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Design, Construction and Assessment of African Locust Bean (Parkia biglobosa) Dehuller and Seperator

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Abstract:* This work was aimed at the design, construction and assessment of African locust bean dehuller and separator. The two units (dehuller and separator) were incorporated in a single machine in order to remove the drudgery and constraints associated with the traditional dehulling and separating method of the African locust bean seed before it is processed into food condiment and flavouring agent. The machine consists of a hopper, dehulling cylinder, dehulling shaft, driving mechanism, two cylinders, stirrer, bevel gear and a chain/sprocket drive. The performance evaluation of the machine was evaluated following the boiling time of the beans and optimum operating conditions of the length of the dehulling head, the speed of rotation of the dehulling shaft and the stirrer of the separator. Based on the above conditions, the machines worked optimally at a rate of 240kg/hr. The results showed that the performance of the machine was 63.335 for the dehuller and 55.04% for the separator. This was obtained at 8hours of boiling of the locust bean, a dehulling head of 800mm 500rpm and 80rpm as the speed of rotation of the dehulling shaft and stirrer of the separator respectively.

***Keywords:* Design, development, dehuller, performance evaluation, separator.**

I. INTRODUCTION

African locust bean (*Parkia biglobosa*) is a leguminous crop commonly grown in the tropics and villages in the savannah areas of West Africa particularly in the middle belt of South Western region of Nigeria (Microsoft Encarta Premium, 2009). The locust bean seed, when dehulled and cooked is fermented to form a strong smelling food condiment in the whole region of West Africa. Its commonly called ‘iru’ in Western Nigeria, ‘dawadawa’ in Northern Nigeria, ‘soumbala’ in Burkina Faso, Mali, Coted’ ivore and Guinea. The dehulled and fermented locust bean seed in paste form contains 32% fat and oil, 40% protein and 25% carbohydrate (Campbell-patt, 1980).

The production of fermented locust bean into food condiments is still largely dominated by traditional method in Nigeria and often carried out by rudimentary utensils. Traditional, the production stages consists of the shelling of the mature pods, sorting into sizes of equivalent range, steaming and boiling in earthen ware pots, dehulling by mashing with pestle and motar, washing in calabash and subsequently fermenting the beans by covering them with cloth or banana leaves into various form of condiments (Adewumi and Olalusi, 1998). Some consumers further grind the fermented bean into a thick paste. Spices and additives such as salts are incorporated before molding into circular palette and sun-dried (Beaumont, 2002).

However, the traditional method of processing locust bean is quite tedious, slow and subjects the bean to excessive water treatment, leading to colour degradation and uncontrolled activities of micro-organisms. The drudgery and constraints associated with processing of the product as identified by Beaumont (2002), is limiting the production and consumption of this local food condiment due to high fuel wood consumption, use of rudimentary equipments, and low production output. As a result, there is decline in consumption of the product hereby promoting importation of foreign soup flavours.

Therefore, there is need to increase the production and supply rate of this food condiment by developing appropriate and efficient processing technology that can improve the quality of the product and increase its production rate. Therefore, this work was aimed at:

- The design and construction of a single machine capable of dehulling and separating boiled locust bean seed from its hull and also,
- Carry out an assessment of the machine.

II. MATERIALS AND METHODS

A. Design Considerations

Engineering properties were design considerations taken into account in order to achieve the purpose of this study. Engineering properties of locust bean are indispensable properties in the design of the machine for dehulling and separating locust bean seed. According to Mohsenin (1970), engineering properties include physical, frictional and rheological properties. The following properties were considered;

a. Compactness b. Human height and c. Simplicity and ease of construction

B. Selection of bearing

In the selection of bearing for this design, careful consideration was given to the bearing life. Khurmi and Gupta (2005) defined the life of a bearing as the number of revolutions or hours at some given constant speed which the bearing runs before the first evidence of fatigue

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develops. Therefore, a single row deep groove ball bearing was used for the design of the machine.

