

### Determination of the effectiveness of the electrocoagulation process in the treatment of leachate from the controlled landfill site in Francisco de Orellana canton

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#### ABSTRACT

The inadequate management of leachate produced in landfill sites, sanitary dumps, or its incomplete treatment generates significant environmental and public health impacts. These conditions are expected in developing countries and are a major concern, especially in sensitive areas like the Amazon. This study investigated the efficiency of electrocoagulation for removing BOD<sub>5</sub>, COD, TSS, turbidity, and color using a laboratory-scale reactor. Samples of raw leachate from the controlled landfill site in Francisco de Orellana canton, located in the Ecuadorian Amazon, were used. First, the initial conditions of the leachate were determined through a physicochemical characterization, where a reduced presence of heavy metals and high biodegradability were identified, suggesting that it is old leachate. In turn, a reactor with 5 electrodes was installed, where aluminum was used as a cathode and iron as an anode. Finally, electrocoagulation was employed with various operational combinations, where a run using 2.5 V and 20 minutes showed the highest removal efficiency on average, with reductions of 85.23% of BOD<sub>5</sub>, 98.20% of COD, 11.30% of TSS, 96.52% of turbidity, and 90.73% of color.

**Keywords:** Electrocoagulation; Leachate; Leachate treatment.

#### INTRODUCTION

The Amazon region, known for its exceptional biodiversity – and for being one of the wealthiest areas in the world in terms of natural resources – faces increasingly pressing challenges in terms of proper solid waste management<sup>1-3</sup>. As part of managing these wastes, fluids that seep through the waste are generated, leading to leachate formation. The production of leachate depends on many factors, such as the waste's degree of compaction and the organic matter's initial moisture content, the latter being the main factor contributing to an accelerated generation of leachate<sup>4</sup>. Other factors include the cell coating material, precipitation, atmospheric moisture, temperature, evapotranspiration, the field capacity of the landfill, and runoff<sup>5</sup>.

Inadequate management of these fluids poses severe environmental problems for remediation due to the high content of organic matter (e.g., carboxylic acids and dissolved solids), toxic chemicals, inorganic salts, heavy metals, ammonia, minerals, and xenobiotic organic compounds<sup>6</sup>. In addition, inadequate leachate treatment poses a real threat to local ecosystems, public health, and the preservation of the natural environment<sup>7,8</sup>.

Leachate from landfills is grouped into three categories according to its age: young (less than 5 years), intermediate (between 5 and 10 years), and old (more than 10 years), based on how long it has been in the landfill site<sup>9,10</sup>. Young leachate from landfills tends to have a BOD/COD ratio greater than 0.5, while old leachate tends to be less than 0.1<sup>11</sup>. Because young leachate is highly biodegradable, conventional biological treatment (aerobic, anoxic, or anaerobic) is applied<sup>12</sup>. However, intermediate and older leachate requires chemical treatment due to the significant presence of recalcitrant substances<sup>13</sup>. The BOD/COD ratio decreases significantly with time, making applying biological treatments to older leachate more complicated. In this scenario, the challenge arises of developing adequate treatment processes for leachate due to variations in their composition and concentration<sup>14</sup>.

To date, various techniques have been employed for leachate treatment; however, electrocoagulation has emerged as a promising alternative<sup>15–17</sup>, which deserves further analysis in the context of the Ecuadorian Amazon. Electrocoagulation stands out for its ability to remove contaminants, such as heavy metals, organic matter, and other dissolved compounds, through coagulation, flocculation, and precipitation<sup>18–20</sup>.

In the local context, there has been a controlled landfill site in operation in Francisco de Orellana canton since 1998, which is why old leachate mainly exists there. In the locality, the leachate is collected and stored in a tank and then transported by suction to a system of several pools, where it is first treated with aluminum sulfate. It subsequently undergoes a phytoremediation process and an oxidation process before being released into the environment.

The main objective of this article was to evaluate and determine the effectiveness of the electrocoagulation process as a viable and sustainable option for treating leachate from this canton's controlled landfill site. An experimental study was carried out to achieve this objective, in which several operational variables of the electrocoagulation process were analyzed. Moreover, the elimination efficiency of specific pollutants in the leachate was measured and quantified by considering both the removal of organic load and the reduced toxicity in the treated effluents.

