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Research Article

DESIGN AND PRODUCTION OF A PALM KERNEL CRACKING MACHINE

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Abstract

Agricultural mechanization is taking the center stage in our today's world, particularly with increasing population and dwindling food supply; it has become imperative to create easier ways of processing agricultural products through mechanization. In this research work ''Design and Production of a Palm Kernel Cracking Machine'' a Palm Kernel Cracking Machine has been designed and produced. The machine has been used to efficiently crack palm kernels, which have various applications both at the household and industrial levels. The work started with the design of the machine which covered design calculations, materials selection, and engineering drawing using AutoCAD software. It was then followed by detail parts production and assembly to produce the complete palm kernel cracking machine. The machine was then subjected to no-load and load tests and the following results were obtained during the performance evaluation of the machine. Palm kernel nut cracking time was found to decrease as the shaft speed was increasing, and was lowest at 1600 rpm with a cracking time of 34.82 Seconds. Effective capacity increased with increasing shaft speed and attained a maximum of 86.16 g/s at 1600 rpm. The best operating shaft speed was however, 1000 rpm because split-nut loss was only 6.65%, un-cracked nut loss was 2.66% and the overall efficiency was 88.37%. The cost of producing the machine was $106.67 as compared to the imported machine which cost $240. It is therefore strongly recommended to produce this machine locally, so as to increase palm kernel nut processing in Nigeria.

Keywords: Palm kernel nuts, Processing, Machine, Design, Production, Assembly, Performance evaluation.

INTRODUCTION

The oil palm (*Elaeisguinensis*) is an indigenous plant to the tropical rain forest region of Africa. The oil palm is the richest vegetable oil plant among all the oil producing plants (Ndegwe, 1987). Oil palm due to its economic importance is now grown as a plantation crop in most countries with high rainfall in the tropical climates within 23°N to 23°S of the equator and longitude 17°N to 102°E (FAO, 2002). The oil palm bear its fruits in bunches which vary from 10 to 40kg. The individual fruit ranging from 60 to 70g and is made up of the exocarp and mesocarp which contains the palm oil in its cell debris, while the central nut is made up of the shell (endocarp) and edible kernel which contains the palm kernel oil that is quite different from palm oil, but resembles coconut oil (FAO, 2004). The palm kernel from cracked palm nuts are normally crushed in mills using expellers to get palm kernel oil. In world trade, these two distinct non-toxic edible oils from the palm fruits are both very important. There are three common varieties of palm kernel nuts. Dura, Pisifera and Tenera. The Tenera is a hybrid of the Dura and the Pisifera. The Dura palm have kernels with a thick shell, the Pisifera palms have kernels with no shell, while the Tenera palm have kernels with a thin shell (Anyane, 1966). In Nigeria it is the Tenera species that is commercially planted hence this research will design and developed a cracker for the Tenera species which is usually between 7-15 mm in length with shell thickness of 1.2mm. The palm tree is one of the greatest economic assets a nation possess. The oils produce from oil palm namely palm oil and kernel oil are used for oil paints, margarine, candle, polish, soap making, glycerin and medical purposes. Oil palm are also used to produce biodiesel. The palm kernel shells are used as a source of energy by blacksmiths and other industries.

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They palm kernel shells are also used for making break pads. Also the palm kernel cakes are used in making livestock feeds which are very rich in the essential nutrients required by livestock. For details on the uses of oil palm tree products see (Mba *et al,* 2015; Mosarof *et al,* 2015; Asadullah *et al,* 2014; Adebayo 2004, Emeka and Julius 2007, and Norazura 2017). According to (Badmus, 1991) Nigeria's oil palm exist in small oil palm plantation and wild groove, even though recently some large scale plantations have been developed. The need of oil palm processing machines suitable for small scale mills cannot be over emphasis. Machine involved in the palm oil mill process are: palm fruit sterilizer, palm fruit thresher, palm fruit digester, palm oil press machine, palm kernel cracker, palm kernel separator machine and palm kernel oil expeller machine. The design and development of these machines for large scale production has been the subject of many research work. These has the resulted in the manufacture of sophisticated and complicated foreign made palm oil processing machines which are not suitable for our small scale production System. This project is concern with the design and development of palm kernel nut cracker suitable for used in small scale mills in Nigeria. The aim of the research project is for the newly developed cracker to be a good replacement for the foreign ones.

MATERIALS AND METHOD

The palm kernel cracking machine

The work aimed at producing a portable cracker with mobility to be used anywhere in the palm kernel producing rural areas characterize by small scale plantation. The design and construction were made simple to reduce production cost of the machine in order to make it affordable. The power requirement of the machine is made minimal so that it can be powered by petrol engine see Toafik *et al,* (2019). Availability of the component parts of the machine was also put into consideration in case of any damage. Following Andoh *et al,* (2010) it was assumed that in the use of the cracking machine the dura species will be separated from the Tenera species using a sieve. It was also assume that the machine will service small scale industries whose quantity of palm nuts for cracking does not exceed 1000kg per day. The nut to be crack were assumed to have been air dried at least for one month in accordance with Okoli (2003); have moisture content of about 11.2% in line with Antia *et al,* (2014) if dried through other means.

Description of the functional Component of the Cracker

The functional components of the cracker machine are: Hopper, Cracking Chamber, Power Transmission Shaft, bearing and bearing housing, pulley, and cracking mechanism.