C. Material Selection

For the development of machine for dehulling and separating locust bean from its coat, the following were considered;

a. Availability of materials
b. Durability of Material
c. Cost of materials
d. Maintenance cost and
e. Ease of construction in order to achieve the desire objectives

Therefore, stainless steel was used to construct the hopper, dehulling cylinder and separating cylinders. This was because stainless steel has high resistant to corrosion and rust. Similarly, the main frame was made up of mild steel because of its strength and rigidity to support load and weight of the machine during operation.

❖ **Major Components of the Machine**

In order to get the desired throughput, the following components of the machine were constructed according to the designed specification based on the selected materials:

i. **Hopper:** through the hopper the boiled locust bean was fed into the dehulling cylinder in form of a frustrum measuring 200 x 150mm as top diameter, 100 x 60mm as bottom diameter and a total slant height of 200mm.
ii. **Dehulling Cylinder:** measures 700mm in length with diameter of 120mm which encloses the shaft and conveyor (dehulling mechanism). The robbing effect of the brush against the wall of the dehulling cylinder helps to dehull the boiled locust bean.
iii. **Cylinder Shaft (Dehuller):** the brush was made up of strong synthetic rubber-like material driven by a shaft. The brush arrangement was in a spiral form that dehulls the beans and conveyed it into the seed separator at the same time. The total length of the brush was 600mm while the shaft length 800mm.
iv. **Inner Cylinder:** 250mm of diameter and 250mm length.
v. **Outer Cylinder:** 300mm of diameter and 420mm length.
vi. **Mainframe:** the frame was made of 50 x 50mm angle bar. It comprises of four stands which were held in position by welding. Based on the design considerations, the stand had dimensions of 700 x 200mm at the top, 700 x 300mm at the bottom and a total height of 650mm from the ground level.

❖ **Principle of Machine Operation**

The machine for dehulling and separating of the boiled locust beans from its coats had two compartments; dehulling cylinder and separating cylinders. The dehulling cylinder houses the dehulling shaft. A 3hp electric motor provides drive through belt connections via pulley to the shaft. As the dehulling shaft rotates with thehelp of bearings, it provides drive to the stirrer inside the separating inner cylinder through the bevel gear connections and pulleys.

A the locust beans and water are being fed into the dehulling cylinder through the hopper, the locust bean was dehulled and at the same time conveyed into the separating cylinders through the opening under adjacent end of the dehuller cylinder. The stirrer which was being enclosed by the inner cylinder gently stirs or agitates the dehulled beans solution in order to dislodge the coats from the seeds. As a result of variations in densities of the coats and seeds from the density of water, the coats floats on water and over floats into the outer cylinder where it was collected through a valve mechanism while the clean beans was retained in the inner cylinder.

❖ **Design of the Machine Components**

For the design of this work, $\pi = 3.142$ and $g = 9.81 m/s^2$. The following are the engineering properties used for the design of the machine components:

Length of the locust bean seed $= 0.8 - 1.2cm$

Width of the locust bean seed $= 0.6 - 0.85cm$

Thickness of the locust bean seed $= 0.45 - 0.6cm$

Average diameter of the locust bean seed $= 0.8cm$

Density of the locust bean seed $= 1156.85\ kg/m^3$

Bulk density of the locust bean $= 551.66\ kg/m^3$

Minimum cracking force (with minimum deviation of 10.21) $= 174.38$ N (Ogunjimi et al., 2002)

Expression of the Capacity in Volumetric rate

This was done in order to avoid over feeding and over working of the machine. The following were considered:

Mass of locust bean to be dehulled in 1 minute $= 4kg$

Density of locust bean $= 1156.85kg/m^3$

$$density\ (\rho) = \frac{mass\ (m)}{volume\ (v)}$$

$$volume_{locustbean} = \frac{mass_{locustbean}}{density_{locustbean}} = \frac{4}{1156.85}$$ If

$$= 0.00346m^3$$

$0.00346m^3$ of locust bean was to be dehulled in one minute, therefore, the expression of the machine capacity in volume per hour is;

$$C_{VPH} = \frac{0.00346x60}{1} = 0.2075m^3/hr$$

Similarly, the expression of the machine capacity in mass per hour is;

$$C_{MPH} = 1156.85x0.2075 - 240.046kg/hr$$

Design of Machine Shaft

a. Determination of Screw Diameter for the Shaft Conveyor:

