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OPTIMIZATION OF PHOSPHORUS AND MOISTURE CONTENT REMOVAL IN SLUDGE PALM OIL USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT. *Sludge Palm Oil is a waste oil produced by palm oil mill activities, but it has an appreciable amount of 0.6% to 0.7% of oil. This means a typical Palm oil mill that produces 3,857,143 tons/year of POME, may produce up to 27, 000 tons/year of SPO. However, this oil has high free fatty acid content (up to 80%), moisture and impurities (up to 3%) and phosphorus content of more than 20 ppm. To increase the quality of SPO, a pre-treatment of the refining process is needed, it includes degumming and bleaching processes. The aim of this research is to optimize the amount of phosphoric acid and bleaching earth added to remove the phosphorus and moisture content via the degumming and bleaching processes. The Response Surface Methodology suggested 20 experiments. The amount of phosphoric acid (0.05wt.% to 2.00wt.%) and bleaching earth (0.05wt.% to 2.0 wt.%) varied. The optimal refining conditions were acid degumming at 75℃ for 50 min, water degumming with 1 litre of hot distilled water at 100℃ for 30 min and bleaching at 80℃ for 1 hour. The interactive effect of the independent variables on the removal of phosphorus content in Sludge Palm oil was investigated using a 3D surface plot. At an initial FFA value of 40%, the highest experimental removal of phosphorus content was 76%, phosphoric acid dosage of 1.027wt.% and bleaching earth dosage of 1.68 wt.%. While the maximum percentage removal of moisture content was 96% phosphoric acid dosage 1.025 wt.% and bleaching earth dosage 1.25 wt.% at 55% initial FFA.*

KEYWORDS. Sludge palm oil, palm oil mill effluent, acid degumming, bleaching, Response Surface Methodology.

INTRODUCTION

In 2019, Malaysia has become the top global exporter of palm oil with 19.86 million metric tons of crude palm oil produced (Hirschmann, 2021). The Palm Oil Mill Effluent (POME) was produced from the palm oil mill activities as 1 ton of crude palm oil production required about 1.5 tons of water. According to Abdullah (2013), Palm Oil Mill Effluent (POME) has a residual oil content of 0.6% to 0.7%, the water content of 95% and a total solids content of 4% to 5%. About 27,000 Sludge Palm Oil (SPO) can be extracted from a typical Palm Oil mill that produces 3,857,143 tons/year of POME. The SPO can be found suspended on the top of POME after a certain time in the cooling pond (Muanruksa, 2019). SPO is a low-quality oil due to its high free fatty acid (up to 80%) (Abdullah, 2017), high moisture and impurities (up to 3%) and phosphorus content of more than 11 mg/kg (Ainie, 1995). Due to the high amount of FFA, the sludge palm oil has yellowish-brown colour and an unpleasant smell (Zuber, 2018).

The number of undesirable components in the SPO may vary depending on the place and duration of the oil exposure in the open ponds. Sludge Palm Oil can be refined by using a physical refining method and this solution has been proposed by Malaysia Palm Oil Board (Wafti, 2010). If refined, the SPO can be applied directly as boiler fuel, raw material for biodiesel, and replace 100% of palm fatty acid distillate in the soap making industry (Wafti, 2012). The SPO is purchased by third world countries at lower prices for making soaps, and fertilizer (Wafti, 2010). Due to the low quality of unrefined SPO, the third countries cannot directly use the oil as a raw material. Therefore, pre-treatment includes degumming and bleaching processes are needed to remove phosphorus and moisture content. Prior to deodorization, the specifications required of the degummed and bleached SPO are below 15 mg/kg phosphorus and below 1 wt.% moisture content (Hou, 2020).

Degumming, bleaching, and deodorization are traditionally part of the physical refining process (Wafti, 2019). In this study, two types of degumming were applied, including acid and water degumming to remove undesirable components, especially the phospholipid that affects the phosphorus level in oil. Combined water-acid degumming has high efficiency in the removal of phosphorus in the palm pressed fibre oil (PPFO). During the acid degumming process, phosphoric acid forms a precipitate with non-hydratable phosphatides components and water is needed for this process to dilute the acid. Water degumming can remove hydratable phosphatides in the oil by water hydration and this forms a product that is insoluble in oil. The degumming process would remove most of the hydrated gums leaving a small amount to almost no gums (Nieuwenhuyzen, 2008). Due to the lack of information on the value of phosphoric acid for degumming, the basis for this chemical was estimated based on the allowable volume in the refinery plant with the range 0.05 wt.% to 2.0 wt.% (Hou, 2020). Phosphoric acid below 0.05 wt.% will not be able to trap the impurities and above 2.0 wt.% the oil will become acidic. If the bleaching earth is used below 0.05 wt.%, the adsorption process does not occur.

