THE EFFECTIVENESS OF ELECTROCOAGULATION PROCESS IN LATEX WASTEWATER TREATMENT IN COMPARISON TO CONVENTIONAL PHYSICAL TREATMENT

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THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SAFETY, HEALTH AND ENVIRONMENT ENGINEERING

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THE EFFECTIVENESS OF ELECTROCOAGULATION PROCESS IN LATEX WASTEWATER TREATMENT IN COMPARISON TO CONVENTIONAL PHYSICAL TREATMENT

Field of Study: **Wastewater Treatment**

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THE EFFECTIVENESS OF ELECTROCOAGULATION PROCESS IN LATEX WASTEWATER TREATMENT IN COMPARISON TO CONVENTIONAL PHYSICAL TREATMENT

ABSTRACT

The aim of this research project was to study on the effectiveness of electrocoagulation process in latex wastewater treatment in comparison to conventional physical treatment. The wastewater sample was collected from three different sampling points from a latex industry. The three different types of samples collected were acid rinsing water, leaching water and equalization tank water. Initial test was conducted using the equalization tank water to determine the optimal factor's range for chemical oxygen demand, pH and foam height parameters. The factors used in this experiment are current (A), inter-electrode distance (cm) and time (seconds). Using the optimal values obtained, other parameters of the wastewater sample were analyzed to determine if Department of Environment (DOE) Standard B criteria could be achieved or not. There was significant reduction in the pollutant parameters in comparison to the conventional physical treatment which has been installed in the selected company. This shows that electrocoagulation is an efficient treatment process in the treatment of wastewater from latex industry. But electrocoagulation alone could not achieve DOE Standard B effluent discharge standard. The aid of biological treatment is required to further reduce the pollutant concentration.

Keywords: Latex, wastewater, electrocoagulation, physical treatment, effluent

KEBERKESANAN PROSES ELEKTROKOAGULASI DALAM RAWATAN EFLUEN LATEX DALAM PERBANDINGAN DENGAN RAWATAN FIZIKAL KONVENSIONAL

ABSTRAK

Tujuan projek penyelidikan ini adalah untuk mengkaji keberkesanan proses electrokoagulasi dalam rawatan air sisa lateks berbanding dengan rawatan fizikal konvensional. Sampel air sisa dikumpulkan dari tiga titik persampelan yang berbeza dari industri susu getah. Tiga jenis sampel yang dikumpulkan adalah air bilas asid, air pencucian dan air tangki penyamaan. Ujian awal dilakukan menggunakan air tangki penyamaan untuk menentukan julat faktor optimum bagi permintaan oksigen kimia, parameter pH dan tinggi busa. Faktor yang digunakan dalam eksperimen ini ialah arus (A), jarak antara elektrod (cm) dan masa (saat). Dengan menggunakan nilai optimum yang diperoleh, parameter lain dari sampel air limbah dianalisis untuk menentukan apakah kriteria Jabatan Alam Sekitar (JAS) Standard B dapat dicapai atau tidak. Terdapat penurunan yang signifikan dalam parameter pencemaran berbanding dengan rawatan fizikal konvensional yang telah dipasang di syarikat terpilih. Ini menunjukkan bahawa electrokoagulasi adalah proses rawatan yang cekap dalam rawatan air sisa dari industri susu getah. Tetapi, electrokoagulasi sahaja tidak dapat mencapai standard pembuangan efluen JAS Standard B. Bantuan rawatan biologi diperlukan untuk mengurangkan kepekatan pencemar.

Kata kunci: Lateks, air sisa, electrokoagulasi, rawatan fizikal, efluen

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LIST OF SYMBOLS AND ABBREVIATIONS

Al ; Aluminum

AN : Ammoniacal nitrogen

ANOVA : Analysis of variance

BOD : Biological oxygen demand

CCD : Central composite design

COD : Chemical oxygen demand

DOE : Department of Environment

EC : Electrocoagulation

ECF : Electrocoagulation-floatation

EQ : Equalization

Fe : Iron

IETS : Industrial Effluent Treatment Systems

JAS : Jabatan Alam Sekitar

PFAS : Polyfluoroalkyl

RSM : Response surface methodology

TOC : Total organic carbon

TPH : Total petroleum hydrocarbon

TSS : Total suspended solids

WWTP : Wastewater treatment plant

CHAPTER 1: INTRODUCTION

1.1 Background of the Research

Electrocoagulation (EC) is a new technique in water as well as wastewater treatment which takes in three processes which are coagulation, flotation, and electrochemistry (Moussa et al.,2017). The ordinary coagulation/flocculation measures include three phases. In the primary stage, coformer is added to the wastewater with the aid of rapid mixing, causing the destabilization of the pollutants, producing small sized flocs. The second phase includes accomplishing the development of flocs with greater size by adding polymer, and it is accomplished by a slower mixing that permits the collision among the small floc particles. The last involves floating or settling of the large sized flocs. An alternate option for these processes is electrocoagulation, which comprises of the in-situ production of coagulants by the electro-dissolution of a sacrificial anode, which usually consists of aluminium or iron (Cañizares, P., et al., 2009).

Latex wastewater contains high suspended solids (the excess latex), high natural matter and nitrogen-containing toxins such as organic nitrogen and ammonia, low pH value and solid smell (Pendashteh, A. R., et al.,2017). This research project is about identifying the effectiveness of EC process in treating the crucial pollutants in latex wastewater such as chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solids (TSS), turbidity, heavy metals and ammoniacal nitrogen (AN) that are present in the wastewater obtained from latex industry.

Apart from this, this research is conducted to identify if EC can be a stand-alone process to treat the wastewater from latex industry and comply the effluent discharge standard A/B set by the department of environment Malaysia without requiring further treatment.

Since the conventional physical-chemical treatment involves cost for the usage of chemical to promote coagulation process, this research will also identify if cost saving is achievable by electrocoagulation process.

1.2 Problem Statement

In line with the current drive by the government and certain sectors of the Malaysian Community for a clean environment, it is important for industries to abide with the Environment Quality Act 1974's Industrial Effluent Treatment Systems (IETS) standards for industries. Hence, proper treatment of their effluent is important to produce final discharge which complies to DOE Malaysia discharge standard A or B. But the cost incurred for the treatment process would sometimes be overwhelming for certain companies especially those with a stringent discharge standard and with more pollutant parameters to be treated. This is because more treatment system must be installed such as coagulation and flocculation tank and more chemicals such as coagulant and flocculant has to be used for the treatment of their industrial effluent which literally means more cost has to be borne by the respective companies.

The conventional biological treatment methods has its own disadvantages such as the requirement of longer hydraulic retention time and inability to accept shock loads. The conventional physical-chemical treatment has drawbacks in terms of having fouling issues and most of its technologies are suitable for primary treatment alone (Pendashteh, A. R., et al.,2017).

Quite a number of research have discussed the advantages and efficiency of electrocoagulation in the treatment of wastewater in terms of pollutant removal and cost saving which was an inspiration for this research project to be carried out.

1.3 Objectives of Study

(a) To optimize electrocoagulation process in latex wastewater treatment

(b) To assess the effectiveness of electrocoagulation process in latex wastewater treatment in comparison to conventional physical-chemical treatment

(c) To study the cost effectiveness of the electrocoagulation process in comparison to the conventional physical-chemical treatment in the selected latex company

1.4 Scope of Study

In general, the research scope holds within three basic areas. Firstly, is on obtaining wastewater samples from selected industry. Wastewater from glove industry would be obtained for research purpose using electrocoagulation process

.

The second area is to conduct testing on important parameters of the obtained wastewater samples which would be crucial in the view of Department of Environment Malaysia (DOE) prior to discharge as treated effluent using electrocoagulation. Such parameters would be pH, chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), turbidity, total suspended solids (TSS), colour and heavy metals such as zinc. These parameters would be tested before and after electrocoagulation process.

The third area of research would be to do cost comparison for latex wastewater treatment using electrocoagulation and conventional physical treatment to estimate if cost saving could be achieved using electrocoagulation.

CHAPTER 2: LITERATURE REVIEW

Regardless of the impressive number of distributions about EC, researchers tend to focus on lab-based testing to justify the efficiency of the technology in treating contaminants. Only several scholars paid attention on the mobility, simulation, cell architecture, financial review, incorporation of EC with current technology, and effectiveness in industrial applications, which are main causes that promotes difficulties to the growth of electrocoagulation. (Moussa et al., 2017).

Firstly, soluble organic carbon, total phosphorus, copper, zinc and manganese can be efficiently removed with both aluminum (Al) and iron (Fe) wastewater electrodes in EC technology. The Al electrode is the most effective in terms of removal and running time and has therefore not developed Al in the final effluent compared to Fe electrode (Mores, et al.,2018).

The impacts of pH and current value on the viability of leachate treatment using EC was the prime focus in the research conducted by Amdan et al.(2018) and it was surely known that utilizing EC approach for the treatment of the leachate effluent, about 81% and 72% of COD and color was treated respectively.

EC method benefits than the conventional methods in terms of simple equipment design, simple operability method, lesser retention time, reduced or no addition of

coagulants and other chemicals, rapid sedimentation of electro-generated flocs and also generates lesser amount of sludge (Hakizimana, et al., 2017).

Fourthly, as compared to the available conventional methods of wastewater treatment today, EC will profit from its simple design; the consumable, clear, color-free and odour-free treated items, the much bigger and stable flocs containing less bound water with satisfactory corrosive obstruction contrasted with the chemical flocs that require membrane filtering, the preparing of effluents with less total dissolved water and no any additional impurities (Amdan et al.,2018).

Fifthly, the discoveries acquired from the running time and time-setting curves show that EC innovation can expand the stream pace of suspended particles and the reducing of COD and turbidity. This implies that EC advances can work on the effectiveness of wastewater (Amdan, et al., 2018).

Based on the exploration led by Bazrafshan and his fellow researchers (2016), EC treatment of wastewater is known to be one of the most recent oxidation strategies, hypothetically an effective emission prevention process, giving high efficiencies to pollutant removal. As of now, the EC cycle has been utilized for the further treatment of polluted water. The objective of the EC interaction was to deal with the contamination in an effective and cost saving manner.

Aside from this, treatment of container washing wastewater (CWW) which encompasses both electrocoagulation (EC) – electrooxidation (EO) techniques has been concentrated by researchers. CWW incorporates an assortment of organic mixtures, for example, surfactants found in washing powders/detergents. Such wastewater was first treated with iron (Fe) and aluminum (Al) electrodes by EC. The cycle productivity was determined based on the expulsion efficiencies of the soluble chemical oxygen demand (sCOD) and color. Greatest sCOD expulsion effectiveness was observed to be 82% and color removal rate was 95%, 95% and 98 percent at 436, 525 and 620 nm, separately, with Fe electrodes under 25 mA/cm^2 current thickness, with an underlying pH of 5- and 120-min working time (Yılmaz and Kara, 2018).

In light of the exploration led by Bracher, et.al. (2020), the ideal conditions for domestic wastewater treatment in the electrocoagulation-floatation (ECF) framework for metropolitan reuse were: agitation of 262.5 rpm, gap between electrodes were of 1 cm, electrolysis period of 25 min, electrical flow of 1.65 A, and introductory pH of 6. In view of the discoveries got, it was feasible to gather that the ECF strategy tried was fruitful in the treatment of domestic wastewater for metropolitan re-use purposes. The rules set out in this postulation empower the replication of the ECF framework in more prominent measurements, in which relatively bigger electrical flows can be applied, with a relatively bigger dynamic surface space of the terminals.

Ninthly, a consolidated electrocoagulation and electro-flocculation techniques have been carried out with a restored detail to fulfill the plant prerequisites to extricate dissolved solids and micropollutants from drainage. Working expenses for Fe and Al

terminals at the current values of 2 A and 1 A most achievable is assessed at €0.04/m3 and €0.03/m3 individually (Sher, et al.,2020).

Oil refinery effluent was treated using EC and more than 88 percentage of the overall chemical oxygen requirement (COD) in wastewater in the optimum operating conditions (6.5 V, 0.1 M NaCl, 4 electrodes without initial pH adjustment) with the elimination of total petroleum hydrocarbon (TPH) marginally more than 80 percentage. Application of the EC has improved the biodegradability of the sample from 0.015, graded as non-biodegradable, to 0.5, generally considered to be biodegradable (Pérez et al.,2016).

The examination by Hussin, F,. et al.(2019) on the evacuation of Pb(II) from solutions utilizing a consolidated sunlight based electrocoagulation and adsorption treatment framework shows that it can go about as a financially savvy treatment framework. The joined framework utilized in this examination was viable to diminish the Pb(II) concentration to beneath the specified value by the Department of Environment in Malaysia, where the greatest passable cutoff points for Pb(II) in industrial effluents is 0.5 mg/L for downstream release. The traditional power supply created double the energy of the sun-based PV framework. The sun-based PV electrocoagulation framework can possibly additionally build energy investment funds. Likewise, the execution of Pb(II) evacuation has been impacted by the characteristic conditions like sun based light, temperature and meteorological conditions.

Polycyclic aromatic hydrocarbons (PAHs) are an important class of water pollutants due to their known ecological and human toxicity. Electrocoagulation (EC) is a promising technology to mitigate industrial wastewater pollution, but the elimination and transformation of PAHs during EC treatment has not yet been understood (Gong et al.,2017).

In the quest for new solutions for urban wastewater treatment, hybrid anaerobic-algae membrane bioreactors have been a very fascinating option. The recovery of algae generated in these reactors has become a crucial point for achieving good economic performance with this technology. Hence, electrocoagulation is studied as an alternative for the gross removal of algae from a biological culture (Souza et al., 2016).