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This was done in order to determine the minimum screw diameter of the conveyor. The theoretical capacity of a full screw conveyor is given by;

$$C = \left(D^2 - d^2\right) xPxNx60 \text{ (Itodo, 2010)}$$

Where,
C = C_{VPH} = 0.2075m^3/hr is the capacity of the machine in volume per hour
D = diameter of the screw for the conveyor =?
d = diameter of the shaft = 0.025m
P = pitch of the conveyor = 0.015m
N = speed of the shaft = 500rpm
The minimum diameter needed for the conveyor was determined thus;

$$0.2075 = \left(D^2 - 0.025^2\right) x0.015x500x60$$

$$0.2075 = \left(D^2 - 0.000625\right) x450$$

$$0.2075 = 450D^2 - 0.2813$$

$$D^2 = \frac{0.2075 + 0.22813}{450}$$

$$D = \sqrt{1.0862x10^{-3}} = 0.033m$$

b. Determination of the Shaft Torque
This was determined using the expression;

$$T_S = \frac{p_s}{\omega_s} \text{ Where,}$$

T_S = torque of the shaft
P_S = power delivered from the motor to drive the shaft
ω_S =angular speed of the shaft

Such that, $\omega_S = \frac{2x\pi xN_2}{60}$ where,

N_2 =speed of shaft pulley = 500rpm

$$\therefore \omega = \frac{2x\pi x500}{60} = 52.361\, rad/\sec$$

Knowing that power generated from the motor = 1.5kW and since power is loss during transmission from the motor to the brush shaft through the creeping and slipping of the belt up to 5% of the power generated from the motor;

$$5\%\ of\ 1.5kW\ of\ power = 1.5x\frac{5}{100} = 0.075kW$$

$$\therefore p_S = (1.5 - 0.075) = 1.425kW$$ c

$$T_S = \frac{1.425x10^3}{52.361} = 27.22Nm$$

. Determination of Minimum Shaft Diameter for the Machine:
In order to determine the minimum shaft material that will withstand the dehulling strength and rigidity of the locust bean seed, the expression below was employed;

$$\sigma = \frac{16T_S}{\sigma\pi} \text{ Where,}$$

T_S = torque of the shaft = $27.22x10^3\ Nmm$
□ = maximum permissible working stress
d = minimum shaft diameter

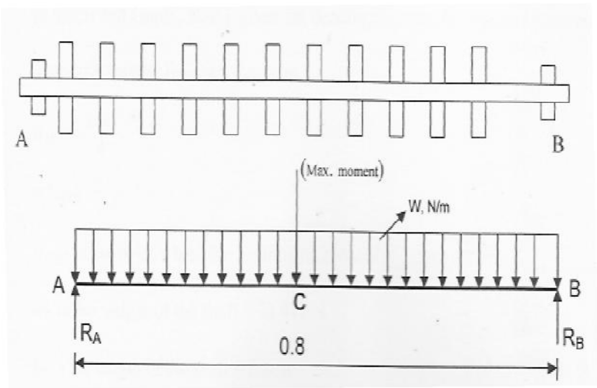

Fig 1: Forces of reaction on the dehulling shaft

$$factor\ of\ safety\ (F.S) = \frac{allowable\ stress}{working\ stress}$$

Factor of safety for steel material = 4 (Khurmi and Gupta, 2005)
Maximum allowable working stress = 112MN/m^2 (Khurmi and Gupta, 2005)

$$\therefore \sigma = \frac{112}{4} = 28 \text{ N/mm}$$

$$d = \sqrt[3]{\frac{16x27.22x10^3}{28x\pi}} = \sqrt[3]{5120.966} = 17.237mm$$

Let the tolerance for the minimum shaft diameter be 20% of the calculated value.
Tolerance $= 0.2x17.237 = 3.45$
The minimum shaft diameter $= 17.237 + 3.45 = 20.687mm$
For safety in the working operation of this design, the shaft used was 25mm

d. Determination of Torsional Deflection of the Shaft
Torsional deflection of a solid shaft is given by;

$$\sigma = \frac{584TL}{D^4G} \text{ (Khurmi and Gupta, 2005) Where,}$$

G = torsional modulus of elasticity of steel = 8000N/mm
D = Shaft Diameter = 25mm
L = Length of the Shaft = 800mm

