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Development of a Palm Kernel Cracking and Separation Machine

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Abstract: *In an attempt to ease, the production of palm kernel oil, a palm kernel cracking and separating machine was developed to crack effectively various sizes as well as to separate the palm kernel nuts from the shell. The palm kernel cracking and separating machine was designed and fabricated with locally available materials from the opinion of a new idea which aims at easing the pain, stress, intensive labour, time consuming, unduly cost and cumbersome operation encountering in the traditional/existing processes of cracking and separating palm kernel nuts from it shell. The machine was tested to ascertain its performance, both performance efficiency and overall efficiency had their highest values at speed of 1600 rpm for 94.75% and 93.329% respectively while the average percentage of broken nuts is 2.1%.*

Keywords: *Cracking, Separating, Performance Efficiency, Broken Nuts.*

1. INTRODUCTION

1.1 Background of the Study

Oil palm (Elaeis guinensis) is an indigenous plant to West Africa. It is the Highest oil yielding crop per hectare in the plant kingdom (Kurki et,al, 2008). The palm tree bears its fruits in bunches which vary in weight from 10 to 40kg. It is made up of outer skin (exocarp), a pulp (mesocarp) containing the palm oil in a fibrous matrix, a central nut consisting of a shell (endocarp) and the kernel which itself contain an oil.

Over the years, extracting and expression of oil from oil seeds involve a wide range of traditional, chemical and chemical processing (Tang, 1985, Olayanju, 2004, Kurki, 2008). However, survey results show that 80 percent of Nigeria's oil palm resource exist in small oil palm plantation and wild groove (Badmus, 2002), this is the nation oil palm industry still subsistent with few large estate plantation that makes large mills and imported mills relatively expensive and unaffordable by most farmers, thereby making the traditional and small scale mill to predominate. (Sami and Adegbenjo, 2002) also reported that while the palm oil production stages in the processing line had undergone a great deal of mechanical. A major viable oil in Nigeria is obtained from the kernel of the palm tree after cracking the palm kernel nut. The kernels are not useful until the kernels are separated from the shell. But the usual way of cracking palm nut to get the kernel is a time consuming and labour intensive process (Badmus, 1990). A safer and more efficient method of cracking palm kernel and separating kernels from shells is desired. Therefore, cracking and the separating processes are two major operations that need serious development for drastic improvement in quality and quantity of palm kernel oil produced in Nigeria. Kernel contains 46 to 54% oil with a free fatty Acid, (FFA) of about 4% and this oil is more stable than palm oil. (Derek and Wiberley, 1997). The by-product after extraction of palm kernel oil can also be used as a valuable substitute for cocoa butter as well as palm kernel cake, animal feed, soap, candle and varieties of industrial used. Palm kernel industry had remained very popular in third world because of the dependency of many companies on palm kernel oil as raw material, which is quite inadequate (Hartley, 1987). Nigeria is one of the world largest exporters of palm kernel product in early sixties, providing about 400,000 metric tons amounting to 65% of the world trade. Nigeria palm kernel nut export reduced drastically within seventies, from 65% to 15% when there was an oil boom (Ndegwe, 1987). Based on high dependent of many companies like soap, vegetable oil and body cream industries within and outside the country. An efficient palm kernel-processing machine is therefore not only necessary but also important to revitalize the production of palm kernel in other to meet up with the ever increasing industrial demand. Removal of palm kernel from its shell involves cracking and separating processes. There are two widely methods commonly used for these processes. Manual (traditional) method and mechanical method.

The manual method of palm nut processing is the traditional way of cracking and separating palm kernel. It is a typical business venture for local youth and old women in the villages in which nuts are cracked using stones and kernel separated by hand picking from the shell at the same time. This method is labour intensive, time consuming and very slow to meet the demand for growing industries (Badmus, 1990). There are two basic mechanical effect that can be use to crack the shell of the nut. The shock caused by an impact against a hard object and the application of direct mechanical pressure to crush, cut or shear through the shell. Palm nut cracking machines are developed on the principle of hurling of palm nut at a high speed against stationary hard surface (Okoli, 1997). Generally, two types of nutcracker are used in palm oil mill; roller crackers and centrifugal impact cracker. In rollers cracker, the nuts are cracked in between two flated rollers revolving in opposite directions. The clearance between the rollers is variable but the nuts are of different sizes which makes the machine to be operating at reduced efficiency. The other cracker is centrifugal impact cracker that uses principle of centrifugal force to flap the palm kernel nuts on the stationary hard surface. This method involves using a shock caused by an impact against hard objects to shear, crush or cut through the shell (Badmus, 1990). Mechanical method will only crack the nut.

