

MATHEMATICAL MODELLING OF TOTAL SUSPENDED SOLID REMOVAL FROM POME VIA MODIFIED ELECTROCOAGULATION

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Abstract

Wastewater defined as 99.0% of liquid and 1.0% of reliable content. Recently in Malaysia, there is a lot of research majoring in wastewater treatment which is majoring in costing reduction and on how to improve the quality of water discharged for ensuring it follows Malaysia's regulation and acts. Removal of total suspended solids (TSS) is one of the cases studied in the wastewater treatment field since the TSS parameter severely affected continuously to the other parameters such as chemical oxygen demand (COD), biochemical oxygen demand (BOD) and odor problems. Response surface methodology (RSM) was applied, and in this study, it involves three significant variables to remove TSS content from palm oil mill effluent (POME). At the last stage of the optimization part as known as validation of the variables suggested by the software, 96.6% of TSS content from POME was removed using modified electrocoagulation. The optimum condition of significant variables studied was the time of the coagulation process at 60.0 minutes, followed by a concentration of salt at 1.0 g/L and inter-electrode distance was 2.5 cm respectively. From the result of the optimization study, it can conclude the TSS content from POME had been removed via electrocoagulation and mathematical modeling should be applied to solve the costing problem, respectively.

Keywords-- Response surface methodology (RSM), optimization, palm oil mill effluent (POME), total suspended solids (TSS), coagulation, wastewater treatment.

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INTRODUCTION

The palm oil industry in Malaysia has grown up over the last few decades, and as a result, Malaysia becomes the second-largest country in the world produced palm oil in the world. It has been an essential source of Malaysia's economic growth, and as a result, it gives a positive impact on Malaysia's economy. On the other side, palm oil is producing a lot of products such as cooking oil, margarine, and vegetable oils; meanwhile, the palm kernel usually used for shampoo, soap, and detergent. Both main products involve a significant process at the palm oil mill. The palm oil mill will produce crude palm oil that gives a great benefit to the consumers. As a result, the process involves creating an effluent called as palm oil mill effluent (POME) which is originally from the extraction process of the fresh fruit bunch (FFB). Palm oil mill process generates a lot of wastewater which will increase the polluting of wastewater known as POME and discharged to the disposal ponds. POME produced a lot of methane (CH₄) gas and can pollute the groundwater and the soil from the disposal pond respectively. [1]

POME also is oily wastewater that contains a bunch of suspended solid and contaminants that have produced from the mill process. The cheapest and incorrect way to dispose of the untreated POME or partially treated POME is just discharged it into the land or river near to the palm oil mill. However, the untreated POME release into the stream can react and decrease the oxygens content in the water, and as a negative result, it can harm the aquatic life. A lot of rivers and nearby people living have significantly been affected by the activity respectively. The various treatment had been done by palm oil mill industries to treat POME to reduce the pollution of the waterways that caused by the POME. However, palm oil mill industries need to balance their economic profitability, environmental protection, ethics, and sustainable development to create a better life. [2]

Coagulation, solvent extraction, membrane separation, and adsorption had been used in the industries as an initial pre-treatment of POME to remove the contaminants that can pollute before discharging it to the river or water catchment. Electrocoagulation is an efficient treatment method that involves the electro dissolution of sacrificial anodes panel and the formation of hydroxo-metal products as coagulants, while the simultaneous production of hydrogen at the cathode panel facilitates the pollutant removal as in solid-state. [3]

MATERIAL AND METHOD

Chemical and Solvent

All chemicals and solvents used in this project were purchased and obtained from the local distributor such as Sigma Aldrich (M) and Merck (M) Sdn. Bhd.

Raw material

Raw palm oil mill effluent (POME) wastewater was requested and then collected from the nearest palm oil mill industry located at Serting, Kuala Pilah, Negeri Sembilan. The samples were kept in a black container to prevent it from exposure to the sunlight or any ray/ light in the laboratory and then placed it in a refrigerator below -20°C. [4]

Characterization of POME

Raw POME wastewater characterized by five parameters such as chemical oxygen demand (COD), total suspended solids (TSS), biochemical oxygen demand (BOD), turbidity (NTU) and pH as a starter of this research.

