CHEMICAL ENGINEERING TRANSACTIONS

VOL. 120, 2025

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Bing Shen How, Viknesh Andiappan, Denny K.S. Ng, Hon Loong Lam, Petar S. Varbanov

ISBN 979-12-81206-21-2; **ISSN** 2283-9216

DOI: 10.3303/CET25120102

Effectiveness of Electrocoagulation in the Treatment of Agricultural Wastewater from the Coffee Industry in the Peruvian Amazon

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The research evaluated the electrocoagulation treatment for the removal of organic matter in agricultural wastewater from coffee processing. The study was conducted over a period of one and a half months at a traditional coffee pulping and washing plant, with weekly sampling (six times in total), using labeled containers and a portable refrigerator. The reactor was batch type (3L) constructed in glass and 6 consecutive weekly sampling events of the wastewater were carried out. Nine treatments were tested, varying the electric current intensity (1.0, 2.5, and 4.0 A) and removal times (15, 30, and 45 min), using aluminum and iron electrodes. The best results were obtained with a treatment of 4.0 A and 45 min of removal time, using aluminum electrodes, achieving average values of 93.99% removal of BOD5, 87.78% removal of COD, and 96.82% removal of TSS. These results met the requirements of current environmental regulations, such as Maximum Permissible Limit (MPL) and Environmental Quality Standard (EQS). It was concluded that the use of aluminum electrodes under optimal conditions is the best alternative for reducing organic parameter concentrations in coffee processing wastewater, contributing to improved environmental quality.

1. Introduction

Coffee processing wastewater poses a major environmental challenge, as nearly 40 liters are generated per kilogram of processed coffee, threatening ecosystems due to its high pollutant load (Alemayehu et al., 2020). With global production reaching 8–10 million tons annually, particularly in Latin America, the cumulative environmental impact is substantial (Harvey et al., 2021). In Peru, the world's seventh-largest coffee exporter (Jasson et al., 2022), untreated effluents intensify coastal risks such as eutrophication and oxygen depletion (Sarma, 2025). Consequently, there is an urgent need for cost-effective solutions, and electrocoagulation has been identified as a promising alternative for wastewater remediation (Boinpally et al., 2023). This study therefore evaluates its effectiveness in the Peruvian Amazon, contributing to regional and global sustainability efforts.

Coffee processing wastewater is characterized by low pH, high organic load, nutrients, suspended solids, and phenolic compounds, posing severe risks to aquatic ecosystems (Asha et al., 2021). Indeed, pollutant levels are extreme, with BOD_5 reaching 20 000 mg/L and COD exceeding 50 000 mg/L, far above international standards (Pires et al., 2021). Given these critical limitations, electrocoagulation has been identified as a sustainable and cost-effective treatment alternative, particularly for applications in the Peruvian Amazon (Dobrosz-Gómez, Ibarra-Taquez, & Gómez-García, 2025). Thus, the persistence of such challenges underscores the urgent need for more efficient and environmentally responsible wastewater management strategies.

Electrocoagulation with Al and Fe electrodes has demonstrated removal efficiencies of up to 82.7% and 72.7% TOC in batch and semicontinuous modes, confirming its potential for wastewater treatment (Sandoval et al.,

Paper Received: 14 July 2025; Revised: 15 September 2025; Accepted: 15 November 2025
Please cite this article as: Chuquimbalqui Marina D., Guerrero Escobedo A.E., Azabache Liza Y.F., Rodriguez Espinoza R.F., Vargas Vasquez L.M., Ayala Diaz M.A., 2025, Effectiveness of Electrocoagulation in the Treatment of Agricultural Wastewater from the Coffee Industry in the Peruvian Amazon, Chemical Engineering Transactions, 120, 607-612 DOI:10.3303/CET25120102

2024). Moreover, studies in Peru indicate that combining electrocoagulation with pitahaya-derived biocoagulant using aluminum electrodes can achieve >95% turbidity/color and 86.21% COD removal (Mao et al., 2023), reinforcing its value as an alternative to conventional methods due to higher efficiency, reduced sludge generation, and lower chemical demand (Moradi et al., 2021). Mechanistically, the process relies on electrolytic oxidation of sacrificial electrodes, where released metal ions destabilize contaminants and microbubbles enhance flotation; however, its application to coffee wastewater requires optimization of parameters such as current density, electrode type, and reaction time to balance efficiency with energy and electrode consumption (Shahedi et al., 2020). Pulsed electrocoagulation effectively treats coffee processing wastewater, achieving high pollutant removal under optimized operational conditions (Asefaw et al., 2024).

