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Statistical Analysis of The Effectiveness of An Electrocoagulator In The Process Of Cleaning Wastewater From The Blanco River

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Abstract*– The lack of wastewater treatment in Honduras is a problem that affects the entire country, even the most important cities such as San Pedro Sula. It has been found that this city does not have water treatment plants, and its rivers are polluted. The Blanco River is one of them, which is reported to be destroyed by the contamination present in the water flowing through it. The electrocoagulation method is a tool used to treat contaminants in water. The purpose of the research is to demonstrate the most efficient way to use the electrocoagulation method for the decontamination of the Blanco River. To do so, the variables of voltage and time at different levels were taken into consideration to check the optimal combination of these variables and to obtain a complete removal of total coliforms. The turbidity indexes found in each of the tests, electrode consumption and energy consumption were also calculated. The levels for voltage were 10 V, 15 V, 20 V and 25 V; on the other hand, the levels for time were 1 min, 5 min, 10 min and 15 min. It was decided to apply a full factorial design to visualize the relationship of the factors andthe best combination of these. Once the design was applied, it was concluded that the best combination of voltage and time to apply in the electrocoagulation method is 15 V for 15 min, which ensures a complete removal of total coliforms with an energy consumption of 0.25 kWh/m^3. In water turbidity, the results showed fluctuations in the indices of the samples taken, so it is not considered a determining factor in the measurement of water contamination. On the other hand, the electrode consumption before and after each run was calculated; these did not present significant changes, so electrode consumption was minimal.

Keywords*-- Electrocoagulation, total coliforms, factorial design, turbidity, electrode consumption

I. Introduction

Water is an irreplaceable resource for the survival of human life and biodiversity on the planet, but despite its importance, it is a finite resource. Several factors put this resource at risk, such as climate change, pollution, deforestation, and poor water management. All agricultural and livestock production activities depend on water, this element is necessary for the life of all living beings. It is of vital importance to be able to supply water to all sectors that need it [1].

Rodríguez [2] indicates that water quality in Honduras is deeply affected by problems of bacteriological and organoleptic origin. Water quality in the national territory of Honduras suffers from major contamination problems, in addition to poor wastewater management, which directly affects water quality. The water on the earth's surface has a great variety of substances, which can be dissolved or suspended. The composition of natural water depends on many factors such as the type of water, its geographical location, and the season of the year among other things [3]. It is of vital importance to be able to supply water to the various sectors of the country, as it represents a great impact on agricultural and livestock production activities. Communities are affected by water scarcity and contamination.

Only 38 of the 66 urban localities in Honduras can carry out wastewater treatment. It is estimated that there are a total of 117 wastewater treatment plants and a total of 56 plants in residential developments [4]. The country's water capacity does not have a uniform distribution in time and territory. This limitation generates shortages in the country, this capacity is supplied by a rainfall regime that fluctuates between 500 and 3,800 millimeters (mm), with an average capacity of 1,800 millimeters (mm) per year [5]. The city of San Pedro Sula, being one of the most important cities in the country, does not have wastewater treatment plants, which reflects a major problem for the country.

It has been reported that the Blanco River, located in the city of San Pedro Sula, is polluted. Roberto Fasquelle [6]states that the Río Blanco is dead; there is no fauna or fish thatused to be caught years ago. The river water is polluted, full ofgarbage and mud. The Blanco River has been invaded for the third time, destroying the structure to build houses on both sides of the Blanco River, adding more contamination to the water.

II. Method Of Electrocoagulation

Electrocoagulation is a method that uses electricity to remove suspended, dissolved, or emulsified contaminants from water [9]. The electrocoagulation process involves chemical and physical phenomena that use electrodes to deliver ions to wastewater [10].

Electrocoagulation has been used to treat urban wastewater, petroleum wastes, dyes, suspended particles, organic contaminants, and solutions containing heavy metals [11]. The electrocoagulation process is carried out by inducing an electric current in the contaminated water through metal plates; the plates commonly used are made of iron or aluminum [9]. Electrocoagulation is an electrochemical

method to treat wastewater, where sacrificial anodes are corroded to release active coagulants into solution [12].

The sacrificial metal anodes or cathodes produce metal ions or hydroxides in solution. Metal cations and hydroxides interact with contaminants by various mechanisms, including charge neutralization, precipitation, and entanglement [13]. In an electrocoagulation process, the ions are produced in situ and involve three successive stages: (¡) formation of coagulants by electrolytic oxidation, (ii) destabilization of the contaminants and breakdown, (iii) aggregation of the destabilized phases to form flocs [14].

