DIFFUSION RATE ANALYSIS IN PALM KERNEL OIL EXTRACTION USING DIFFERENT EXTRACTION SOLVENTS

Egbuna S.O[1], Ozonoh. M[2], Aniokete. T .C[3]

[1, 2, 3]*Department of chemical engineering, Enugu State University of Science and Technology, Enugu, Nigeria.*

Abstract

This study investigated the rate of diffusion on the extraction of palm kernel oil using various solvents, namely, n-hexane, Benzene, Trichloroethylene, and Carbondisulfide. The solvents and the extracted palm kernel oil were characterized using the AOCS standard methods, and the results are shown in tables 1 and 2. The palm kernel used in the study was obtained from Akpugo in Nkanu West local Government Area of Enugu State. The effects of extraction time and temperature as well as quantity and nature of solvent were investigated as reported in figures 1-3. The characterized PKO was used to determine parameters used in establishing the Diffusivity ($6.47 \times 10^{-9} m^2/s$), which in turn was used to calculate the rate of diffusion,($4.00 \times 10^7 kmole/m^2.s$), and the coefficient of mass transfer, ($3.2 \times 10^{-5} kmloe/m^2.s$), all of which conformed to the standard values, [12]..

--***--

1. INTRODUCTION

Vegetable oils are triglycerides of fatty acid extracted from plants. Such oils have been part of human culture for millennia, (4,000-year old "kitchen" unearthed in Indiana)[1]. The term "vegetable oil" can be narrowly defined as referring only to substances that are liquid at room temperature, or broadly defined[1] without regard to the substances state of matter at a given temperature[3].Hence vegetable oils that are solid at room temperatures are sometimes called vegetable fats. Vegetable oils are primarily extracted from seeds and nuts, even though it can be extracted from other parts of the plant.

Since ancient times human beings have known how to extract oils from their various natural sources and make them fit for their own use. The natives in the tropical regions of the world have long extracted these oils after drying the nuts and seeds under the sun, 4,000-year-old "Kitchen unearthed in Indiana" Archaeo News, January 26, 2006, Retrieved 30 - 06 - 2013[1]. These oils were consumed raw, since very little or no treatment was made order than filtration and/or decantation. Mahatta[2] observed that olive oil was extracted as far back as 3000 BC in ancient Egypt. Vegetable oils are used as ingredient or component in many manufactured products, including soap, candle, perfumes, cosmetics, margarine, shortening, hydraulic fluid biodiesel and lubricants[4].

A large number of articles have been published on extraction of oils from their mother seeds and nuts using various methods, and characterization of the extracted oils. [5] and [6], noted that mechanical method of extraction, termed crushing or pressing offers advantage in terms of purity over the solvent extraction method. The oil is conditioned by bringing the kernel to optimum condition of moisture in order to obtain the maximum yield. Roasting is one of the most important steps in the extraction of palm kernel oil. It serves to regulate the moisture content, render the cell walls porous, rupture the cell walls by generating steam within the cell, and coagulating the protein so that filtration is made easy. The meal obtained by grinding the kernel must not be too wet or too dry so as to prevent imperfect extraction of the oil or poor yield.

Solvent extraction which is essentially a separation process based on apparent equilibrium steps, on the other hand offers the advantage of penetrating action on the cell of the prepared oil seeds to improve yield tremendously, [7] and is less expensive. However, the effects of diffusion of the oil from the main bulk of the oil seed of the ruptured cells into the solvent in liquid phase, and mass transfer coefficient, have received little attention.[8], have studied the equilibrium condition of expression after a constant pressure has been maintained until no further flow of oil occurred. They considered the quantity of oil expressed as the difference between the quantity originally present and that which remained in the cake after expression. They noted that an increase in pressure on a system of expressible material considered as a fractional increase over the previous pressure causes a proportional increase in the bulk of the solid portion of the system. Hence.

$$\frac{dP}{P} = kd\rho_S = k'd\left(\frac{1}{V}\right) \qquad\qquad 1$$

or $\qquad \dfrac{dP}{d(1/V)} = k'P$ $\qquad\qquad$ 2

The equation is integrated to get,

$$\text{Log} P \;=\; K + \dfrac{k'}{V} \qquad\qquad 3$$

Where K, k and k$'$, are constant, depending on the nature of material, and on the expression conditions. ρ_s is bulk density of the solid portion of the system, P, the pressure, and V, specific volume of the system based on the solid content. Many factors affect the rate at which the oil diffuses into the palm kernel grit, including time of exposure, nature and quantity of solvent, and temperature of the system.

