

The Development of Expeller for Palm Kernel based Seed and its Oil Characterization

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Abstract: Palm kernel oil (PKO) is under-exploited and the rural-based oil extraction equipment has a low efficiency in Nigeria. Therefore, development of a palm kernel oil expeller and investigation of the suitability of the oil extracted are presented. The expeller is modified in such a way that the expulsion unit and palm kernel cake section are carried out simultaneously thereby minimizing tardy time and boosting productivity. The key principal units of the machine namely, hopper, upper and lower barrel, hand wheel, etc. are designed. The expeller is robust and easy to operate. The efficiency of the expeller and production capacity were detected to be 60.3% and 35 kg/h, respectively. The basic properties of the PKO concur with those of vegetable oils and *Jatropha* oil extracted from expeller machine in literatures but are not within the ranges of ASTM and EU standards. Proper utilization of the oil can be ensured by blending it with diesel fuel or subjecting it to transesterification process. The adapted oil expeller is feasible for the extraction of oil from palm kernel seed.

Keywords: Design, Palm kernel seed, Properties, Performance, Extraction, Efficiency

1. Introduction

Various methods are available for oil extraction from oilseeds such as coconut, olive, palm fruit, shea butter, etc. Traditional Ghanis originated from India is majorly used to crush oil from mustard and sesame seed, coconut and groundnut [1]. This method of extraction is slow and not sustainable [2]. Oil plate presses adopted for expressing oil from palm fruit is affected by intensity of pressure application [3]. Solvent extraction as a mean of extraction of oil is highly capital-intensive, imparting quality of oil [4]. On the other hand, oil expellers are mostly used to crush oil from assorted lipid feedstocks. Oil expeller is easy to operate, versatile to various oil seeds, less complex and cheap to maintain [5].

Long time ago, Omobuwajo et al. [6] investigated the heat generation and temperature distribution in the barrel of the oil expeller. However, the researchers recommended a critical study of thermal influence of the expeller. Khan and Hanna [7] highlighted that extracting factors such as pressure, temperature, pressing time and moisture content of the seed significantly affect the oil yield during extraction. William et al. [8] hinted that increase in the temperature and decrease in the moisture content increase the rate of oil extraction. Isobee et al. [9] indicated over 93% oil recovery from a screw press fabricated for untreated sunflower seed.

Tunde-Akintunde [10] reported temperature in the range of 70-80 °C and heating temperature for extracting oil from soybean seed expeller. Ajibola et al. [11]

indicated 64% extraction efficiency for palm kernel seed. Akinoso et al. [12] investigated effects of the compressive stress, feeding rate and speed of operation on an oil expeller. Of all investigated parameters, compressive stress mostly influences the oil yield. Martins et al. [13] developed a low-cost expeller for extracting oil from *Jatropha* and castor seeds. The authors highlighted that their designs enable control of compression ratio and pressure drag. Samuel and Alabi [14] recommended laboratory test and analysis for improving the productivity of palm kernel oil mills. Olaniyan et al. [15] designed a portable screw expeller for palm kernel and soybean oil expeller. The authors identified high oil yield and extraction efficiency with the expeller.

Onto et al. [16] reported that properties of oil obtained from oil expeller are superior to solvent extraction. Akerele and Ejiko [17] reported 72.94% of extraction efficiency for the horizontal expeller designed for groundnut oil. Recently, innovations are being introduced to improve the oil yield of expeller. Bahadar et al. [18] simulated pressure distribution inside the barrel of the screw press Odewale et al. [19] fabricated a U-shaped screw jack for oil extraction.

Extraction loss in the screw jack was slight. The existing literature discussed expellers on seed such as roaster cum [20]; ground nut [21]; sunflower [22]; *jatropha* [23] and rice bran seed [24]. However, few authors report on palm kernel oil expeller while none mentioned property of its oil. The study attempted not

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only to fabricate screw expeller but also characterize the oil.

2. Material and Design Theory

Procurement of palm fruit took place at Effurun market, Delta State, Nigeria. After cleaning and drying of seeds, extraction commenced. The palm kernel oil expeller is designed to have components such as hopper, screw conveyor, barrel, power transmission elements, oil container, bearings and machine base.

The criteria for choice of the materials for the various components of the machine is on the type of force application, applicability, environmental condition in which they will function, useful physical and chemical properties, cost and availability in the local market [25]. The basic components of the expeller were mild steel with torsional shear stress, τ of 55 MN/m²; density of 7850 kg/m³; modulus of elasticity, E of 200 GN/m²; modulus of rigidity, G of 80 GN/m² and angle of twist of 3 °/m [26].

