

Design, Fabrication and Testing of a Fragmentation Unit to Enhance Palm Kernel Separation

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Abstract – This study was conducted to enhance kernel separation by dry method using a designed fragmentation unit that would fragment shells with little damage on the kernel wholeness. This would facilitate easy separation of cracked of cracked nut mixture to obtained high percentage of purity kernels when suitable sieves are used. Samples of cracked palm nut mixtures having a moisture content of 3.8% were obtained from a mill and were subjected to repeated impact in a designed fragmentation unit. Sieve aperture sizes of 12 mm, 8 mm, 6 mm, and 4 mm were incorporated in the designed machine to test the shell fragmentation efficiency. Data were obtained and were used to analyze for kernel purity, kernel recovery and percentage of split kernels and shell fragmentation efficiency. Result showed that the machine efficiency in terms of kernel purity was 97.9%, shell purity 95.9%, kernel recovery 98.2%, wholeness of kernel retention 96.5%, split kernel 5.4% and shell recovery 98.6% and the separation efficiency of 96.9%.

Keywords – Fragmentation, Kernel, Separation Efficiency, Shell.

I. INTRODUCTION

The oil palm plant (*Elaeis Guineensis*) is one of the most important crops grown in the tropics. Nigerian is known as one of the leading exporters of palm oil. Palm oil plant is grown abundantly in the eastern part of Nigeria and on average in the western part of the country. There are basically three distinct varieties of palm kernel fruit. These are the Dura, *Tenera* and *Pisifera*. The Dura have large kernel, *Tenera* have medium kernel, and *Pisifera* have small or no kernel. The palm oil plant is a cash crop that has a wide variety of uses through the oil extracted from the seed and from the fleshy part of the plant. Palm oil is mainly used for the manufacture of soap, production of margarine, lubricating oils, and candle. It is also used in tin plate and sheet steel industries [15]. Palm kernel oil has application in the making of soap, margarine and drugs etc.

The kernels are not useful until the kernels are separated from the shell, however, the usual way of cracking palm nut to get kernel is a time consuming and labor intensive process [14], [24]. Therefore, cracking and the separating process are two major operations that need serious development for drastic improvement in quality and quantity of palm kernel oil produced in Nigeria. Removal of palm kernel from its shell basically involves cracking and separating processes. There are two widely methods commonly used for these processes: Manual (traditional) method and mechanical method [18], [23].

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 youths and old women in the villages in which nuts are cracked using stone and kernel separated by hand picking from the shell at the same time. This method is labor intensive, time consuming, cumbersome and very slow to meet the demand of growing industry [13], [10].

Mechanical method will only crack the nuts and leave the product as a mixture of shells and kernels, which needs to be separated before it can become a useful product. Picking by hand is too cumbersome at this stage, the separation processes is done using a pot containing viscous mixture of water and clay [3], [16], [22], [11]. The purpose of the clay is to aid the shells to sink while the kernels float on top of the water clay mixture. This method consumes a lot of time in washing and drying the kernel and make the palm kernels to be liable to quick infection of fungal thereby reduces the quality of oil produced. Another mechanized wet method of separation is the hydrocyclone where the principle of flow resistance is applied [20]. This method of separation has wide industrial applications but is capital intensive [9].

There is therefore need to design palm shell fragmentation unit that would fragment shell particles to small sizes relative to kernel sizes accompanying little or no objectionable damage to kernel wholeness. The product obtained would enhance easy separation using dry method (sieving technique). Effective palm kernel and shell separating machine would save time, power and cost of producing high purity kernels following kernel separation from cracked nut mixture.

The objective of this study is to design, develop and improve the performance of the palm shell separating machine to give a safer and more efficient method of separating kernels from shells to obtained high purity kernel.

The design and construction of a palm shell fragmentation unit that would minimize drudgery involve in the separation of palm kernel from shells to meet industrial need. The study is limited to the use of available local material for its construction.

II. EXPERIMENTAL PROCEDURES

Palm nuts of mixed varieties of the Dura, the *Tenera* and the *Pisifera* were purchased from a palm fruit processing mill in Itam, Uyo Local Government Area, Akwa Ibom State. The unwanted materials such as foreign materials, broken and immature nuts were screened out from the bulk nut samples. These nuts were graded into large, medium, and small sizes. The nut moisture content was determined using a total of 300 nuts per experimental run composed of

100 nuts from each of the three graded sizes. For each experimental run, the nuts were air oven dried at 104 °C and nuts weight measured at two hourly intervals until a constant weight was obtained. Three replicate were carried out.

