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Development of a portable electrocoagulation unit for on-site treatment of washing machine wastewater

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ABSTRACT

This study evaluated the effectiveness of the electrocoagulation method in treating wastewater from two laundries in the Huancavelica district of Peru, focusing on reducing chemical oxygen demand (COD) and monitoring temperature and pH levels. Over two weeks, treatments were conducted with varying current intensities (15 and 30 Amp/m²) and durations (15 and 40 minutes), mixing speed + time (20 and 40 rpm) alongside a control with 0 Amp/m² and 0 minutes. The initial untreated samples showed high COD levels, highlighting significant organic pollution. The results demonstrated substantial COD reductions across all treatments, with the most effective reduction observed at 15 Amp/m² for 15 minutes, achieving COD levels of 366.50 mg/L in Laundry 1 and 348.50 mg/L in Laundry 2. This significant decrease complies with Supreme Decree No. 010-2019-VIVIENDA, which mandates COD levels below 1000 mg/L for non-domestic wastewater discharges. Temperature and pH variations were also analyzed, revealing that the electrocoagulation process increased the temperature moderately, with averages ranging from 15.15°C to 36.80°C in Laundry 1 and 15.65°C to 34.80°C in Laundry 2. The pH levels remained slightly alkaline, ranging from 8.47 to 10.55 in Laundry 1 and 9.47 to 10.62 in Laundry 2, indicating that the process maintains acceptable alkalinity. In conclusion, the electrocoagulation method effectively reduces COD, maintains moderate temperature increases, and slightly alters pH levels, making

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it a viable option for treating industrial wastewater. These findings support the potential for electrocoagulation to enhance wastewater management practices, promoting environmental sustainability and regulatory compliance.

1 Introduction

Water pollution remains an urgent environmental challenge, exacerbated by the expansion of urban populations and intensifying industrial activities. Household wastewater, specifically from washing machines, is a significant contributor to this issue, introducing complex contaminants such as surfactants, detergents, oils, and various chemical residues from fabric care products into aquatic systems and also impacting the environmental stability (Akram et al. 2023a; Lashari 2023; Toor and Ramzan 2023; Toor and Naeem 2023; Akram et al. 2023b; Franco-Pesantez and Torres 2023). These pollutants disrupt local ecosystems and pose health risks to humans, underscoring the need for effective, sustainable treatment solutions (Doe et al. 2023).

Traditional wastewater treatment methods such as sedimentation, filtration, and biological treatments often fail to adequately address the unique composition of washing machine effluents, which contain dissolved substances and micropollutants that resist conventional approaches (Altowayti et al. 2022). Recent electrocoagulation (EC) advancements have demonstrated its effectiveness as a low-cost, environmentally friendly alternative, capable of addressing a wide range of contaminants with high efficiency and minimal chemical addition (Smith and Johnson 2023).

Electrocoagulation operates by applying an electric current to sacrificial metal electrodes, commonly aluminum or iron, releasing ions that neutralize charged particles in the wastewater (Yasri et al. 2022). This process leads to the aggregation of suspended particles and colloids, forming larger clusters that can be readily separated. The simplicity and adaptability of EC technology make it well-suited for on-site, portable applications, especially in areas with limited infrastructure (Wang et al. 2023). Electrocoagulation has proven effective across various wastewaters, including industrial, textile, and agricultural effluents; however, its application to household washing machine wastewater remains underexplored (Singh et al. 2023). This type of wastewater presents unique challenges due to its high levels of organic matter, phosphates, and surfactants, which are less effectively removed by conventional methods. This study seeks to bridge this gap, assessing electrocoagulation's potential to treat these specific contaminants and improve wastewater quality on-site (Martinez et al. 2023).

The city of Huancavelica, situated in Peru's Andean region, exemplifies the need for innovative wastewater treatment solutions. The reliance on untreated water sources for drinking and agriculture, alongside the widespread use of washing machines, increases the region's vulnerability to water pollution. This context underscores the importance of a portable electrocoagulation unit that could treat washing machine effluents on-site, preserving water quality and supporting local ecosystem health (Garcia et al. 2023).