Previous studies have shown significant advances in the treatment of effluents using electrocoagulation. Most studies have focused on processed coffee effluents and the use of one or two operating parameters. However, there are still some significant gaps in knowledge regarding its application to agricultural coffee wastewater in a tropical environment such as the Peruvian Amazon. This study evaluates the performance of aluminum and iron electrodes, current intensity, and treatment time as operating variables, focusing on the reduction of BOD_5, COD, and TSS.

In this regard, this research optimizes the operating parameters of electrocoagulation for the treatment of agricultural wastewater from a coffee plantation in the Peruvian Amazon. This work makes an original contribution by using two types of electrodes to seek the optimal treatment conditions, validating its environmental viability as an alternative and its compliance with local regulations. The study expands the knowledge base on treatments applied to agricultural coffee systems and promotes sustainable solutions aligned with Sustainable Development Goals 6 and 12, related to access to clean water and responsible production.

2. Materials and Methods

2.1 Materials

The equipment and reagents used in this study included the following: BIOEVOPEAK incubator, HACH HQ40D portable multimeter, HACH DRB200 single-block digital thermoreactor, HACH DR900 colorimeter, HACH DR1900 spectrophotometer, BIOEVOPEAK DON-65 stove, METTLER TOLEDO ME204T analytical balance, and HACH BOD Nutitent Buffer Pillows.

2.2 Methods

Sampling and Field stage

The wastewater is the water from washing the coffee beans, which is carried out four times, also known as honey water. Sampling was carried out six times in total, once a week for a month and a half, using labeled 3-L containers and a 40-L cooler. Two bags of cooling gel were also used to maintain the temperature of the samples during transport. The sampling campaign was conducted from August to October 2023. To ensure sample integrity, all wastewater samples were transported to the laboratory within 1 hour of collection and stored at 25 °C prior to analysis and treatment. Sampling was carried out following the recommendations of APHA, AWWA, WEF (2012).

Experimental design

The research was carried out in the province of Moyobamba, Peru, over a period of six months. An experimental design adapted to a full factorial design was used to evaluate the efficacy of the electrocoagulation process in the removal of organic matter in agricultural coffee wastewater. The experimental design consisted of 2 factors, 3 levels, 2 applications, 9 treatment combinations, and 2 replicates, with 36 trials in total. Different intensities of electric current were applied according to the capacity of the energy source (1.0, 2.5, and 4.0 A) with removal times of 15, 30, and 45 minutes.

Reactor Design

The following table shows the parameters and values used for the design and subsequent construction of the electrocoagulation reactor, including materials and design conditions according to the process. The design criteria and operational considerations were based on the methodology reported by Sandoval et al. (2024).

Table 2. Design parameters of the electrocoagulation reactor.