1.2 Statement of the problem

The separation of kernel from shell is a very difficult process. The manual (traditional) method of palm nut processing is the traditional way of cracking and separating palm kernel.

It is a method which nut are cracked using stones and kernel are separated by hand picking from the shell at the same time. This manual method is labour intensive, time consuming, cumbersome and very slow to meet the demand of growing industries. The imported machines for cracking palm kernel are very expensive for local farmers to buy. Therefore, there is need to develop a low cost palm Kernel Cracker.

1.3 Objectives of the Study

The main objective of the work is to develop a machine that will crack palm kernel and separate kernel nut from the shell.

The specific objectives are:

1. To design a palm kernel cracking machine
2. To construct the palm kernel cracking machine
3. To evaluate the performance of the palm kernel cracker

1.4 Justification of the study

This project work seeks to proffer solution to the teeming population of local palm kernel and medium scale industries involved in palm kernel business in their quest for a convenient, available and cheap method of cracking their palm nuts, which in most cases are still being done manually due to either very high cost or unavailability of cracking machines.

2. MATERIALS AND METHOD

In the existing cracking machine, the different sizes of nuts were not put into consideration. when a mixture of different sizes of nuts are fed into the existing cracking machines some will be too small or too big to crack which will be the major reason for low efficiency of the machine. Base on the above findings an experiment will be carry out to determine the average size, average mass, moisture content strength and coefficient of friction of shell and kernel to aid in the design and fabrication of the machine.

2.1 MATERIALS

The use of palm kernel cracking machine is limited to local farmers and medium scale industries whose quantity of palm nuts for cracking does not exceed 1000kg per day.

The improve design is made-up of some components.

2.1.1 Function of the components of the machine

1. The hopper

The hopper is made up of mild steel materials plate. it serves as an inlet through which the kernel enters into the spinning bowl. The top of the hopper will be wide enough to take sufficient kernels at a time. The volume, which was obtained as follows:

V= L.B.H (m^3)

Where:

V=Volume of hopper

L= Hopper length

B= Hoppers breath

H= Hoppers height

2. Rotor (Rigid Beater)

The rotor is a rotating part of the machine. The rotor receives palm kernel from the hopper at high speed and flap it against the cracking wall for easy cracking of the nuts.

3. The Shaft

The shaft is a rotating element made from a mild steel rod of which aid the cracking of palm kernel nut. The reason for its selection is based on its high tensile strength, resistance to wear and low cost. (Khurmi and Gupta, 2007)

$$d^3 = \frac{16}{\pi Ss}\sqrt{(K_b M_b)^2 + (K_t M_t)^2}$$

Where:

S_s= Maximum shear stress (N/m)

$m_{t=}$ Torizonal moment (N/m)

m_b= Combine shocks and factors applied to bending moment (N/m)
k_t =or for bending and torsional moment respectively [N/m]

4. Bearing

This takes pure radial loads, pure thrust load or the combination of both.
A unit has its own bearing housing
It has self-alignment ability
It has longer life than ball bearing
It is easier to replace
It has the ability to reduce friction to the minimum
It has the ability to withstand weight of shaft and can easily be mounted.

L = $\frac{[C]k}{P} \times 10^6$ revolution

Where ;
L= rated life
P =equivalent
C= basic dynamic load
K = constant = 3 for ball bearing

5. Supporting Frame

The stand is made up of 2 inches angle iron cut into sizes and welded together to form a frame structure. A foundation with a mixture of sand, cement, aggregates and water will be provided to prevent vibration of the machine.
The machine will be installed on the required stand through the foundation base on the stand. The frame is design to withstand shock and vibration to prevent twisting and maintain firm stability.

