DEVELOPMENT OF A LABORATORY MODEL MECHANICAL PALM KERNEL OIL EXPELLER

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ABSTRACT

In the laboratory, small quantities of freshly expelled oil are often required for on-the-spot analysis. This small quantity of oil can be obtained from oil bearing seeds or nuts like palm kernel at an affordable price using a model mechanical rig coupled to a Universal Testing Machine (UTM) or any suitable press. In this study, a model mechanical expression rig with a heater band was designed, fabricated and tested using ground palm kernel. In the design, the size of the cylinder (diameter and length), the size of the piston, the maximum pressure desired, the maximum load available from the universal Testing Machine, the maximum cross-head travel from the load frame of the UTM, and the temperature controller were considered and determined. A travel or loading speed of 2.5mm/min suitable for agricultural materials was adopted during the testing of the model.

Results from the tests carried out showed that an average value of 38.32% oil yield corresponding to 76.63% oil recovery was obtained for pre-heated grounded palm kernel sample, while oil yield of 20.42% corresponding to 40.83% oil recovery efficiency was obtained for grounded palm kernel samples not pre-heated before oil expression. These values compares favourably with values obtained from literature. Statistical analysis using t-test also revealed that there was significant difference between the values of oil yield and oil recovery efficiency respectively obtained from the pre-heated and the non pre-heated samples at 5% confidence level.

Quality evaluation of the crude palm kernel oil expressed using the model showed that the free fatty acids, iodine value and the solid fat content values of the oil obtained from pre-heated samples were lower than that obtained from samples not pre-heated, implying that oil expressed from pre-heated palm kernel is of better quality when compared to the oil obtained from palm kernel not pre-heated. Also the characterization values obtained from the oil expressed using the model compares favourably to values obtained from literature.

KEYWORDS: Vegetable oil, palm kernel, oil expeller, palm fruit.

1. INTRODUCTION

In the world of oils and fats, the lauric oils are the aristocrats. There are very few of them, they move in their own higher price plateau and they do not mix comfortably with the common oils and fats. Among the 17 major oils and fats in the world trade there are only two lauric oils, coconut oil (CNO) and palm kernel oil (PKO) (Oil World Annual, 2000) and they are called lauric because lauric acid is the major fatty acid in their composition at about 50%, while no other major oil contains more than about 1%. (Malaysian Palm Oil Board (MPOB), 2001).

The coconut palm is scientifically called *Cocos nucifera*, while the Oil Palm which gives both Palm Oil (PO) and PKO is referred as *Elaeis guineensis* (Hartley, 1988). The palm fruit looks like a plum. The outer fleshy mesocarp gives the palm oil (PO), while the kernel which is inside a hard shell, gives the PKO and it is rather strange that the two oils from the same fruit are entirely different in fatty acid composition and properties. Unfortunately, the two oils were often confused by nutritionists in earlier days. In PO, most of the fatty acids are C16 and higher, while in PKO, they are C_{14} and lower. PO has iodine value (IV) 50 minimum, while PKO has 21 maximum (Codex Alimentarices Commission, 1999). Because PKO are Semi-solid in temperate climates, it can be fractionated into solids and liquid fractions known as Sterin and Olein respectively.

Oil can be extracted from nuts and seeds by heat, solvents or pressure. Extraction by heat is not used commercially for vegetable oils (Casten and Snyder, 2001). Pressure extraction separates the oil from the solid particles by simply squeezing the oil out of the crushed mass of seeds. The simplest method is to fill a cloth bag with the ground seed pulp and hang the bag so that it can drain. Some of the oil, called free oil flows out, the rest must be pressed out mechanically. The simplest way is by placing heavy rocks on the materials or bags of oil seed pulp can be placed one above another in a box or cylinder, and great pressure can be slowly applied on the whole mass. A long lever can exert up to 4.58 KN. Since great pressure provides greater oil recovery, heavy and strong mechanical jacks of several designs (screw jacks, ratchet jacks and hydraulic jacks) have often replaced the lever (Casten and Snyder, 2001).

