International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.9, No.05 pp 758-770, 2016

Extraction of Oil from Jatropha Seed Kernels: Optimization and Characterization

Sulaiman Yahaya[1], Saidat Olanipekun Giwa[2]*, Maryam Ibrahim[3]and Abdulwahab Giwa[4]

[1,2,3]Chemical Engineering Department, Faculty of Engineering and Engineering Technology, Abubakar Tafawa Balewa University, Tafawa Balewa Way, Bauchi, Nigeria
[4]Chemical and Petroleum Engineering Department, College of Engineering, Afe Babalola University, KM. 8.5, Afe Babalola Way, Ado-Ekiti, Ekiti State, Nigeria

Abstract : In this work, optimization of Jatropha seed oil extraction has been carried out using solvent extraction method accomplished in a Soxhlet apparatus with the aid of Design Expert. The effects of three factors (particle size, extraction temperature and extraction time) on the percentage yield of oil obtained from the seed kernels were considered. Using the Box-Behnken design approach of response surface methodology (RSM), seventeen experimental runs were generated. With n-hexane as the solvent, each experimental run was carried out in 250 ml Soxhlet extraction apparatus. The results obtained from the experiments together with the factors considered during the experiments were modelled and analysed by choosing a cubic model. The results obtained from the analysis of variance of the model developed for the percentage of oil yield as a function of particle size, extraction temperature and extraction time revealed the good representation of the system by the model because its square of correlation coefficient (R-squared) value was found to be 0.9956. Also, it was discovered that the model and all its terms were significant because their probability values (p-values) were discovered to be less than 0.05 that was chosen based on 95% confidence level. Comparing the results obtained from the physical and chemical analysis of the extracted oil with the available standards in the literature, it was seen that the liquid extracted from the seed kernels was actually Jatropha oil. Finally, the optimization of the extraction process carried out indicated 61.52%of oil yield could be attained if the particle is 0.62 mm, the extraction temperature is 52.13^{o}C and the extraction time is 4.06 hr. An experiment carried out using the optimum conditions estimated gave an oil yield of 60.46%. Thus, it can be concluded that Box-Behnken design based RSM has been used successfully in optimizing Jatropha oil extraction.
Keywords: Jatropha seed oil, extraction, Box-Behnken, response surface methodology, Design Expert.

1.0 Introduction

Jatropha curcas is a poisonous, semi-evergreen shrub or small tree, reaching a height of up to 6m (approximately 20ft). It is a native of the Mexican tropics and have now dispersed and naturalized throughout the tropics of the whole world [1].

The names used to describe the plant vary per region or country. It is most commonly known as "physic nut". In Mali, it is known as "Pourghere". In Ivory Coast, it is known as "bagani". In Senegal, it is known as "tabanani". In Tanzania, it is known as "makaen"/mmbono" [2].

Jatropha plant can be used for different purposes. For example, it is used in the process of making cleaning fluids, dyes for clothes, organic fertilizer and as antidotes for snake bites as well as for other medicinal purposes. Each part of Jatropha plant such as its leaf,flower, fruit, bark, root and seed has its own uses,and that has made the plant a multipurpose type. The fact that Jatropha oil cannot be used for nutritional purposes because it is harmful to human body makes it very attractive as a source of fuel [3].Jatropha plant is associated with a type of seed that is oil-rich and the oil produced from the seeds is a very attractive feed stock for biofuel production. Jatropha kernel consists of about 47-50% oil, which can be transformed via esterification into biodiesel. The seed-oil of Jatropha is viscous in nature, and, apart from its use for biodiesel production that has already been mentioned, it can also be used for manufacture of candles and soap [4].

Different methods can be used to obtain Jatropha oil from its seeds, but the common methods used for the extraction of the oil include mechanical pressing, supercritical fluid extraction,and solvent extraction. Mechanical extraction is the most widely used method. However, the oil produced with this method is not always pure (that is, it isturbid) and contains significant amount of water, metals and dust contents that make it less suitable for biodiesel production. The extraction using solvent has several advantages over mechanical pressing especially in obtaining higher yield of oil that is less turbid. The oil obtained using solvent extraction method has a very suitable viscosity compared to fossil fuel [4].

