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Effect of voltage and pH on the electrocoagulation process for chemical oxygen demand removal in wastewater from Mollendo, Peru

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ABSTRACT

The discharge of urban wastewater to receiving bodies represents a growing environmental threat in cities such as Mollendo, Peru, where the absence of a treatment plant has caused the discharge of untreated effluents into the sea, causing a serious ecological impact. Therefore, the objective of this study is to evaluate the influence of voltage and pH on the electrocoagulation process for the removal of Chemical Oxygen Demand (COD), whose initial concentration is approximately 670 mgL^{-1}. A system of 5 L batch reactors with iron electrodes was used, which presented fast removal kinetics, achieving a 94.4% reduction of COD in only 20 minutes under optimal conditions (pH 7.5 and 7 V) complying with local regulations. The rate constant around 0.1204 min^{-1} indicates a high level of accuracy of the mathematical model. In addition, the operating cost was estimated at 0.3919 USD/Kg COD which corresponds to energy consumption of 0.363 USD/Kg COD. These results demonstrate the potential of electrocoagulation as an effective, economical and sustainable alternative to mitigate water pollution in coastal urban environments.

Keywords: electrocoagulation, pH, removal, time, voltage, wastewater.

Efeito da voltagem e do pH no processo de eletrocoagulação para remoção da demanda química de oxigênio em águas residuais de Mollendo, Peru

RESUMO

O descarte de águas residuais urbanas em corpos receptores representa uma ameaça ambiental crescente em cidades como Mollendo, no Peru, onde a ausência de uma estação de tratamento causa um sério impacto ecológico na região. Portanto, o objetivo deste estudo é avaliar a influência da voltagem e do pH no processo de eletrocoagulação para a remoção da demanda química de oxigênio (DQO), cuja concentração inicial é de aproximadamente

670 mg L^{-1}. Foi utilizado um reator em batelada de 5 L com eletrodos de ferro. O sistema apresentou uma cinética de remoção rápida, alcançando uma redução de 94,4% da DQO em apenas 20 minutos sob condições ideais (pH 7,5 e 7 V), em conformidade com os limites máximos permitidos estabelecidos na regulamentação. A constante de taxa de k≈0,1204 min^{-1} e um coeficiente de determinação de R2 = 0,998 indicam um alto nível de precisão do modelo matemático. Além disso, o custo operacional foi estimado em US$0,324 por Kg DQO para um consumo de energia de US$0,24 por Kg DQO. Esses resultados demonstram o potencial da eletrocoagulação como uma alternativa eficaz, econômica e sustentável para mitigar a poluição da água em ambientes urbanos costeiros.

Palavras-chave: águas residuais, eletrocoagulação, pH, remoção, tempo, voltagem.

1. INTRODUCTION

The discharge of domestic and industrial wastewater without any type of treatment into receiving bodies such as bays, lakes, and marine areas generates harmful effects that impact the health and development of all living beings, causing deterioration in the quality of water, air, and soil due to its content of heavy metals, domestic and industrial waste, petroleum products, fats, fertilizers, pesticides, and excess organic matter (Adou *et al.*, 2022) endangering the sustainability of natural resources and the health of nearby populations (Cuadros Segura *et al.*, 2021).

The city of Mollendo, located on the coast of Arequipa, Peru, with an approximate population of 30,000 inhabitants, faces a serious environmental problem due to the direct discharge of untreated wastewater into the sea, lacking an urban wastewater treatment plant. This causes the accumulation of organic matter, nutrients, metals and pathogenic microorganisms in the marine ecosystem, resulting in the degradation of water quality, loss of biodiversity and harm to aquatic species of economic and food importance. Furthermore, human exposure to contaminated water increases the risk of waterborne diseases such as gastroenteritis, skin infections and parasitic infections, generating direct impacts on public health and economic activities (Musa Yahaya *et al.*, 2023). In this context, there is an urgent need to evaluate efficient, cost-effective and locally applicable treatment technologies.

Electrocoagulation (EC) is currently considered an emerging technology in wastewater treatment and has proven effective in effluent treatment. This process also generates electrodeposition (Costa *et al.*, 2022); electroflotation (Hacha *et al.*, 2019); electrooxidation (Valenzuela *et al.*, 2025) and electro-disinfection (Hakizimana *et al.*, 2017c).

This treatment has proven to be an effective option for removing various organic and inorganic contaminants from wastewater (Ahmad *et al.*, 2022; Dede Sağsöz *et al.*, 2022). This process stands out to be more economical than other treatment methods, such as advanced oxidation or filtration (Alam *et al.*, 2021; Ensano *et al.*, 2017).

