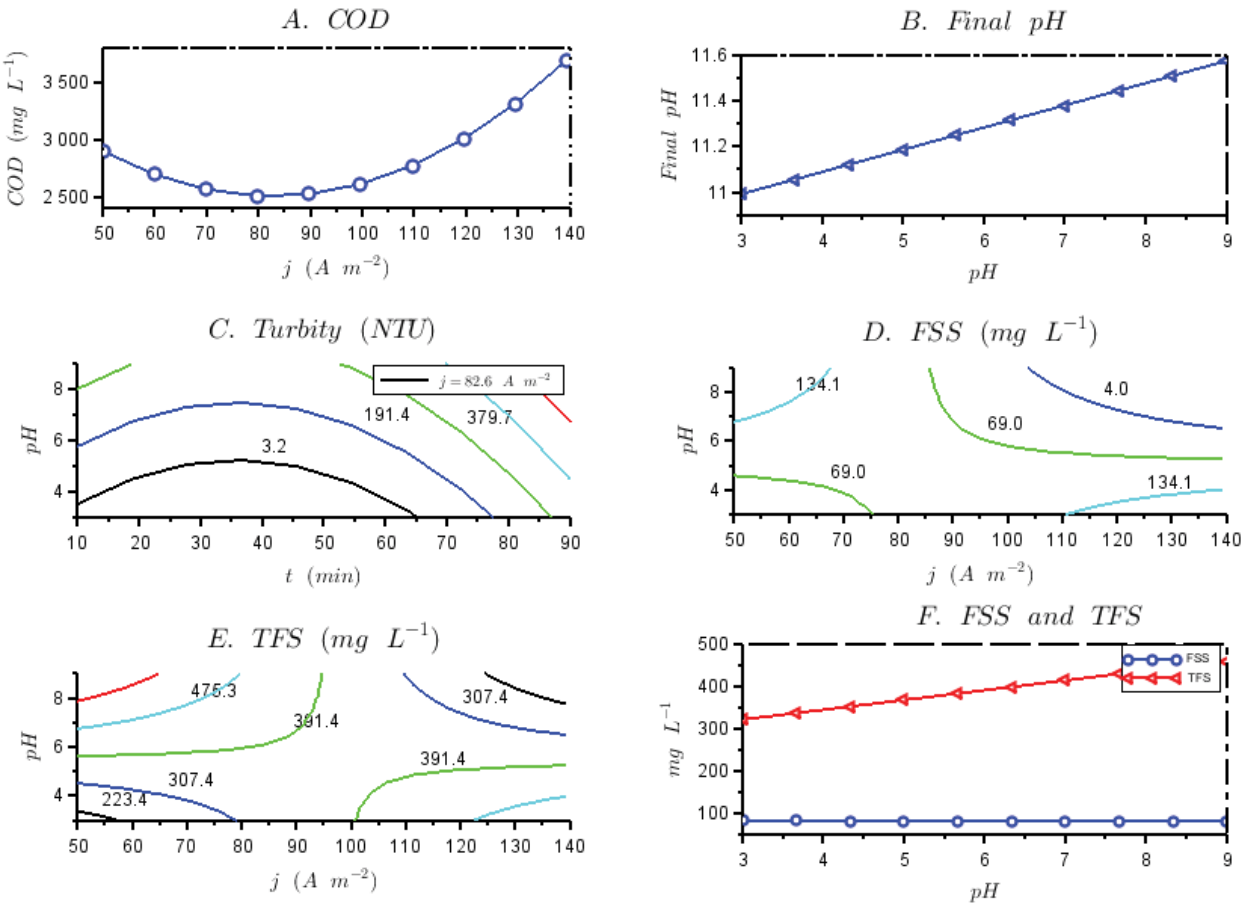

Fig. 1. COD, final pH, turbidity, FSS, and TFS as a function of factors (electrolysis time – *t*, pH, and current density). (A) COD as a function of the current density, (B) final pH as function of pH, (C) turbidity as a function of pH and electrolysis time for a current density of 86.2 A m^{-2}, (D) FSS as a function of pH and current density, (E) TFS as a function of pH and the current density, and (F) TFS and FSS as a function of pH for a current density of 86.2 A m^{-2}.