- **A. Hopper**: The hopper is connected to the conveying channel that leads to the cracking chamber. It is constructed as a truncated square base pyramid with mild steel sheet metal of 1.4mm gauge.
- **B. Cracking Chamber**: The cracking chamber is cylindrical in shape with diameter 370 mm. It is made of a mild steel plate of 3mm thickness. The front and the rear ends of the chamber are covered with circular plates of the same material, thickness and diameter. The internal walls of the cylinder are lined with 12mm iron rods to form the cracking ring.
- **C. Power Transmission Shaft**: The power transmission shaft is made of a 25mm diameter by 1200mm length rod of tool steel with two, or three beaters welded to one end and a pulley pinned down the other end with a pillow bearing.
- **D. Bearing and Bearing Housing:** Two UC 206, 30mm diameter pillow block bearing are used. The bearing housing is used to hold the bearing firmly to the frame, while the bearing itself holds the shaft in position to minimize fiction during rotation.
- **E. Pulley:** Two pulleys of different diameters are used in the design. The pulley is the device that transmit power from prime mover to the cracking mechanism shaft, via two v-belts. The smaller pulley connected to the prime mover is 50mm in diameter while the larger pulley connected to the shaft of the cracking machine is 80mm in diameter.
- **F. Cracking Mechanism**: These are the 2,3 or 4 hammers which crack the kernel nut by beating it against the wall of the cracking chamber. The walls of the cracking chambers are lined with 12mm iron rods to form the cracking ring. The hammers are placed at the angle 180^0, or 90^0 of 120^0 to each other around the shaft. The rotation of the shaft enable the hammers to hit the kernel laterally and let out the seed from the palm nut in a neat form.

Operating Principles of the Cracker

The Palm Kernel nuts are fed into the cracking chamber through the hopper and the hoppers slanting nature facilitates the smooth movement of the kernels as feeding continues. Power is transmitted to the rotor from the prime mover through the v-belt. As the nut are fed from the hopper at moderate speed through the centralized hole in the flywheel, the centrifugal rotating two, three, or four arms hammer beats the palm kernel against the cracking chamber giving rise to a very great impact force that eventually cracked the palm nuts. The cracked kernels and shells thereafter passed into the lower circumference of the cracking chamber and are collected for separation.

Design Analysis

Carrying out the design analysis of the palm kernel nut cracker machines requires the determination of shaft diameter, speed of shaft, power transmitted by shaft to the cracking mechanism, centre distance between pulleys, belt tensions, the angle of twist of shaft, belt length, centrifugal forces on hammers, the dynamic loading rating of the bearing, and moisture content of the palm kernel. Antia *et al,* (2014) observed that the optimal moisture content for effective cracking of palm kernel nut is 11.2%, while Udo *et al,* (2015) maintained that moisture content of less than 16% will give good results. Okoli, (2003) stated that air drying of palm kernel nuts for one month will give a good moisture content for effective cracking.

(A) Determination of shaft diameter

Shafts are either solid or hallow. In this work a solid shaft is used. The shaft diameter is determined using equation (1).

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

where d is shaft diameter (mm); $\tau_s$is torsional shear stress (MP_a); M_b is bending moment (Nm); K_b is shock + fatigue factors on bending moments; T is torque and k is shock + fatigue factor on torsional moment (Khurmi and Gupta 2005).

(B) Determination of Shaft Speed

The shaft speed is determined using equation (2).

$$\frac{N^1}{N^2} = \frac{D^1}{D^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where $N^1$is the speed of small pulley (rpm); N^2 is speed of large pulley (rpm); D^1 is small pulley diameter (mm); and D^2 is large pulley diameter (mm). Generally rotational speed value reduces by 4% due to slop and creep on belts and pulleys.

(C) Determination of power transmitted by the shaft to the cracking mechanism

The power transmitted by the shaft to the cracking mechanism and the efficiency of drive can be computed using equation (3), (4) and (5) respectively.

$$Pc = \frac{P.Ns}{Nm} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$Pf = P - Pc \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$f = \frac{Pc}{P} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where P^c is the power transmitted by the shaft to the cracking mechanism; P is the power transmitted by the electric motor; N^s is speed of the smaller pulley; N^m is speed of the larger pulley; P^f is power loss due to friction; f is the efficiency of the drive (Apeh *et al.,* 2015).

(D) Determination of Centre distance between pulleys.

The distance between centers of the pulleys can be calculated using equation (6), (7) and (8).

$$C = \frac{L\pi (D + d)}{4} + \frac{}{8} \sqrt{\frac{L\Pi (D + d)^2}{4} \quad \frac{}{8} \left(\frac{(D - d)^2}{8}\right)} \qquad \ldots\ldots\ldots (6)$$

$$\beta = \sin^{-1}\left(\frac{R - r}{C}\right) \qquad \ldots\ldots\ldots (7)$$

$$\alpha^1 = 180 - 2\beta \qquad \ldots\ldots\ldots (8)$$

where C is distance between centres of the two pulleys; L is the length of the belt (m); D is diameter of the larger (machine) pulley (mm); d is diameter of the smaller (Engine) pulley (mm); β is belt contact angle (rad); R is the radius of the larger (machine) pulley; r is the radius of the smaller (engine) pulley and α^1 is angle of wrap (rad).