Bleaching is a process to remove the colour of the substance, impurities pigment (chlorophylls), soaps, pro-oxidant metal, and products of decomposition of peroxide that are dissolved or in a colloidal suspension (Sampaio, 2015). There are several types of bleaching agents including activated carbon, acid-activated bleaching earth, and natural bleaching earth (Pohndorf, 2016). Acid activated bleaching earth (ABE) is used in this study. It has large pores that enable the adsorbate to reach the adsorption sites (Almeida, 2019). Although adsorption is used on an industrial scale for the bleaching of edible oils, the understanding of its thermodynamic properties is limited. One of the reasons for this lack of understanding is that the proposed adsorption is a multicomponent process, involving carotenes, phospholipids and metals removal (Silva, 2013).

The final stage in the physical refining method is the deodorization process. This process is used to remove the short-chain acids in the SPO oil which is known as FFA (Wafti, 2010). This study did not include deodorization but was focused on the removal of phosphorus and moisture content in SPO via degumming and bleaching processes. The phosphorus should be removed during the pre-treatment process because it may cause pipeline equipment fouling at high temperature processing (Wafti, 2019) and avoid colour fixation during the deodorization process (Gibon, 2007). While moisture present in palm oil needs to be removed because it can lead to hydrolysis and oxidation reactions in the refining process (Rohani, 2006).

Recently, industries that produce refined SPO face a processing problem. There is no supporting information on the refining of SPO with FFA more than 5%. The information needed is the specific amounts of phosphoric acid and bleaching earth as this would change with varying initial FFA content. In this study, a Response Surface Methodology (RSM) approach was used for the optimization of the process parameters for the removal of phosphorus and moisture content. To the best of our knowledge, no studies have been done on the optimization of process variables using an RSM approach for the removal of phosphorus and moisture content in SPO refining. Analysis of variance (ANOVA) which is used to determine the adequacy of the developed model revealed a good fit between the experimental data and the proposed model. The aim of this research is to optimize the amount of phosphoric acid and bleaching earth used in the removal of phosphorus and moisture content in the degumming and bleaching processes at varying initial FFA of the SPO.

METHODOLOGY

Chemical and Materials

Crude Sludge Palm Oil (SPO) samples were collected from the storage tanks of a Refining Palm Oil mill which is located at Lahad Datu, Sabah. Phosphoric acid 85% (Neylex), Sodium Hydroxide 0.1M (Merck), and Acid activated bleaching earth (Bleaching earth Taiko Supreme 1b) were obtained from the Asia Oil Products Sdn. Bhd.

Degumming and Bleaching Experiments

The Crude SPO was pre-treated by a combination of processes including acid degumming, washing, water degumming, bleaching, and filtration. For each run, 250 g of Crude SPO was pretreated via

degumming and bleaching processes. First, the SPO sample was heated to 75℃ in a conical flask with agitation using a magnetic stirrer at 900 rpm rotational speed. When the temperature reached 75℃, acid degumming was carried out for 50 minutes at constant rotational speed (900 rpm) by adding phosphoric acid based on the experimental design in the RSM (see Table 1. In this table, 1 wt% means 2.5g of phosphoric acid liquid or 2.5g of bleaching earth). After 50 minutes, the oil was washed with hot distilled water (100 ℃). 10 ml of oil and 10 ml of hot distilled water were added into the centrifuge tube and the washing process was carried out for 5 minutes at 3000 rpm using a centrifuge. Next, the water was separated from the oil sample using a separating funnel. Following that a three-step water degumming process was carried out. First, 300 ml of hot distilled water (100℃) was added and shaken in the separating funnel for 30 minutes, the mixture was left to separate, and the water was removed. The second step is a repetition of the first step. Thirdly 400 ml of hot distilled water was added instead of 300 and step 1 was repeated. Then, the oil was transferred into a conical flask, heated to 80℃ on a hot plate at 900 rpm rotational speed. After a temperature of 80℃ was reached, acid-activated bleaching earth was added based on the experimental design in the RSM (see Table 1) and this mixture was stirred (900 rpm) for an hour. The bleached mixture was then filtered by using Whatman filter paper and this filtration process was conducted on the furnace at temperature of 100℃ to prevent the oil from solidifying.

Experimental Design with Response Surface Methodology (RSM)

A Central Composite Design (CCD) experiment was used to model the removal of phosphorus and moisture content, using Design-Expert V12 (stat-Ease, USA). Three factors were used, namely initial FFA value (40%-70%), phosphoric acid dosage (0.05 wt.% to 2.00 wt.%), and bleaching earth dosage (0.05 wt.% to 2.00 wt.%) as independent variables. The response variable were the amount of phosphorus (mg/kg) and moisture content (wt.%). The type of CCD used in this work is the Central Composite Circumscribed (CCC). The CCC design creates a factorial design that uses values outside the limits. There will be a total of five points, three of which are within the limit and two outside of the limit. Therefore, certain tests were conducted in this study with the independent variables exceeding the limits. Based on the CCD approach, twenty experiments were proposed, as shown in Table 1.

