REVISTA eixo
revistaeixo.ifb.edu.br

ISSN 2238-5630
Brasília-DF, v. 14, n. 1, janeiro-abril de 2025

ELECTROFLOCCULATION: A PROMISING TECHNIQUE TO TREATMENT WASTEWATER FROM CASSAVA PROCESSING

ELETROFLOCULAÇÃO: UMA TÉCNICA PROMISSORA PARA TRATAMENTO DE ÁGUAS RESIDUAIS DO PROCESSAMENTO DA MANDIOCA

Geisi Aparecida Zang Fabricio[1]
Leandro Fleck[2]
Izabel Melz Fleck[3]
Tiago Zoz[4]

Abstract: The processing of cassava generates effluents with harmful properties to the environment. In this context, the study aimed to optimize the electrochemical treatment of wastewater from cassava starch production. The experimental module contains a reactor containing the sacrificial electrodes and the liquid effluent. The effects of electrochemical process reaction time and amperage applied to the system on pH variation, color, and turbidity removal were evaluated using a CCRD. A quadratic mathematical model was generated for color and turbidity removal, validated with a 95% confidence interval. The highest turbidity removal occurred under the conditions of 1.05 A and 17.50 minutes, and the lowest (67.94%) occurred under the conditions of 1.05 A and 30.00 minutes. The analyzed factors did not significantly influence turbidity removal. For the color, it was observed that in the condition of 0.10 A and 17.50 minutes, occurred the lowest removal (57.40%), and in the conditions of 1.05 A and 17.50 minutes, occurred the highest removal (86.78%). The electric current density and the hydraulic detention time (quadratic terms) significantly influenced the color removal efficiency, which is the mathematical model statistically significant. When applied to real conditions, the model described the color removal efficiency satisfactorily, presenting an error of 1.05%. The electrochemical tests raised the pH of the effluent. It is concluded that the system employed responded satisfactorily to the objectives of the present study, and the electro-flocculation is a promising alternative to the conventional treatments of wastewater from cassava starch production.
Keywords: Liquid effluent; mathematical modeling; environmental pollution; electrochemical treatment.

Resumo: *O processamento da mandioca gera efluentes com propriedades nocivas ao meio ambiente. Nesse contexto, este estudo teve como objetivo otimizar o tratamento eletroquímico de águas residuais provenientes da produção de fécula de mandioca. O módulo experimental é constituído por um reator que contém os eletrodos de sacrifício e o efluente líquido. Os efeitos do tempo de reação do processo eletroquímico e da amperagem aplicada ao sistema sobre a variação do pH, da cor e a remoção de turbidez foram avaliados utilizando um DCCR. Foi gerado um modelo matemático quadrático para remoção de cor e turbidez, validado com intervalo de confiança de 95%. A maior remoção de turbidez ocorreu nas condições de 1,05 A e 17,50 minutos, e a menor remoção (67,94%) ocorreu nas condições de 1,05 A e 30,00 minutos. Os fatores analisados não influenciaram significativamente a remoção de turbidez. Para a cor, observou-se que, na condição de 0,10 A e 17,50 minutos, ocorreu a menor remoção*

1. Tecnóloga Ambiental
Graduada pela Universidade Estadual de Mato Grosso do Sul (UEMS/Mundo Novo)
E-mail: gelci-zang@hotmail.com
Lattes: http://lattes.cnpq.br/0277769422600198
ORCID: https://orcid.org/0009-0004-8531-6676

2. Docente da Universidade Estadual de Mato Grosso do Sul (UEMS/Mundo Novo)
E-mail: E-mail: leandro.fleck@uems.br
Lattes: http://lattes.cnpq.br/2381929054098695
ORCID: https://orcid.org/0000-0001-8763-6404

3. Mestranda do Programa de Pós-Graduação em Biodiversidade e Sustentabilidade Ambiental (PGBSA/UEMS/Mundo Novo)
E-mail: izabelmelz.melz@gmail.com
Lattes: http://lattes.cnpq.br/9057842109153802
ORCID: https://orcid.org/0009-0007-0953-768X