Extraction of oil using solvents is the most effective method for oil recovery of almost 98%, especially with materials having low oil content. This method is not absolutely applicable tooilseeds with high oil content, like peanut and sunflower that require a prior step of pressing the seeds and then extracting oil from the cake produced using a solvent. When performed at low temperature, solvent extraction has another advantage over screw-pressing because it gives better quality of produced oil[5].

Moreover, solvent extraction involves the use of chemicals referred to as the solvents in the extraction of oil from oilseeds. It is known for its high yielding of oil output, easiness and swiftness to carry out, and it is relatively cost effective. The use of this method requires a complete refining process to ensure that traces of the solvents are removed totally from the oil in order to avoid contamination. [6]and[7] indicated that hexane, a petroleum-derived product had been extensively used as a solvent for oil extraction of some seeds because of its low vaporization temperature, high stability, low corrosiveness and low greasy residual effect [8].Generally, the process of solvent extraction can be considered in three parts: first is the change of phase of the solute as it dissolves in the solvent, secondis its diffusion through the solvent in the pores of the solid to the outside of the particle, and the thirdone is the transfer of the solute from the solution in contact with the particles to the main bulk [3].

If solvent extraction method is to be used to get oil from a plant seed, the values of the factors (input variables) affecting the extraction have to be carefully selected in order to get high yield of the oil, and the proper selection of these values can be achieved through optimization.

Optimization is defined as the process of finding the conditions that give minimum or maximum value of a function, where the function represents the effort required or the desired benefit.Nowadays, high-speed digital computers have made implementation of complex optimization procedures possible, and this has also stimulated further research on more novel methods of optimization [9]. For instance, the use of statistical software like Design Expert is gaining high ground when finding the optimum conditions for a process such as the extraction of oil from Jatropha seed.Before optimizing, the Design Expert is normally employed to design the experiments that are required to be carried out for the optimization through the use of methods like response surface methodology(RSM).

RSM is a widely used technology for rational experimental design and process optimization when the mechanistic information of the process is not available ([10], [11], [12]). RSM initiates from Design of Experiments (DoE) to determine the values of the factors to be used for conducting experiments and collecting data. The data are then used to develop an empirical model that relates the process response to the factors. Subsequently, the model facilitates the search for better process response, which is validated through

experiment(s). The above procedure is repeated until an optimal process is identified or the limit on experimental resources is reached ([13],[12]). RSM has seen diverse applications in almost every area of scientific research and engineering practiceincluding the development of chemical and biochemical processes ([14],[15],[16],[17],[18],[19],[20], [21],[12]).

In RSM, when all independent variables ($x_1, x_2, \ldots, x_k$) are measurable, manipulable and continuous in the experiments, with negligible error, the response surface y is expressed as:

$$y = f(x_1, x_2, \ldots, x_k) + \varepsilon \quad (1)$$

where the form of the true response function f is unknown and perhaps very complicated, and ε is a term that represents other sources of variability not accounted for in f. Usually, ε includes effects such as measurement error on the response, background noise, effects of other variables and so on. ε is usually treated as a statistical error, it is often assumed to have a normal distribution with mean zero and variance ε^2([22],[23]).

From the information obtained from the literature, it was discovered that [24] carried out statistical optimization of oil extraction from *Jatropha curcas* kernel using Box-Behnken design of response surface methodology (RSM). The results they obtained revealed that oil yield of 63 wt% could be obtained using solvent to kernel ratio of 15:1, extraction time of 4.4 hr and reaction temperature of 47 ^oC with fixed stirring rate of 200 rpm.[25]found the optimum conditions for the extraction of oil from Jatropha seeds and obtained that extraction time of 8 hr, temperature of 68 °C, coarse particle size of 0.5-0.75 mm and hexane to seed ratio of 6:1 could give a yield of 47.3% of oil.[26]carried out optimization of Jatropha seed using D-optimal design of the response surface methodology. The results they obtained indicated that 1.75 M ethanolic KOH, temperature of 65 ^oC and 2 hr reaction time were the conditions required to obtain optimum oil yield. Other researchers that worked on statistical investigation of effects of solvent composition, ratio, temperature, and extraction time include [4] and[27]. As can be observed, most of the researches have concentrated on factors other than particle size for Jatropha oil extractions, it isdeemed necessary to further investigate the extraction of oil from Jatropha seeds so as to gain knowledge into the how variation of particle size together with other factors can improve oil extraction.

