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Dynamics of Centrifugal Impact Nut Cracker

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Abstract: *This paper presents the dynamics of vertical axis centrifugal nut cracker. The cracker consists of a feed hopper with a flow rate control device, cracking unit, separating unit and power system which consists of a single phase 3hp, 1500-rpm electric motor with belt and pulley system. The cracking unit consists of impeller with four vanes mounted on a vertical shaft and an impeller casing which served as the cracking surface. The working principle of the cracker is similar to that of centrifugal pump. The nuts to be cracked are rotated and pushed by the vanes of the impeller in the direction of the vanes motion, thereby imparting mechanical energy to the nuts. The direction of motion of nuts through the impeller is radially outward. When leaving the impeller, the nuts gain kinetic (velocity) energy and the velocity components are studied graphically by means of velocity vectors. The results of the analysis showed that the radial velocity is 0.66 m/s, tangential velocity is 15.71 m/s, resultant velocity is 15.72 m/s, while the cracking velocity is 10.41 m/s which gave an impact (cracking) energy of 0.55 J. The cracker was evaluated using sheanut at four moisture levels of 6, 13, 22.7 and 27.9% (db) and nut feed rates of 11.4, 15.5, 23.1 and 45.2 kg/h. The study showed that at nut moisture content of 22.7% (db) and feed rate of 11.4 kg/h, the cracking efficiency of 100% was achieved.*

Keywords: *Dynamics, impeller, sheanut, centrifugal, cracking efficiency, coefficient of friction.*

1. Introduction

Some oil bearing crops such as sheanut, coconut, palm kernel and legumes crops like bambara groundnut are covered in pods or shells. Mechanized cracking or shelling to obtain the kernel or fruit is very necessary to eliminate the rigour involved in the manual cracking/shelling of the pods/shell in order to increase the production output.

To meet this need, researchers have worked on different types of crackers/shellers. Adigum and Oje (1993) reported that nuts whose shells/pods cannot be easily broken by the roller cracker are commonly cracked using centrifugal cracker. Dicken (1961) developed a simple device to subject individual seeds to impact forces in order to see the possibility of using impact force for shelling/cracking seeds. Makanjuola (1975) evaluated some centrifugal impaction devices for shelling melons seeds using three types of impellers; Impeller A: with four slots, impeller B: with eight slots and impeller C: with two slots. The result showed that shelling melon by impaction method is possible and concluded that impeller A is the most efficient out of the three impellers evaluated. Odigboh (1979) also evaluated three types of impeller each with four vanes but different vanes angulations. Impeller A: radially positioned vanes, impeller B: vanes positioned at 45^0 to the radius and impeller C: vanes positioned at 90^0 to the radius and concluded that impeller B gave the best combination of higher shelling efficiency and low percentage of breakage. The sheller gave shelling efficiency of about 96% at an average capacity of 145kg/h. Oluwole et al (2004) developed and tested a sheanut cracker working on the principle of impaction and pneumatically separates the shell from the kernel. This cracker gave a 100% cracking efficiency at moisture content of 22.7% (db).

Shahbazi (2012) investigated effects of moisture content, impact direction and impact energy on the cracking characteristics of Apricot Pit, his results showed that moisture content; impact energy and impact direction significantly influenced the cracking characteristics of pits at 1 % level of significance. He reported that the optimum moisture content was 18 % and impact energy was 0.6 J in the direction along width of pit.

The cracking of sheanut to obtain clean kernels has been a bottleneck to sheanut processing. To eliminate this bottleneck requires the development of effective and appropriate technological equipment for cracking of the nut. Oluwole (2004) investigated the impact energy needed to crack sheanut at moisture content range of 6% - 27.9% (db). He suggested that to effectively cracked sheanut by impaction, the impact energy should be within the range of 0.50J and 0.52J and that the sheanut be conditioned to moisture content ranging between 13% - 22.7% (db) prior to cracking. The average mass of sheanut at moisture content range of 6% -27.9% (db) is 0.0079kg - 0.0106kg (Oluwole, 2004).

