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THE OPTIMIZATION OF THE ELECTROCOAGULATION OF PALM OIL MILL EFFLUENT WITH A BOX-BEHNKEN DESIGN

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ABSTRACT

Unmanageable industrial wastewater will have an impact on the environment. One of the alternative wastewater treatment technologies is electrocoagulation. This study investigates the effects of voltage, time, and NaCl concentrations on wastewater through electrocoagulation–specifically, how they affect the total suspended solid (TSS), the total dissolved solid (TDS), and the chemical oxygen demand (COD) reduction of palm oil mill effluent (POME)–with *response surface methodology*. An iron electrode was used with a time variation of 15, 30, and 45 minutes; a voltage variation of 10, 15, and 20 volts; and NaCl concentrations of 0.0, 0.5, and 1.0 M. A Box-Behnken design in the response surface method formed the model and optimized the electrocoagulation. Optimization of COD, TSS, and TDS reductions with the response surface methodology was accomplished at 93.12%, 97.70%, and 41.06% respectively, in 37 minutes with 20 volts, and no NaCl concentration. The analysis of variance (ANOVA) showed that the quadratic model, with the R^2 coefficients of COD, TSS, and TDS at 0.99, 0.97, and 0.92, respectively, and the adjusted-R^2 values at 0.97, 0.94, and 0.83, respectively. Conformity testing for the optimum conditions proved the model's validity, yielding COD, TSS, and TDS reduction efficiency at 93.27%, 97.64%, and 40.78%, respectively. The results of this study were useful for predicting and controlling the COD, TSS, and TDS removal efficiencies in different conditions, and they will provide information on wastewater disposal's impact on the environment without going through the first processing stage. Therefore, electrocoagulation is a more economical POME processing technique.

Keywords: Box-Behnken; Electrocoagulation; POME; Response surface method

1. INTRODUCTION

Wastewater is water-carried wastes that combine with surface water, groundwater, and stormwater. Many types of equipment has been made for treating wastewater, such as settling basins, strainers, filters, and reactors. Furthermore, many technologies can remove pollutants from wastewater, including membrane filtration, an ion exchange, and precipitation (Lee et al., 2014). Regulations compel the industry to keep pollutants within tolerable limits in the environment. The number of microorganisms in wastewater is a measure of the water's quality. The palm oil industry is the most developed industry in the world because palm oil extraction results in palm kernel oil and crude palm oil (CPO). Indonesian law allows people to dispose of wastes as the standard. As such, Indonesia produces 47% of the world's CPO, making it the largest CPO producer globally after Malaysia (Carter et al., 2007). A palm bunch consists of 20% oil, 6% kernel, 15% fibers, 7% shells, 20% bunches, and wastewater (Ozturk et al., 2017).

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POME is black and contains grease, plant nutrients, total suspended solid (TSS), biochemical oxygen demand (BOD), and chemical oxygen demand (COD); (Mohammed et al., 2014). It has a maximum COD of 80,000 ppm, a BOD of 40,000 mg/l, a solid of 95,000 mg/l, and a TSS of 50,000 mg/l (Chairunnisak et al., 2018). The Indonesian Regulation of Environment states that the maximal limits are a pH of 6–9, a COD of 350 mg/l, a TSS of 250 mg/l, and a BOD_5 of 100 mg/l for this pollutant. Many POME processes use anaerobic ponds, a combination of open-waste ponds and land, various membrane materials (Faisal et al., 2016), and adsorbents (Kusrini et al., 2016). These processes have problems related to the large open reactors, large surplus sludge, low process efficiency, and high energy. Therefore, this study tried an alternative, using an electrocoagulation technique or method to process POME from the second aerobic pond effluent in PT Syaukat Sejahtera, Bireuen, Aceh, Indonesia.