3. Docente da Universidade Estadual de Mato Grosso do Sul (UEMS/Mundo Novo)
E-mail: zoz@uems.br
Lattes: http://lattes.cnpq.br/9952504782549223
ORCID: https://orcid.org/0000-0003-2991-5485

Recebido em: 14/05/2024
Aceito em: 29/10/2025

ISSN 2238-5630
Brasília-DF, v. 14, n. 1, janeiro-abril de 2025

(57,40%); enquanto, nas condições de 1,05 A e 17,50 minutos, ocorreu a maior remoção (86,78%). A densidade de corrente elétrica e o tempo de reação (termos quadráticos) influenciaram significativamente na eficiência de remoção de cor, sendo o modelo matemático estatisticamente significativo. Quando aplicado em condições reais, o modelo demonstrou a eficiência de remoção de cor de forma satisfatória, apresentando um erro de 1,05%. Os testes eletroquímicos elevaram o pH do efluente. Conclui-se que o sistema empregado respondeu satisfatoriamente aos objetivos do presente estudo, sendo a eletrofloculação uma alternativa promissora aos tratamentos convencionais de águas residuárias da produção de fécula de mandioca.

Palavras-chave: Efluente líquido; modelagem matemática; poluição ambiental; tratamento eletroquímico.

Recebido em: 14/05/2024
Aceito em: 29/10/2025

INTRODUCTION

Cassava is a plant of great global importance, widely consumed in various cultures around the world, being widely cultivated in Latin America, Africa, Asia, and some parts of Oceania, such as Papua New Guinea (Maung, 2017). On the African continent, the cassava crop plays a crucial role in combating hunger and ensuring food security, especially in sub-Saharan regions, with high consumption for human food in countries such as Nigeria, Congo, Tanzania, Ghana, Mozambique, and Angola (FAO, 2018). On the Asian continent, cassava is widely consumed in India, Indonesia, Philippines, Thailand, and Vietnam (FAO, 2013). In Thailand, cassava is used to produce bioethanol in addition to human consumption (Sriroth *et al.*, 2019). In Latin America, cassava and its derivatives, especially cassava flour, are essential and traditional foods for many countries and cultures, including Brazil, Colombia, Paraguay, Venezuela, Argentina, and Mexico (FAO, 2020). Cassava is grown in all states and is relevant in human and animal food, besides being used as a raw material base in several industrial processes (Cardoso, 2005).

As a consequence of the industrial processing of cassava, serious environmental problems can be originated, considering that even small factories, such as flour mills and flour houses, can produce relevant quantities of solid (bark and bagasse) or liquid (manipueira - a liquid residue obtained from the cassava industrialization) waste (Camargo *et al.*, 2008).

Even with adverse characteristics to the ecosystem, the final discharge of effluents from cassava starch industries is mostly made in water bodies near the industrial units or on the ground, being able to cause contamination in groundwater and rivers. If not treated properly, this effluent may offer toxic potential to the environment due to free cyanide, a compound existing in the plant cells of the roots, which is toxic to animals and humans (Santos, 2016). Additionally, it presents high rates of organic matter, and its disposal in the open air or waterways can result in various environmental damages (EPAGRI, 2019), such as eutrophication from excess nutrients.

Due to the environmental impacts of liquid effluents, the search for the development of alternative wastewater treatment systems has been carried out as a way to reduce the impacts caused to the natural environment (Wang *et al.*, 2012), among which is the electro-flocculation (Natal *et al.*, 2020; Grecco *et al.*, 2022).

Electro-flocculation consists of the deposition of coagulants *in situ* by electrolytic oxidation reactions of conductor and semiconductor metals (Santos *et al.*, 2022). The treated effluent runs between electrodes, usually aluminum and/or iron plates, arranged together in vertical or horizontal flow instigated by the constant electric current supplied by a self-regulating source (Loureiro, 2008).