Table 1. Set of number experimental work for degumming and bleaching processes

Run Order	FFA Content (%)	Bleaching Earth Dosage (wt.%)	Phosphoric Acid Dosage (wt.%)	FFA Category
1	70.0	0.50	2.000	C
2	55.0	1.25	0.000	B
3	70.0	2.00	2.000	C
4	55.0	1.25	1.025	B
5	55.0	1.25	1.250	B
6	70.0	0.50	0.050	C
7	55.0	1.25	1.025	B
8	70.0	2.00	0.050	C
9	55.0	1.25	1.025	B
10	55.0	0.00	1.025	B
11	29.8	1.25	1.025	A
12	80.2	1.25	1.025	C
13	55.0	1.25	1.025	B
14	55.0	2.51	1.025	B
15	40.0	0.50	2.000	A
16	40.0	0.50	0.050	A
17	40.0	2.00	0.050	A
18	40.0	2.00	2.000	A
19	55.0	1.25	2.665	B
20	55.0	1.25	1.025	B

Analysis of Oil

Free Fatty Acid (FFA), (%)

FFA content was determined according to PORAM Test methods (1995) by using titration methods. The results were expressed as the percentage of palmitic acid, %. The FFA content can be calculated using this formula:

$$FFA\ \% = \frac{25.6 \times N \times V}{W} \qquad \textit{(Equation 1)}$$

where N = normality of Sodium Hydroxide (NaOH) solution, V = volume of NaOH solution in ml, and W= weight of the sample.

Moisture Content, (wt.%)

The moisture content experiment will be conducted according to AOCS Recommended Practice Ca 2f-93 method. The moisture content can be calculated by using the equation below:

$$Moisture\ content\ \% = \frac{(m_1 + m_s) - m_2}{m_s} \times 100 \qquad \textit{(Equation 2)}$$

where m_1 = mass of the dish (g), m_2 = mass of the product (dish +sample), and m_s = mass of the sample.

Phosphorus Content, mg/kg

The phosphorus content in SPO before and after degumming and bleaching processes was measured using an Agilent 5800 ICP-OES, an inductively coupled plasma-optical emission spectrometry instrument. The ICP-OES is normally used by the palm oil industries for measuring the quality of the oil. It uses a vertically oriented plasma optimized for the robust, long-term analysis of samples with high solids content or organic matrix. This test was conducted by the Asia Oil Products Sdn Bhd Laboratory.

RESULTS AND DISCUSSION

Characteristics of Sludge Palm Oil

Table 2 below shows the characteristics of SPO used in this study. The SPO is characterized by its FFA content (between 30%-80%), moisture content (below 10 wt.%), and phosphorus content (> 20 mg/kg). It was found that the characteristics of SPO used in this study were within the range of SPO feedstocks studied by Ainie *et al*. (1995).

Table 2. Characteristics of Sludge Palm Oil

Free fatty acid, FFA %	Moisture content (wt.%)	Phosphorus content (mg/kg)
29.8	1.678	23.606
40	2.893	29.971
55	3.532	33.245
70	4.329	30.951
80	5.043	25.893

The SPO exists in the semisolid phase or solid phase at room temperature (30 ± 2 °C) due to its high percentage of saturated fatty acids and free fatty acids. Hence, SPO has higher pour and cloud points as compared to normal crude palm oil.

Assessment of Experimental Results with Response Surface Methodology (RSM)

A total of 20 experiments were conducted according to the CCD to determine the amount of phosphoric acid and bleaching earth by predicting the percentage removal of phosphorus and moisture content from SPO by varying three independent variables. For phosphorus and moisture removal, the effects of three independent variables were evaluated which are initial FFA value (40% to 70%), phosphoric acid (0.05 wt.% to 2.00 wt.%) and bleaching earth (0.05 wt.% to 2.00 wt.%). This work included experiments that exceeded the limit of the independent variables, i.e., initial FFA value 29.8% and 80%, phosphoric acid 0.0 wt.% and 2.665 wt.% and bleaching earth 0.0 wt.% and 2.665 wt.%. These experiments were used to see the performance of phosphoric acid and bleaching earth on the removal of phosphorus and moisture content at parameters that exceed the limits. The percentage removal of phosphorus and moisture content in SPO after degumming and bleaching processes were recorded. The RSM modelling produced two predicted-vs-actual graphs (Figure 1 (a) and Figure 1(b)) and six 3D response graphs (Figure 2 and Figure 3). It also produced two quadratic model correlations that best described the relationship between the removal of phosphorus and moisture content when the initial FFA, phosphoric acid and bleaching earth were varied. These quadratic correlation models are shown in the following equations:

$$Mass\ of\ phosphorus\ removed\left(\frac{mg}{kg}\right) = 11.18 + 1.75A - 1.83B + 1.54C - 0.1802AB + 0.9495AC - 0.7770BC - 1.67A^2 + 1.50B^2 + 2.56C^2 \quad \textit{(Equation 3)}$$

$$Percentage\ of\ moisture\ removed\ (wt.\%) = 0.1378 - 0.0250A - 0.6517B - 0.0603C - 0.0923AB + 0.0735AC - 0.0285BC - 0.0111A^2 + 0.6169B^2 + 0.0654C^2 \quad \textit{(Equation 4)}$$

Table 3. ANOVA response surface for quadratic model removal of phosphorus from SPO