Electrocoagulation uses aluminum and iron electrodes because they have good coagulant property, and they are non-toxic, effective, cheap, and easy to procure. Iron electrodes are washed with distilled water prior to implementation to dispose impurities, such as oil and pollutants. The method is electrolysis by oxidation and reduction, when the electric current flows into an electrolyte solution (Kuokkanen et al., 2013), which is helpful because the equipment is simple, easy to run, low energy, and relatively low cost. Electrocoagulation can also neutralize a large pH, purify wastewater content, and precipitate the smallest colloid. Furthermore, electrocoagulation treats textile dyes, heavy metals, oil, and organic compounds in wastewater. This method is reliable, effective, simple, and friendly, as a result of no added chemicals. The method is extremely physical, but more economical because the little electricity is used. The advantage and efficiency make it possible to achieve optimum results by decreasing the response on a larger scale. This reduction of COD, TDS, and TSS by electrocoagulation, using iron as an electrode, is highly attractive for researchers to investigate. This study aims to determine the optimum conditions for reducing COD, TSS, and TDS.

Studies on the use of electrocoagulation to produce safer POME have been conducted to treat industrial textile wastewater containing Direct Red 81. Factors that influence electrocoagulation include time, voltage, electrode type, inter-electrode distance, and electrolyte concentration. Studies have shown that higher voltage and time increase COD, TSS, and TDS reduction. A few researchers focused on electrocoagulation to achieve more effective voltage, time, and electrolyte concentrations. However, few studies have focused on the effect that voltage, time, and electrolyte concentration have on these reductions. Furthermore, the previous research has not investigated the optimum voltage, time, and electrolyte concentrations to reduce COD, TSS, and TDS simultaneously using the response surface methodology (RSM). The present study, therefore, investigates the effects of the optimum time, voltage, and NaCl concentrations on POME COD, TSS, and TDS reduction from a second aerobic pond utilizing RSM.

Without RSM, research would be ineffective because it would require repetition, a higher price, and a longer time. Optimization uses many response surface designs, such as the Doehlert and the Box-Behnken design (BBD). Research took place randomly to diminish the error systematically. The BBD was appropriate because it uses a formula that consists of a simple combination. The resulting design was extremely effective in deciding the amount of research that should be carried out. The present study investigated the optimal electrocoagulation method for iron electrodes as well as the time, voltage, and electrolyte concentrations for reducing pollutants of COD, TSS, and TDS. It employed an electrolyte to guide the flow of ions from the POME by adding sodium chloride to stimulate electrical current. This study focused on wastewater disposal in the environment without passing a primary treatment. The method could be a POME-processing alternative with more economical, simple, and friendly properties than other POME processes. The study's results are expected to be a reference for investigations that focus on wastewater processing techniques, specifically the POME process.

2. METHODS

2.1. Materials

The POME came from the second aerobic pond effluent in PT. Syaukat Sejahtera, Bireuen, Aceh, Indonesia. This treatment was used in the first and the second sedimentation ponds before being discharged. This study used dimethyl ether ($\geq$ 99.9%, Merck), sodium chloride (99%, Merck), sulfuric acid (97%, Merck), silver sulfate ($\geq$ 99.99%, Merck), and distilled water from a distributor in Banda Aceh. The sample required preservation using sulfuric acid until a pH of < 2 and cooling at $4^oC \pm 2^oC$ was achieved. This preservation inhibited microorganisms from maintaining the initial COD; thus, the wastewater was able to endure and be used for a longer time, namely, 28 days. The electrocoagulation used a glass reactor ($14\times12\times15$ cm^3) and two pairs of Fe electrodes ($12\times10\times0.2$ cm^3) with a purity of 99%. The reactor contained the cleaned electrodes.

2.2. The Procedure

The Fe electrodes were washed with distilled water, dried using a tissue, immersed in 0.1 liter of hydrochloric acid (35%) for approximately 5 minutes, and rinsed in acetone. The water washed the electrodes, and sandpaper refined them to wash out impurities, such as oil, and to make them clean and ready for use. Each study used 1.5 liters of wastewater in a reactor equipped with a power supply to set the determined voltage and current. The room temperature became the maintained operating temperature. The TSS, COD, and TDS (Total Dissolved Solid) contents were analyzed before and after the treatments at every variable (Figure 1). RSM optimized the COD, TDS, and TSS removal using BBD with a time of 15–45 minutes (A), a voltage of 10–20 volts (B), and a NaCl concentration of 0.0–1.0 M (C). The Design-Expert 10.0.1 software was used, resulting in only 17 treatment times (Table 2). Such a design optimized the electrocoagulation using the quadratic equation, as shown in Equation 1.