Paschoal and Tremiliosi-Filho (2005) state that in electro-flocculation, there is no addition of flocculants, which avoids the generation of residual sludge. It is an electrochemical treatment based on gases, oxygen, and hydrogen formation, where the flocculant additives change. The process consists of four stages, these being: (1) generation of small gas bubbles; (2) contact between the bubbles and the suspended particles; (3) adsorption of the small gas bubbles on the surface of the particles; and (4) rising of the particle/bubble assembly to the surface. Thus, all suspended matter is electro flooded, clarifying the treated liquid. On the surface, a layer of foam is created, which involves the floated particles that are easily removed.

Briefly, according to Cerqueira *et al.* (2011), in the electrochemical process of wastewater treatment using aluminum electrodes, oxidation occurs at the anode (Equation 1), which undergoes hydrolysis (Equation 2) with the formation of the coagulant agent $Al(OH)_3$.

$$Al \rightarrow Al^{3} + (aq) + 3e-$$
Eq. (1)

$$Al(H_2O)_6^{3+} \rightarrow Al(OH)_{3(S)} + 3H^{+}3H_2O$$
Eq. (2)

In addition to forming the coagulant agent, electro-flocculation generates microbubbles of gas (Equation 3), which are responsible for the flotation of oils, greases, and other particulate compounds.

$$3H_2O + 3e \rightarrow 3/2H_2 + 3OH^{-} \text{ (cathode)}$$
Eq. (3)

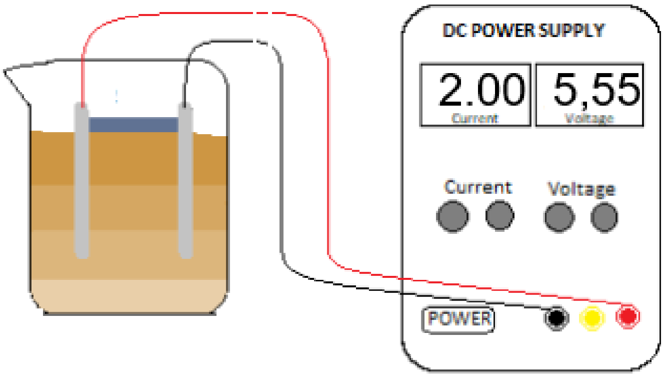
In this context, the present study aimed to evaluate the use of electro-chemical treatment of wastewater from cassava starch production as an alternative to conventional treatments.

METHODOLOGY

Experimental Module

The experimental module consists of a reactor operating in batch mode, using a benchtop system (1 L beaker) containing the aluminum sacrificial anodes, 9 cm long and 5 cm wide, spaced 1 cm apart, and the liquid effluent to be electrochemically treated. The electrodes, separated by a plastic insulator, were connected to a direct current source to make the electrolytic process possible, as shown in Figure 1.

Figure 1 – Experimental module used in the treatment of wastewater from cassava starch production



Source: adapted from Prieto *et al.* (2024).

Wastewater

The liquid effluent for the electrochemical trials was collected from a cassava starch industry in Mato Grosso do Sul/Brazil in the Cone-sul region. After collection, the effluent was stored at -5 °C, so the physical-chemical characteristics were not altered until used in the experimental tests.

Treatment design and parameters analyzed

The effects of electric current density (amperage) and hydraulic detention time (minutes) on the removal efficiency of color, turbidity, and pH variation were evaluated using a Central Composite Rotatable Design (CCRD), i.e., a factorial scheme of treatments, composed of 4 axial trials, 4 factorial trials, and 4 repetitions at the central point, totaling 12 trials, according to coded and actual conditions presented in Table 1. It should be noted that the actual values of the coded variables were determined from preliminary analyses.

Table 1 – Real and coded values of the variables in the CCRD used in the treatment of wastewater from cassava starch production with electro-flocculation

Electric current density (C.I)		Hydraulic detention time (HDT)	
Encoded	**Real (A)**	**Encoded**	**Real (min)**
-1	0.38	-1	8.63
+1	1.72	-1	8.63
-1	0.38	+1	26.37
+1	1.72	+1	26.37
-1.41	0.10	0	17.50
+1.41	2.00	0	17.50
0	1.05	-1.41	5.00
0	1.05	+1.41	30.00
0	1.05	0	17.50
0	1.05	0	17.50
0	1.05	0	17.50
0	1.05	0	17.50

Source: research data.