In EC, an electric current is applied through an array of electrodes, usually made of aluminum (Al) or iron (Fe) (Hakizimana *et al.*, 2017a) to destabilize and remove suspended, emulsified, or dissolved contaminants from wastewater (Garomsa *et al.*, 2024). While Al electrodes have demonstrated good adsorption capacity in various treatment scenarios, numerous studies have reported that Fe electrodes achieve superior removal efficiencies, particularly organic compounds in highly contaminated effluents (Takdastan *et al.*, 2014; Zhao *et al.*, 2014). This improved performance is mainly attributed to the *in-situ* generation of ferric ions and iron hydroxides, which are highly reactive and facilitate coagulation, flotation, and sedimentation mechanisms. In addition, Fe electrodes offer significant advantages in terms of cost, and availability. Their shorter hydraulic retention times while maintaining high removal efficiency. While Fe is more prone to corrosion than other electrode materials, this limitation is generally offset by its lower cost and superior performance. Compared with Al, copper, or

stainless steel, Fe electrodes consistently demonstrate greater efficacy in treating wastewater with high concentrations of heavy metals and organic contaminants (Bani-Melhem *et al.*, 2023).

Coagulants are generated on the electrodes due to the redox reaction, releasing metal hydroxides, where the metal anodes oxidize and produce cations (Al-Qodah *et al.*, 2025; Shahedi *et al.*, 2023). Therefore, the ions in these particles are neutralized and agglomerate more easily, forming sediments. The resulting reaction is a redox process, involving oxidation at the anode, which releases metal ions, and a reduction reaction at the cathode terminals, producing hydrogen gas (Farhan Abbass *et al.*, 2024) (Olajire, 2020). As shown in the following oxidation-reduction reactions (Moneer *et al.*, 2012):

Under alkaline conditions, iron electrodes undergo oxidation, forming ferric hydroxide along various reactions.

Anode: $Fe_{(s)} \leftrightarrow Fe_{(aq)}^{2+} + 2e^-$

Cathode: $2H_2O_{(l)} + 2e^- \leftrightarrow H_{2(g)} + 2OH_{(aq)}^-$

In general: $Fe_{(S)} + 2H_2O_{(l)} \leftrightarrow Fe(OH)_{2(g)} + H_{2(g)}$

On the other hand, in an acidic medium, the oxidation of iron follows other mechanisms.

Anode: $4Fe_{(s)} \leftrightarrow 4Fe_{(aq)}^{2+} + 8e^-$

Precipitation: $4Fe_{(aq)}^{2+} + 10H_2O_{(l)} + 10O_{2(g)} \leftrightarrow 4Fe(OH)_{3(g)} + 8H_{(g)}^+$

Cathode: $8H_{(g)}+ + 8e^- \leftrightarrow 4H_{2(g)}$

In general: $4Fe_{(aq)}^{2+} + 10H_2O_{(l)} + 10O_{2(g)} \leftrightarrow 4Fe(OH)_{3(g)} + 4H_{2(g)}$

The batch reactor allows for process study and variable control. The area surrounding the electrodes is defined as the reaction area, where particles charge destabilization, coagulation, and sedimentation occurs (El-Taweel *et al.*, 2023).

For this reason, the variables studied in this process are voltage, pH, and time, to determine its effectiveness in the removal of contaminants (Hakizimana *et al.*, 2017b; Tenodi *et al.*, 2024). Voltage is necessary for the formation of stabilizing agents that neutralize contaminants. pH influences the metal solubility process to form hydroxide. In several studies, it is observed that the pH varies depending on the type of electrodes considering the distance and the initial pH of the water to be treated during the CE process (Mao *et al.*, 2023). The pH increases in acidic wastewater, an effect attributed to the generation of molecular hydrogen at the cathode. Conversely, in alkaline wastewater, the pH decreases (Asefaw *et al.*, 2024). The longer the EC treatment time, generally the greater contaminant removal is obtained. However, there is a trade-off point, as excessively long treatment durations do not lead to significant improvements (Gonzáles Paredes *et al.*, 2020).

