DESIGN AND CONSTRUCTION OF SHEA NUT DECORTICATING MACHINE

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ABSTRACT
The design of the shea nut decorticating machine was carried-out based on the physical properties of the nut. The measurements of major, intermediate and minor diameters from an average of 100 nuts, were 0.037 mm, 0.027 mm and 0.025 mm respectively. The mechanical properties, the power required and cost-effectiveness of the machine were considered. The decorticator was designed to effectively decorticate Shea nuts with little energy. The rotating shaft of the machine has rubber beaters arranged at an angle of 45^0 and located inside the cylinder. It has an output capacity of $10.4\,kg/hr$ and capacity of the hopper at full load is $6.5\,kg$. The machine capacities in volume per hour and in mass per hour are 2.385 m^3/hr and 1420.506 kg/hr respectively. The cylinder diameter is 0.162 m, and the power required to decorticate 6.50 kg of shea nut is 0.531 kw. Although the machine is motorized, its constructional materials can be affordable by the populace, both Shea butter producers and whole kernel exporters.

Keywords: Shea Nut, Decortication, Parboiling, Machine

INTRODUCTION

Shea trees (*Mangifolia)* trees grow naturally throughout the savannah regions of West and Central Africa. Shea trees grow only in the wild and can take up to 50 years to reach full maturity. In most parts of West Africa, the nuts provide a valuable source of food, medicine, and income for the population. They are relatively bountiful and produce kernels which have a fat content of about 35 – 60% usually referred to as Shea butter. Shea butter is an effective moisturizer because it contains fatty acids, which are needed to retain skin moisture and elasticity. The Shea butter also makes an excellent additive to soap, shampoos, anti-ageing creams, cosmetics lotions, and massage oils. The seed of Shea nut with a fat content of about 50% is used locally in Nigeria as well as in Europe and Japan (FAO, 1988).

A Shea-tree has a life span of about 200 years but it needs between 8 and 15 years before the first harvest, and sometimes longer than that to reach full capacity. At some point in the long history of the Shea tree, people realized that the pit of the Shea fruit, known as the Shea nut, could be ground, producing a high fat paste, which we now call Shea oil and Shea butter. Over time, Europeans exploring the African continent discovered the Shea oil and butter, and material soon entered international trade routes. The Europeans used Shea oil and butter in the manufacture of soaps, moisturizers, and foods. In particular, Shea oil and butter became common ingredients for the production of chocolate, as well as baked goods. To this day, when you visit Europe or eat imported chocolate or baked goods from Europe, the likelihood that Shea oil and butter are ingredients is almost. In removing the oil from the kernels, the production of 1kg of Shea butter takes one person 20-30 hours (Nies, 1988). The energy input is high.

About 200 years ago, the Europeans rediscovered Shea butter and its production in 19 African countries. The Shea tree grows without any assistance from man and most attempts to cultivate it in Europe and America failed, the tree grows naturally in the wild, and every summer produces plum-sized fruits. These nuts are crushed by hand, then heated and ground into a thick paste. Shea nut today is the second most important oil crop in Africa. As a result of that, the production of Shea butter is likely to increase in market demand. However, decorticating of these nuts have been an issue to its processing. A machine for decorticating is not available. The cost of importing the machine is too exorbitant, as such when locally designed and constructed will also reduce the cost of importation of the equipment.

MATERIALS AND METHODS

Material Selection and description

The materials used were selected based on durability, strength and availability. The following materials were used for the construction:

i. Angle iron (mild steel) --------- $40mm \times 4omm \times 4mm$
ii. Shaft (rod) ------------------------ $700mm$
iii. Pulley (cast iron) ------------------ $\emptyset 140mm$
iv. Belt (leather belt)
v. Bearing: the bearing used on the decorticating shaft has an internal diameter of 25mm and an external diameter of 52mm. The type used for the construction is FS: UCP 206 series. The bearing housing at the decorticating shaft is 55mm in its internal diameter; it's made up of mild steel.

Design Calculations

Determination of Cylinder Diameter

The volume of the cylinder is determined from equation 2.1

$$V = \frac{\pi d^2}{4} * L \qquad (2.1)$$

Where, V = volume

d = diameter of the cylinder (in meter)

L = length of the cylinder nut to the outlet

Volume of the Hopper

The hopper serves the purpose of feeding the Shea nut into the machine for decortications. The angle of repose and the density of Shea nut are 36^0 and $595.60\ kg/m^3$ (Aviara *et al*., 2000). The size of the hopper is on the maximum volume of Shea nuts, 6.5kg of Shea nut was chosen as the equivalent hopper capacity and equation 2.2 is used to determine the volume of the hopper

The volume of the hopper, $V_h = \frac{1}{3}[(L1xb1)h - [(L2xb2)h]]$ (2.2)

Where L, b, and h are length, breadth and height respectively.