The electrical conductivity of the effluent was adjusted before each experimental trial to 2.5 Ω/cm to ensure system efficiency. Different concentrations of sodium chloride (NaCl) were added as needed.

After each experimental trial, the electro flocculated effluent remained at rest on the bench for 30 minutes for flotation/sedimentation of impurities present in the liquid effluent. After this period, the samples were collected for physical-chemical analysis. The effluent sample was collected from the center of the electrochemical reactor, with the aid of a hose adapted to a syringe, without agitation.

Color removal efficiency analyses followed method 2120B (APHA, 2012). The turbidity removal efficiency was evaluated using a benchtop turbidimeter, and pH variation was evaluated using a digital benchtop pH meter. All analytical determinations were performed in triplicate, and only the mean values of these measurements were considered.

Generation of mathematical models

For each response variable (color and turbidity removal), a quadratic mathematical model representative of the process was generated, obtained from the statistical adjustment of the results corresponding to all the trials of the treatment design. The coded mathematical model, adjusted from the experimental data, is shown in Equation 4.

$$\text{Response variable} = a_1 + a_2 C.I + a_3 C.I^2 + a_4 HDT + a_5 HDT^2 + a_6 (I.C)(HDT) \quad \text{Eq. (4)}$$

a = coefficients fitted from the experimental data.
C.I = coded value of the electric current density.
HDT = coded value of the hydraulic detention time.

Validation of the proposed mathematical models

The statistical significance of the mathematical models originated in the system was tested by analysis of variance (ANOVA) with a 95% confidence interval. Subsequently, the mathematical model representing the color removal efficiency was validated based on efficiency data obtained in an experimental validation trial conducted under experimental conditions within the limits in which it was generated.

RESULTS AND DISCUSSION

Turbidity removal efficiency

Table 2 shows the turbidity removal efficiency in the different experimental conditions of the studied factors: electric current density and hydraulic detention time. It is observed that the highest turbidity removal occurred in the center point conditions (1.05 A and 17.50 minutes), with an average removal in these tests of 69.27%. On the other hand, the lowest turbidity removal, 67.94%, occurred in the conditions of 1.05 A and 30.00 minutes. It is emphasized the low variability between the efficiencies obtained in the different experimental conditions, which indicates that in the studied range of independent variables, their influence on the efficiency of the system does not present statistical significance.

Table 2 – Turbidity removal efficiency in the treatment of wastewater from cassava starch production with electro-flocculation

Electric current density (C.I)		Hydraulic detention time (HDT)		Removal (%)
Encoded	Real (A)	Encoded	Real (min)	
-1	0.38	-1	8.63	69.01
+1	1.72	-1	8.63	70.00
-1	0.38	+1	26.37	69.12
+1	1.72	+1	26.37	69.12
-1.41	0.10	0	17.50	69.24
+1.41	2.00	0	17.50	68.59
0	1.05	-1,41	5.00	68.45
0	1.05	+1,41	30.00	67.94
0	1.05	0	17.50	69.03
0	1.05	0	17.50	70.03
0	1.05	0	17.50	69.23
0	1.05	0	17.50	68.80

Source: research data.

Módenes *et al.* (2017) applied the electro-flocculation technique to treat poultry slaughterhouse effluents; a complete factorial design with three independent variables (electric current, pH, and electrolysis time) was used. The maximum turbidity removal efficiency that the authors found was 99.96%, a value higher than that in the present study.

Orssatto *et al.* (2016) verified that electro-flocculation is a good option for treating effluents from industrial laundries since it presents high DQO, color, and turbidity removal. Thus, it is possible to enable the reuse of the treated effluent, either in the first rinse in the washing processes or for other less noble uses. The best experimental condition observed was 20 V for the potential difference and 20 minutes for the hydraulic detention time.

Cerqueira (2006) showed the best results in pollutant removal efficiency (93.00% for turbidity) using aluminum electrodes under 3 A current intensity, 10 min operation time, 0.5 cm distance between electrodes, and initial pH 5.