Therefore, this work has been carried out to find the optimum values for particle size, temperature and time required for the extraction of oil from Jatropha seeds by taking the objective function of the optimization to be the percentage yield of oil obtained. Furthermore, the obtained oil has been analysed so as to know its chemical and physical characteristics in order to be sure that the liquid obtained from the seeds was actually the expected oil with negligible contamination as a result of the solvent used.

2.0 Methodology

2.1 Seed Preparation

Jatropha curcas seeds(Figure 1) used in this study were obtained from Yelwan Makaranta Market of Bauchi in Bauchi State of Nigeria. After the seeds were obtained, they were cracked and their shells were carefully removed to obtain the kernels (see Figure 2). Thereafter, they were dried at 30 ^oC until their moisture content became constant after which they were ground and sieved to get three particle size classes, which were below 0.6mm (powder size), 0.89mm (coarse size) and 1.18mm.

Figure 1: Jatropha seeds

Figure 2: Jatropha kernel

2.2 Experimental Design

The design of the experiments carried out in this work was based on the fact that oil yield and its properties are functionally related to three factors: particle size, extraction time and extraction temperature.The experiments to be carried out were designed with the aid of Design Expert 7.0.0 [28] using the Box-Behnkenapproach of Response Surface Methodology (RSM).The maximum and the minimum levels used for the factors considered were as given in Table 1. Using the levels of the three factors given in Table 1, the design of experiment gave seventeen (17) runs to be carried out.

Table 1. Minimum and maximum levels of the experimental factors

Variable	Unit	Minimum	Maximum
Size (A)	mm	0.60	1.18
Temperature (B)	^{o}C	40.00	70.00
Time (C)	hr.	4.00	8.00

2.3 Extraction Procedure

For each experiment carried out for the oil extraction, 10 g of ground Jatropha seed (Figure 3) was wrapped in a filter paper and placed inside the thimble chamber of the 250 ml Soxhlet extractor shown in Figure 4. A round bottom flask containing n-hexane as well as a condenser was fixed to the extractor. 150ml of n-hexane was measured and poured into each of the tied Jatropha seed samples with a foil used to cover the flasks to avoid evaporation of the solvent (n-hexane). Cool water flowing through the condenser was used to condense the evaporating solvent back into the Soxhlet extractor where the sample was packed to ensure sufficient extraction of the oil from the seeds. After a specified time, the mixture of the n-hexane and the extracted oil was

separated from the solid chaff and the n-hexane was removed from the extracted oil by gently heating off the mixture to evaporate the solvent. At the end of each experiment, the yield of the oil was obtained as the percentage of the extract from the seed using Equation (2). The cake obtained after the extraction can be seen to be different from the initial material (shown in Figure 3) used, and the cake is shown in Figure 5.

$$\%\ oil\ yield = \frac{weight\ of\ oil\ extracted\,(g)}{weight\ of\ seed\ sample\ used\,(g)} X\ 100 \qquad (2)$$

Figure 3: Ground Jatropha seed sample

Figure 4: Soxhlet apparatus setup used for the oil extraction

Figure 5: The cake remaining after the oil extraction

2.4Statistical Analysis,Optimizationand Validation

After obtaining the oil yield given by each of the experiments, their valueswere entered into the appropriate column in Design Expert, and the response together with the input values considered were analysed, and a cubic model relating the percentage oil yield to the input variables considered were developed for the extraction. Using the model, a numerical optimization was carried out and the values of the three input variables required to give optimum oil yield were obtained. In maximizing the response using the developed cubic model, the goals of all the factors were "in range" while that of the response (percentage oil yield) was set to "maximize".The validation of optimum conditions found, was achieved by carrying out an extraction experiment at a selected set of optimum values of particle size, extraction temperature and time given by RSM.