In determining the geometric mean diameter of shell particles, sieves were used. The weight of shells retained on each sieve was used to determine the Geometric Mean Diameter (GMD_s) and the Geometric Standard Deviation of the shell particles (GSD_s). Geometrical mean diameter of the shells (GMD_s) was determined using logarithmic normal distribution parameters given in (1) and (2) as provided in [7].

$$GMD_s = \text{Log}^{-1} \left[\frac{\sum(W_s \text{Log } d_i)}{\sum W_s} \right] \quad (1)$$

$$GSD_s = \text{Log}^{-1} \left[\frac{\sum(W_s \text{Log } d_i - \text{Log } GMD_s)^2}{\sum W_s} \right]^{1/2} \quad (2)$$

Where:

W_s = The weight of sample on each sieve in g.

d_i = The diameter of opening of each sieve = (d_r x d_p)^{1/2}

d_r = The size of sieve on which particles are retained in mm.

d_p = The size of sieve through which particles will pass in mm.

III. DESIGN CONCEPT

The machine involves three working parts, the fragmenting unit which caused the reduction in shell size, the incline trays which were three in numbers sustained at an angle of repose to allow sliding of the material (kernel and shell) and rotating rug table to enhance purity kernel recovery. These working parts can be classified into two sections: the fragmenting unit section and separating unit section that includes the rotating rug table and the screening trays.

IV. MACHINE DESCRIPTION

The major functional parts of the machine are the fragmenting unit and the separating unit. It is design to have a rotating screen merges and rocking sieve trays. The frame also has other components mounted on it. The machine is made up of a funnel shape hopper divided into equal half vertically. It is designed to hold 3.08 x 10⁻⁴ m³ volume of the feed at a time and was constructed with mild steel plate of thickness 2 mm with the dimension of 170 mm in diameter and 145 mm in height. It is attached at one side of the drum cover with a hole of 60 mm diameter at the centre. The impact drum for fragmenting shells is made with a mild steel of 5 mm thickness. It has internal and external diameter of 295 mm and 300 mm diameter respectively and it carries a rotor that consist of 11 outlets of 45 mm x 45 mm angle iron, cut into 35 mm length to form an extension of 70 mm on the circular 200 mm rotor diameter; mild steel plate. An auger with a diameter 80 mm and a length of 380 mm attached beneath the fragmenting drum to channel or convey the feed to the sieve barrel.

The sieve barrel is made up of 210 mm and 280 mm inlet and outlet diameter respectively. The barrel has a length of 355 mm and consists of a 2.5 mm rod spaced at equidistance

of 7.4 mm and 10 mm from the inlet to outlet channel. The 2.5 mm rod is to assist any shell or kernel not to rest on top of the rod. The sieve trays are three (3) in numbers, and 40 mm x 40 mm angle irons having a thickness of 2 mm were used on the sides. The trays are 655 mm long, 560 mm wide, and 40 mm high. The first tray has a 2.5 mm rod spaced at equidistance of 8 mm, the second tray has a 2.5 mm rod spaced at equidistance of 6 mm and the third tray has 2.5 mm rod spaced at equidistance of 4 mm.

There is a rotating rug carpet fixed to collect some kernels and shells from an inclined mild steel tray at an angle 20° to the horizontal. The rug carpet is also inclined at an angle of 18° in order to allow only the kernels to slides through, while the shells are carried to the opposite direction as it rotates. A galvanized steel pipe of 20 mm diameter, a 40 mm x 40 mm angle iron and four 20 mm diameter bearings aid the rug carpet to rotate.

The machine consists of the following motion transmission elements: Electric motor (1.5 kW), V-belt, pulleys, shaft, and bearings. The electric motor transmits motion to the shaft through the pulley and belt, the bearings aid circular or rotational motions.

The machine has a frame of 1200 mm in length, 598 mm in width, and 1000 mm in height. The frame is made of mild steel material of 3 mm thickness and 45 mm x 45 mm angle iron, to give rigidity, strength and stability.



Fig. 1. Front, End and Plan views of the machine

V. PARAMETERS FOR PERFORMANCE TESTING

The results for the enhancement of a palm kernel separation machine, designed and constructed was tested on the basis of these five criteria; percentage kernel purity, percentage kernel recovery, percentage shell purity, percentage shell recovery and the separation efficiency [1], [17], [2], [21]. The capacity was determined based on the material input per unit cycle time. 100g of kernel and shell mixtures were used to run a test on the machine to determine the effectiveness of the fragmentation unit that will aid in the proper design of the separator for high purity kernel recovery.