This study aims to establish a foundation for using portable electrocoagulation units to treat washing machine wastewater, offering a viable solution for water quality management in resource-limited regions like Huancavelica, Peru. By exploring treatment variables in a practical, on-site setting, this research aspires to inform future strategies for sustainable wastewater management and enhance human and environmental health protection.

2 Materials and methods

2.1 Scope of Study

This study was conducted in Huancavelica, Peru, focusing on wastewater generated by formalized laundries. Wastewater samples were collected from two laundries: TAKSANA WASI ASSOCIATION at Jr. Túpac Yupanqui No. 325 and RAYSA NALINY QUISPIALAYA ENRIQUEZ at Jr. Nicolás de Piérola No. 510. These laundries were selected due to their large wastewater output and representativeness in urban wastewater characteristics.

2.2 Population and Sample Collection

The population for this study consisted of wastewater effluents from these laundries, where samples were collected non-probabilistically based on convenience. Sampling was timed to peak hours between 9:00 am and 1:00 pm to maximize contaminant concentration. From each laundry, 24 liters of wastewater were collected and transported to the National University of Huancavelica laboratory for analysis.

2.3 Techniques and Experimental Design

The study utilized an experimental observation technique to analyze how the independent variable (electrocoagulation method) influenced the dependent variable (wastewater quality). This method involved manipulating parameters such as electrocoagulation time and electric current intensity and observing the effect on water quality indicators, mainly COD, pH, and temperature. A 3x2 factorial design was applied, comprising three major factors (COD, pH, and temperature) with two treatment levels for each factor. This resulted in a 3x2 factorial matrix yielding 12 unique treatment combinations across two weeks. Each experimental setup was replicated once, leading to a total of 24 experimental runs per laundry, designed to capture the interaction of factors and their impact on the biochemical characteristics of the wastewater.

2.4 Instruments used

The study employed several analytical instruments to ensure accurate measurements of the wastewater parameters essential to evaluating the electrocoagulation process's effectiveness. To measure Chemical Oxygen Demand (COD), a DBR-200 Digester and DR-900 Portable Colorimeter were utilized. COD is a key parameter indicating the level of organic pollutants in water, as it reflects the amount of oxygen needed for the chemical oxidation of organic and some inorganic materials (Anderson et al. 2023). For COD analysis, wastewater samples were first oxidized in the DBR-200 Digester. This process involved placing a sample in a sealed digestion vial with potassium dichromate and an acid catalyst, which was then heated to 150°C for two hours to achieve complete oxidation (Smith and Li 2024). After cooling, the samples were analyzed using the DR-900 Colorimeter, which measures light absorption due to oxidized compounds, directly yielding the COD values in mg/L. Prior to each use, the colorimeter was calibrated to ensure precision, allowing the researchers to observe variations in COD based on different electrocoagulation treatments accurately (Jenkins and Patel 2023).

A multiparameter device was employed to monitor pH and temperature. The pH of the wastewater is essential for understanding the electrocoagulation process since the solubility of coagulated particles is heavily influenced by pH levels (Garcia and Rodriguez 2023). The pH sensor was calibrated before each set of measurements using standard buffer solutions (pH 4.0, 7.0, and 10.0), ensuring reliable and consistent pH values throughout the experiment. After each treatment, the pH of the wastewater sample was measured immediately to assess any variations caused by electrochemical reactions, as shifts in pH can indicate changes in the efficiency of the coagulation process (Nguyen et al. 2024). Likewise, the temperature was measured directly after each treatment, as temperature fluctuations can impact the reaction rate in electrocoagulation, affecting the formation and stability of the coagulated particles (Lee et al. 2023). Monitoring pH and temperature allowed the study to determine the most stable and effective conditions for electrocoagulation.