A succinct review of published literatures on liquid – liquid extraction explained the important influence of solvent nature on extraction. [9], observed that direct solvent extraction is used for low oil content, (< 20% oil) seed such as soya bean, rice bran and dry milled corn germ. [10] experimented on a homogeneous oil impregnated material consisting of thin platelets of uniform thickness with two phases as the total surface area based on simple diffusion and observed that the theoretical rate of extraction is given by;

$$E = \dfrac{8}{\pi^2} \sum_{n=0}^{n=0} \dfrac{1}{(2n+1)^2} e^{-(2\pi+1)n/2} \dfrac{D\theta}{4R^2} \qquad 4$$

Where E is the fractional total oil unextracted at the end of time, θ; R is one-half of the plate thickness (ft); and D, and diffusion coefficient in ft^2/hr. For $\pi = 0$, equation reduces to,

$$E = \left(\dfrac{8}{n^2} e^{-n/2} \right)\left[\dfrac{D\theta}{4R^2} \right] \qquad 5$$

Or

$$\text{Log}_{10} E = -0.091 - 1.07 \dfrac{D_o}{R^2} \qquad 6$$

Trebal,, [11] gave an expression to be used to determine the diffusivity of a liquid in another, considered to be stagnant as,

$$D_A = \dfrac{(117.3 \text{X} 10^{-18}) \psi (M_B)^{0.5} T}{\mu V_B^{0.6}} \qquad 7$$

Where D_A - Diffusivity of oil, T – absolute temperature, M_B is molecular weight of solvent, V_B - molar volume of solvent ψ is association factor of solvent, and μ - viscosity .

The rate at which the glyceride of fatty acid diffuses into hexane is given by as; [12]

$$N_A = \dfrac{D_{AB}}{Z_2 - Z_{1(X_B)LM}} \left[\dfrac{\rho}{M} \right]av (X_{A1} - X_{A2}) \quad 8$$

Where ρ - density of oil, and $\left[X_B \right)_{LM}$ is log mean of mole fraction of the oil and solvent. Perry and Chilton, [13], also gave the mass transfer coefficient as;

$$N_A = K_A (X_{AI} - X_{A2}) \qquad\qquad 9$$

Fan, [14] observed two solvent extraction methods, solution extraction, in which oil is extracted from ruptured cells, and diffusion extraction, in which the oil is extracted from unruptured cells. This gives reason for the variation of diffusion coefficient with time.

Treybal,, [15], also gave an expression from which efficiency can be estimated, namely;

$$E_o = \dfrac{1}{1 + 3.7(10^4)\dfrac{KM}{hT\rho}} \qquad 10$$

In the present work, the extraction was carried out using N-hexane, Benzene, Trichloroethylene, and Carbon disulphide, as solvents. The efficiency of these solvents in terms of yield, suitability in terms of quality, and kinetics of the extraction in terms of diffusion rate were all investigated.

2. EXPERIMENTAL METHODS

The experimental work was aimed at obtaining data, on a practical basis, that would be used in the evaluation of the diffusion rate. The effects of time of extraction, type and quantity of solvent used, nature of the solvent and temperature of the system on the efficiency of extraction, were determined.

The fundamental method of experiment, in this respect, is to contact the prepared oil bearing kernel with appropriate solvent in order to extract its oil content to a specified minimum level. The oil-bearing seeds were pretreated to make their oils extractable. The oil - solvent mixture (Miscella), was separated into pure components by distillation. Traces of solvent entrained in the meal were removed by desolventization, and the desolventized meal was dried with steam, and the last traces of solvent removed by stripping.

2.1 Extraction of Palm Kernel Oil (PKO)

This experiment was carried out with a view to determining the amount of extractable oil in the representative samples of PKO grit, The following parameters were determined; Percent weight of drained solution (extract), percent weight of the cake, amount of oil in the extract, amount of oil retained in the cake, and quantity of solvent used in the extraction. The

equipment and materials used in the extraction experiment include: 600ml glass beakers, laboratory glass distillation column, heating mantle, water circulating tube, flasks, solvents and palm kernel. The properties of the solvents used are given in table 1[16]

Table 1 Characterization of Solvents used in the Extraction

Oil Seed	Specific Gravity at 15°C	Specific heat per litre	Latent heat per litre	Vapour pressure at 20°C(mm)	Toxicity limit, at 20°C (mg/m^3)	Boiling point, ^{o}C
N - Hexane	0.680	0.358	54	88	10.80	68.60
Benzene	0.700	0.360	56	80	10.80	60.70
Carbon disulfide	1.292	0.310	112	298	1.50	46.26
Trichloroethylene	1.489	0.327	84	70	11.00	87.00

Sample Preparation: l00g of PKO seed, were cleaned, roasted in seed cooker, and ground.

Experimental procedure: The experiment was carried out by using the method of [17],as follows:
100g of palm kernel grit, was charged into each of 600cm^3 beaker in separate experiments, and 100cm^3 of n - hexane gradually added with stirring. The mixture was filtered and the filtrate (the miscella) was collected at interval and recycled. This process was repeated many times, without a fresh solvent charge. The miscella was collected in a beaker at the last stage. This process was repeated for each of the solvents, and the results reported in figures 1-3

$$\text{Calculation: } W_m = \frac{W_2 - W_1}{G} \qquad 11$$

Where W_m - percent weight of oil extracted, W_2 - the weight of extract, and,W_1 - the weight of solvent, G-weight of palm kernel grit used.