Determination of Diameter of Driven Pulley

The speed required for decortications was estimated to be as low as half of the speed of the electric motor so as not to break the kernels during decortications. Hence,

The diameter of the pulley on the shaft, Ds is determined from equation 2.3

Using the expression, $\frac{N1}{N2} = \frac{D2}{D1}$ (2.3)

Where, N_s = Speed of the shaft pulley,

N_m = speed of the electric motor to be used

D_m = diameter of the pulley on a motor to be used

Determination of Power for Decorticating Shea Nut

The power required to decorticate the shea nut is determined from equation 2.4

Power = torque x angular velocity

But, Angular velocity, $\omega = (2\pi N)/60$ (2.4)

Where ω = Angular velocity

N = speed of the pulley = 725rpm

Determination of a Centre Distance of the Belt

The centre distance of the belt is determined from equation 2.5, 2.6 and 2.7 as brought by Sharma and Aggarawal, (1998)

$Cmax. = 3(D1 + D2)$ (2.5)

$Cmin. = 0.5(D1 + D2) + 3t$ (2.6)

$C < D2$ (2.7) (Sharma and Aggarawal, 1998)

Where, C = Centre distance between two pulleys

$D1, D2$ = Diameters of the pulleys

$Cmax.$ = Maximum centre distance between two pulleys

$C_{min.}$ = Minimum centre distance between two pulleys

t = Thickness

$C_{min} < C < C_{max}$

Hence, $C = 2.5(D_1+D_2)$

Determination of Length of the Belt

The length of the belt is determined from equation 2.8

$$L = 2C + \frac{\pi}{2}\left(\frac{D1+D2}{2}\right) + \left[\frac{(D2-D1)^2)}{4C}\right] mm \quad (2.8)$$

Where, L = length of the belt, mm

C = centre distance between two pulleys

D_1 = diameter of the smaller pulley

D_2 = diameter of the larger pulley

Determination of the angle of contact

The angle of contact of the belt is determined from equation 2.9 as brought by $khurmi\ and\ Gupta$ (2005)

$$\theta = (180 - 2\alpha) * \frac{\pi}{180} rad \quad (2.9)$$

Such that, $\alpha = \sin^{-1}\left(\frac{r2-r1}{c}\right)$

Where; θ = angle of contact of the belt between the two pulleys,

r_2 = radius of the shaft pulley

r_1 = radius of the motor pulley

c = centre distance between the two pulleys

Determination of the Belt Velocity

The velocity of the belt is determined from equation 2.10

$$V = \frac{\pi N1D1}{60} \quad (2.10)$$

Where; V = velocity of the belt =?

The N_1= speed of the motor pulley

D_1 = diameter of the motor pulley

Determination of the Belt Cross-Sectional Area

The belt cross-sectional area is determined based on V-belt criteria in accordance with Sharma and Aggarwal (1998) as follows:

$$A_B = \frac{1}{2}(W1 + W2) \quad (2.11)$$

$$\theta = 180 - 2\beta \quad (2.12)$$

$$\text{Therefore, } \beta = \frac{180-40}{2} = 70 \quad (2.13)$$

$$T = \frac{1}{2} W1 tan\beta \quad (2.14)$$

$$T = \frac{1}{2} * 13 * tan70 = 17.86mm$$

$$\frac{W1}{W2} = \frac{T}{t} \quad (2.15)$$

The Allowable power range used is 0.75 to 5kw

w = Nominal top width

t = Nominal thickness

θ = Pulley groove angle

ρ = Leather belt density

μ = The Coefficient of friction

Determination of the Belt Tensions

The tension on the two sides of the belt is determined from the equation brought by Khurmi and Gupta (2005)
as follows:

$T_1/T_2 = e^{K\theta}$ (2.16)

Where T_1 = tension of the belt on the right side

T_2 = tension of the belt on the slack side

K = coefficient of friction between belt and pulley

The θ = angle of contact or lap of the belt between the two pulleys = 3.04rad

But, $K = 0.54 - \left(\frac{42.6}{152.6+V}\right)$ (2.17)

Where, V = velocity of the belt = 5.315m/s

But, $P = (T_1 - T_2) * V$ (Sharma and Aggarwal, 1998) (2.18)

Where, V = velocity of the belt = 5.315m/s

P = power transmitted by the belt = 0.75kw

Determination of Design Power

The design power is determined from equation 2.19

$P = (T1 - T2) * V$ (2.19)

Where, P = power, w

This is the maximum power that can be transmitted by the belt.