6. Pulleys

The recommended pulleys for this machine is mild steel. The criteria for selecting mild steel material is base on the comparatively lighter weight than cast iron pulley, higher strength and durability, less tendency of failure or breakage, both pulley grooved and belt run on v-groove pulley.

$N_1 D_1 = N_2 D_2$ (Ndirika, 1993)

Where:
N_1 = speed of driven pulley
N_2 = speed of driven pulley
D_1 = Diameter of driven pulley (mm)
D_2 = Diameter of driven pulley (mm)

7. Electric Motor

The main purpose of electric motor is to drive the rotor at a very high speed. The combined effect of centrifugal force and kinetic energy of rotating are employed in palm kernel cracking machine that can be obtain from electric motor of two [2] horse power and revolution per minute.

8. V-Belt

The selected v-belt for the machine is a single v-belt. A belt provides convenient means of transmitting power from the electric motor shaft to the cracking rigid beater through shaft..

This belt operates on v-groove pulley. The selection of v-belt is based on obtaining along, trouble free life, and quiet running. The important part in absorbing shock load and in damping out and isolate the effect of vibration by (Khurmi and Gupta, 2007).

$$L = \frac{\pi}{2}(D + d) + 2c + \frac{(D-d)2}{4c}$$

Where

C = distance between the driving and driven pulleys (mm)

D = diameter of driven pulley (mm)

d = diameter of driving pulley (mm)

9. Main Housing (Cracking Drum)

The main housing was constructed from medium carbon steel with reliable strength, toughness and good weld ability. This is to make the machine easier for servicing and repair when maintenance is necessary.

10. Bolts and Nuts

This help to fasten the front case of the cracking drum for easy opening during either preventive or breakdown maintenance. It is also used to fasten the two palm kernel separating sieve.

2.1.2 Operating Principle of a Palm Kernel Cracking and Separating machine

The palm nuts are feds into the machine through the hopper and its slanting nature facilitates the smooth movement of the kernels as feeding continues. As the nut are feds from the hopper at moderate speed through the centralised hole in the flywheel, they first make impact with the cracking flywheel and the walls of the cracking rectangular channel welded to the flywheel rotating at a **high speed of 2500 rpm a**nd giving rise to a very great impact force that eventually cracked the palm nuts. The cracked kernels and shells thereafter passes or falls into the cracking drum and finally goes out through the outlet at the bottom part of the cracking drum on the first screen attached to the supporting frame. The cracked kernels with average size of 11mm from observation and cracked shells with size less than 12mm falls through the first separating screen (sieve) which will be design with hole of 12mm there by retaining cracked shells with sizes bigger than 12mm as well as very few kernels bigger than 11mm. The second filter will be design with holes of 10mm retains 90% of kernels and filter off nearly all cracked shells with size 10mm and less than 10mm that falls on it from the first sieve. The kernels will be remove or collected from the second screen while, the cracked shells will also be remove from the first screen and underneath the second screen.

2.2.1 Force to crack palm kernel nut (F)

The cracking strength of palm kernel as determined from an experiment was 1423.25NM^{-2} (Okoli, 1997)

F = A x S

Where,

A = area of palm kernel cracking

S = strength

F = cracking force

2.2.2 Angle of repose (Φ) of shell and kernels

Angle of repose (Φ) is the angle at which the separating tray is tilt for kernel and shell to move down with uniform velocity.

Where,

$\mu = \tan$ _ Φ

μ = Coefficient of friction, Φ = Angle of repose, Φ = Angle of repose shell, Φ = Angle of repose of kernel, μ_2 = Coefficient of friction of shell = 0.50 and μ_t = Coefficient of friction of kernel = 0.26 (Okoli, 1997)

$\Phi = \tan^{-1} \mu_t = \tan^{-1} 0.5 = 26.6°$

$\Phi_t = \tan^{-1} \mu_t = \tan^{-1} 0.26 = 14.57°$

2.2.3 Power required to vibrate the separating screen (sieve)

$P_t = (F_{t} + Wpt)\, Vt$

Where,

Wpt = weight of the pulley

Vt = Peripheral Velocity of the Can

ft = Vibrating force

P_t = Power

2.2.4 Design Concept and Calculation

The machine was developed to cater for all the physical characteristics of the palm kernels varieties (Dura and Tenera) such as the different size of the palm kernel (from local sampling) the shell and kernel weight of palm kernel and as well as coefficient of friction for shell and kernel with respect to carbon steel was put into consideration. For best performance to be released before the fabrication of the machine, different palm kernel nuts were randomly picked and measured with average measurement size of 11.0 to 18.0mm in diameter and the thickness size of shell ranged from 0.8 to 2.7mm.