A. Electrode Configuration

The electrode material and electrode arrangement have a great impact on the performance of the electrocoagulator. A good selection of electrode types will improve and optimize the electrocoagulation process [15]. The removal efficiency of heavy metals in wastewater is influenced by different conditions such as removal time, the type of electrodes selected, and the distance between them [16]. Normally, the most used electrodes in the electrocoagulation method are aluminum and iron, due to their coagulating properties. These materials are the most widely used and most accepted coagulants in water treatment. In addition, they are accessible and low-cost materials [17].

Another factor to take into consideration is the electrode configuration, many systems and reactors have a parallel or series configuration of electrodes, with monopolar or bipolar connections. Monopolar electrode connections require an external power source. In parallel monopolar connections, the anodes and cathodes are in parallel and the current is divided between all electrodes [18].

In series connections each pair of sacrificial electrodes is internally connected to each other. The sacrificial anode reduces the dissolution potential and minimizes the reduction of the cathode. The sacrificial electrode and the cathode can beof the same or different material [19]. On the other hand, a bipolar series connection only two monopolar electrodes are connected to the power source with no interconnections between the inner (bipolar) electrodes [20]. A literature surveyshowed that most of the studies conducted on electrocoagulation have been carried out with either monopolar or bipolar electrode plate configuration systems[21].

B. Assembly Conditions

The set-up configuration in terms of electrode spacing is a very important factor for electrode effectiveness [22]. Increasing the electrode spacing reduces particle removal due to a decrease in current flow and coagulant generation [23]. Using this approach, as the electrode spacing is reduced the resistance decreases, leading to an increase in current flow. Increased electrode spacing reduces the efficiency of an electrocoagulation process [15]. According to Rodríguez Díaz et al. [24], some precedents suggest distances of 2cm, 3cm, 4cm, 6cm and 7cm. The intensity of the electric field will work oppositely, if the intensity of the electric field is increased the electrostatic attraction also increases and theremoval of the metal decreases. When the intensity of theelectric field is reduced, the cathodic attraction decreases, increasing the elimination of contaminants [23].

The reactor models for the electrocoagulation method are batch or continuous flow. The batch reactor is mostly used for the operation of wastewater treatment in small quantities [25]. In the batch model, the liquid is introduced, the treatment is applied and at the end the reactor is emptied and refilled to treat another volume of water. On the other hand, in the continuous model, the liquid enters the reactor, flows through it receiving a treatment and exits at another point [26].

C. Applications Of the Electrocoagulation Method

The electrocoagulation process has been applied for the treatment of various wastewaters, such as electroplating wastewater, chemical-mechanical polishing wastewater, textile wastewater, and olive oil wastewater [27]. However, despite its effectiveness in treating wastewater, its efficiency under various variables has not been critically examined [28].

Many of the published articles on the application of the electrocoagulation method to remove pollutants can be divided into the following categories: removal of metal ions and hydroxides, organic matter removal and surface water purification [29]. Table 1. shows the different areas in which the electrocoagulation method can be used for wastewater treatment.

Operating Conditions

For the development of the research, the effect of factors A: voltage supplied to the electrodes and B: retention time, these are taken into consideration in 4 and 4 levels. Therefore, a complete 4 × 4 factorial with two replicates was decided, which will allow obtaining sufficient information regarding the effect of these factors on the electrocoagulation treatment of wastewater. The electrocoagulation procedure is affected by conditions such as: voltage, time, and current. It was decided to use direct current at different voltage levels which are 10V, 15V, 20V, and 25V. The times to be considered for the experiment are the following: 1 min, 5 min, 10 min, 15 min.

TABLE I
APPLICATION OF THE ELECTROCOAGULATION METHOD IN WASTEWATER

Type of wastewater	Electrode Arregment	Contaminant Removal	Reactor Type	Time	Ref.
Coffee pulp and mucilage	Fe-Al	CO = 93% DQO = 32%	Batch	50 min	[30]