This research seeks to contribute significantly to scientific knowledge in leachate treatment in the Amazon region, providing relevant information for decision-making in public policies and environmental management strategies. Likewise, the results obtained are expected to encourage the adoption of more responsible and environmentally friendly practices in solid waste management, thus contributing to the conservation and preservation of the Amazon region's invaluable biodiversity.

## MATERIALS AND METHODS

### Collection of leachate samples

The leachate samples were taken from the storage pool of the controlled landfill in Francisco de Orellana canton, located in the Ecuadorian Amazon. This leachate received no prior treatment apart from the partial sedimentation generated in the pool.

The collected samples were stored in a cooler with a refrigerant to preserve their original characteristics. They were transported to the AqLab and GADPO laboratories in the city of Coca for analysis. In addition, the containers were protected from direct light in a cool environment and sealed to prevent contamination during transport <sup>21</sup>.

### Analysis and characterization of the leachate

The leachate was characterized by analyzing physical and chemical parameters presented in Tables 1 and 2.

Parameter	Unit	Method	Instrument
Temperature	C	IN SITU	Multi-thermometer
Turbidity	NTU	SM 2130 B, 23rd Ed.	Turbidity meter
Hydrogen potential	~	SM 4500-H + B, 23rd Ed./PT-01	Electrometer
Total solids	mg/L	SM 2540 D, 23rd Ed.	Gravimeter

Table 1. Characterization of physical parameters

Parameter	Unit	Method	Instrument(s)
Zinc	mg/L	SM 3030 B, SM 3111 B, 23rd Ed./PT-05	Atomic absorption spectrophotometry
Cadmium	mg/L	SM 3030 B, SM 3111B, 23rd Ed./PT-05.	Atomic absorption spectrophotometry
Copper	mg/L	SM 3030 B, SM 3111 B, 23rd Ed./PT-0	Atomic absorption spectrophotometry
Chromium	mg/L	SM 3030 B, SM 3111 B, 23rd Ed./PT-05	Atomic absorption spectrophotometry
Lead	mg/L	SM 3030 B, SM 3111 B, 23rd Ed./PT-05	Atomic absorption spectrophotometry
Chemical oxygen demand	mg/L	SM 3030 B, SM 3111 B, 23rd Ed./PT-05	Spectrophotometry

<b>Chemical oxygen demand</b>	mg/L	SM 5210 D / 08	Oxygen meter and incubator
<b>Actual color</b>	U Pt-Co	SM 2120 C / 23	Photometer

**Table 2. Characterization of chemical parameters**

### Process of design and construction of a laboratory-scale reactor for the electrocoagulation process

Both <sup>22</sup> and <sup>23</sup> indicated in their studies that acrylic glass is an effective electrical insulator in the application of electrocoagulation processes; it is also necessary to consider that this material is low-cost and is available in the market. For this reason, the prototype for the electrocoagulation process with an acrylic glass reactor was designed and constructed.

To determine the volume of the reactor, as recommended by <sup>24</sup>, the following Equation 1 was used:

$$V_{\text{reactor}} = x * y * z * (0.001 \text{ L/cm}^3) \text{ (Equation 1)}$$

Where:

$V_{\text{reactor}}$ : reactor volume (L)

$x$  = reactor height (cm)

$y$  = reactor length (cm)

$z$  = reactor width (cm)

To determine the number of electrodes, we took what was stated by <sup>23</sup> as a reference. They used a reactor length of 28 cm and a separation distance of 4 cm between the plates, using Equation 2:

$$\text{Number of electrodes} = \frac{(\text{cell length}) - 2 * (\text{distance between electrodes and side face})}{(\text{maximum electrode distance} + \text{plate thickness})} \text{ (Equation 2)}$$

### Determination of the optimal conditions for the electrocoagulation treatment of leachate

Voltage, time, and amperage were considered to determine the optimum conditions for the electrocoagulation treatment. The operating variables obtained for the electrocoagulation reactor were voltages of 2.5V and 3.0V, with a current intensity of 5 amperes and a reaction time of 15 and 20 minutes. These variables are comparable to the study by Yagual and Revelo <sup>24</sup>, who analyzed types of water from leachate using the same variables.