2.2.5 Determination of engine power for cracking

The cracking force required (Fc) was calculated as follow by equation (1) to (3).

$F_c = mw^2r$

Where: M= mass of the nuts (g)

w= speed in radian per second (red/s).

r= radius of the rotor (m).

N= revolution per minute (rpm).

$F_c = mw^2r$

Density p $\left(\frac{kg}{ms}\right) = \frac{mass\ (kg)}{\text{volume(cm)}}$

Mass = pv =m

$F_c = PVw^{2r}$

Density of carbon steel used P= 7.85 x 10^3kg/ms the volume of the rotor V= 1 x b x t= (350 x 50 x 10) mm^3

$W = \frac{2\pi N}{60}$

The maximum and minimum speeds for the machine to crack are 2,400 and 800 rev/mm respectively based on literature review where some authors used a minimum of 800 and maximum of 2400rpm (Oke, 2007).

Average speed = $\frac{2400+800}{2} = 1{,}600rpm$

From equation (4): w= 157.08rad/s

Radius of the rotor r = 0.175m

From equation (1)
$F_c = 7.85 \times 10^3 \times 0.00028 \times (157.08)^2 \times 0.175 = 9.49kw$.
Note: one horsepower is equivalent to 0.746 kw
1HP = 0.746 x service factor table (www.rathicouplings.com).
Then 9.49kw = 8.48hp
8.48hp was determined to crack the palm kernel nuts therefore 9.0hp engine was selected from what is available in the market.
Impacted forces on the shaft
Figures 1 and 2 shows the tension on two sides of the belt.
The net force FN impacted by the belt on the shaft was calculated by Equation.
$FN = F_1 - F_2$

2.2.6 Torque acting on the engine pulley TEP was determine by equation

TEP = force x radius of engine pulley = $(F_1 F_2)\ (\frac{DEP}{2})$
Torque acting on the machine pulley TMP , was also calculated by equation.
TMP = $(F_1 F_2)\ (\frac{DMP}{2})$
Where:
DEP = Engine pulley diameter
DMP = Machine pulley diameter
The magnitude of the net driving force is computed from the torque transmitted by equation.
$FN = \frac{mt}{D/2}$
The machine pulley diameter was 250 mm and the engine pulley diameter was 110 mm.
Diameter ratio R = DMP/DEP = 2.3

2.2.7 Calculating Torque Acting on the Shaft

Pulley Engine rated horse power = 9 HP (6.71kw)
$Torgue\ M_t = \frac{power\ transmitted}{2\pi N}$, at 2400 rpm = 26.714 Nm
For machine pulley
$F_N = \frac{M_t}{pulley\ radius}$ = 53.40 N
Therefore; $F_1 - F_2 = \frac{M_t}{R_2}$
$M_t = R_2(F_1 - F_2)$
$\frac{F_1}{F_2} = 2.3$
Then F_2 = 41.08N and F_1 = 94.48N
Tension of the belt $T_b = F_1 + F_2$ = 135.56N
Where;
M_t =Torsional moment on the shaft, F_1 = Tight side tension, F_2 = Slack side tension.
R_2 = Radius of driven (machine) pulley.