2.5 Determination of the Chemical Propertiesof the Oil

2.5.1 Determination of iodine value

Several methods are available for iodine value determination, but Hanus method (Association of Analytic Chemists) was used in this work for the determination, and its procedures that were adopted are as described thus.

0.01 g of oil was placed in a 250ml conical flask; 1ml of anhydrous chloroform was added to the flask, followed by 3ml of Hanus solution and the flask was covered with a flask stopper. Then, the content was mixed and placed in a drawer for exactly 30 minutes after which potassium iodide solution (1ml of 15% w/v) was added to the flask in order to wash down any iodide that might be found on the stopper. The solution was then titrated against 0.14M Na_2SO_3 until it became light yellow, which was achieved by the addition of 2 ml of starch indicator. A blank determination was carried out under the same conditions. The titre values were recorded, and the iodine value was calculated using the relationship (Equation 3) that is given as:

$$Iodine\ \ Value = \frac{(B-R)\times Molarity\ of\ Na_2SO_3 \times 12.69}{Weight\ of\ sample} \qquad (3)$$

where B is thetitre value of the blank (distilled water) and R is the titre value of the real solution.

2.5.2 Determination of free fatty acid (FFA)

2g of oil was placed in a 250ml conical flask and warmed. Thereafter, 2.5 ml of methanol was added and stirred thoroughly, followed by addition of two drops of phenolphthalein indicator and a drop of 0.14M of sodium hydroxide solution. The content was then titrated against 0.14 M sodium hydroxide solution while shaking vigorously until a permanent light pink colour, which persisted for one minute, was observed. The end point was recorded. The FFA value was calculated using Equation (4).

$$\%FFA = \frac{Titre \times N \times 28.2}{Weight\ of\ sample} \tag{4}$$

where N = Molarity of base

2.5.3 Determination of acid value

The method used for this determination was the same as that used for the determination of free fatty acid (FFA) only that the acid value was estimated using the expression given in Equation (5).

$$Acid\ Value = \%FFA \times 1.99 \tag{5}$$

2.5.4 Determination of peroxide value (PV)

To determine the peroxide value of the oil, 0.1g of it was placed in a 250ml conical flask and 3ml glacial acetic acid/chloroform (3:2 v/v) was added. The content was shaken until homogenous solution was obtained. Saturated 0.1 ml of potassium iodide solution was added followed by the addition of 0.1ml starch indicator solution. The mixture was then titrated against 0.1M $Na_2S_2O_3$, until the disappearance of dark blue colourthat was formed, to obtain the titre value of the mixture (S). Blank determination was also carried out without adding oil to obtain the titre value of the blank (B), and the peroxide value was calculated using Equation (6).

$$Peroxide\ Value = \frac{(S - B) \times Molarity\ of\ Na_2SO_3}{Weight\ of\ sample} \tag{6}$$

2.6 Determination of the Physical Properties of the Oil

2.6.1 Determination of cloud point

The cloud point is defined as the highest temperature at which an oil type begins to solidify. In order to determine this for the oil extracted in this work, a little quantity of it (the oil) was placed in a test tube and the entire content was put on an ice bath with a fixed thermometer. The temperature at which the oil began to condense was then recorded as the cloud point.

2.6.2 Determination of pour point

In determining the pour point of the extracted Jatropha oil, a manual method was used by cooling the oil inside a bath to allow formation of paraffin wax crystals. At about 9°C above the expected pour point, and for every subsequent 3°C, the test tube was removed and tilted to check for surface movement. When the specimen did not flow when tilted, the test tube was held horizontally for 5 s and 3°C was added to the corresponding temperature, and the resultthereby obtained was recorded as the pour point temperature of the oil.