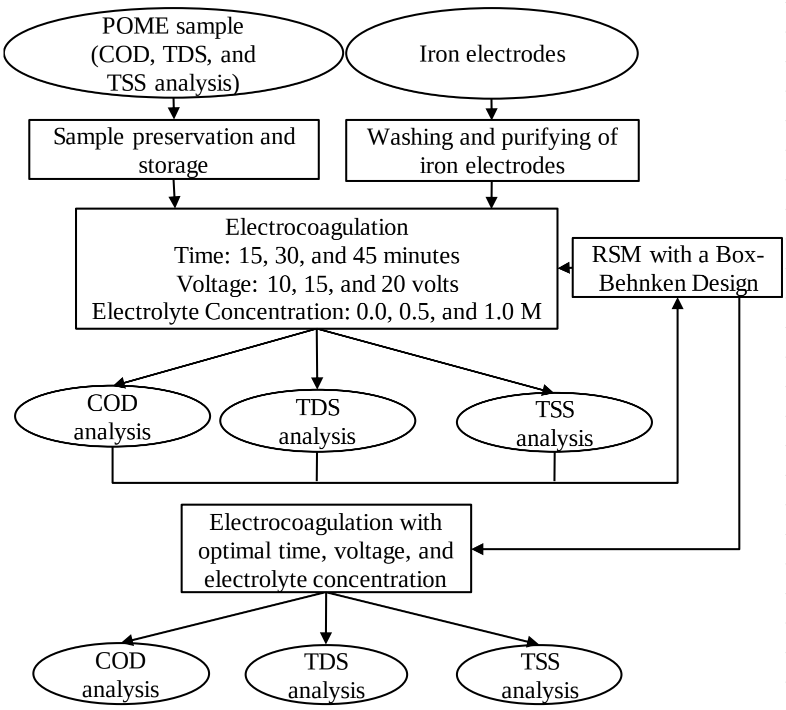


Figure 1 Diagram of the electrocoagulation sequence

$$y = \alpha_0 + \Sigma\, \alpha_i x_i + \Sigma\, \alpha_{ii} x_i^2 + \Sigma\, \alpha_{ij} x_i x_j \quad (1)$$

Here, y was the response, α_0 was the intercept, and α_i, α_{ii}, and α_{ij} were the linear, square, and interaction effects, respectively. The desirable response was located by simultaneous variation, with the model significance and the coefficients determined by analysis of variance (ANOVA).

2.3. Parameter Analysis

The COD in the POME was analyzed with a close reflux by using a V-630 UV-VIS spectrophotometer. The sample was diluted before testing. $Cr_2O_7^{2-}$ oxidized the compound in close reflux to generate Cr^{3+} (SNI 6989.2:2009). The required oxidant appeared as an oxygen equivalent (O_2 mg/L), measured by a spectrophotometer in the wavelength of 600 nm. Meanwhile, TDS analysis used a sample of 100 ml, stirred until homogeneous and placed into a filter equipped with filter paper (SNI 06-6989.27:2005) and a suction pump. The suction was continued for about three minutes after completing the filtration. A constant weight cup retained the results, including 10 mL of distilled water, used for flushing the paper three times. A steam bath evaporated the filtered results until dry, and the cup containing the solids was heated in an oven at 180°C for one hour. The cup was taken outside using nippers, left in an exicator, and weighed. The cooling took place until the weight was constant, and the TDS was calculated.

TSS analysis used the gravimetric method (SNI 06-6989.3-2004) without measuring the floating material, volatile matter, or salt-decomposition. The sample of 100 ml was stirred beforehand to achieve a more homogeneous test. An oven heated a filter paper at a temperature of 100ºC±3ºC until its weight loss was less than 0.5 mg. Then, a vacuum filter filtered the sample by using a weighed filter paper, wetted with a little water. An oven dried the residue filtered at 100ºC±5ºC, and an exicator cooled the filter paper before being weighed until the weight was constant. The TSS was measured using the following equation.

$$\frac{mg\ TSS}{liter} = \frac{(A-B)\times 1000}{volume\ of\ the\ sample\ (ml),} \quad (2)$$

where A was the weight of the paper and the residue (mg), and B was the paper's weight (mg).

