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Removal of Chromium by Electrocoagulation Process from Tannery Industry Wastewater in Cusco, Peru

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Removal of chromium from tannery wastewater was studied using the electrocoagulation process at laboratory level, aluminum and steel electrodes was employed to remove chromium ions during electrocoagulation process. Tannery wastewater were collected from industries located in Sicuani, Cusco, Peru. Considering an initial concentration of chromium of 237 ppm, and pH of 3.75. First, the removal efficiency of chromium was tested by electrocoagulation process from synthetic solutions using three level factorial design of experiments, in this case two variables were assessed: current density (3.09, 6.17, and 9.26 mA/cm^2), and pH (6, 7, and 8). A statistical analysis was employed to these factors in order to find better conditions of electrocoagulation operation. The most influent factor was the pH, follow by current density, and in less proportion their interaction. The best conditions for removing chromium were at 9.26 mA/cm^2, and pH of 8, reaching 99.99% of removal. All experiments were tested at fixed 35 minutes of treatment. Then, a kinetic study was developed, where experimental data were fitted better to first order reaction, reaching equilibrium at 15 minutes. Finally, tannery industry wastewater was treated by electrocoagulation, where a removal efficiency of 98.6% was achieved.

1. Introduction

The tanning industry is one of the most polluting industries, especially in Andean zone from Latin America, where there is an intensive farming of camelids, and sheep. This activity has been developed in the southern of Peru intensively, especially in Arequipa, Puno, and Cusco, and its environmental impact on superficial water is higher than other regions (Morales-Paredes et al., 2025). It is due to its high water consumption and the use of toxic elements such as chromium, which is primarily used in the tanning process to stabilize the collagen fibers in leather (Lofrano et al., 2008). During this process, a considerable chromium concentration did not stick over the leather, and when it is discharged into the sewer, without any treatment, it generates significant risks for aquatic ecosystems, and human health (Costa and Klein, 2006). Long-term exposure to chromium compounds could trigger genetic mutations, respiratory problems, kidney damage, and cancer (Hossini et al., 2022).

There are two kinds of conventional treatments for removing chromium from tannery effluent such as physicochemical and biological processes. For example, adsorption, chemical precipitation, coagulation, and flocculation, electrochemical treatment, ion exchange, membrane filtration, bioremediation, and phytoremediation (Nur-E-Alam et al., 2020). Within electrochemical treatment, the electrocoagulation is the process where colloidal particles are destabilized by using electric current through polluted water. This process employs sacrificial electrodes, generally made from either aluminium or iron. Then when they are dissolved under electric current, they release coagulant species in situ, facilitating the formation of metal hydroxides that adsorb and precipitate contaminants like chromium (Pranjal et al., 2022).

The reactions that occur during an electrocoagulation process that contains an aluminium anode, are shown below (Aguilar-Ascón et al., 2019):

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At the anode:

$$Al \rightarrow Al^{3+} + 3e^{-} \quad (1)$$

At the cathode:

$$3H_2O + 3e^{-} \rightarrow \frac{3}{2}H_2(g) + 3OH^{-} \quad (2)$$

General reaction:

$$Al^{3+}(aq) + 3H_2O \rightarrow Al(OH)_3 + 3H^{+}(aq) \quad (3)$$

There are several studies that have reported high chromium removal efficiencies by electrocoagulation, reaching values greater than 95% under optimal conditions of current density, pH and reaction time (Aguilar-Ascón et al., 2024, 2019; Morales-Paredes et al., 2025). Furthermore, its application contributes to improving compliance with the Maximum Admissible Values (MAV) established by Peruvian environmental regulations for discharges into the sewage system (Córdova Bravo et al., 2014), reducing the ecological impact from tannery industry.
The purpose of this research was to evaluate the chromium electrocoagulation from tannery industry wastewater located in Sicuani, Cusco, Peru. Analysing chromium efficiency removal in function of current density, pH and reaction time in polluted synthetic solutions. Then, chromium electrocoagulation from tannery industry wastewater was performed considering better operational conditions, and VMA.