Source	Sum of Squares	Mean Square	F-value	p-value
Model	299.52	33.28	22.84	0.0001
A-FFA	41.95	41.95	28.79	0.0003
B-B. E	45.35	45.35	31.12	0.0002
C-P. A	25.70	25.70	17.63	0.0018
AB	0.2599	0.2599	0.1784	0.6817
AC	7.21	7.21	4.95	0.0503
BC	4.83	4.83	3.31	0.0987
A^2	40.48	40.48	27.78	0.0004
B^2	32.31	32.31	22.17	0.0008
C^2	60.73	60.73	41.67	0.0001
Residual	14.57	1.46		
Lack of Fit	14.15	2.83	33.28	0.0008
Pure Error	0.4251	0.0850		

Table 4. ANOVA response surface for quadratic model removal of moisture from SPO

Source	Sum of Squares	Mean Square	F-value	p-value
Model	11.42	1.27	7.67	0.0019
A-FFA	0.0085	0.0085	0.0514	0.8251
B-B. E	5.78	5.78	34.93	0.0001
C-P. A	0.0395	0.0395	0.2389	0.6356
AB	0.0681	0.0681	0.4117	0.5355
AC	0.0432	0.0432	0.2613	0.6203
BC	0.0065	0.0065	0.0393	0.8468
A^2	0.0018	0.0018	0.0108	0.9194
B^2	5.44	5.44	32.92	0.0002
C^2	0.0394	0.0394	0.2385	0.6358
Residual	1.65	0.1654		
Lack of Fit	1.65	0.3298	347.23	0.0001
Pure Error	0.0047	0.0009		

The ANOVA F-test and p-values were used to evaluate the statistical significance of quadratic correlation models above. The statistical significance of the correlation model was suggested with a condition of greater F-value and low probability value which is below 0.05. If the p-value of the model is less than 0.05 (i.e., 95% confidence interval), the effect of the three independent variables on the response was statistically significant. Thus, based on Table 3 and Table 4, the three variables on the removal of phosphorus and moisture were significant since the p-values of the models were less than 0.05. The lack of fit F-value for the phosphorus removal from SPO was low (33.28), while removal of moisture was high (347.23). The phosphorus model shows a good reproducibility of experimental data, however the moisture content removal model was less reproducible. This was because the moisture model content removal model shown in Figure 1 (b), showed predicted and actual values spread out from the linear line. This is because the SPO sample was obtained from an actual sludge pond and the moisture content in the samples were not standard, there was a large variation of moisture content.

Based on the Predicted vs Actual graphs in Figure 1 (a) and Figure 1 (b), it was shown that the correlation for the moisture content is not as good as that for phosphorus content. However, we chose to further investigate the model generated to determine the optimal parameters as the coefficient of correlations were high for both models as shown in Table 5.

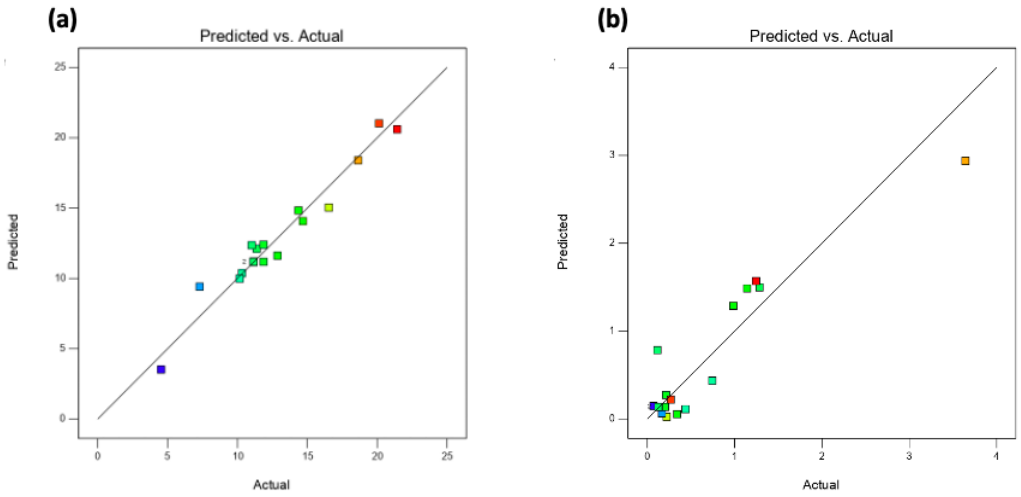

Figure 1. Experimental versus predicted the plot of correlation models for the removal of (a) phosphorus content (b) moisture content

Summary of Fit Statistics

Table 5. Fit Statistics (ANOVA) for Quadratic Models of Mass of Phosphorus Removed and Percentage of Moisture Removed

Model	R^2	Adjusted R^2	Predicted R^2	Adequate Precision (signal to noise ratio)
Mass of phosphorus removed	0.9536	0.9119	0.6079	20.5079
Percentage of moisture removed	0.8735	0.7596	-0.0995	10.1302

Table 5 shows the fit statistics (ANOVA) for the quadratic models of phosphorus and moisture content obtained from RSM. Based on this table, the quadratic model of phosphorus showed an R^2 value close to 1.0 (0.9536), which means the model fits the data. While the quadratic model of moisture content showed R^2 was 0.8735. Adequate precision is a signal-to-noise ratio which is a measure to indicate a better precision and reliability of the experiments. A value of more than 4 is desired to reflect adequate precision. In the present case, the ratio 20.5079 and 10.1302 indicates an adequate signal for models to be used effectively to navigate the design space.

