

Experimental Determination of the Rotor Speed of a Vertical Shaft Centrifugal Nut Cracking Machine

P. O. Ajewole

Department of Agricultural and Bio-Environmental Engineering, The Federal Polytechnic, P.M.B. 5351, Ado-Ekiti, Nigeria
Email: peterajewole@gmail.com, Mobile: +2347068675164

ABSTRACT: The impinging velocity that gives that maximum cracking efficiency of a vertical shaft centrifugal palm nut cracking machine was determined in this study. A nut cracking energy instrument which consists of a hammering mass falling vertically on palm nuts placed on a base was used to determine potential energy required to crack the nuts. This energy was equated to the kinetic energy required to crack the nuts in a centrifugal palm nut cracking machine, from which the average impinging velocity was determined. Experiment was carried out to generate cracking energy data for both Dura and Tenera varieties of palm nuts available in the study area. For Dura type, highest percentage of fully cracked (FC) nuts and average impinging velocity of 32.50 m/s were obtained when the height of the hammering mass was set at 0.15m, 0.25m and 0.30m for nuts sorted into diameter ranges of $d < 15\text{mm}$, $15\text{mm} \leq d \leq 18\text{mm}$, and $18\text{mm} \leq d \leq 22\text{mm}$ respectively. For the Tenera type, highest percentage of fully cracked (FC) nuts and average impinging velocity of 39.56 m/s were obtained when the height of the hammering mass was set at 0.09m, 0.10m and 0.13m for nuts sorted into diameter ranges of $9\text{mm} < d < 13\text{mm}$, $13\text{mm} \leq d \leq 15\text{mm}$, and $15\text{mm} \leq d \leq 20\text{mm}$ respectively. The overall average impinging velocity of 36m/s was obtained for both varieties of palm nut and which was used in the design and construction of a centrifugal palm nut cracker. The results of testing the cracker showed that it has cracking efficiency of 98.75% and kernel extraction efficiency of 63.4%.

KEYWORDS: Impinging velocity, palm nut, cracking, Dura, Tenera, oil palm, efficiency, cracker

INTRODUCTION

Palm kernel is an important part of oil palm produce, which is obtained by cracking of palm nuts and separation of the kernels from the shell [1]. However due to global demand of palm kernel and its by-products, an effort has been geared towards an improved method of palm kernel extraction. In Nigeria National Milling capacity, palm kernel stands at about 23% potential from fresh fruit production in 1991 [3].

There are three varieties of oil palm as reported by Jimoh, [6] namely *dura*, *tenera* and *pisifera*. *Dura* is characterized by thin mesocarp, thick endocarp (shell) with generally large kernel. The *dura* type is genetically homozygous and dominant for shell. It is denoted by DD. *Tenera* possesses thin mesocarp, thin endocarp with large kernel. This is a dual-purpose palm for the production of mesocarp oil and kernel. It is genetically heterozygous and is denoted by Dd and it is also the highest oil yielding variety for both mesocarp and palm kernel oils as reported by Opeke, [11]. *Pisifera* possesses thick mesocarp with very little oil content, no endocarp (shell less) with small kernel, the female flowers are often sterile, this results in bunch failure and it is genetically homozygous, recessive for shell and it is denoted by dd [7]. Badmus, [2] stated that typical African *dura* is about 8-20 mm in length and has a fairly uniform shell thickness of about 2 mm. The *tenera* is about 7-15 mm in length with shell thickness of 1.2 mm. Since *pisifera* was not readily available in the country for commercial purpose, this was replaced with *local* palm nut that is common in Africa and is about 15-40 mm in length with shell thickness of 2.2 mm. It is characterized with too hard brittle shell with small and heavy kernel. Kernel is an edible endosperm, which is covered by reddish brown to black testa. The kernel fits tightly into the shell and varied in shape and size depending on the shape and size of the nuts [8].