Based on the research done by Tahreen, A., et al. (2021), electrocoagulation has been done on few samples of 200 mL of biotreated palm oil mill effluent (BPOME) using aluminium electrodes at inter-distance of 10 mm at pH value of 3-8, current density of 40- 160 mA/cm^2 and electrocoagulation time between 15 to 60 minutes. From the experimental research, a maximum of 71.5% of COD removal of 71.5% , 99.68% of total suspended solid, 99.39 % of turbidity and 97.95% of colour was removed at optimum pH of 6, current density of 160 mA/cm^2 (with 1.75 A) and electrocoagulation time of 15 minutes.

The research conducted by Kasmuri et al. (2021) on treating heavy metals in leachate from unfilled electrocoagulation concluded that upon conduction electrocoagulation for

3 hours in 5 L of leachate sample using aluminium electrodes of size 20cm X 25cm X 0.2 cm, current of 5 A at 18 V, about 40% of cadmium, 76% of iron and 81% of lead were able to be treated .

The treatment of old leachate using batch electrocoagulation with vibration-induced electrode plate was done by Niza,N.M, et al. (2021). The experimental results concluded that the evacuation of ammoniacal nitrogen (AN) was ideal when the plates vibrated at 2.8 V, the rate evacuation of AN was improved at an underlying pH of 10 for both the vibrating and fixed plates an ideal season of 35 min was accomplished for the treatment utilizing the vibration-incited plates and the higher the current force, the higher the expulsion of AN.

Finally, Demirbas and Kobya (2017) expressed that maximum chemical oxygen demand and total organic carbon (TOC) elimination via EC were seen at a pH of 5 for the Al electrode and a pH of 7 for the Fe electrode. The maximum electricity for the two terminals was 80 A/m^2 in light of the fact that the most extreme convergences of COD (94% for Al and 90 percent for Fe) and TOC (83% for Al and 80 percent for Fe) were seen at this recurrence. Working expenses at this current value were assessed US$ 1,190/m3 for Al electrode and US$ 1,813/m3 for Fe electrode.

2.1 General Effluent Pathways in A Glove Manufacturing Line

Figure 2.1 shows the general flow diagram of effluent pathway in glove manufacturing line. The effluent produced encompasses acid rinsing water and leaching water. The wastewater from both the streams will be directed to equalization tank. Hence, the samples for the research project will be taken from three different locations. The explanation for the different types of effluent samples are as such:

(a) Acid Rinsing Water

The glove formers have to be cleaned prior to usage to form contaminant-free hand-shaped gloves. Hence, acid will be used for the cleaning of the formers where the formers will be dipped into the tank which contains acid. Then, the formers will be dipped in neutralization tank and then rinsed using water. The effluent after the rinsing process will be directed to wastewater sump.

(b) Leaching Water

The leaching process in the glove production process removes residual chemicals and proteins on the gloves surface. The leaching tank is filled with water. The water from the leaching line will be directed to wastewater treatment plant in a different stream from the acid rinsing water.

(c) Equalization Tank

In the WWTP, all the incoming water will be directed to the equalization (EQ) tank which will equalize the pH, temperature, flowrate of the effluent using the aid of coarse bubble diffusers which will be helpful for the further treatment processes of the effluent using physical-chemical and biological means.

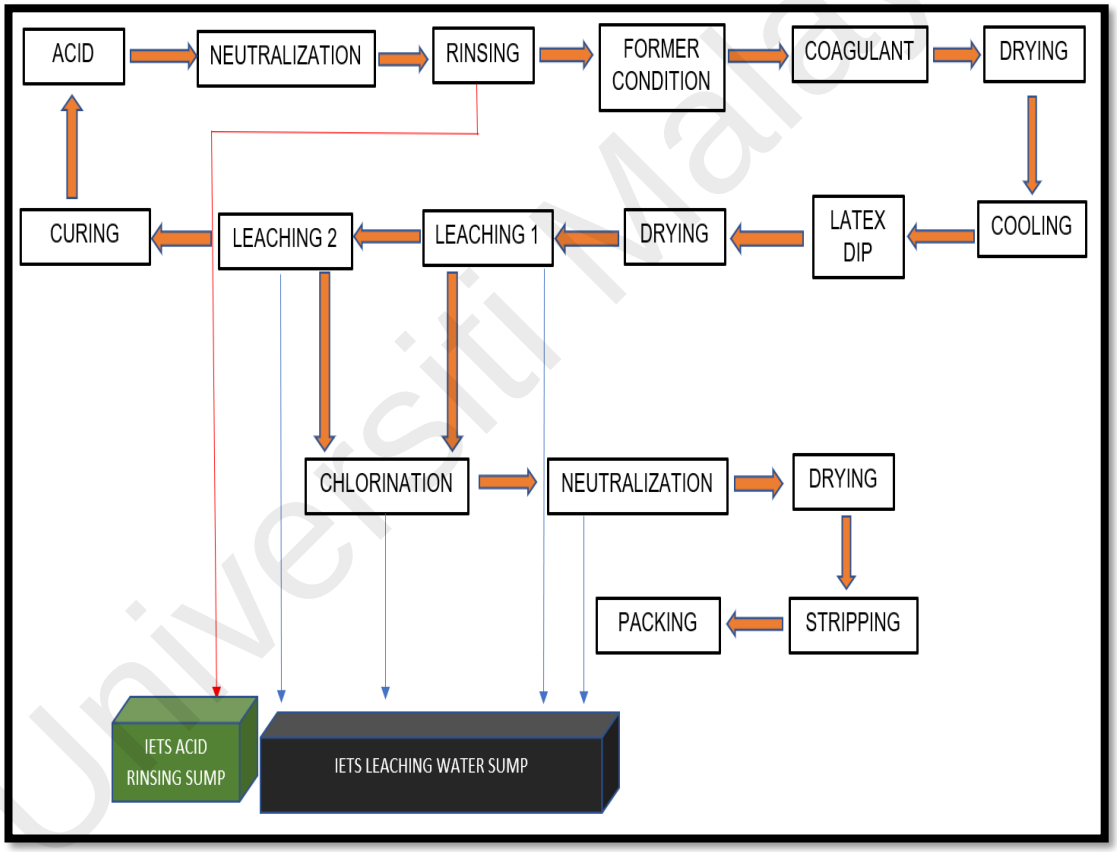

Figure 2.1: General Flow Diagram of Effluent Pathway in Glove Manufacturing Line

2.2 Raw Material Analysis and Treatment Efficiencies of Selected Parameters Using Electrocoagulation

The raw materials used for the glove production process are as shown in table 2.1. These chemicals would be the constituents in the wastewater which is being received at the treatment plant.

Table 2.1: Raw Materials Used in Glove Manufacturing Process

No.	Chemical	Constituents
1	Surfactant	Poly(oxy-1,2-ethanediyl), a-(nonylphenyl)-ω-hydroxy-, branched
		Ethane-1,2-diol
		2,4,7,9-Tetramethyldec-5-yne- 4,7-diol
2	Polyvinyl Co-polymer	Copper phthalocyanine pigment
		Dioxazine pigment
		Water
3	Chelate	Ethylenediaminetetraacetic Acid
		Sodium
4	Anti-tack Coagulant	Calcium stearate
		Non-ionic surfactant
		Water
5	Dispersing agent	Tetradonium bromide
		Ethanol
6	Industrial Ingredient	Biocide
		Water
		Paraffin wax
		Slack wax
		Microcrystalline wax
7	Coagulant	Calcium Nitrate
8	Anti-tacking agent	Calcium stearate
		Surfactants
9	Thickener	Germanium Oxide

10	Antifoam	Synthetic waxes
		Non-ionic surfactant
11	Industrial Ingredient	Ammonia
12	Stabiliser	Alkylbenzene sulfonated salt
13	Surfactant	Alkoxylated alcohol
		Alcohol derivatives

2.3 Central Composite Design

According to Varank, G., & Sabuncu, M. E. (2015), central composite design (CCD) in the design of experiment (DOE) software is the most generally utilized plan under response surface methodology (RSM), is an effective and adaptable strategy in giving adequate information on the impacts of factors and overall analysis errors with least number of analyses. The parameters which were used for analysis in this experiment were COD, foam height and pH. Since both COD and BOD are crucial parameters to be treated in the treatment process of wastewater, COD is therefore chosen as a factor to be measured in the experiment run. As COD is usually higher than BOD since it measures both chemically oxidizable and biologically oxidizable pollutants of wastewater, hence as COD values reduces, BOD value reduced as well.

2.4 Foam Formation

According to Shi, H.,et al, (2021), foam formation in the latex wastewater is due to the presence of polyfluoroalkyl (PFAS) substances which has been removed in the form of foams in the wastewater after treatment. According to the researcher's experiment, foam was formed when current density was set higher than 1mA cm^{-2} and if the PFAS concentration was more than 0.1 μM. The foam helps to separate the PFAS from the wastewater, especially for long-chain PFAS's. Hence, higher foam height in the experiment indicates higher removal efficiency of the PFAS using EC treatment process.

2.5 pH and Metal Precipitation

Figure 2.2 shows the concentration of different metals at different pH. pH is a crucial parameter in wastewater treatment. This is because different metals precipitate as hydroxides or sulphides at different pH ranges (Tchobanoglous,G.,et al.,2021). In the selected latex industry, zinc is one of the major heavy metals found in the wastewater from the production. As shown in figure 2.2, zinc precipitates at pH between 7.8 to 9.8. Hence, this pH range should be maintained/obtained in the electrocoagulation process for the removal of zinc concentration from the selected industry's wastewater.

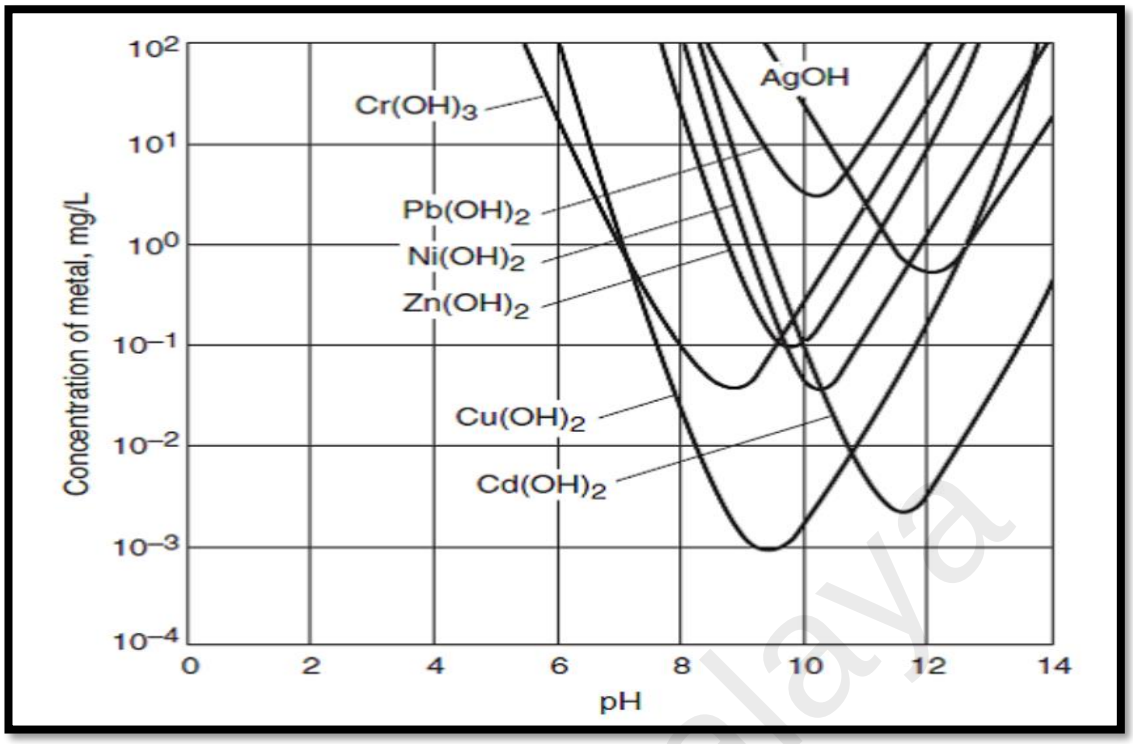

Figure 2.2: Graph of concentration of metal versus pH (Tchobanoglous, G.,et al, 2021)

CHAPTER 3: METHODOLOGY

This chapter presents the research methodology used for the research project. Several analysis methodologies which are quantitative, qualitative and case study approaches (mixed-methods) are used to carry out this project. Using various analysis methodologies, different perspectives on the topic are given. This research was carried out in three main phases: preliminary study, fieldwork and data analysis. In the preliminary study phase, literatures relevant to the research are obtained and studied to get more understanding on the research. In the fieldwork phase, wastewater from latex industry is collected. In the data analysis phase, laboratory analyses are used to carry out testing on the initial condition and condition prior to electrocoagulation process using the fresh wastewater samples obtained. Such laboratory analyses are COD, BOD_5, pH, ammoniacal nitrogen, turbidity, total suspended solids and zinc.

3.1 Electrodes Preparation

An aluminium plate was bought from a local hardware shop and cut into 13cm (length) X 4cm (width). These dimensions were chosen as it can fit properly into a 250 mL beaker. The prepared electrodes were scrubbed using sandpaper to remove the outer electroplated coating of the electrodes which may interfere with the process later.

3.2 Sample Collection

The samples were collected from the wastewater treatment plant (WWTP) from a glove manufacturing company located in Klang valley. The samples were collected from different collection sumps/tank of the WWTP which are acid rinsing water sump, leaching water sump and equalization tank.