2.6.3 Density determination

To determine the density of the oil extracted, the weight of a small beaker was determined using an electronic weighing balance. 1 ml of the oil was poured into it and the weight was noted. The mass of the 1 ml oil poured into the beaker was determined by taking the difference in the mass measurements. Then, the density of the oil was calculated using Equation (7).

$$Density = \frac{Mass\ of\ oil}{Volume\ of\ oil\ \ weighed} \quad (7)$$

2.6.4 Viscosity determination

In order to determine the viscosity, which is a measure of resistance to flow, of the oil extracted, a digital electronic viscometer was employed. The electronic viscometer normally measures fluid viscosity at a given share rate. The principle of operation of the digital electronic viscometer used was to rotate a spindle (which was immersed in the test oil) through a calibrated spring and, then, measuring the viscous drag of the fluid against the spindle deflection by the spring deflection. Spring deflection was measured with a rotary transducer, which provided a torque signal. The measurement range of the digital electronic viscometer was determined by the rotational speed of the spindle, the size and the shape of the spindle rotating, and the full-scale torque of the calibrated spring.

2.6.5 Determination of flash point

An improvised method was used to determine the flash point of the extracted oil. In doing this, a 50 ml conical flask was filled with 1 ml of the oil and heated at alow constant rate on a hot plate. The flash point was obtained when the application of a test flame caused the vapour above the oil to ignite.

3.0 Results And Discussion

Shown in Table 2 are the values obtained for each of the factors (particle size, extraction temperature and extraction time) considered in this work for the extraction of oil from Jatropha seeds. As can be seen from the table, a set of seventeen (17) experiments were designed and carried out.The responses obtained from the runs, which was the percentage yield of oil obtained, are also given in the table.

Table 2: The Box-Behnken experimental design matrix and responses

Run	Particle size, (mm)	Temperature(^{o}C)	Extraction time (hr)	Oil yield (%)
1	0.60	40.00	6.00	29
2	0.89	55.00	6.00	57
3	0.89	55.00	6.00	56
4	0.89	55.00	6.00	53
5	0.89	70.00	4.00	25
6	1.18	40.00	6.00	55
7	1.18	70.00	6.00	55
8	1.18	55.00	4.00	36
9	0.89	70.00	8.00	61
10	0.89	40.00	8.00	53
11	0.89	55.00	6.00	55
12	0.89	40.00	4.00	51
13	0.60	55.00	4.00	61
14	0.60	55.00	8.00	36
15	0.60	70.00	6.00	38
16	1.18	55.00	8.00	51
17	0.89	55.00	6.00	55

As shown in Table 2, the results obtained revealed that variation of particle size, temperature and extraction time were mutually affecting the Jatropha oil yield.

After analysing the results obtained from the experiments, a model equation was developed for the extraction process. The model obtained using the results of the experiments designed with Box-Behnken

methodology is given in Equation (8). The model equation was obtained to describe the relationship between the factors considered, that is, the input variables, and the response, that is, the output variable that was the percentage yield of oil given, in terms of the actual factors of the process. In Equation (8), A, B and C are particle size, extraction temperature and extraction time, respectively.

$$\begin{aligned} \%Yield = {} & -734.5102 + 662.4052A + 34.6504B - 16.8365C - 22.8544AB + \cdots \\ & \cdots + 17.2414AC - 1.3000BC - 74.0190A^2 - 0.3617B^2 + \cdots \\ & \cdots + 5.4437C^2 + 0.2031AB^2 + 0.0267B^2C - 0.1125BC^2 \end{aligned} \quad (8)$$

Table 3: Analysis of variance (ANOVA) table of the developed model

Source	Sum of squares	df	Mean square	F value	p-value
Model	2009.082	12	167.4235	76.1016	0.0004
A-Size	25	1	25	11.36364	0.0280
B-Temperature	20.25	1	20.25	9.204545	0.0386
C-Time	25	1	25	11.36364	0.0280
AB	20.25	1	20.25	9.204545	0.0386
AC	400	1	400	181.8182	0.0002
BC	289	1	289	131.3636	0.0003
A^2	163.1605	1	163.1605	74.16388	0.0010
B^2	94.00263	1	94.00263	42.72847	0.0028
C^2	37.26579	1	37.26579	16.939	0.0147
AB^2	351.125	1	351.125	159.6023	0.0002
B^2C	288	1	288	130.9091	0.0003
BC^2	91.125	1	91.125	41.42045	0.0030
Pure Error	8.8	4	2.2		
Cor Total	2017.882	16			