Phosphorus Content Removal (mg/kg)

Table 6. Phosphoric acid and bleaching earth amounts that gave the highest percentage removal of phosphorus for 40%, 55% and 70% initial FFA

Percentage removal (%)	Initial FFA content (%)	Phosphorus content before degumming & bleaching (mg/kg)	phosphorus content after degumming & bleaching (mg/kg)	Phosphoric acid (wt.%)	Bleaching earth dosage (wt.%)
76	40	29.971	7.32	1.027	1.68
68	55	33.245	10.525	0.754	1.64
67	70	30.951	10.210	0.684	1.67

Table 6 shows the phosphoric acid and bleaching earth amounts that gave the highest percentage removal of phosphorus for 40%, 55% and 70% initial FFA. For all three conditions the final phosphorus content was below 15mg/kg which fulfilled the requirement for the pre deodorization treatment. The phosphorus content in the SPO is usually higher than 11 mg/kg (Ainie, 1995) before degumming and bleaching processes and thus it will significantly decrease when it is pre-treated with a considerable volume of phosphoric acid and bleaching earth. The phosphorus content in SPO does not depend on the initial FFA value. It is expected to be higher when too much phosphoric acid is added and bleaching earth with poor adsorption properties. Thus, it is important to know the optimum amount of phosphoric acid and bleaching earth. Figures 2(a), 2(b) and 2(c) show the effect of phosphoric acid and bleaching earth on the phosphorus content at initial FFA values of 40%, 55% and 70%. These figures have similar response surface forms. Based on these figures, all three response surfaces showed >60% phosphorus content decrease. This means the amount of phosphoric acid and bleaching earth within the range of 0.05 wt.% to 2.0 wt.% was suitable for removing the phosphorus in the SPO.

Figure 2(a) shows that as the amount of phosphoric acid was increased, the amount of phosphorus content increased which means the percentage removal was reduced. While an increase in

bleaching earth up to about 1.68 wt.% showed a decrease in phosphorus content (means a higher removal of phosphorus) and further increase of bleaching earth increased the phosphorus content. This implies that the performance varies depending on the amounts of phosphoric acid, and bleaching earth. The maximum removal of phosphorus content at 40% initial FFA was 76%, at 1.027wt.% phosphoric acid and 1.68 wt.% bleaching earth.

Figure 2(b) shows that the maximum removal of phosphorus content at 55% initial FFA was 68%, at 0.754 wt.% phosphoric acid and 1.64 wt.% bleaching earth. At 1.025 wt.% phosphoric acid and 0.0 wt.% bleaching earth, the removal of phosphorus after degumming and bleaching processes was 45%. This meant when no bleaching earth was added during the bleaching process, the percentage removal of phosphorus was affected, no adsorption of phosphorus by the bleaching earth.

Figure 2(c) shows that the maximum removal of phosphorus content at 70% initial FFA was 67%, at 0.684 wt.% phosphoric acid and 1.67 wt.% bleaching earth. Nevertheless, the percentage removal of phosphorus was below 50% two sets of points, i.e. for the amount of 2.0 wt.%, phosphoric acid and 0.5 wt.% bleaching earth and also for the amount of 0.5 wt.%, phosphoric acid and 2.0 wt.% bleaching earth. For these two points the phosphorus content cannot be efficiently reduced because the amount of phosphoric acid and bleaching earth were not optimum. The amount of phosphoric acid has a significant impact on the removal of phosphorus at 70% initial FFA. This could be due to the feed sample having a higher phospholipids value. As a result, a low phosphoric acid concentration was required to prevent phosphorus formation. This is because a high amount of phosphoric acid may lead to the greater formation of phosphorus during the degumming process, which cannot be decreased by bleaching clay treatment (Zschau, 1983). As seen in the value of phosphorus at 2.665 wt% phosphoric acid and 0 wt% bleaching earth.