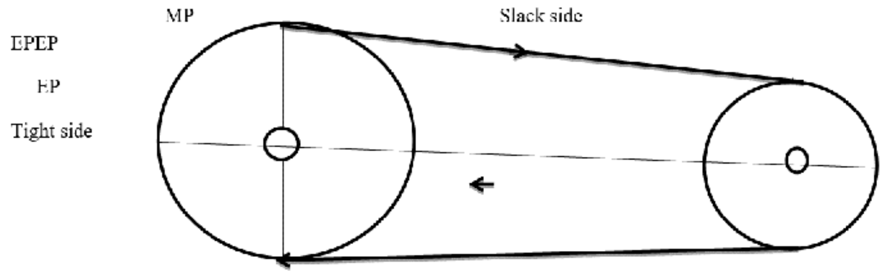

Figure 1: Tight and slack sides of belt tension

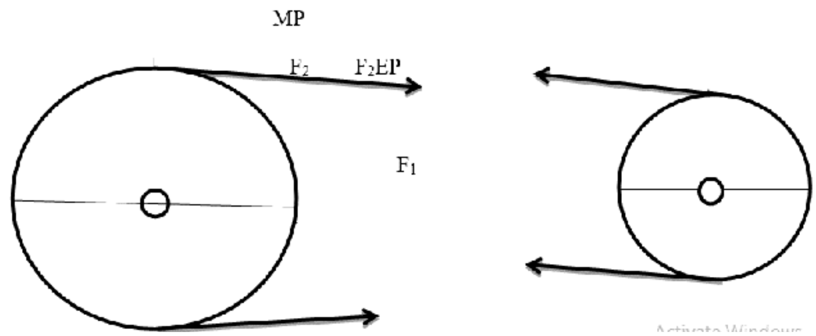

Figure 2: Impacted forces by the belt

Where:
MP = Machine Pulley and EP = Engine pulley

2.2.8 Design of pulleys

The v-belt class B type (17x1325) were selected for the drive of this machine. The width of pulleys grooves (w) were selected based on the suggestion that the width of pulley must be about 25% more than the width of the belt (Ndukwu and Asoegwu, 2000). The design of the pulley is shown in figure 1.

W = t+ (25% of t) (mm)

Where,
W = width of the pulley,
t = width of the v-belt.

For machine and engine pulleys
W = 17+ (25% x 17) = 21.25mm

2.2.9 Speed Ratio

The speed ratio and the pulley diameters were designed using equations;

$$\frac{N1}{N2} = \frac{D}{d}$$

Where;
N_1= Speed of engine pulleys (rev/min);
N_2 = Speed of machine pulley (rev/min.);
D = diameter of the large pulley (machine) (mm);
d =diameter of the smaller pulley

2.3 EVALUATION PARAMETERS

(i) Throughput capacity (kg/h)

This is the quantity of the nuts fed into the hopper divided by the time taken for the cracked mixture to completely leave the collecting chute (Cornish, 1991). It is given by equation:

$$Throughput = \frac{M}{T}(\text{kg/h}) \qquad (19)$$

where:

M = total mass of the palm nuts fed into the hopper (kg)

T = total time taken by the cracked mixture to leave the chute (h)

(i) Bulk density

The bulk density was calculated with the method described by Akintunde (2007); this was done by packing some seeds in a measuring cylinder. The seed was taped gently to allow the seed to settle into the spaces. The volume occupied by the seed in the cylinder was used to calculate the bulk density as shown in equation:

$$Bulk\ Density\ (BD) = \frac{Mass\ of\ packed\ palm\ kernel\ nuts}{Volume\ occupied\ by\ the\ palm\ kernel\ nuts}\ (\text{N/m}^3)$$

(iii) Performance Efficiency (Ɛp)

$$\mathcal{E}p\ (\%) = \frac{Total\ mass\ of\ un-broken}{Total\ mass\ of\ expected\ kernel}$$

$$= \frac{M_{UN}}{M_{UB}+M_{BN}+M_{PK}+M_{UC}}\ x\ 100$$

(iv) Percentage of Broken Nuts

$$PD(\%) = \frac{Mass\ of\ Broken\ Nuts}{Total\ Mass\ of\ expected\ kernel}$$

$$= \frac{M_{BN}}{M_{UB}+M_{BN}+M_{PK}+M_{UC}}\ x\ 100$$

(v) Cracking Efficiency (Ɛc)

$$\mathcal{E}c(\%) = \frac{Mass\ of\ cracked\ nuts}{Total\ Mass\ of\ the\ nut\ feed\ in}$$

$$= \frac{M_{TN}-M_{UB}}{M_{TN}}\, x100$$

(vi) Overall Efficiency,

(Ɛo)$(\%) = \mathcal{E}p\ x\ \mathcal{E}c$

where:

M_{UB} = weight of un-broken kernel from the chute

M_{BN} = weight of broken nuts from the chute

M_{PK} = weight of partially cracked kernels

M_{TN}= Total weight of the nut feed into the hopper

M_{UC}= weight of the un-cracked nuts

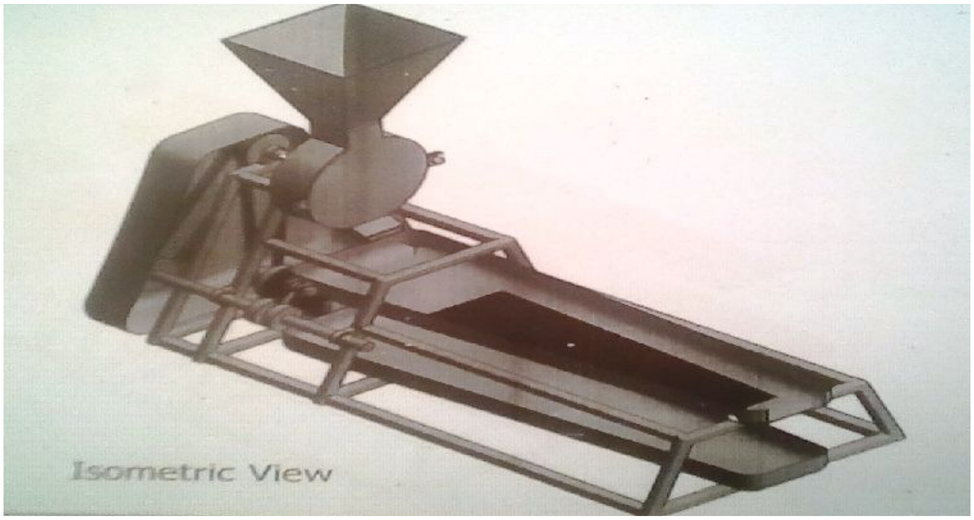

Figure 3a: Isometric View of the Machine

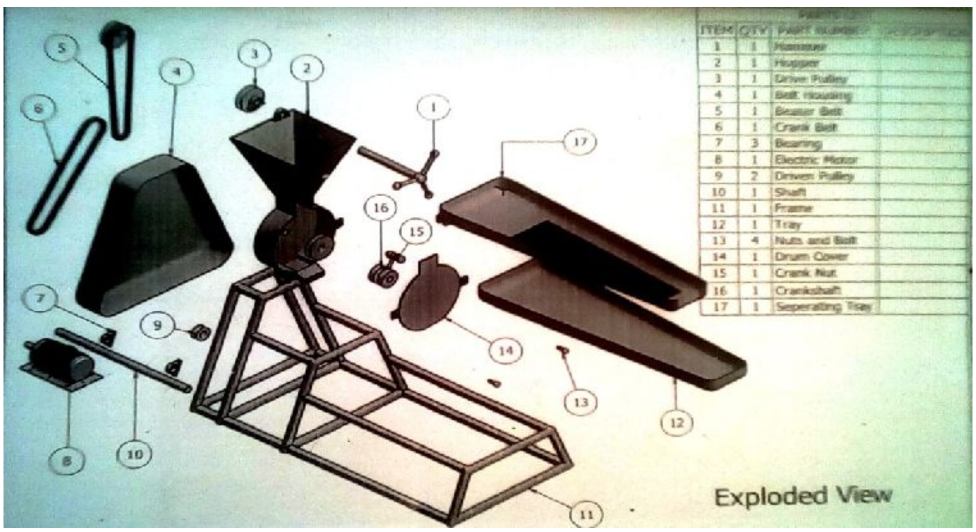

Figure 3b: Exploded View of the Machine

3. RESULTS AND DISCUSSIONS

Evaluation Performance of the Developed Machine

Table 1 shows the performance tests for the developed palm kernel nuts cracking machine, with minimum speed of 800 rpm and highest speed of 2400 rpm. It was noticed that the total number of cracked palm kernel nuts increased with increase in the speed of the shaft while the number of un-cracked nuts decreased. It was also observed that the partially cracked palm kernel nuts at 800 rpm was 2.75 % and at the highest speed of 2400 rpm was 1.75 %. Also the least un-broken kernels (1.50 %) was noticed at shaft speed of 1600 rpm. The highest broken nuts (3.25 %) was observed at the highest shaft speed of 2400 rpm.