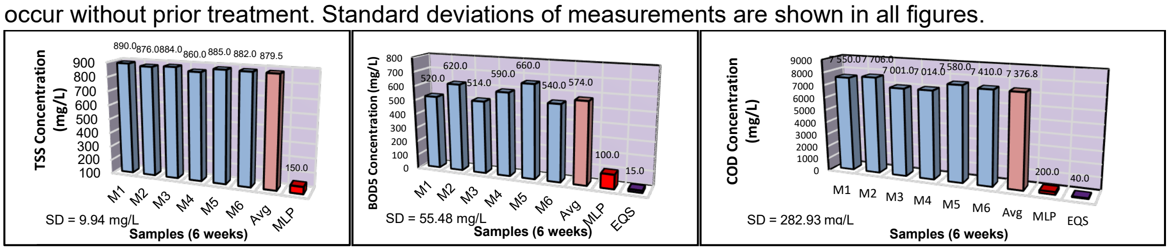
Parameter	Value
Volume of treatment	3 L
Type of reactor	Batch - Discontinuous
Power source	AC 110 V / 220 (05 A / 30 V)
Electrodes	Anode (5 aluminium plates and 5 iron plates), Cathode (5 aluminium plates and 5 iron plates)
Electrode configuration	Monopolar - parallel
Total electrode area	377 cm^2
Effective electrode area	234 cm^2
Distance between electrodes	1 cm
Current intensity levels	1.0 A, 2.5 A and 4.0 A
Current density	42.74 A/m^2, 106.84 A/m^2 and 170.94 A/m^2
Voltage levels	1.6 V, 3.8 V y 5.1 V
Treatment time	15 minutes, 30 minutes and 45 minutes
Total volume of the cell	6 300 cm^3
Effective volume of the cell	4 059 cm^3
Cell material	glass
Cell thickness	0.5 cm
Dimensions of the cell	Long: 15 cm; Width: 15 cm; Height: 28 cm
Connecting fitting	05 red wires (Power supply - Anodes) 05 blue wires (Power supply - Cathodes)
Sampling point / diameter	Reaction zone, 4.5 cm from the base, 1/4 inch diameter

Pre and Post Treatment Analysis

Physicochemical analyses were carried out to determine the initial and final concentrations of TSS, BOD_5, and COD, and secondary parameters (temperature and pH) were determined in order to evaluate the effect of the treatment on these parameters. The analyses were performed following the standardized procedures described in Hach (2012).

3. Results and discussions

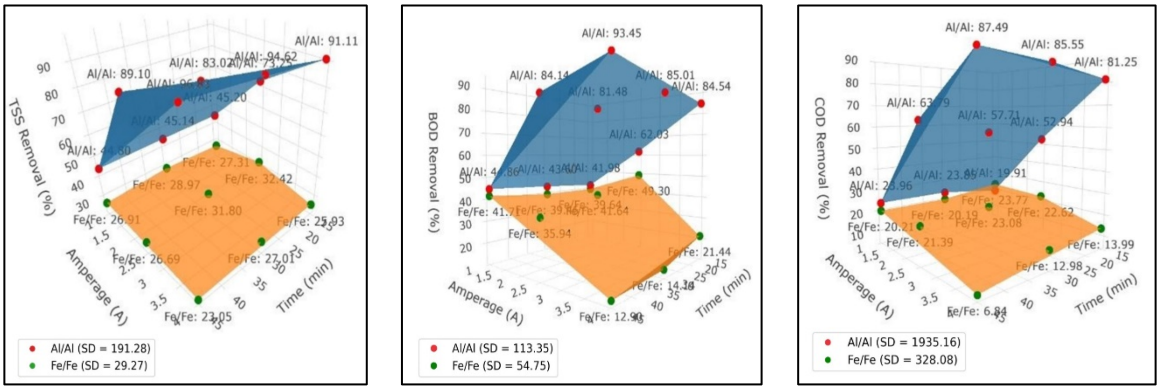
Figure 1a shows the initial concentrations of the Total Suspended Solids parameter for each sampling for the six weeks, accompanied by their average value; these values are not very different from each other according to the Wilcoxon statistical test. The highest value of this parameter was obtained in the measurement of the first sample (M1), which was 890.0 mg/L and the lowest value was obtained in the measurement of the fourth sample (M4), with a value of 860.0 mg/L. The average concentration of the TSS parameter for the six samples was 879.5 mg/L. The high level of these concentrations is evident in comparison with the Maximum Permissible Limits required by the Peruvian Ministry of the Environment for its correct emission, which is 150 mg/L. Figure 1b shows the initial concentrations of BOD_5 for each sampling, obtaining 660 mg/L as the highest initial concentration in the fifth sampling (M5) and 514 mg/L as the lowest initial concentration in the third sampling (M3). The final average concentration of the six samples analyzed was 574 mg/L, which is far from the levels required by the environmental regulations: Maximum Permissible Limits (MPL) and Environmental Quality Standards (EQS), which are 100 mg/L and 15 mg/L, respectively. Figure 1c presents the initial COD concentrations recorded in each sampling. This parameter is one of the most significant indicators for assessing organic matter pollution in water bodies. The results show that the agricultural wastewater analyzed has COD concentration levels that represent a considerable risk of environmental pollution if direct discharges were to occur without prior treatment. Standard deviations of measurements are shown in all figures.



