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Mathematical Modeling of the Solvent Extraction of Palm Kernel Oil from Palm Kernel

Omeiza James Momoh[1], Vincent Nwoya Okafor[1], & David Olubiyi Obada[2]

1 Chemical Engineering Department, Nnamdi Azikwe University, Awka, Nigeria
2 Mechanical Engineering Department, Ahmadu Bello University, Zaria, Nigeria

* Email: obadavid4@gmail.com, ojamesmomoh@gmail.com

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Abstract: The model for the solvent extraction of palm kernel oil from palm kernel was generated for the process at varied particle sizes of palm kernel, temperature of extraction, duration of extraction and mass of palm kernel respectively using Least Square Linear Equation. Petroleum ether was used as solvent to carry out the extraction in a soxhlet apparatus. The percentage oil yield was determined for every extraction carried out. The experimental results obtained showed that percentage oil yield decreases with increase in particle size and mass, but increases with increase in the temperature and duration of extraction. The characterization of the extracted oil was also done to determine its physiochemical properties, which revealed palm kernel oil as non-drying oil. Statistical analyses of the percentage oil yield of each variable studied were carried out followed by the modeling of the extraction process for each parameter using least square linear equation. The interpretation of the model developed revealed a model which was significant in the variations obtained from the experimental results.

Key words: Palm Kernel, Modeling, Extraction, Least square, Solvent

Introduction

Oil seeds are essentially valued for the oil obtained through extraction from the fruit and/or seed obtained from them. Palm kernel oil is a primary raw material for some key manufacturing industries,and it finds useful application in the food and beverage, chemical and pharmaceutical industries for the production of refined edible oil, margarine, cosmetics, livestock feeds etc. Palm kernel oil is frequently confused with palm oil to the extent that their names are often interchanged; palm kernel oil and palm oil have different chemical and physical properties and come from different parts of tropical oil plant like the *Elaesis guineesis* (Amira *et al*., 2014). Palm kernel oil is extracted from kernel (or seed) that is encased in the endocarp of the palm fruit while palm oil is extracted from the carotene and vitamin E-rich fleshy mesocarp of the palm fruit (Surbhi *et al*., 2012).

The extraction of oil from oil-bearing seeds can be done by mechanical or solvent method or combination of both. In mechanical extraction, expellers (also known as screw press) or hydraulic press are used. In mechanical method by screw press, a rotating screw forces the oil bearing material down the length of the cylinder pressing cage, and increasing the pressure squeezes the oil through perforation in the sides of the cage, allowing the cake then to emerge from the end of the press.

The cake obtained in the mechanical extraction of palm kernel oil still retain considerable amount of oil between 5 to 12 percent depending on the extent of extraction compared to the solvent extraction that is between 0.5 to 3.0 percent (Chin *et al*., 2001). Therefore, if it be desired to obtain larger quantities than are yielded by mechanical method, the extraction by solvent must be resorted to.

Solvent extraction of palm kernel oil is a leaching process which involves the removal of soluble fraction in the form of a solution, from an insoluble permeable solid phase which it is associated (Perry *et al*., 2003). In leaching, to separate the desired solute constituent or remove an undesired solute component from the solid phase, the solid is

contacted with a liquid phase, resulting in separation of the component originally in the solid.
Generally, mathematical model describes physical/chemical process in mathematical language. It is a more convenient and economic tool to understand the factors that influence the performance of a process. Mathematical models are of great importance in engineering because they provide information about the variations in the measureable macroscopic properties of a system using output from microscopic equations which cannot usually be measured in the laboratory. On the other hand, mathematical models can lead to wrong conclusions or decisions about the system under investigation if they are not validated with experimental test (Anselmo and Monica, 2011). Nearly all applied science consist of performing experiments and interpreting the result, this may be done quantitatively by taking accurate measurement of the system variables which are subsequently analyzed and correlated by investigating the general function of the system in terms of one variable influencing another.

Despite the fact that many research works such as (Eromosele,1998; Hanim, 1992; Bucic-Kojic, 2007; Sayyar,2009) investigated the factors affecting seed oil extractions, the factors affecting extraction varies for different oil seeds since the cellular structures of oilseeds varies (Olawale, 2012).

In this study, extractions parameters such as particle size, temperature of extraction, duration of extraction and mass in relations with percentage oil yield of palm kernel oil was studied using petroleum ether as solvent in a soxhlet extractor. This was followed by the physiochemical study of the extracted oil. A model was then developed for the extraction process to determine the extent to which the parameters investigated correlates to oil yield.