Design of mini electrocoagulation reactor and experimental setup

In this study, the voltage value was constant to reduce the cost of electricity at 10V. The reactor of electro-coagulation was designed using a 250mL beaker as the main character and connected to the electric DC power supply. A simple wire clip used in between the plate (aluminum plate) and power supply. The schematic diagram of

the electro-coagulation reactor, as shown in Figure 1. The process was obtained using a fed-batch scheme. The criteria of electrode design were selected due to the highest performance from the previous study. The bottom of the mini reactor was stirred by a stirrer consistent at 80 rpm to enhance the coagulated process. The stirrer used was a simple magnetic stirrer bar (2.0 cm) placed on the hot plate stirrer. The current intensity was controlled by a precision digital direct current power supply, DC Power Supply purchased from the local distributor.

For the experiment to determine the effect of time in electrocoagulation, the process was operated at constant with 1.0 g/L concentration of salt, inter-electrode distance with 2.5 cm and playing around the time from 0-70 minutes. While for the experiment to determine the effect of inter-electrode distance, the process was operated at a constant concentration of salt (1.0 g/L) and constant time (60 minutes). For the experiment to determine the effect of concentration of salt, the process was operated at a constant time (60 minutes) and inter-electrode distance (2.5 cm). [5]

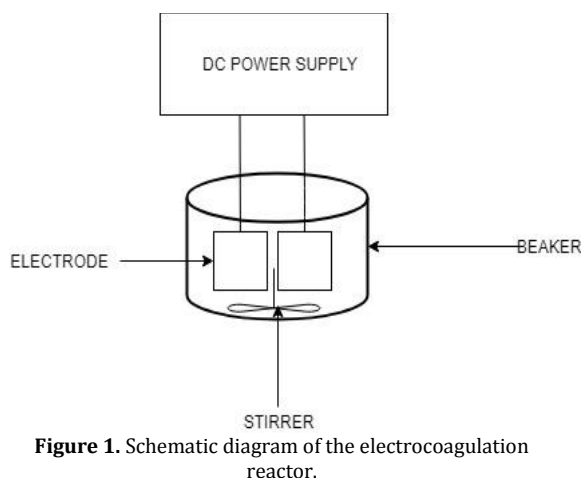


Figure 1. Schematic diagram of the electrocoagulation reactor.

RESULTS AND DISCUSSION

Characterization of fresh POME

The raw POME wastewater was characterized once collected to avoid any interactions or activities of microorganisms and POME wastewater itself such as degradation of plant dry matter, breaking down lipids bond, degradation, and decomposition of fatty acid of the sample. The identification of DO, pH, COD, BOD, turbidity, and TSS were characterized and noted for further research activity. Table 1 below shows the main characteristic of raw POME wastewater collected. The sample used in the characterization was fresh.

Table 1. Main characteristic of POME wastewater

No	Parameters	Concentration
1	pH	4.77
2	Chemical oxygen demand, COD	650 mg/L
3	Biochemical oxygen demand, BOD	30,000 mg/L
4	Total suspended solids, TSS	15,000 mg/L
5	Turbidity, NTU	762 NTU

One factor at a time (OFAT)

All the conducted experiments involve in this study were run by triplicates and in batch style. In the electro-coagulation process, the gas bubble had a substantial contribution to the treatment effectively. The liberate hydrogen gas bubble

serves as an excellent floatation agent and carry the suspended particles to the surface. The gas bubble generated increased proportionally with the time, but the bubble size decreases with increasing the concentration of salt and other significant variables. An increase in the gas bubble density with a reduction in their size enhances the upward flux, resulting in higher pollutant removal by floatation. [6]

Besides acting as a floatation agent, the gas bubbles also attributed as an oxidizing agent towards the pollutant by a direct or indirect oxidation process. Oxygen gas produced at anode were able to oxidize organic pollution. When sufficient voltage is developed (at 10V) across the electrodes, direct oxidation takes place near the anode due to the release of electrons by the organic compounds to maintain the flow of current, whereas indirect oxidation occurs due to the strong oxidants that form during the reaction. [7]

Effect of time on Total suspended solids (TSS) removal

In the electrocoagulation process, the most crucial variable for controlling the coagulant dosing rate and reaction rate into the medium sample is time. Therefore, a few experiments have been conducted to determine the effect of time manipulation on the treatment of POME.

Figure 2 below shows the impact of time on the removal of suspended solid for POME. The graph shows the relationship between removal efficiencies and the time taken for the coagulation process. After 10 minutes, the coagulation process reacted rapidly and continuously removed the suspended solids with the time made. From the experiment done, the floating particles become likes bubbles and coagulated on the POME water surface. After 60 minutes, the reaction becomes slow, and from the response, it shows depletion of floatation matters or coagulated particles. Once the analysis of TSS removal, the suspended solids decrease after 60 minutes. This depletion indicates the maximum points of aluminum plate interacted with the POME achieved the maximum limits.