3.3 Electrocoagulation

The apparatus for electrocoagulation was set up as shown in figure 3.1. A programmable DC power supply device were used to supply the electricity to the anode and cathode at the required current (A). A magnetic stirrer was used to stir the solution in the beaker which was placed onto it at the required rpm with the aid of a magnet which was placed in the beaker. Tongue depressors were used to hold the electrodes which are clipped with the anode and cathode crocodile clips.

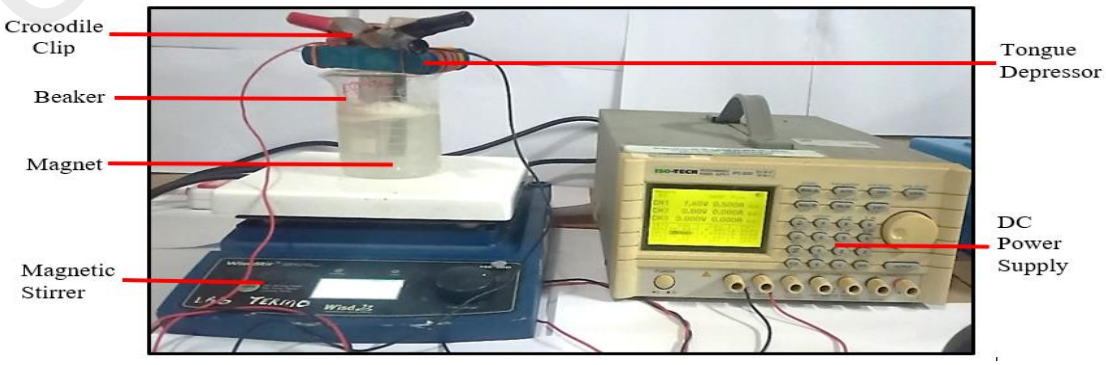

Figure 3.1: Complete Electrocoagulation Setup with Programmable DC Power Supply Device

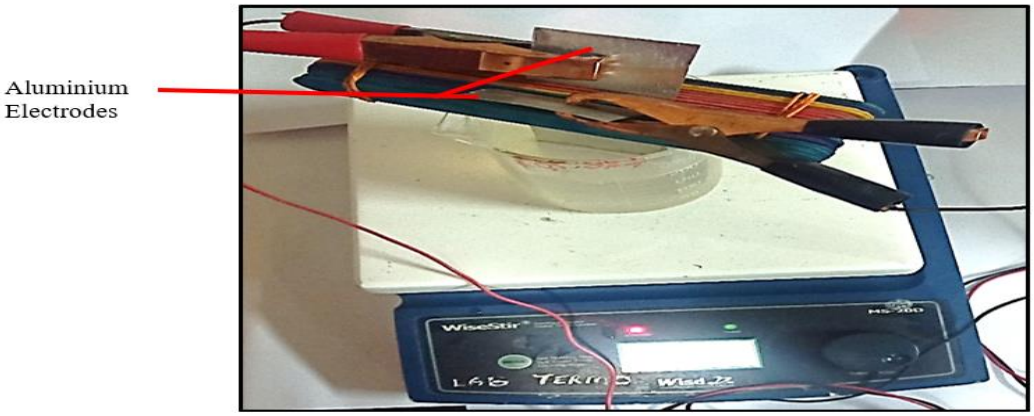

Figure 3.2: Top View of Electrocoagulation Setup

3.4 Sample Analysis

The raw samples before the EC process and the treated effluent after the EC process were analysed to identify the treatment efficiency of the EC process. The parameters which are measured for the effluent samples are as shown in table 3.1 below:

Table 3.1: List of Parameters to Be Analysed for EC Samples

Parameter	Abbreviation	Unit	Apparatus and Materials
Biochemical Oxygen Demand	BOD_5	mg/L	N/A (Samples are sent to external laboratory for analysis)
Chemical Oxygen Demand	COD	mg/L	Colorimeter - HACH COD 1500 Reagent
Potential Hydrogen	pH	-	pH Meter
Temperature	-	^0C	pH Meter with temperature probe
Total Suspended Solid	TSS	mg/L	Colorimeter
Turbidity	-	FAU	Colorimeter
Ammoniacal Nitrogen	AN	mg/L	HACH Nitrogen-Ammonia Reagent
Zinc	Zn	mg/L	HACH Zincover 5 Reagent

3.5 Design of Experiment

To obtain the optimal run for the experiment, Design of Expert (DOE) software was downloaded, and central composite design (CCD) module was used under Response Surface Methodology (RSM) programme. Inter-electrode distance(cm), current(A), time(minutes) were the factors which were used in the experimental runs. An electrode distance from 1 cm to 5 cm were used in this experiment as these are the suitable distances which can fit in the 250 mL beakers. The current value used for the runs are from 0.1A to 0.5A. The timing ranges for the runs were between 15 minutes to 60 minutes.

CHAPTER 4: RESULTS

This chapter displays the results obtained from the experimental analysis and software analysis of the research project.

4.1 Statistical Significance of Responses' Models

Table 4.1 shows the results obtained for 20 sets of experimental runs under using central composite method using the effluent from equalization tank. The initial parameters of the effluent were analysed to determine the treatment efficiency of the electrocoagulation process. The COD and pH for the raw equalization tank effluent sample were as follows:

Table 4.1: COD and pH Results for Raw Equalization Sample

Sample: Raw Equalization Tank Effluent	
COD	**pH**
728.7	7.67

Table 4.2 shows the range used for the factors involved in the 20 sets of experimental runs:

Table 4.2: Range of Factors Used for Experimental Runs

Factor	Current (A)	Distance (cm)	Time (seconds)
Range	0.1 – 0.5	1-3	15-60

Table 4.3 shows the response data obtained for different factors in the experimental runs:

Table 4.3: Response Data for Different Factors

	Factor 1	Factor 2	Factor 3	Response 1	Removal Efficiency of COD, %	Response 2	Respo-nse 3
Run	**A:Current (Amphere)**	**B:Distance (cm)**	**C:Time (Minutes)**	**COD**		**Foam Height (cm)**	**pH**
1	0.30	3.00	37.50	248.33	65.92	1.50	9.51
2	0.30	3.00	37.50	295.33	59.47	1.50	9.42
3	0.30	3.00	37.50	265.67	63.54	1.70	9.41
4	0.10	3.00	37.50	426.33	41.49	1.00	8.75
5	0.50	3.00	37.50	291.00	60.07	2.50	9.97
6	0.30	3.00	37.50	281.33	61.39	2.00	9.34
7	0.50	5.00	15.00	380.67	47.76	1.30	8.80
8	0.10	1.00	15.00	494.67	32.12	0.50	8.27
9	0.50	1.00	60.00	277.67	61.90	4.00	9.92
10	0.10	1.00	60.00	331.67	54.49	1.50	8.95
11	0.30	3.00	60.00	246.00	66.24	1.50	9.85
12	0.30	1.00	37.50	360.67	50.51	1.80	9.16
13	0.30	3.00	37.50	275.00	62.26	1.80	9.27
14	0.30	5.00	37.50	349.00	52.11	2.00	9.41
15	0.30	3.00	37.50	274.33	62.35	1.50	9.49
16	0.10	5.00	15.00	566.00	22.33	0.60	8.20

17	0.30	3.00	15.00	404.00	44.56	1.00	8.60
18	0.50	5.00	60.00	228.67	68.62	3.00	10.53
19	0.10	5.00	60.00	405.33	44.38	0.70	8.82
20	0.50	1.00	15.00	367.33	49.59	1.00	8.91

4.2 Analysis of Variance (ANOVA) for COD

Table 4.4 shows the ANOVA report obtained for COD from the 20 sets of experiment conducted. The Model F-value of 20.17 and P-value lesser than 0.0500 proves that the model and its terms are significant. The term A, B and C stands for current, distance and time respectively. In this case A, C, AB, A^2, B^2 are significant model terms. This indicates that current and time can affect the COD of the sample individually but not the inter-electrode distance. Inter-electrode distance can give effect to the COD in its quadratic form and when considered with the value of current.

Table 4.4: ANOVA Report for COD

Source	Sum of Squares	df	Mean Square	F-value	p-value	Remarks
Model	1.41×10^5	9	15708.43	20.17	< 0.0001	significant
A-Current	46058.84	1	46058.84	59.13	< 0.0001	
B-Distance	953.88	1	953.88	1.22	0.2944	
C-Time	52321.11	1	52321.11	67.16	< 0.0001	
AB	4080.06	1	4080.06	5.24	0.0451	
AC	840.5	1	840.5	1.08	0.3234	
BC	450	1	450	0.5777	0.4648	
A^2	5621.37	1	5621.37	7.22	0.0228	

B^2	4708.56	1	4708.56	6.04	0.0338	
C^2	366.57	1	366.57	0.4706	0.5083	
Residual	7789.94	10	778.99			
Lack of Fit	6554.38	5	1310.88	5.3	0.0455	significant
Pure Error	1235.56	5	247.11			
Cor Total	1.49×10^5	19				

Table 4.5 shows the fit statistics of COD which is obtained from ANOVA. The R^2 value obtained is 0.9478 which indicates that there is good corelation between the predicted data and the experimental data as the closer the R^2 value to 1, the more accurately the optimal run experiment was carried out. Adequate Precision measures the signal to noise ratio and a ratio greater than 4 is desirable. The obtained ratio of 17.695 indicates an adequate signal and this model can be used to navigate the design space.

Table 4.5: Fit Statistics of COD

Std. Dev.	27.91	**R^2**	0.9478
Mean	338.45	**Adjusted R^2**	0.9008
C.V. %	8.25	**Predicted R^2**	0.7213
		Adeq Precision	17.6951

Figure 4.1 shows the graph of predicted COD value by CCM versus actual results obtained from the 20 sets of experimental runs. There is no vast difference between the predicted and actual values obtained. This indicates that the experimental runs were conducted with minimal error and has not been much affected by the surrounding factors such as noise.

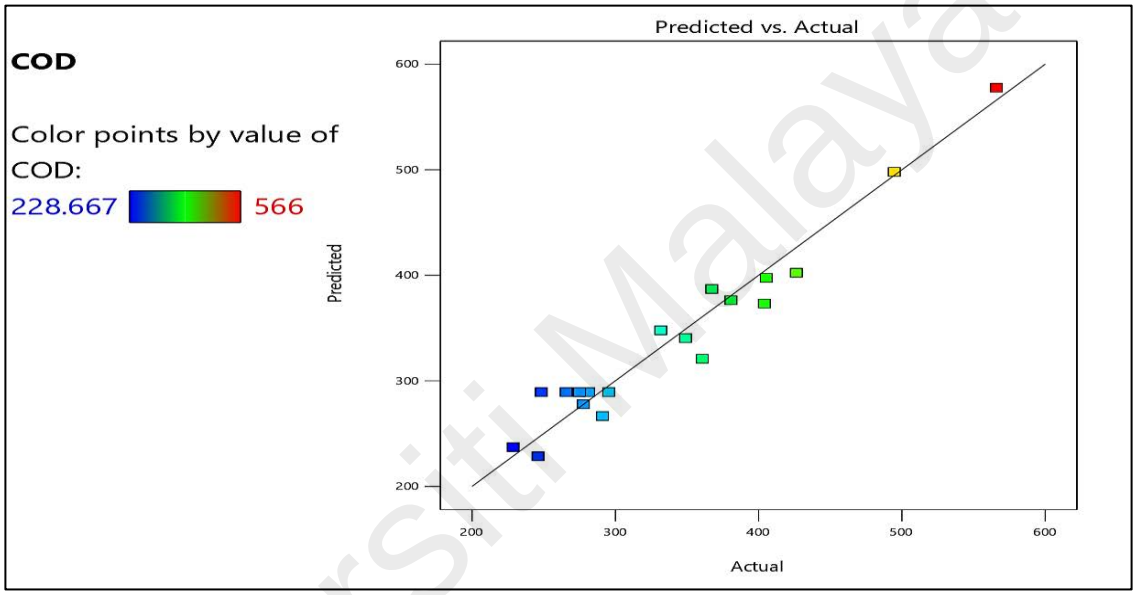

Figure 4.1: Graph of Predicted versus Actual COD

Figure 4.2 and 4.3 respectively shows the 2D and 3D graphs of COD values at different current and distance values. The shift of the graphs from green to dark blue colour indicates that higher COD treatment efficiency could be achieved as the current value increases as the values of the COD is reducing towards the right of the graph. The inter-electrode distance does not give significant effect to COD at the distance range used in the experiment.