2.2 Determination of Residual Oil in Cake

The aim is to determine the amount oil that remains in the cake after extraction. This is useful in sizing extraction equipment. The equipment and materials used include; separating funnel, stop watch, retort stand, micro boiling flask for distillation, thermometer, heating mantle, glass wool, palm kernel grit sample and solvents.

Experimental procedure: Glass wool was inserted into a separating funnel to plug the liquid outlet and form, somewhat, a false bottom. 100g of the oil-bearing material (palm kernel grit) was placed at the base of the funnel, and the

latter was stoppered with rubber bung which has hole in the center where glass tube of 15cm long was inserted to extend into the mass of the sample. This tube served as both solvent delivery as well as stirrer. The separating funnel was clamped to the retort stand, and 50ml of n-hexane was added gradually over the bed of the sample, with occasional stirring using the glass tube. Equal volume samples of extract were withdrawn at 20 minutes interval by means of a pre-weighed micro - boiling flask which was connected to the micro-distillation unit which distilled the oil hexane solution (miscella), at 20°C over a heating mantle. Solvent was recovered by condensation and the boiling flask was cooled in a desiccator and reweighed. Temperature was varied between 20 and 50°C, Time , 20 to 120 min. and quantity of solvent from 50 to 250ml.

Extraction time: The aim was to determine the time required to reduce the oil content of the given oil seed sample to minimum. In the experiment, temperature and weight of oil seed were kept constant while time of extraction and amount of solvent were varied proportionately according to the following sequence: 20 min to 50ml; 40min to 100ml; 60min to 150ml; etcetera. The amount of oil grit used was 125gms and the solvents were used in turn. The result are given in figure 1.

Quantity of solvent: The aim of this experiment was to determine the amount of solvent required in order to obtain the lowest possible level of oil in the residue. Extraction time was kept constant at 60min, and temperature was maintained constant during the test. The results are given in figure 2

Solvent Temperature: This test was carried out to determine the temperature of solvent that would give the best result. The

condition under which it was done were: Solvent quantity, 250ml; sample used 125gms and extraction time, 120min. Temperature was varied from 20 to 50°C. The results are given in figure 3

Nature of solvent: This was aimed at ascertaining the dissolving power of the solvent. The temperature of the system was kept at 45°C, and Extraction time was 4hours, while other conditions of weight and solvent quantity remained constant.

2.3 Characterization of Extracted Palm Oil:

The raw palm kernel oil was characterized so as to determine its physical and chemical properties, and hence the level and extent of refining required in order to stabilize the quality of the final product. The properties of the oil that were determined include: color, melting point, specific gravity, refractive index, moisture content, (Ppm), FFA(%), PV(m.eq/kg), AV(m.eq/kg), Fe(Ppb). These were done by using the American Oil Chemists Society (AOCS), standard test methods.

2.3.1 Specific Gravity:

The Method of the AOCS, Cc 5 – 25, [18]was used. Specific gravity of a raw oil sample is the ratio of density of the oil relative to that of water. It is a measure of the level of purity of an oil sample, since it involves conversion of volume into weight. The aim is to determine the level of adulteration in a given sample of oil.

Procedure: 100g of the raw oil sample was heated to a temperature of 50°C and weighed. It was then introduced into a known weight of density bottle and the bottle reweighed. The oil was removed and the density bottle washed thoroughly with detergent and rinsed with distilled water to avoid contamination. It was then refilled to the same level with water and the weight taken. The specific gravity was then calculated as;

$$\text{Sp.gr.} = \frac{\text{Density of oil at } 50^{O}\text{C}}{\text{Density of equal volume of water at } 5^{O}\text{C}}$$

12

2.3.2 Refractive Index:

The Method of the AOCS, Cc 7 – 25, was used. Refractive Index is used to determine the angle by which a beam of light is bent when passing through a thin film of melted fat or oil. It helps to check the quality in terms of purity of the raw oil sample.

Procedure: 5 drops of melted raw oil sample were placed on the face of a prism block. The latter was closed and tightened

firmly. The temperature was maintained at 40°C. The illuminating light in the refractometer was adjusted such that the field dwindling line was coincident with the cross line. At this setting, the reading on the gauge indicated the refractive index of the oil sample.

2.3.3 Moisture Content:

The Method of the AOCS, Cc 4 – 25, was used. Moisture in raw oil sample causes hydrolysis of the sample, and this in turn aggravates rancidity and oxidation at high temperatures. The result of oxidation is the formation of hydro - peroxides and other cleavage products like aldehydes and ketones. Experiment is aimed at determining the amount of water contained in a given sample of raw oil as impurity.