(E) Determination of Belt Tensions

According to Ibiyeye *et al,* (2022) the most important tension is the one pulling the belts towards one another especially when at rest. High tension in the belts lead to unnecessary stress, subsequently causing wear in the bearings. A slack belt or too low belt tension will result in belt slip. Generally, belt tension is calculated using equation (9).

$$\frac{T_1 - Tc}{T_2 - Tc} \qquad \frac{\mu x}{e^{\sin(\theta/2)}} \qquad \ldots\ldots\ldots (9)$$

Where Tc is the centrifugal force due to the belt (N); T_1 is the belt's tight side tension (N); T_2 is the belt's slack side tension (N), θ is the groove angle for the v-belt, μ is the coefficient of friction between the belt and the pulley and α is the angle of lap or wrap (rad).

(F) Determination of the Angle of Twist of Shaft

In this research since the angle of twist of shaft desired (0.0072^0) is considerably less than that of the allowable deflection of between 2.50 to 3^0 per meter length as stated by Khurmi and Gupta (2005), then the selected shaft diameter is safe for the design. The angle of is calculated using equation (10).

$$\theta_t = \frac{32T_tL}{T_1Gd^4} \qquad \ldots\ldots\ldots (10)$$

Where θ_t is the angle of twist of the shaft (rods); T_t is the torque (N^m); L_s is the length of the shaft (m); G is the modulus of rigidity of steel (GP_q) which is usually 84GPa and d is the diameter of the shaft(m).

(G) Determination of Belt Length

In this work, speed increase while torque reduce. As shown in Figure 2.1 this was achieved using pulleys having different diameter Ibiyeye *et al,* (2022). Pulleys and belts arrangement are used to transfer rational motion from one shaft to another. The center to centre distance between the large and small pulleys in this design is 0.33m and the length belt required can be calculated from equation (6).

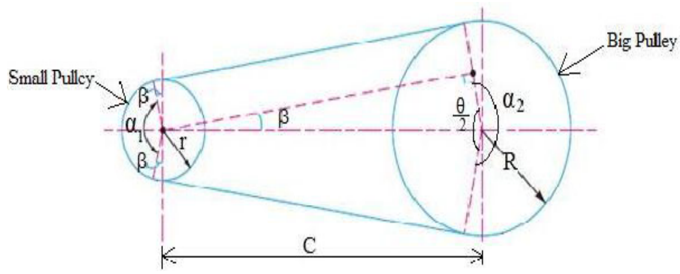


Figure 1. Schematic diagram of the belt and pulleys with different diameters arrangement

(H) Determination of Centrifugal Forces on Hammers

The centrifugal force that may be exerted by the hammers on the main shaft of machine could be calculated using equation (11)

$$F_c = \frac{mv}{r} \qquad \ldots\ldots\ldots (11)$$

where F^c is the centrifugal force; m is mass, r is radius and v is the velocity of the main shaft.

(I) Determination of the Dynamic Load Rating for the Bearing

The dynamic load rating for the bearing can be calculated using equation (12) and (13).

$$L^{10h} = \frac{10^6}{60n}\left(\frac{C}{P}\right) \qquad \ldots\ldots\ldots (12)$$

$$P = XVF_p + YF_a \qquad \ldots\ldots\ldots (13)$$

where C is the dynamic load rating for the bearing; L^{10h} is the basic rating life in operating hours; n is the rotation speed (rev/min); P is an exponent for the life equation (P = 3 for ball bearing and P = 10/3 for roller bearing); X is the radial load factor for the bearing; Y is the axial bearing load factors for bearing; F_r is the actual radial bearing load; $F_a$is the actual axial bearing load and V is the rotation factor = 1.2.

(J) Determination of moisture content

The machine was designed for low moisture content palm kernel nuts. From the work of Okoli (2002), Antia *et al,* (2014) and Udo *et al,* (2015) palm kernel nuts arriving at moisture content of more than 16% were to be further oven dried before cracking. This was necessary because if the moisture is high, the amount of damaged kernel nut will be high. The moisture content of the palm kernel nuts to be cracked can be calculated using equation (14).

$$W = \frac{W_i - W_f}{W_i} \times 100\% \qquad \ldots\ldots\ldots (14)$$

Where W is the moisture content (%), $W_i$is the initial weight before drying and W_f is the final weight after drying. A survey reveals that nuts in Nigeria are normally dried for about one month before being presented for cracking, hence from the work of Okoli, (2002) it can be assumed the cracker will be used for low moisture content palm kernel.

Design of the palm kernel nut cracking machine

The design of the palm kernel cracking machine follows an approach similar to Ibiyeye *et al,* (2022) but differs in that depending on the operating parameters it adopted a two, three or four arms centrifugal mild steel hammer arranged in 180^0, 120^0 or 90^0 radially as against the fix four arm arrangement use in Ibiyeye *et al,* (2022). Another important aspect of this design was the mobility of the cracker provided for by large tyres. Figure 2.2 shows isometric drawing of the palm kernel nut cracking machine developed using AutoCAD. Figure 2.3 shows orthographic drawing of the palm kernel nut cracking machine using AutoCAD. Figure 2.4 shows the isometric drawing of the component parts of the developed palm kernel nut cracking machine. Figures 2.5-2.7 show other AutoCAD generated components of the palm kernel cracking machine.