Additionally, in the electrocoagulation process, other operating parameters, particularly the use of supporting electrolytes such as sodium carbonate (Na_2CO_3), sodium bicarbonate ($NaHCO_3$), sodium chloride (NaCl) or calcium chloride ($CaCl_2$), can play a critical role in improving system performance. These salts are typically added to low electrical conductivity wastewater, thus facilitating more efficient coagulant generation at the electrodes (Govindan *et al.*, 2020; Liu *et al.*, 2023b; Tchamango *et al.*, 2021). EC generates, the removal efficiency of organic matter, microplastics, dyes and phosphates, therefore impacting on the physicochemical characteristics of the wastewater and the optimization of operating conditions (Bakshi *et al.*, 2020; Hu *et al.*, 2023; Subair *et al.*, 2024). However, the use of certain electrolytes, such as

sodium chloride, should be evaluated, since its ions can promote the formation of chlorinated products. While these compounds possess effective disinfectant properties against thermotolerant coliforms, they can also be toxic, corrosive and environmentally persistent. (Ndjomgoue-Yossa *et al*, 2022). Furthermore, chloride ions accelerate the corrosion rate of iron electrodes, leading to shorter electrode life, increased sludge production, and higher operating costs. COD measures the number of substances that can be chemically oxidized. It is used to assess the degree of pollution and is expressed in milligrams of diatomic oxygen per liter (mg L^{-1}) (Ruiz *et al.*, 2019). Therefore, the objective of this research was to analyze the effect of voltage and pH parameters on the performance of the CE reactor for the reduction of oxidizable matter, measured as COD, in wastewater from the Mollendo sewage system. This study proposes CE as a viable alternative for the treatment of urban wastewater discharged in coastal areas, optimizing critical operating parameters to maximize organic matter removal and minimize operating costs.

2. MATERIAL AND METHODS

2.1. Area and sample collection

The wastewater samples were collected in the city of Mollendo, located in Arequipa, Peru. Two monitoring points were established at the locations where the effluent is discharged into the sea, with the following coordinates: 18K, 0817292E - 8114990N at 66 m.a.s.l. and 18K, 0817760E - 8114499N at 38 m.a.s.l. The samples were composite, collected from combined monitoring points. A final volume of 150 L was obtained from both points. The sampling was carried out in accordance with the local regulations. The samples were preserved at 4°C during transport.

2.2. Chemical analysis

The COD analysis was conducted using the closed reflux colorimetric method EPA (APHA *et al.*, 2023) with the TECHCOMP S1010/S1020 spectrophotometer. For this, all reagents, such as potassium dichromate, were of analytical grade provided by Merck. The tests were performed in the analytical chemistry laboratory of the Department of Chemistry at the National University of San Agustín of Arequipa.

2.3. Electrocoagulation batch reactor setup

The reactor was constructed of acrylic material in the shape of a parallelepiped, with dimensions of 19 cm high, 20 cm long and 17.8 cm wide, and a capacity of 5 L. Iron electrodes were used, divided into 3 anodes and 3 cathodes. Each electrode had a thickness of 0.1 cm, a contact area of 12.0 cm × 14.0 cm (equivalent to 0.0168 m²) and a total surface area of 17.8 cm × 14.0 cm (equivalent to 0.0249 m²). The system was powered by a variable voltage direct current (DC) source, with an output capacity of up to 120 A and a range of 0–90 V. The electrical connection was made using 2/0 AWG copper cables, screws and conductive rods, ensuring efficient transmission of energy to the electrodes (Figure 1).

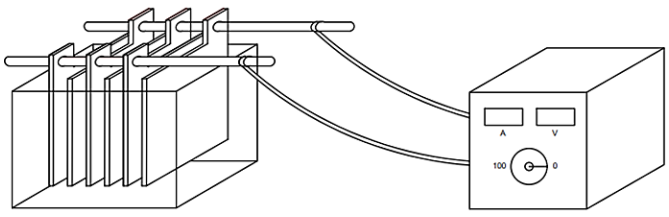

Figure 1. Schematic Diagram of the Cell.

2.4. Quality control

The analytical data quality was guaranteed through the implementation of laboratory quality and control methods. Method accuracy and quality control were verified by triplicate analysis of proficiency testing material.

2.5. Experimental procedure

For each experimental run, 2.5 L of the sample was used, following 15 minutes homogenization, with factors voltage (5, 6, and 7 V) and pH (6.5, 7, and 7.5) were tested, with a distance between electrodes of 2 cm, at ambient temperature (18°C). COD samples were taken every 5 minutes up to a limit time of 90 minutes. The response variable is the percentage of removal of oxidizable matter, estimated as the percentage of COD removal (%COD) (Equation 1).

$$\%COD = (CODi - COD)/CODi * 100 \quad (1)$$

Where: CODi and COD represent the initial and final concentrations of oxidizable matter (mg/L), respectively.

In this way, the effect of the operational variables: electrical potential (V) and pH on the COD removed over the residence time is determined.