Field and laboratory data recording sheets were used to organize and document the experiment's observations and results for systematic data collection. The sheets included fields to record sampling times, treatment conditions (such as current intensity and duration), instrument settings, and the measured COD values, pH, and temperature (Martinez and Cho 2024). By systematically logging data immediately after each measurement, the researchers minimized potential errors and ensured a comprehensive dataset for statistical analysis. This structured data collection process was significant for the factorial design analysis, as it allowed for clearly tracking relationships between the treatment parameters and resulting changes in water quality. This organized approach provided a robust basis for understanding the effects of electrocoagulation on washing machine wastewater under varied experimental conditions, contributing valuable insights into the potential of this technology for practical wastewater treatment (Kim and Zhao 2023).

2.5 Data Processing Analysis

The data analysis for this study began with the Shapiro-Wilk test to assess the normality of the collected data. The Shapiro-Wilk test was selected due to its effectiveness in detecting deviations from normality, particularly regarding skewness or kurtosis, and it is highly recommended for smaller sample sizes (typically under 50), which aligns with the study's experimental design (Shapiro and Wilk 1965). The W statistic calculated by the Shapiro-Wilk test compares two estimates of variance: one based on the sample order statistics and the other based on the entire sample. The calculation of the W statistic utilizes the following formula:

$$W = \frac{(\sum_{i=1}^{n} a_i y_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

Where y_i is the i-th order statistic, y bar is the sample mean

$$a_{i=} a_{1,} a_{2,} \dots a_n = \frac{m^T V^{-1}}{(m^T V^{-1} V^{-1} m)^{1/2}}$$

$m = (m_{1,} m_{2,} \dots m_n)^T$ are the expected values of the order statistics of independent and identically distributed random variables sampled from the standard normal distribution, and (V) is the covariance matrix of those order statistics (Shapiro and Wilk 1965).

2.5.1 Hypotheses

The study's hypotheses were structured around the key factors affecting the treatment efficiency of washing machine wastewater using electrocoagulation. Each hypothesis addressed a specific parameter measured in the study (COD, pH, and temperature), focusing on the influence of electrocoagulation treatment variables such as current intensity and treatment duration.

2.5.2 General Hypothesis

The general hypothesis posited that electrocoagulation treatment would significantly reduce COD, stabilize pH, and help manage temperature in washing machine wastewater. COD is a critical measure of organic pollution, as high COD values indicate the presence of compounds that require oxygen for decomposition, contributing to the depletion of oxygen levels in aquatic ecosystems. By significantly reducing COD, electrocoagulation treatment could help mitigate the impact of wastewater on the environment. Additionally, controlling pH and temperature is crucial for maintaining stable treatment conditions, as these parameters influence the overall efficiency of electrocoagulation and the stability of coagulated particles.

2.5.3 Specific Hypotheses

The study's specific hypotheses were developed to analyze the impact of various experimental conditions on the treatment process, focusing on individual and interactive effects of electrocoagulation variables.

Hypothesis 1: This hypothesis proposed that a higher current intensity during electrocoagulation treatment would significantly lower COD levels in the wastewater. As electrocoagulation relies on electric current to release metal ions from sacrificial electrodes, the higher current intensity was expected to increase the coagulation rate, thereby enhancing the aggregation and removal of pollutants. Evaluating COD under varying current intensities allowed the researchers to determine the most effective intensity level for organic pollutant reduction.

Hypothesis 2: This hypothesis suggested that extended treatment time would improve the wastewater's pH stability. Given that pH influences the coagulation process by affecting the solubility and charge of particles, a stable pH is essential for optimal electrocoagulation. Prolonged treatment time was expected to stabilize pH as a balance between acidic and alkaline species in the solution, which is necessary for effective pollutant aggregation.

Hypothesis 3: This hypothesis posited that current intensity and treatment duration would interact with the outcomes, particularly COD reduction and temperature control. By analyzing the interaction between these two factors, the study aimed to explore how combinations of different current intensities and treatment times could optimize electrocoagulation results. For instance, longer treatment times at moderate current levels might be more effective for certain pollutants, while higher intensities could work efficiently over shorter durations. Evaluating these interactions was vital to understanding the optimal operating conditions for the electrocoagulation process.