Construction of the palm kernel nut cracking machine

In the construction of the palm kernel nut cracking machine special attention was given to finishing from the welding stage to the painting stage, since poor finishing has been identified as one of the reasons why some made in Nigeria products have marketability problems in the international markets. All the construction work were done at the Department of Mechanical and Aerospace Engineering, University of Uyo, Nigeria.

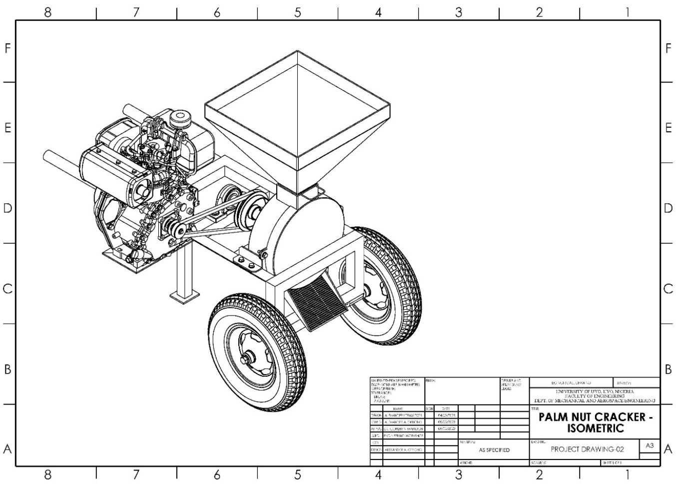


Figure 2. Isometic drawing the palm kernel nut cracking machine

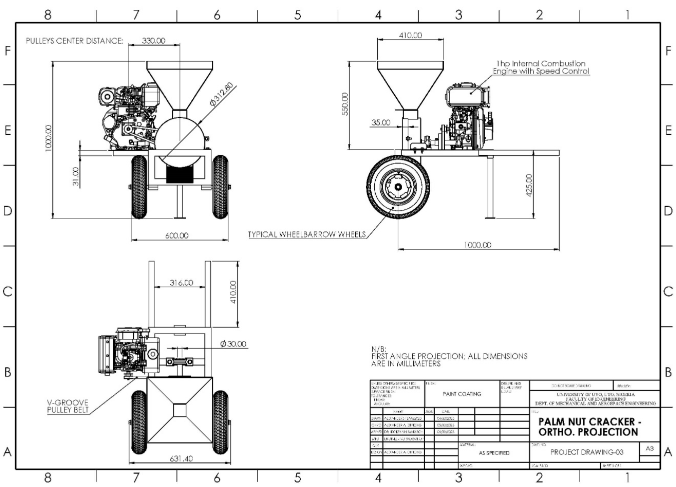


Figure 3. Orthographic drawing the palm kernel nut cracking machine

The cost of the produced palm kernel nut cracking machine is one Hundred and Sixty Thousand Naira (₦160,000.00) ($106.67). Figure 2.8 shows the pictorial view of the developed palm kernel nut cracking machine. Fig. 2.9 shows the pictorial view of the components parts of the developed palm kernel nut cracking machine.

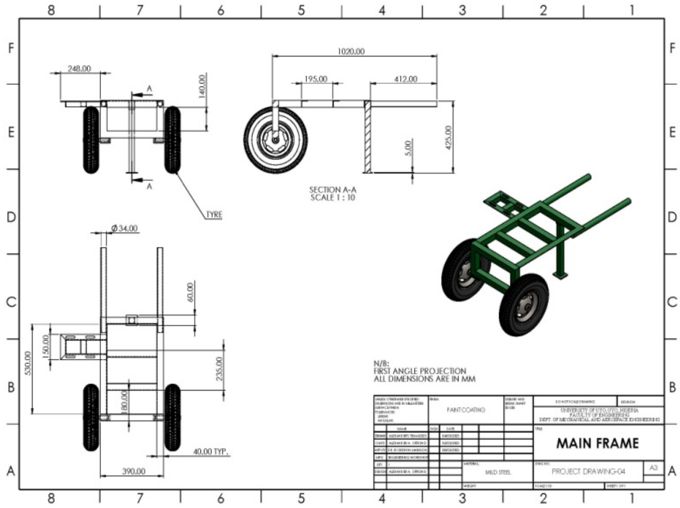


Figure 4. Components drawing the palm kernel nut cracking machine [Main Frame]

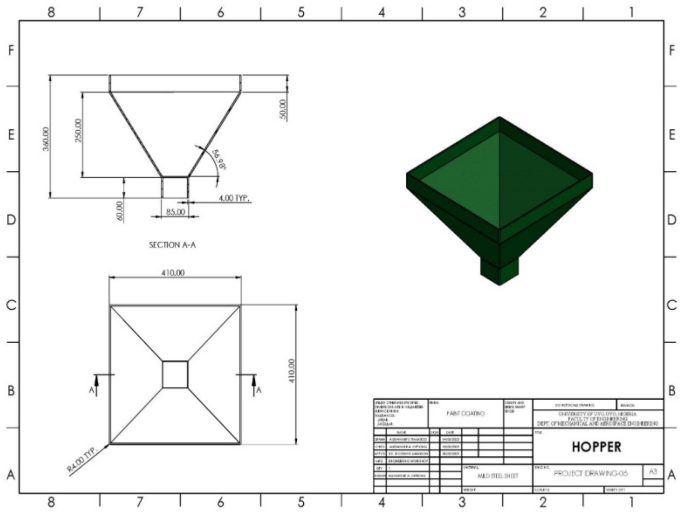


Figure 5.Components drawing the palm kernel nut cracking machine [Hopper]