2.6. Statistical Analysis.

A factorial design was conducted to determine the significance of the factors and their levels. Additionally, the effect of the factors on the removal of oxidizable matter was studied, and a mathematical model was established to relate the investigated factors. Statgraphics Centurion 18-X64 software was used to perform statistical analysis.

2.7. Evaluation of removal kinetics

To analyze the kinetics of contaminant removal (COD), the residual concentration will be monitored at different times during the batch process (initiated in 5 to 5 and finalized in 30 minutes), and the COD concentration will be determined at each point (Equation 2).

$$\ln(\frac{C_0}{C_t}) = kt \quad (2)$$

Where C_0 is the initial concentration of COD, C_t is the concentration at time t, and k is the removal rate constant.

2.8. Operational cost

Estimating the costs associated with domestic wastewater treatment processes generally involves a variety of factors, such as electricity consumption, sludge disposal, labor, and equipment use, among others (Elazzouzi *et al.*, 2017).

However, in non-conventional processes such as laboratory scale electrocoagulation, the factors that have the greatest influence on operating costs are the electrode material and electrical energy consumption (Patel *et al.*, 2024).

In this case, the total operating cost is defined as the sum of the energy consumption cost and the electrode consumption cost, according to Equation 3.

$$Operating\ cost\ of\ EC = A.C_{electrode} + B.C_{energy} \quad (3)$$

Where C_{energy} and $C_{electrode}$ represent the consumption per kilogram of treated water, while A corresponds to the cost of iron metal (0.245 USD/kg Fe) and B is the cost of electrical energy

(0.1366 USD/kWh).

These costs are determined by Equations 4 and 5, respectively.

$$C_{energy}(\frac{kWh}{kg}COD) = \frac{U \times I \times T_{EC}}{V \times C_i \times R_e} \quad (4)$$

$$C_{electrodo}(\frac{kg\ Fe}{kgCOD}) = \frac{I x\ T_{EC}\ x\ M_w}{n \times F \times V \times C_i \times R_e} \quad (5)$$

Where U is the voltage (V), I is the current (A), T_{EC} is the operation time (h), V is the volume of wastewater (m^3), Ci is the initial COD concentration (kg/m^3), Re is the COD removal efficiency, Mw is the molecular mass of the metal (g/mol), n is the number of moles (mol) and F is the Faraday constant (96487C/mol).

3. RESULTS AND DISCUSSION

3.1. Effluent characterization

The initial characteristics of the wastewater were: pH 7 ± 0.02; temperature 26 ± 2 °C; conductivity 3.6 ± 0.2 mS/cm; turbidity 137.3 ± 5.0 NTU; oils and greases 61 ± 3 mg/L; suspended solids 329 ± 5 mg/L; thermotolerant coliforms $94x10^6$ MPN/100 mL; biochemical oxygen demand (BOD) 325 ± 5 mg/L; and COD 670 ± 5 mg/L. These values significantly exceed, by more than 95% local regulations of Peruvian Maximum Permissible Limits (MPL) for effluent discharge into receiving bodies, according to Supreme Decree No. 003-2010-MINAM.

3.2. Effect of voltage and pH

To investigate the effect of voltage and pH on COD removal in wastewater, electrocoagulation was carried out using different voltages (5, 6, and 7 V) and pH levels (6.5, 7.0, and 7.5) over a period of 90 minutes (Figure 2). Our results revealed that at 5, 10, 20, and 40 minutes, the COD concentration decreased significantly, and after 40 minutes, the COD remained constant throughout the remainder of the experiment.

In the reaction process at 5 minutes (Figure 3.A), at a pH of 6.5, the COD removal is less than 50%, at pH 7.0, the COD removal ranges from 50-60%, while at pH 7.5 it ranges from 60-90%. Additionally, at pH 7.5 and 7 V, COD removal reached 88.42%. This is attributed to the voltage, which promotes the generation of ferrous ions that react with water to form hydroxides during the initial phase. During this time, the flocs are small and less dense (Gönder *et al.*, 2017; Jiang *et al.*, 2019). Additionally, during these first few minutes, hydrogen gas bubbles are formed at the cathode due to the dissolution of the metal (Liu *et al.*, 2023a). As the operation time is increased to 10 minutes (Figure 3.B), a greater generation of coagulants occurs, which interact with oxidizable matters. At this time, it is observed that at a pH of 6.5, the removal increased between 50-75%, at pH 7.0 it increased to 75-85%, and at pH 7.5, it ranged from 85-95%. At pH 7.5 – 7.0 V, a COD removal of 90.28% is achieved. For 20 minutes of reaction (Figure 3.C), at pH 6.5, the COD removal presents a range of 75-85%, at pH 7.0, it ranges from 85-95%, while at pH 7.5, it ranges from 90-95%. At this stage, the process is operating at its optimal performance (Boinpally *et al.*, 2023; Chow and Pham, 2021) this allows for a balance in the EC process (Abfertiawan *et al.*, 2024). At pH 7.5 – 7.0 V, a COD removal of 94.39% is achieved, indicating a 4% increase after 10 minutes of reaction.