3. RESULTS AND DISCUSSION

3.1. Preserved Wastewater

Liquid waste processed in this study came from the second aerobic pond effluent (Table 1). The COD showed the organic matter (dissolved, suspended) of the biodegradable or non-biodegradable POME. The pH was initially neutral, but the COD and TSS in the second aerobic pond were above the POME standard of 350 mg/l of COD and 250 mg/l of TSS (Permen LH No. 5, 2014). The initial COD was lower than the common COD range because the POME was from the second pond, which was previously treated in the first aerobic pond.

In this POME, the dissolved organic matter composition was lesser than the suspended matter. In this pond, the organic matter was destabilized by a coagulant and an electrical field. The physical bonds between the organic molecules were broken, adsorbed by a coagulant, and precipitated. The resulting hydrogen and oxygen made the organic and dissolved material float. It included hydroxide flocs that caught organic waste that was not deposited on the cathode, as floating flocs may precipitate if they are heavy enough.

A BBD can determine the effects of the voltage, time, and NaCl concentration on the reduction efficiency of COD, TSS, and TSS.

Table 1 The initial characteristics of the preserved POME before electrocoagulation

No	Parameter	Without H_2SO_4	With H_2SO_4
1	pH	7.27	2.00
2	TDS (mg/L)	900–2000	900–1011
3	TSS (mg/L)	4000–5000	4000–4720
4	COD (mg/L)	8000–12000	6000–9000
5	Turbidity (NTU)	942–1022	3445–4868
6	Color	Blackish-brown	Blackish-brown
7	Odor	Bad smell	Bad smell
8	Temperature	±45°C	18–30.2°C

It proposes a model to describe their correlation by considering the interaction effects and controlling the reduction efficiency in different conditions. The tendency to influence the reduction of every case was investigated using a response surface. The optimum condition determination was useful for technical necessity. COD, TSS, and TDS reduction in this study and the predictions appear in the Table 2. The lowest reduction of COD was 72.85%, with 0.5 M of NaCl, 15 minutes, and 10 V (run 13). The greatest reduction of COD was 95.01%, with the same NaCl concentration, 45 minutes, and 20 V. This occurred because of the relatively short-contact time and the higher voltage applied. It appeared that the longer the time and the larger the voltage applied, the greater the COD removal. This reduction shows the decrease of an organic compound, or the oxygen needed to oxidize it. This fits the double layer theory, where the positive charge coagulant adsorbs negative ions. As positive and negative charges meet, the Van der Waals force among the ions forms a bond. They form a coagulant and flocs to adsorb the organic compounds in the waste. Therefore, the electrocoagulation is a physical process that reduces pollutants, such as solids.

The highest TSS reduction was 97.27%, with a voltage of 20 V, a time of 30 minutes, and without sodium chloride (run 3 in Table 2). This TSS fulfilled the Permen LH No. 5/2014 standard (declining from 4,720 mg/l to 130 mg/l). The TSS decreased to around 4% in 30 minutes, with 20 V and a 1.0 M condition. This showed that the higher NaCl concentration made the reduction smaller. The higher NaCl concentration (1.0 M) had higher levels of electrical conduction to accelerate the colloidal floc bond in the electrodes. The electrolysis reaction in these combined plates of Fe-Fe was $2H_2O + Fe \rightarrow H_2 + 2Fe(OH)_2$.

Table 2 Percentages of COD, TSS, and TDS reduction after electrocoagulation

Run	Time (minutes)	Voltage (V)	NaCl (M)	% COD		% TSS		% TDS	
				Exp.	Est.	Exp.	Est.	Exp.	Est.
1	30	15	0.5	88.28	88.07	96.33	95.26	34.92	37.49
2	30	10	0.0	78.10	79.20	89.10	89.20	26.81	30.20
3	**30**	**20**	**0.0**	91.27	90.76	**97.27**	**97.50**	**44.11**	**41.98**
4	30	15	0.5	89.08	88.07	95.34	95.26	38.18	37.49
5	30	15	0.5	87.75	88.07	96.78	95.26	43.22	37.49
6	30	10	1.0	84.80	85.31	92.80	92.57	31.16	33.29
7	15	20	0.5	82.59	83.38	91.59	91.26	24.23	26.08
8	45	10	0.5	89.64	88.85	92.64	92.97	36.31	34.46
9	45	15	0.0	90.59	90.27	95.55	95.12	39.66	38.12
10	30	15	0.5	86.46	88.07	94.08	95.26	39.07	37.49
11	45	15	1.0	92.87	93.15	90.87	90.77	30.56	30.28
12	**30**	**20**	**1.0**	93.20	92.10	**93.20**	**93.10**	40.85	37.46
13	**15**	**10**	**0.5**	**72.85**	**72.02**	**81.86**	**81.66**	**4.95**	**1.28**
14	15	15	0.0	75.05	74.78	85.05	85.15	14.34	14.62
15	30	15	0.5	88.78	88.07	93.75	95.26	32.05	37.49
16	15	15	1.0	79.03	79.35	88.03	88.46	19.49	21.03