This paper presents the analysis of the dynamics of a vertical axis centrifugal impact sheanut cracker in relation to nuts moisture content.

2. Description of the Centrifugal Cracker

The cracker consists of a feed hopper, nut cracking unit, winnowing unit and power unit Figure 1. The hopper is mounted on the tool frame and held in place by a hopper support frame. It is connected to the cracking unit by an adjustable nut flow channel to be inclined at angle of repose of the nut to be cracked. The outlet of the nut flow channel is 200mm above the impeller surface. A nut flow rate control device that regulates the quantity of nut entering the cracking chamber per unit time is located between the hopper and the feed flow channel.

The cracking unit consists of cylindrical casing (which served as the cracking surface), an impeller (with four vanes) that is concentrically positioned within the casing and horizontally mounted on a vertical shaft. The impeller is mounted to give inner clearance that is equal to nut size with cracking surface of the casing. This impeller is driven by the vertical shaft powered by a single phase 3 hp, 1500-rpm electric motor through a system of belt and pulley.

The winnowing unit consists of the separating chamber, and blower powered by the electric motor to supply the air stream required for winnowing. These components were assembled and mounted on a rectangular tool frame that gave the machine a compact design and a sturdy outlook.

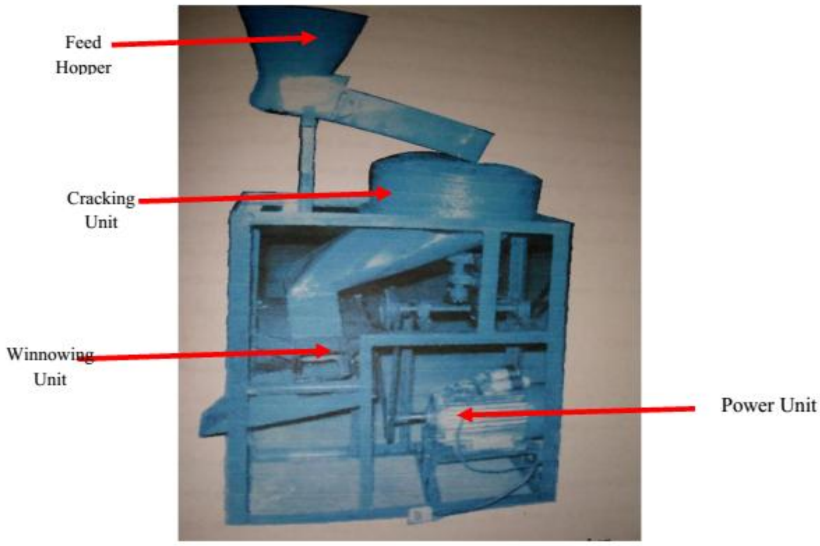

Fig1. *Photograph of the nut cracker*

3. Operational Principle

To operate the cracker, the flow rate control device is shut completely. The hopper is then filled with nuts and the control switch is switched on to activate the electric motor, which runs the impeller in the cracking chamber. The gate opening that delivers the desired feed rate is selected using the flow rate control device and the nut are allowed to flow into the cracking chamber and fall upon the surface of the impeller . The centrifugal force developed by the particles as they roll and slide on the impeller surface and along the vane, throws the nut against the impact surface and causes them to crack. The mixture of kernel and broken shells flows down to the winnowing chamber through the inclined transition channel. Here the shells, which are lower in density than the kernel (Aviara et al, 2002) are pneumatically separated from the mixture and blown out through the chaff outlet. The denser kernel falls through the air current into the kernel collection chute.