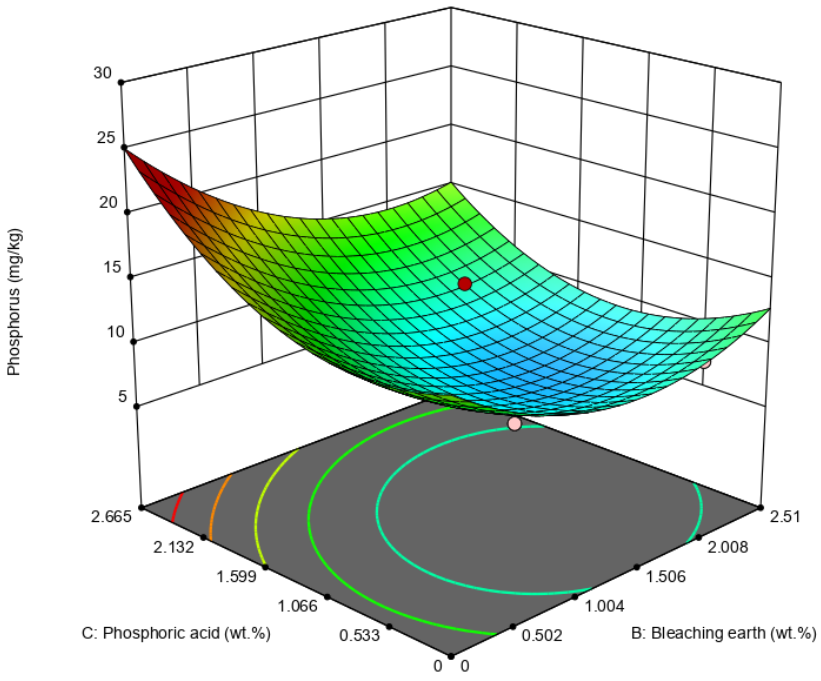

Figure 2 (a). The effect of varying phosphoric acid (wt.%) and bleaching earth (wt.%) amounts on phosphorus content at 40% initial FFA

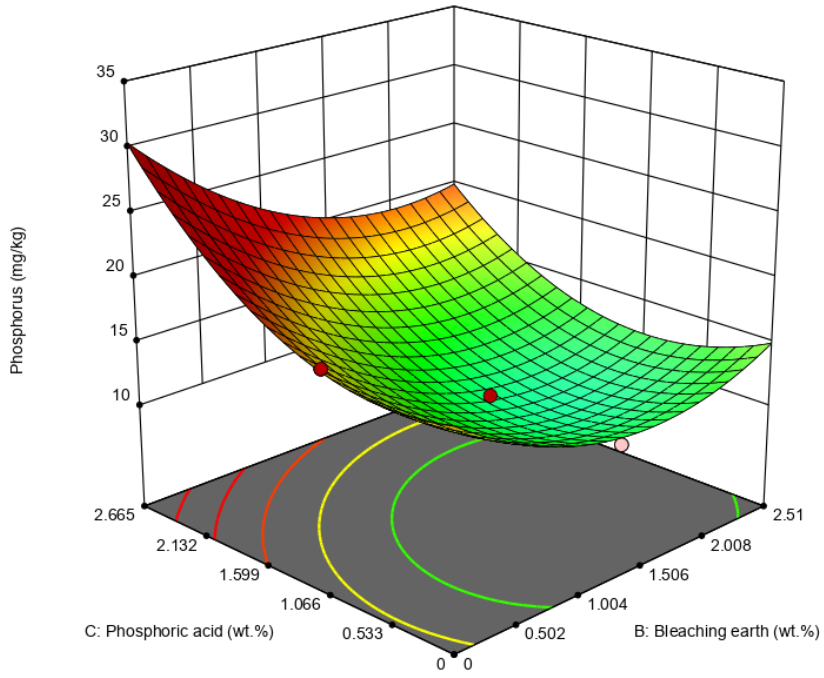

Figure 2 (b). The effect of varying phosphoric acid (wt.%) and bleaching earth (wt.%) amounts on phosphorus content at 55% initial FFA

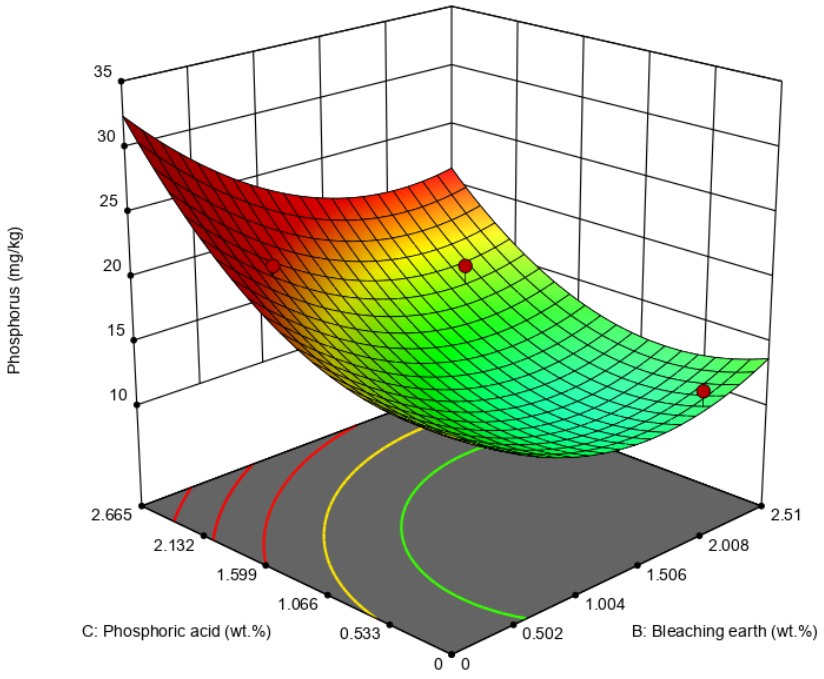

Figure 2 (c). The effect of varying phosphoric acid (wt.%) and bleaching earth (wt.%) amounts on phosphorus content at 70% initial FFA