Domestic wastewater	Al-Al	DQO = 70% Coliformes fecales = 97-99.9%	-	40-50 min	[31]
Hospital wastewater	Fe-Al	DQO = 75.5% DBO = 59.2% Fosfatos = 85.3% TDS = 75.6%	Continuous flow	15 min	[32]
Dairy Industry Wastewater	Fe-Al	DQO = 93% DBO = 82% SS = 76% Turbidez = 19.9 NTU	-	30-60 min	[33]
Mixed wastewater from the dairy and meat industry	Fe-Fe	DQO = 96% Turbidez = 94% pH = 12.63	Batch	15-60min	[34]
Treatment of raw leachate from landfill sites	Fe-Fe	Color = 82.7% DQO = 45.1%	-	60 min	[35]
Urban Wastewater Treatment	Al-Al	DQO = 85% DBO = 84% TDS = 94%	Batch	30min	[36]
Wastewater from French fries factories	Al-Fe	DQO = 60% Turbidez = 98%	-	<40min	[37]
Wastewater treatment for olive oil mill	Al-Al Fe-Fe	Color = 90-97% CO = 52%, 42% SS = 48 – 68% pH = 6	-	30min	[38]

For each of the voltage samples were taken at the times mentioned above, two runs for each voltage. As a result, there will be 32 runs. The variables used in the experiment are shown in Table 2.

Table 2. Variables Voltage and Time

Variables (Factors)	**Level 1**	**Level 2**	**Level 3**	**Level4**
Factor A: Voltage(V)	10 V	15 V	20 V	25 V
Factor B: Time (min)	1min	5 min	10 min	15 min

D. Collection of water from the Blanco River

The first step in collecting water from the Blanco River was to obtain sterilized containers for storing water samples, which were provided by the agro-industrial laboratory. Several bottles of purified water were disinfected and sterilized for the collection of the water from the Blanco River to be treated. After collection, the water was transferred to the University's chemistry laboratory, where it was stored until it was used.

1. Reactor preparation

To begin with, the reactor was checked for existing leaks, a layer of silicone was applied to the corners to seal leaks and an oasis key was added, which will be used to obtain the water samples that have been treated. Once the reactor was ready, the electrodes were placed, and the connection clamps were connected to the 18-gauge cable; a monopolar arrangement in series was used; Figure 1 shows the reactor assembly.

Then the connection to the power supply was made, and once the connection was made, the continuity between the anode and cathode pairs and the electrode system was checked with the multimeter. As a last step, the reactor was filled with the water obtained from the river and the tests were applied with the different voltages and times establishedin the factorial design

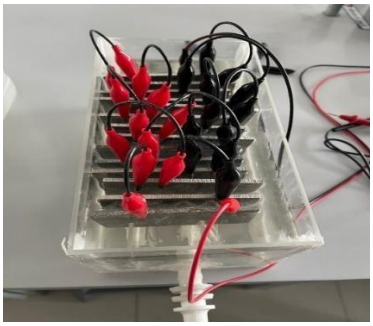

Fig. 1 Reactor Assembly

2. Electrode weights

Prior to the application of the process, the weight of each electrode was measured and noted. This process was repeated at the end of the Blanco River water treatmentprocesses to measure the level of consumption carried out with each wastewater treatment.

3. Method of application

According to Scientific Investigations Report [11] the density levels of E. coli and the level of turbidity present are closely related, although turbidity alone is not a direct health risk, it can be associated with the presence of bacteria in the water. The turbidity of the samples was measured by means of a turbidity meter. Once the procedure was completed, the indicated value was taken and placed in the database to be used for comparison of the values.

To use the electrocoagulator, the reactor was filled with approximately one gallon of water from the Blanco River, then the voltage was adjusted as needed starting at 10V and jumping every 5V until reaching 25V. Once the voltage was ready, voltage and amperage measurements were taken using the voltmeter. The reactor was allowed to run and at minute 1, 5, 10 and 15 samples were taken which werefiltered each one in a laminated beaker and then inserted oneby one in the turbidimeter.

Then 1mL syringes were used to apply the samples on the Petrifilms plates. Once all the samples were placed on the slides, wait a minute and a half before inserting them in the incubator at a temperature of 35 degrees Celsius for a total of 24 hours. See Figure 2.

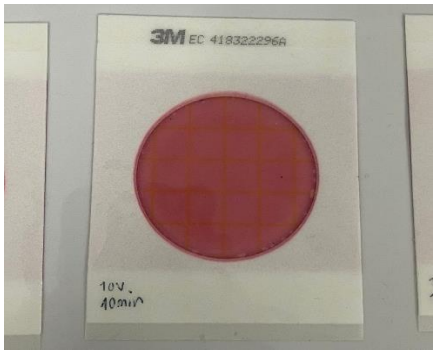

Fig. 2 3M Petrifilm

After placing all the samples in the incubator, the reactor is emptied, the used syringes are disposed of and the beakers used in the procedure are duly cleaned, when everything is ready, the process is repeated to obtain the following runs. At the end of 24 hours, the Petrifilm plates are removed from the incubator and the results obtained are counted and analyzed.