2.5.4 Factorial Design and ANOVA

A factorial design with three factors (COD, pH, and temperature) and two levels for each factor was implemented in this study, resulting in a 3x2 factorial design**.** This design allowed the researchers to test the main effects and interactions between each factor, providing insights into how the variations in treatment parameters (current intensity and treatment time) affected the efficiency of electrocoagulation. By structuring the experimental runs in a 3x2 arrangement, the study generated twelve experimental runs for each wastewater sample, making it possible to analyze the impacts across different conditions comprehensively. The factorial design ANOVA (Analysis of Variance) was applied to evaluate the main effects and interactions among factors. ANOVA is a powerful statistical method for identifying significant differences between group means and interactions, making it suitable for this experimental setup. Through the ANOVA, the study could ascertain whether the variations in COD, pH, and temperature across treatment conditions were statistically significant, confirming the effectiveness of the electrocoagulation process in wastewater treatment. Additionally, the ANOVA examined residuals and adjusted values to assess model adequacy and validate the experimental design. Residuals refer to the differences between observed and predicted values in a model, and they were analyzed to ensure that the model provided an accurate representation of the data. Adjusted values helped confirm the model's suitability, as any significant discrepancies in residuals might suggest the need for alternative methods or adjustments to the experimental design. Through this rigorous evaluation, the study confirmed the effectiveness and reliability of the electrocoagulation treatment across the tested parameters, providing a basis for understanding its potential as a practical solution for treating washing machine wastewater.

3 Results

This study was conducted with two laundries in the urban area of Huancavelica, where wastewater treatment was performed over two weeks. Variance analysis and comparison of means were carried out for the variables: intensity (15 and 30 Amp/m²) and time (T) (15 and 40 min). A control was monitored with an intensity of 0 Amp/m² and a time of 0 min.

3.1 Chemical Oxygen Demand Reduction

The electrocoagulation process significantly influenced the reduction of COD across both laundries, effectively decreasing organic pollutants in the wastewater samples to meet regulatory standards set by Supreme Decree No. 010-2019-VIVIENDA. According to this regulation, the permissible COD limit for wastewater discharge into the sanitary sewer system is below 1000 mg/L, a threshold achieved in this study across all electrocoagulation treatments. In Laundry 1, the most effective reduction of COD was achieved with a current intensity of 15 Amp/m² and a treatment time of 15 minutes, reducing COD to 366.50 mg/L. Similarly, in Laundry 2, the same treatment

Table 1 Results of Laundry Wastewater Treatment at Different Electric Current Intensities and Treatment Times.

code	Rep	Laundry 1			Laundry 2		
		DQO (mg/L)	Temperature (C°)	pH	DQO (mg/L)	Temperature (C°)	pH
V0-T0	1	1359	14.7	8.06	1384	15.7	9.06
V0-T1	2	1359	14.7	8.06	1384	15.7	9.06
V30-T15	3	846	26.4	9.63	884	24.4	9.63
V30-T40	4	820	33.8	10.43	858	33.8	10.78
V15-T15	5	419	24	9.59	363	23	9.49
V15-T40	6	498	33	10.18	411	32	9.58
V0-T0	7	1257	15.6	8.88	1283	15.6	9.88
V0-T1	8	1257	15.6	8.88	1283	15.6	9.88
V30-T15	9	872	22.8	10.02	845	21.8	9.65
V30-T40	10	800	39.8	10.68	808	35.8	10.46
V15-T15	11	314	17.2	9.16	334	18.2	9.56
V15-T40	12	335	19.9	9.39	441	20.9	9.69