Table 4
Physicochemical characteristics: dairy wastewater and wastewater after EC

Parameter analyzed	Wastewater	Wastewater after EC	Difference (%)
pH	6.7	10.99	+64
Turbidity (Nephelometric turbidity units – NTU)	2,040	3.2	–99.8
COD (mg L^{-1})	5,046	2,505.3	–50.4
Solids and fractions (mg L^{-1})			
Total solids (TS)	3,717	2,817.1	–24.2
Volatile total solids (VTS)	3,448	2,431.7	–29.5
Total fixed solids (TFS)	273	321.2	+17.7
Dissolved solids (TDS)	2,660	2,541.6	–4.5
Volatile dissolved solids (VDS)	2,474	2,235.4	–9.6
Fixed dissolved solids (FDS)	186	306.2	+64.6
Suspended solids (TSS)	1,060	277.3	–73.4
Volatile suspended solids (VSS)	924	185.7	–79.9
Fixed suspended solids (FSS)	86	82.5	–4.1
Sedimentable solids (SSed) (mL L^{-1})	11	–	–

experiment had a high concentration of suspended solids and a low concentration of dissolved solids.

The operating condition for zinc electrodes showed higher electric current density, but shorter electrolysis time when compared to the results obtained by Valente et al. [2,3]. These parameters are important factors for the definition of the operating cost of the wastewater treatment system by EC.

Another important point is the operating cost is the conductivity of wastewater. Foco and Cuba Terán [32] verified that the increase in electrical conductivity in wastewater with NaCl allows the reduction of the applied voltage, but there is a significant increase in the TDS in the stages in which there was the addition of NaCl. This increase is verified by comparing the data with the removal of TSS at the stage in which there was no increase of sodium chloride. The difference was 19.74% in the removal of TSS without the addition of NaCl, while with the addition of NaCl, an increase of 302.48% of TDS in the wastewater. The addition of NaCl for increase the electrical conductivity of wastewater should be produce treated wastewater with a large concentration of TDS.

The treatment of wastewater with electrocoagulation has been used for heavy metals removal. Several studies have been conducted for chromium removal [33], Pb(II) ions [34], arsenic [35], and zinc [26]. Electrocoagulation and adsorbent materials have been studied for the removal of heavy metals from rivers, lakes, and other water sources in developing countries [34]. Lenzi et al. [26] analyzed the treatment of effluent produced by an atomic absorption spectrometer (AAS) containing the heavy metal zinc, utilizing the capacity of Zn^{2+} to react with hydroxide ion (HO^-), forming $Zn(OH)_2$. The solubility of $Zn(OH)_2$ with pH variation was analyzed. The values of zinc concentration in the different situations were measured using AAS in the research of Lenzi et al. [26]. The results in the different situations of a solution and medium pH for the minimum solubility of $Zn(OH)_2$ were: the theoretical value of 2.3 mg L^{-1}, experimental value for the $Zn(OH)_2$ solution of 0.92 mg L^{-1}; in natural effluent 0.092 mg L^{-1}, respectively. These values comply with BRAZIL-CONAMA Resolution number 397/2008 [36]. However, adjusting the pH of wastewater after treatment is of fundamental importance to reduce the residual concentration of zinc.

The best-operating conditions for the treatment of dairy wastewater in this research were electric current density 82.6 A m^{-2}, electrolysis time around 10 min, and initial sample pH of approximately 3.0. This operating condition allowed a difference with reduction of 50.4% in COD when compare to the initial value in wastewater, 99.8% in turbidity, 24.2% in TFS, 9.6% in VDS, 73.4% in TSS, and 79.9% in VSS. The negative effects of the zinc electrode were that the TFS in 17.7%, FDS in 64.6%. Probably, the increase of these solids' fractions is related to the increase of zinc in solution. Again, it is important to highlight the importance of pH adjustment at the end of electrocoagulation treatment to avoid the formation of soluble zinc electrolytes.

It's necessary to analyze the influence of electric conductivity on treatment efficiency and cost, and another parameter is the consumption of zinc electrodes by electrocoagulation process [12], as well as, zinc concentration in wastewater treated by electrocoagulation using zinc electrodes.

This research had lighting point the electrolysis time, only 10 min. When compared to treatment by conventional activated sludge, the retention time is near to 8 h. Whenever the efficiency of the activated sludge is greater, but when compared to the biological anaerobic process, the efficiency is similar.

4. Conclusions

In this research, the removal efficiency of EC process with zinc electrodes and the effect of operating parameters, such as current density, electrolysis time, and initial pH for the treatment of a dairy wastewater batch system has been studied and concluded that conditions for treatment of dairy wastewater were electrical current density 82.6 A m^{-2}, electrolysis time around 10 min, and initial sample pH of approximately 3.0. This operating condition allowed a difference with reduction of initial values of 50.4% in COD, 99.8% in turbidity, 24.2% in TFS, 9.6% in VDS, 73.4% in TSS, and 79.9% in VSS. The negative effects of the zinc electrode were that the TFS increase in 17.7%, FDS in 64.6%. It was concluded that the EC process by the zinc electrode is an alternative method for the treatment of dairy wastewater.

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