<b>Time (min)</b>	<b>Voltage (V)</b>	<b>Amperage (A)</b>
<b>15</b>	2.5	5
	3	
<b>20</b>	2.5	5
	3	

**Table 3. Operational variables of the leachate electrocoagulation process**

### Efficiency of the electrocoagulation process

To determine the efficiency of the electrocoagulation process, the values obtained for the parameters at the beginning of the characterization and after the application of the electrocoagulation process were compared by applying Equation 3:

$$n = \frac{C_i - C_f}{C_i} * 100 \text{ (Equation 3)}$$

where:

$n$ : Removal percentage of the parameter analyzed (%)

$C_i$ : Initial concentration of the parameter (mg/L)

$C_f$ : Final concentration of the parameter (mg/L)

## RESULTS

### Characterization of leachate from the controlled landfill site in Francisco de Orellana canton

Table 4 shows the results characterizing the raw leachate from the landfill above the site.

Parameter	Expressed as	Unit	Maximum permissible limit	Initial conditions
Cadmium	Cd	mg/L	0.02	< 0.03
Zinc	Zn	mg/L	5.0	< 0.10
Copper	Cu	mg/L	1.0	< 0.30
Actual color	Actual color	Units of color	Inappreciable in dilution: 1/20	133
Hexavalent chromium	Cr+6	mg/L	0.5	< 0.30
Chemical oxygen demand	BOD <sub>5</sub>	mg/L	100	5,700
Chemical oxygen demand	COD	mg/L	200	113,715.45
Lead	Pb	mg/L	0.2	< 0.30
Hydrogen potential	pH		6–9	6.73
Total suspended solids	TSS	mg/L	130	295.00
Temperature	°C	°C	Natural condition +3	28
Turbidity	Turbidity	NTU		7,372.804

**Table 4. Leachate Characterization Results**

The results show a high concentration of biochemical oxygen demand, chemical oxygen demand, total suspended solids, turbidity, and actual color. All listed parameters are outside the maximum permissible limits established in current regulations. These values are attributed to the high presence of decomposing, including organic matter, detergent dregs, and other liquids, which mix to form leachate (Torres-Lozada et al., 2014). On the other hand, the presence of heavy metals is deficient.

## Design and construction of the prototype for the electrocoagulation process

### Reactor dimensions and volume

The acrylic glass reactor was constructed with the following dimensions: 21 cm wide, 28 cm long, 11 cm tall, and a thickness of 2 mm, as shown in Figure 1. These measurements were taken from the research by Reyes and Bermeo<sup>23</sup>.

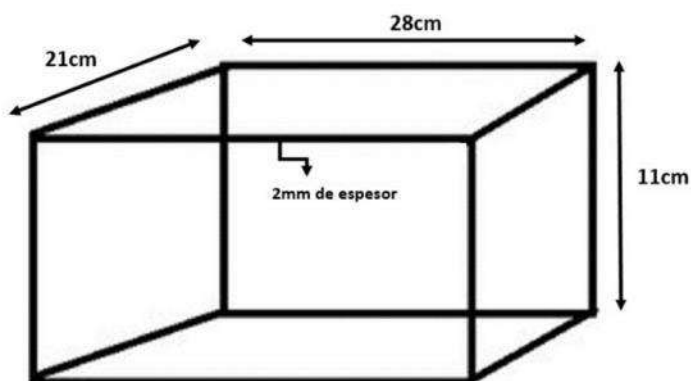


Figure 1. Reactor dimensions

Furthermore, considering the dimensions above, the reactor's volume was 6.5 liters.

### Number of electrodes

Similarly, the number of electrodes calculated was 5, where 3 serve as cathodes (aluminum) and 2 as anodes (iron), as shown in Figure 2.