Let: g = Mass whole kernel in the separated kernel.

h = Mass of split kernel in separated kernel.

i = Mass of whole kernel in separated shell.

j = Mass of split kernel in separated shell.

k = Mass of uncracked nut in the separated kernel.

m = Mass of shell in the separated shell.

p = Mass of other impurities such as fine shell particles.

q = Mass of shell in separated kernel.

A. Percentage Whole Kernel (W_{ker}) in the Separated Kernel

$$W_{ker} = \frac{g}{g+h+k+l+q} \times 100 \quad (3)$$

Where:

W_{ker} = Mass of whole kernel with respect to the total mass of material in the separated kernel.

B. Percentage Whole Kernel Recovery in the Separated Kernel

$$W_{KR} = \frac{g}{(g+l)} \times 100 \quad (4)$$

Where:

W_{KR} = Mass whole kernel to the total amount of whole kernel contained in the mixture sample.

C. Percentage Split Kernel in the Separated Kernel (S_k)

$$S_k = \frac{(h)}{(g+h+k+l+q)} \times 100 \quad (5)$$

Where:

S_k = Mass of split kernel with respect to the total mass material in the separated kernel.

D. Percentage Kernel Purity of the Separated Kernel (K_p)

$$K_p = 1 - \frac{l+q+k}{(g+h+k+l+q)} \times 100 \quad (6)$$

Where:

K_p is the absence of shell, uncracked nut and other impurities in the separated kernel.

E. Percentage Shell Recovery in the Separated Shell (S_r)

$$S_r = \frac{(m)}{(m+q+p)} \times 100 \quad (7)$$

Where:

S_r is a measure of shell separated to the amount of shell contained in the kernel/shell mixture sample.

F. Percentage Shell Purity of the Separated Shell (S_p)

$$S_p = \frac{(i+j+p)}{(m+i+j+p)} \times 100 \quad (8)$$

Where:

S_p is the absence of kernel, uncracked nut and other impurities in the separated shells.

G. Percentage Kernel recovery in the Separated Kernel (K_r)

$$K_r = \frac{(g+h)}{(g+h+k+l+q)} \times 100 \quad (9)$$

Where:

K_r is the measure of the amount of kernel to the amount of kernel contained in kernel/shell mixture.

H. Separation Efficiency

$$S_{er} = 100(K_R \times S_R) \times 100 \quad (10)$$

$$Z = 100 - \frac{(100 - S_{er})}{S_{er}} \times 100 \quad (11)$$

Where; Z = machine reliability

VI. RESULTS AND DISCUSSION

A. Physical Properties of Palm Kernels and Shells for Effective Separation

The physical properties necessary for effective separation of kernels include shell particle sizes, kernel and shell shape, energy for shell fragmentation and kernel wholeness retention. The physical properties of palm nuts, kernels and shells are presented in Table I.

Table I. Physical Characteristic of Palm Kernels and Shell with an Average Moisture Content of 9.5% w.b. for Kernels, 8.5% w.b. for Shell and 9.1% w.b. for Nuts.

Parameters	Mean Values		
	Palm Nut	Palm Kernel	Palm Shell
Major diameter, cm	2.68 (3.4)	1.57 (2.25)	1.39 (3.0)
Intermediate diameter, cm	1.97 (1.62)	1.21 (1.62)	0.94 (2.03)
Minor diameter, cm	1.57 (2.0)	0.92 (1.40)	0.48 (2.15)
Geometric mean diameter, cm	2.02 (0.40)	1.20 (0.5)	0.8 (0.3)
Sphericity	0.8 (0.02)	0.8 (0.01)	0.60 (1.03)
Bulk density, kgm ⁻³	594.31(2.40)	568.90 (1.74)	565.30 (1.23)
Specific gravity	1.15 (0.01)	1.10 (0.02)	1.30 (0.01)
Static angle of repose, degree	43.20 (0.98)	38.0 (0.56)	47.90 (1.50)
Unit weight, g	1.86 (0.36)	1.11 (0.32)	0.40 (0.33)

Values in parentheses are standard deviations.

Source: [1]

B. Moisture Content Evaluation

The effect of moisture content on the extent of shell fragmentation and kernel wholeness retention was investigated as carried out by [5], [6], [8]. The moisture content of palm nut was 3.8% w.b. The rotor speed employed for fragmentation was maintained at 1609 rpm. 100 g of cracked palm nuts with three different replicates at five cycles of fragmentation were used for this evaluation and also shows the level of separation by carrying out sieving analysis using the four sieves of 12 mm, 8 mm, 6

mm, and 4 mm. Average values of the three replicates are presented in Table II.