The solvent extraction method involves milling of the kernel, pressing the meal and dissolving the cake in some appropriate solvent, e.g. Hexane. The oil-solvent mixture is filtered off, while the cake and the solvent are later evaporated to recover the oil. The screw press method involves the feeding of the pre-heated kernels into the screw mechanism made of an interrupted helical thread (worm), which revolves within a stationary perforated cylinder called the cage or barrel. The fed kernels are ferried through the barrel by the action of the revolving worms. The volume axially displaced by the worm diminishes from the feeding end to the discharge end, thus compressing the meal as it passes through the perforation of the lining bars of barrel, while the de-oiled cake is discharged through an annular orifice. Mechanical oil expression (rig) equipment is designed for optimum performance in order to meet specified usage. In the laboratory, small quantities of oils are usually required for analysis; hence it is desirable that a model mechanical oil expression rig that can efficiently handle small quantities of oil-seeds or nuts be provided. Although there exist small capacity screw and hydraulic presses, the importation cost of such units is prohibitive, it is therefore desirable that the alternatives be fabricated locally, hence this study.

The objectives of this study were:

i) Design and fabricate laboratory model mechanical oil expression rig for oil seeds and nuts.
ii) Test the model mechanical oil expression rig using Universal Testing Machine (UTM) in order to determine its optimum operating conditions
iii) Characterize the oil obtained from the test.

2. MATERIALS AND METHODS

2.1 Design Considerations

The mechanical oil expression process normally involves the application of compressive forces to the oil seed/nut sample enclosed in a suitable filtering or retaining envelops. In this work, the mechanical expression rig was designed as a piston-cylinder assembly coupled to the TESTOMETRIC Universal Testing. Machine (Model M500-50KN) or any suitable hydraulic press as shown in figures 1 and 3 respectively.

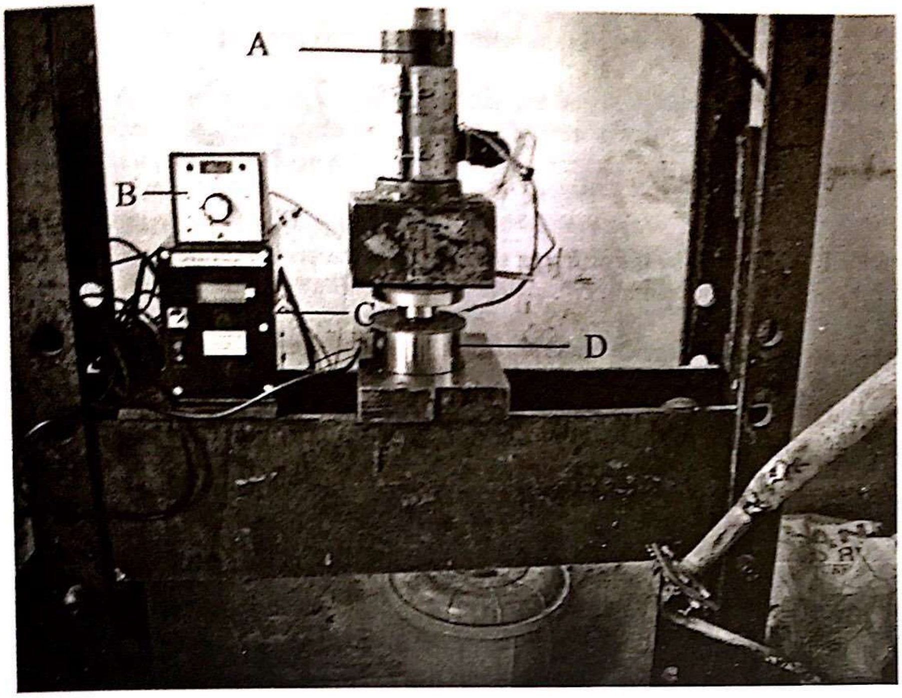

Figure 1. Assembly of the designed mechanical oil expression rig on hydraulic press.
(a) Mechanical Oil Expression Rig, (b) Temperature Controller, (c) Amplifier with display Unit, (d) Load Cell