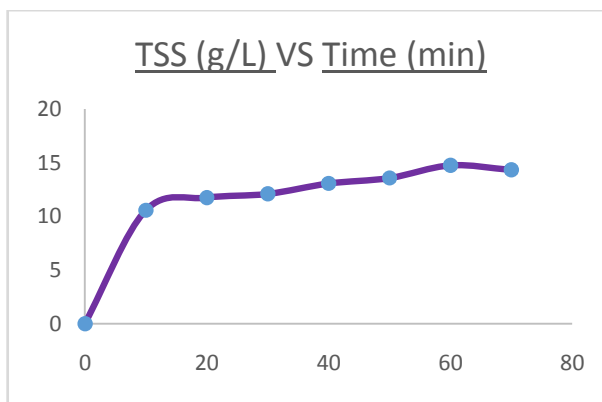


Figure 2. Effect of time on total suspended solids (TSS) removal.

Effect of inter-electrode distance (cm) on Total suspended solids (TSS) removal

The distance between anode and cathode is one of the parameters that influence the treatability of POME wastewater by electrocoagulation process. Therefore, an experimental had been made to determine the effect of inter-electrode distance on the treatment of POME. The removal of TSS efficiencies with all investigated inter-electrode distances was compared and discussed.

Figure 3 below shows the interaction between the inter-electrode with the removal efficiencies of suspended solids with time at 60 minutes and concentration of salt at 1.0 g/L. The inter-electrode distances were manipulated at 1.0 cm, 1.5 cm, 2.0 cm, 2.5 cm, 3.0 cm, 3.5 cm, until 5.5 cm. From the result of suspended solids, it shows at

2.5 cm, the removal of suspended solids at maximum value with 14.5 g/L.

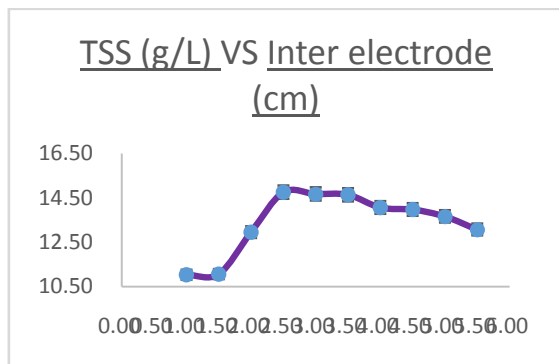


Figure 3. Effect of inter-electrode distance (cm) on total suspended solids (TSS) removal

Effect of concentration of salt used (g/L) on Total suspended solids (TSS) removal

Although theoretically increasing of salt concentration for pH balancing will increase pollutant removal, however, increasing the salt concentration did not show any significant improvement in the percentage of suspended solids removal but based on percentage decrease once the concentration of salt change from 1.0 g/L to the higher concentration. As explained previously in the effect of time of total suspended

solids removal part, the rate of gas bubble production increase with the increase of salt concentration, yet more gas bubble production also will somewhat decrease the specific area of the alum plate or acted as electrode which makes it vulnerable and did not perform on its full potential.

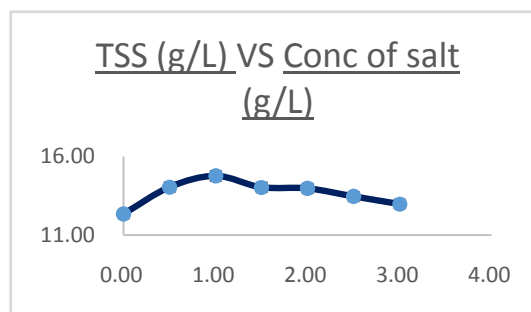


Figure 4. Effect of concentration of salt used on total suspended solids (TSS) removal.

Response Surface Methodology (RSM)

The response of total suspended solids (g/L) removal as a function of coagulated time (minutes), the concentration of salt (g/L) and inter-electrode distance (cm) were evaluated in central composite design (CCD). All the experiments were carried out with 10V of current intensity and 100 mL of POME sample. The design of the study and responses are shown in Table 2. A full quadratic model was proposed by the Design of Experiment version 7.0.6.

Table 2. The experimental design and responses using CCD from Design of Experiment software.