4. Dynamics of the Cracking Operation

The nuts to be cracked are fed unto the impeller via the inlet chute 200mm above the impeller surface as soon as the impeller attains its operational speed. These nuts reach the impeller surface with a velocity, V_1 [Hannah and Hillier, 1971]

$V_1 = \sqrt[2]{2gh}$ (1)

Where

h = height of the inlet chute above the impeller, m

g = acceleration due to gravity, m/s²

Odigboh (1979) gave the expression of radial velocity of egusi seed emerging from a rotating impeller as

$V_r = \frac{dr}{dt} = A\omega Pe^{\omega Pt} - B\omega Me^{-\omega Mt}$ (2)

Where

$P = \sqrt{(\mu^2 + 1) - \mu}$

$M = \sqrt{(\mu^2 + 2) + \mu}$

r = radius of impeller, m

ω = angular velocity of the impeller, rad/s

μ = coefficient of friction between seed and impeller surface

t = time, sec

A and B =constants

Hannah and Stephen (1972) gave an expression for the velocity of a body sliding on a rotating disc as:

$V_P = V_{P'} + V_{P/P'}$ (3)

Where V_p = velocity of the sliding body, m/s

$V_{p/}$ = velocity of a point on the rotating disc coinciding with the sliding body, m/s

$V_{p/p}{}^{/}$ = velocity of sliding body relative to the point $p^{/}$ on the rotating disc, m/s

Equation [3] is represented in Figure 2.

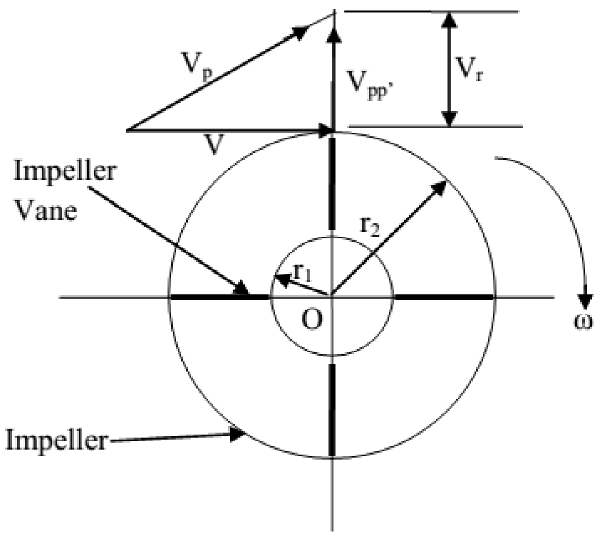

Fig2. *Velocity of nut emerging from the impeller*

Source: *Massey, (1989)*

From Figure 2,

$V_P^2 = V_t^2 + V_{P/P'}^2$; but $V_{P/P'} = V_r$

Therefore

$$V_P = \sqrt{V_t^2 + V_r^2} \tag{4}$$

Where V_t = tangential velocity, m/s

V_r = radial velocity of nut, m/s

The velocity of flow in a centrifugal impeller is given by Douglas *et al*., (1985) as

$$r_1 \; b_1 \; V_{f1} = r_2 \; b_2 \; V_{f2} \tag{5}$$

where

$b_1=b_2$; $V_{f1}=V_1$; $V_{f2}=V_r$; and θ = outlet blade angle.

Equation [5] becomes

$$V_r = r_1 . {}^{V_1}/_{r_2} \tag{6}$$

$$V_t = \omega r_2 \tag{7}$$

The nut will emerge with resultant velocity vp at an angle ∝ to the tangent at the tip of the blade

$$\propto = \sin^{-1}\left({}^{V_r}/_{V_p}\right) \tag{8}$$

The cracking surface is concentric with the impeller; this resultant velocity V_p has two components on the cracking surface;

- Normal component V_N, responsibel for the effective splitting of shell by impact
- Tangential component Vs, responsible for seprating the kernel from the split shells (Figure 3) (Odigboh,1979).