2. Materials and Methods

The electrocoagulation cell was assembled using aluminum, and steel as electrodes. Then, chromium solution was prepared to assess current density, and pH. Finally, tannery wastewater was tested considering better operational conditions.

2.1 Materials

NaOH, sulfuric acid, and chromium sulfate were acquired by Sigma Aldrich (St. Louis, MO).

2.2 Reactor implementation

The experimental system was a batch-type glass electrolytic cell with a volume of 2 L. The cell was assembled with aluminum, and stainless steel as anode and cathode respectively (two pairs of electrodes). They were arranged alternately and separated by a distance of 1 cm. This distance was established to avoid the high electrical resistance with greater separations. On the other hand, at smaller distances, they produced sludge saturation (Pranjal et al., 2022). The reactor implementation included a DC power supply connected in a parallel monopole configuration, allowing control of both current density, and applied voltage.

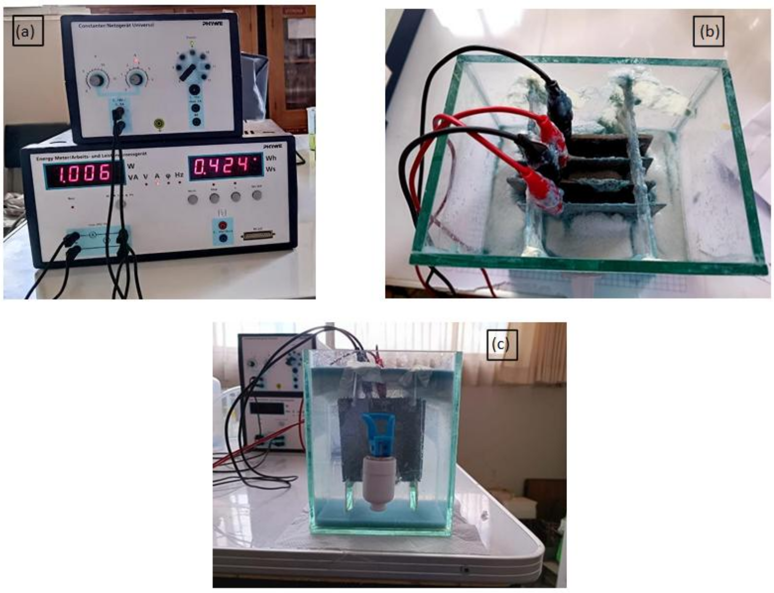

Figure 1: Electrocoagulation system: (a) DC power supply; (b) electrodes connection; (c) reactor

2.3 Electrocoagulation tests using chromium solutions

Chromium sulfate was used to prepare 237 ppm of chromium solution as initial concentration for each test. A three-level factorial design was applied, considering two factors pH, and current density (3^2). The pH levels, and current density were 6, 7, 8, and 3.09, 6.17, 9.26 mA/cm² respectively. The pH was adjusted using NaOH solution (1:1 diluted at 50 ml), and sulfuric acid solution (1:1 at 85%). All experiments were tested at environmental temperature (15 °C), and for 35 minutes. Electrocoagulation tests were replicated three times, at the end of each test, the samples were decanted for 30 minutes and then filtered using Whatman No. 1 filter paper. The supernatant was analyzed using Atomic Absorption Spectroscopy (AAS) in order to determine chromium concentration. The removal efficiency was calculated using the following equation:

$$\eta(\%) = \frac{(C_i - C_f)}{C_i} * 100 \quad (4)$$

Where $\eta(\%)$ is efficiency expressed in percentage, C_i is initial concentration, and C_f is final concentration.

2.4 Kinetic study

Chromium removal was tested at different times (1, 2, 3, 5, 10, 15, 20, and 35 minutes), at better conditions of pH, and current density from previous experiments in synthetic solutions. The experimental data was fitted to first, and second order kinetic equations.