Such that, $T = \left(\frac{D}{2.26}\right)^4$ Where,

D = Diameter of the Shaft = 25mm

$$T = \left(\frac{25}{2.26}\right)^4 = 14973.602Nmm$$

From $\sigma = \frac{584TL}{D^4G}$,

$$\sigma = \frac{584x14973.602x800}{20^4 x80000} = 0.55^0$$

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Determination of Forces, Reactions and Bending Moments on the Driving Shaft

As the machine operates, there is combined bending and torsional stresses acting on the solid shaft driving the dehulling mechanism. The forces of reaction acting at the bearings that supports the solid shaft are shown below:

From the above diagram,

Given the effective mass of the shaft = 7.28kg

The weight per unit length of the shaft is

$$w = \frac{7.28x9.81}{0.8} = \frac{71.417}{0.8} = 89.271\text{N/m}$$

The reactions at the support were determined thus:

For a point load;

$$R_A = R_B = \frac{wl}{2} = \frac{89.271x0.8}{2} = 35.71N$$

$$\therefore R_A = 35.71N,\ R_B = 35.71N$$

For the bending moments;

$$B_{MA} = B_{MB} = 0$$

Where,

B_{MA} = bending moment of the shaft about the support reaction A

B_{MB} = bending moment of the shaft about the support reaction B

Khurmi and Gupta (2005) give the bending moment for a point reaction uniformly distributed across the shaft length as,

$$B_{MX} = \frac{wxl}{8} \text{ Where}$$

B_{MX} = point where the bending moment is at maximum

L = length of the shaft = 0.8m

Therefore, the bending moment at point C is $B_{MC} = \frac{71.41x0.8}{8} = 7.142Nm$

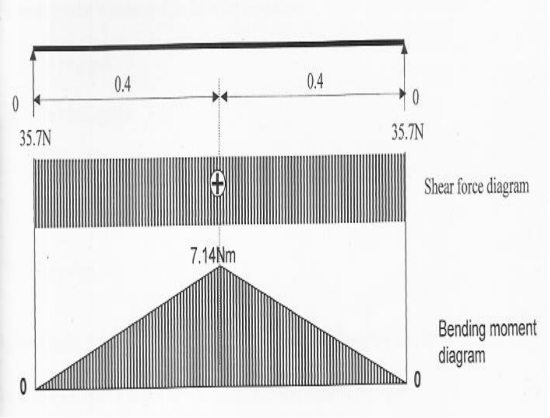

Fig 2: Shear forces and Bending moment reactions on the dehulling shaft

The Separator Unit

a. Design of the Separator Cylinders

Since the separation was to be done by principle of buoyancy, water was needed for the separation of the dehulled beans. In order to achieve this, the following specifications were used;

Volume of the dehulled locust bean = 0.00346m^3 = 3.46 litres

Let the volume of water needed for the operation be 5 x volumes of dehulled beans

Therefore, volume of water = (5 x 3.46) = 17.3 litres

The total volume = volume of dehulled bean + volume of water = 3.46 + 17.3 = 20.76 litres

Design of the two cylinders capacities was such that the inner cylinder was less in volume than the total volume while outer cylinder was more in volume than the total volume.

In order to achieve this, the specifications below were adopted;

Let the volume of the cylinder be 15 litres and volume of the outer cylinder be 2x the volume of the inner cylinder = (2 x 15 litres) = 30 litres

Therefore, $v_{inner\,cylinder} = \pi x \frac{d^2}{4} xh$ (John, 2004)