Material and methods

Sample Collection and Preparation

The palm kernel used for this research was obtained from Eastern-Nigeria. Foreign materials were handpicked from it ,before oven-drying it to constant moisture content, after which it was ground using an electric grinding machine before it was taken to the laboratory where a mechanical sieve was used to sieve it into five different particle sizes of 0.5, 1.0, 1.5, 2.0 and 2.5mm diameter and labeled sample A, B, C, D and E respectively.

Solvent Extraction

The solvent extraction was carried out using petroleum ether as solvent in a soxhlet extractor. The first set of extraction was carried out using 20g of sample A, B, C, D and E respectively and the percentage oil yield for the various particle sizes was obtained using equation 1.

$$\%\ \text{Oil Yield} = \frac{\text{Mass of Sample} - \text{Mass of Cake}}{\text{Mass of sample}} \times 100\% \qquad (1)$$

It should be noted that mass of sample-mass of cake = mass of oil

From the extraction result obtained at various particle sizes, sample A, with the least particle size diameter gave the highest percentage of oil yield, and as such, it was used to carry out other experiments to determine temperature and mass at varied time. The second set of extraction was carried out using 10g of sample A for a constant time of 45mins at varied temperature of 30, 35, 40, 45, 50, 55 and 60^{0}C. The third set of extraction was carried out for time variation of 20, 30, 40, 50, 60, 70 and 80 mins, the last set of extraction was carried out at varied mass of 20, 30, 40, 50, 60 and 70g respectively in each case, percentage oil yield was determined.

Characterization of the Extracted Oil

The following physiochemical properties of the extracted oil- saponification value, acid value, free fatty (FFA), iodine value, refractive index, peroxide value, specific gravity value (S.G) were carried out to ascertain its quality, purity and for its identification using the procedures in (Onwuka, 2005; Pearson, 1981; AOAC Official Methods of Analysis,2005).

Statistical Analysis of Experimental Results

Correlation Coefficient (R): This parameter shows the extent to which the regression model correlates the experimental data.

For linear X, Y pairs of observations:

$$R = \frac{\Sigma(XY)}{\sqrt{(\Sigma X^2 \Sigma y^2)}}) \qquad (2)$$

Coefficient of Determination (R^2): Coefficient of determination is the parameter that shows the goodness of the model and cannot be greater than unity.

R^2 = (Correlation Coefficient)^2
Standard Error of Estimate (SEE)
For X- estimate (SEXest)

$$\text{SEXest} = \sqrt{\frac{\sum(X - X_{est})^2}{N}} \qquad (3)$$

$$\text{SEYest} = \sqrt{\frac{\sum(Y - Y_{est})^2}{N}} \qquad (4)$$

Sum of Squares
Regression sum of squares (X^2reg)

$$X^2_{reg} = \sum\frac{(Y - Y_{est})^2}{Y} \qquad (6)$$

Standard deviation (SY)

$$SY = \sqrt{\frac{\sum(Y - Y_{mean})^2}{N}} \qquad (7)$$

Variance (SY^2)

$$SY^2 = \frac{\sum(Y - Y_{mean})^2}{N-1} \qquad (8)$$

Where (N-1) = degree of freedom V.

$$S^2_{res} = \frac{\sum(Y - Y_{est})^2}{(N-1)(N-2)} \qquad (9)$$

F-distribution test

$$F = \frac{SY^2}{S^2res} \qquad (10)$$

Modelling Methodology

The Least Square Linear equation was used to generate the model for the behaviour of temperature, particle size and time with oil yield. The coefficient of determination which is the parameter that shows the goodness of the model for the various factors affecting extraction studied was obtained, followed by the coefficient of correlation which shows the extent to which the regression model correlates the experimental data. The estimated error for various parameters was calculated and finally F-value was determined and compared with F_{99} percentile to know if, the variation in the experimental data was significant or by chance. Using the least square linear equation to generate the model for the behaviour of oil yield (Y), with changes in each of the factor of extraction (X) under study, the least square linear equation was used:

$$Y_{est} = a_0 + BX \qquad (11)$$

Where Y is the % oil yield (the dependent variable), X is the independent variable. a_0 is constant while B is the coefficient of X.The normal to B above will be

$$\sum Y = a_0 N + B\sum X \qquad (12)$$

$$\sum XY = a_0 \sum X + B\sum X^2 \qquad (13)$$

Where N is the number of data points
Solving equations (12) and (13) simultaneously gives.