(a) (b) (c)

Figure 1: (a) Initial TSS concentration (b) Initial BOD_5 concentration (c) Initial COD concentration in the effluent

Electrocoagulation demonstrated significant efficacy in treating coffee processing wastewater, with aluminum electrodes exhibiting superior performance compared to iron electrodes across all measured parameters. As shown in Figure 2a, aluminum electrodes achieved 96.83% total suspended solids (TSS) removal at 170.94 A/m^2 for 45 minutes, consistent with findings by Bukhari (2008), while iron electrodes only reached 32.42% efficiency, aligning with observations by Rookesh et al. (2022). Similarly, Figure 2b illustrates that aluminum electrodes reduced BOD_5 by 93.45% under optimal conditions (170.94 A/m^2, 45 minutes), bringing concentrations below the maximum permissible limit (MPL) of 100 mg/L but still exceeding the environmental quality standard (EQS) of 15 mg/L, corroborating results from Esfandyari et al. (2015). In contrast, iron electrodes exhibited markedly lower BOD_5 removal (≤49.30%), with minimal efficiency (14.14%) at higher currents. For COD removal (Figure 2c), aluminum electrodes achieved 87.49% reduction, whereas iron electrodes plateaued at 23.77%, though neither met Peruvian regulatory thresholds (MPL: 200 mg/L; EQS: 40 mg/L). While electrocoagulation with aluminum electrodes proves highly effective for organic pollutant removal (M. Iqbal et al., 2021), these results suggest the need for process optimization or hybrid approaches, as biological methods may offer complementary advantages in sludge reduction and complex pollutant degradation (Akinnawo et al., 2023). Standard deviations of the removals are shown in all figures.



(a) (b) (c)

Figure 2: (a) TSS removal percentage (b) BOD_5 removal percentage (c) COD removal percentage

Figure 3 indicates that the wastewater in question is acidic, which is an important characteristic to consider. The acidic pH of these waters could generate potential risks of contamination or alteration of the environment when discharged directly into the environment. According to current MPL and EQS regulations, the pH of wastewater should be in the range between 6.5 and 8.5.

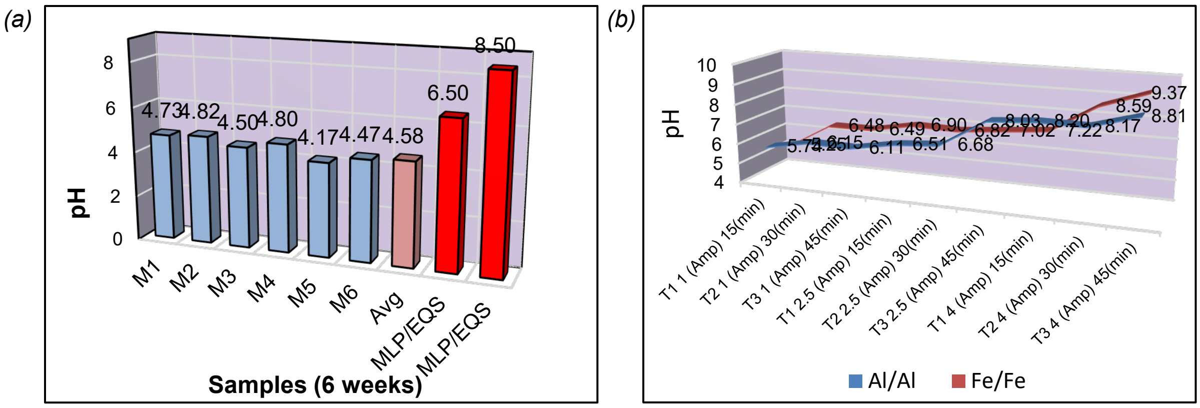


Figure 3: (a) Initial pH concentration (b) Post-treatment pH concentration

Figure 4 provides visual evidence of the effectiveness of electrocoagulation for treating wastewater with high organic load, highlighting its ability to improve water quality at optimal levels of current intensity and removal time.