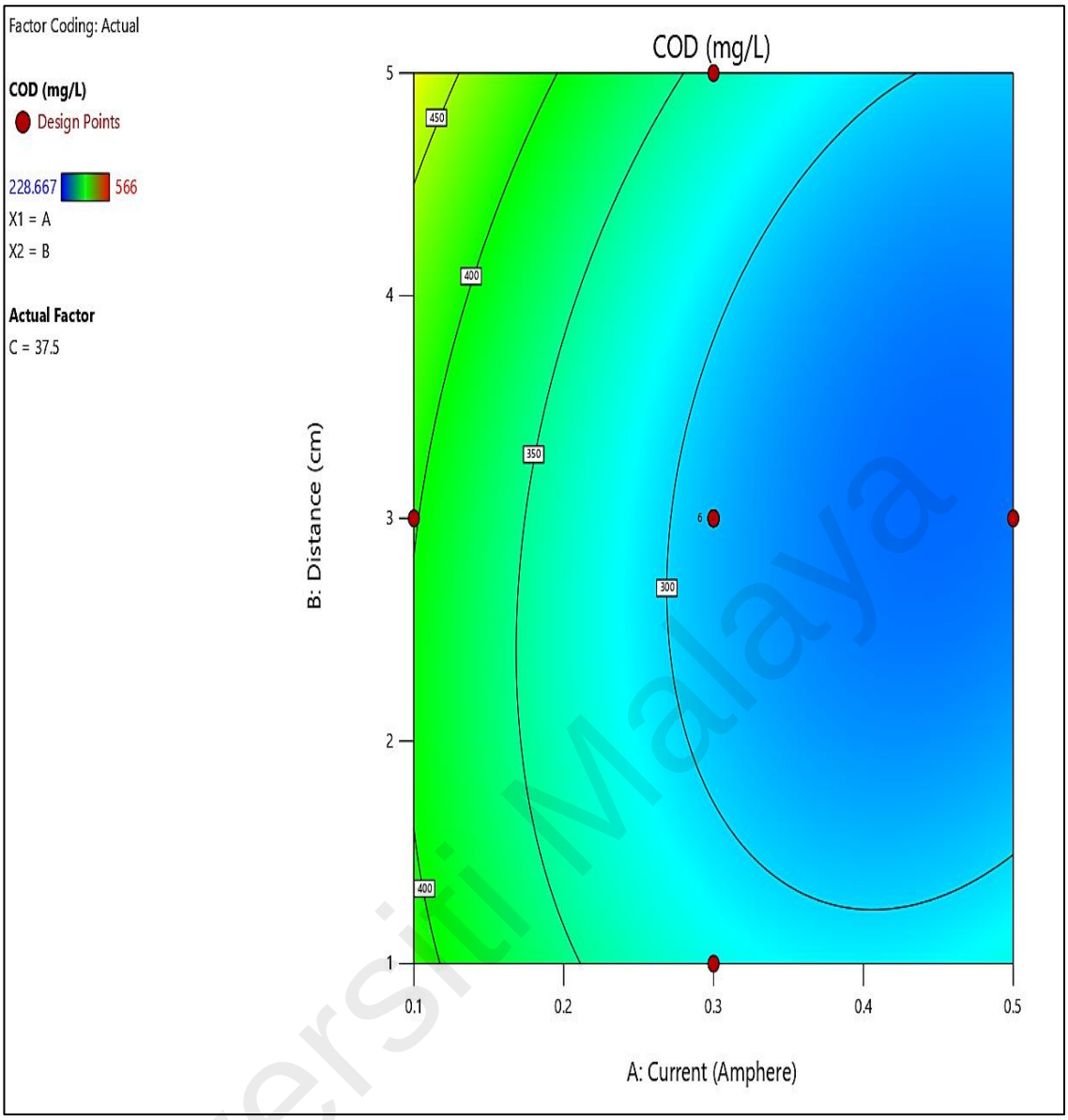

Figure 4.2: 2D Graph of COD Values at Different Current and Distance Values

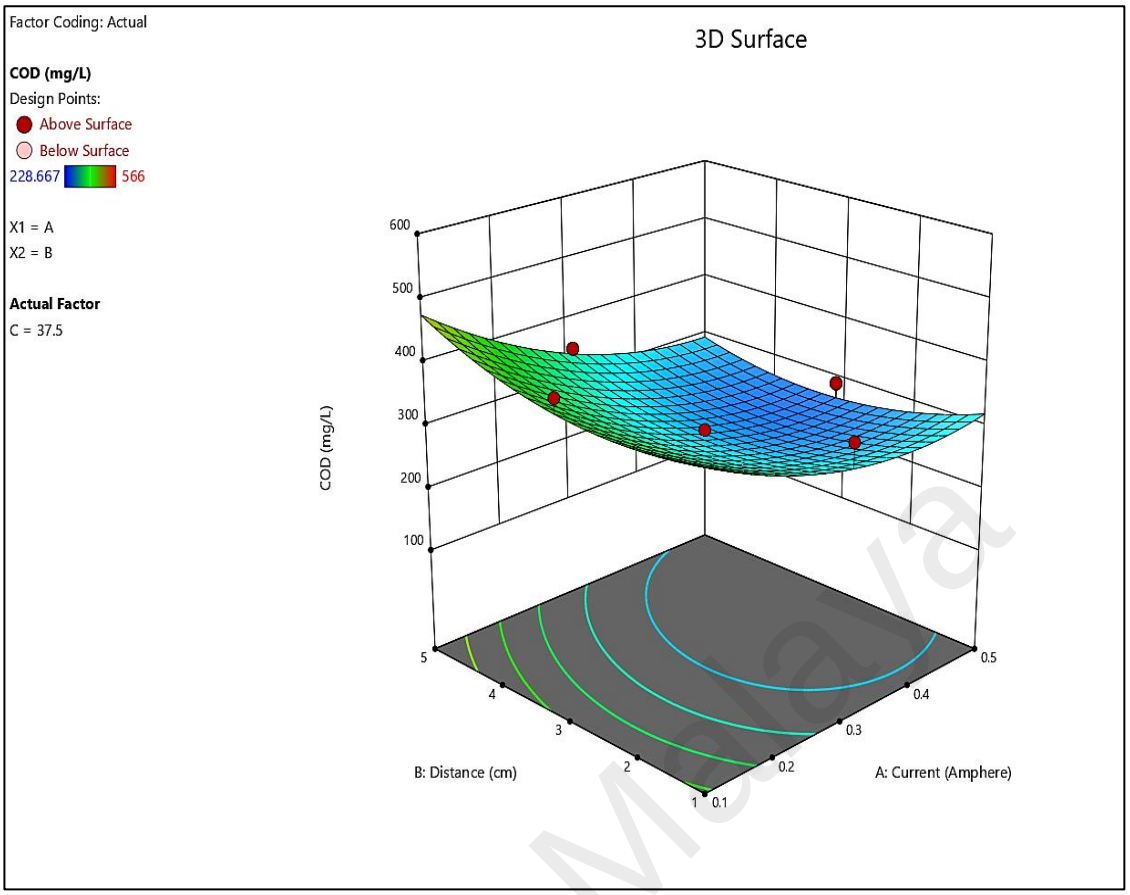

Figure 4.3: 3D Graph of COD Values at Different Current and Distance Values

4.3 Analysis of Variance (ANOVA) for Foam Height

Table 4.6 shows the ANOVA report obtained for foam height from the 20 sets of experiment conducted. The Model F-value of 21.44 and P-value lesser than 0.0500 proves that the model and its terms are significant. The term A, B and C stands for current, distance and time respectively. In this case A, C, AC, and BC are significant model terms. This indicates that current and time can affect the foam height of the sample individually and when combined with other terms whereas the inter-electrode distance can only affect the COD with the reaction time. Although higher foam height indicates better removal efficiency of PFA's, but high current density is required for higher foam removal rate as could be seen from table 4.3. This will contribute to higher electricity consumption at

places where EC treatment system is installed. Apart from this, as the formed foam could not be removed by defoamer, additional equipment may be required to remove it which also contributes to increased price for the EC technology installation. Hence, the foam factor was set to minimum instead of maximum for the optimized run.

Table 4.6: ANOVA Report for Foam Height

Source	Sum of Squares	df	Mean Square	F-value	p-value	Remarks
Model	11.96	6	1.99	21.44	< 0.0001	significant
A-Current	5.63	1	5.63	60.48	< 0.0001	
B-Distance	0.144	1	0.144	1.55	0.2353	
C-Time	3.97	1	3.97	42.68	< 0.0001	
AB	0	1	0	0	1	
AC	1.62	1	1.62	17.42	0.0011	
BC	0.605	1	0.605	6.51	0.0242	
Residual	1.21	13	0.093			
Lack of Fit	0.9957	8	0.1245	2.92	0.1268	not significant
Pure Error	0.2133	5	0.0427			
Cor Total	13.17	19				

Table 4.7 shows the fit statistics of foam height. The R^2 value obtained is 0.9082 which indicates that there is good corelation between the predicted data and the experimental data as the closer the R^2 value to 1, the more accurately the optimal run experiment was carried out. Adequate Precision measures the signal to noise ratio and a ratio greater than 4 is desirable. The obtained ratio of 18.3465 indicates an adequate signal and this model can be used to navigate the design space.

Table 4.7: Fit Statistics for Foam Height

Std. Dev.	0.305	**R^2**	0.9082
Mean	1.62	**Adjusted R^2**	0.8659
C.V. %	18.82	**Predicted R^2**	0.7585
		Adequate Precision	18.3465

Figure 4.4 shows the graph of predicted foam height value by CCM versus actual results obtained from the 20 sets of experimental runs. There is much deviation between the predicted and actual values obtained. This indicates that the experimental runs were conducted with minimal error and has not been much affected by the surrounding factors such as noise.

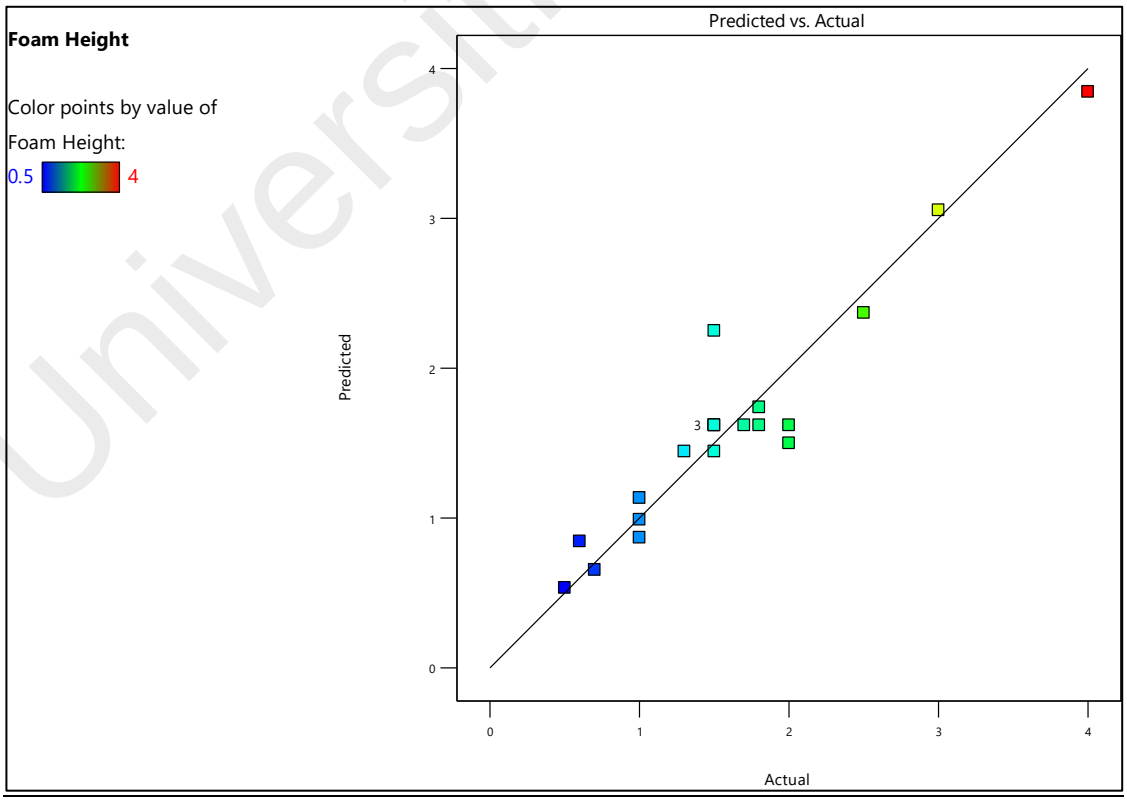

Figure 4.4: Graph of Predicted versus Actual Foam Height Results

Figure 4.5 and figure 4.6 shows the 2D and 3D graph of foam height values at different current and distance values. The graph indicates that lower foam height could be achieved with lower current value and higher inter-electrode distance.