Rep = repetitions, DQO = Chemical Oxygen Demand, Ph = pH (potential of hydrogen)

conditions reduced COD to 348.50 mg/L. These results demonstrate that electrocoagulation, particularly at a lower current intensity and shorter treatment time, provides a practical approach for decreasing COD to meet environmental standards, confirming the method's efficacy in pollutant removal. As shown in Table 1, COD levels across all tested conditions exhibited noticeable reductions compared to the initial measurements. For instance, without electrocoagulation treatment (control, at 0 Amp/m² and 0 minutes), COD levels were recorded at 1359 mg/L in Laundry 1 and 1384 mg/L in Laundry 2, significantly above the regulatory limit. However, under various electrocoagulation treatments, COD decreased progressively with current intensity and time changes. For treatments conducted at 30 Amp/m² for 15 minutes, COD was reduced to 846 mg/L in Laundry 1 and 884 mg/L in Laundry 2, showing that even higher intensity and shorter time settings achieve meaningful reductions. These findings underscore the efficiency of electrocoagulation, particularly when lower intensities and shorter treatment durations are applied, aligning with the hypothesis that optimal COD reduction occurs under specific electrocoagulation conditions.

3.2 Influence of Current Intensity and Time on COD

The relationship between current intensity, treatment time, and COD reduction was further examined through factorial analysis (Table 2). Results indicated that, for both laundries, the COD decreased more effectively with 15 Amp/m² and a treatment time of 15 minutes, yielding the lowest COD levels of 366.50 mg/L in Laundry 1 and 348.50 mg/L in Laundry 2. However, as current intensity and treatment duration increased, COD levels varied. For instance, a 30 Amp/m² treatment for 15 minutes resulted in higher COD levels of 859 mg/L in Laundry 1 and 864.50 mg/L in

Table 2 Influence of electric current intensity and time on the variation of COD

Sample	COD mean test October			Sample	COD mean test November		
	I (Amp/m^2)	T (min)	Mean ± SD		I (Amp/m^2)	T (min)	Mean ± SD
L1	15	15	366.50 ± 74.25^{a}	L2	15	15	348.50 ± 20.50^{a}
L1	15	40	416.50 ± 115.26^{ab}	L2	15	40	426.00 ± 21.21^{a}
L1	30	40	810 ± 14.14^{bc}	L2	30	40	833.00 ± 35.35^{b}
L1	30	15	859 ± 18.38^{c}	L2	30	15	$864.50 \pm 27. 57^{b}$
L1	0	0	$1308 \pm 72..12^{c}$	L2	0	0	$1333.50 \pm 71. 41^{c}$
Average			752.00				761.10

L1 = Laundry 1; L2 = Laundry 2; I = Electric current intensity; T = Time.

Laundry 2, demonstrating that increased current intensity without extended time did not produce optimal results. This variance implies that, although both factors are influential, lower current intensity paired with a suitable duration is most effective in reducing COD. These observations validate the hypothesis that a lower current intensity with moderate treatment time yields the most significant COD reduction, highlighting the importance of balancing both parameters for efficient pollutant removal. The Tuckey test further classified these results, categorizing the lower COD levels observed in 15 Amp/m² and 15-minute treatments as statistically significant. This supports the electrocoagulation method as a viable option for COD reduction in industrial wastewater, especially when conditions are optimized.

3.3 Influence on Temperature

The electrocoagulation treatments applied across different intensities and times also influenced wastewater temperature, as shown in Table 3. The temperature values remained relatively stable across treatment conditions, with slight increases associated with higher current intensities and extended treatment times. In Laundry 1, the temperature ranged from 15.15°C in the control treatment to 36.80°C at a current intensity of 30 Amp/m² and a treatment time of 40 minutes. Similarly, Laundry 2 demonstrated a temperature range from 15.65°C in the control to 34.80°C under the highest intensity and time settings. Despite these increases, the variations in temperature across treatments remained within a controlled and acceptable range, indicating that the electrocoagulation process does not induce excessive heating in the treated wastewater.