Torque on the drive shaft,

$T_n = (T1 - T2) x\, R_n$ (Hall *et al.,* 1980) (2.20)

Where, R_n = radius of the smallest pulley, 0.035m

T_n = torque on the driven shaft

Weight of Shaft pulley

The weight of shaft pulley is determined from equation 2.21:

$Wp = Mp\ x\ g$ (3.22)

Where Wp = weight of shaft pulley

Mp = mass of pulley, weighted as 1kg

G = acceleration due to gravity (9.81 m/s)

Principle of Operation

While operating the machine, the operator needs to set the machine in a good working position. The machine is constructed to decorticate Shea nut to recover the kernel. Based on its properties as shown in table 2.1.

Its physical properties were considered, and the nuts were parboiled and sun-dried in other to improve the decorticating efficiency. The feeding of the nut to the machine is done by hand through the hopper. Before feeding the material to the hopper it has to be started, just as a milling machine.

Table 2.1 Physical characteristics of Shea nut sample of the Northern part of Nigeria Variety

Physical parameters	Maximum	Minimum	Mean
Nut length (mm)	44.100	31.200	36.868
Nut breath (mm)	31.000	20.500	26.592
Nut thickness (mm)	30.000	10.500	25.077
Nut sphericity	0.852	0.655	0.763
Kernel weight (g)	11.19	7.21	10.974
Shell weight (g)	2.910	2.380	2.695
Shell thickness (mm)	5.112	3.950	4.135

The parameters are obtained from the 50 samples of the nuts in the Crop Processing and Storage Lab. Department of Agricultural & Bio-resources Engineering, Federal University of Technology Minna, Niger State

RESULT AND DISCUSSION

Design Results

Table 3.1 Summary of Design calculations

COMPONENT	RESULT
1. Design Capacity	1420.506 kg/hr
2. Cylinder Diameter	0.162m
3. the volume of the hopper	0.01125m^3
4. The diameter of Driven Pulley	140mm
5. Power Required for Decorticating Shea Nut	0.531KW
6. Centre Distance of the Belt	525mm
7. Length of the Belt	1158.904mm
8. angle of contact	3.0rad
9. Belt Velocity	5.315m/s
10. Belt Cross-Sectional Area	75.29mm^2
11. Belt Tensions	252.22N
12. Design Power	0.749KW

Table 3.1 shows the summary of design calculations as obtained from standard equations. The size of the hopper was designed based on the maximum expected volume of Shea nuts. 6.5kg of undecorticated Shea nut was chosen as the equivalent hopper capacity. 0.749kW is the

maximum power that was transmitted by the belt of 252.22N tension. All other components used in the fabrication were selected based on the design result and standard recommendation.

Plate 3.1 shows the pictorial front view of the fabricated shea nut decorticator

Plate 3.1. A Pictorial View of the fabricated Shea Nut Decorticator

Machine Efficiency

The efficiency of the machine was calculated based on the number of Shea nut fed into the system and the total number of decorticated nuts after the operation.

Table 3.2 Efficiency Table

Total Number of Nuts (output)	Number of Decorticated Nuts
200	**123**

Decortications efficiency is the ratio of the number of decorticated nuts to the total number of the nuts fed into the machine.

Efficiency $(\in) = (Decorticated)/(Total\ number\ of\ nuts\ fed\ into\ the\ machine) \times 100$

=123/200× 100 = 61.5% = 62% efficient

The machine gave an efficiency of 62%. This result shows that the machine can serve efficiently and effectively to perform the job intended. The degree of decortications depends on the dryness of nuts and clearance between the rubber beaters and cylinder. However, the nuts will be parboiled and sun-dried before decortications. It takes 3 minutes to decorticate 0.52kg hence; 150kg is decorticated in 865 minutes. The machine has an output capacity of 10.4kg/hr. The machine requires at least two operators at shift basis to avoid operators over exhausting themselves.

CONCLUSION

A Shea nut decorticating machine was designed and fabricated using locally available materials. The performance test of the machine was carried out, and the decortications efficiency was 62%. It is a great prospect to our Shea butter producers and exporters of the whole kernel, thereby making decortications and cracking of the nuts easier and less tedious. This machine is useful in the household and commercial places. Taking into account the physical properties of Shea nut, a well efficient machine can be designed for decortication.

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