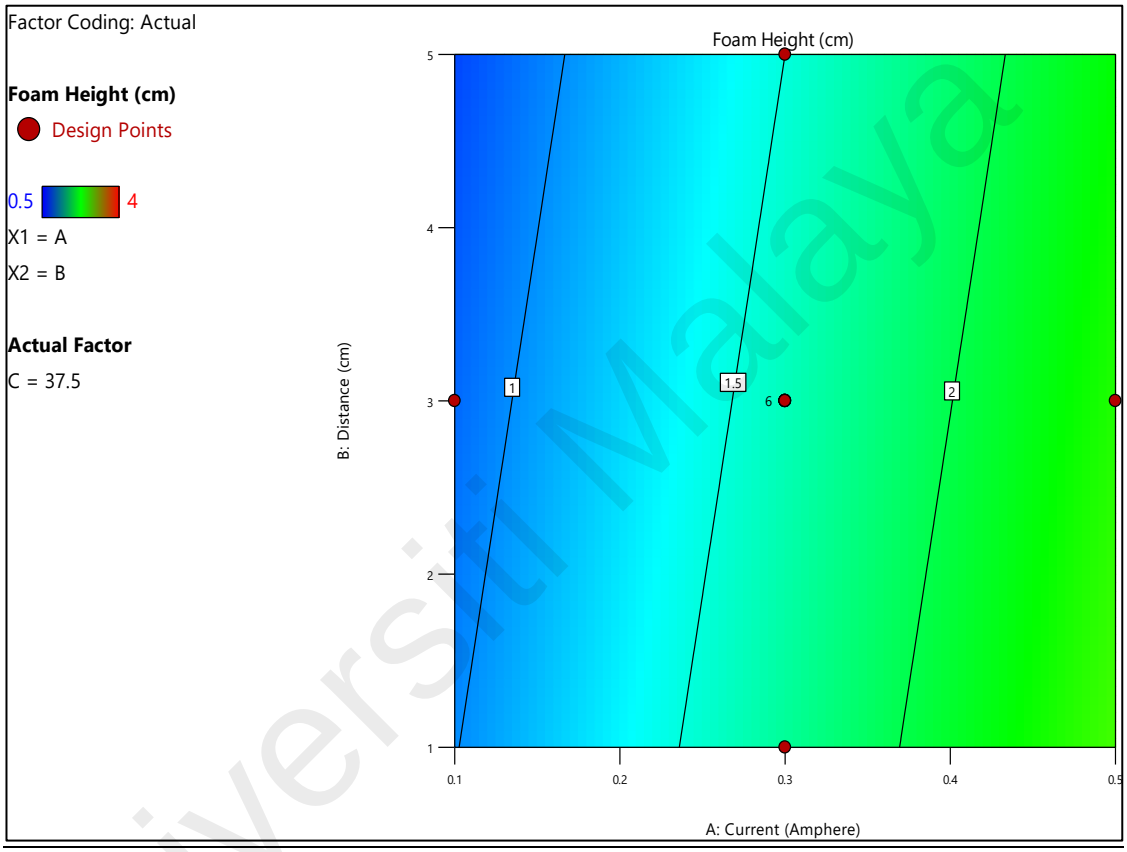

Figure 4.5: 2D Graph of Foam Height Values at Different Current and Distance Values

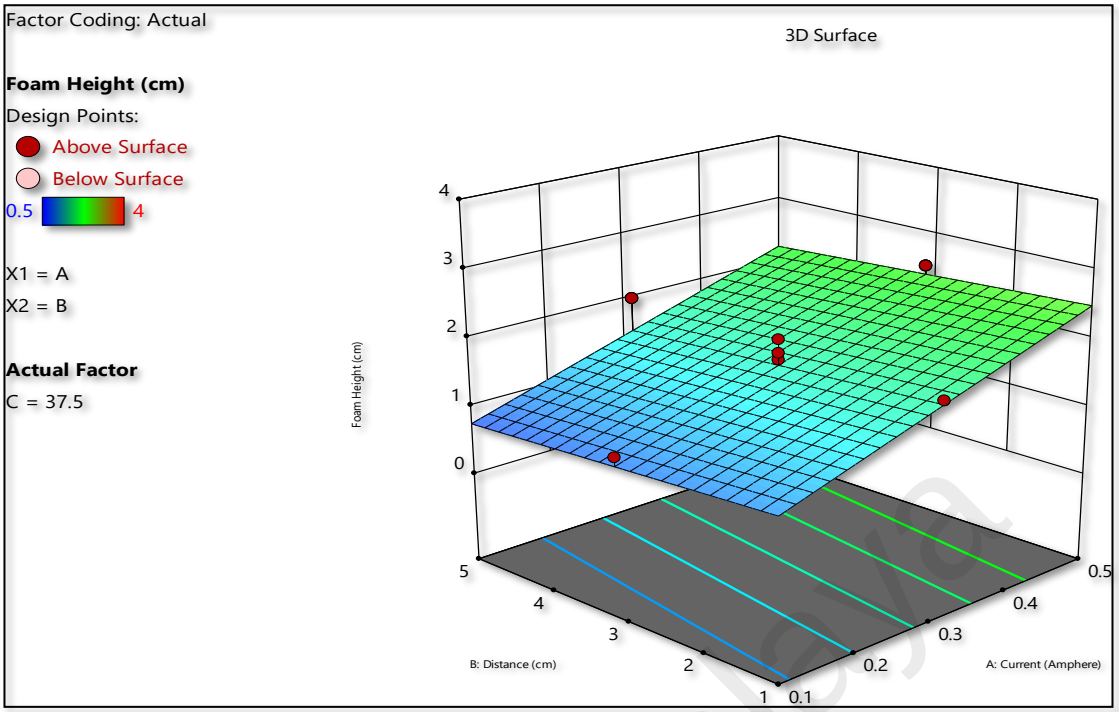

Figure 4.6: 3D Graph of Foam Height Values at Different Current and Distance Values

4.4 Analysis of Variance (ANOVA) for pH

Table 4.8 shows the ANOVA report obtained for pH from the 20 sets of experiment conducted. The Model F-value of 40.76 and P-values lesser than 0.0500 proves that the model and its terms are significant. The term A, B and C stands for current, distance and time respectively. In this case A, C and AC are significant model terms. This indicates that current and time can affect the pH of the sample individually and when combined but inter-electrode distance cannot affect the pH individually nor when combined with other factors.

Table 4.8: ANOVA Report for pH

Source	Sum of Squares	df	Mean Square	F-value	p-value	Remarks
Model	6.36	9	0.7065	40.76	< 0.0001	significant
A-Current	2.66	1	2.66	153.24	< 0.0001	
B-Distance	0.0306	1	0.0306	1.77	0.2133	
C-Time	2.8	1	2.8	161.68	< 0.0001	
AB	0.0642	1	0.0642	3.7	0.0832	
AC	0.2604	1	0.2604	15.03	0.0031	
BC	0.0539	1	0.0539	3.11	0.1083	
A^2	0.0059	1	0.0059	0.3389	0.5734	
B^2	0.0438	1	0.0438	2.53	0.1429	
C^2	0.0954	1	0.0954	5.5	0.0409	
Residual	0.1733	10	0.0173			
Lack of Fit	0.1336	5	0.0267	3.37	0.1044	not significant
Pure Error	0.0397	5	0.0079			
Cor Total	6.53	19				

Table 4.9 shows the fit statistics of pH. The R^2 value obtained is 0.9735 which indicates that there is good corelation between the predicted data and the experimental data as the closer the R^2 value to 1, the more accurately the optimal run experiment was carried out. Adequate Precision measures the signal to noise ratio and a ratio greater than 4 is desirable. The obtained ratio of 26.1336 indicates an adequate signal and this model can be used to navigate the design space.

Table 4.9: Fit Statistics of pH

Std. Dev.	0.1316	**R^2**	0.9735
Mean	9.23	**Adjusted R^2**	0.9496
C.V. %	1.43	**Predicted R^2**	0.6531
		Adequate Precision	26.1336

Figure 4.7 shows the graph of predicted foam height value by CCM versus actual results obtained from the 20 sets of experimental runs. There is much deviation between the predicted and actual values obtained. This indicates that the experimental runs were conducted with minimal error and has not been much affected by the surrounding factors such as noise.

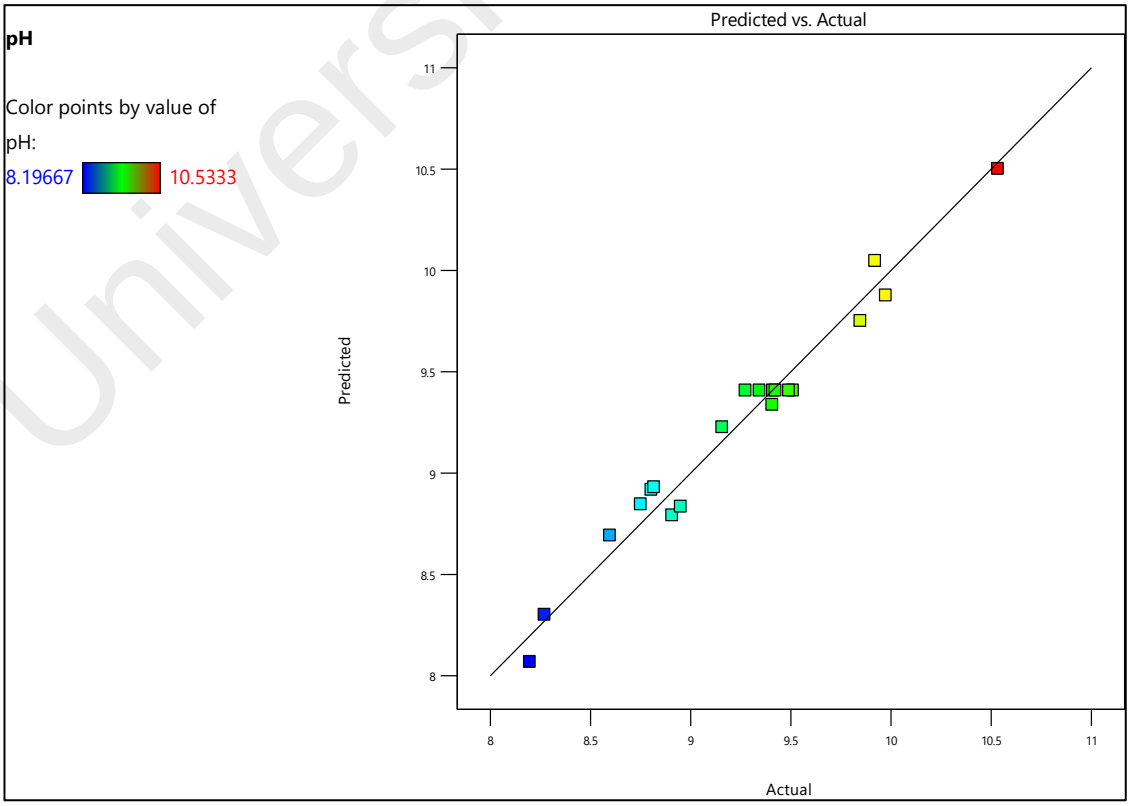

Figure 4.7: Graph of Predicted versus Actual pH Results

Figure 4.8 and figure 4.9 shows the 2D and 3D graph of foam height values at different current and distance values. The graph indicates that higher pH could be achieved with lower current value. The inter-electrode distance does not give significant effect to the change in pH.