Moisture content removal (wt.%)

Table 7. Phosphoric acid and bleaching earth amount that gave the highest percentage removal of moisture content for 40%, 55% and 70% initial FFA

Percentage removal (%)	Initial FFA content (%)	Moisture content before degumming & bleaching (wt.%)	Moisture content after degumming & bleaching (wt.%)	Phosphoric acid (wt.%)	Bleaching earth dosage (wt.%)
89	40	2.893	0.221	0.470	1.14
96	55	3.532	0.134	1.025	1.25
95	70	4.329	0.174	1.0	2.0

Table 7 shows the phosphoric acid and bleaching earth amounts that gave the highest percentage removal of moisture content for 40%, 55% and 70% initial FFA. For all three conditions the final moisture content was below 1 wt.% which fulfilled the requirement for the pre deodorization treatment. Figures 3(a), 3(b) and 3(c) revealed that the percentage removal of moisture content from SPO could achieve up to 96% after degumming and bleaching processes. From this study, we can observe that phosphoric acid had little effect on moisture removal, but the varying amount of bleaching earth had a large effect on the moisture content removal. For all three graphs, initially, the moisture content removed increased when treated with an increasing amount of bleaching earth until the optimum amount. But the further increase of bleaching earth resulted in a decrease in moisture content removal. This optimum amount was varied for different amounts of initial FFA.

Figure 3(a) shows that the maximum removal of phosphorus content at 40% initial FFA was 89%, at 0.470 wt.% phosphoric acid and 1.14 wt.% bleaching earth. The minimum percentage removal was 4%, at 1.05 wt.% phosphoric acid and 0.006 wt.% bleaching earth. This indicated a high volume of pore in bleaching earth which was sufficient for adsorption of moisture content in the SPO. Figure 3(b) shows that the maximum removal of phosphorus content at 55% initial FFA was 96%, at 1.025 wt.% phosphoric acid and 1.25 wt.% bleaching earth. At 0.0 wt.% of bleaching earth and 1.25 wt.% of phosphoric acid, the moisture content increased from 3.532 wt.% to 3.643 wt.%. This is because no adsorption occurred as water was not removed from the oil due to the absence of bleaching earth.

Figure 3(c) shows that the maximum removal of phosphorus content at 70% initial FFA was 95%, at 1.0 wt.% phosphoric acid and 2.0 wt.% bleaching earth. The minimum percentage removal of moisture content at 70% initial FFA is 23% at 2.66 w.t% phosphoric acid and 0.001 wt.% bleaching earth. This is because 0.001 wt.% of bleaching earth has less volume of pore and active site for adsorption compared to 2.0 wt.% of bleaching earth. Then, the high value of phosphoric acid contains a high amount of water, thus, the amount of bleaching earth was not sufficient to remove the moisture content.

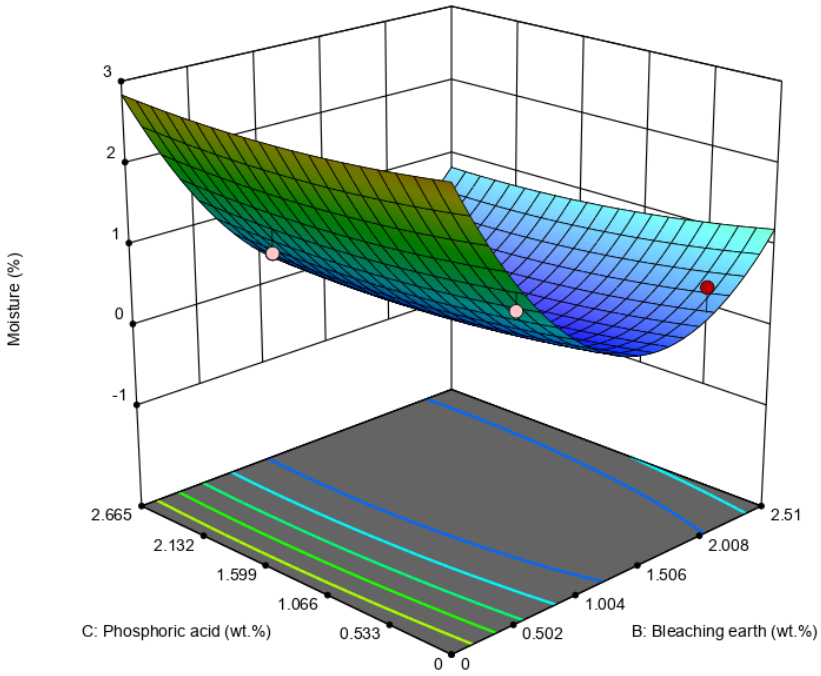

Figure 3. The effect of varying phosphoric acid (wt.%) and bleaching earth (wt.%) amounts on moisture content at 40% initial FFA