Figure 4: Agricultural coffee wastewater before and after electrocoagulation treatment

4. Statistical Analysis

The results in Table 3 show statistically significant differences in the corrected model and in the intercept for all dependent variables, according to the Wilcoxon statistical test with the average data from three repetitions. Current intensity shows highly significant effects in all conditions ($p<0.001$) except for TSS with iron electrodes ($p=0.010$). Removal time shows significant effects on all dependent variables. The current intensity-removal time interaction has no effect in half of the cases.

Table 3: Tests for inter-subject effects (Dependent variable / Electrodes)

Source	Dependent Variable					
	BOD_5		TSS		COD	
	Electrodes: Aluminum/ Aluminum	Electrodes: Iron/ Iron	Electrodes: Aluminum/ Aluminum	Electrodes: Iron/ Iron	Electrodes: Aluminum/ Aluminum	Electrodes: Iron/ Iron
	p	p	p	p	p	p
Corrected model	<.001	<.001	<.001	.038	<.001	<.001
Intersection	<.001	<.001	<.001	<.001	<.001	<.001
A) Current intensity	<.001	<.001	<.001	.010	<.001	<.001
B) Removal Time	<.001	.015	<.001	.041	.027	<.001
AB) Current intensity * Removal Time	<.001	.064	<.001	.595	.685	<.001
Standard deviation (pre-treatment)	55.4765	55.4765	9.9366	9.9366	282.9299	282.9299
Standard deviation (post-treatment)	113.3527	54.7507	191.28	29.2673	1935.1567	328.0790

5. Conclusions

Electrocoagulation is an efficient technique for treating liquid effluents, such as liquid coffee effluents, significantly reducing pollution. In this study, average removals of 93.45% in BOD_5, 87.49% in COD and 96.83% in TSS were achieved according to three repetitions.The study shows that the use of aluminium electrodes in optimal conditions of 4.0 A (170.94 A/m^2) and 45 minutes of treatment allows an efficient removal of pollutants and a significant reduction of organic matter in wastewater. In addition, aluminium electrodes show superior performance compared to iron electrodes, highlighting the influence of the material on the efficiency of the electrocoagulation process.The application of electrocoagulation as a treatment process can be considered a sustainable and efficient alternative to mitigate the negative effects of agricultural wastewater pollution, especially in contexts such as coffee, where effluents have specific characteristics that require technical attention.

References

Akinnawo S.O., Ayadi P.O., Oluwalope M.T., 2023, Chemical coagulation and biological techniques for wastewater treatment, Ovidius University Annals of Chemistry, 34(1), 14–21. DOI: 10.2478/auoc-2023-0003.

Alemayehu Y.A., Asfaw S.L., Tirfie T.A., 2020, Management options for coffee processing wastewater: A review, Journal of Material Cycles and Waste Management, 22(2), 454–469. DOI: 10.1007/s10163-019-00953-y.

Alimohammadi M., Darvishi Cheshmeh Soltani R., Baziar M., Kakavandi B., Mahvi A.H., 2017, Elimination of natural organic matter by electrocoagulation using bipolar and monopolar arrangements of iron and aluminum electrodes, International Journal of Environmental Science and Technology, 14, 2125–2134. DOI: 10.1007/s13762-017-1402-3.

APHA; AWWA; WEF, 2023, Standard Methods for the Examination of Water and Wastewater (24th. ed.). Washington, D.C., USA: American Public Health Association.

Asefaw K.T., Bidira F., Desta W.M., Asaithambi P., 2024, Investigation on pulsed-electrocoagulation process for the treatment of wet coffee processing wastewater using an aluminum electrode, Sustainable Chemistry for the Environment, 6, 100085. DOI: 10.1016/j.scenv.2024.100085.

Asha Gururaj B., Manoj Kumar K.N., Achyuth B.R., Manoj B.R., 2021, Coffee processing wastewater management: An overview, Journal of Engineering Research and Reports, 20(11), 52–61. DOI: 10.9734/jerr/2021/v20i1117405.

Boinpally S., Kolla A., Kainthola J., Kodali R., Vemuri J., 2023, A state-of-the-art review of the electrocoagulation technology for wastewater treatment, Water Cycle, 4, 26–36. DOI: 10.1016/j.watcyc.2023.01.001.