No of exp	Time (min)	The conc. of salt (g/L)	Inter-electrode (cm)	TSS (mg/L)
1	43	1.0	2.50	12.58
2	60	1.0	2.50	14.60
3	50	1.5	3.00	13.67
4	77	1.0	2.50	12.33
5	77	1.0	2.50	12.76
6	60	1.0	2.50	14.60
7	70	1.5	3.00	12.65
8	60	0.2	2.50	11.97
9	60	1.0	2.50	14.60
10	70	0.5	2.00	12.45
11	70	0.5	3.00	12.59
12	60	1.0	2.50	14.63
13	60	1.0	3.34	12.56
14	60	1.0	2.50	14.59
15	50	1.5	2.00	12.88
16	60	1.0	1.66	14.07
17	50	0.5	2.00	11.86
18	60	1.8	2.50	13.75
19	60	1.8	2.50	13.39
20	50	0.5	2.00	11.28
21	60	1.0	3.34	11.49
22	70	0.5	2.00	12.35
23	60	0.2	2.50	11.46
24	70	1.5	3.00	12.87
25	43	1.0	2.50	12.69
26	70	1.5	2.00	12.39
27	60	1.0	2.50	14.53
28	50	1.5	2.00	11.26
29	50	0.5	3.00	12.07
30	50	1.5	3.00	13.52
31	60	1.0	1.66	13.45
32	70	1.5	2.00	12.34
33	50	0.5	3.00	11.59
34	70	0.5	3.00	12.54

Then, using the Design of Experiment (DOE) software, an analysis of variance (ANOVA) was conducted for the evaluation of the effect of the variables and their probable interactions. Table 3 shows the ANOVA for the response surface quadratic model (partial of some square) and the responses for the TSS removal.

Table 3. Analysis of variances, ANOVA for the response surface quadratic model (partial some of square), responses; TSS removal (g/L).

Source	Sum of square	Mean Square	F value	p-value
				Prob> F
Model	29.1738	3.2415	78.9413	< 0.0001 ^a
A-time	0.0001	0.0001	0.0024	0.9611
B-conc of salt	5.7415	5.7415	139.8225	< 0.0001
C-inter electrode	0.4734	0.4734	11.5292	0.0030
AB	2.0498	2.0498	49.9193	< 0.0001
AC	0.0239	0.0239	0.5816	0.4550
BC	0.0802	0.0802	1.9526	0.1784
A ²	9.6160	9.6160	234.1792	< 0.0001
B ²	9.1182	9.1182	222.0561	< 0.0001
C ²	3.2487	3.2487	79.1151	< 0.0001
Residual	0.7802	0.0411		
Lack of Fit	0.1550	0.0517	1.3223	0.3018 ^b
Pure Error	0.6252	0.0391		
Cor Total	29.9540			

*a significant

*b not significant

Table 4. R-squared Table content

Std. Dev.	0.2026	R-Squared	0.9740
Mean	12.9493	Adj R-Squared	0.9616
C.V. %	1.5649	Pred R-Squared	0.9281
PRESS	2.1541	Adeq Precision	25.8601

The multiple regression equations for TSS removal by using three significant variables time (minutes), inter-electrode distance (cm) and concentration of salt (g/L) and acts as the main variables are given in Equation 1 and Equation 2.

The final equation in terms of coded factors:

$$\text{Total suspended solids (TSS) removal} = + 14.59 - 0.002A + 0.47B + 0.18C - 0.38AB - 0.04AC - 0.07BC - 0.71A^2 - 0.69B^2 - 0.69C^2 \quad \text{(Equation 1)}$$

The final equation of terms of actual factors:

$$\text{Total suspended solids (TSS) removal} = - 37.66 + 0.95 \times \text{time} + 10.22 \times \text{concentration of salt} + 14.31 \times \text{inter-electrode distance} - 0.08 \times \text{time} \times \text{concentration of salt} - 0.008 \times \text{time} \times \text{inter-electrode distance} + 0.30 \times \text{concentration of salt} \times \text{inter-electrode distance} - 0.0071 \times \text{time}^2 - 2.76 \times \text{concentration of salt}^2 - 2.75 \times \text{inter-electrode distance}^2 \quad \text{(Equation 2)}$$

The equation 2 and 3 in terms of coded and actual factors respectively were empirical model equations. They are mathematical correlation models that can be employed to predict and optimize the suspended solids removals within

the range of variable factors of this research. The relationship between the response and variables was visualized through a response construct according to the full model.