The analysis of variance (ANOVA) of the model equation developed for percentage oil yield was used to check the adequacy of the empirical model and the results obtained were as summarized in Table 3. To measure how well the suggested model was able to fit the experimental data, parameters such as probability value (p-value) and square of correlation coefficient (R-squared) value were used. The p-values of the model and that of each of the factors of the model were meant to show their significances. From the results obtained, it was discovered the entire model was significant because its p-value was less than the chosen 0.05 based on 95% confidence level. Also, each of the terms of the model was found to have a p-value that was less than 5% (0.05), which was indicating that each of them was also significant in the developed model.

Moreover, the R-squared value of the model was considered to ascertain how well it could represent the data used to develop it, and it was obtained that the model had 0.9956 as its R-squared value. This close-to-unity (1) value of the R-squared value was another indication that the developed model equation for the oil yield was a good representative of the system.

In order to clearly see the performances of the developed model, it was simulated and the results obtained were compared with the experimental values of the percentage oil yield as shown in Figure 6. From the figure, it was discovered that there were good agreements between the results obtained from the simulation and those recorded from the experiments carried out. The good graphical comparison of the results was found to be supporting the good R-squared value obtained from the analysis of variance of the developed empirical model.

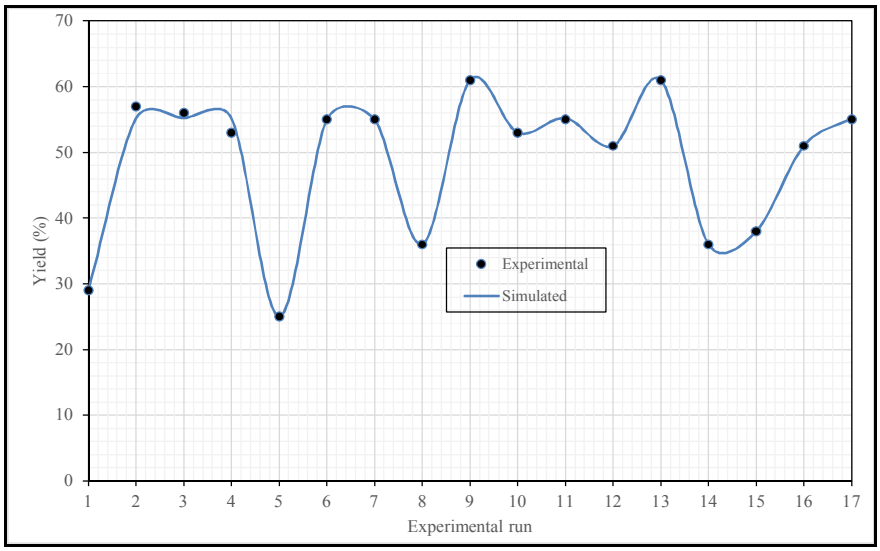

Figure 6: Experimental and simulated percentage oil yield

Apart from developing a model equation to be used to predict the yield of oil obtainable from the Jatropha seeds, the properties of the extracted oil were also determined to be sure that the obtain liquid from the seeds was actually Jatropha seed oil.

From the chemical analysis of the seed oil carried out, it was found that the extracted Jatropha oil had a free fatty acid of 4.68 mg KOH/mg and a peroxide value of 2 Meq/kg. These values were discovered to indicate that the oil could be used for biofuel production as those values fell within the ASTM standard of the oil that can be used for biofuel production.Besides, the fatty acid value reported in this study was in agreement with the values reported by [29] and[30]. Furthermore, the value obtained for the peroxide value showed the reason why *Jatrophacurcas* oil is not used in the food industries[31] as a result of phorbolester contained in it, which is a major antinutrient[32]. Generally, peroxide value of an oil type shows the oxidative stability of the oil. The higher the peroxide value of an oil type, the greater its development of rancidity, and this limits its value in food industries.