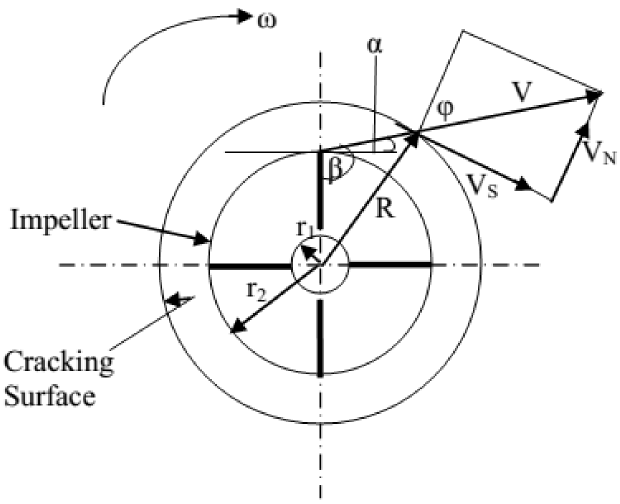

Fig3. *Velocity diagram of nut emerging from the impeller and making impact with the cracking surface*

From Figure 3

$$\varphi = \sin^{-1}\left(\frac{1}{R} r_2 \sin(90^0 + \alpha)\right) \tag{9}$$

$$\varphi = \sin^{-1}\left(\frac{1}{0.2} \; 0.15 \sin(90^0 + \alpha)\right)$$

$$V_N = V_p \; \cos\varphi \tag{10}$$

$$V_S = \sin\varphi \tag{11}$$

Oluwole *et al.*, (2007) investigated the impact energy required to crack sheanut at moisture content ranging of 6 - 27.9% (db) and was found to range between 0.13J and 0.65J.

The average mass of sheanut at the above moisture content range was found to be between 0.0078kg and 0.0106kg (Aviara *et al.*, 2005)

From law of conservation of energy

Impact energy = kinetic energy

Impact energy, $$T = \frac{1}{2} m V_N^2 \quad (12)$$

Where

m = mass of sheanut, kg.

The impeller is mounted on a vertical shaft driven by a horizontal shaft via two bevel gears of the same number of teeth. For an electric motor having angular velocity ω_1 and pulley diameter D_1 to drive the horizontal shaft with pulley diameter D_2 through an angular velocity ω_2, this relationship most hold:

$$\omega_2 = \omega_1 \, {}^{D_1}/_{D_2} \text{ rads/s} \quad (13)$$

In this study,

ω_1=1500rpm; D_1= 0.08m; D_2= 0.12m

Substituting these values into equation [13] we have ω_2= 1000 rpm =104.76 rads/sec

From equation [7]

Tangential velocity

$V_t = \omega_2 \text{ x } r_2$ =15.71m/s

From equation [1]

V_1=1.98m/s

Substituting these values into equation [6], the radial velocity, Vr = 0.66m/s

Therefore from equation [4] resultant velocity, Vp of nut emerging from radial vane impeller is

Vp = 15.72m/s

From equation [8]

$\propto$=2.41°

From equation [9]

Ø=48.53°

From equation [10]

V_N = 10.41m/s

Vs = 11.78m/s

5. Performance Evaluation of the Cracker

To carry out the performance tests, the hopper base was completely closed with the flow rate control device. The hopper was filled with sheanuts at a particular moisture content and the total number of nuts (N_T) was determined by counting. The nuts were poured back into the hopper after counting, the control switch was switched on to run the electric motor and set the working components of the cracker in motion. The nut flow rate control device was adjusted to select the opening that will deliver the nuts into the machine at a particular feedrate. The number of nuts that were completely cracked and unbroken (effectively cracked) (N_C), completely cracked but broken (N_b), partially cracked (N_{pc}) and number of uncracked nuts (N_{uc}) were determined at the end of each run. Each test was replicated thrice and the average values were recorded. The performance of the cracker was evaluated on the basis of the following indices:

- Percentage of effective cracking

$$\eta_C = \frac{N_C}{N_T} x\, 100\% \quad (14)$$

- Percentage of broken nuts

$$\eta_b = \frac{N_b}{N_T} x\, 100\% \quad (15)$$

- Percentage of partially cracked nuts

$$\eta_{pc} = \frac{N_{pc}}{N_T} x\, 100\% \quad (16)$$

- Percentage of uncracked nuts

$$\eta_{uc} = \frac{N_{uc}}{N_T} x\, 100\% \quad (17)$$

The data obtained were compared with the results obtained by Oluwole *et al.*, (2007) for the impact energy required to crack sheanut.