Procedure: 10g of the raw oil sample was weighed into a beaker containing stirring rod. The beaker, with the stirring rod, was weighed empty and also with the oil sample. Heating was done using the Bunsen burner, and drops of acetone were gradually added to accelerate evaporation of moisture. The system was maintained at a maximum temperature of 105°C. The complete evaporation of water was indicated when no more bubbles were observed. The beaker, with its content, was allowed to cool and was reweighed. The difference in weight showed the weight of water that has evaporated, and it was calculated as;

$$\text{Moisture(\%)} = \frac{\text{Weight of Moisture}}{\text{Weight of crude oil sample}} \times 100$$

13

2.3.4 Phosphorous:

ALFA – LAVAL[19] , was used. The phosphorous in the oil sample was determined by ashing. The phosphate obtained was transferred into phosphomolybdate which was reduced to a blue - coloured compound. The concentration of the blue compound was determined by comparison with blue coloured glass disks.

Procedure: 5g raw oil sample was weighed into a platinum dish, and 0.5g calcium oxide added and both ashed. The ash was dissolved in 10 - 15 cc of 2N hot dilute hydrochloric acid, and filtered into a 100cc volumetric flask. The dish was washed into the volumetric flask, filtered, and made up to l00cc. A blank experiment was similarly prepared, but with no oil sample present. 5cc of the filtrate was taken in a tube and 2cc and 1 cc of molybdate and hydroquinone solution added in that order. The mixture was allowed to stand for 5 minute for the green phosphate colour to develop. 2cc of carbonate/sulphate solution was quickly added and stirred, (CO_2 evolved). Both the test experiment and its blank were placed in the comparator against a uniform light for comparison. The result was reported as; Phosphorous (Ppm)

$$\frac{A \ x \ V \ x \ 5 \ 0.326}{G \ x \ v \ 10000} \qquad 14$$

Where A - comparator scale reading (Ppm), V - volume of ash solution, v - volume of ash solution taken for the colour development, and G - weight of oil sample.

2.3.5 Determination of Color:

The Method of the AOCS, Ca 20 – 25, was used. Color pigments present in raw Palm kernel oil include; chlorophyll and gossypol. The aim is to find the amount of colour pigment present in the oil sample.

Procedure: Lovibond Tintometer with 1-inch cell was used for the analysis of colour, and the latter read in terms of red or yellow colour band that matched the colour of the oils.

2.3.6 Free Fatty acid:

ALFA – LAVAL , [19],was used. Free fatty acid results from chemical or enzymatic hydrolysis of the fatty acid glycerides. Its presence in oil sample is a measure of the quality of the oils, unrefined or refined. The aim of the experiment was to determine the degree of enzymatic hydrolysis of triglycerides of the fatty acid that has occurred.

Procedure: 2.8ml of oil of an unknown FFA content was measured into a conical flask and diluted with 25ml of ethanol. A drop of phenolphthalein was added. This was titrated against 0.1N sodium hydroxide until a permanent pink colour was registered, and the results recorded as;

$$FFA(\%) = \frac{V \ x \ M \ x \ N}{10W} \qquad 15$$

Where, N - Normality of NaOH; V - Volume of NaOH, W - Weight of oil sample, M - Molecular weight of oil sample used.

2.3.7 Oxidation products

Kharasch et al method, adapted from [19], was used. When an unsaturated fatty acid chain reacts with air at room temperature, (a process known as autoxidation), hydroperoxides are formed. At high temperature, these peroxides break down to hydrocarbons, aldehydes and ketones. These cleavage products impart odour and flavor to oil and must be removed.

2.3 8 Determination of Peroxide Value;

This is a measure of primary oxidation whose product is hydrocarbons. These hydrocarbons are further oxidized to water, which causes rancidity of the oil on storage. The aim is to determine the degree of primary oxidation which the oil has passed through.

Procedure: 30ml of chloroform - glacial ethanoic acid mixture in the volume ratio of 1:2 was transferred to a conical flask connected to a reflux condenser. The mixture was then heated to boiling and the vapor condensed in the lower part of a jacketed tube. When the reflux became steady, about 1.6ml of potassium iodide was added from the top of the condenser. The precipitate of KI was dissolved by adding 5 drops of water. The mixture was heated for 5 minutes and 2ml of the oil was pipetted into the mixture through the top of the condenser also. The pipette was rinsed with 2ml of chloroform into the boiling mixture, and boiling continued for 5 minutes. 50ml of distilled water was added, and 2ml of the sample was then titrated with 0.02N thiosulphate solution, using starch solution as indicator. The result was reported as;

$$PV \qquad = \frac{V \ x \ N \ x \ 1000}{G} \qquad 16$$

Where V - vol. of thiosulphate used (ml), N - normality of thiosulphate solution, and G - vol. of sample (ml).

2.3.9 Determination of Anisidine value:

This measures the amount of secondary oxidation in a raw sample of oil. Its products are aldehydes and ketones, whose oxidation induces higher rancidity effect to the oil. The experiment is aimed at determining the level of secondary oxidation which the oil has passed through.

Equipment /Materials and Procedure; These are the same as for the PV, except that the temperature at which these cleavage products were formed was higher

2.3.10 Determination of Iodine value:

Wij's method, adapted from[19] , was used. It is a measure of the degree of unsaturation of fat or oil. It is the number of gram of iodine which combines with the unsaturated bonds in 100g of fat. The aim is to determine the degree of unsaturation of fatty acid in the oil.