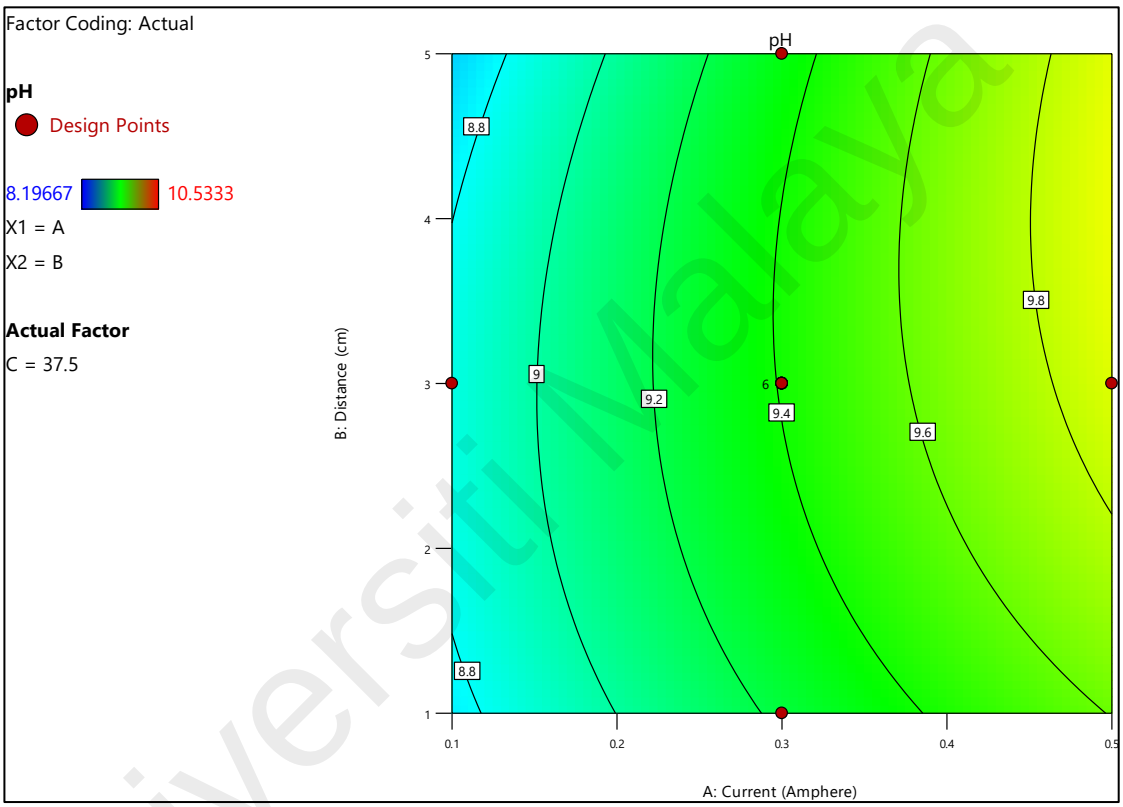

Figure 4.8: 2D Graph of pH Values at Different Current and Distance Values

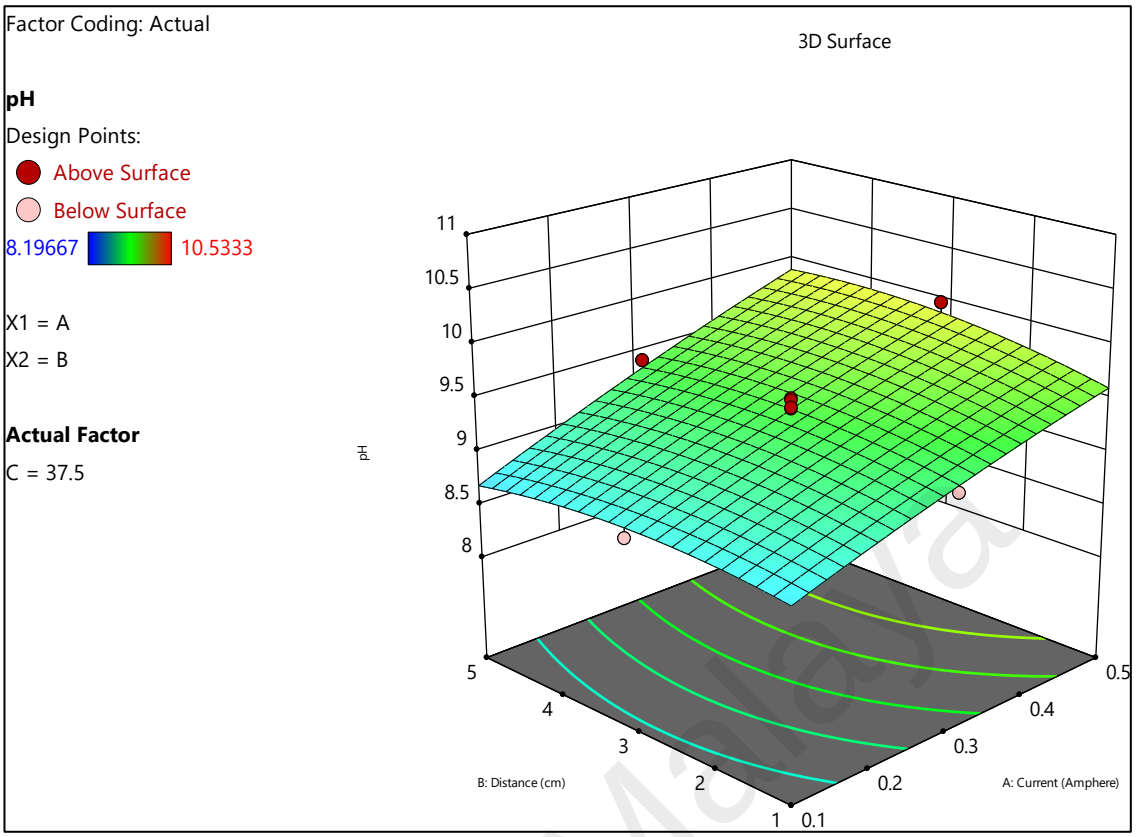

Figure 4.9: 3D Graph of pH Values at Different Current and Distance Values

4.5 Optimal Sample Run

Table 4.10 shows the best current, distance and duration values which can provide a better treatment efficiency using electrocoagulation.

Table 4.10: Confirmation Location

Current	Distance	Time
0.271339	1.00	59.9991

Upon getting the confirmation location data derived from CCM, an optimum sample run was carried out using the equalization tank sample. The COD, pH and foam height or the sample after electrocoagulation was tested and the results obtained were compared with the confirmation location's predicted mean. Table 4.11 shows the response data obtained for the optimum run and table 4.12 shows the confirmation data obtained with the predicted mean and data mean.

Table 4.11: Response Data

COD	Foam Height	pH
303	2.8	9.12

Table 4.12: Confirmation Data

Analy-sis	Predicted Mean	Predicted Median	Std Dev	n	SE Pred	95% PI low	Data Mean	95% PI high	Eror Value (%)
COD	273.656	273.656	27.9105	1	36.499	192.331	303	354.981	-10.7229514
Foam Height	2.473	2.473	0.30496	1	0.35853	1.69845	2.8	3.24755	-13.2228063
pH	9.39983	9.39983	0.13164	1	0.17215	9.01625	9.12	9.78341	2.97696873

Two-sided Confidence = 95%

4.6 Electrocoagulation Using Different Effluent Points

Upon obtaining the confirmation data, electrocoagulation was carried out using acid rinsing water and leaching water. Complete parameter analysis was done for the treated effluents of equalization tank, acid rinsing and leaching water. Table 4.13 shows the obtained results analysed after electrocoagulation process. Figure 4.10, 4.11 and 4.12 shows the comparison of equalization tank sample, leaching water sample and acid rinsing tank sample before and after electrocoagulation using CCM respectively.

Table 4.13: Complete Analysis Results for Equalization Tank Water, Acid Rinsing Water and Leaching Water After Electrocoagulation

SAMPLE	Raw COD (mg/L)	COD After EC (mg/L)	Treatment Efficiency (%)	RAW TSS (mg/L)	TSS After EC (mg/L)	Treatment Efficiency (%)	Raw Turbidity (FAU)	Turbidity After EC (FAU)	Treatment Efficiency (%)	pH After EC
Equalization Tank	672	329	51.04	164	0	100.00	182	3	98.35	8.93
Acid Rinsing Water	1266	930	26.54	83	9	89.16	92	13	85.87	9.57
Leaching Water	672	391	41.82	59	3	94.92	67	8	88.06	8.78

SAMPLE	Raw Zinc (mg/L)	Zinc After EC (mg/L)	Treatment Efficiency (%)	Raw Ammoniacal Nitrogen (mg/L)	Ammoniacal Nitrogen After EC (mg/L)	Treatment Efficiency (%)	Raw BOD (mg/L)	BOD After EC (mg/L)	Treatment Efficiency (%)
Equalization Tank	0.7	ND	100	ND	12	NEGATIVE	129	54	58.14
Acid Rinsing Water	ND	ND	-	ND	10	NEGATIVE	414	241	41.79
Leaching Water	0.05	ND	100	5	8	NEGATIVE	135	67	50.37

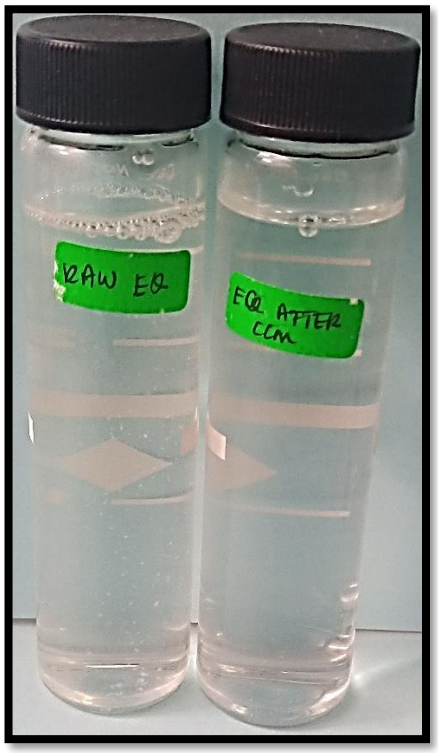

Figure 4.10: Comparison of Equalization Sample Before and After Electrocoagulation Using CCM

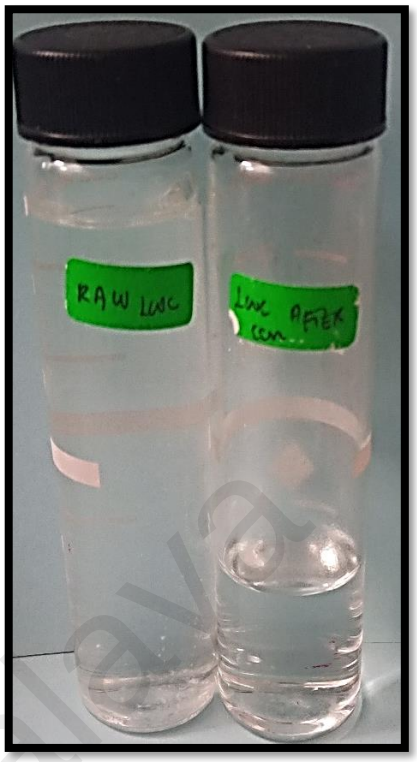

Figure 4.11: Comparison of Leaching Water Sample Before and After Electrocoagulation Using CCM

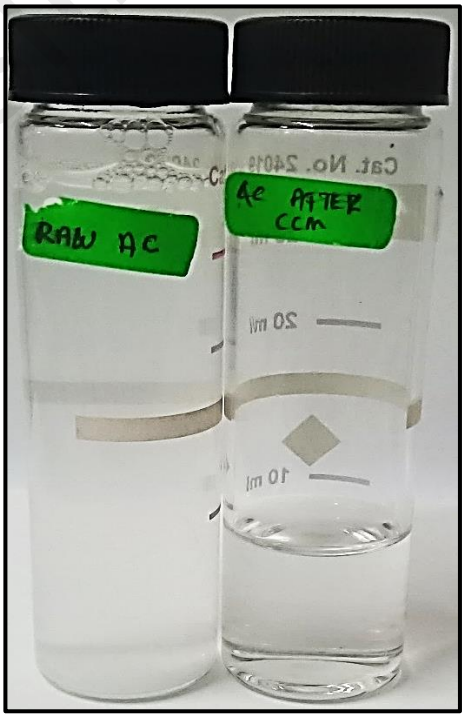

Figure 4.12: Comparison of Acid Rinsing Water Sample Before and After Electrocoagulation Using CCM

4.6.1 Treatment Efficiency of Chemical Oxygen Demand (COD)

COD test measures all components that can be oxidized by the oxidizing agent including some inorganic components. Based on table 4.13, the treatment efficiency of COD was 51.04%, 26.54% and 41.82% for equalization tank water, acid rinsing water and leaching water respectively. The highest treatment efficiency was for equalization tank water. This is because the effluent from acid rinsing sump and leaching water sump would be thoroughly mixed and equalized in the equalization tank causing the cod of the incoming effluents to the tank to be reduced due to dilution upon the mixing process. The treatment efficiency was lower for acid rinsing water and leaching water with acid rinsing water having the lowest. This could be because of the initial constituents of the effluent which contributes to elevated COD value and makes it harder for the treatment of the effluent at shorter period.

4.6.2 Treatment Efficiency of Biochemical Oxygen Demand (BOD)

BOD is the amount of oxygen used by microorganisms to biochemically biodegrade the organic matter in the effluent. Based on table 4.13, the treatment efficiency of BOD was 58.14%, 41.79% and 50.37% for equalization tank water, acid rinsing water and leaching water respectively. The corelation between COD and BOD was seen with the results obtained as the treatment efficiency of BOD was highest for EQ water followed by leaching water and the lowest for acid rinsing water, which is similar to the pattern observed for the treatment efficiency of COD. This is because as the COD value decreases, the BOD value will decrease too because COD measures the total organic

matter in the water sample but BOD measures only the biodegradable portion of the organic matter in the water sample.

4.6.3 Treatment Efficiency of TSS

Electrocoagulation shows excellent treatment efficiency for all three water samples with treatment efficiency between 89%-100% as shown in table 4.13. The treatment efficiency for EQ water sample was 100% followed by 94.92% for leaching water and 89.16 for acid rinsing water. The TSS value for raw EQ sample was the highest compared to other samples. This is because of the mixture of the TSS from the acid rinsing sump and leaching water sump effluents. Still, the treatment efficiency was 100% with no TSS being present in the treated effluent using EC. This could be because the particle size of the suspended solids in the acid rinsing sump and leaching water sump effluents are too small and hence it is a little difficult to coagulate at the given time frame as the particles are dispersed far compared to EQ tank effluent where the particles are larger in size upon good mixing which makes the particles easily settleable, easily coagulated by EC process and hence easily removable by filtration.

4.6.4 Turbidity

Turbidity is measure of the light-transmitting properties of water and is usually affected by the colloidal and residual suspended matter in the solution itself (Tchobanoglous, G.,2021). Hence, the higher the concentration of colloids and suspended matter in the solution, the more turbid the solution would be. The turbidity value for EQ tank, leaching water sump and acid rinsing sump effluents are 98.35%, 88.06% and 85.87% respectively as shown in table 4.13. TSS and turbidity's relation can be derived as TSS, mg/L= $(TSS_f)(T)$ where T is turbidity, NTU and TSS_f is factor used to convert turbidity readings to TSS (Tchobanoglous, G.,2021). The corelation between the TSS and turbidity can be seen with the results obtained whereby as the TSS value gets higher, the turbidity value also gets higher and vice versa. Similar to TSS, the raw EQ tank effluent has got the highest turbidity value compared to other effluents and at the same time, it has got the highest treatment efficiency too. The reason for this phenomenon is because of the proper mixing of the acid rinsing effluent and leaching effluent in the equalization tank causing the solids and flocks to be in larger size and easier to be attached together or coagulated by electrocoagulation process, removed by filtration, and hence reducing the turbidity of the treated effluent.

4.7 Effect of different electrodes on Foam Formation

Due to the formation of foams througout the electrocoagulation, different electrodes were used in the experiment to study on the formation of foams. Electrodes with higher hydrogen overpotentials than aluminium were used for the research purpose. Figure 4.13 shows the hydrogen overpotential values of metals. Iron was chosen for the trial run as it has higher electopotential than hydrogen. Stainless steel, which is composed of mainly iron and carbon as well as some smaller portion of chromium and other alloy materials like nickel (Burnett,C.,2014) was also used for the trial run. Both iron and stainless steel electrodes were used in this experiment as these items are easier to be purchased and both this metals has higher hydrogen electopotential than alumimium (with hydrogen overpotential of -1.70) which is -0.44 for iron and -0.44,-0.23, -0.56 for iron, nickel and chromium respectively which are the components of stainless steel metal as seen in Figure 4.13.