Bukhari A.A., 2008, Investigation of the electrocoagulation treatment process for the removal of total suspended solids and turbidity from municipal wastewater, Bioresource Technology, 99(5), 914–921. DOI: 10.1016/j.biortech.2007.03.015.

Dobrosz-Gómez I., Ibarra-Taquez H.N., Gómez-García M.Á., 2025, Evaluation of the environmental and economic scope of an electrocoagulation process for the treatment of wastewater from the instant coffee industry, Journal of Solid State Electrochemistry, 29(10), 3441–3463. DOI: 10.1007/s10008-024-05940-4.

Esfandyari Y., Mahdavi Y., Seyedsalehi M., Hoseini M., Safari G.H., Ghozikali M.G., Kamani H., Jaafari J., 2015, Degradation and biodegradability improvement of the olive mill wastewater by peroxi-electrocoagulation/electrooxidation-electroflotation process with bipolar aluminum electrodes, Environmental Science and Pollution Research, 22(8), 6288–6297. DOI: 10.1007/s11356-014-3832-5.

Hach, 2012, Water Analysis Handbook (7th ed.). Loveland, CO, United States: Hach Company.

Harvey C., Pritts A., Zwetsloot M., Jansen K., Pulleman M., Armbrecht I., Avelino J., Barrera J., Bunn C., García J., Isaza C., Muñoz-Ucros J., Pérez-Alemán C., Rahn E., Robiglio V., Somarriba E., Valencia V., 2021, Transformation of coffee-growing landscapes across Latin America: A review, Agronomy for Sustainable Development, 41, 71. DOI: 10.1007/s13593-021-00712-0.

Jasson Yllescas, Vega H., De La Cruz P., Pantoja J., Cancho-Rodriguez E., 2022, System based on market segmentation to improve the export of Peruvian coffee, European Business & Management, 8(2), 55–61. DOI: 10.11648/j.ebm.20220802.14.

Iqbal M., Nauman S., Ghafari M., Gomes A., Gomes C., Parnianifard A., 2021, Treatment of wastewater for agricultural applications in regions of water scarcity, Biointerface Research in Applied Chemistry, 12(5), 6336–6360. DOI: 10.33263/BRIAC125.63366360.

Mao Y., Zhao Y., Cotterill S., 2023, Examining current and future applications of electrocoagulation in wastewater treatment, Water, 15(8), 1455. DOI: 10.3390/w15081455.

Moradi M., Vasseghian Y., Arabzade H., Mousavi Khaneghah A., 2021, Various wastewaters treatment by sono-electrocoagulation process: A comprehensive review of operational parameters and future outlook, Chemosphere, 263, 128314. DOI: 10.1016/j.chemosphere.2020.128314.

Pires J.F., Viana D.C., Braga R.A. Jr., Schwan R.F., Silva C.F., 2021, Protocol to select efficient microorganisms to treat coffee wastewater, Journal of Environmental Management, 278, 111541. DOI: 10.1016/j.jenvman.2020.111541.

Rookesh T., Samaei M.R., Yousefinejad S., Hashemi H., Derakhshan Z., Abbasi F., Jalili M., Giannakis S., Bilal M., 2022, Investigating the electrocoagulation treatment of landfill leachate by iron/graphite electrodes: Process parameters and efficacy assessment, Water, 14(2), 205. DOI: 10.3390/w14020205.

Sandoval M.A., Coreño O., García V., Salazar-González R., 2024, Enhancing industrial swine slaughterhouse wastewater treatment: Optimization of electrocoagulation technique and operating mode, Journal of Environmental Management, 349, 119556. DOI: 10.1016/j.jenvman.2023.119556.

Sarma V.V.S.S., 2025, Do discharge of agricultural effluents and municipal sewage damage coastal ecosystem along the Indian coast? A reanalysis, Journal of Earth System Science, 134(2), 36. DOI: 10.1007/s12040-024-02494-x.

Shahedi A., Darban A.K., Taghipour F., Jamshidi-Zanjani A., 2020, A review on industrial wastewater treatment via electrocoagulation processes, Current Opinion in Electrochemistry, 22, 154–169. DOI: 10.1016/j.coelec.2020.05.009.