The following criteria were considered in the design of the mechanical oil expression rig:

- (i) The minimum pressure required to be applied on the sample before oil can be squeezed out;
- (ii) The maximum load available from the Universal Testing Machine (UTM) – 50 KN
- (iii) The maximum travel distance of cross head of UTM – 1000 mm.
- (iv) Desired maximum distance the piston can travel in the cylinder – 100 mm.
- (v) The optimum processing temperature of oil seeds/nut, especially palm kernel.
- (vi) Ability of the supporting platform to bear the maximum allowable load from the UTM.
- (vii) Heat treatment, temperature sensing and temperature controller.
- (viii) Ease of collection of the expressed oil.

2.2 Design Theory

The components of the model mechanical expression rig including the press cage cylinder, the drainage area, the compression piston and the supporting platform were designed based on the following theory.

2.2.1 Maximum Pressure on the Press Cage Cylinder

The press cage cylinder is considered as a thick cylinder under pressure from the compression piston coupled to the UTM. Since the UTM has a maximum capacity of 50 KN, the pressure exerted on the sample in the press cage cylinder was computed using equations 1:

$$P = \frac{F}{A} \qquad (1)$$

$$A = \frac{\pi D^2}{4}$$

$$\therefore P = \frac{F}{\frac{\pi D^2}{4}}$$

$$= \frac{4F}{\pi D^2} \quad (2)$$

Where F = Force from the UTM exerted by the piston on the sample in the press cylinder = 50 KN; D = internal diameter of the press cage cylinder (mm); P = applied pressure. (MPa).

2.2.2 Combined Stresses on the Press Cage Cylinder

Due to the pressure applied by the piston on the sample in the cylinder, the cylinder is subjected to three principal stresses. According to Ryder (1985), these stresses were obtained as follows:

The circumferential stress;

$$\sigma_1 = \frac{PR}{t} \quad (3)$$

The longitudinal stress is given as

$$\sigma_2 = \frac{PR_i}{2t} \quad (4)$$

The radial stress is given as;

$$\sigma_3 = -P \quad (5)$$

Where: P = maximum pressure applied on the pressed sample in the press cage cylinder (MPa); Ri = inside radius of the press cage cylinder (mm); t = thickness of the press cage cylinder (mm); R = outside radius of the press cage cylinder (mm); σ_1, σ_2, and σ_3 = circumferential, longitudinal and radial stresses respectively (MPa).

2.2.3 Thermal Stress on the Press Cage Cylinder

Due to heating, there is very high tendency that there will be change in temperature which will have effect on the strength of mild steel material used for the construction of the press cage cylinder. According to Perry (1988), the thermal stress at the heating surface of the press cage cylinder was obtained using the equation given below:

$$\sigma_1 = \frac{-\alpha(\Delta T)E}{2(1-\theta)} \quad (6)$$

Where: σ_t = thermal stress at the outside of the press cage cylinder in contact with the heating device; α = coefficient of linear expansivity of mild steel = 12 156/^{0}C (Nash; 1977); E = Modules of elasticity of mild steel = 205 GN/m2 (Ryder, 1985); ΔT = temperature change (^{0}C); θ = Poisons ratio = 0.291 for mild steel material (Ryder, 1985).

2.2.4 Design of the Compression Piston

From Mrema and McNutty (1985), it was reported that for a piston – cylinder mechanical oil expression rig the relationship between the piston diameter and the cylinder diameter can be expressed as:

$$D_p = \frac{D_l}{1.0004} \quad (7)$$

Where D_p = piston diameter; D_i = inside diameter of cylinder.