Procedure: 0.5g of oil sample was weighed into a 250ml stoppered bottle, and 15ml of chloroform was added to dissolve the oil. 25ml of Wij's solution was added and mixture was kept in a dark place and allowed to stand for 30minutes. At the end of the period, 20ml of 15% KI solution was added. This was shaken vigorously and the inside of the stoppered bottle was washed with 1ml of boiled and cooled water. This was titrated against a standard 0.1N sodium thiosulphate solution. The reagent was added with constant shaking until the yellow colour of the iodine almost disappeared. 2ml of 1% starch solution indicator was added before the titration was

continued. The end point was reached when the blue colour of iodine disappeared. A blank experiment was also carried out with equal proportion of the Wij's solution. The iodine Value was calculated as;

$$IV = \frac{(B-S)\ N \times 0.1269 \times 100}{W} \qquad 17$$

Where B - Volume of the standard Na_2SO_3 S - Volume of the standard Na_2SO_3 required for sample, N - Normality of the standard sodium thiosulphate solution, W - Weight of Oil sample in gram.

2.3.11 Determination of Iron (Fe)

Method of Cock and Rede, [20] , was used. Iron is a metal element which, with copper, induces oxidation of the unsaturated fats and oils at the double bond. Removal of iron will reduce the rate of oxidation reaction at the high temperature of deodorization. The aim is to determine the degree at which oxidation of the fatty acid is expected in raw palm kernel oil.

Procedure: 0.2mg Fe stock solution was pipetted into 100ml conical flask. 10ml of 10% hydroxylamine hydrochloride was added. The solution was diluted with water and mixed. 10ml of 0.25% phenolphthalein indicator was added and allowed to stand for 15 minutes and diluted to the mark. Using about 5ml test tube, the transmittance was read in spectrophotometer 20 at 510 UV light. The results of characterization experiments are presented in table 5

2.4 Diffusion parameters

2.4.1 Diffusivity

Equations 7, 8, and 9 were used to determine the diffusivity, diffusion rate, and mass transfer coefficient, respectively. Using 7, M_B was calculated from the normal boiling point of the oil which is oleic or luaric acid. For oleic and lauric acids with the molecular formulae of $C_{17}H_{33}COOH$, and $C_{11}H_{23}COOH$, the molecular weight is, 282Kg/Kmole and 241 Kg/Kmole respectively. Temperature, T=333.15K. Viscosity of pure substances is given by, $\mu = 0.324\sqrt{\rho t_b}$, [21] [22], where the normal boiling point of oil $t_b = 225.31$K, and density of oil at this point $\rho t_b = 0.87$g/cm^3, $\mu = 0.324(0.87)^{0.5} = 0.000302$Kg/m.s Molar volume V_B, of the oil at the normal boiling point is obtained by summing up the atomic volume of elements that make up the compound, $C_{11}H_{23}COOH$, Treybal, (1980), and the value was found to be 0.2812m^3/Kmole. Hence, $D_A = 4.0 \times 10^{-9}$m^2/s

2.4.2 Diffusion Rate

The rate at which the fatty acid diffuses into the solvent is given in equation 8. Now $D_A = 4.0 \times 10^{-9}$m^2/s, $M_{Hexane} = 86$ Kg/Kmole, $M_{oil} = 241$Kg/Kmole. It shall be assumed that the interphase is small and taken to be 0.001mm. The concentration of oil in solution of hexane at the meal side is assumed to be about 2%, the residual value, and 1% on the other side. Oil is glycerol ester of fatty acid, called triglycerides. As such, it may be assumed that the fatty acid composition of PKO is predominantly that of lauric acid. Hence we may use the density of glycerol ester as presented by Perry and Chilton, (1973), to compute the densities of 2% and 1% palm kernel oil respectively to be used in computing the rate of diffusion of oil into the solvent.

At 333.15K, density of 2% and 1% solution of oil as lauric acid is 1000.4Kg/m^3, and 998Kg/m^3, respectively, (Perry and Chilton,1973). Now mole fraction of oil in one side of the interphase

$$x_{A1} = 0.0072, \quad x_{B1} = 0.9927.$$

Molecular weight of mixture

$$M_1 = 87.123\text{Kg/Kmol}$$

$$\left(\frac{\rho_1}{M_1}\right) = \frac{1000.4}{87.123} = 11.483\text{Kmole/m}^3$$

Similarly, $x_{A2} = 0.0275, \quad x_{B1} = 0.9725.$

$$\left(\frac{\rho_2}{M_2}\right) = \frac{998}{236.74} = 4.216\text{Kmole/m}^3$$

Average molecular weight of the mixture

$$\left(\frac{\rho}{M}\right)_{av} = 7.849\text{Kmole/m}^3$$

Logmean of mole fraction,

$$(x_B)_{LM} = \frac{0.9927 - 0.9725}{\ln\dfrac{0.9927}{0.9725}} = 0.9823$$

This gave

$$N_A = 6.47 \times 10^{-7}\text{Kmole/m}^2.\text{s}$$

2.4.3 Mass Transfer Coefficient

The mass transfer coefficient is given by Eq. 9 as ;

$$N_A = K_x(x_{A1} - x_{A2}), \ [11],$$

where K_x - Mass transfer coefficient in the liquid phase.
Now Eq. 8 is,

$$N_A \quad = \quad \frac{D_{AB}}{z_2 - z_1(x_B)_{Lm}}\left(\frac{\rho}{M}\right)_{av}(x_{A1} - x_{A2})$$