In its study, Nascimento (2018) concluded that optimizing the electro-flocculation process through factorial planning allowed satisfactory efficiency in clarifying surface spring water so that the results acquired for color and turbidity fell within the potability standards established by legislation. It also demonstrated that the efficiencies in removing turbidity and color of the water depended significantly on the three factors considered: conductivity, electrolysis time, and pH of the water, which are of great importance for the process. The aluminum electrodes proved very efficient, reaching 100% for color removal and 93.00% for turbidity removal.

Table 3 shows the effects of the factors studied (electric current density and hydraulic detention time) on the response variable (turbidity removal efficiency). For turbidity removal, none of the factors and the interaction between them was considered statistically significant because the p-value obtained is higher than the adopted significance level of 95%.

Table 3 – Effects analysis for turbidity removal in the treatment of wastewater from cassava starch production with electro-flocculation

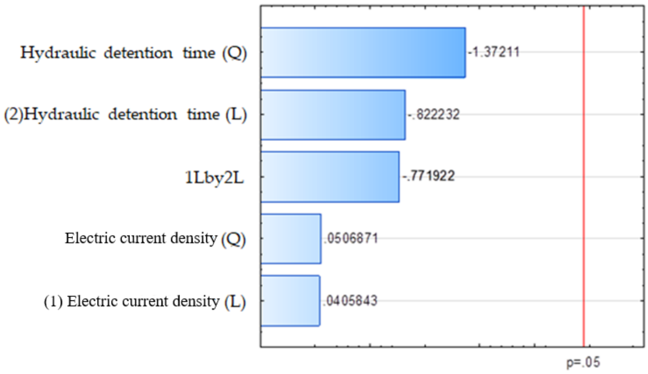
Factor	Effect	p-value
Average	69.270	0.000
C.I (L)	0.018	0.969
C.I (Q)	0.026	0.961
HDT (L)	-0.373	0.442
HDT (Q)	-0.699	0.219
I. Current x HDT	-0.495	0.469

Source: research data.

The electric current density (linear and quadratic terms) positively affected the dependent variable; that is, at higher electric current intensities, there is a greater probability of greater turbidity removal. However, the HDT (linear and quadratic terms) and the interaction between the factors presented a negative effect, with a significance level of 95%.

In the Pareto Chart (Figure 2), the standardized effect estimate that each independent variable exerts on the response variable are represented, with a statistical significance of 95% ($p < 0.05$). It is possible to observe that none of the controlled factors (independent variables) significantly affected turbidity removal efficiency. However, even not being significant in the confidence interval of 95%, it is evident that the HDT exerted greater influence on the process evaluated.

Figure 2 – Pareto chart of turbidity removal in the treatment of wastewater from cassava starch production with electro-flocculation



Source: prepared by the authors based on research data.

None of the factors were analyzed, and the interaction between them significantly influenced the removal of turbidity for the electrochemical treatment of wastewater from cassava starch production since the p-value obtained is greater than the significance level adopted, 5% (Table 4).

These results corroborate the discussion in Table 2, where the low variability between the turbidity removal efficiencies obtained by the electrolytic system was evidenced. However, it is emphasized that these conclusions apply exclusively to the operating ranges of the independent variables applied to the system.

Table 4 – Analysis of variance for Turbidity removal in the treatment of wastewater from cassava starch production with electro-flocculation

Factor	Sum of Squares	Degrees of Freedom	Mean Square	p-value
C.I (L)	0.0007	1	0.0007	0.969
C.I (Q)	0.0011	1	0.0011	0.961
HDT (L)	0.2780	1	0.2780	0.442
HDT (Q)	0.7742	1	0.7742	0.219
C.I x HDT	0.2450	1	0.2450	0.469
Residue	2.4673	6	0.4112	
Total	3.7663	11		

Source: research data.

Table 5 shows the summary of the Analysis of Variance (ANOVA) for the statistical validation of the mathematical model proposed for turbidity removal, which is not statistically significant.

Table 5 – Statistical validity of the proposed mathematical model for turbidity removal in the treatment of wastewater from cassava starch production with electro-flocculation

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	p-value
Regression	1.2990	5	0.2598	0.685
Residue	2.4673	6	0.4112	
Total	3.7663	11		

Source: research data.