With this diameter, a piston length longer than the height of the press cage cylinder was selected. This was to prevent the upper attachment of the UTM from coming in contact with the top of the press cage cylinder during oil expression process.

2.2.5 Design of the Press Cage Cylinder Base Perforations

The total area of the holes of 3mm diameter was expected to occupy 12.5 percent of the area of this section and this serves as the drainage area for oil expression. Thus the number of holes to be drilled was computed using equation 8 below:

$$N = 0.125\frac{A_s}{A_h} \qquad (8)$$

Where: $A_s = \frac{\pi d_s^2}{4}, A_h = \frac{\pi D_h^2}{4}$

Where: N = number of holes to be drilled as base perforations; d_s = diameter of the section of the supporting platform covered by the cylinders circumference; D_h = diameter of a hole to be drilled; A_s = area of the section of the supporting platform covered by the cylinders circumference; A_h = area of a hole.

2.2.6 Design of the Supporting Platform

The supporting platform is a built-up channel of a square cross-section. Due to the action of the applied pressure from the UTM through the compression piston, failure can occur in two ways. The two failure possibilities are bending of horizontal portion and buckling of the vertical member. Since the maximum load from the UTM is 50 KN, the design was predicted on the fact that member horizontal will not fail by bending and that the vertical member, will not fail by buckling.

2.2.7 Design of Heating System

The quantity of heat (Q) in Joules absorbed by a body of Mass (M) kilogram and specific heat capacity (C) in Joule per kilogram per degree centigrade, when there is a temperature change of $(\theta_2 - \theta_1)$ if the losses is negligible is given by Okeke et al (2000) as:

$$Q = MC\theta \qquad (9)$$

The mass of the rig barrel was determined to be 2.5 kg. The barrel was made of mild steel therefore; the specific heat capacity is 450 J/Kg^{0}C. The maximum temperature expected is 130^{0}C and the minimum is the room temperature which was taken as 30^{0}C. Therefore, the highest value of temperature difference was determined to be 100^{0}C. From equation (9) the heat required to bring the barrel from room temperature θ_1 to the maximum (required) temperature θ_2 is

Q = 2.5 X 450 X 100 Joule;
=112,500 Joules.

Electricity was used as the source of power for this work. Therefore, the heat generated (Q) is related to current (I), voltage (V) and the time (t) taken for the current to flow according to Okeke and Anyakoha (2000);

$$A = IVt \qquad (10)$$

From (10) the power rating of the heater band used P is given by

$$P = \frac{Q}{t} \qquad (11)$$

For the purpose of this work the time t was taken to be 3 minutes and the power rating for the heater band was found to be 625 Watts.

2.2.8 Selection of Temperature Controller

To maintain the rig temperature constant, a temperature controller with ease of operation was required. Thus, an electronic temperature controller operating at the range of 0^0C to 400^0C (model JTC-902) was selected because it met all the aforementioned requirements and was also compatible with K-type thermocouple which further made it easier to be used with the rig.

2.3 Description of the Fabricated Model Laboratory Mechanical Oil Expression Rig

Figure 2 shows the exploded view of the designed model laboratory mechanical oil expeller. The model laboratory mechanical oil expeller is made up of three major components: the compression piston, the press cage cylinder and the supporting platform. The press cage cylinder was made from a mild steel pipe with an inside diameter of 66 mm, 7 mm thick and 140 mm long. Using the hand drilling machine, a 5 mm hole was drilled on one side of the press cage cylinder at a height of 7 mm from the base. This hole is for the fixing of thermocouple probe for temperature monitoring.

The compression piston of 220 mm was cut out using power hacksaw and turned to about 65 mm diameter using a lathe machine. From the height of 30 mm from the base, the piston was stepped down to a diameter of 45 mm. At a height of 10 mm from the top, a hole of 15 mm diameter was drilled through the transverse section of the piston. From the top of the piston, a bore of 32 mm diameter was made downwards to a height of 60 mm. All these were done for easy attachment of the piston to the upper crosshead of the UTM during oil expression.