Where, v = volume of the inner cylinder

d = diameter of the inner cylinder

h= height of the cylinder

$$v_{inner\,cylinder} = 15litres = 0.015m^3$$

$$height\ of\ the\ cylinder = 0.31m$$

$$0.015 = \pi x \frac{(d^2)}{4} x0.31,\ d^2 = \frac{4x0.015}{0.31x\pi}$$

$$d = \sqrt{0.062} = 0.25m$$

Similarly, the outer cylinder was design using the expression thus;

$$v_{outer\,cylinder} = \pi x \frac{D^2}{4} xH \text{ Where,}$$

$V_{outer\ cylinder}$ = 30litres = 0.03m^3

D = diameter of the outer cylinder

H = height of the outer cylinder = 0.42m

$$0.03 = \frac{\pi x D^2}{4} x0.42,\ D^2 = \frac{4x0.03}{0.42x\pi}$$

$$D = \sqrt{0.091} = 0.30m$$

Power Requirement of the Machine

a. Determination of power required to dehull boiled locust bean

This was determined using the expression;

$$p_h = T_S W \text{ Where,}$$

P_h = power required to dehull the locust bean

T_S = Torque of the shaft = 27.22Nm

W = angular speed of the shaft = 52.361 rad/sec

$$\therefore p_h = 27.22x52.361 = 1.425kW$$

b. Determination of power required to drive the shaft conveyor

It was determined as;

$$p_c = w_c x r_c \text{ Where,}$$

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P_c = power required to drive the shaft
W_c = weight of the conveyor
r_c = radius of the conveyor = 0.0165.
Mass of the conveyor 7.28kg

$$w_c = mg = 7.28x9.81 = 71.42N$$

$$p_c = 71.42x0.0165 = 0.00118kW$$

c. Determination of power required to drive the pulley

$p_p = w_p x r_p$ Where,

P_p = power required to drive the pulley
w_p = weight of the pulley
r_p = radius of the pulley = 0.09m
Mass of the pulley = 23kg

$$w_p = mg = 23x9.81 = 225.63N$$

$$\therefore p_p = 225.63x0.09 = 0.0203kW$$

d. Determination of power required to drive the stirrer

$P_{Stirrer} = T_{stirrer} x W_{stirrer}$ Where,

$T_{stirrer}$ = torque of the stirrer = 37.654N
$W_{stirrer}$ = critical speed of the stirrer
= $3.81x10^{-4}$rad/sec

$$P_{stirrer} = 37.654x3.81x10^{-4} = 0.0000143kW$$

The total power required by the machine

$$= p_h + p_b + p_p + p_{stirrer} = 1.447kW$$

As result of losses due to friction, creeping and slipping of the belt drive, a 3hp motor equivalent to 2.2kW power was therefore selected for the machine

Design of the Pulley and Belt

This was done in order to know the equivalent ratio between size of the motor pulley and that of shaft pulley. This was determined as follows;

$N_1 D_1 = N_2 D_2$ (Khurmi and Gupta, 2005)

Where, N_1 = speed of motor pulley = 1500rpm
N_2 = speed of shaft pulley = 500rpm
d_1 = diameter of motor pulley = 60mm
d_2 = diameter of the shaft =?
Adewumi and Igbeka (1996) gave the average dehulling speed as 500rpm

$$d_2 = \frac{N_1 d_1}{N_2} = \frac{1500x60}{500} = 180mm$$

This showed that the ratio between the sizes of the shaft pulley to motor pulley is 3:1

Determination of the Total Length of Belt

The length of belt needed to drive the pulley and shaft pulley was determined by using the expression below;

$l = 2c + \frac{\pi}{2}(d_1 + d_2) - \left(\frac{d_2 - d_1}{4c}\right)$ Where,

C = centre distance between the motor pulley and the shaft pulley = 120mm
d_1 = diameter of the motor pulley = 60mm
d_2 = diameter of the shaft pulley = 180mm

$$\therefore\ l = (2x120) + \frac{\pi}{2}(60 + 180) - \left(\frac{180 - 160}{4x120}\right)$$

$$l = (240) + \frac{\pi}{2}(240) - \left(\frac{120}{480}\right)$$

$$l = 240 + 376.991 - 0.25 = 616.741mm$$

Determination of speed of the shaft

The speed of the shaft was determined using the expression;