The acid value of the extracted oil was also determined to be 9.32 mg KOH/g that was found to be similar to the value reported in the work of [33] for Jatrophaseed oil.

The iodine value, which is a measure of the unsaturation of the oil extracted from Jatropha seeds in this study was found to be103 mg/g. This value obtained was also found to fall within the ASTM standard for oils suitable for biodiesel production as well as in close agreement with the work of [34]. Iodine number normally indicates the tendency of a fuel to be unstable as it measures the presence of C = C bonds that are prone to oxidation, and instability increases by a factor of one for every C = C bond on the fatty acid chain [35]. Therefore, seed sources with higher iodine value may not be suitable for production of biodiesel because poor oxidation stability can cause fuel thickening, formation of gums and sediments, which in turn, can cause filter clogging and injector fouling.

In addition to the chemical properties of the extracted oil that were investigated, some of its physical properties were also examined. Among the physical properties determined in this work for the extracted Jatropha oil was viscosity. The value obtained as the viscosity of the oil extracted in this work was found to be 40.25 centistokes. This viscosity value was observed to be in good agreement with the one reported by [36]. This was another indication that the liquid extracted was actually Jatropha seed oil.

Also determined for the oil was the flash point. The flash point of an oil type is the temperature that indicates the overall flammability hazards of the oil in the presence of air. The flash point is related to the safety requirement in handling and storage of the Jatropha oil for biofuel production.For the Jatropha oil reported in this study, its flash point value was obtained to be 187^{o}C. The obtained flash point value revealed that the

oilwas safe for usage.Besides, the value wasfound to compare very well with that obtained in the research work of [33].

The cloud point temperature of the extracted Jatropha seed oil was obtained to be 14 ^{o}C. Knowing that cloud point is the temperature at which cloud crystals first appear in the oil when it is cooled. This property is related to the usability of the oil in cold regions[37]. The value obtained for the oil in this study has shown that the oil would be suitable for use in any region where the atmospheric temperature is greater than 14 ^{o}C. Apart from that, the value was observed to be similar to that reported by[38].

Another physical characteristic of the oil that was determined was pour point, and it was obtained to be 5 ^{o}C, which was in concord with the work of [38].

The mass per unit volume, otherwise known as the density, of the extracted Jatropha seed oil was determined and obtained to be 0.837 g/cm^3. The value reported in this study was discovered to be similar to those obtained by [39],[32] and [40].

Furthermore, the results of the optimization carried out revealed that the values of the input parameters required to give approximately 61.52% yield of oil were particle size of0.62 mm, temperature of 52.13^{o}C and extraction time of 4.06 hr. Validating the result obtained by running the system experimentally using the estimated optimum conditions, 60.46% oil yield was achieved, which resulted in an absolute error of 1.75% that was small enough to say that the optimization carried out was successful.

5.0 Conclusion

The results obtained from the analysis of variance of the model developed for the percentage of oil yield as a function of particle size, extraction temperature and extraction time revealed that it (the model) was a good representative of the system because its estimated R-squared value was 0.9956. Also, it was discovered that the model and all its terms were significant because their p-values were less than 0.05 that was chosen based on 95% confidence level for the analysis. Comparing the results of the physical and the chemical analysis of the extracted oil with the standards available in the literature showed that the liquid obtained from the seeds was actually Jatropha oil. Finally, the optimization carried out made it known that 61.52% of oil yield could be obtained from the seeds if the particle size, the extraction temperature and extraction time of the system are 0.62 mm, 52.13^{o}C and 4.06 hr, respectively.The achievement of an oil yield of 60.46% that compared very well with the predicted one (61.52%) was an indication of the success and the reliability of the optimization carried out with the aid of Design Expert through the Box-Behnken method of RSM in optimizing Jatropha oil extraction.

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