At a particular time, the sample temperature of the electrocoagulation increased from 30.2ºC to 64ºC. It caused suspended solids to collide, break before forming flocs, and produce large TSS (the reduction decreased). Both reductions are better than TDS reduction. The highest TDS reduction was 44.11%, with a time of 30 minutes, 20 volts, and without the NaCl (Table 2). The lowest TDS reduction was 4.95%, with a time of 15 minutes, 10 V, and 0.5 M of NaCl (run 13). A longer time and concentration until a given time increased the reduction; then, it decreased. As the NaCl concentration was too large, some of the NaCl caused the TDS sample to increase.

NaCl can also inhibit the electrocoagulation process in degrading wastewater. Sodium chloride solution, as a supporting electrolyte, can be decomposed into Na^+ and Cl^-. When a reaction occurs in the Fe anode, it results in Fe^{2+}, which will bind the chloride ion to form $FeCl_2$. The other cause is the principle of the electrocoagulation, which is based on an electrolysis cell process. Every electrolysis cell has two electrodes, the cathode and the anode. The anode functions as a coagulant in the coagulation-flocculation process that occurs in the cells. At the cathode, a reaction forms hydrogen gas that raises flocs that are not precipitated. The reduction- oxidation mechanism simplicity in the plates of Fe-Fe combined is as follows:

$$\text{Anode: } Fe \rightleftharpoons Fe^{2+} + 2\,e^- \quad (3)$$

$$\text{Anode: } Fe^{2+} + 2\,OH^- \rightleftharpoons Fe(OH)_2 \quad (4)$$

$$\text{Cathode: } 2\,H_2O + 2\,e^- \rightleftharpoons H_2 + 2\,OH^- \quad (5)$$

$$\text{Total: } Fe + 2\,H_2O \rightleftharpoons Fe(OH)_{2(s)} + H_2. \quad (6)$$

3.2. The Statistical Model of the COD, TSS, and TDS

Based on the model analysis, the quadratic model showed conformity with the data. It was appropriate because the adjusted-R2 and the coefficient of the regression were higher than those of a cubical model. R2 is a ratio of the variance detected to the total variance. A cubical model and a linear model were not proper for the study data. The R2 for the COD, TSS, and TDS was 0.99, 0.97, and 0.92, respectively, at a confidence level of 95%. The large size of the regression coefficient was a measure of the model’s uniformity. The good uniformity of a model should result in a R2 of at least 0.8 (Aravind et al., 2014). This shows that the model assessed in this study could explain the reduction very well. The COD, TSS, and TDS percentages showed that the software predicted a response using equations (Tables 2–3). Equations 7–9 revealed a correlation among the COD, TSS, and TDS reductions and the three factors.

$$COD = 32.227 + 1.469\,A + 1.947\,B + 16.308\,C - 0.012\,A2 - 0.012\,B2 - 3.73\,C2 - 0.015\,AB - 0.057\,AC - 0.47\,BC \quad (7)$$