Combining Eqs 8and 9, we have;

$$K_x = \frac{D_{AB}}{z_2 - z_1(x_B)_{Lm}}\left(\frac{\rho}{M}\right)_{av}$$

$$= \quad 3.2 \text{ x } 10^{-5} \text{ Kmole/m}^2.s$$

Similar calculations were carried out for other solvents and results presented in Table 3.

3. DISCUSSION

3.1 Extraction of Palm Kernel Oil From Oil Nuts

Ashton, [23], observed that a number of solvents can be used to leach out oil from the prepared seed. He noted that efficiency of extraction depends on a number of factors, including, extraction time, quantity of solvent, temperature of the system and the nature of solvent used.

Extraction time is a fundamental factor that affects the efficiency of oil extraction. This was explained by the observed relationship between the time of extraction and the residue oil in the cake. This relationship is given in Fig.1.
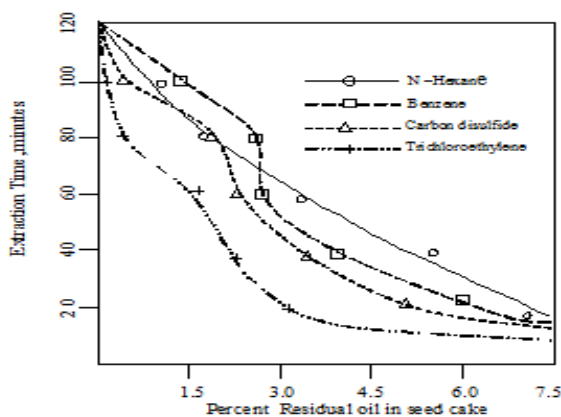

Fig. 1 Effect of extraction time on Oil Extraction

From the figure, it is noted that greater amount of oil was extracted during the first 30min of extraction. An extremely long extraction time is required to obtain a residue oil content of less than 1 percent. Every type of solvent behaves differently during the extraction process. The extraction time relate to quantity of oil extracted by a linear function down to a residual oil content of about 5%, below which the function has a curvilinear nature as shown.

3.1.1 Quantity of Solvent

Fig.2 shows the effect of solvent quantity on extraction efficiency at constant temperature and time
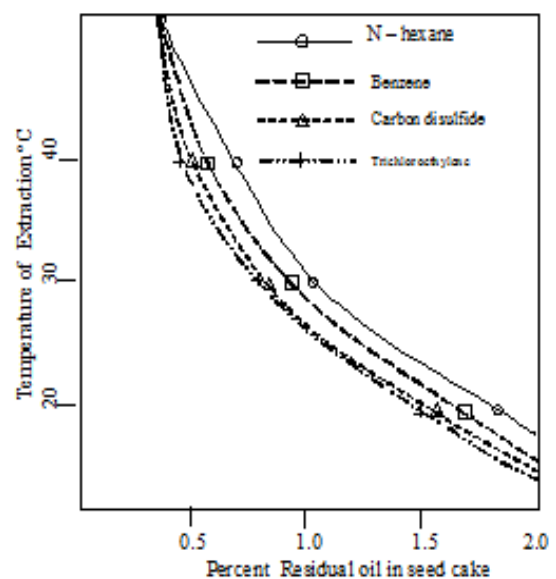

Fig.2 Effect of quantity of solvent on Oil Extraction

From the figure, it was observed that efficiency of extraction first increases with increase in solvent and after reaching a limit, the increase becomes marginal. The quantity of solvent used to reduce the residue oil content to less than 1% varies with the type of solvent as shown.

In Fig.3, the result of the effect of temperature on efficiency of solvent extraction is presented.
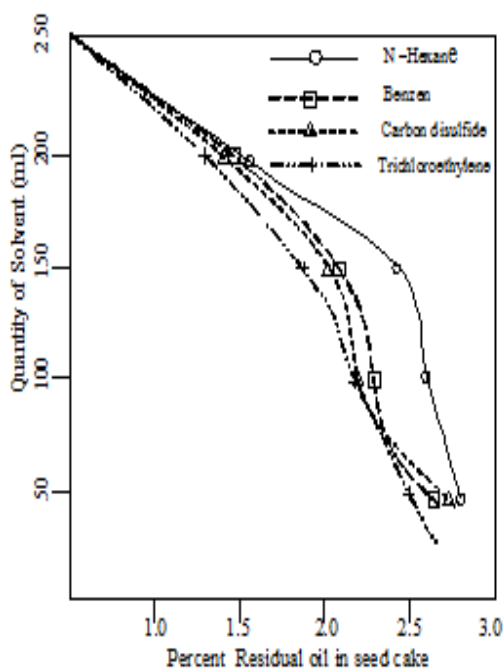
Fig.3 Effect of Temperature on Oil Extraction

phosphatide in the extracted oil. Odour is characteristic palm kernel oil odour, but taste is of palm kernel oil. The specific gravity increases in the order H-B-C-T, but marginal with Hexane and Benzene than Carbondisulfide and Trichloroethylene. The same judgement passed for the melting point, moisture, refractive index, Phosphorous, Iron, FFA, Peroxide and Anisidine values, and, of course Iodine value. Lovibond Tintometer Red colour reading confirmed the physical appearance where Hexane and Benzene extracted oils were found to be lighter in colour than Carbondisulfide and Trichloroethylene.