Table II. Average values of fragmentation in five different cycles at 3.8% Mc

	1Cycle	2Cycles	3Cycles	4Cycles
Bulk weight (g)	100	100	100	100
Initial shell weight (g)	84.0	89.1	84.9	90.0
Weight of shells on sieve 2 (g)	4.2	4.5	3.2	1.4
Weight of shells on sieve 3 (g)	3.0	4.2	4.0	2.4
Weight of shells on sieve 4 (g)	5.3	6.1	7.3	3.9
Weight of shells on spout (g)	55.8	62.9	68.4	76.7
∑ of shell weight on spout & sieves (g)	68.4	77.6	82.9	84.8
% shell loss	18.5	13.0	2.3	5.8
% fragmented shells	81.5	87.0	97.7	94.2
% fragmented shells on spout	66.4	70.6	80.6	85.2
Initial number of whole kernel	30.3	24.7	31.3	25.7
Final number of whole kernel	29.3	20.7	24.0	16.3
Number of whole kernel splits	1.7	4.0	7.3	9.3
Number of split kernels	5.0	18.0	25.0	35.3
Number of whole kernel in sieve 1	9.0	7.0	6.3	4.0
Number of whole kernel in sieve 2	10.7	6.7	11.0	5.0
Number of whole kernel in sieve 3	5.7	5.3	3.7	4.0
Number of whole kernel in sieve 4	3.0	1.7	2.0	2.7
Number of whole kernel in spout	1.0	0.7	1.0	0.7
% kernel recovery	98.2	83.8	76.8	63.4
% split kernel	5.4	16.2	23.2	36.6

C. Average Percentage Shell Fragmented on Number of Shell Input

Table II shows the analysis of the palm nut shells in 5 cycles of impact. It shows bulk weight of cracked mixture, initial shell weight, weight of shell on sieve 2, weight of shell on sieve 3, weight of shell on sieve 4, weight of shell on the spout, total weight of shell after fragmentation and percentage of fragmented shells in three replicate and their averaged.

Averaged percentage of fragmented shells produced during the fragmentation increase from 81.5% in 1 cycle to 87.0% in 2 cycles to 97.7% in 3 cycles to 94.2% in 4 cycles and 98.1% in 5 cycles as shown in Fig. II. The result shows that the increase in cycle of impact increases the level of shell fragmentation which is important in kernel separation to obtained high purity kernel.

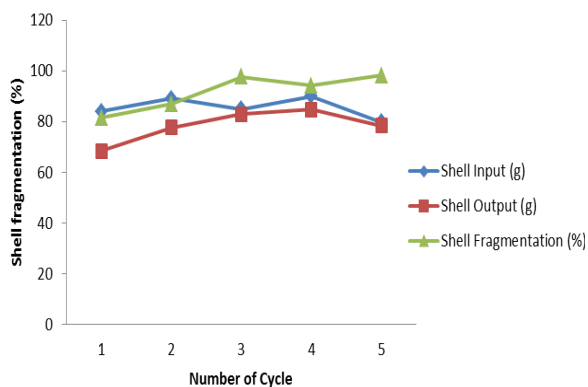


Fig. 2. Average percentage shell fragmented on number of shell

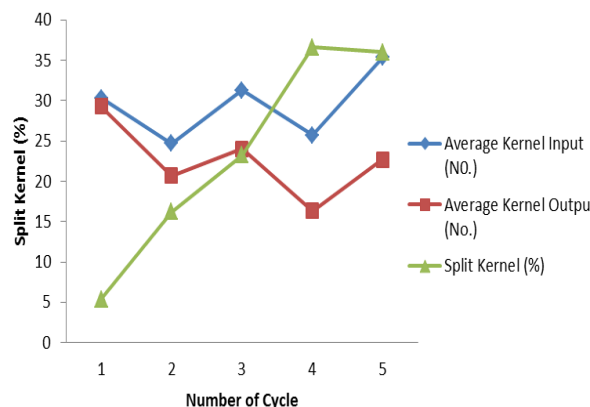


Fig. 3. Average percentages split kernel on number of kernel input

D. Average Percentage Split Kernel on Number of Kernel Input

The percentage of split kernel increases from 5.4% to 16.2% to 23.2% to 36.6% and 36.0% with 1 to 5 cycles of impact respectively as shown in Fig. III. At 1 cycle of impact the percentage kernel split is 5.4% which is tolerable but from 2 cycle to 5 cycle of impact the percentage of split kernel increases to 16.2%, 23.2%, 36.6% and 36.0% respectively which is intolerable for any production purposes, therefore 1 cycle of impact is recommended to have a good production profit. Also when the number of split kernel increase in a cracked mixture, it would pass through the sieve alongside shells during separation thereby reducing the quantity of kernel obtained.