Table 3 ANOVA for the COD, TSS, and TDS of the POME with the quadratic model

Source	P-value Prob COD	P-value Prob TSS	P-value Prob TDS	Remark
Model	< 0.0001	0.0001	0.0036	Significant
A – Time	**< 0.0001**	**< 0.0001**	**0.0014**	
B – Voltage	**< 0.0001**	**0.0006**	**0.0410**	
C –NaCl concentration	0.0033	0.5147	0.8292	
A^2	0.0023	< 0.0001	0.0007	
B^2	0.6312	0.0462	0.2215	
C^2	0.1567	0.1246	0.6032	
AB	0.1130	0.0018	0.0074	
AC	0.5038	0.0088	0.1585	
BC	0.0885	0.0083	0.4272	
Lack of Fit	0.2783	0.9213	0.3875	Not significant

$$SS = 27.442 + 2.043\ A + 3.374\ B + 22.425\ C - 0.02\ A^2 - 0.05\ B^2 - 3.627\ C^2 - 0.035\ AB - 0.026\ AC - 0.777\ BC \quad (8)$$

$$TDS = 129.84 + 5.844\ A + 8.085\ B + 20.161\ C - 0.056\ A^2 - 0.118\ B^2 + 4.789\ C^2 - 0.112\ AB - 0.48\ AC - 0.76\ BC \quad (9)$$

3.3. Statistical Analysis

The results of the COD, TSS, TDS, and the estimation using the BBD appear in Table 2. The ANOVA decided the interaction significance between the factors and response variables. The test differentiated the average value of at least three groups of data by comparing the variance. Table 3 shows the ANOVA results of the model. The technique found the model and the significance using the Student's *t*-test, and it decided the regression coefficient significance by using a p-value. The value showed a more significant coefficient. The quadratic coefficients were time, voltage, and the NaCl concentration with a p-value less than 0.05. Those variables were significant and had an effect on COD, TSS, and TDS reduction. A value of 0.05 was suitable because most analyses use 0.05 as the cutoff for significance. As it was less than 0.05, it showed a significant difference. If it was higher than 0.05, a significant difference would not exist. The time (with p-values of < 0.0001 and 0.0014) and voltage (with p-values of < 0.0001, 0.0006, and 0.0410) had more influence on the POME than the NaCl concentration.

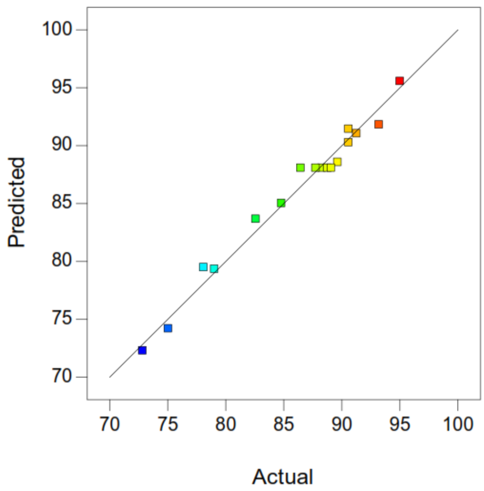
For the time and voltage, the coefficient in the quadratic term appeared extremely significant. This meant that these factors had a great influence on their removal efficiency. However, the effect of the NaCl was insignificant because the quadratic effect was extremely small. The effect showed that only the interactions between the time and voltage were significant for the TSS and TDS. This was because the size of the reaction zone increased as the voltage increased, and it increased the number of cavitations/the volume. As the capitation effect increased, more NaCl was decomposed, and it affected the optimum NaCl. As the amount of sodium chloride was too great, it was likely to cause a coagulant stabilization effect. The p-values for the lack of fit were above the value of 0.05, namely, 0.2783, 0.9213, and 0.3875. The insignificant lack of fit proved that the models and the COD, TSS, and TDS were compatible.

3.4. Optimization by Box-Behnken Design

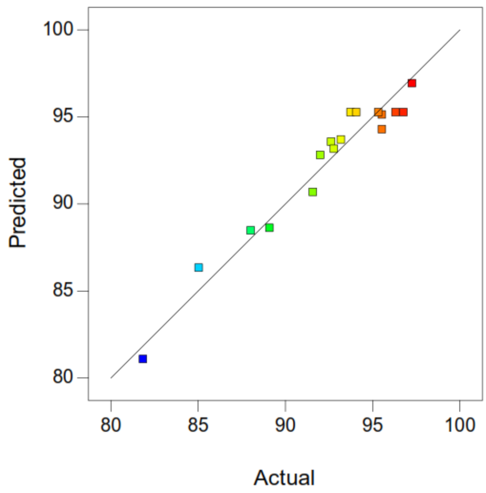
A model accuracy check is necessary to achieve an adequate model. The comparison between the experimental value and the predicted value determined the model accuracy. The study value and the predicted value of the electrocoagulation showed a linear relationship (Figure 2). This meant that the relationship was suitable to achieve an adequate model. The BBD included:

1. The design of research based on the selected condition;
2. Research statistically designed;
3. The predictions of the model coefficient and checking for the model's accuracy; and
4. Response analysis to estimate the optimum conditions and predictions through the research.