III. Results and Discussion

A. *Pilot testing*

In the pilot test, 3M Petrifilm plates for E. coli and total coliforms were used to understand their operation and veracity. For the use of the Petrifilm plates, 1mL of the collected river water was withdrawn with a syringe and spread on the gel area of the plate.

Since the number of contaminants in the water was unknown and the Petrifilm plates are only capable of reading 150 total coliforms in 1mL, it was decided to dilute the contaminated water to get a better reading. Dilutions of 9,999mL of distilled water plus 1mL of contaminated water, 99mL of distilled water plus 1mL of contaminated water, 99mL of distilled water plus 1mL of contaminated water, 39mL of distilled water plus 1mL of contaminated water and a sample of undiluted contaminated water were made. The Petrifilm plates were left in the incubator for 24h at a temperature of 35ºC ± 1ºC.

When the microbiological results of the sample were obtained by Agroindustrial Laboratories and compared with the results obtained from the Petrifilm plates, very similar results of MPN (most probable number) of total coliforms were obtained. Considering the validity of the data obtained, the runs were carried out using the electrocoagulation reactor.

B. *Experimental procedure*

Taking into consideration the pilot test, it was decided to take the samples during the following times: 1 minute, 5 minutes, 10 minutes, and 15 minutes. The values considered for the voltage range from 5 volts, 10 volts, 15 volts, 20volts and 25 volts, performing two runs for each voltage. Prior to the start of the tests, all the laboratory instruments tobe used were disinfected and the beakers were labeled for better control of the process. Once everything was disinfected, the process of weighing each of the electrodes was started to compare the weights at the beginning of the test and at the end of the test. Then, approximately 3 liters ofresidual water were added to the electrocoagulator.

Before connecting the power supply to the electrocoagulator, the connection of the electrodes was verified. After turning on the power supply and making the necessary connections,a multimeter was used to check the amount of voltage required for the run to be carried out and that an electric current was passing through the electrodes. Every so often, using a multimeter, was ensured that the voltage passing through the electrocoagulator was adequate.

When the previously mentioned times were fulfilled, the key of the electrocoagulator was used to obtain each one of the samples, these were placed in their respective beakers. Then, filter paper was used for the filtration process of the samples, to obtain accurate results.

Once the filtration process was completed, a sample of approximately 1 mL was taken and placed in a bottle for turbidity measurement. Simultaneously, a syringe was used to extract 1 mL of filtered water and apply it to the Petrifilm plate. Once all the contents of the syringe were applied, the plate was closed, and the gel zone waited for more than one minute to form. While waiting for the time to expire, the electrocoagulator was emptied and the electrodes were weighed to make a comparison between weights. The plates were then placed inside the incubator, and the results were awaited 24 hours after insertion. The next day the samples were removed from the incubator and the total coliforms present were counted.

C. *Statistics*

1. Full Factorial Analysis

Once the 32 runs were completed and the total coliform MPN count was performed in the Petrifilm plates, the data were collected to perform the ANOVA calculations. Table 3 shows the results obtained in each of the runs. This data was entered into the Minitab statistical tool to obtain the desired results. For the factorial design, it was decided to use a 2-factor design with 4 levels each with 2 replications. Two

replications were carried out to increase the precision of the data obtained. For this design we opted for a 95%confidence level, a bilateral confidence interval type, and considered an $\alpha = 0.05$.

When analyzing the factorial design, the following results were obtained, see Figure 3, it can be observed that the p-value for factor B (Time) and the interaction of the AB terms (Voltage x Time) is greater than $\alpha = 0.05$, which means that the effect is not significant on the total coliform MPN response variable.

Table 3. Variance analysis of the factorial design

Source	GL	SC Ajust.	MC Ajust	Value F	Value p
Model	16	42550	2836.6	3.34	0.0011
Linear	6	33530	5588.3	6.57	0.001
Voltage (V)	3	25528	8509.2	10.01	0.001
Time (min)	3	8002	2667.4	3.14	0.055
Interactions of 2 thermals	9	9020	1002.2	1.18	0.37
Voltage (V) * Time (min)	9	9020	1002.2	1.18	0.37
Error	16	13604	850.2		
Total	31	56153			

On the other hand, it can be observed that the Voltage factor has a p-value of less than 0.05, exactly 0.001. This means that the null hypothesis is rejected, and it is concludedthat there is a difference and that the effect is significant, it means that the Voltage factor is contributing to the model, tothe variation of the response variable and that the Voltage has an important role in the removal of total coliforms.