Table 1: Performance Tests on the Developed Palm kernel Nuts Cracking Machine

Number of palm kernel nuts (4Reps)	Shaft speed (rev/min)	Cracking time taken (s)	Un-cracked nuts (%)	Partially cracked nuts (%)	Un-broken kernels (%)	broken kernels (%)
400	800	64	2.50	2.74	93.01	1.75
400	1200	44	2.02	2.74	93.74	1.50
400	1600	33	1.52	2.24	94.74	1.50
400	2000	21	1.26	2.02	94.24	2.50
400	2400	20	1.02	1.74	94.01	3.25

The cracking time and the throughput of the developed machine are shown in Table 2. The cracking time in seconds declined (from 64 to 20 seconds) with increased in shaft speed from 800 to 2400 in revolution per minute. The experimental test that was carried using the designed machine showed that throughput capacity increased from 11.5625 to 37.000 g/s with an increase in shaft speed from 800 to 2400 rpm. Plate 1 shows the developed palm kernel nut cracking machine for the research work. The total cost of production of this machine was found to be fifty five thousand Naira only (N73,000.00). The price range of similar imported palm kernel nuts cracking machine capacity was found to be ranged between N250, 000 to N300,000.

Table 2: Cracking Time and the Throughput of the machine

No of palm kernel nuts (4 Rep)	Mass of kernels (g)	Shaft speed (rpm)	Cracking time (s)	Throughput (g/s)
400	740	800	64	11.5625
400	739	1200	44	16.7955
400	741	1600	33	22.4546
400	738	2000	21	35.1429
400	740	2400	20	37.0000

Figure 4 shows the graph of machine efficiencies against the shaft speed and it was noticed that both performance efficiency and overall efficiency had their highest values at speed of 1600 rpm for 94.75 and 93.329% respectively while cracking efficiency increased with an increase in shaft speed from 97.5 to 99%. The percentages of broken nuts were 1.75, 1.5, 1.5, 2.5, 3.25% at speeds of 800, 1200, 1600, 2000 and 2400 rpm respectively (with average 2.1%).

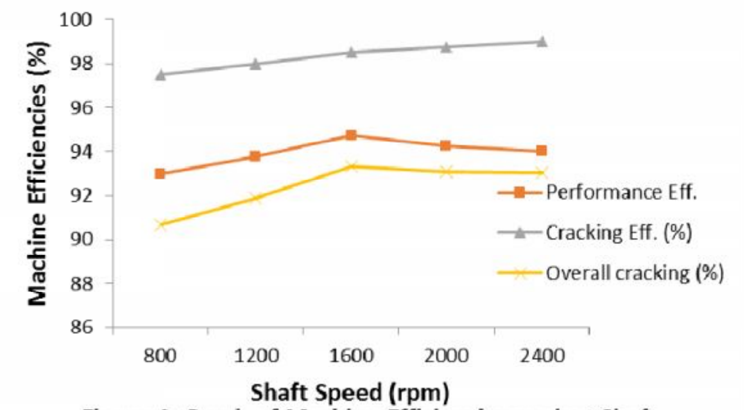

Figure 4: Graph of Machine Efficiencies against Shaft Speed

4.1 CONCLUSION AND RECOMMENDATION

4.1.1 Conclusions

In this research, a Palm kernel nut-cracking machine was developed and constructed; the materials used are locally available. The fabricated machine is a good replacement for the foreign ones. The locally made machine is economical for the establishment of small scale industry especially in the developing countries like Nigeria. The newly developed machine has broken the bearer of cost implication of the existing ones in the market, which ranges from ₦250, 000.00 to ₦300, 000.00 while this developed machine cost just only ₦73, 000.00 for unit production, which is readily affordable from the result of this study. Conclusively, the locally-produced machine was economical for the establishment of small-scale industry especially in the developing countries like Nigeria.

4.1.2 Recommendations

The following recommendations are made for the developed palm kernel cracking and separating machine.

1. The design consideration should minimise noise and vibration by using a low-noise bearing.
2. The design should be made in order to regulate the number of nuts going into the cracking chamber.

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