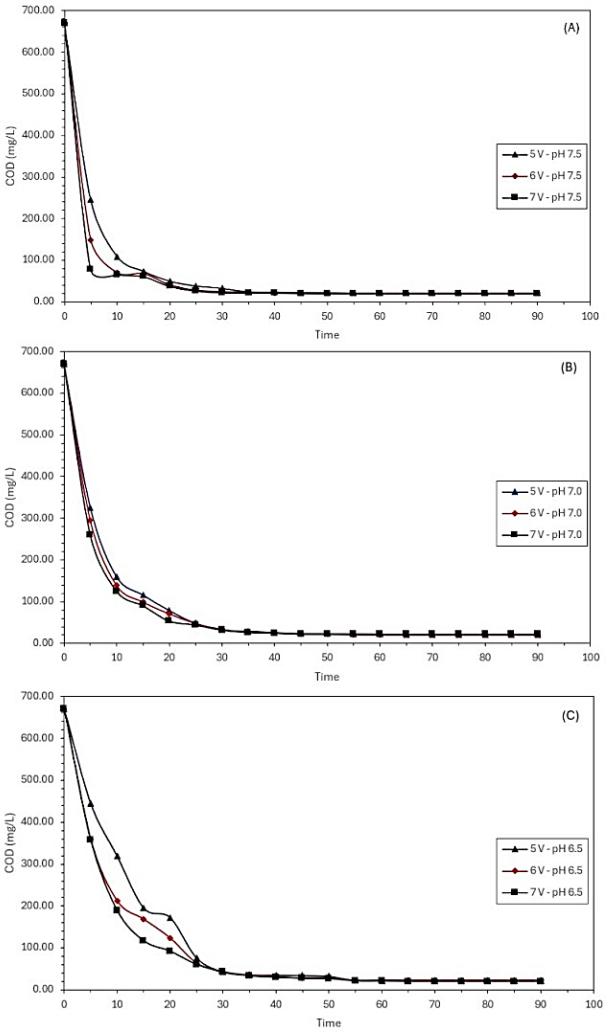

Figure 2. COD removal as a function of time and voltage (5, 6, and 7 V) in the electrochemical treatment of wastewater at different pH levels. A) pH 7.50, B) pH 7.00, and C) pH 6.50.

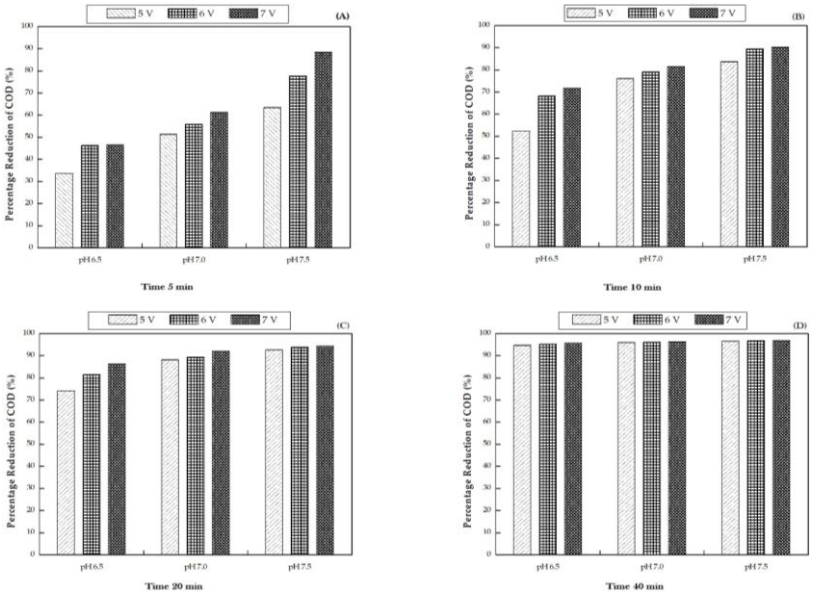

Figure 3. This is a figure. COD removal percentage for the following times: A) 5 min. B) 10 min. C) 20 min. D) 40 min.