Table 4. Full Factorial Design

StdOrder	RunOrder	PtType	Blocks	Voltage (V)	Time (min)	MPN Total Coliforms
1	1	1	1	10	1	15
2	2	1	1	10	5	6
3	3	1	1	10	10	7
4	4	1	1	10	15	9
5	5	1	1	15	1	1
6	6	1	1	15	5	3
7	7	1	1	15	10	0
8	8	1	1	15	15	0
9	9	1	1	20	1	90
10	10	1	1	20	5	37
11	11	1	1	20	10	9
12	12	1	1	20	15	10
13	13	1	1	25	1	48
14	14	1	1	25	5	13
15	15	1	1	25	10	11
16	16	1	1	25	15	2
17	17	1	1	10	1	4
18	18	1	1	10	5	2
19	19	1	1	10	10	7
20	20	1	1	10	15	6
21	21	1	1	15	1	3
22	22	1	1	15	5	0
23	23	1	1	15	10	0
24	24	1	1	15	15	0
25	25	1	1	20	1	150
26	26	1	1	20	5	150
27	27	1	1	20	10	90
28	28	1	1	20	15	47
29	29	1	1	25	1	100
30	30	1	1	25	5	8
31	31	1	1	25	10	15
32	32	1	1	25	15	0

This can be seen in the Pareto diagram shown in Figure 4, where the Voltage term (A) exceeds the critical value of 2.120. It can also be seen that the Time term (B) is very close to passing this critical value.

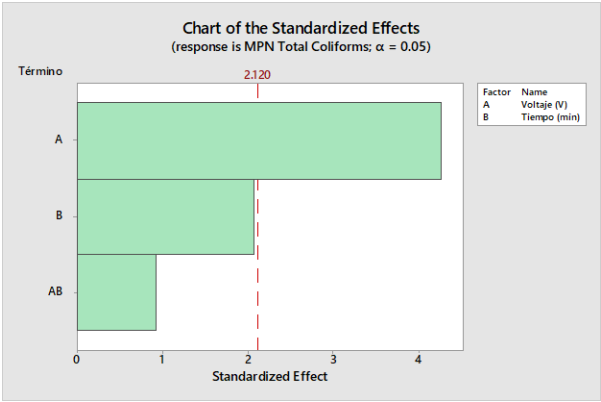

Fig. 4 Chart of Standardized effects

In Figure 5 the interaction graph for the response variable is shown, which in the experiment was considered total coliform MPN as this variable. In the graph it can be observed that the 15 V from 5 min onwards begins to clean the water in its totality, at the same time it can be observed that when applying a higher voltage in the first minutes the water becomes more infected, but as time goes by this water becomes cleaner.

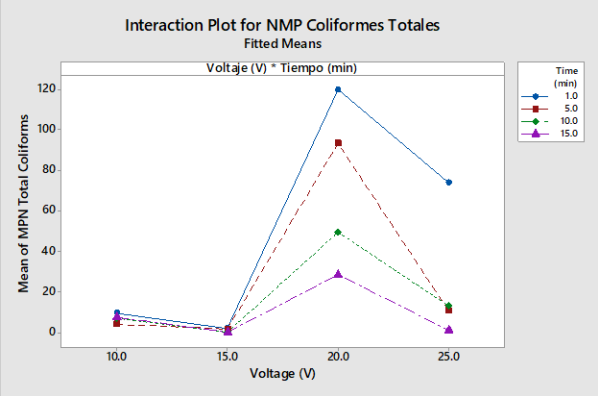

Fig. 5 Interaction Plot

2. Energy Consumption

The energy consumption was calculated for the optimum combination of factors, which is 15 V and 15 min.

$$\text{Energy consumption} = (\text{kWh/m}^3) = \frac{IVt}{V_s} \quad [39]$$

Where I is the applied current (A), V is the voltage (V), t is the electrocoagulation time (h) and Vs is the volume of treated water (dm^3) which is equal to (L).
For a current of 0.2 A, a voltage of 15 V, an electrocoagulation time of 5 min (0.0.83h), a volume of 3 L anenergy consumption of 0.083 kWh/m^3 was calculated and for15 min (0.25h) an energy consumption of 0.25 kWh/m^3 was calculated.

$$\%\ electrode\ consumption = \frac{initial\ value - final\ value}{initial\ value} x100\% \quad [40]$$

The consumption of electrodes present during the electrocoagulation process was minimal, so it was not considered as a factor that determines the quality of the water.