$$a_0 = \frac{(\sum Y)(\sum X^2) - (X)(\sum XY)}{N(\sum X^2) - (\sum X)^2} \qquad (14)$$

$$B = \frac{N(\sum XY) - (\sum X)(\sum Y)}{N(X^2) - (\sum X)^2} \qquad (15)$$

Results and Discussion

Interpretation of Parameters Studied on Oil Yield

Particle Size Effect on Oil Yield

Fig. 1 is the experimental result obtained at varied particle sizes of palm kernel for extraction. The particle size relates to the surface area available for extraction and is obviously one of the most important factors for extraction study (Mani, 2007). From Fig.1, as the particle size increases the oil yield decreases; this implies that the rate of transfer of the solvent into the solid mass of smaller particle size is quite rapid compared to the larger particle size. However, the reduction of solid to finer particle size has its limitations. Too fine division may result in packing of solids during extraction; preventing free flow of the solvent through solid bed, in such a case, extraction is more difficult, especially when finely divided solids are treated in an unagitated vessel (Richardson and Harker,2002).It can also be deduced that leaching process is favoured by increased surface per unit volume of solid to be leached and by decreased radial distance that must be traversed within the solid, both of which are favoured by decreased particle size (Perry *et al.,* 2003).

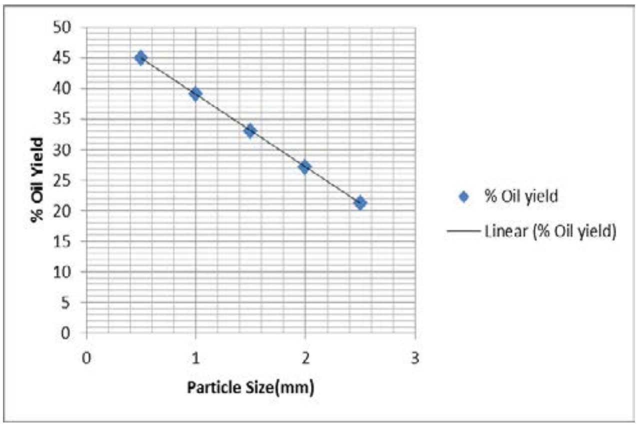

Figure 1: Effect of Particle size on % Oil yield

Temperature Effects on Extraction of Oil Yield

Temperature at which extraction is carried out is a very important factor that affects extraction; **Fig. 2** shows increase in oil yields with increased extraction temperature. Higher temperature results in higher solubility of the solute in solvent and it is therefore desired to realize higher solute concentration in the extract (Richardson and Harker, 2002). Although very high temperature operation may not be permissible because unacceptable solvent losses may occur, safety consideration is also important, as such a compromise is necessary in the selection of extraction temperature.

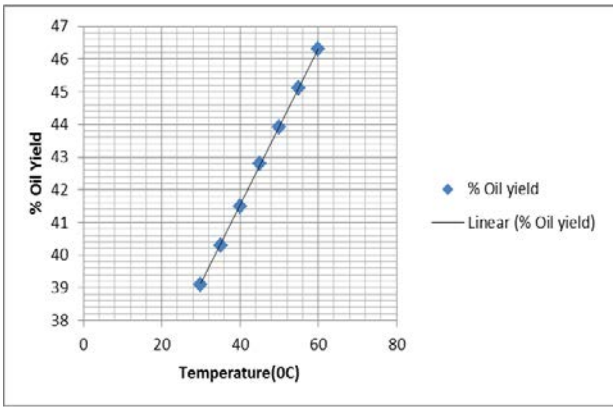

Figure 2: Effect of Temperature on Oil yield

Duration of Extraction on Oil Yield

Fig. 3 is the experimental result of extraction at varied time. It shows an increase in the oil yield with a corresponding increase in time. This is expected because if the solvent contact duration with the solute is longer, more oil will definitely be extracted. Contact could be by relative motion of solid particles to each other or relatively to the liquid as in dispersed contact (Perry *et al.,* 2003). But in this case the particles are stationary.