E. Average Percentage Shell Fragmentation and Split Kernel against Number of Cycle

Fig. IV shows that average percentages of shell fragmentation (81.5%, 87.0%, 97.7%, 94.2 and 98.1%) and percentages of split kernel (5.4%, 16.2%, 23.2%, 36.6% and 36.0%) increases with respect to number of cycle of impact. The 1 cycle of impact has percentage of shell fragmentation to be 81.5% with corresponding 5.4% of split kernel which is reasonably advantageous over 5 cycle of impact with 98.1% of shell fragmentation with corresponding 36.0% of split kernel. The 5 cycle of impact have more shell fragmentation which is important for kernel separation but the percent of split kernel render it irrelevant since the objective is to obtained whole purity kernel.

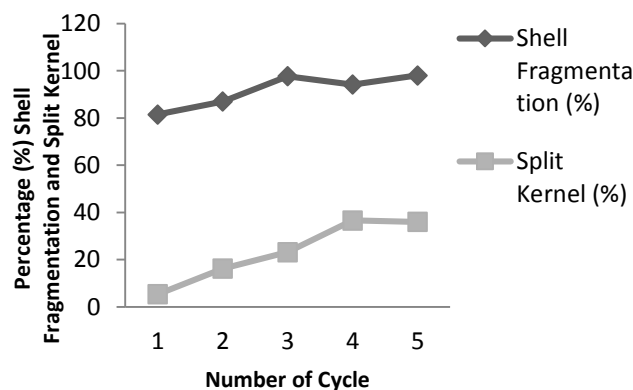


Fig. 4. Average percentage shell fragmented and split kernel against number of cycle

F. Percentage Kernel/Shell Recovery and Efficiency

The efficiency of the machine depends on the percentage recovery of kernel and shell which was evaluated using the expression in section 3.6. Table III shows the average kernel and shell recovery in percentages and efficiencies on each number of cycles. The percentage for kernel recovery, shell recovery and efficiency (98.2%, 98.6% and 96.9% respectively) increased in 1 cycle of impact. At 1 cycle of impact the percentage of split kernel is less than 10%, more of whole kernel is collected which give a higher efficiency as compare to other cycles.

Table III. Percentage kernel/shell recovery and efficiency per cycle number

No of Cycles	Kernel Recovery (%)	Shell Recovery (%)	Efficiency (%)
1 cycle	98.2	98.6	96.9
2 cycles	83.8	81.1	90.1
3 cycles	76.8	82.5	83.4
4 cycles	63.4	90.5	77.4
5 cycles	64.0	92.3	69.1

G. Percentage Kernel and Shell Purity

The percentage kernel and shell purity was estimated per different number of cycles and represented as shown in Table IV. The percentage of shell purity decreases from 1 cycle of impact to 5 cycles. The percentage of kernel purity decreases and starts increasing from 3rd cycle of impact.

Table IV. Percentage kernel and shell purity per cycle number

No of Cycles	Inputs (g)	Kernel purity (%)	% Shell purity (%)
1 cycle	100	97.9	95.9
2 cycles	100	79.8	80.0
3 cycles	100	81.0	80.2
4 cycles	100	87.8	81.9
5 cycles	100	91.2	79.2

H. Correlative Relationship

Correlating kernel purity with kernel recovery and shell purity with shell recovery show that there is relation with positive coefficient of correlation and no or little relationship with negative coefficient of correlation. The relationship here implies that, percentage kernel purity is almost equal to the level of the kernel recovery.

VII. CONCLUSIONS

The following conclusions are made:

1. The machine performs best at moisture content of 3.8% (w.b).
2. Percentage fragmented shells efficiency increases with increase in number of cycle of impact.
3. Percentage of split kernel increases with respect to moisture content and number of cycle of impact.
4. Rotor speed of 1609 rpm is adequate for fragmenting palm nut shell to obtained whole purity kernel.
5. The machine efficiency in terms of Kernel purity was 97.9%, shell purity 95.9%, kernel recovery 98.2%, and shell recovery 98.6%, and the separation efficiency of

96.9%.

6. The separation rate of 515 kg/hr is far greater than the manual hand picking rate of 60 kg/hr.

RECOMMENDATIONS

The following recommendations are made:

1. The cracked mixture should be cracked at rotor speed of 1609 rpm. The cracked mixture should be crack at different moisture content. More sieve aperture sizes should be provided to check for the efficiency of the machine.

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