The supporting platform was constructed using a built-up channel of 84 mm x 84 mm x 8 mm from which 140 mm length was cut out using power hacksaw. Sharp edges were smoothened to prevent injuries during handling using a manual grinding machine. 61 holes of 3 mm each were drilled in the section of the supporting platform covered by the press cage cylinder's circumference. Internally-threaded circular knot of 80 mm, 10 m thick and 12 mm high was made from a mild steel material and welded to the top of the supporting platform. This knot encircles the drainage area and also serves as the cylinder holder/guide. The press cage cylinder was threaded externally to a height of 12 mm from the base. It was then screwed down inside the cylinder guide to fit firmly on the supporting platform.

A 600 W electric band heater was installed round the press cage cylinder to serve as a heating device for the expression process. The rig was adequately instrumented with a temperature controller to control the expression temperature, while the pressure for oil expression was obtained from the UTM. The temperature controlling exercise was achieved with thermocouple connected to an Electronic Temperature Controller (Model JTC-902) which was designed and manufactured in Japan.

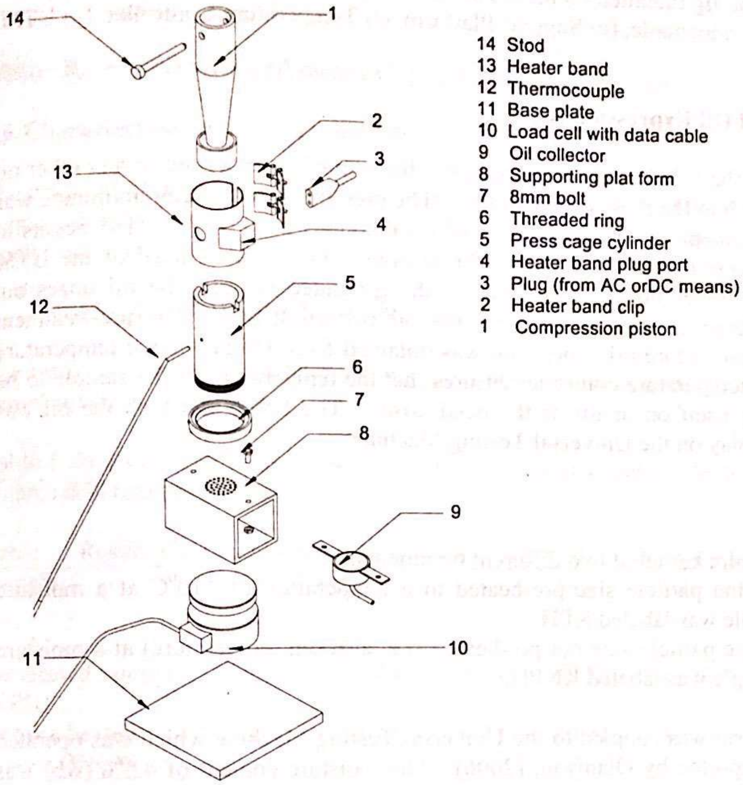

Fig. 2. Exploded view of the designed model laboratory mechanical oil expeller

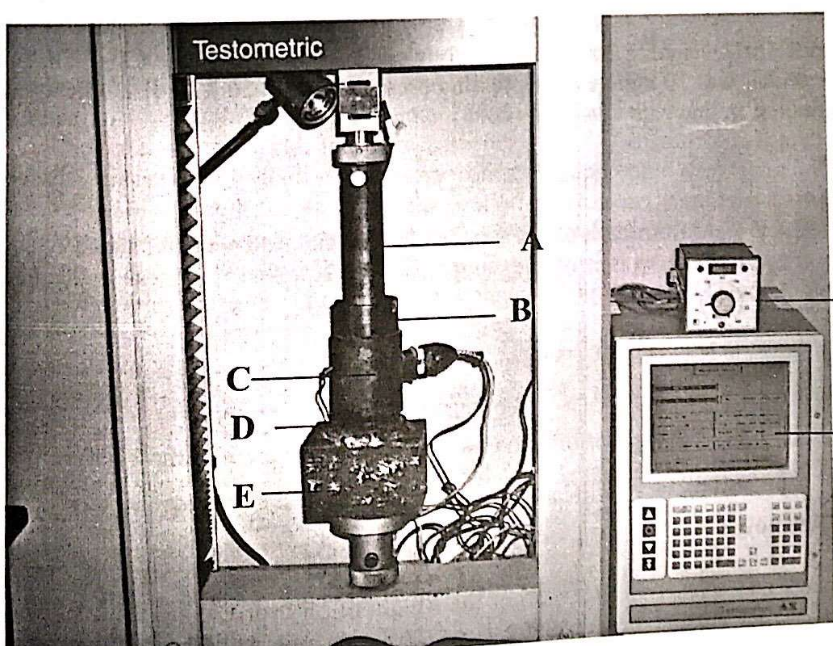

Figure 3. Mechanical oil expression rig mounted on the UTM. (a) Compression Piston, (b) Press Cage Cylinder, (c) Heater Band, (d) Thermocouple, (e) Support Platform, (f) Temperature Controller, (g) UTM Display Unit.

2.4 Operation of the Mechanical Oil Expression Rig

After the rig had been coupled to the UTM as shown in figure 4 the ground palm kernel or any other oil seed or nut to be pressed were put into the press cage cylinder. The pressing speed of 2.5mm/minute was selected from the UTM, and the compression piston mounted on the cross head of the UTM begins to move downward into the press cage cylinder containing the sample. As the cross head of the UTM carrying the compression piston moves