During the 40 minutes of the process, a 95% COD removal efficiency is achieved for all treatments. At this stage, system saturation begins due to the accumulation of inhibitors deposited on the surface of the counterelectrode (cathode), limiting the flow of electric current (Othmani *et al.*, 2022; Safari *et al.*, 2016). Furthermore, the working electrode (anode) continues to be consumed and shows accumulation of oxidized products due to the lack of an adequate system (Khan *et al.*, 2023; Sher *et al.*, 2020; Syam Babu *et al.*, 2021), this increases electrical resistance and energy consumption (Abed Al-Rubaye *et al.*, 2024). Therefore, only a 2% increase (96.86% removal of COD) is observed during the reaction period from 20 to 40 minutes for pH 7.5-7.0 V.

Figure 4 compares the Peruvian regulation with the COD results over time (5, 10, 20, and 40 min.) in the process. The regulation establishes a COD concentration of 200 mg L^{-1} to ensure the protection of aquatic ecosystems and guarantee that the discharge does not affect the water quality in the receiving.

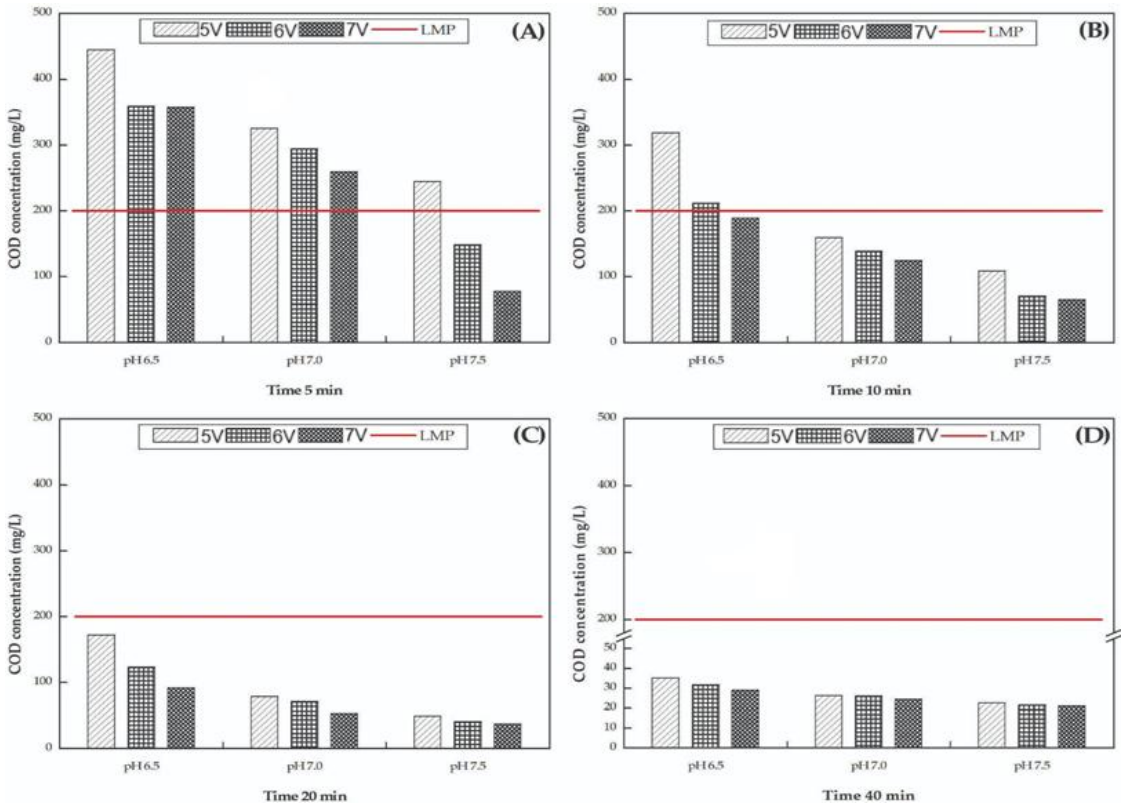

Figure 4. LMP compliance based on COD concentration mg/L, A) COD concentration at 5 min. of the process, B) COD concentration at 10 min. of the process, C) COD concentration at 20 min. of the process, D) COD concentration at 40 min. of the process.