2.1 Shaft Design

The design of the shaft was based on combined shock and fatigue, bending and torsional moment [26] and evaluated with equation (1a).

$$d^3 = \frac{16}{\pi\tau} [(K_b M_b)^2 + (K_t T_t)^2]^{1/2} \quad (1a)$$

where τ is the torsional shear stress, K_b is the combined shock and fatigue factors applied to the bending moment, K_t is the combined shock and fatigue factors applied to the horizontal component, M_b is the bending moment and T_t is the torsional moment. The respective values of $K_b = 1.5$, $K_t = 1$, $M_b = 3.55 \text{ Nm}$, $T_t = 687.89 \text{ Nm}$ were substituted in equation (1a) and the value of shaft diameter calculated in equation (1b) as follow:

$$d^3 = \frac{16}{3.14 \times 55 \times 10^6} [(1.5 \times 3.55)^2 + (1 \times 687.89)^2]^{1/2} = 45.7 \text{ mm} \quad (1b)$$

Hence, a 45 mm diameter rod of length 700 mm was used.

2.2 Screw thread design

The screw threading system was designed with a decreasing screw depth as reported by Adetola et al. [27] and evaluated in equation (2).

$$U_n = a + (n - 1)d \quad (2)$$

where U_n is the screw depth at the discharge end, a is the screw depth at the discharge end, n is the number of turns and d is the common difference between next successive screw depths. Given that $U_n = 2 \text{ mm}$, $a = 8 \text{ mm}$ and $n = 9$ turns; hence, $d = -0.75 \approx -1 \text{ mm}$.

2.3 Design for torque

The design for the torque is in line with the maximum shear theory stipulated by Oyinlola et al [28] and evaluated with the aid of equation (3)

$$T = \frac{\pi d^3 \tau}{16} = 983.58 \text{ Nm} \quad (3)$$

where T , d and τ are the torque exerted (Nm), diameter of the shaft (45 mm) and torsional shear stress (55 MN/m²), respectively.

2.4 Design for Power Requirement

The power required to drive the screw shaft was evaluated as indicated by Khurmi and Gupta [26] and computed using the expression outlined in equation (4).

$$P = \frac{2\pi N}{60} \times T = 3.09 \text{ kW} \quad (4)$$

where P , N and T are the required power (kW), maximum speed of the shaft, 30 rpm and torque, 983.58 N/m

2.4 Power of the Electric Motor

The power of the electric motor to drive the screw press was estimated as given by Adetola et al. [27] and computed with equation (5).

$$P_m = \frac{P}{\eta} = 4.12 \text{ kW} \quad (5)$$

where P_m and η are the power of the electric motor and the drive efficiency, 75%.

2.5 Design for Expeller Barrel

Selection of mild steel for design as it can withstand shock and vibration [29]. Clearance of 1.5 mm adopted between the shaft and barrel. Computation of internal diameter of the barrel was achieved by equation (6).

$$d_i = d_s + 2C = 48 \text{ mm} \quad (6)$$

where d_i , d_s and C are the internal diameter of the barrel, shaft diameter, 45mm, and clearance, 1.5mm respectively.

2.6 Outer Diameter of the Barrel

The outer diameter, d_o , was calculated with equation (7) employing the wall thickness, t_w , of 10 mm as suggested by Adetola et al. [27] and Ojolo et al. [30].

$$d_o = d_i + 2t_w = 68 \text{ mm} \quad (7)$$

2.7 Design for hopper

The hopper is the component that receives the oilseeds for expelling. It was designed to facilitate loading, maximum volume utilization and reliable and complete gravity discharge through its outlet [31-32]. The volume of frustrum is calculated using equations (8a) and (8b) while the areas of upper base and lower base were calculated using the expressions in equations (8c) and (8d) as reported by Salawu et al. [33].

$$V_h = \frac{h}{3} [A_1 + A_2 + \sqrt{A_1 A_2}] \quad (8a)$$

$$V_h = \frac{155}{3} [59925 + 4875 + \sqrt{59925 \times 4875}] = 4231 \text{ cm}^3 \quad (8b)$$

$$A_1 = 255 \text{ mm}^2 \quad (8c)$$

$$A_2 = 75 \text{ mm}^2 \quad (8d)$$

where V_h , h , A_1 and A_2 are the volume of the hopper, height of the hopper, and area of the upper and lower base of the hopper, respectively.