6. Results and Discussion

Table 1 shows the results of impact energy required to crack sheanut at moisture content of 6.2 %, 13.0 %, 22.7 % and 27.9 % (db).

Table1. *Results of Impact Energy Required to Crack Sheanut at Different Moisture Content*

Impact Energy, I (J)	Moisture Content (%)											
	6.2			13.0			22.7			27.9		
	Performance Indices (%)											
	η_c	η_b	η_{uc}	η_c	η_b	η_{uc}	η_c	η_b	η_{uc}	η_c	η_b	η_{uc}
0.13	53.3	0.0	46.7	40.0	0.0	60.0	30.0	0.0	70.0	2.8	0.0	97.3
0.26	80.0	0.0	20.0	56.7	0.0	43.3	43.3	0.0	56.7	6.7	0.0	93.3
0.39	83.3	16.0	0.7	65.0	0.0	35.0	53.3	0.0	46.7	15.7	0.0	84.3
0.52	60.7	39.3	0.0	93.0	5.3	1.7	97.3	0.0	2.7	57.3	0.0	42.7
0.65	58.3	41.7	0.0	86.7	13.3	0.0	92.0	6.7	1.3	83.3	5.7	11.0

Source: *Oluwole et al., (2007)*

It can be observed from Table 1 that the percentage of fully cracked nut increased with increase in impact energy at all the four moisture content levels to a maximum value and then decreases with further increase of impact energy. It is evident from this table that the higher the moisture content of the nut, the higher the impact energy required for cracking. However, the percentage of broken kernels decreased with increase in nut moisture content but increased with increase in impact energy, this was as a result of the brittle nature of the shell of the sheanut at lower moisture content. However, the percentage of uncracked nut decreases with increase in impact energy. It is also observed from this table that at moisture content of 6.2 %, the effective impact energy was 0.39 J while at moisture content of 13.0 % and 22.7 %, the effective impact energy was 0.52 J. However, at nut moisture content of 27.9 %, the effective impact energy was 0.65 J. But the combination of higher percentage of fully cracked nut and lower percentage of broken nut was achievable at nut moisture content of 22.7 % and impact energy of 0.52 J.

The corresponding average mass of sheanut, the kinetic energy possessed by nuts emerging from the impellers at these moisture contents and the performance indices are presented in Table 2.

Table2. *The Performance Indices of the Cracker*

Moisture Content (%)	Average Mass of Nut (kg)	Cracking Velocity V_N (m/s)	Kinetic Energy (J)	Performance Indices (%)			
				η_c	η_b	η_{pc}	η_{uc}
6.2	0.0078	10.41	0.42	67.50	28.75	3.75	0.00
13.0	0.0092	10.41	0.50	83.75	16.25	0.00	0.00
22.7	0.0102	10.41	0.55	93.75	3.75	2.50	0.00
27.9	0.0106	10.41	0.57	60.00	1.25	33.75	5.00

Table 2 indicates that the kinetic energy possessed by nuts emerging from the impeller at moisture content of 6.2 %, 13.0 %, 22.7 % and 27.9 % (db) were 0.42 J, 0.50 J, 0.55 J and 0.57 J respectively. These variations are as a result of nuts weight different due to the moisture present in the nuts. The percentage of fully cracked nuts were 67.5 %, 83.75 %, 93.75 % and 60.0 %, while the percentage of broken nuts were 28.75 %, 16.25 %, 3.75 and 1.25 % respectively. However, the percentage of partially cracked nuts was 3.75 %, 0.00 %, 2.5 % and 33.75 % respectively. There were no uncracked nuts at moisture contents of 6.2 % - 22.7 %, while the percentage of uncracked nuts was 5.0% at moisture content of 27.9 %.

