Design and Performance Evaluation of Horizontal-Shaft Palm Kernel Cracking Machine

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***Abstract*—The need to support the small and medium scale industries involved in palm kernels, led to the design, fabrication and evaluation of a horizontal shaft palm kernel cracking machine. All the materials were sourced locally in Nigeria which makes it affordable for small and medium scale farmers involved with palm kernel. The basic features of the machine include a horizontal shaft, hopper, cracking chamber, pulleys, bearings with housing, discharge outlet and electric motor (prime mover). The mean efficiency of the machine under good operating conditions is 75.5%. The production cost of the machine excluding electric motor was estimated to be one hundred and fifty-one dollar forty-sixcents (US$151.46), based on the exchange rate when it was manufactured. The cost can further be reduced, if mass-produced.**

Keywords—Palm kernel;machine efficiency; machine design; performance evaluation

I. Introduction

The oil palm (Elaeis guineesis) belongs to the Palmae family. Among the oil producing plants, it is the richest vegetable oil plant [1]. Palmae contains about 225 family members with over 3600 species. The oil palm is characterized by a bunch of fruits attached to the upper part of the tree in the region of the palm leaf. There are three common varieties of palm kernel fruit, viz: dura, tenera and pisifera and their characteristics are shown in Table 1. According to Badmus [2], a typical African dura kernel is between 8-20 mm in length and has a fairly uniform shell thickness of 2 mm. The tenera is between 7-15 mm in length with ashell thickness of 1.2 mm. This research employed the use of teneraspecies (Fig. 1) that is commercially planted in Nigeria with varying use, depending on particular applications. The oils (palm oil and kernel oil) are used for margarine, candle, oil paint, polish, soap making, glycerine and medicinal purposes [3]. Palm biodiesel are also produce from oil palm [4]. The shells are used for brake pad, source of energy by the local blacksmiths and bio-coal [5]. In addition, the kernel cakes are used as one of the ingredients in livestock feeds, which is highly rich in the essential nutrient needed by livestock [6, 7].

Malaysia is one of the leading palm oil producing country in the world. These has greatly contributed to their economic growth [8]. The increasing production of oil from the palm fruit gives rise to palm kernel nut. The bye product and utilization of palm kernel shell for biofuel and other application, led to the demand for quick and easy separation of palm kernel nut from it shell.

For more than five to six decades, several methods have been adopted in order to crack palm kernel. The methods include cracking with stone and smashing against a rock. These methods are time-consuming, extend human energy, thedanger of smashing the fingers and low production. Due to the continuous increase in demand for palm kernel nuts for soap, cream, and cooking oil, a result of increasing human population, researchers are forced to come up with better, faster and safer ways of separating the palm kernel nut from its shell. The flowchart in Fig. 2 shows the process involved in the oil extraction of palm kernel fruit [9].

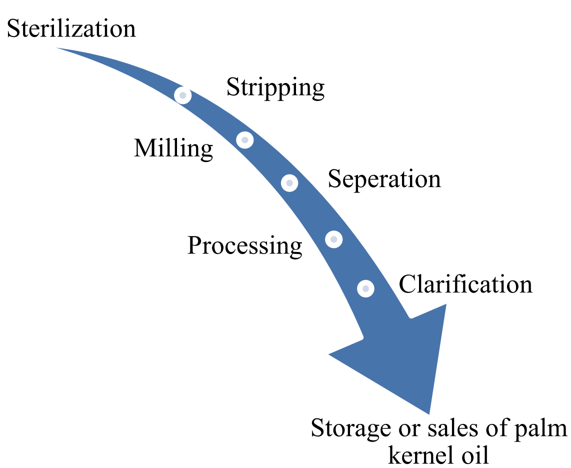
TABLE I. Physical properties of selected oil palm [10, 11]

Species	Mesocarp	Endocarp
Dura	Thin	Thick
Tenera	Thick	Thin
Pisifera	Thick	No endocarp

Fig. 1.Tenera Palm Nuts

A prototype centrifugal palm nut cracker was designed, fabricated and tested by Babatunde and Okoli [12], using a horizontal shaft and a vertical rotor at the National Centre for Agricultural Mechanization (NCAM), Ilorin, Nigeria. Their concept was that the nut will hurl against the hard breaker plate by the mill, based on centrifugal principle. The prototype recorded nut cracking efficiencies of 94.50 and 87.50 with 14.70 and 6.0 % kernel damage respectively. Optimum efficiency was discovered to be 77.85 % at a throughput of 115.30 kg/h with minimal kernel breakage. Manuwa [13] and Ologunagba [14] used locally available materials to minimize cost and also ensured that the machine is easy to maintain. The observed challenges were put into consideration during the design and fabrication processes of the nut cracking machine. The electric motor (prime mover) of 2.25 kW power rating was used at a speed of 5,500 rpm. Optimum efficiency of 89 and 10 % mechanical damage on kernel was recorded with a maximum throughput capacity of 1.2 ton/h. The process of hurling the palm kernel nut against a hard surface at a high speed is known as a centrifugal process. This process led to better productivity, however, it has its setback; large kernel breakage.