2.8 Maximum mass of seed

Maximum mass of seed processed was determined with equation (9).

$$m_s = V_h \rho_b = 2.58 \text{ kg} \quad (9)$$

where m_s , V_h and ρ_b are the unknown mass of palm kernel seed (kg), volume of the hopper (cm^3) and bulk density of palm kernel seed (0.61 g/cm^3), respectively

2.9 Computation of shaft speed

The shaft speed was computed with equation (10) as indicated by Khurmi and Gupta [26].

$$N_s = \frac{N_m d_m}{d_s} = 435 \text{ rpm} \quad (10)$$

where N_s , $N_m d_m$ and d_s are the unknown shaft speed, motor speed (1450 rpm) and diameter of motor pulley (76.2 mm)

2.10 Computation of maximum center

The maximum center distance, C_m , was obtained with equation (11) as in Orji et al. [31].

$$C_m = \frac{(d_m + d_s)}{2} + d_m = 241.3 \text{ mm} \quad (11))$$

2.11 Computation of theoretical length of belt

The theoretical length of the belt was computed with equation [26] as indicated by Orji et al. [31].

$$L = 2C + 1.57 \frac{(d_s + d_m)}{2} + \frac{(d_s - d_m)^2}{4C} = 986.43 \text{ mm} \quad (12)$$

3. Performance evaluation of the expeller

The machine adopted for performance test has a 3-phase, 1450 rpm of speed and 5.5 hp power of electric motor. 300 g of dried palm kernel nuts are fed to feed hopper. Experimental runs were conducted with palm kernel seeds at the moisture content of 3.0% (w.b) as in References [34-345]. An average of extraction time and weight of cake recorded. The oil yield, oil extraction efficiency, capacity of the expeller and oil flow rate were determined using equations (13) to (16) respectively.

$$Y = \frac{(W_1 - W_2)}{W_1} \times 100 \quad (13)$$

Y , W_1 and W_2 are oil yield (%), the weights of un-milled palm kernel nut and cake (after milling).

$$E = \frac{Y}{C_o} \times 100\% \quad (14)$$

$$C = \frac{M_{pkm}}{t} \quad (15)$$

$$F = \frac{M_o}{t} \quad (16)$$

where C , M_{pkm} , M_o and t are the oil content (50% maximum for palm kernel nut), the mass of palm kernel milled, mass of oil extracted and the time taken respectively.

4. Extracted oil characterization

Fuel related properties of the oil were analyzed according to the ASTM specification.

5. Results and Discussion

Expeller developed is done with the designed parameters highlighted in Table 1. Spray painting of different parts of the expeller to prevent corrosion (see Fig. 2).



Fig. 2 Schematic set-up of palm kernel seed expeller.

Table 1 Calculated design variables for palm kernel seed expeller.

S/N	Designed parameters	Values
1.	Shaft diameter	45.7 mm
2.	Power requirement for screw shaft	3.09 kW
3.	Power requirement for screw press	4.12 kW
4.	Internal diameters of the expeller's barrel	48 mm
5.	External diameters of the expeller's barrel	68 mm
6..	Volume of the hopper	4231 cm^3
7.	Speed of the shaft	435 rpm

Table 2 shows the performance indicators of expeller for palm kernel seeds at the moisture content of 3.0%. 2.95 g/s of mass flow, 36.17% of oil yield and 60.33% of

extraction efficiency obtained for the performance indicator of oil screw expeller. The efficiency (60.33%) of the fabricated machine was similar to that obtained by Ikhide [36] (66.7%). Proper maintenance and modification of the expeller component can improve the performance of the expeller [37].

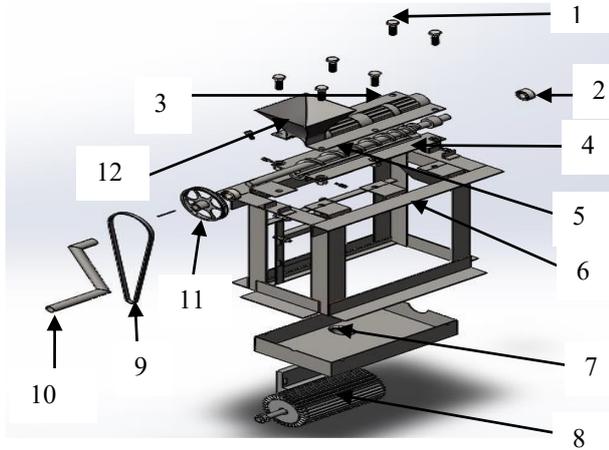


Fig. 1. Exploded view of oil expeller: 1: Bolt, 2: bearing, 3: upper bearing, 4: lower bearing, 5: screw shaft, 6: frame, 7: oil sprout, 8: electric motor, 9: belt, 10: hand wheel, 11: shaft pulley, 12: hopper