3.2 Properties of the extracted palm oil

3.2.1 Nature of Solvent

Figs. 1-3 also show the effect of solvent nature on the extraction process, that is , their dissolving power. The following were kept constant during the experiment; amount of palm kernel grit processed, time of extraction, solvent quantity and extraction temperature. From the figures, it was found that hexane and Benzene have the same solvent efficiency. Carbondisulfide has a higher solvent efficiency than Hexane and Benzene, but lower efficiency than trichloroethylene. It may be erroneously concluded that trichloroethylene has the highest extraction efficiency and hence the most suitable, but quality of oil is also an important factor which must be given due consideration

The results of characterization experiments are shown in table 2 for the extracted oils. The result showed that with increase in solvent temperature, the efficiency of extraction is improved.

From Table 2, it may be observed that colour of the extracted oil, when extraction was done with Hexane and Benzene, was light yellow compared with deep yellow obtained with Carbondisulfide and Trichloroethylene. This colour position was because, the latter have very high efficiency of extraction than the former, but also higher degree of impurities like

Table 2 Physio-Chemical Properties of the palm Oil extracted with Hexane, Benzene, Carbon disulfide and Trichloroethylene

Properties	n- Hexane	Benzene	Carbondisulfide	Trichlorothylene
Colour (Physical Appearance)	Light Yellow	Light Yellow	Light Yellow	Light Yellow
Odour	Characteristic of PKO	Characteristic of PKO	Characteristic of PKO	Characteristic of PKO
Taste	PKO taste	PKO taste	PKO taste	PKO taste
Specific Gravity	0.8752	0.8757	0.8756	0.8759
Melting Point(°C)	29	29	30	31
Moisture (%)	1.12	1.12	1.13	1.135
Refractive Index	1.4400	1.4401	1.4402	1.4403
Free Fatty Acid (%)	4.2	4.3	4.35	4.38
Lovibond Red Unit (1" Cell)	4.2	4.3	4.53	4.54
Anisidine Value (M.eq/kg)	6.5	6.5	6.95	7.25
Peroxide Value (M.eq/kg)	2.45	2.43	2.44	2.48
Phosphorous (Ppm)	6.5	6.51	6.52	6.54
Iron (Ppb)	3.5	3.45	3.52	3.48
Saponification Value	240	241	242	243
Iodine Value	22	22	23	24

3.2 Diffusion parameters

Diffusivity, Diffusion rate, and Mass Transfer Coefficient.

The diffusion parameters for the diffusion of Palm oil from meal into the solvent were calculated from Eqs 7, 8 and 9. The viscosity used in Eq 7 was given by Perry, (1973), as

$\mu = 0.324\sqrt{\rho t_b}$ = 0.000302Kg/m.s. The calculated diffusivity of 4.00 x

10^{-9} m^2/s was used in Eq. 8 to determine the rate of diffusion which was found to be 4.67 x 10^{-7}Kmole/m^2.s. The mass transfer coefficient was obtained by comparing Eq 9 with 8 and was found to be 3.20 x 10^{-5}Kmole/m^2.s for Hexane. Similar calculations were carried out and the results of table 3 obtained.

Table 3 Diffusion rate, Diffusivity and Mass Transfer Coefficient for the diffusion of Palm oil into solvents

Diffusion Parameters	Hexane	Benzene	Carbondisulfide	Trichloroethylene
Diffusion rate (10^{-7}) Kmol/m^2.s	4.00	4.10	4.50	4.90
Diffusivity(10^{-9})m^2/s	6.47	6.72	6.78	7.00
Mass Trans. Coef (10^{-5}) Kmol/m^2.s	3.20	3.50	3.80	4.00

From the table, it is observed that Hexane and Benzene have almost the same diffusion rate which is lower than those of Carbondisulfide and Trichloroethylene. This explains why extraction is more with the latter than the former. However, diffusivity of Benzene is marginally higher than that of Hexane. This shows that the penetrating power of Benzene is more than that of Hexane, but lower Carbondisulfide and Trichloroethylene. Since Extraction rate depends on time, Temperature , quantity and nature of solvents used, it then follows that same is proportional to diffusion rate. Diffusivity is inversely proportional to viscosity, but directly proportional to Temperature, other factor being constant. Extraction is essentially a diffusion process and the amount of oil extracted depends on the rate of diffusion of the oil into the solvent.