2.5 Electrocoagulation tests using tannery industry wastewater

Tannery wastewater was collected from the association of leather artisans (ASAPES), located in Sicuani, Cusco. The sample was characterized physicochemically, and treated using electrocoagulation process. For this treatment, better conditions of pH, and current density was employed from previous chromium electrocoagulation tests in synthetic solutions.

3. Results and Discussion

Prior to electrocoagulation process, tannery wastewater was characterized.

3.1 Physicochemical characterization from tannery wastewater

The initial physicochemical characterization from tanning effluent showed a high pollutant load; for example, chemical oxygen demand (CDO) concentration was 2240 mg/L, and chromium total concentration was 237.14 mg/L. They exceeded the maximum contaminant limits (MCL) for Peruvian discharges of non-domestic wastewater (Morales-Paredes et al., 2025). Table 1 reports all analyzed parameters.

Table 1: Physicochemical characterization from tannery wastewater

Parameters	Unit	Initial sample	MCL
pH		3.75	6-9
Turbidity	NTU	281.00	
Total Suspended Solids	ppm	172.80	30
Fats and Oils	ppm	12.7	10
CDO	ppm	2240.00	50
Total Chromium	ppm	237.14	0.5

3.2 Electrocoagulation of chromium solutions

For all the electrocoagulation experiments, the chromium removal efficiency was greater than 99%, reaching the maximum value (99.99%) at pH 8, and a current density of 9.26 mA/cm². Optimal electrocoagulation performance with aluminum anodes is achieved under neutral or slightly alkaline conditions, and higher current densities (Aguilar-Ascón et al., 2019). At pH 8, the formation of amorphous aluminum hydroxides adsorbed and precipitated the chromium via $Cr(OH)_3$ (Mouedhen et al., 2009). Figure 2 reports the effects of pH, and current density on removal efficiency of chromium. When pH was increased from 6 to 8, the removal efficiency of chromium was increased from 99.38 to 99.99% as well. In the same way, when current density was increased from 3.09 to 9.26 mA/cm^2, the removal efficiency of chromium was increased from 99.59 to 99.69% as well. According with that tendency, the pH is more significant that current density; however, there is a necessary interaction between both factors during electrocoagulation process. At higher pH, and at higher current density, higher removal efficiency of chromium.

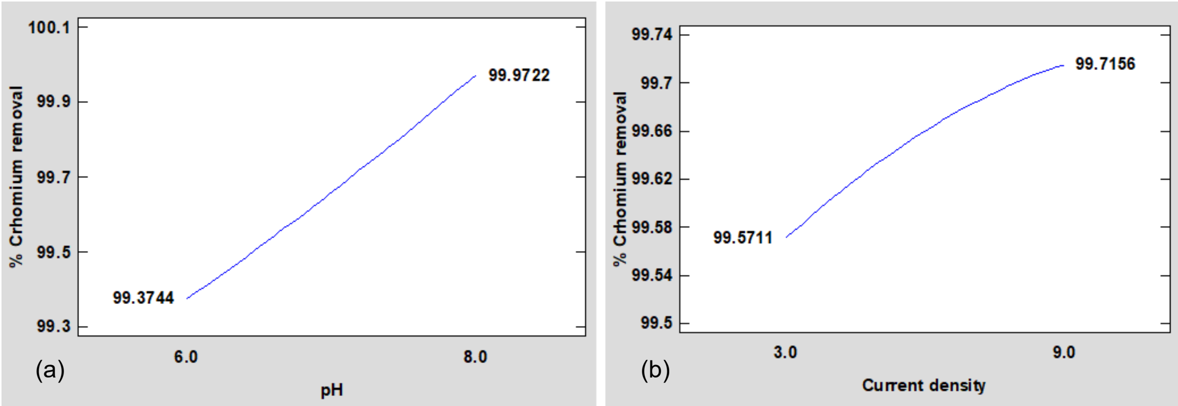

Figure 2: Effects of pH, and current density on the efficiency removal of chromium

In addition, an ANOVA statistical method was tested. Where the variables pH, current density and their interaction (pH-density) were statistically significant ($p < 0.05$), considering to adjusted coefficient of determination, R^2 = 98.04%. The pH factor had more significance in electrocoagulation process than current density, and their interaction (pH – current density).