Palm kernel processing industry is very popular in the third world countries because of dependency of many companies on palm kernel and palm oil as raw material [5, 13]. The modern crackers are of two types, the hammer-impact and the centrifugal-impact types. The hammer-impact type as reported by Koya, [9] breaks or cracks the nut by impact when the hammer falls on the nut, while centrifugal-impact nut cracker uses centrifugal action to break the nut. Centrifugal nut cracker is of two models based on shaft orientation. They are vertical and horizontal shaft cracker. The horizontal shaft centrifugal nut cracker has been used in larger medium and small scale palm kernel recovery plants imported to Nigeria. The nut is fed into the hopper and it falls into the housing where a plate attached to the rotor is rotating [10].

Ndukwu and Aseogwu, [10] identified three major factors affecting the efficiency of centrifugal nut crackers which are: the shaft speed, moisture content and feed rate. With higher speed of the cracker, they obtained higher cracking efficiency but higher kernel breakage ratio. The author in a previous research had observed that the centrifugal cracker can work at a high efficiency if operated at an optimum speed. Obiakor and Babatunde, [12] reported that centrifugal nut crackers are characterized by significant kernel breakage but Ofei (2007) stated that centrifugal nut crackers are majorly used in Nigeria due to their high productivity. Badmus, [2] also reported

that the vertical shaft centrifugal nut crackers give a better cracking effect because of the large diameter of the rotor, taking into consideration the aerodynamic properties of the nuts. If the gap between the rotor and cracker ring is made extra wide (say 100mm), the nuts will be brought into the optimum aerodynamic position (that is, thick end foremost) and then strike the cracker drum at the most favourable angle [2].

Badmus, [2] further reported that the Tenera nuts having a distinct rounded head and tapering fibre-covered tail are enabled to take up a 'head-foremost' position in the extra distance covered and so be cleanly cracked on hitting the plate. If the fibre-covered tail hits the plate, the nut may not crack. Secondly, in the confined space of a vertical nut cracker, the tenera nuts may be deflected by rebounding shell fragments. Thirdly, the larger the distance between the cracker rotor and the cracker ring, the more obtuse will be the angle at which the nut strikes the ring and there will then be less likelihood of the nut glancing off the ring surface. The speed of the nut crackers varies from 800-2500 revolution per minute according to the diameter of the rotor [4]. The above phenomenon is explained with the diagram in Figure 1.