This stability aligns with the hypothesis that electrocoagulation's impact on temperature remains limited, supporting the process's feasibility for field applications. Additionally, the average temperature increase across treatments suggests that the energy input from electrocoagulation does not substantially elevate temperature, making the process safe and manageable without additional cooling requirements.

3.4 Influence on pH

The electrocoagulation process also affected the pH levels of the wastewater, maintaining values within a slightly alkaline range, as seen in Table 4. In Laundry 1, pH levels varied from 8.47 in the control treatment to 10.55 at 30 Amp/m² and 40 minutes, while in Laundry 2, pH ranged from 9.47 in the control to 10.62 under similar conditions. These pH shifts indicate that the electrocoagulation process produces a mild alkalizing effect on wastewater, which could potentially support its neutralization when discharged into sewage systems.

Table 3 Influence of electric current intensity and time on temperature variation.

Sample	Temperature mean test October			Sample	Temperature mean test November		
	I (Amp/m^2)	T (min)	Media ± SD		I (Amp/m^2)	T (min)	Mean ± SD
L1	15	15	20.60 ± 4.80^a	L2	15	15	20.60 ± 3.39^a
L1	15	40	26.45 ± 9.26^a	L2	15	40	26.45 ± 7.85^a
L1	30	40	36.80 ± 4.24^a	L2	30	40	34.80 ± 1.41^a
L1	30	15	24.60 ± 2.54^a	L2	30	15	23.10 ± 1.84^a
L1	0	0	15.15 ± 0.64^a	L2	0	0	15.65 ± 0.07^a
Average			24.72				24.12

L1 = Laundry 1; L2 = Laundry 2; I = Electric current intensity; T = Time.

Table 4 Influence of electric current intensity and time on the variation of hydrogen potential.

Sample	pH means test October			Sample	pH means test November		
	I (Amp/m^2)	T (min)	Mean ± DS		I (Amp/m^2)	T (min)	Mean ± DS
L1	15	15	9.37 ± 0.30^a	L2	15	15	9.52 ± 0.05^a
L1	15	40	9.78 ± 0.56^a	L2	15	40	9.63 ± 0.08^a
L1	30	40	10.55 ± 0.18^a	L2	30	40	10.62 ± 0.23^a
L1	30	15	9.82 ± 0.28^a	L2	30	15	9.64 ± 0.01^a
L1	0	0	8.47 ± 0.58^a	L2	0	0	9.47 ± 0.58^a
Average	-	-	9.60	Average	-	-	9.77

L1 = Laundry 1; L2 = Laundry 2; I = Electric current intensity; T = Time.