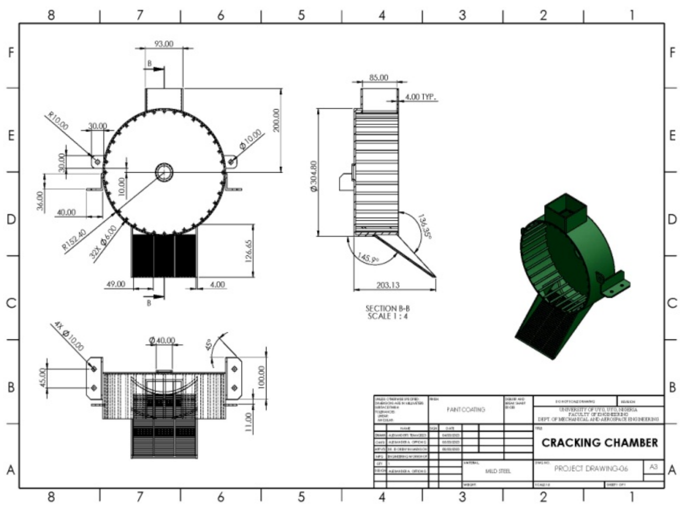


Figure 6. Components drawing the palm kernel nut cracking machine [Cracking Chamber]

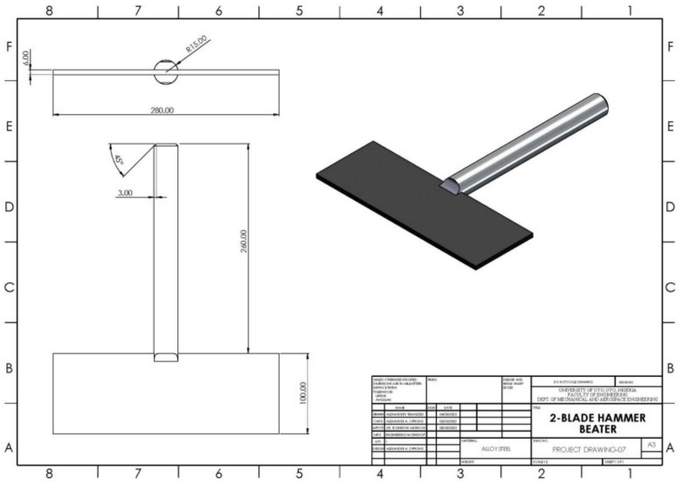


Figure 7. Components drawing the palm kernel nut cracking machine [Two Blade Hammer Shaft]

Figure 8. Three dimensional model of the developed palm kernel nut cracking machine

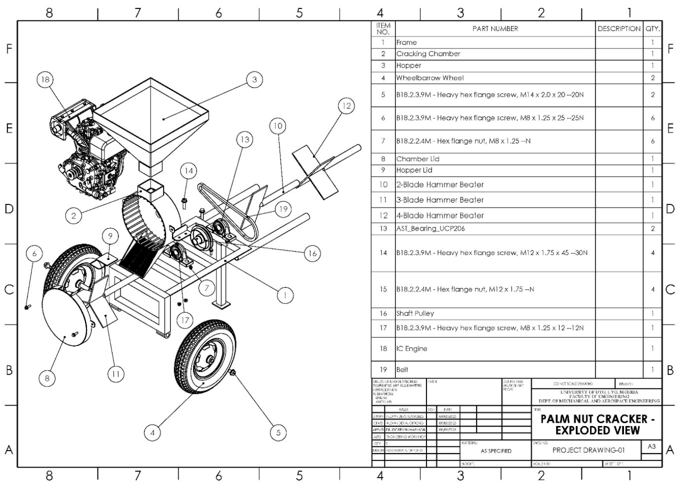


Figure 9. Exploded view of model components of the developed palm kernel nut cracking machine

Determination of evaluation parameters

Evaluation parameters for the developed crackers include Effective capacity (EC), cracking efficiency (CE), performance efficiency (PE), split-nut loss (%), (SL), un-cracked less (%) (UL); and overall efficiency (OE). These parameters can be calculated using equation (15-20) respectively.