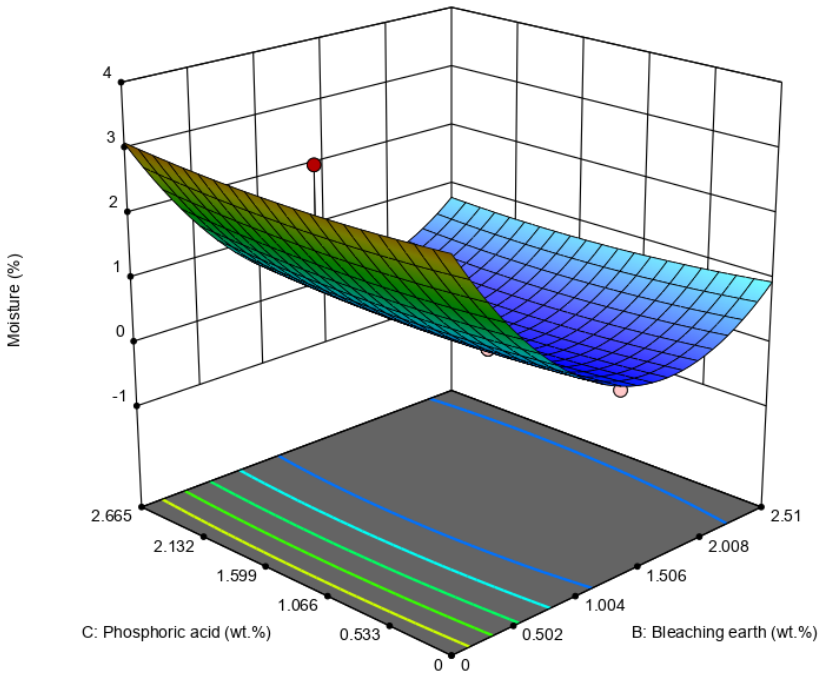

Figure 3(b). The effect of varying phosphoric acid (wt.%) and bleaching earth (wt.%) amounts on moisture content at 55% initial FFA

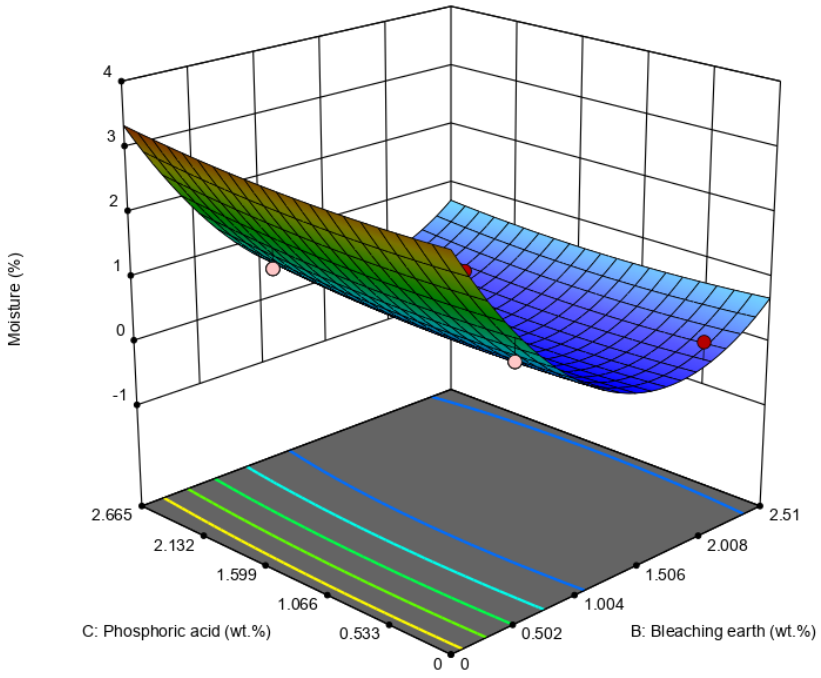

Figure 3(c). The effect of varying phosphoric acid (wt.%) and bleaching earth (wt.%) amounts on moisture content at 70% initial FFA

CONCLUSION

The amount of phosphoric acid and bleaching earth was successfully optimized by using RSM. The RSM design for quadratic models of phosphorus and moisture content removal was significant and the fit statistics showed that the models were adequate for prediction. This study developed two quadratic models to predict the removal of phosphorus and moisture content using CCD for varying initial amounts of FFA (40% to 70%) for degumming and bleaching processes. These models can be used to estimate the phosphoric acid and bleaching earth dosage at varying initial FFA content to obtain the highest phosphorus and moisture content removal percentage. These processes were a pre-treatment to deodorization of the SPO refining process. The deodorization required an inlet specification of <15 mg/kg phosphorus and <1 wt.% moisture content for optimum performance, which this study achieved. The phosphorus content decreased within the range 67% to 76% and moisture content decreased within 89% to 96% after degumming (0.05 wt.% to 2.0 wt.%), and bleaching (0.05 wt.% to 2.0 wt.%) process at initial FFA (40% to 70%). At 0.0 wt.% of bleaching earth dosage, the performance of removal phosphorus and moisture content was lower because there was no removal by adsorption.

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