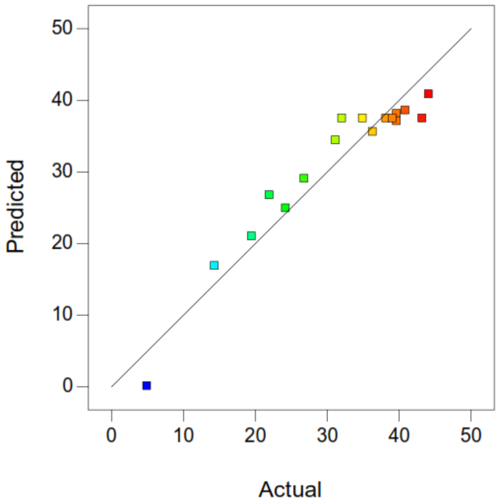
The relationship between the three variables and responses appeared in Figure 3. Three-dimensional and two-dimensional plot contours show the regression equations of the model. Every plot depicts the effect of two variables in a range, where the other variable is in a zero condition. The response surface drew the interaction of every influential variable concerning the COD, TSS, and TDS reduction. The contour form showed the characteristics of the interaction influences among the variables in response. The elliptical contour plot indicates the interactions among the variables that affect each other. A spherical plot shows that the variables' interactions are less influential regarding the COD, TSS, and TDS. Without NaCl, their reduction increases, namely, by 72.02–95.84%, 85.15–97.5%, and 14.62–41.98%. It is clear that variations in time and voltage caused an increase in degrading POME.



(a) COD



(b) TSS



(c) TDS

Figure 2 The relationship between the experimental value and the predicted value of the COD and TSS

Figure 3 indicates the time evolutions of TDS, TSS, and COD during the electrocoagulation of the POME. The best COD reduction occurred in a longer time and at a larger voltage. A high voltage eased the reaction; more coagulants bound impurities, such as N and NH_3, which caused the increase of COD in the POME. The longer time caused many coagulant and hydrogen gas bubbles to form and the COD content to decrease. It was evident that the optimum COD reduction was achieved at 37 minutes of electrocoagulation. The TSS removal also increased as the time increased in 15–37.5 minute intervals because the electrical current influenced the amount of Fe^{3+} produced from the electrodes. The dissolution of the iron increased at a high current, resulting in a larger amount of precipitate; moreover, the bubble rate increased and its size decreased with the increasing current. Then, TSS and TDS were reduced in a high time and voltage because the process did not reduce them anymore (Qiu et al., 2014). The removal of TSS was low during the first 15 minutes, and, after 37 minutes, it decreased because of the effect of NaCl on the coagulant stabilization. As NaCl entered the system, Na^+ was reduced into Na, and the removal increased. As $Fe(OH)_3$ sol grew, it adsorbed Na^+ and pushed each other.