Diffusion rate of liquids is given in Eq 8 as;

$$N_A = \frac{D}{z}\left(\frac{\rho}{m}\right)_{av}\left(X_{A1} - X_{A2}\right)$$

Where D – Diffusivity, m^2/s

It follows that rate of diffusion, N_A is proportion to Diffusivity, D. But Diffusivity foe liquid substances is given by; $D = \dfrac{\psi(M)^{0.5}T}{\mu(V_A)^{0.6}}$. When the two equations are combined we obtain,

$$N_A = \frac{\psi(M)^{0.5}T}{\mu(V_A)^{0.6}{}_z}\left(\frac{\rho}{m}\right)_{av}(X_{A1} - X_{A2}),$$

from which we obtain,

$$N_A = \frac{D'T}{z}(X_{A1} - X_{A2}),$$

where

$$D' = \frac{\psi(M)^{0.5}}{\mu(V_A)^{0.6}{}_z}\left(\frac{\rho}{M}\right)_{av}$$

However, $(Z_{A1}-X_{A2})$ is fixed based on the extracted oil, then $N_A = D''T$, where, $D'' = D'(X_{A1} - X_{A2})$. It therefore means that rate of diffusion (extraction) of oil is proportional to temperature, and hence the higher the temperature the higher the extracted oil.

CONCLUSIONS

The results of our experiments have shown that the various solvents used in the extraction of oil from their oil seeds, have different performance capacities.

The results (Figs 1-3) show that Carbondisulfide is the most efficient in terms of yield, followed by Trichloroethylene , when the purity of the final product is not the major factor of consideration. N-hexane and Benzene are ideal for extraction when oil of premium quality is required. Infact, they are needed in the extraction of oils for edible purposes. The results also showed that time, and temperature of extraction, as well as, the nature and quantity of solvent used play a vital role on the extraction yield.

REFERENCES

[1] 4,000-year old "kitchen" unearthed in Indiana. Archaeo News. January 26, 2006. Retrieved 30 – 12 – 2011.
[2] Mahatta, T.L (1975), Technology of refining oils and fats, Small Business Publications (SBP) Building 4//45 Roop Nagar, Delhi.
[3] Anderson A.J.C. (1962), "Refining of oil for edible purposes," 2nd ed. Pergamon Press London.
[4] Pahl G, (2005), Biodiesel growing a new energy economy,White River Junction VT; Chelsea Green Publishing Co.
[5] Janet Bachmann, Oil seed Processing for Small – Scale Producers.   http://www.attra.org/attar-pub/oilseed.html. Retieved 2012 – 10 - 11
[6] "Kalu (Oil presser)" Banglapedia. Retrieved 12 – 11 - 2012.
[7] Rydberg, J., Musikas, C.,Choppin, G.R., (1992), Principles and practice of solvent extraction, Marcel Dekker
[8] Gurnhan and Masson (1975), Industrial Engineering Chemistry, 38, 1309
[9]Davie, and Vincent, (1980), Extraction of vegetable oils and fats, Simon Rosedown Ltd, Cannon Str. Hull, U K.
[10]Tray and Bilbe,((1987), Solvent Extraction of vegetable oils, Chem. Eng. (N.Y),54,5,139.
[11] Treybal, R. (1980), Liquid – Liquid extraction, McGraw – Hill New York.
[12] Bird, B.R., Warren, E.S ., and Edwin, N.L (2003), Transport Phenomena, John Wiley and Sons New York
[13] Perry, R.H., and Chilton, C.H., (1993), Chemical Engineering Handbook, 5th ed. McGraw – Hill New York.
[14] Fan and Co workers, (1987)Industrial Engineering Chemistry, 38,905.
[15] Treybal, R. (1980), Liquid – Liquid extraction, McGraw – Hill New York.
[16] Mahatta, T.L (1987), Technology of refining oils and fats, Small Business Publications (SBP) Building 4//45 Roop Nagar, Delhi.
[17] Walter, L.B. ,James, T.B. (1975), Vegetable Oil Extraction, Theory and Procedure, Vicka Publishing House, PVI Ltd, New Delhi.
[18] AOCS Official Method Cd 8 - 53. Surplus peroxide Value Acetic acid – Chloroform method Definition; AOCS Cold Spring Harbour, New York, NY, U.S.A
[19] ALFA-LAVAL (1978), Analysis of Fats and Oils, Laboratory manual, Sweden.
[20] Cocks, L.V and Rede, V.C, (1966), Laboratory Handbook for Oil and Fat Analysis, Academic Press London.
[21] Perry, R.H., and Chilton, C.H., (1973), Chemical Engineering Handbook, 5th ed. McGraw – Hill New York.
[22] Egbuna S.O., (2005), The Fundamentals of Mass Transfer, Sege Ventures, Pp. 8 – 22, ISBN 978-37147-9-1.
[23] Ashton, N.F, (1983), Handbook of Chemistry, 2nd ed. W.H Freeman and Company, New York, Pp280-480.