Table 2 Performance characteristics of palm kernel seed expeller

S/N	M _{PS} g	M _C g	M _{OE} g	T S	M _{FR} g/s	O _Y (%)	O _{EE} (%)
1	300	207	93.0	32	2.91	31.00	62.00
2.	300	209	91.0	29	3.14	30.33	60.66
3.	300	204	90.0	34	2.82	32.00	64.00
4.	300	218	82.0	29	2.83	27.33	54.66
M		209	90.5	31	2.93	30.17	60.33

M_{PS} = Mass of palm kernel seed; M_C = Mass of cake; M_{OE}=Mass of oil extracted; T= time;M_{FR} = Mass of flow rate; O_Y = Oil yield;;O_{EE} = Oil extraction efficiency; M= average

There is 300 USD was spent on palm kernel oil expeller, as presented in Table 3. The cost seems to be cheaper compared with the commercial expeller in the market. Table 4 highlights properties of palm kernel oil (PKO). These properties, namely, viscosity, density, flash point and pour points, are further compared with those of coconut oil (CNO), waste cooking oil (WCO), palm kernel oil and Jatropha seed oil from other researchers. The density of PKO (895 kg/m³) was lower than the density of oils specified by other researchers [38-43] and it was within the range specified by European Union standard (860 – 900 kg/m³).

The viscosity of PKO (33.20 mm²/s) was comparable to those of other researchers [38, 39, 41, 43] and it was within the norms specified by European Union specification (3.5 – 5.0 mm²/s) and ASTM standard (1.9 – 6.0 mm²/s). Oil having viscosity might cause engine

misfiring, engine deposits and poor atomization in diesel engines [44-45].

Table 3. Costs associated with the expeller

S/N	Parts	Quantity	Cost (USD)
1.	2mm mild steel sheet	1	5.6
2.	10mm mild steel rod, length 7m.	1	56
3.	60mm × 40mm angle iron, length 8m.	2	84
4.	45mm mild steel rod, length 700mm.	2	16.8
5.	roller bearings	2	9.8
6.	10in. Diameter pulley	1	4.2
7.	V- belt	1	1.4
8.	Bolts and nuts	10	8.4
9.	Filing stone	1	11.2
10.	Cutting stone	1	11.2
11.	Welding electrode	1	5.6
12.	Electric motor	1	84
13.	Miscellaneous		42
Total			330

The flash point (FhP) of the PKO (242 °C) was within the range of the earlier works reported by other researchers [38, 40, 41]. However, the FhP was much higher than the specified value of European and American standards. The high FhP of the PKO indicates that it can easily be transported and stored without fire hazard. The pour point of the PKO concurred with values reported by other researchers [40]. Palm kernel oil can be blended with diesel to promote its wide application in cold region.

Table 4 Basic properties of palm kernel oil

	Density Kg/m ²	Viscosity @ 40°C mm ² /s	Flash point ^o °C	Pour point °C
PKO ^a	895	33.20	242	20
CNO ^b	910.9	30.52	220	-9
WCO ^c	931	33.17	ND	ND
PKO ^d	886	115.55	242	22
ASTM Standard D6751-02	NS	1.9-6.0	>120	NS
EU standard EN 13214	860-900	3.5 – 5.0		NS
CNO ^e	940	33.10	242	20
PKO ^f	972.0	29.60	ND	ND
JSO ^g	870	34.88	ND	ND

a, present study; b, Samuel et al. [38]; c, Samuel [39]; d, Musa [40]; e, Bello et al. [41] f, Aladetuyi et al.[42]; g, Pradhan and Kumar [43].

6. Summary

In this study, for boosting domestic production and encouraging proper utilization of palm kernel oil

(PKO) for industrial purposes such as soap, cosmetic, biofuels, etc. and thus curtailing high energy expended in extracting oil from palm kernel seeds, (1) design and fabrication of a low cost palm kernel oil expeller, (2) determination of the suitability of PKO, finally (3) comparison of the oil with vegetable oils and Jatropha oil from palm kernel expeller. The following conclusion can be deduced:

1. The expeller design is easy to operate and affordable.
2. The efficiency (60.33%) of the fabricated palm kernel expeller was similar to those reported in literature, Proper maintenance and modification of the expeller component can improve the performance of the expeller.
3. The basic fuel properties are comparably with vegetable oils specified in literature but not within the ranges of ASTM and EU standards. Properties utilization of the oil can be ensured by blending the oil with diesel fuel or subjecting it to transesterification process.

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