down, it compresses the grounded sample, the oil oozes out through the perforations at the base of the cylinder into the oil collecting pan. The pre-treatment temperature of the grounded sample before oil expression was obtained from the automatic temperature controller preset. The automatic temperature controller ensures that the temperature of the sample to be pressed is maintained by tripping itself on or off as the need arises. The Force at which the oil was expressed is read out from the display on the Universal Testing Machine.

2.5 Test Procedures

Two tests were performed using palm kernel of two different treatments:

i) Ground palm kernel of fine particle size pre-heated to a temperature of 110^{0}C at a moisture contents of 4.5% the sample was labeled KPH
ii) Ground palm kernel of fine particle size not pre-heated (I.e. at room temperature) at a moisture content of 4.5%. The sample was labeled KNPH.

The fabricated model mechanical rig was coupled to the Universal Testing Machine which was operated at a speed of 2.5mm/minute as reported by Olaniyan, (2006). The moisture content of 4.5% (wb) was used based on preliminary investigations and literature search, as reported by Akinoso et al (2006). The palm kernel sample used was of fine particle size because preliminary investigation showed that the fine particle size gave the highest oil yield when compared to the medium and coarse particle size respectively.

Each sample, (KPH and KNPH) weighing 200g respectively were used for each of the tests. The heating time of the press cage cylinder was 20 minutes, the pressing pressure was 13.56 MPa (i.e. 45KN) and the pressing time was 10 minutes, in line with Olaniyan (2006).

2.5.1 Oil Yield

At the end of the test runs, oil yield from each of the samples for the trial tests was calculated as the ratio of the weight of oil expressed to the weight of the sample before expression. It was mathematically expressed by Adeeko and Ajibola (1989) as:

$$Y_o = \frac{W_o}{W_s} \times \frac{100}{1}\% \quad (12)$$

Where: Y_o = Oil yield (%); W_o = Weight of oil expressed (g); W_s = Weight of sample before expression (g).