Fig. 2. Palm kernel Processing Flowchart [9]



II. Materials and Methods

A. The Hopper

The hopperis made of mild steel sheet metal of 1.4 mm gauge and constructed as a truncated square base pyramid. It is connected to the conveying channel that leads to the cracking chamber.

B. The Cracking Chamber

The cracking chamber is made up of a mild steel plate of 3 mm thickness. It is cylindrical in shape and of diameter 370 mm. The front and the rear ends of the rings are covered with circular plates of the same material, thickness and diameter in order to form the cracking ring.

C. Power Transmission Shaft

The power transmission shaft is made of mild steel and one of its ends is step turned to $\emptyset 29\,\text{mm} \times 85\,\text{mm}$. It accommodates the two bearings. The shaft has a total length of 600 mm with a diameter of 35 mm.

D. Bearing and the Bearing Housing

The bearings are held firmly in place to the frame by the bearing housing. While the bearing itself holds the shaft into position in order to minimize friction during rotation, the specification of the bearing used is 34.9 mm and 97.5 mm internal and external diameters, respectively.

E. Pulley

This is the unit that transmits power from the electric motor shaft (prime mover) to the cracking mechanism shaft, via two V-belts. There is a smaller pulley of diameter 60 mm and a larger pulley of diameter 85 mm. The smaller pulley is attached to the shaft of the prime mover and the larger pulley is attached to the shaft of the cracking machine.

F. The Cracking Mechanism

These are the hammers (3 in number) which crack the kernel nuts by hurling it against the wall of the cracking chamber. They are placed at the angle of 120^{o} to each other around the shaft.

III. Design Considerations

In solving the challenge of a successful cracking of palm kernel nut without crushing the kernel itself, a lot of design considerations were put in place in order to ensure a significant reduction in the production cost and reduction in drudgery. The followings were put into consideration:

- The physical and mechanical characteristics of the palm kernel
- Durability of the machine
- Energy conservation of the operator when nuts are cracked manually
- Ease of operation
- Ease of maintenance

IV. DESIGN ANALYSIS

A. Determination of Shaft diameter

The shaft design has to be determined for correct shaft diameter in order to ensure satisfactory strength and rigidity when power is transmitted by the shaft under the various loading conditions. There are either hollow or solid shafts. For the sake of this research, a solid shaft was used, see equation (1).

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

Where, d is the diameter of the shaft (m), τ_s is the torsional shear stress (MPa), M_b is the bending moment (Nm), T_t is the torque, K_b is the combined shock and fatigue factors applied to bending moment and K_t is the combined shock and fatigue factors applied to torsional moment [15].

B. Determination of Speed of Shaft

$$\frac{N_m}{N_s} = \frac{D_s}{D_m} \quad (2)$$

Where N_s is the speed of the larger pulley, connected to the machine shaft, D_s is the diameter of the larger pulley, connected to the machine shaft, N_m is the speed of the smaller pulley, connected to the prime mover and D_m is the diameter of the smaller pulley, connected to the prime mover. The above equation (2) is used to determine the shaft speed.

C. Determination of Power Transmitted by the Shaft to the Cracking Mechanism and Efficiency of Drive

The power transmission by the shaft and the drive efficiency can be calculated using equations (3-4) and (5) respectively.

$$P_c = \frac{P \times N_s}{N_m} \quad (3)$$

$$P_f = P - P_c \quad (4)$$

$$\int = \frac{PC}{P} \times 100 \quad (5)$$

Where P is the power transmitted by the electric motor, P_c is the power transmitted by the shaft to the cracking mechanism; P_f is the power loss due to friction and $\int$ is the efficiency of the drive.

D. Determination of Centre Distance between Pulleys

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

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

$$\alpha_1 = 180 - 2\beta \quad (8)$$

Where α is the angle of lap or wrap (rad), R is the radius of the larger pulley, r is the radius of the smaller pulley, L is the length of the belt (m) and C is the distance between the centres of the two pulleys. Fig. 3 shows the schematic diagram of a belt and two pulleys having different diameters.

E. Determination of Belt Tensions

$$\frac{T_1 - T_c}{T_2 - T_c} = e^{\frac{\mu\alpha}{\sin\left(\frac{\theta}{2}\right)}} \quad (9)$$

Where T_1 is the belt's tight side tension (N), T_2 is the belt's slack side tension (N), T_c is the centrifugal force due to thebelt (N), θ is the groove angle for the V-belt andμ is the coefficient of friction between the belt and the pulley.