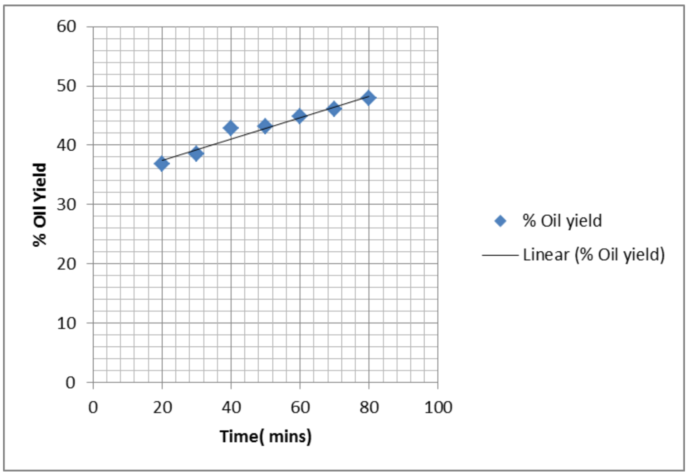

Figure 3: Time Effect on % Oil yield

Mass of Kernel on Oil Yield

From the experimental result obtained, **Fig. 4** shows a decrease in the percentage oil yield with increase in mass, it can be deduced from this trend that at a smaller mass the solvent penetrates the palm kernel easily and increases extraction efficiency, compared to larger mass, if same quantity of solvent is used. It shows that the mass transfer rate is higher for small mass. It can also be deduced that leaching process is favoured by increased surface per unit volume of solid to be leached and by decreased radial distance that must be traversed within the solid, both of which are favoured by decreased particle size (Richardson and Harker, 2002).

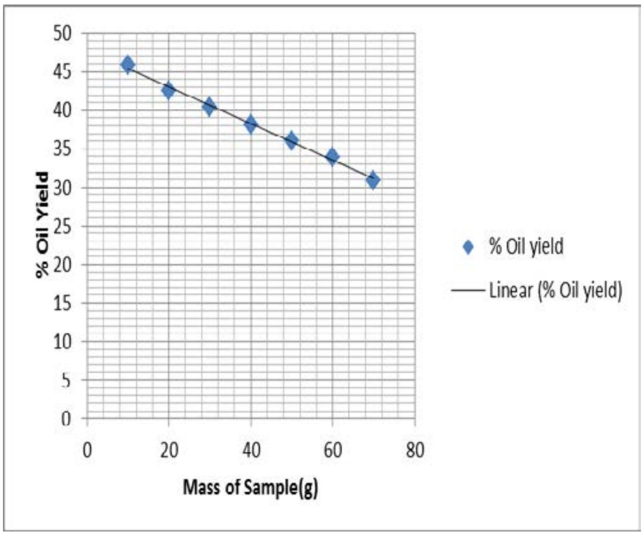

Figure 4: Mass Variation Effect on % Oil yield

Physiochemical Properties of Extracted Oil

Table 1 shows the characteristic of the extracted oil for the identification and assessment of the quality and purity of palm kernel oil extracted. The acid value which is the number of milligram of potassium hydroxide KOH required to neutralize the free fatty acid present, was found to be 3.7 mgKOH/g .The saponification value representing the milligram of potassium hydroxide required to change 1g of fat completely to glycerol and potassium soap, was 223 mgKOH/g. Iodine value of 15.00 mgKOH/g was obtained. The iodine value show the degree of unsaturation of the oil and it is expressed as the number of iodine absorbed by 1g of oil, the iodine value show that palm kernel oil is non-drying. The Peroxide Value (PV) of an oil or fat is used as a measurement of the extent to which rancidity reactions have occurred during storage. Other methods are available but peroxide value is the most widely used. A lower number of peroxides indicate a good quality of oil and a good preservation status. It was obtained as 10.3 mEq/kg.

Table 1: Physiochemical Properties of Extracted Oil

Saponification value	243 (mgKOH/g)		
Acid value	3.70 (mgKOH/g)	Subhead	Subhead
Free fatty (FFA)	1.81 (mgKOH/g)		

Table 2: Statistical Results for Modeling

Statistical analysis	Particle Size	Temperature	Time	Mass
Coefficient of Variable(B)	-0.1165	0.241	0.002	-36.448
Constant (ao)	0.4987	31.850	0.336	47.76
Coefficient of determination(R^2)	0.960	0.996	0.919	0.83
Correlation coefficient(R)	0.980	0.998	0.9589	0.91
Standard error of P estimate	0.05801	0.30741	4.93288	0.113897
Standard error of Y-estimate	0.002127	0.19731	0.009336	4.2942
Regression sum of square	0.00064	0.006356	0.0012019	2.4229
Residual sum of square	0.000023	0.2725	0.000523	129.0808
Standard deviation	0.0801	2.40	0.0329	4.759
Variance	0.00802	6.770224	0.001302	26.42
F-value	4255	147.9576	49.79	6.1418
Degree of freedom	4	6	5	6