Figure 3 shows response surface graphic. It showed that an increase in pH from 6 to 8, increased removal efficiency of chromium by 0.59%, while raising the current density from 3.09 to 9.26 mA/cm² resulted in an additional increase of 0.14%, confirming the direct relationship of both variables with removal efficiency. The yellow region is the conditions where maximum chromium removal was achieved. On the other hand, at less pH, and current density; for example, at pH of 6, and current density of 3 mA/cm², the removal efficiency of chromium reduced to 99% approximately, pink region principally.

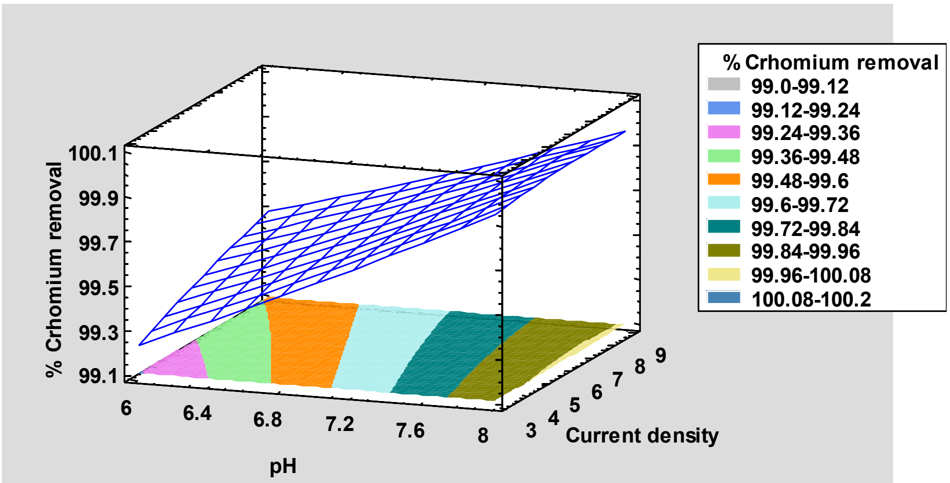

Figure 3: Effects of pH, and current density on the efficiency removal of chromium

3.3 Chromium removal kinetics

The kinetic study of chromium removal by electrocoagulation was performed using an initial concentration of 237.14 ppm, at pH 8, and a current density of 9.26 mA/cm² during 35 minutes. The experimental results showed a rapid decreasing in chromium concentration during the first 10 minutes, reaching a removal of 92.48%, then reaching equilibrium at 15 minutes approximately with a removal of 98.21%. At the end of the electrocoagulation process, it reached its maximum efficiency at 35 minutes with removal efficiency of 99.99%, and a final chromium concentration of 0.01 ppm. complying with the maximum contaminant limits (MCL) for Peruvian discharges (Morales-Paredes et al., 2025). Figure 4 reports the chromium removal kinetics.