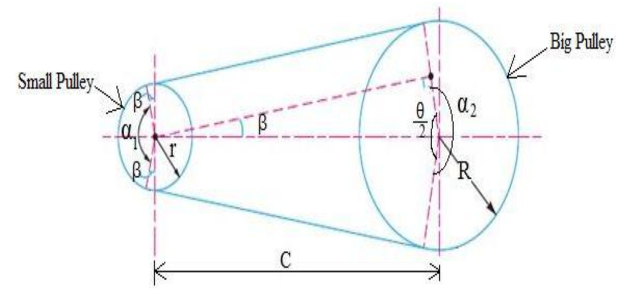


Fig. 3.Schematic diagram of the belt and the pulley [15]

F. Determination of the Angle of Twist of Shaft

$$\theta t = \frac{32 T_t L}{\pi G d^4} \quad (10)$$

Where, θt is the angle of twist of the shaft (rads), T_t is the torque (Nm), L is the length of the shaft (m), d is the diameter of the shaft and G is the modulus of rigidity of steel (GPa) = 84 GPa. Since the angle of twist derived (0.0072°) is considerably less than that of the allowable deflections of between 2.50 to 3° per metre length as quoted by Khurmi and Gupta [15], and then the selected shaft diameter is safe for the design.

G. Determination of the Number of Belts

$$N_b = \frac{A_b}{A} \quad (11)$$

$$A_b = T_1/\sigma_b \quad (12)$$

Where N_b is the number of belts, A_b is the belt area, A is the area per belt and σ_b is the shear stress of the belt. From the calculations, the number of belts required by the machine is 2.

H. Determination of the Dynamic Load Rating for the Bearing

$$L_{10h} = \frac{10^6}{60n}\left(\frac{C}{P}\right)^p \quad (13)$$

$$P = XVF_r + YF_a \quad (14)$$

Where L_{10h} is the basic rating life in operating hours, n is the rotation speed (rev/min), *P* is the equivalent dynamic load rating, p is an exponent for the life equation (p = 3 for ball bearing and p = $\frac{10}{3}$ for roller bearing), *X* is the radial load factor for the bearing, *Y* is the axial load factor for the bearing, F_r is the actual radial bearing load, F_a is the actual axial bearing load, *C* is the dynamic load rating for the bearing and *V* is the rotation factor = 1.2.

I. Determination of Moisture Content

The moisture content of the palm kernel contributes the crack efficiency of the machine. If the moisture content is high, the amount of damaged kernel nut will be high. The moisture content can be calculated using equation (15)

$$W = \frac{W_i - W_f}{W_i} \text{ x } 100\% \quad (15)$$

Where W is the moisture content (%), W_i is the initial weight before drying and W_f is the final weight after drying.

V. Machine Testing and Performance Evaluation

Having fabricated and assembled together all the parts of the machine as shown in Fig. 4, the machine was tested in order to determine the efficiency of the new machine. Three different tests were carried out with test samples of 100, 100 and 200 palm kernels. Each of the samples was fed into the hopper through the flow channel to the cracking chamber at a low and steady machine speed. The results were recorded and the machine performance efficiency, percentage cracked efficiency and mechanical damage kernel efficiency were calculated using equations (16 – 18) respectively.

$$E_m = \frac{W_U}{W_T} \text{ x } 100 \quad (16)$$

$$E_c = \frac{W_C}{W_T} \text{ x } 100 \quad (17)$$

$$M_d = \frac{W_C - W_U}{W_T} \text{ x } 100 \quad (18)$$

Where E_m is the machine performance efficiency, E_c is the percentage cracked kernel, M_d is the mechanical damaged, W_U is the undamaged cracked kernel, W_C is the total cracked kernel (damaged and undamaged) and W_T is the total number of kernel fed into the hopper.

VI. Results and Discussion

The results of the performance test carried out are summarized and presented in Table 2. The overall performance of the palm kernel cracking machine was based on the percentage cracked palm kernel. The result was favourable due to the low moisture content of kernel.

VII. Conclusion

Snam The results show that palm kernel cracking machine can be designed and fabricated locally. The machine was designed and fabricated in order to minimize expending of human energy and time during the cracking of palm kernel nuts, using local and primitive methods. The machine has a mean efficiency, under good operating conditions of about 75.5%. The machine is easy to operate and it is cost-effective as all the materials were sourced locally. The total production cost is about one hundred and fifty-one dollar, forty-six cents (US$151.46), based on the exchange rate when it was manufactured. This can further be reduced if the machine is mass-produced. The machine is therefore recommended for small and medium scale producers. The government and financial institutions should make provision for loans to farmers in order to boost the production of the kernel and its byproducts.

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TABLE II. Results from the test carried out

Input	Cracked kernel	Un-cracked kernel	Damaged kernel	Undamaged kernel	Percentage cracked (%)	Machine efficiency (%)	Machine damage (%)
100	76	24	1	75	76	75	1
100	79	21	2	77	79	77	2
200	143	57	3	140	71.5	70	3

Fig. 4: A pictorial view of the palm kernel cracking machine