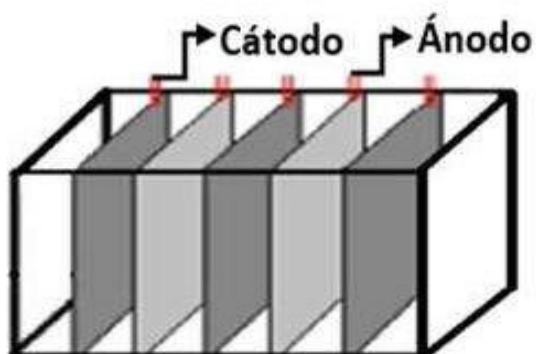
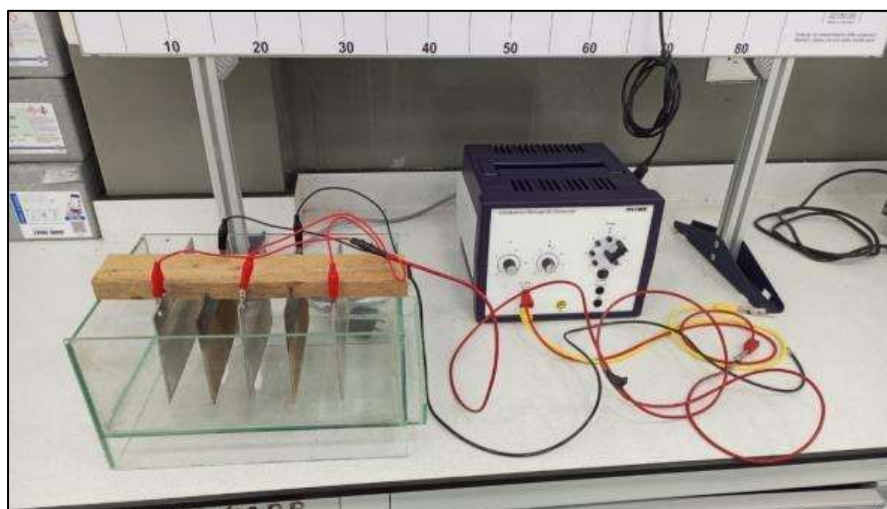


Figure 2. Number of electrodes

Finally, the laboratory-scale reactor was installed in the primary and specialized science laboratory of the Escuela Superior Politécnica de Chimborazo (ESOCH), Orellana campus, as shown in Figure 3.



**Figure 4. Final reactor prototype.**

The installation had a power source of 5 amperes and 15 volts, 5 plates or electrodes (3 aluminum and 2 iron), an acrylic glass reactor, and a black wire for the positive charge and red wire for the negative charge, designed to achieve a better conductivity of electricity.

**Effectiveness of the electrocoagulation process**

Below is the behavior of the parameters examined in the electrocoagulation process by considering the times and voltages used in the experimental tests.

PARAMETER	UNIT	MAXIMUM PERMISSIBLE LIMIT	INITIAL CONDITIONS	TIME (MIN)											
				15 MIN			20 MIN								
				Voltage: 2.5		Voltage: 3.0		Voltage: 2.5		Voltage: 3.0					
BOD	mg/L	100	5,700	1,175	925	1,250	1,075	1,225	1,050	825	1,025	1,000	975		
COD	mg/L	200	113,715.45	2,752.6	2,839.51	2,887.61	3,061.43	2,697.75	2,381.33	1,814.3	2,280.92	2,552.37	2,564.43		
TSS	mg/L	130	295.00	150	265	260	200	250	240	285	220	245	115	295	
Turbidity	NTU	NR	7,372.804	377.14	396.54	289.0	218.8	258.13	226.39	233.2	288.73	248.62	136.58	100.2	
pH		6-9	6.73	6.95	6.93	6.93	6	7.07	6.94	7	6.78	7.1	6.97	6.94	7
Actual color	Color units	Inappreciable in dilution: 1/20	133	10	10	10	10	10	10	17	10	10	10	10	10

**Table 5. Detailed results after electrocoagulation**



PARAMETER	UNIT	MAXIMUM PERMISSIBLE LIMIT	INITIAL CONDITIONS	AVERAGES			
				TIME: 15 MIN		TIME: 20 MIN	
				VOLT-AGE: 2.5 V	VOLT-AGE: 3.0 V	VOLT-AGE: 2.5 V	VOLT-AGE: 3.0 V
				BOD	mg/L	100	5,700
COD	mg/L	200	113,715.45	2826.57	2713.50	2050.55	2572.31
TSS	mg/L	130	295.00	225.00	230.00	261.67	218.33
Turbidity	NTU	NR	7,372.804	354.23	234.46	256.85	111.57
pH		6–9	6.73	6.94	6.67	6.96	6.97
Actual color	Units of color	Inappreciable in dilution: 1/20	133	10.00	10.00	12.33	10.00

Table 6 shows the average performance of the elimination process for each parameter.

### Efficiency of the electrocoagulation process for the treatment of leachate

The efficiency of the electrocoagulation process developed at a laboratory scale is shown in Table 7.