$$EC = M/T \quad \ldots\ldots (15)$$

$$CE = [N_{cr}/N_{to}].100 \quad \ldots\ldots (16)$$

$$PE = [N_{wh}/N_{to}].100 \quad \ldots\ldots (17)$$

$$SL = [N_{br}/N_{to}].100 \quad \ldots\ldots (18)$$

$$UL = [N_{uc}/N_{to}].100 \quad \ldots\ldots (19)$$

$$OE = CE \times PE \quad - \quad \ldots\ldots (20)$$

$$N_{br} = N_{to} - (N_{wh} + N_{uc}) \quad \ldots\ldots (21)$$

$$N_{cr} = N_{wh} + N_{br} \quad \ldots\ldots (22)$$

where M is total mass of palm nuts fed into the hopper (kg); T is total time taken by the cracked mixture to leave the chute (h) [Cornish, 1991]; N_{to} is the total number of kernel nuts fed into the hopper; N_{cr} is the total number of cracked kernel [damaged and undamaged] after cracking; N_{wh} is the number of whole [un-broken] kernel nut after cracking; N_{br} is the number of broken kernel nuts after cracking; and N_{uc} is the total number of un-cracked kernel nuts after cracking. In the experiment a constant volume of kernel to which N_{to} and M has been assigned will be employed and equation (21) and equation (22) will be used in the calculation of N_{br} and N_{cr} respectively. This means that for every cracking operation during the experiment only shaft speed, N_{wh}, N_{cu}, and the cracking time T was recorded. $N_{br}$and N_{cr} was calculated.

Experimental Procedure

A constant volume cylindrical container of diameter of 0.174m and height 0.180m was used in measuring the palm kernel nut for the cracking experiment. The container was examined and found to contain an average of 640 palm kernel nuts weighing 3000grams at full load. Using this container 640 palm kernel nuts were used to test the developed palm kernel cracking machine when assembled with a two arm hammer beaters.Speed was determined by the use of a tachometer. The procedure was that each set of the 640 palm kernel nuts was cracked at the shaft speed of 800, 1000, 1200, 1400 and 1600 rpm and the total number of whole kernel nuts and total number of un-cracked kernel nuts sorted. In each case the total mass of palm kernel nut fed into hopper together with the time taken by the cracked mixture to leave the chute was recorded. These data were then analyzed using Microsoft excel 2010 of window 7.

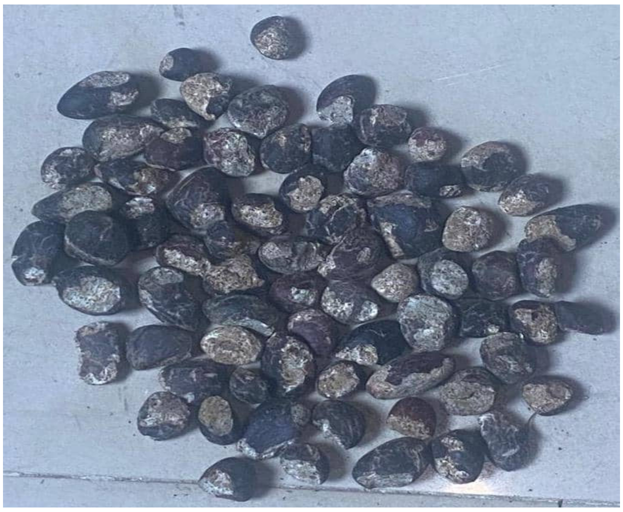
RESULTS

Performance Evaluation of the Developed Machine

After the construction of the various parts of palm kernel cracking machine, all the parts were assembled together, and the machine was tested to evaluate its performance during operation when assembled with a two arm hammer beaters. Figure 10 shows the test run results of the developed palm kernel nut cracking machine (a) Un-separated cracking palm kernel shells and nuts after cracking; (b) Sample of whole [un-broken] kernel nuts after cracking; (c) Sample of broken kernel nuts after cracking; and (d) Sample of un-cracked kernel nuts after cracking operation. Table 3.1 and Table 3.2 shows the data obtained from the experiment carried out to determine the performance of the developed palm kernel nut cracking machine at the speed of 800, 1000, 1200, 1400, and 1600rpm when assembled with a two arm hammer beaters.

(a) Un-separated cracking palm kernel shells and nuts after cracking

(b) Sample of whole [un-broken] kernel nuts after cracking



(c) Sample of broken kernel nuts after cracking

(d) Sample of un-cracked kernel nuts after cracking

Figure 10. Test run results of the developed palm kernel nut cracking machine (a) Un-separated cracking palm kernel shells and nuts after cracking; (b) Sample of whole [un-broken] kernel nuts after cracking; (c) Sample of broken kernel nuts after cracking; and (d) Sample of un-cracked kernel nuts after cracking

Cost Analysis of the Palm Kernel Nut Cracking Machine

Tables 1 and 2 show the cost analysis of the palm kernel nut cracking machine and also the analysis for batch production of four palm kernel nut cracking machines.

Table 1. Data obtained from the experiment carried out to determine quality performance of the developed palm kernel nut cracking machine

Shaft speed in rpm	No. of palm kernel nuts (N_{to})	Mass of Kernels (M) in (g)	Cracking Time (T) in (s)	Number of whole nuts (N_{wh})	Number of un-cracked nut (N_{uc})	Number of broken nuts (N_{br})	Number of cracked nuts (N_{cr})
800	640	3000	42.33	431	71	138	569
1000	640	3000	40.43	581	17	42	623
1200	640	3000	38.90	415	6	219	634
1400	640	3000	36.69	296	4	340	636
1600	640	3000	34.82	258	3	379	637

Calculations: (1) $N_{br} = N_{to} – (N_{wh} + N_{uc})$; (2) $N_{cr} = N_{wh} + N_{br}$