Color Removal Efficiency

Table 6 shows the efficiency of color removal for the different experimental design tests. In 0.10 A and 17.50 minutes, the lowest color removal occurred among all experimental tests performed, 57.40%. On the other hand, the highest color removal occurred in the conditions of 1.05 A and 17.50 minutes, 86.78%.

Módenes *et al.* (2017), when applying the electro-flocculation technique in the treatment of poultry slaughterhouse effluents, using a complete factorial design with three independent variables, obtained 100% of color removal in the conditions of 2 A, pH equal to 10, and electrolysis time of 80 minutes. The higher percentage of color removal can be justified by the higher amperage and electrolysis time than those in the present study.

It is also observed that in all tests conducted in the central point condition (1.05 A and 17.50 minutes), the color removal efficiency was similar, which was expected, since the tests were conducted under the same experimental conditions, proving that the experiment and the results obtained are reliable, presenting low variability.

Table 6 – Efficiency for color removal efficiency in the treatment of wastewater from cassava starch production with electro-flocculation

Electric current density (C.I)		Hydraulic detention time (HDT)		Removal (%)
Encoded	**Real (A)**	**Encoded**	**Real (min)**	
-1	0.38	-1	8.63	69.27
+1	1.72	-1	8.63	57.77
-1	0.38	+1	26.37	70.05
+1	1.72	+1	26.37	63.78
-1.41	0.10	0	17.50	57.40
+1.41	2.00	0	17.50	60.15
0	1.05	-1.41	5.00	59.69
0	1.05	+1.41	30.00	71.45

Electric current density (C.I)		Hydraulic detention time (HDT)		Removal (%)
Encoded	Real (A)	Encoded	Real (min)	
0	1.05	0	17.50	81.24
0	1.05	0	17.50	84.27
0	1.05	0	17.50	86.22
0	1.05	0	17.50	86.78

Source: research data.

As shown in Table 7, HDT and electric current density (quadratic terms) significantly negatively affect the dependent variable since the p-value obtained in both cases is lower than the adopted significance level of 95%. In theoretical terms, the effect of a factor can be understood as the variation caused in the response, when we go through all the levels of that factor, independently of the other factors (RODRIGUES; IEMMA, 2014). In this context, the significant results obtained indicate that in higher conditions of electric current density and hydraulic detention time there is a tendency for the system efficiency to reduce.

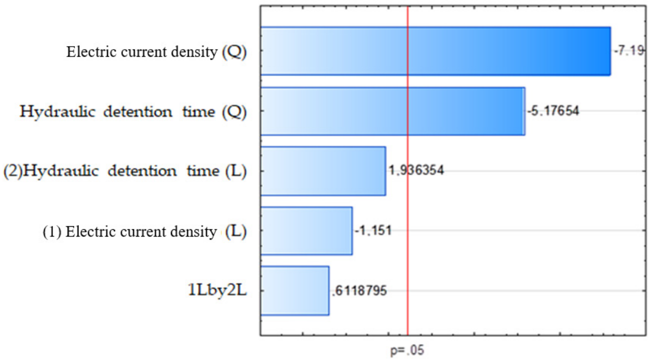
Table 7 – Effects analysis for color removal in the treatment of wastewater from cassava starch production with electro-flocculation

Factor	Effect	p-value
Average	84.62	0.000
C.I (L)	-3.48	0.294
C.I (Q)	-24.40	$3x10^{-4}$*
HDT (L)	5.86	0.101
HDT (Q)	-17.56	0.002*
C.I x HDT	2.62	0.563

Source: research data. *Statistically significant with a 95% confidence interval.

In the Pareto Graph for the color removal efficiency (Figure 3), it is possible to observe that the electric current density (Q) and the hydraulic detention time (HDT) exerted a significant effect on the color removal efficiency. However, the electric current density (Q) influenced the evaluated process more.

Figure 3 – Pareto chart of color removal in the treatment of wastewater from cassava starch production with electro-flocculation



Source: prepared by the authors based on research data.