Metal	Metal / Formed Ion	Potential* (V)
Lithium	Li / Li +	– 2.96
Rubidium	Rb Rb +	– 2.93
Potassium	K / K +	– 2.92
Strontium	Sr / Sr ++	– 2.92
Barium	Ba / Ba ++	– 2.90
Calcium	Ca / Ca ++	– 2.87
Sodium	Na / Na +	– 2.71
Aluminum	Al / Al +++	– 1.70
Beryllium	Be / Be ++	– 1.69
Manganese	Mn /Mn ++	– 1.10
Zinc	Zn / Zn ++	– 0.76
Chromium	Cr / Cr ++	– 0.56
Iron (Ferrous)	Fe / Fe ++	– 0.44
Cadmium	Cd / Cd ++	– 0.40
Indium	In / In +++	– 0.34
Thallium	Tl /Tl +	– 0.33
Cobalt	Co / Co ++	– 0.28
Nickel	Ni / Ni ++	– 0.23
Tin	Sn / Sn ++	– 0.14
Lead	Pb / Pb ++	– 0.12
Iron (ferric)	Fe / Fe +++	– 0.04
Hydrogen	H2/ H +	0.00
Antimony	Sb / Sb +++	+ 0.10
Bismuth	Bi / Bi +++	+ 0.23
Arsenic	As /As +++	+ 0.30
Copper (cupric)	Cu / Cu ++	+ 0.34
Copper (cuprous)	Cu /Cu +	+ 0.47
Tellurium	Te / Te ++++	+ 0.56
Silver	Ag / Ag +	+ 0.80
Mercury	Hg / Hg ++	+ 0.80
Platinum	Pt/ Pt ++++	+ 0.82
Palladium	Pd / Pd ++++	+ 0.86
Gold (auric)	Au / Au +++	+ 1.36
Gold (auras)	Au / Au +	+ 1.50

Figure 4.13: Hydrogen Overpotential of Metals (Veleva, L.,2005)

Figure 4.14 and figure 4.15 shows the treated effluent samples using iron electrodes and stainless steel electrodes repectively at the anode with aluminium electrode at cathode.

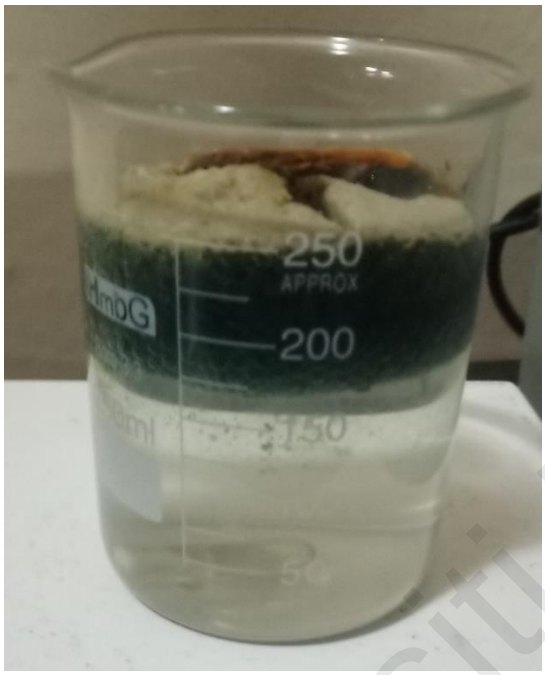

Figure 4.14: Electrocoagulated Effluent Using Iron at Cathode and Aluminium at Anode

Figure 4.15: Electrocoagulated Effluent Using Stainless Steel at Cathode and Aluminium at Anode

The formation of foams is present despite using metals with higher hydrogen overpotential at anode. Apart from that, a new problem has arisen when these two metals were introduced at the anode as a replacement for aluminium which is the formation of colour. Whilst using iron electrode at anode, green foams were formed due to reduction of Fe^{3+} to Fe^{2+}. While using stainless steel electrode, the entire solution and the foam formed went light brown in colour due to reduction of the metal constituents in the electrode. The formation of colour could lead to the necessity of additional treatment to remove it from the treatment plant of industries to abide with the government industrial

effluent discharge limit of colour which can incur additional cost. Hence, both the iron and stainless-steel electrodes were omitted from being used for the electrocoagulation setup.

4.8 Defoaming

A portion of the foams from the electrocoagulation process were scooped out and transferred into two different containers. HI-FLOC A601 defoamer and vegetable oil were used at both the containers with foams respectively. The defoamer and vegetable oil were diluted with water at ratio of 1:1 in two small bottles respectively and well shaken for proper mixing beforehand spraying into the respective containers. Since vegetable oil would not dissolve in water readily, few drops of Decone-90 soap solution were added into the mixture to ensure complete mixing of the contents in the bottle. Both the solutions were sprayed onto the containers with foams to observe if the foams could be eliminated but the foams remained undisturbed.

4.9 Zinc

Based on table 4.13, the treatment efficiency for zinc was 100% for EQ tank and leaching sump effluent. The effluent from acid rinsing sump has got no zinc content. The obtained treatment efficiency was because of the high pH of the effluent after EC process which has caused the zinc to precipitate, reducing its concentration in the effluent and hence easily removed upon filtration.

4.10 Ammoniacal Nitrogen

The treatment efficiency for ammoniacal nitrogen was negative for all three different samples as displayed in table 4.13. This could be because of the limitation of the colorimeter which was used to analyse the AN parameter. To confirm on this matter, the samples were sent to external laboratory to test the samples using spectrophotometer. A colorimeter is generally any tool that characterizes colour samples to provide an objective measure of colour characteristics whereas a spectrophotometer is a photometer, a device for measuring light intensity, that can measure intensity as a function of the colour, or more specifically, the wavelength of light (Colorimeter, Spectrophotometers, 2011).

4.11 External Lab Verification for Ammoniacal Nitrogen

Table 4.14 shows the analysis results for AN using spectrophotometer obtained from external laboratory. The results obtained from external lab also shows negative treatment efficiencies for every sample after EC. The negative treatment efficiency could be because the raw materials has got nitrogen in complex forms such as in Dioxazine, Calcium Nitrate and Ethylenediaminetetraacetic Acid. The nitrogen which is strongly bonded to carbon is in its complex form, making it harder to be detected by colorimeter and spectrophotometer. Electrocoagulation may break the strong bond between carbon and ammoniacal nitrogen and thus making it easier for the colorimeter/ spectrophotometer to detect the ammoniacal nitrogen content in the effluent after electrocoagulation. Hence, the increase in ammoniacal nitrogen value after electrocoagulation process does not indicate negative treatment efficiency. The zero AN value in the raw EQ tank and acid rinsing sump effluent indicates that there are no simple or free moving AN present in it and instead, most of the AN are in complex forms. The 5 mg/L AN in the raw leaching sample indicates that there are about 5mg/L of free moving/simple AN molecule as well as other quantity of complex AN present in the effluent. For better treatment efficiency in removing AN, aeration based biological system such as activated sludge system, trickling filter etc. will be installed in wastewater plants. This is because the food for the aerobic microorganisms would be carbon, and the nutrient source for the microorganisms would be nitrogen and phosphorus. Hence, complex carbon-nitrogen bonds can be easily broken down by the microorganisms and hence better treatment efficiency of COD and AN would be obtained. Another proof of the presence of complex carbon-AN bond can be seen from the actual results obtained in the WWTP of the selected latex industry as shown in table 4.14, where the AN from the dissolved air floatation (DAF) tank is lesser than the effluent after aeration tank. The

complex carbon-AN bond which is present in the DAF effluent is not readable by the colorimeter used in the internal laboratory of the company. After the effluent undergoes treatment in the biological system, an increase in AN value is observed. This is a proof that the breaking of the complex carbon-nitrogen has been done by the aerobic microorganisms, which caused the nitrogen to be in free moving or simpler form. As carbon is the main food source for the microorganisms and nitrogen being just a nutrient source, not much of nitrogen will be consumed by the microbes, so the leftover, unconsumed nitrogen in various forms such as organic nitrogen, nitrate, nitrite and AN will be discharged from the aeration tank with the treated effluent. This is the reason for the increase in AN reading after the aerobic treatment process.

Table 4.14: Ammoniacal Nitrogen Analysis Results Using Spectrophotometer at External Lab

Sample	Raw Ammoniacal Nitrogen (mg/L)	Ammoniacal Nitrogen After EC (mg/L)	Treatment Efficiency (%)
Equalization Tank	6	9	NEGATIVE
Acid Rinsing Water	0	10	NEGATIVE
Leaching Water	8	(Test could not be carried out by the external lab technician due to insufficient of reagents)	Not Available

Table 4.15: Treatment Efficiency of AN in The Aeration System of Selected Latex Industry's WWTP

Unit	mg/L	mg/L	%
Date	**DAF Ammoniacal Nitrogen**	**FD Ammoniacal Nitrogen**	**AN Reduction By Aeration**
1/5/2021	9	10	-11.11
3/5/2021	5	9	-80.00
4/5/2021	4	9	-125.00
5/5/2021	7	8	-14.29
6/5/2021	9	9	0.00
7/5/2021	8	11	-37.50
8/5/2021	6	9	-50.00
10/5/2021	7	8	-14.29
11/5/2021	8	9	-12.50
12/5/2021	6	7	-16.67
15/5/2021	14	16	-14.29
17/5/2021	17	19	-11.76
18/5/2021	7	18	-157.14
19/5/2021	4	19	-375.00
20/5/2021	11	15	-36.36
21/5/2021	7	12	-71.43
22/5/2021	10	13	-30.00
24/5/2021	10	11	-10.00
25/5/2021	10	17	-70.00
27/5/2021	11	19	-72.73
28/5/2021	6	13	-116.67
29/5/2021	7	10	-42.86
31/5/2021	4	13	-225.00
Average	**8.13**	**14.92**	**-69.33**

4.12 Comparison of Electrocoagulated Sample Parameters with Conventional Physical-Chemical Treatment System in Wastewater Treatment Plant of Latex Industry

Table 4.16 shows the one-month data for physical-chemical treatment (PCT) from the wastewater treatment plant of the selected latex company. Since the PCT in the selected company ends at the dissolved air floatation (DAF) tank, the data is analyzed from the incoming sumps which are the acid rinsing sump and leaching water sump, followed by equalization tank effluent as this is from where the PCT will receive the influent water for treatment, and finally DAF effluent which is where the PCT ends.

Table 4.16: Treatment Efficiency by Physical-Chemical Process in Latex Wastewater Treatment Plant

Unit	mg/L	mg/L	mg/L	mg/L	%	mg/L	mg/L	mg/L	mg/L	mg/L	%	NTU	NTU	mg/L	mg/L	mg/L	mg/L	%
Date	**COD Acid Rinsing Sump**	**COD Leaching Water Sump**	**COD EQ Tank**	**COD DAF Outlet**	**COD Reduction DAF**	**TSS Leaching Water Sump**	**TSS Acid Rinsing Sump**	**TSS EQ Tank**	**TSS DAF Inlet**	**TSS DAF Outlet**	**TSS Reduction DAF**	**Turbidity Acid Rinsing Sump**	**Turbidity Leaching Water Sump**	**ZINC Leaching Water Sump**	**Zn Acid Rinsing Sump**	**Zn EQ Tank**	**Zn DAF Outlet**	**Zn Reduction DAF**
1/5/2021	1431	877	915	511	44.15	138	128	118	129	38	70.54	114	127	0.61	0	0.84	0.56	33.33
3/5/2021	1484	804	1117	627	43.87	82	145	110	143	27	81.12	160	93	0.8	0	0.68	0.58	14.71
4/5/2021	1378	790	1048	624	40.46	90	93	120	154	23	85.06	109	98	0.63	0	0.69	0.53	23.19
5/5/2021	1383	1010	1037	712	31.34	118	107	97	122	45	63.11	118	135	0.94	0	0.12	0.27	-125.00
6/5/2021	1264	806	923	528	42.80	112	94	89	118	52	55.93	106	121	1.7	0	0.61	0.78	-27.87
7/5/2021	1550	838	981	673	31.40	115	171	90	134	41	69.40	162	124	1.29	0	1.03	0.25	75.73
8/5/2021	1234	734	1019	638	37.39	121	97	81	157	40	74.52	101	127	1	0	0.44	0.48	-9.09
10/5/2021	1154	672	880	267	69.66	121	73	72	160	43	73.13	81	128	1.2	0	0.17	0.35	-105.88
11/5/2021	1316	935	896	621	30.69	125	151	106	125	74	40.80	161	137	0.65	0	0.46	0.75	-63.04
12/5/2021	1489	824	916	675	26.31	119	143	112	131	67	48.85	174	132	0.74	0	0.38	0.47	-23.68
15/5/2021	1613	950	810	583	28.02	84	134	188	123	58	52.85	131	92	0.3	0	0.66	0.55	16.67
17/5/2021	1520	776	779	478	38.64	85	252	226	168	39	76.79	251	94	1.2	0	0.07	0.18	-157.14
18/5/2021	2054	759	786	535	31.93	77	156	160	171	39	77.19	168	90	1.17	0	0.19	0.9	-373.68
19/5/2021	1426	759	960	551	42.60	101	137	133	557	81	85.46	151	114	1.66	0	1.46	0.45	69.18
20/5/2021	1398	780	942	808	14.23	118	143	138	180	85	52.78	156	115	2.1	0	0.79	0.18	77.22
21/5/2021	1532	875	937	611	34.79	100	140	104	157	53	66.24	114	110	1.44	0	0.28	0.25	10.71
22/5/2021	1562	785	950	649	31.68	121	154	117	141	67	52.48	167	135	1.15	0	0.26	0.47	-80.77
24/5/2021	1744	834	952	619	34.98	117	354	110	125	58	53.60	344	130	1.84	0	0.63	0.36	42.86
25/5/2021	1248	976	1018	698	31.43	112	53	118	154	54	64.94	55	141	0.2	0	0.94	0.42	55.32
27/5/2021	1572	738	822	702	14.60	71	60	183	41	56	-36.59	70	81	1.49	0	0.59	0.79	-33.90
28/5/2021	1688	926	1040	598	42.50	120	155	201	80	66	17.50	161	125	0.95	0	1.66	1.62	2.41
29/5/2021	1266	820	1016	679	33.17	107	138	191	112	52	53.57	154	112	1	0	0.6	0.41	31.67
31/5/2021	1310	852	668	681	-1.95	71	126	186	68	43	36.76	142	193	0.77	0	0.13	0.14	-7.69
Average	1183.19	831.3	931	611.7	**33.68**	105.4	139.3	133.3	150	52.2	**57.22**	145.7	119.7	1.08	0	0.59	0.51	**-26.73**

Table 4.17 shows the comparison of treatment efficiencies between EC and PCT processes. From the table, it could be seen that the treatment efficiency was higher by EC process compared to physical-chemical treatment process for all the 3 parameters which are monitored in DAF influent and effluent.