Table 2. Performance tests for the developed palm kernel nut cracking machine

Shaft speed in rpm	No. of palm kernel nuts (N_{to})	Mass of Kernels (M) in (g)	Cracking Time (T) in (s)	Effective Capacity(EC) in (g/s)	Cracking efficiency (CE)	Performance efficiency (PE)	Split-nut loss % (SL)	Un-cracked nut loss % (UL)	Overall Efficiency (OE)
800	640	3000	42.33	70.87	88.91	67.34	21.56	11.09	59.87
1000	640	3000	40.43	74.20	97.34	90.78	6.65	2.66	88.37
1200	640	3000	38.90	77.12	99.06	64.84	34.22	0.94	64.23
1400	640	3000	36.69	81.77	99.38	46.25	53.12	0.63	45.96
1600	640	3000	34.82	86.16	99.53	40.31	59.21	0.47	40.12

Calculations: (1) EC = M/T; (2) CE = (N_{cr}/N_{to}).100; (3) PE = N_{wh}/N_{to}).100; (4) SL = (N_{br}/N_{to}).100; (5) UL = (N_{uc}/N_{to}).100; (6) OE = CE x PE.

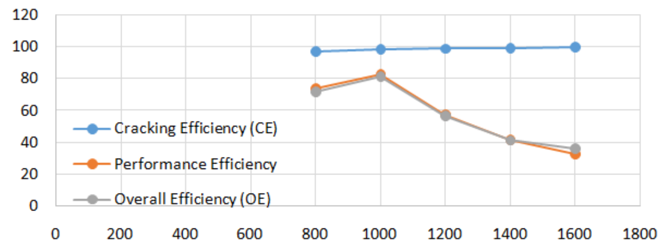


Figure 11 Graph of machine efficiency against operational speed of the palm cracking machine

Cost Analysis of the Palm Kernel Nut Cracking Machine

Tables 3 and 4 show the cost analysis of the palm kernel nut cracking machine and also the analysis for batch production of four palm kernel nut cracking machines.

Table 3. Breakdown of the cost of the developed palm kernel nut cracking machine by component/activity

S/N	Component / Activity	Estimated cost (₦)
1	Frame Assembly	20,000.00
2	Hopper Unit	10,000.00
3	Bearings	7,000.00
4	Bearing Cover	6,000.00
5	Cracking Chamber	12,000.00
6	Cracking Hammer	5,000.00
7	Shaft	7,000.00
8	Puller	8,000.00
9	Rolling Tyre	10,000.00
10	Finishing/Painting	10,000.00
11	Gasoline Motor	45,000.00
12	Labour	18,000.00
	TOTAL	160,000.00 ($106.67)

Table 4. Breakdown of the cost by component/activity assuming batch production at fourcracker per batch

S/N	Component / Activity	Estimated cost (₦)
1	Frame Assembly	15,000.00
2	Hopper Unit	10,000.00
3	Bearings	7,000.00
4	Bearing Cover	4,000.00
5	Cracking Chamber	9,000.00
6	Cracking Hammer	5,000.00
7	Shaft	7,000.00
8	Puller	8,000.00
9	Tyre	8,000.00
10	Finishing/Painting	7,000.00
11	Gasoline Motor	45,000.00
12	Welding	15,000.00
	TOTAL	140,000.00 ($93.33)

DISCUSSION

Table 1 shows the data obtained from the experiment carried out to determine performance of the developed palm kernel nut cracking machine when assembled. The results showed that as the shaft speed in rpm was increased the cracking time was reduced. This is shown by the fact that as the speed increased from 800 rpm to 1600 rpm the cracking time decreased from 42.33 seconds to 34.82 seconds at 1600rpm. This trend has earlier been observed by Offiong (2024); who cracked palm kernel nuts using newly developed palm kernel nut cracking machine. With increased shaft speed from 800rpm, the number of whole nuts increased from431 at 800rpm to 581 and then continued to decrease as the shaft speed increased until it reached 258 at 1600 rpm. The number of uncracked nuts dropped from 71 at 800rpm to 3 at 1600rpm. The number of unbroken nuts was 138 at 800 rpm as the speed continue to increase, it dropped drastically at 1000rpm to 42 and then continued to increase with increase in shaft speed until it reached the highest value of 379 at 1600rpm. The number of cracked nuts however, continued to increase with shaft speed from569 at a speed of 800rpm to the highest value of 637 at the shaft speed of 1600rpm. This same trend of the performance of a newly developed palm kernel cracking machine have been observed by other researchers like Babatude, *et al.,* (1988); Babatude and Okoli (1988);Khurmi and Gupta, (2006);Asoiro and Udo, (2013); Ibiyeye, *et al,* (2022); Okoli,(2022); and Offiong (2024).