$v = \frac{\pi x N_1 x d_1}{60}$ Where,

N_1 = speed of the motor pulley = 1500rpm
d_1 = diameter of the motor pulley = 60mm
= 0.06m

$$v = \frac{\pi x1500x0.06}{60} = 4.712 \text{ m/s}$$

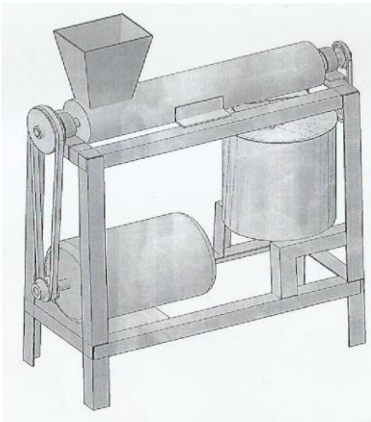

Fig 3: Isometric view of the Dehuller and Separator

III. PERFORMANCE EVALUATION OF THE MACHINE

The machine was first run under no load condition using an electric motor of 3hp with speed rating of 1500rpm whereas the dehulling shaft was run at a speed of 500rpm. This was done in order to assess how smooth the machine parts operations. The evaluation was conducted by the use of 12kg locust bean seed. The performance evaluation was aimed at determine its dehulling efficiency, separating (cleaning) efficiency and percentage losses based on the following parameters; boiling time, length of dehulling head, rotation speed of dehulling shaft and the stirrer of the separator.

The overall effects of these parameters were investigated majorly on the dehulling and separating efficiencies. To run the test, 12kg of boiled locust bean seed was used. It was divided into three equal parts of 4kg each. The expected designed capacity of the machine in volumetric rate was 240kg/hr and was achieved at a dehulling speed of 500rpm and separating speed of 80rpm.

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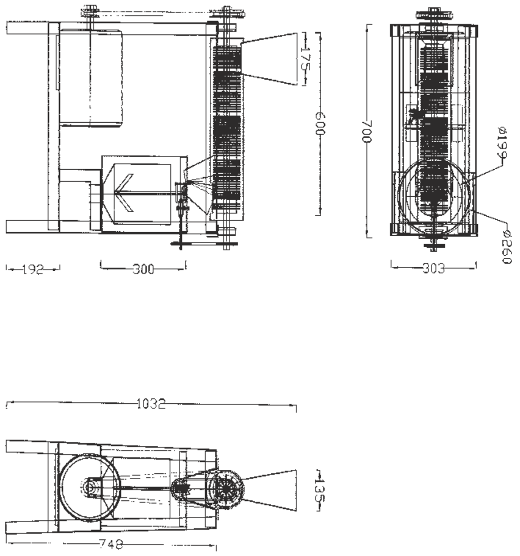

Fig 4: Orthographic view of the machine

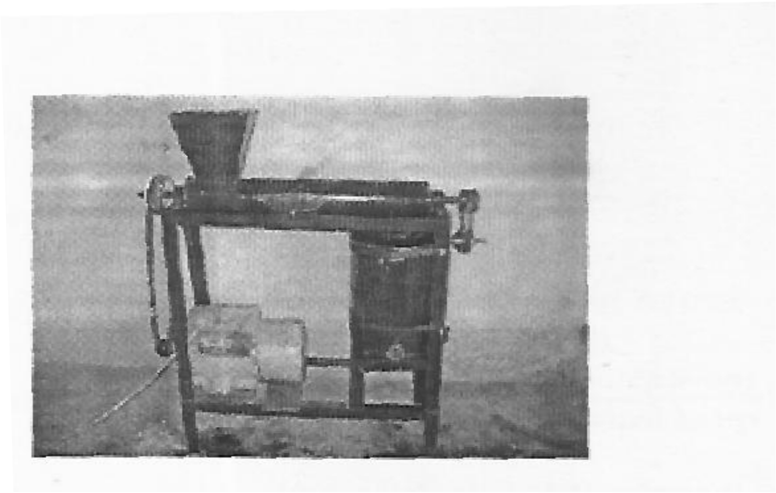

Fig 5: The Constructed Locust Bean Dehuller and Separator

IV. RESULTS AND DISCUSSION

Table 1: Results obtained from Performance Evaluation f the Machine

Mass of Beans (kg)	Boiling Time (hrs)	Dehulling Time (secs)	Dehulling Efficiency (%)	Cleaning Loss (%)	Percentage Loss (%)	
4kg	6	129	51.25	47.48	48.75	
4kg	8	86	68.25		55.11	31.75
4kg	10	69	70.5	62.54	29.50	
Average	8	95	63.33	55.04	36.67	