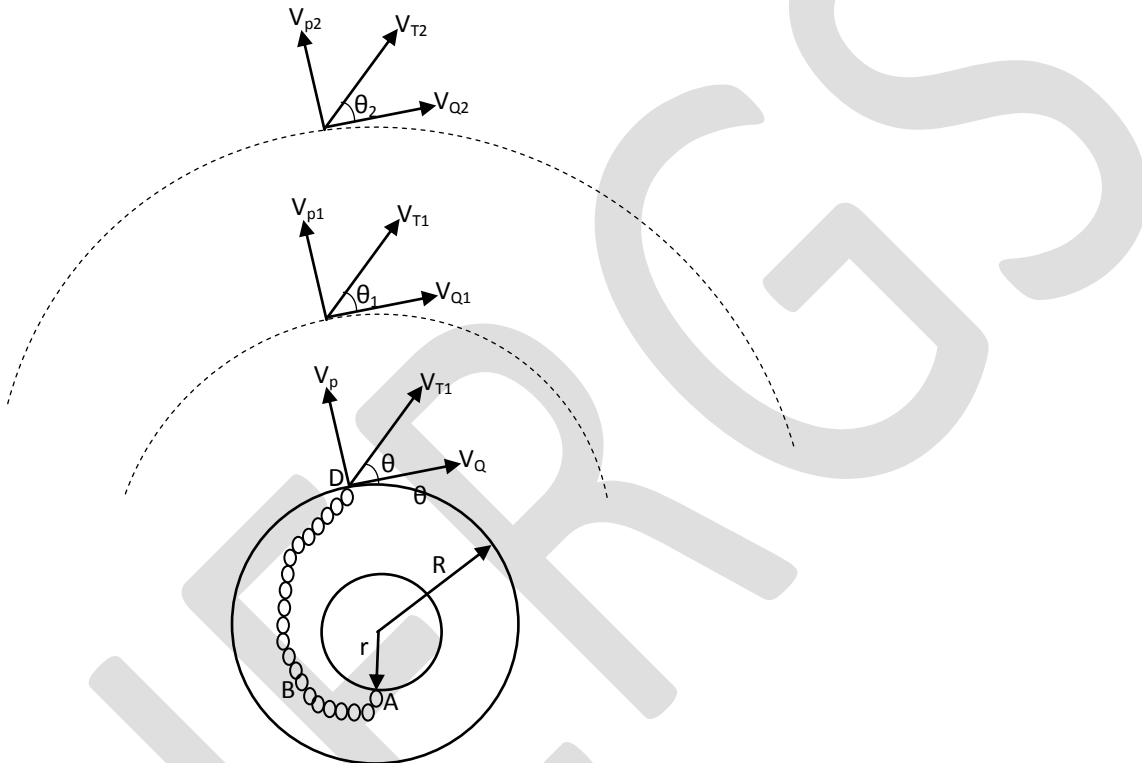


Figure 1: The motion of tenera nuts in the cracking drum

The nut enters cracker rotor at A, transverses the spiral route ABD to leave the rotor at point D. The radial outgoing speed, V_p is given by:

$$V_p = \omega \sqrt{R^2 - r^2} \quad \dots \dots \dots (1)$$

Assuming that friction of the nut with the rotor is negligible; the peripheral speed of the rotor, V_Q is given by:

$$V_Q = \omega R \quad \dots \dots \dots (2)$$

Since r is very small compared to R , V_p is approximately equal to V_Q and the angle between V_Q and V_T is less than 45° .

$$V_T^2 = V_p^2 + V_Q^2 \quad \dots \dots \dots (3)$$

$$\text{Hence, } V_T = \sqrt{V_p^2 + V_Q^2} \quad \dots \dots \dots (4)$$

METHODOLOGY

Nut Cracking Energy Instrument

Average impinging velocity required to crack palm nuts in palm nut crackers was determined experimentally for both Dura and Tenera varieties palm nuts using Nut Cracking Energy Instrument which consists of a 1.34kg iron block (hammer) that is moved a vertical scale. The hammer was raised to various heights by means of a rope attached to it. The base was made of cast steel of 15cm thickness. A graduated wooden bar attached to the base was used to measure the height through which the hammer falls to crack the nut placed on the wooden base. The nut absorbs the energy of the falling hammer due to the height (h - d) through which it falls. Thus, the cracking energy is equal to the potential energy (PE):

$$E = P.E = Mg(h - d) \quad \dots\dots\dots (5)$$

If the nut is cracked by flinging it on to a hard static surface, the wall absorbs the kinetic energy due to its impinging velocity (V) component normal to the surface. Therefore, the cracking energy was equated to the kinetic energy (KE) of the palm nut and was given by:

$$E = K.E = \frac{1}{2}mV^2 \quad \dots\dots\dots (6)$$

Assuming that energy losses during cracking are negligible, P.E. = K.E.

Therefore, $\frac{1}{2}mV^2 = Mg(h - d) \quad \dots\dots\dots (7)$

Thus the impinging velocity of the nut is given by:

$$V = \frac{[2Mg(h - d)]^{1/2}}{m} \quad \dots\dots\dots (8)$$

Where M= mass of the hammer (1.34kg), g = acceleration due to gravity (9.81m/s²), h = initial height of the hammer, d = relative diameter of the nut, and m = mass of the nut. Substituting known values, the impinging velocity is then given as:

$$V = \frac{5.1275(h - d)^{1/2}}{m} \quad \dots\dots\dots (9)$$

Experimental Procedure

In order to generate the cracking energy data for palm nuts, a large quantity of fresh palm nuts (Dura and Tenera varieties) were sun-dried until a moisture content of 10% was achieved. Since it was known that different sizes of nuts require different speed and energy to crack, nominal diameters of the nuts were then measured with vernier caliper and both varieties were grouped in the different size ranges as shown in Table 1.