Table 2 further shows the performance tests carried out on the developed palm kernel nut cracking machine as the operational speed was increased from 800rpm- 1600rpm the effective capacity in g/s was increased from 70.87g/s at 800rpm to 86.16g/s at 1600rpm. The increase in operational speed from 800- 1600rpm also affected the cracking efficiency which increased from 88.91 – 99.53. The performance efficiency however, increase from 67.34 at 800rpm and attained the highest value of 90.78 at 1000rpm and then continued to decrease to 40.31 at 1600rpm. The increase in operational speed showed that split-nut loss % at 800rpm was 21.56% this value dropped to 6.65% at 1000rpm and thereafter the split-nut losses increase with increase in operational speed to the value of 59.21% at 1600rpm.The increase in operational speed also affected un-cracked nut loss %, at 800rpm the value of un-cracked nut % was 11.09% as the speed increased, at 1000rpm there was a drastic drop to 2.66%, this was followed by a gradual drop to 0.47% at 1600rpm. The overall efficiency of operating the developed palm kernel nut cracking machine showed that as the operational speed was increased from 800rpm the overall efficiency was 59.87, this increased to 88.37 at 1000 rpm subsequently the overall efficiency of the developed machine dropped with increase in operational speed to 40.12 at 1600rpm. The above trend which has been observed during the testing of the machine has equally, been observed by several other authors as noted in the references (Ologunagba, 2012; Ibrahim *et al.*; 2016; Ibiyeye, *et al,* 2022). Udo *et al,* (2015) developed a palm kernel nut cracking machine for rural use; performance evaluation of the machine indicated that the throughput of the machine increased from 10.91 to 38.00g.s as the speed increased from 800 to 2400 r/min. The performance efficiencies of the palm nut cracker machine developed were 93%, 94%, 95%, 94.5% and 94% at set speed of 800, 1200, 1600, 2000 and 2400 r / min. respectively.

Figure 11 is a further illustration of the graph of machine efficiency against operational speed of the machine. The cracking efficiency increased with the operational speed, while theperformance efficiency peaked at operational speed of 1000rpm and then gradually decreased with operational speed down to 40.31 at 1600rpm. The same trend is observed with the overall efficiency which peaked at operational speed of 1000rpm and then gradually reduced. Many researchers in carrying out the performance analysis of their produced palm kernel nut cracking machine also observed these trends (Udo *et al.,* 2015; Taofik *et al.,* 2019; Ibiyeye, *et al,* 2022; Offiong, 2024).

Cost Analysis of the Palm Kernel Nut Cracking Machine.

The palm kernel nut cracking machine was constructed at the Department of Mechanical Engineering, University of Uyo, Nigeria. Special attention was given to the finishing of the machine in terms of welding, sand papering and painting. The estimated cost of the machine was One Hundred and Sixty Thousand Naira (₦160,000.00) ($106.67) only, including the cost of petrol engine which was bought from the market at the cost of Forty Five Thousand Naira (₦45,000.00) ($30)only. Even though most of the materials were source from scrap metal shop, attempts have been made to place an appropriate market value on them. Only the cost of actual material used were added in the costing, as left over material were assumed to have alternative use within the workshop. Table 3 shows the breakdown of the cost of the developed palm kernel nut cracking machine by component/activity including labour cost. The total cost of the developed palm kernel nut cracker was One Hundred and Sixty Thousand Naira (₦160,000.00) ($106.67), while imported machine of similar capacity had market price value of about Three Hundred and Sixty Thousand Naira (₦360,000.00) ($240) at the current exchange rate, which is more than double the cost of the locally constructed machine. Further analysis reveal that the cost of the machine could actually reduce to about ₦140,000.00 ($93.33), if the machine were to be produce in batches of four, where material usage/labour cost will be maximized.

Table 4 shows the estimated breakdown of the cost of the developed palm kernel nut cracking machine by component/activity including labour cost assuming the machine were to be produced in batch production at four cracker per batch. Table 3.4 show a drastic reduction in cost of the frame assembly, hopper unit, bearing cover, tyres, finishing /painting, and labour cost due to: (i) bulk buying of 1.4mm gauge flat plates, angle iron, and tyres (ii) reduce cost of labour in welding, painting/finishing and construction of cracking chambers occasioned by producing four crackers at a time. The batch production projected there will require first the promotion of the product among small scale mills owners and rural/traditional mill owners. Table 3.4 reduction in cost of the produced palm nut cracking machine is a common phenomenon in mass production (khurmi and Gupta, 2006).

Conclusion

The use of the palm kernel nut cracker machine made from locally sourced materials will overcome most of the problems associated with the production of palm kernel oil. This will help to eliminate waste of the palm kernel seed, which is common among rural and small scale processors. The study ‘’Design and Production of a Palm Kernel Nut Cracking Machine’’ has led to the following findings and conclusions:

- The developed palm kernel nut cracker machine maximum performance and long service life is ensured when there is proper maintenance and operations among which are; regular lubrication of bearings, operation of the machine on a level ground in other to prevent excessive vibration, preventing the machine from having contact with rainfall, and retightening of any loose bolts or nut before each operation.
- The machine has excellent performance of effective capacity of 74.20g/s, cracking efficiency of 97.34%, performance efficiency of 90.78%, split-nut loss 6.56%, un-cracked nut loss 2.66%, and overall efficiency of 88.37%, at the optimum speed of 1000rpm,
- iii.Shorter palm nut cracking time are obtained with the machine at higher shaft speeds but at high speed broken nuts also increase
- The best operating speed of the machine has been established to be 1000 rpm, this speed has less broken nuts.
- The machine will eliminate the associated problems and difficulties in the existing/traditional method of cracking. Also considering the fact that the newly developed palm kernel nut cracker cost one hundred and sixty thousand naira (₦160,000.00) ($106.67) only, when compared with the imported machines of similar capacity which had market price value of about three hundred and sixty thousand naira (₦360,000.00) ($240), it is highly recommended to produce the machine locally to promote and expand local mills for palm oil processing.

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