It is evident from Tables 1 and 2 that impact energy of nuts at moisture content of 6.2 % emerging from the impeller is higher than the optimum impact energy for cracking at this moisture, this is the reason for the highest percentage of broken nuts (28.75 %) recorded. It is observed from these tables that impact energy of nuts at moisture content of 13.0 % emerging from the impeller is not as high as that of the optimum impact energy for cracking at this moisture, as a result, the percentage of fully cracked nuts (83.75 %) is less compared to that of the optimum value (93.0 %) recorded. However, for nuts at moisture content of 22.7 % the impact energy possessed was 0.55 J which is slightly higher than 0.52 J. This is responsible for the nuts breakage recorded at this moisture level. It is obvious that the lower percentage of fully cracked nuts (60.0 %) recorded for nuts at moisture content of 27.9 % is as a result of lower impact energy (0.57 J) possessed by nuts emerging from the impeller compared to the optimum impact energy of 0.65 J required for effective cracking at this moisture level.

7. Conclusion

The following conclusions were drawn from the performance evaluation of the sheanut cracker:

- The cracking velocity of nut (V_N) emerging from the impeller is 10.41 m/s.
- The optimum moisture content and impact energy for cracking sheanut was found to ranged between 13.0 – 22.7 % and 0.52 – 0.65 J respectively.
- The combination of moisture content and impact energy that gave the best machine performance was 22.7 % and 0.55 J respectively.

References

Adigun Y. J. and Oje K., 1993. Thevetia fruit processing: energy requirements for cracking the nut. *Proceedings of Nigerian Society of Agricultural Engineers, 15, 128-139.*

Aviara, N. A., Haque, M. A. and Izge, I. A. 2000. Physical and frictional properties of sheanut. *Agroscience*, 2(1): 19 – 34.

Aviara, N. A., Oluwole, F. A. and Haque, M. A. 2005. Effect of moisture content on some physical properties of sheanut (*Butyrospernum paradoxum*). *International Agrophysics*,19: 193-198.

Dicken J. W., 1961. Kernel spliter and inspection belt for peanuts. Market Research Report No. 452 AMS – USDA.

Douglas J. F., Casiorek J. M. and Swaffield J. A. 1985. Fluid mechanics; 2nd ed John Wiley and Sons.

Hannah, J. and Hillier, M. J. 1971. Applied Mechanics. Pitman Publishing, New Zealand Ltd, Wellington.

Hannah, J. and Stephen, R. C.(1972. Mechanics of Machines. Advanced Theory and Examples; 2nd edition, Published by A Butterworth-Heinemann

Odigboh E. U., 1979. Impact Egusi Shelling Machine. *Transactions of the ASAE*, 22(6), 1264-1269.

Makanjuola G. A., 1975. An evaluation of some centrifugal impaction devices for shelling melon seeds. *Journal of Agricultural Engineering Research*, 20, 71-77.

Oluwole, F. A. 2004. Design, Construction and Performance Evaluation of a Sheanut Cracker. M.Sc thesis, University of Maiduguri.

Oluwole F. A., Aviara N. A., and Haque M. A., 2004. Development and Performance Tests of a Sheanut Cracker. *Journal of Food Engineering 65, 117-123.*

Oluwole, F. A., N. A. Aviara and M. A. Haque (2007). Effect of moisture content and impact energy on crackability of sheanut. *Agricultural Engineering International: the CIGR Journal of Scientific Research and Development Manuscript FP 07 002 Vol. IX. October, 2007.*

Shahbazi, F. (2012). Effects of Moisture Content, Impact Direction and Impact Energy on the Cracking Characteristics of Apricot Pit. *World Applied Sciences Journal 20 (11): 1520-1528.*