The proposed mathematical model, representative of the process for color removal, is presented in Equation 6. The coefficients were estimated by multiple linear regression analysis using the least squares method. The non-significant terms were maintained in the mathematical model to ensure that the model is robust to variations in the conditions imposed by the operating conditions of the electrochemical reactor. Furthermore, maintaining all terms in the mathematical model ensures that the loss of information of practical relevance is avoided, in addition to enabling the capture of the complete dynamics of the treatment system employed.

$$CR = 84.62 - 1.74\ C.I - 12.20\ C.I^2 + 2.93\ TDH - 8.78\ HDT^2 + 1.31\ C.I \times HDT \qquad \text{Eq. (6)}$$

CR: Color removal (%)
C.I: coded value of the electric current density.
HDT: coded value of the hydraulic detention time.

The electric current density (Q) and the hydraulic detention time (Q) significantly influenced the efficiency of color removal for electrochemical treatment of wastewater from cassava starch production because the p-value was less than the adopted significance level of 95%.

Table 8 – Analysis of variance for color removal in the treatment of wastewater from cassava starch production with electro-flocculation

Factor	Sum of Squares	Degrees of Freedom	Mean Square	p-value
C.I (L)	24,197	1	24,197	0.294
C.I (Q)	944,556	1	944,556	$3x10^{-4*}$
HDT (L)	68,483	1	68,483	0.101
HDT (Q)	489,431	1	489,431	0.002*
C.I x HDT	6,838	1	6,838	0.563
Residue	109,588	6	18,2647	
Total	1643.093	11		

Source: research data.

*Statistically significant with a 95% confidence interval.

Table 9 summarizes the Analysis of Variance (ANOVA) for the statistical validation of the mathematical model proposed for color removal, which is statistically significant. In practical terms, it is understood that the mathematical model can be applied to the simulation of future scenarios, simulating the color removal efficiency of wastewater from cassava starch production within the range of the independent variables in which it was generated.

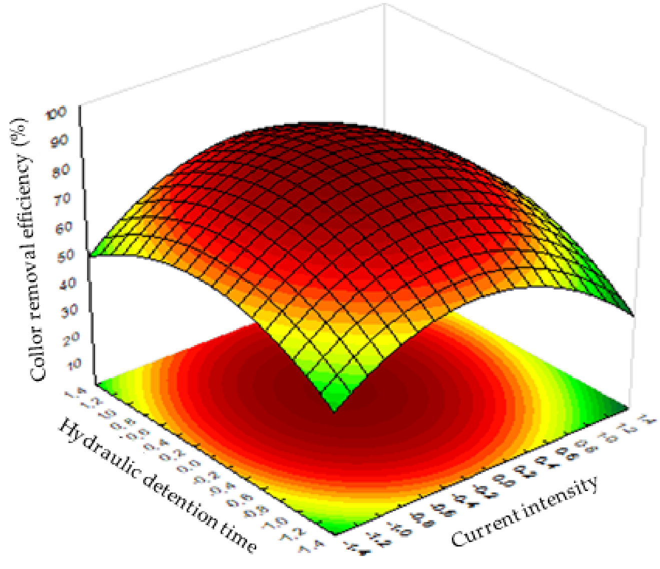
Table 9 - Statistical validity of the proposed mathematical model for color removal in the treatment of wastewater from cassava starch production with electro-flocculation

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	p-value
Regression	1533.51	5	306.70	0.0018*
Residue	109.59	6	18.27	
Total	1643.10	11		

Source: research data.

*Statistically significant with a 95% confidence interval.

Figure 4 – Response surface for color removal efficiency in the treatment of wastewater from cassava starch production with electro-flocculation



Source: prepared by the authors based on research data.

Table 10 shows the predicted and observed efficiencies for the removal of color, according to an experimental test conducted in triplicate in the optimal operation conditions of the electro-flocculation system (1.05 A and 17.50 min). The proposed mathematical model described the color removal efficiency satisfactorily, presenting an error of 1.05%. Based on this result, it is possible to infer that the mathematical model generated for color removal presents high predictive capacity and can be used to simulate real situations for the electro-flocculation technique applied to treating wastewater from cassava starch production.