PARAMETER	UNIT	MAXIMUM PERMISSIBLE LIMIT	INITIAL CONDITIONS	REMOVAL EFFICIENCY			
				TIME: 15 MIN		TIME: 20 MIN	
				VOLT-AGE: 2.5	VOLT-AGE: 3.0	VOLT-AGE: 2.5	VOLT-AGE: 3.0
				BOD	mg/L	100	5,700
COD	mg/L	200	113,715.45	97.51%	97.61%	98.20%	97.74%
TSS	mg/L	130	295.00	23.73%	22.03%	11.30%	25.99%
Turbidity	NTU	NR	7,372.804	95.20%	96.82%	96.52%	98.49%
pH		6 – 9	6.73	0.62%	4.44%	0.29%	0.14%
Actual color	Color units	Inappreciable in dilution: 1/20	133	92.50%	92.48%	90.73%	92.48%

Table 7. Removal efficiency of the electrocoagulation process

## DISCUSSION

During the initial diagnosis of the contaminant load of the leachate analyzed, it was determined that the concentrations of heavy metals were low, falling below the maximum permissible limits established by Ecuadorian regulations. Heavy metal concentration levels are influenced by the composition of the buried waste and by the age of the leachate<sup>28–30</sup>, the latter being the primary condition in this study.



The results obtained for BOD<sub>5</sub> and COD show a non-biodegradable fluid since the BOD<sub>5</sub>/COD biodegradability index is less than 0.3. This suggests that it is an old leachate<sup>31,32</sup>, as aforementioned. Similarly, TSS and turbidity show high values – 295 mg/L and 7,372.8 NTU, respectively – which agrees with other studies in the country<sup>33</sup>.

Regarding treatment efficiency, high reductions of both BOD and COD were obtained, reaching removal percentages of 85.23% and 98.20%, respectively. This high efficiency has also been found in several other laboratory-scale studies<sup>9,20</sup>.

Currently, electrocoagulation is combined with various advanced oxidation processes such as peroxide-coagulation<sup>34</sup>, sulfate radical-based advanced oxidation process (SR-AOP) and electro-Fenton (EF)<sup>35</sup>, and electrooxidation (EO) and peroxymonosulfate (PMS)/UV/CuFe<sub>2</sub>O<sub>4</sub><sup>20</sup>. Equally, the change in polarity from anode to cathode presents significant results<sup>36</sup>. This presents a valuable opportunity for further research into the most efficient option for each operating condition.

The operating variables obtained for the electrocoagulation reactor with voltages of 2.5V and 3.0V, a current intensity of 5 amperes, and a reaction time of 20 minutes are in line with previous studies, such as the analysis of water types from leachate by Yagual and Revelo<sup>24</sup>, where high removal efficiencies were also obtained.

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## CONCLUSIONS

The physicochemical properties of the leachate from the controlled landfill site in Francisco de Orellana canton showed concentrations of color of 133 Pt/Co, biological oxygen demand of 5,700 mg/L, chemical oxygen demand of 113,715.45 mg/L, total suspended solids of 295 mg/L, and turbidity of 7,372.804. These are outside the maximum permissible limits set down by current TULSMA (Ecuadorian Environment Ministry's Unified Text of Secondary Legislation or Texto Unificado de Legislación Secundaria del Ministerio del Ambiente) regulations in Book VI, Table 9. Heavy metals were found within the maximum permissible limits due to the nature of the waste in the study area and the age of the leachate.

For the design and construction of the prototype, calculations were made to establish reactor dimensions, reactor volume, number of electrodes, and electrode dimensions for the electrocoagulation process of the leachate. The optimum conditions in the electrocoagulation treatment for leachate were a voltage of 2.5 and 3.0 V and a time of 20 minutes for the reduction of 5 parameters: biochemical oxygen demand, chemical oxygen demand, total suspended solids, turbidity, and actual color.

The efficiency of the applied method is evidenced in the percentages of pollutant removal obtained. Specifically, with a voltage of 2.5 V and a time of 20 minutes, these were 85.23% for biochemical oxygen demand and 98.20% for chemical oxygen demand. Meanwhile, a higher voltage (3.0 V) and the same period resulted in removals of 98.49% for turbidity, 92.48% for actual color, 25.99% for total suspended solids, and 13.21% for temperature.

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