Interpretations of Model

Particle Size Model

Equation 16 represents the model for the correlation between oil yield (Y) and particles size of palm kernel (P) for the solvent extraction of palm kernel oil from palm kernel

$$Y = 0.4987-0.1165P \qquad (16)$$

In **Table 2** an F-distribution test for particle size model was obtained as 4255 which is greater than F_{99} i.e. 99th percentile of 5.41 obtained from F-distribution chart. It can be deduced from this that the model is relatively in order, meaning the variation obtained in the experiment was significant and not by chance. The obtained coefficient of 0.960 or 96.0% shows an acceptable model since the closer it is to unity, the better the model, though it must not be greater than one. An unexplained variation of 4.0% obtained accounts for other factors affecting the extraction at that particle size. The standard error of estimate of 0.05801 and 0.002127 respectively for particle size and oil yield represents the plus and minus error difference between the experimental results and the model. The residual sum of square which gives 0.00002262 accounts for the vertical scatter, this value signifies that virtually all the points fall on the line of best fit.

Temperature Model

Equation 17 shows the modeled equation for the temperature (T) effect on oil yield

$$Y = 31.85+0.24T \qquad (17)$$

In **Table2**, the statistical analysis of the result of extraction at varied temperature of extraction (T) shows standard error of estimate for temperature and oil yield as 0.30741 and 0.19731respectively, this indicates deviation of the model from the experimental data obtained. The F-value of 147.9576 which is greater than F_{99} of 3.47 signifies that the variation obtained on the experiment is not by chance. A coefficient of distribution of 0.996 or 99.6% shows a good modeled equation as coefficient of distribution of a model in order should not be more than one or too small. The residual form of square of 0.2725 obtained accounts for the points that don't fall into the line of best fit in the plotted graph. Unexplained variation of 0.4 accounts for others factors affecting extraction at that temperature.

Model for Duration of Extraction

Equation 18 shows the correlation between oil yields with the duration of extraction (t)

$$Y = 0.336 + 0.002t \qquad (18)$$

An F distribution test for time was obtained as 49.79 which is greater than F_{99} i.e. 99th percentile obtained from the F – distribution chart. It can also be deduced from this that the model is in order, as such variation obtained in the experimental result was significant and not by chance. The obtained coefficient of distribution of 0.9589 or 95.9% in table2 shows a good model since the closer it is to one the better the model, though it must not be greater than one. An unexplained variation of 4.1% accounts for other parameters that affect the extraction at that temperature. The standard error of estimate of 4.93288 and 0.009336 respectively for time and oil yield represent the plus or minus error different between the experimental result and the model. The result of oil yield is okay while that of the time variable is unacceptable. The residual sum of square of 0.000523 accounts for the vertical scatter, this value signifies that virtually all the points falls on line of best fit.

Model for Mass of Palm Kernel

Equation 19 is the model that correlates oil yield with mass of sample (M)

$$Y = 47.76 - 36.448M \qquad (19)$$

From the statistical analysis of extraction result at varied mass of kernel in **Table 2**, an unexplained variation of 17% for mass ratio was obtained. It can be deduced that other factors has 17% influence on the extraction for mass. The model is a good one owing to the fact that F-value of 6.1418 obtained is greater than the F_{99} of 3.47 obtained from F-chart. A standard error of estimate of 0.11389 and 4.2942 for mass and oil yield respectively show more error for yield in the modeled equation, this could result from the condition prevailing in the laboratory during experiment or probably error in the measuring instrument used, or lack of adherence to precaution during the mass variations during experiments.

Conclusion and Recommendation

This work has provided deep insight into how varying particles size of palm kernel, temperature of extraction, duration of extraction and mass of palm kernel affects the extraction process of palm kernel oil from palm kernel using solvent extraction method. The physiochemical analysis of the extracted oil obtained confirms that palm kernel oil can be classified as non-drying oil. Furthermore, the modeled equation successfully predicted the correlations between the oil yield and the variables investigated. The model proved acceptable from the statistical analyses of the experimental results obtained. It is therefore recommended that further research should be carried out to investigate other possible factors that may affects the solvent extraction of palm kernel oil from palm kernel aside those investigated in this work.

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