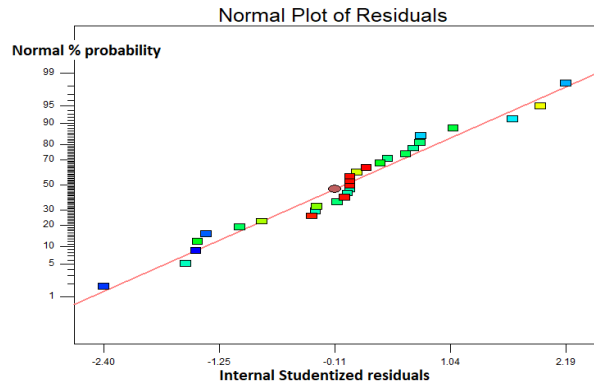


Figure 5. Normal plot of residuals for TSS removal responses

Figure 6, 7, and 8 show the interactions and three dimensional (3-D) response surface plot of TSS (g/L) removal.

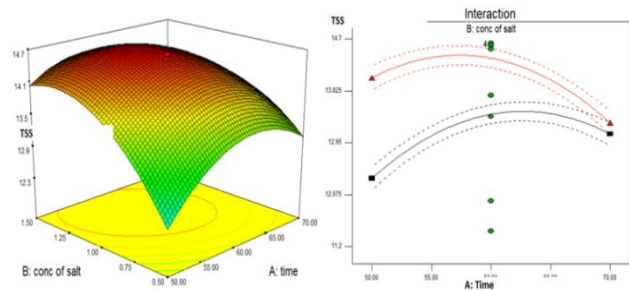


Figure 6. Three dimensional (3-D) graph of the effect of concentration of salt (g/L) and time (minutes) to the TSS (g/L) removal

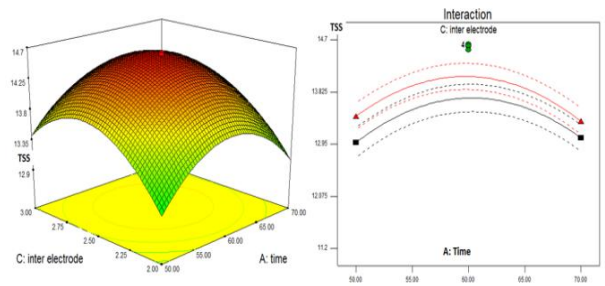


Figure 7. Three dimensional (3-D) graph of the effect of inter-electrode distances (cm) and time (minutes) to the TSS (g/L) removal

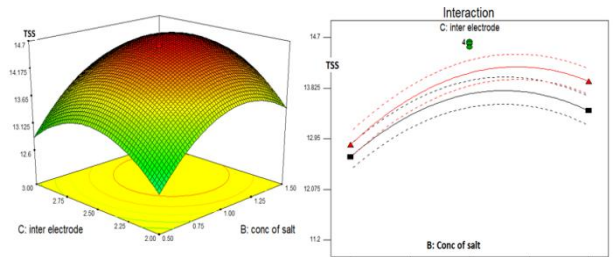


Figure 8. Three dimensional (3-D) graph of the effect of concentration of salt (g/L) and inter-electrode distance (cm) to the TSS (g/L) removal

Validation of variables (optimization process)

Table 5 shows the validation of TSS removal using electrocoagulation process by the experimental design. From this table, the coagulation time (57 minutes), the concentration of salt (1.2 g/L) and inter-electrode distance (2.5 cm) yielded a TSS removal of 14.64 g/L. It was also shown the lowest percentage (%) error within the agreed value of 0.13%. The benefits mean that the developed empirical model was considered accurate for the prediction of TSS removal since the percentage error was well between predicted and actual values.

Prospectives. *Electrochemical Water and Wastewater Treatment*, 61–76.

Table 5. The results of the optimum operational conditions for TSS removal (g/L)

No	Time	Conc. of salt (g/L)	Inter-electrode (cm)	Predicted TSS (mg/L)	Actual TSS (mg/L)	% error
1	59	1.3	2.5	14.66	14.58	0.53
2	58	1.3	2.5	14.64	14.60	0.26
3	60	1.2	2.5	14.67	14.65	0.16
4	59	1.2	2.5	14.66	14.59	0.46
5	57	1.2	2.5	14.65	14.63	0.13
6	62	1.2	2.5	14.64	14.60	0.26
7	59	1.1	2.5	14.67	14.57	0.65

CONCLUSION

The TSS (g/L) removal was optimized in this project using response surface methodology (RSM) to study the effect of variable parameters in TSS removal. This method was suitable for fitting a quadratic surface which will help to optimize the significant variables with a minimum number of experiments as well as to analyze the interaction between the variables.

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