At 5 minutes (Figure 4.A), at pH 7.5 with voltages of 6 and 7 V, the COD concentrations were 148.83 mg L^{-1} and 77.60 mg L^{-1}, respectively, which fall within the regulation limits. However, at 5 V, the concentration exceeded the regulation with a value of 244.71 mg L^{-1}. For pH 6.5 and 7.0, the values exceeded the regulation limits. At 10 minutes (Figure 4.B), at pH 6.5 with voltages of 5V and 6V, the concentrations were 318.91 mg L^{-1} and 212.27 mg L^{-1}, respectively, exceeding the maximum permissible limits (LMP). At the same pH with 7.0 V, the COD concentration was within the LMP, with a result of 189.14 mg L^{-1}. On the other hand, at pH 7.0 and 7.5, the concentrations met the LMP, with the minimum concentration of 65.09 mg L^{-1} at 7 V and pH 7.5, showing a reduction of 12.51 mg L^{-1} compared to the first 5 minutes. Both at 20 minutes (Figure 4.C) and 40 minutes (Figure 4.D), the values remained within the

LMP, so a treatment time of 20 minutes is optimal to meet the regulation for wastewater treatment.

3.3. Statistical Analysis

3.3.1. Factorial Analysis

The results of the factorial analysis for COD removal, where the effects of voltage (A), pH (B), and their interactions on the efficiency of the electrocoagulation process are evaluated.

The p-values indicate the statistical significance of 95% of each factor. In this case, both voltage (A) and pH (B) have a significant impact on COD removal, with p-values of 0.0102 and 0.0010, respectively, as they are below the common threshold of 0.05. The interaction between voltage and pH (AB) is also significant (p = 0.0257), indicating that these factors do not act independently, but rather their combination influences the efficiency of the process.

On the other hand, the quadratic interaction of voltage (AA) is not significant (p = 0.7562), suggesting that voltage itself does not have a relevant quadratic effect on COD removal. The quadratic interaction of pH (BB) shows a p-value of 0.0526, which is close to the significance threshold, indicating a possible marginal influence.

The low value of the total error (1.53856) compared to the total sum of squares (348.104) supports the robustness of the model. Therefore, the alternative hypothesis is supported, suggesting that the specific combination of pH and voltage directly influences the efficiency of COD removal.

3.3.2. Regression Model

The regression model used to predict COD removal is represented in Figure 5, showing the relationship between pH and voltage. Low values of pH (<6.8) and voltage (<5.5V) result in low removal efficiency (<81.2%). As pH and voltage increase, COD removal improves, reaching its optimal point at pH 7.5 and voltage 6.5-7.0 V with an efficiency of 96-98%. Lower values are not recommended, as they reduce contaminant removal.

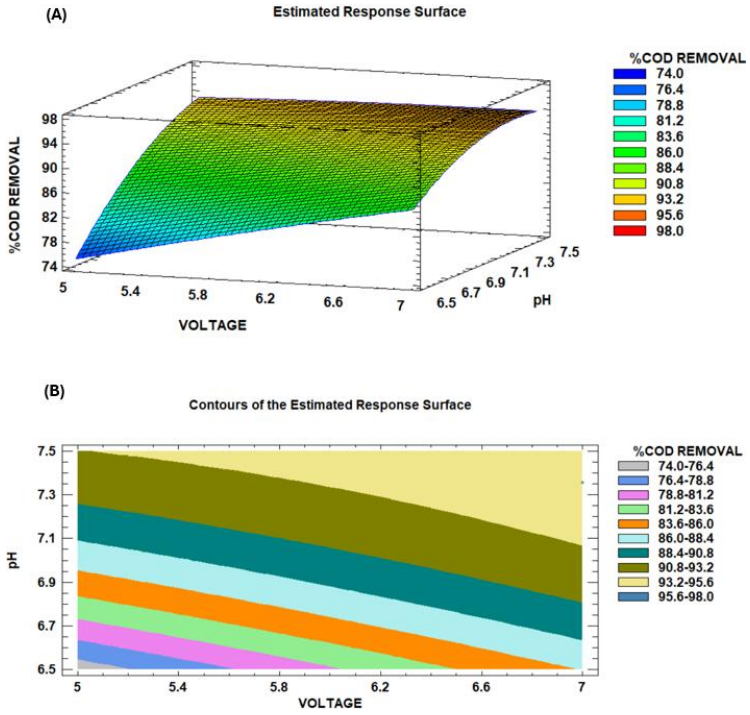

Figure 5. (A) Estimated response surface and (B) contour plot illustrating the influence of voltage and pH on COD removal efficiency. The surfaces were obtained from the fitted quadratic model (Equation 6).

The mathematical model that represents the removal of %COD is (Equation 6):

$$\%COD = -779.884 + 42.4317*V + 196.76*pH - 0.298333*V^2 - 5.13*V*pH - 10.9333*pH^2 \quad (6)$$

An R^2 of 98.67% and an adjusted R^2 of 96.46% were obtained, indicating that the model can explain that percentage of the variation in COD removal. It can predict removal based on the mentioned factors and fits the experimental data well.