Table 10 – Experimental validation of the proposed mathematical model for the treatment of wastewater from cassava starch production with electro-flocculation

Parameter	Expected Efficiency (%)	Observed Efficiency (%)	Error (%)
Color	84.62	83.74	1.05

Source: research data.

Influence of electro-flocculation on pH

Table 11 shows the behavior of the pH of the wastewater from cassava starch production after undergoing electrochemical treatment in different experimental conditions. In the condition of 2.00 A and 17.50 minutes, it is possible to observe the lowest pH (4.42) among the electrochemical tests performed. On the other hand, the highest pH (5.42) was observed in the conditions of 1.05 A and 17.50 minutes.

Table 11 – Variation of pH according to the different experimental conditions for the treatment of wastewater from cassava starch production with electro-flocculation.

Electric current density (C.I)		Hydraulic detention time (HDT)		pH variation
Encoded	**Real (A)**	**Encoded**	**Real (min)**	
-1	0.38	-1	8.63	4.50
+1	1.72	-1	8.63	4.66
-1	0.38	+1	26.37	4.59
+1	1.72	+1	26.37	4.92
-1.41	0.10	0	17.50	4.48
+1.41	2.00	0	17.50	4.42
0	1.05	-1.41	5.00	4.72
0	1.05	+1.41	30.00	5.10
0	1.05	0	17.50	5.08
0	1.05	0	17.50	5.42
0	1.05	0	17.50	5.40
0	1.05	0	17.50	5.38

Source: research data.

The pH of the raw effluent, without the application of the electrochemical treatment, is 4.38, which shows that performing the electrochemical tests using aluminum electrodes raises the pH of the effluent. Furthermore, adequate wastewater treatment is necessary to comply with CONAMA Resolution 430/2011, which defines effluent discharge conditions as pH between 5 and 9.

In this context, Crespilho *et al.* (2004) state that electro-flocculation has the property of increasing the pH value of the effluent after its treatment if the effluent has acidic characteristics, which is mainly due to the principle that electro-flocculation produces OH- ions.

The electric current density and the hydraulic detention time (quadratic terms) significantly negatively affect the pH variation (Table 12).

Table 12 – Analysis of effects for the pH change in the treatment of wastewater from cassava starch production with electro-flocculation

Factor	Effect	p-value
Average	5.32	0.000
C.I (L)	0.10	0.356
C.I (Q)	-0.88	$2x10^{-4}$*
TDH (L)	0.22	0.071
TDH (Q)	-0.42	0.011*
C.I xTDH	0.09	0.575

Source: research data. *Statistically significant with a 95% confidence interval.

Based on the results obtained, we can observe that electroflocculation is a promising and alternative technique to the traditional treatment of cassava effluent, which usually involves microbiological processes, whose efficiency is directly influenced by environmental factors, demand large areas for the installation of the treatment system and high time of microbial action (Colin *et al.*, 2006; Fleck *et al.*, 2017; Fleck *et al.*, 2018).

As an advantage of electro-flocculation, we can highlight the possibility of applying the technology anywhere, regardless of climatic conditions. In addition, when compared to traditional chemical coagulation, electro-flocculation avoids the generation of chemical compounds that are harmful to health (Silva *et al.*, 2020), besides reducing the formation of residual sludge (Crespilho; Rezende, 2004), which can be understood as an environmental liability of great relevance when not properly managed.

CONCLUSIONS

Electrochemical tests increase the pH of the effluent from the processing of cassava starch. For turbidity, it was observed that the controlled independent variables did not significantly influence the system efficiency. However, the greatest turbidity removal occurs close to the central point for the reaction time and in conditions greater than the central point for electric current density.

The greatest color removals are obtained close to the central point conditions and the mathematical model representative of the process can be used to simulate color removal efficiencies of wastewater from the processing of cassava starch, within the limits of the independent variables in which it was generated.

In conclusion, the system used satisfactorily met the objectives of this study and that the electro-flocculation shows itself as a promising alternative to conventional wastewater treatments, being efficient, requiring simple and easy-to-operate equipment, and limiting the use of chemicals harmful to the ecosystem.

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