Table 4.17: Comparison of Treatment Efficiencies Between EC and PCT Process

Treatment Efficiency for COD by EC (%)	Treatment Efficiency for COD by Physical-Chemical Treatment (%)	Treatment Efficiency for TSS by EC (%)	Treatment Efficiency for TSS by Physical-Chemical Treatment (%)	Treatment Efficiency for Zinc By EC (%)	Treatment Efficiency for Zinc By Physical-Chemical Treatment (%)
51.04	**33.68**	**100.00**	**57.22**	**100**	**-26.73**

The physical-chemical treatment process in the WWTP plant of the latex industry firstly involves the addition of sodium hydroxide (NaOH) for pH adjustment to increase the pH of the effluent from EQ tank to above 9.0 to make the effluent suitable for coagulation process and also to precipitate zinc. The addition of coagulant which is acidic in nature in the coagulation process will then reduce the pH of the effluent to almost neutral. The neutral pH of the effluent facilitates the flocculation process where large flocs are formed upon the addition of polymer. The polymer promotes the aggregation of the suspended solids into particles which are large enough to settle by forming bridges between the flocs. Then, the flocculated effluent will flow into the DAF tank where the flocs will be floated in the tank and scrapped-off. With these much addition of chemicals and processes being involved, the COD, TSS and Zinc reduction is not as efficient as the EC process. Hence, via EC, chemicals such as NaOH, coagulant and polymer can be

omitted in the system and at the same time, better treatment efficiency of the effluent can be obtained. Hence, EC can improve the treatment efficiency of the wastewater treatment process and helps reducing the cost incurred in purchasing chemicals for pH adjustment, coagulation, and flocculation process.

4.13 Cost Comparison

Table 4.18 shows the cost incurred by the selected latex company in the wastewater treatment plant for caustic soda and coformer as well the cost which can be saved if electrocoagulation process is installed in the plant. A total of RM 85,165 is estimated to be saved in the plant if electrocoagulation system is installed in comparison to conventional physical-chemical process.

Table 4.18: Cost Incurred by the Selected Latex Company for Caustic Soda and Coformer and Total Savings by Electrocoagulation

Chemical	General Name	Usage Purpose	Unit Cost/kg	Total kg Used per Month	Total cost per month (RM)	Total cost per year (RM)
Caustic Soda 50%	Caustic Soda	To increase the pH of the wastewater to 9 - 9.5 to make the wastewater suitable for coagulation process	0.83	1500	1500 X 0.83 = 1245	1245 X 12= 14940
Coformer 1500	Coformer/Polymer	To coagulate the flocs present in wastewater to make it suitable for flocculation process	1.33	4400	1.33 X 4400 = 5852	5852 X 12= 70224

Total Savings per Year Via Electrocoagulation :
RM 85,164

Table 4.19 shows the total electricity cost incurred for EC process using a current value of 0.271A and calculated for 24 hours basis for better display of the cost. For 1 litre of sample, the total cost incurred for the setup is RM 0.08 for 24 hours basis.

Table 4.19: Total Electricity Cost Incurred for Electrocoagulation Process

Optimum Current Value	Voltage Used	Power	Operating Time	Consumption	Unit Cost for Industry	Total Cost
0.271 A	30 V	0.00813 kW	24 hours	0.00813 X 24 = 0.19512 kWh	RM 0.408 (kWh)	RM 0.08 /day

CHAPTER 5: CONCLUSION AND RECOMMENDATION

This chapter simplifies the results and findings of this research project and recommends the future scope which could be focused on the same project by upcoming researchers.

Based on the research project carried out, all the objectives of the experiment were successfully fulfilled. The optimization of electrocoagulation (EC) process in latex wastewater treatment we carried out after determining the suitable electrodes, current (A), electrocoagulation time (minutes), and inter-electrode distance (cm). Based on the 20 sample runs made using central composite design (CCD) module from the Design of Expert software, the optimum current (I), electrocoagulation time (minutes), and inter-electrode distance (cm) factors were 0.271 A, 59.99 minutes and 1 cm respectively.

After obtaining the optimum values for the three factors, comparison was done between different electrodes at cathode which are aluminium, stainless steel and iron whilst maintaining aluminium at anode. This was to determine if better treatment efficiency could be achieved using the optimum range obtained initially using different electrodes. But iron and stainless-steel electrodes at cathode changed the color of the solution to green and light brown respectively. This would demand additional treatment requirements for the color produced to abide with DOE final effluent discharge standards. Hence, no additional analysis was carried out for the treated solutions using stainless-

steel and iron electrodes. Instead, aluminium electrode was used at cathode for the optimum sample run as there is no color formation in the sample after the EC process.

The effectiveness of EC process in latex wastewater treatment in comparison to conventional physical-chemical treatment were proven to be effective when compared with the results of equalization tank water. The treatment efficiency of the equalization tank water with EC for COD, total suspended solids and zinc was 51.04%, 100% and 100% respectively compared to 33.68%, 57.22% and -26.73 respectively with conventional physical-chemical process used in the plant. But, in terms of ammoniacal nitrogen, it was hard to make judgement of the treatment efficiency using EC process as the results were shown negative treatment efficiency with EC and conventional physical-chemical process which is due to the limitation of the colorimeter and spectrophotometer used for the sample analysis.

In terms of cost effectiveness, it is estimated about RM 85,164 could be saved in the plant in terms of usage of chemicals such as caustic soda and coformer if EC system has been installed in the plant compared to conventional physical-chemical process. This is because at the end of the EC process, the pH of the solution increases to ± 9.0, making it suitable to undergo coagulation process without the usage of caustic soda. Then, flocs are also formed at the end of the EC process without the need to add coformer.

Unfortunately, the usage of EC process alone could not achieve the standard A or B industrial effluent discharge standard requirements of DOE Malaysia for all the

parameters tested except for zinc and total suspended solids. Thus, further treatment of the samples is required with the aid of biological treatment system to further treat the biological components and ammoniacal nitrogen in the effluent.

For future studies, it is recommended that suitable instrument for the analysis of complex molecules in wastewater samples is identified and used for the sample analysis. This is to overcome the issue of obtaining negative treatment efficiency results such as what has been obtained for ammoniacal nitrogen in the research project that has been carried out. Apart from that, the usage of polymer (flocculant) should also be tested on the sample after EC process to determine the quantity of polymer dosage required to form large sized flocs and if cost savings could be achieved compared to conventional physical-chemical process. Finally, since EC process requires the usage of electricity, the amount of electrical consumption required for the actual installation of the EC setup in plant scale should be studied and methods to reduce the electrical cost should also be determined such as by introducing solar based EC setup etc. Finally, the method to remove the foam formed during EC process should be identified as well.

REFERENCES

1. Varank, G., & Sabuncu, M. E. (2015). Application of Central Composite Design approach for dairy wastewater treatment by electrocoagulation using iron and aluminum electrodes: modeling and optimization. *Desalination and Water Treatment*, *56*(1), 33-54.

2. Shi, H., Chiang, S. Y. D., Wang, Y., Wang, Y., Liang, S., Zhou, J., ... & Huang, Q. (2021). An electrocoagulation and electrooxidation treatment train to remove and degrade per-and polyfluoroalkyl substances in aqueous solution. *Science of The Total Environment*, 147723.

3. Tchobanoglous, G., Burton, F. L., & Stensel, D. H. (2021). *Solutions Manual for use with Wastewater Engineering Treatment and Reuse Metcalf & Eddy* (4th ed.). McGraw Hill.

4. Veleva, L. (2005). Veleva L., "Soils and Corrosion" (Chapter 32), in Corrosion Tests and Standards: Application and Interpretation , 2nd Edition, R. Baboian Ed., ISBN: 0-8031-2058-3, ASTM International, OH, pp.387-404, 2005.

5. Burnett, C. (2014, February 18). *What Is Stainless Steel? Part I*. Analyzing Metals. https://www.thermofisher.com/blog/metals/what-is-stainless-steel-part-i/

6. *Colorimeters, Spectrophotometers*. (2011). Global Water. http://www.globalw.com/support/colorimeter.html

7. Amdan, N. S., Zin, M., & Salleh, S. N. A. M. (2018). Leachate treatment by conventional coagulation, electrocoagulation and two stages coagulation (conventional coagulation and electrocoagulation). *Water and Environmental Issues (Vol. 2)*, *5*, 10.

8. Hakizimana, J. N., Gourich, B., Chafi, M., Stiriba, Y., Vial, C., Drogui, P., & Naja, J. (2017). Electrocoagulation process in water treatment: A review of electrocoagulation modeling approaches. *Desalination*, *404*, 1-21.

9. Bazrafshan, E., Alipour, M. R., & Mahvi, A. H. (2016). Textile wastewater treatment by application of combined chemical coagulation, electrocoagulation, and adsorption processes. *Desalination and Water Treatment*, *57*(20), 9203-9215.

10. Yılmaz Nayır, T., & Kara, S. (2018). Container washing wastewater treatment by combined electrocoagulation–electrooxidation. *Separation Science and Technology*, *53*(10), 1592-1603.

11. Bracher, G. H., Carissimi, E., Wolff, D. B., Graepin, C., & Hubner, A. P. (2020). Optimization of an electrocoagulation – flotation system for domestic wastewater treatment and reuse. *Environmental Technology*, 1-11.

12. Sher, F., Hanif, K., Iqbal, S. Z., & Imran, M. (2020). Implications of advanced wastewater treatment: Electrocoagulation and electroflocculation of effluent discharged from a wastewater treatment plant. *Journal of Water Process Engineering*, *33*, 101101.

13. Pérez, L.S., Rodriguez, O. M., Reyna, S., Sánchez-Salas, J. L., Lozada, J. D., Quiroz, M. A., & Bandala, E. R. (2016). Oil refinery wastewater treatment using coupled electrocoagulation and fixed film biological processes. *Physics and Chemistry of the Earth, Parts A/B/C*, *91*, 53-60.

14. Demirbas, E., & Kobya, M. (2017). Operating cost and treatment of metalworking fluid wastewater by chemical coagulation and electrocoagulation processes. *Process Safety and Environmental Protection*, *105*, 79-90.

15. Moussa, D. T., El-Naas, M. H., Nasser, M., & Al-Marri, M. J. (2017). comprehensive review of electrocoagulation for water treatment: Potentials and challenges. *Journal of environmental management*, *186*, 24-41.

16. Souza, F. L., Cotillas, S., Saéz, C., Cañizares, P., Lanza, M. R., Seco, A., & Rodrigo, M. A. (2016). Removal of algae from biological cultures: a challenge for electrocoagulation?. *Journal of Chemical Technology & Biotechnology*, *91*(1), 82-87.

17. Gong, C., Shen, G., Huang, H., He, P., Zhang, Z., & Ma, B. (2017). Removal and transformation of polycyclic aromatic hydrocarbons during electrocoagulation treatment of an industrial wastewater. *Chemosphere*, *168*, 58-64.

18. Mollah, M. Y., Morkovsky, P., Gomes, J.A., Kesmez, M., Parga, J., & Cocke, D. L. (2014). Fundamentals, present and future perspectives of electrocoagulation. *Journal of hazardous materials*, *114*(1-3), 199-210.

19. Hakizimana, J. N., Gourich, B., Chafi, M., Stiriba, Y., Vial, C., Drogui, P., & Naja, J. (2017). Electrocoagulation process in water treatment: A review of electrocoagulation modeling approaches. *Desalination*, *404*, 1-21.

20. Mores, R., Mello, P. D. A., Zakrzevski, C. A.,Treichel, H., Kunz, A., Steffens, J., & Dallago, R. M. (2018). Reduction of soluble organic carbon and removal of total phosphorus and metals from swine wastewater by electrocoagulation. *Brazilian Journal of Chemical Engineering*, *35*(4), 1231-1240.

21. Hussin, F., Aroua, M. K., & Szlachta, M. (2019). Combined solar electrocoagulation and adsorption processes for Pb (II) removal from aqueous solution. *Chemical Engineering and Processing-Process Intensification*, *143*, 107619.

22. Tahreen, A., Jami , M. S., Ali, F., Yasin, N. M. F. M., & Ngabura, M. (2021). Promising Potential of Electro-Coagulation Process for Effective Treatment of Biotreated Palm Oil Mill Effluents. *Pollution*, *7* (3), 617-632.

23. Kasmuri, N., Adnan, N., Ahmad, R., Santiagoo, R., & Ramasamy, S. (2021). Heavy metals reduction using electrocoagulation in enhancing the water quality near unlined landfill: A case study. In *IOP Conference Series: Earth and Environmental Science* (Vol. 646, No. 1, p. 012003). IOP Publishing.

24. Cañizares, P., Jiménez, C., Martínez, F., Rodrigo, M. A., & Sáez, C. (2009). The pH as a key parameter in the choice between coagulation and electrocoagulation for the treatment of wastewaters. *Journal of Hazardous Materials, 163(1),* 158-164.

25. Pendashteh, A. R., Haji, F. A., Chaibakhsh, N., Yazdi, M., & Pendashteh, M. (2017). Optimized treatment of wastewater containing natural rubber latex by coagulation-flocculation process combined with Fenton oxidation. *J. Mater. Environ. Sci*, *8*, 4015-4023.