3.4. Final Characterization of the Effluent

The results demonstrate a significant improvement in the quality of the wastewater treated through electrocoagulation. The pH was 8, temperature 28°C, and conductivity 4.0 mS/cm. A notable reduction in turbidity was achieved, reaching a value of 39.1 NTU, indicating a lower presence of suspended particles. Additionally, the concentration of oils and fats decreased to 5.63 mg/L, meeting the limits established by Peruvian regulations.

Regarding suspended solids, they were reduced to 4.2 mg/L, showing high efficiency in the removal of suspended materials. Furthermore, the Biochemical Oxygen Demand (BOD) decreased from 325 mg/L to 24 mg/L, while the COD reduced from 670 mg/L to 38 mg/L, reflecting the effective removal of contaminating organic matter.

A key aspect of the treatment was the near-total elimination of thermotolerant coliforms, with values lower than 1.8 MPN/100 mL, ensuring a significant microbiological improvement in the treated water.

3.5. Evaluation of removal kinetics

The kinetic analysis demonstrated high efficiency in the removal of COD. As shown in Figure 2, the evolution of COD removal over time showed an exponentially decreasing trend.

The experimental data were fitted to the first order kinetic model with high agreement, yielding a coefficient of determination of (R2) obtained was 0.998, confirming the robustness of the fit with a calculated rate constant of $k \approx 0.1204$ min-1, which implies that approximately 12% of the remaining COD is removed per minute. This value reflects rapid reaction kinetics, especially in the first minutes of the process.

After 5 minutes of treatment, 88.42% removal was achieved, increasing to 90.28% at 10 minutes and 94.39% at 20 minutes, representing a substantial decrease in the organic load in a short period of time.

As the treatment progresses, the removal rate tends to stabilize, reaching a cumulative removal of 96.86% at 40 minutes, indicating sustained process efficiency, albeit with a progressive decrease in the elimination rate.

3.6. Operating cost

Operating costs were estimated in this study considering the associated energy costs and iron electrode consumption, determined using Equations 3, 4, and 5 in Section 2.8, based on the optimal values for voltage, pH, and operating time obtained experimentally.

For the treatment of 5 L of sample, the energy consumption was 2.951 kWh/kg COD, which represents a cost of 0.363 USD/kg COD, considering a market price of 0.132 USD/kWh. Iron electrode consumption was 0.122 kg Fe/kg COD, equivalent to a cost of 0.028 USD/kg COD, based on a reference price of 0.237 USD per electrode sheet.

The total estimated cost for the treatment was 0.3919 USD/kg COD, with approximately 92.85% corresponding to energy consumption and 7.15% to electrode consumption. Consistently, (Bani-Melhem *et al.*, 2023) pointed out that the total cost of electrocoagulation can be substantially reduced by optimizing operating conditions and exploring different electrode characteristics, highlighting the importance of pilot and laboratory scale testing before its large scale application for wastewater treatment. The efficiency obtained in this work,

combined with the low operating cost, reinforces the economic viability of the process under optimal conditions and its potential as an efficient and competitive alternative for wastewater treatment.

4. CONCLUSIONS

This study aimed to remove oxidizable matter from domestic wastewater using an electrocoagulation process with iron electrodes in a batch system. After evaluating COD removal under different operating conditions, a COD removal efficiency of 94.39% was achieved, with an operating cost of 0.3919 USD/Kg COD and an energy consumption of 0.363 USD/Kg COD at pH 7.5, a voltage of 7 V, and a treatment time of 20 minutes, complying with the Maximum Permissible Limits established for treated effluents in Peru.

The kinetic behavior of the EC process was evaluated at different times (5, 10, 15, 20 and 30 minutes) with a rate constant of k≈0.1204 min-1 showing a rapid reaction rate during the initial stages, obtaining a progressive stabilization after 40 minutes, it was identified that higher pH and voltage values generate a greater removal of oxidizable material, which is favorable in the production of coagulant species and in the dynamics of the electrochemical reactions involved.

The results obtained support the efficiency and viability of the electrocoagulation process for wastewater treatment in coastal areas, positioning it as an ecologically and economically competitive alternative to conventional technologies.

5. DATA AVAILABILITY STATEMENT

Data availability not informed.

6. CONFLICT OF INTEREST

The authors declare no conflicts of interest; the founders had no role in the study design, data collection, analysis, or interpretation; in the writing of the manuscript; or in the decision to publish the results.

7. ACKNOWLEDGMENTS

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