$$Dehulling\ \ Efficiency\ = \frac{mass\ of\ \ the\ dehulled\ \ beans}{total\ \ mass\ of\ \ boiled\ \ beans} x100$$

$$Cleaning\ \ Efficiency\ = \frac{w_c}{w_o + w_s} x100$$

Where, w_c =weight of clean beans
w_c = weight of coat
w_s = weight of dehulled beans

$$Percentage\ \ Loss = \frac{mass\ of\ \ undehulled\ \ beans}{total\ \ mass\ of\ \ boiled\ \ beans} x100$$

At the 6th hour of boiling, the following results were obtained;
Total mass of boiled locust beans = 4kg2kg
Mass of cleaned beans = 1.3kg
Mass of coat = 0.73kg
Mass of dehulled beans = 1.32 + 0.73 = 2.05kg
Mass of undehulled beans = (4-2.05)kg = 1.95kg

$$Dehulling\ \ Efficiency\ = \frac{2.05}{4} x100 = 51.25\%$$

w_s =2.05kg, w_o= 0.73kg, w_c = 2.05-0.73= 1.32kg
Therefore,

$$Cleaning\ \ Efficiency\ = \frac{1.32}{0.73 + 2.05} x100 = 47.48\%$$

A

$$Percentage\ \ Loss = \frac{1.95}{4} x100 = 48.75\%$$

t the 8th hour of boiling, the following results were obtained;
Total mass of boiled locust beans = 4kg
Mass of cleaned beans = 1.94kg
Mass of coat = 0.79kg
Mass of dehulled beans = (1.94+0.79)kg=2.73kg
Mass of undehulled beans = (4-2.73)kg=1.27kg

$$Dehulled\ \ Efficiency\ = \frac{2.73}{4} x100 = 68.25\%$$

w_s = 2.73kg, w_o= 0.79kg, w_c = 2.73-0.79=1.94kg

$$Cleaning\ \ Efficiency\ = \frac{1.94}{0.79 + 2.73} x100 = 55.11\%$$

$$Percentage\ \ Loss = \frac{1.27}{4} x100 = 31.75\%$$

At the 10th hour of boiling, the following results were obtained;
Total mass of boiled beans = 4kg
Mass of clean beans = 2.17kg
Mass of coat = 0.65kg
Mass of dehulled beans = (2.17+0.65)kg=2.82kg
Mass of undehulled beans = (4-2.82)kg=1.18kg

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$$Dehulling\ Efficiency\ = \frac{2.82}{4} x100 = 70.50\%$$

w_s = 2.82kg, w_o = 0.65kg, w_c= 2.82-0.68=2.14kg

$$Cleaning\ Efficiency\ = \frac{2.17}{0.65 + 2.82} x100 = 62.54\%$$

$$Percentage\ Loss = \frac{1.18}{4} x100 = 29.50\%$$

The performance of the machine revealed that for each sample dehulled the dehulled increased by 69secs, 29secs and 9secs respectively from the designed time. This was as result of differences in boiling time and losses in the power transmission via the belt drive due to its slipping and creeping effect which led to less effect in the friction between dehulling shaft and wall of dehulling cylinder.

V. CONCLUSION AND RECOMMENDATION

The locust bean dehuller and separator works more efficiently as the boiling time increases. On the average, the dehulling and separating efficiencies were 63.33% and 55.04% respectively. The optimum operating parameters that were responsible for the results include; 8hrs of boiling locust bean seeds, length of dehulling head of 800mm, 500rpm and 80rpm rotation speed of dehulling shaft and separating stirrer respectively.

However, water pump could be provided as this will help control and minimize the volume of water required for cleaning and separating of seed coat. Also, the dehulling unit should be tilted at a most appropriate angle to allow for dehull beans fall under gravity.

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