2.5.2 Oil Recovery Efficiency

The oil recovery efficiency was calculated as a ratio of the weight of oil expressed to the total weight of oil in the milled palm kernel sample before expression. Adeeko and Ajibola (1989) expressed it mathematically as:

$$R_e = \frac{W_o}{XW_s} \times \frac{100}{1} \% \quad (13)$$

Where: R_e = oil recovery efficiency (%); X = oil content of palm kernel (50%).

2.6 Characterization of Expressed Oil

The crude oil obtained was characterized by determining the free fatty acid, the saponification values and iodine values; all in replicates using appropriate methods of chemical analysis, Association of Official Analytical Chemists (AOAC) (1975). The values obtained are shown in table 5.

3. RESULTS AND DISCUSSION

The results of the tests carried out using the model mechanical oil rig on two different samples of palm kernel are presented in tables 1 - 3.

Table 1 shows the values of oil yield and oil recovery efficiency obtained for each sample of palm kernel at three different replications.

Table 1. Result of oil yield and oil recovery efficiency of ground palm kernel.

Sample	Oil yield (%)			Avg. (%)	Oil Recovery Efficiency (%)			Avg.
	1	2	3		1	2	3	
Pre-heated sample (KPH)	39.11	37.40	38.44	38.32	78.22	74.80	76.88	76.63
Not pre-heated sample (KNPH)	22.30	18.22	20.72	20.41	44.60	36.44	41.44	40.83

These results were subjected to statistical analysis using Student t method (t-test).Tables 2 and 3 respectively shows the results of the analysis. The statistical analysis shows that there is significant difference between the pre-heated palm kernel samples (KPH) and the non pre-heated palm kernel samples (KNPH) in both oil yield and oil recovery efficiency at 5% level of significance. A higher oil yield of 39.11% which corresponds to 78% oil recovery efficiency was obtained from the pre-heated palm kernel sample (KPH), while the sample not pre-heated (KNPH) gave a lower oil yield of 22.3% corresponding to 44.6% oil recovery efficiency. These results show that pre-heating of the sample before expression increases the oil yield; this is in agreement with Olaniyan (2006) and Akinoso et al (2006) respectively. Values of oil yield, oil recovery efficiency and some characterization of palm kernel oil from palm kernel oil using the designed mechanical oil expression rig was compared with values obtained from literature, Tables 4 and 5 shows that the values obtained compare very favourably with values obtained from literature. This implies that the locally designed and constructed low cost model expeller performs comparably well with the imported expensive oil expellers.

Table 2. Sample literature values of oil yield and oil recovery efficiency compared to the values obtained using the developed model.

	Literature values [a]	Model Values	
		PKH	KNPH
Oil yield (%)	38.18	38.32	20.41
Oil recovery efficiency (%)	76.80	76.62	40.83

[a]Akinsono et al 2006

Table 3. Some characterization literature values of palm kernel compared to the values from the developed model.

	Literature values [b]	Model values	
		KPH	KNPH
Free fatty acids (Lauric acid C_{12})	48.5%	48.3%	49.2%
Iodine values	16.2 – 19.2%	18.7%	20.40%
Solid fat content (%) at 20^0C	40%	38.7%	40.60%

[b]Pantzaris and Ahmad, 2001

4. CONCLUSION

A model mechanical oil expression rig was designed and fabricated. The unit was tested with pre-heated and non pre-heated ground palm kernel samples and found capable of expressing oil. Statistical analysis showed that there was significant difference in the oil yield and oil recovery efficiency respectively between the pre-heated and non pre- heated samples at 5% confidence level. The model gave an average of 38.32% oil yield which corresponds to 76.63% oil recovery efficiency for pre-heated ground palm kernel and 20.41% oil yield corresponding to 40.83% oil recovery efficiency for non pre-heated ground palm kernel respectively; which is favourably comparable to values obtained from literature. Also, crude oil obtained was found to be of high quality as its characteristics were comparable to literature values for palm kernel oil.

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