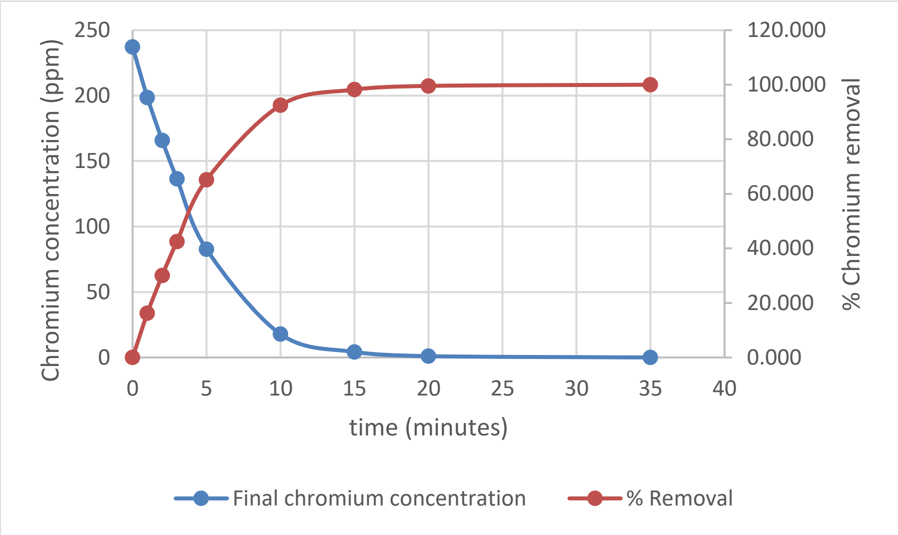

Figure 4: Chromium removal kinetics

The experimental data were fitted to kinetics models of first, and second order. The linear formula of each model can be introduced in the following equations:

Linear first-order model:

$$Ln\left(\frac{C_i}{C_f}\right) = k_1 t \tag{4}$$

Linear first-order model:

$$\frac{1}{C_f} - \frac{1}{C_i} = k_2 t \tag{5}$$

The first-order model best described the behavior of the electrocoagulation process, with a coefficient of determination $R^2 = 0.9983$, and a rate constant $k_1 = 0.2901\ min^{-1}$. On the other hand, the second-order model presented an $R^2 = 0.6596$, and a rate constant $k_2 = 2.3374$ L/mg·min. This result reports that removal rate depends primarily on the chromium concentration (El-Gawad et al., 2023).

3.4 Chromium electrocoagulation from tannery wastewater

At pH of 6, and 3.09 mA/cm^2 were the operational conditions for tannery industry wastewater treatment using electrocoagulation. Table 2 reports the results both, previous, and after electrocoagulation process.

Table 2: Physicochemical results tannery electrocoagulation at pH 6 and 3.09 mA/cm^2

Parameters	Unit	Initial contidions	Final conditions	MCL
pH		3.75	6.85	6-9
Turbidity	NTU	281.00	23.70	
Total Suspended Solids	ppm	172.80	19.96	30
Fats and Oils	ppm	12.7	5.30	10
CDO	ppm	2240.00	151.60	50
Total Chromium	Ppm	237.14	3.78	0.5

In this case, pH, turbidity, total suspended solids, fats, and oils accomplished MCL; however, COD (Erasga et al., 2025), and total chromium were not reached MCL. The removal efficiency of chromium was 98.6%, it was a little bit less than previous tests. That is because there are interferences in real water in comparison with synthetic solutions that only have chromium in their matrix. At low pH, was selected in order to accomplish the pH range from MCL, and low current density was selected considering economical budget as well. Nevertheless, increasing current density, a better performance could achieve.

4. Conclusions

In conclusion, the electrocoagulation process proved to be an efficient, and environmentally sustainable technique for chromium removal. For synthetic solutions, the chromium removal efficiency was greater than 99%, reaching the maximum value of 99.99% at pH 8, and a current density of 9.26 mA/cm² using aluminum and steel electrodes. The kinetic study showed a rapid decreasing in chromium concentration during the first 10 minutes, then reaching equilibrium at 15 minutes, and finally it reached its maximum efficiency of 99.99% at 35 minutes. The first-order kinetic model was the best that described the behavior of the electrocoagulation process, with a coefficient of determination R^2 = 0.9983, and a rate constant k_1 = 0.2901 min^{-1}. For tannery industry wastewater with a chromium initial concentration of 237.14 ppm, a removal efficiency of 98.6% was achieved at pH of 6, and a current density of 3.09 mA/cm^2.

Nomenclature

NTU – Nephelometric Turbidity Unit
CDO – chemical demand oxygen, mg/L
k_2 – second kinetic order, L/mg·min
k_1 – first kinetic order, min^{-1}
t – time, min
C_f – final concentration, mg/L
C_i – initial concentration, mg/L
η – removal efficiency, %

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