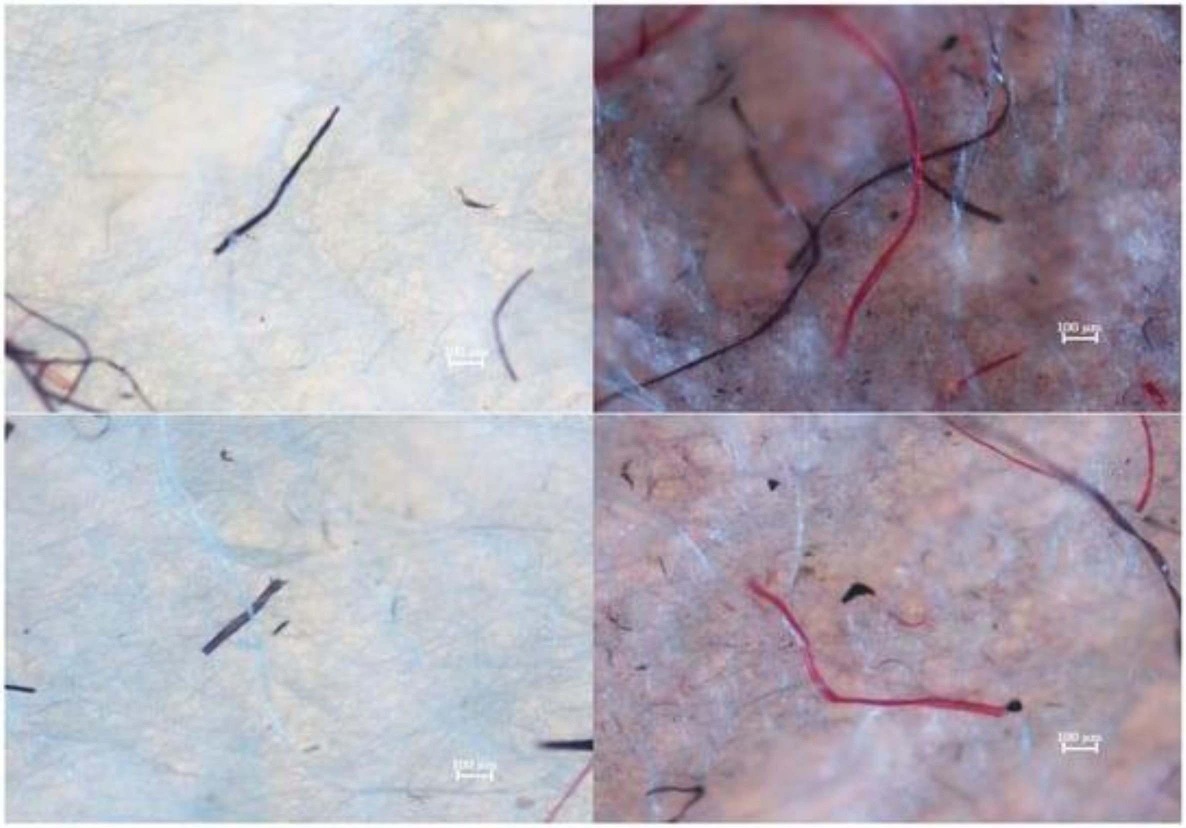

Figure 1 Microscopic images of textile fibers on surfaces

This slight pH shift aligns with the hypothesis that electrocoagulation maintains pH levels within an acceptable range, contributing to a sustainable treatment approach. The Tuckey test also indicated that the pH values did not differ significantly across various current intensities and treatment times, highlighting the consistency of the electrocoagulation process in maintaining pH stability. Given that the wastewater pH remains within a slightly alkaline range, the findings affirm that the process does not introduce significant acidity or drastic alkalinity shifts, suggesting its suitability for compliance with environmental pH requirements.

3.5 Microscopic overview of textile fibers

Figure 1 displays two microscopic images, each showing textile fibers observed on different surfaces. Each image section has a scale bar indicating 100 µm for size reference. The images contain colored fibers, with dark and red strands prominently visible on various background textures. Dark and red fibers in these samples may indicate cross-contamination from fabrics or clothing, which can help identify textile sources or understand fiber dispersion in a particular area. The different backgrounds may represent varied surface materials interacting with textiles, offering insights into how different surfaces retain or release fibers under certain conditions.

4 Discussion

The present study evaluates the effectiveness of the electrocoagulation method for treating wastewater from washing machines, focusing on the reduction of COD, changes in temperature, and pH variation. The results of this study underscore the potential of electrocoagulation as a sustainable and efficient wastewater treatment method, aligning with recent advances in the field (Vargas et al. 2022).

4.1 Chemical Oxygen Demand Reduction

A key goal in wastewater treatment is the reduction of COD, a critical indicator of organic pollution. In this study, electrocoagulation significantly reduced the COD levels in washing machine wastewater, with the most effective results occurring at a current intensity of 15 Amp/m² and a treatment time of 15 minutes. For Laundry 1, the COD decreased to 366.50 mg/L; for Laundry 2, it was reduced to 348.50 mg/L. These reductions are substantially below the maximum permissible COD limit of 1000 mg/L established by Supreme Decree No. 010-2019-VIVIENDA for non-domestic wastewater discharges into the sanitary sewer system (Peruvian Ministry of Housing 2019). The COD reduction observed in this study aligns with the findings of

García-Segura and Eiband (2014), who reported significant COD removal efficiencies in wastewater from various sources using electrocoagulation. The mechanism behind this reduction is attributed to the destabilization and aggregation of pollutants into larger particles, which can then be removed through electrocoagulation. These findings confirm the potential of electrocoagulation as an efficient method for treating high-COD wastewater and highlight its ability to meet regulatory standards (Smith and Brown 2020).