3. Turbidity

Turbidity reflects contamination because it shows colloidal, mineral or organic matter found in watersamples. A high level of turbidity causes disinfection treatments to be ineffective [41]. To obtain the turbidity of the water, data extracted directly from a turbidity meter was used. The turbidity present in the water extracted from the Blanco River is 1.72 NTU. Table 3 shows the turbidity values obtained for all the runs that were carried out.

Table 5. Turbidity

Turbidity in wastewater			
10V			
First Sample		**Second Sample**	
Time (min)	NTU	Time (min)	NTU
1	1.82	1	0.84
5	1.81	5	0.52
10	2.47	10	0.52
15	2.68	15	0.44
15V			
First Sample		**Second Sample**	
Time (min)	NTU	Time (min)	NTU
1	1.08	1	0.74
5	1.03	5	0.66
10	0.44	10	0.47
15	0.99	15	0.87
20V			
First Sample		**Second Sample**	
Time (min)	NTU	Time (min)	NTU
1	0.54	1	3.75
5	0.4	5	2.24
10	0.86	10	1.88
15	0.34	15	0.99
25V			
First Sample		**Second Sample**	
Time (min)	NTU	Time (min)	NTU
1	1.22	1	2.88
5	0.79	5	2.35
10	0.8	10	1.11
15	0.72	15	0.96

4. Analysis

When observing the results of the relationship between the applied voltage, time and disinfection of total coliforms, it can be noted that increasing the applied voltage does not necessarily speed up the electrocoagulation method, nor are more favorable results obtained.

In the results it can be observed that for 10 V there is a reduction of total coliforms, however, the wastewater is not completely cleaned since the presence of contaminants canstill be detected. At the same time, it can be observed that in minute 5 less total coliforms are identified with an average of 4 compared to minute 1 where an average of 9.5 NMP of total coliforms was obtained.

On the other hand, when a voltage of 15 V was applied to the electrocoagulator, a total reduction of total coliform MPN was observed after 5 minutes, as opposed to minute 1, which showed an average of 2 total coliforms. When 20 V is applied in the first minutes, the wastewater begins to become more infected and as time goes by it begins to decontaminate. At minute 1 an average of 120 total coliforms was identified, at minute 5 an average of 93.5 total coliforms, at minute 10 an

average of 49.5 total coliforms and at minute 15 an average of 28.5 total coliforms.

The last applied voltage of 25 V also shows high contamination rates in the first minutes, and as time passes the water begins the decontamination process. At minute 1, itshows an average of 74 total coliforms, at minute 5 an averageof 10.5 total coliforms, at minute 10 an average of 13 total coliforms and at 15 minutes it shows an average of 1 total coliform.

Upon analyzing the various combinations of voltage and time, it was found that the most efficient voltage for the electrocoagulation method is 15 V, since with this voltage it was possible to observe that from minute 5 onwards the wastewater is free of total coliforms. When using 15 V for 5 min, an energy consumption of 0.083 kWh/m^3 was calculated. To guarantee absolute cleanliness of total coliforms in the water, it is preferable to use the combination of 15 V with 15 min; this combination presented an energy consumption of 0.25 kWh/m^3.

When analyzing the data collected for turbidity, it can be inferred that there is variability in the data since they do not follow a pattern. Therefore, turbidity is not considered as an indicator to determine the level of contamination present in the water samples. At the same time, the results of the percentage of electrode consumption did not show significant changes, the most noticeable change was a 1g reduction in weight. At the end of the runs, it was determined that most of the electrodes maintained their initial weight.

IV. Conclusions

After the application of the electrocoagulation method and it was defined that the most convenient statistical tool to apply is the full factorial design, 4×4 with 2 replications. This design allows combining the voltage and time factors at the different levels required. The full factorial design made itpossible to visualize the interaction of these factors and the optimal combination.

After applying the method and analyzing the results obtained from the factorial design, it was concluded that the optimum combination of voltage and time to be applied using the electrocoagulation method is 15 V for 15 min. This combination of voltage and time results in a complete elimination of Total Coliform MPN with an energy consumption of 0.25 kWh/m^3. As future work we intend to develop a larger dispositive to improve the quality of the water in the river in real time. For this purpose, it is necessary to estimate the duration times of the electrodes with a greater number of cycles.

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