Table 1: Grouping of the palm nuts into different sizes

	Dura Variety	Tenera Variety
1.	d < 15mm	9mm ≤ d ≤ 13mm
2.	15mm ≤ d ≤ 18mm	13mm ≤ d ≤ 15mm
3.	18mm ≤ d ≤ 22mm	15mm ≤ d ≤ 20mm

The mass of each nut was measured using an electronic weighing balance. Each nut was then placed at the centre of the instrument base plate. The hammer was raised to a height indicated on the scale and released to fall on the nut. The observations made were recorded with the following symbolic representations:

- FC - Fully Cracked -the shell is broken and the kernel is released from pieces of the shell.
- FCW - Fully Cracked with wound - the kernel is separated from the pieces of the shell but with wounds on it.
- NFC - Not Fully Cracked - this comprises half-cracked and uncracked nuts.
- SM – Smashed - the kernel is broken along with the shell.

Ten nuts (10) from each size range were tested at each height of the hammer for both varieties. Three (3) or two (2) different heights were used for different size ranges. 80 nuts were tested for Dura variety and 80 nuts for Tenera variety making a total of 160 nuts. The percentage of fully cracked nuts was calculated for each size range at different heights. The impinging velocity corresponding to each height for each nut in the different size ranges were also calculated using equation (9). The size ranges at a particular height having highest cracking efficiency were selected from the size ranges and the average impinging velocities of the nuts in these selected size ranges were found. Then the overall average impinging velocities were also found. This procedure was carried out for both Dura and Tenera palm nut varieties. The average of the overall average impinging velocities for both Dura and Tenera was then found

RESULTS AND DISCUSSION

The results of the experiment and calculation of impinging velocities of the nuts observed were presented in Tables 2 and 3.

Table 2: Average impinging velocities obtained for Dura nut variety

Size Range (mm)	Height of cracking (m)	Percentage fully cracked (%)	Average Impinging Velocity (m/s)
d < 15	0.15	90	34.76
	0.17	80	38.58
	0.18	80	37.61
15 ≤ d ≤ 18	0.25	80	33.33
	0.26	60	35.34
	0.28	70	34.36
18 ≤ d ≤ 22	0.30	80	29.41
	0.35	40	33.39
Average impinging velocity where highest percentage of fully cracked nuts were obtained			32.50

Table 3: Average impinging velocities obtained for Tenera nut variety

Size Range (mm)	Height of cracking (m)	Percentage fully cracked (%)	Average Impinging Velocity (m/s)
9 ≤ d ≤ 13	0.08	60	50.53
	0.09	80	46.49
13 ≤ d ≤ 15	0.10	80	36.13
	0.11	60	43.58
	0.12	50	49.62
15 ≤ d ≤ 20	0.12	60	38.19
	0.13	80	36.07
	0.14	50	39.06
Average impinging velocity where highest percentage of fully cracked nuts were obtained			39.56

As shown in Tables 2 and 3, for Dura variety, the highest percentages 90%, 80% and 80% were obtained for size ranges of d < 15mm, 15mm ≤ d ≤ 18mm and 18mm ≤ d ≤ 22mm respectively. For Tenera variety, the highest percentages 80%, 80% and 80% were obtained for size ranges 9mm ≤ d ≤ 13mm, 13mm ≤ d ≤ 15mm and 15mm ≤ d ≤ 20mm respectively. The overall average of impinging velocities for both varieties were thus calculated and used in the design and fabrication of a nut cracking machine. The fabricated

CONCLUSION

The average impinging velocity of the rotor of a centrifugal palm nut cracking machine was determined using a nut cracking energy instrument. Dura and Tenera varieties of palm nut were considered. The overall average impinging velocity for both varieties were found to be 35m/s which could be used in the design and fabrication of a vertical shaft centrifugal palm nut cracker.

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