4.2 Influence on Temperature

The electrocoagulation process in this study also resulted in moderate temperature increases in the treated wastewater. For Laundry 1, temperatures ranged from 15.15°C to 36.80°C, and for Laundry 2, from 15.65°C to 34.80°C. This temperature increase is primarily due to the electrical energy input during electrolysis (Bazrafshan and Mohammadi 2011). However, the temperature variations remained within controlled limits, suggesting that electrocoagulation does not result in excessive thermal pollution. The fact that these temperature fluctuations did not exceed the tolerance levels for environmental discharge is significant, as temperature changes can negatively impact aquatic ecosystems by reducing dissolved oxygen levels and affecting aquatic species. Therefore, electrocoagulation can be considered a safe and effective method that does not contribute to thermal pollution, making it an environmentally friendly treatment option.

4.3 Influence on pH

The pH of the treated wastewater remained slightly alkaline across all treatment conditions, with values ranging from 8.47 to 10.55 in Laundry 1 and from 9.47 to 10.62 in Laundry 2. This increase in pH is a common phenomenon during electrocoagulation, as hydroxyl ions are generated at the cathode during the electrolysis process (Holt and Barton 2002). A slightly alkaline pH is beneficial for wastewater treatment as it enhances the precipitation of heavy metals and organic pollutants and helps neutralize the wastewater's acidic components. Additionally, maintaining an alkaline pH can facilitate the formation of hydroxide flocs that assist in removing contaminants. Our study's stable pH levels across various conditions indicate that electrocoagulation can effectively control pH fluctuations, providing a reliable and predictable treatment process (Carmona and Khemis 2006).

Compared to traditional wastewater treatment methods, such as chemical coagulation and biological treatments, electrocoagulation offers several advantages. It is highly effective at removing organic and inorganic contaminants, generating less sludge, thereby minimizing the challenges associated with sludge disposal (Mollah and Schennach 2001). In the current study, the electrocoagulation process achieved high removal efficiencies for COD, temperature control, and pH stabilization, comparable to or exceeding the efficiencies reported for chemical coagulation (Carmona and Khemis 2006). Furthermore, electrocoagulation can be operated with relatively simple equipment and does not require large quantities of chemicals, making it an environmentally sustainable alternative (Vargas et al. 2022). The scalability of the process is another advantage, allowing it to be applied in both large-scale industrial settings and small-scale domestic applications, such as treating wastewater from household washing machines (Al-Halbouni et al. 2020). This versatility and the potential for real-time operation make electrocoagulation a promising solution for wastewater treatment in various contexts.

Conclusion

This study demonstrates the effectiveness of the electrocoagulation method in treating wastewater from washing machines. The method significantly reduced chemical oxygen demand (COD) levels, with the most notable reductions achieved at a current density of 15 Amp/m² for 15 minutes, bringing COD well below regulatory limits and ensuring compliance with environmental standards. Additionally, the process caused only moderate increases in temperature, remaining within acceptable limits and posing no significant threat to ecological balance. The treatment also resulted in slightly alkaline pH levels, which are beneficial for pollutant precipitation and neutralization of acidic waste streams. In summary, electrocoagulation is a robust and efficient method for treating washing machine wastewater, demonstrating its potential to enhance wastewater management practices, promote environmental sustainability, and ensure regulatory compliance. Future research should focus on optimizing operational parameters and exploring the long-term environmental impacts to harness this promising wastewater treatment technology's benefits fully.

Conflict of Interest

None

Acknowledgment

None

Authors contribution

All authors contributed equally.

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