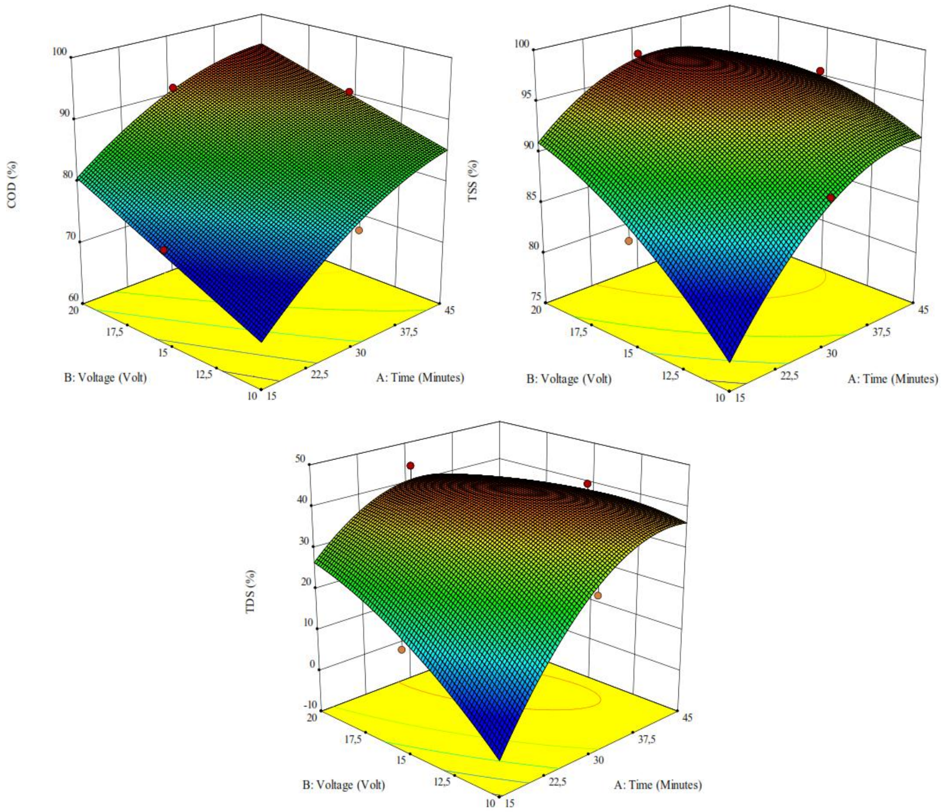


Figure 3 The effects of the voltage and time on COD, TSS, and TDS reduction without an electrolyte

Water reduction tended to occur more in the cathode compared to Na^+. Particles did not collide anymore, stopped growing, were not coagulated, and became stable. The Cl^- oxidation and H_2O reduction appeared in Equations 10 and 11:

$$2\,Cl^-_{(aq)} \rightarrow Cl_{2(aq)} + 2\,e^- \quad (10)$$

$$2\,H_2O_{(l)} + 2\,e^- \rightarrow H_{2(g)} + 2\,OH^-_{(aq)}. \quad (11)$$

The electrocoagulation achieved optimum time in 36.46 minutes using the NaCl solution. The percentage of TSS reduction declined with the decrease of the outset system voltage. The optimum voltage was 20 V while the electrocoagulation process degraded the POME. The efficiencies varied quadratically with voltage (Figure 3). Optimization occurred through determining the target from every expected response. The determined target was in the form of a range of particular values. Desirability showed a 0–1 value, with the higher value indicating the more optimum condition from the range analyzed. Some options were selected to achieve the most optimum reduction in degrading the POME. The results showed that the degradation occurred optimally without NaCl. The optimum COD, TSS, and TDS reductions were 93.12%, 97.70%, and 41.06%, respectively, at 37 minutes and 20 V, and without NaCl because the highest desirability was 0.945. This optimization was useful to achieve an optimum result from the electrocoagulation in the conditions. To confirm the optimum response validity, three tests were conducted in the conditions. COD, TDS, and TSS reductions from the study were 93.27%, 97.64%, and 40.78%, respectively. TSS met the national standard while COD did not, and TDS was not required per standard; however, the method was suitable for POME treatment.

4. CONCLUSION

Time and voltage were more influential in POME electrocoagulation than the electrolytes. A longer time and a higher voltage resulted in higher COD reduction, but not in higher TSS and

TDS reduction. As contact time is longer and the voltage is too high, the reduction of TSS and TDS is less. This study's electrocoagulation reduced the COD, TSS, and TDS from the second pond's effluent. The highest results obtained were 95.01%, 97.27%, and 44.11%, respectively. The TSS (130 mg/l) fulfilled the Permen LH No. 5 standard from 2014. The optimum conditions using BBD were comprised of 37 minutes, 20 V, and without the NaCl, resulting in COD, TSS, and TDS reductions of 93.12%, 97.70% and 41.06%, respectively. These values show that iron electrodes are well suited to this kind of electrocoagulation. Such conditions were implemented to treat the POME from the second pond effluent. Nevertheless, the COD did not meet the standard, TSS fulfilled it, and TDS was not required. Therefore, the optimization needs improvement, referring to other electrodes and the energy consumed.

5. ACKNOWLEDGEMENT

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