Design Modification of a Cassava Attrition Peeling Machine

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Abstract-

There is still an increase in the demand for engineering innovations in designing cassava peeling attrition machines which will limit drudgery which its operators are being subject to. However, one major factor that has limited all existing designs is the fact that cassava tubers have irregular geometries. Hence, the emphases of this thesis is to design based on modifications, fabricate test and performance evaluation of a cassava tuber peeling machine using standard available materials by basically inculcating two contra-rotating shafts with brushes as deflectable knife edges and an auger that is inclined at an angle thus being powered by an electric motor and gravitational energy of the earth. The components of this machine include a main frame, feeding hopper, cylindrical peeling chamber, auger conveyor, belt and pulley transmission system, chain and sprocket transmission system, waste outlet, manual handle bearings and 1hp electric motor. By operation, cassava tubers are introduced into the feeding hopper which is then collected by the auger into the extracting compartment at an angle of 10 degrees, the auger conveyor which is well fitted inside the peeling chamber then translates the cassava tubers, and then presses the cassava tubers against the brushes. Each brush acts as a knife edge and also deflects to create an opening to accommodate the variable irregular cross sections along the length of any cassava tuber. The minimum and maximum mass of cassava tubers that are loaded into the peeling chamber from the introductory sector in different time intervals are 4.5kg and 5.0kg respectively. The Throughput Capacity of the machine is 47.9kg/h. The minimum and maximum force exerted per unit length of cassava tuber by each brush is 1.02Nmm⁻¹ and 1.85Nmm⁻¹ respectively. The machine was evaluated at stepwise speed of 50rpm from 50rpm to 250rpm. The minimum moisture content of each cassava tuber was 45% and a maximum of 70%. The maximum peeling efficiency was obtained at the minimum speed of 50rpm and a maximum moisture content of 70%.

Keywords: Cassava tubers; brushed shafts; auger: peeling chamber

1 Introduction

The botanical name of cassava is Manihot esculanta, Crantz. It is an annual crop with an edible and starchy tuberous root. It is an excellent source of carbohydrate and a very poor source of protein [2]. The agricultural origin of cassava as a domestic crop can be traced to about 5000 – 7000 years BC and this is based on archaeological findings [1]. Presently, cassava is cultivated in tropical and subtropical regions: regions of Africa, Asia and South-America continents for human and livestock products [3].
However, cassava was introduced in the late 16th century from Central America into Africa and currently being cultivated in over thirty African countries where an estimated average of at least 100kg of cassava products is being consumed annually per person. It is also a basic food for marginal regions in the African continent being fraught by civil wars and other disasters. The energy content of cassava in diets in tropical regions of Africa, America and Asia is 37%, 12% and 7% respectively [4]. Cassava has been processed by different unit operations due to the effect of engineers as peeling, grating, boiling, drying, milling, sifting, etc. [5]. However, cassava peeling is still a global difficulty to design engineers [6]. It was scientifically characterized that some engineering properties of cassava would further advance the development of cassava processing equipment. However, some physical properties have been determined such as roundness, shape, and tube weight of cassava varieties with a reported mean roundness range of 0.65 – 1.00, tuber weight range of 24g to 400g and conical shapes as the prevailing geometry of the tubers [7]. Other mechanical properties such as creep compliance, stress relaxation modulus, shear stress, peeling stress, cutting force, rupture stress, peel thickness, poison ratio, coefficient of friction and rolling resistance of cassava tubers were determined [8], [9], [10], [11], [12].

However, it was posited that most of the study made by researchers in studying parameters to improve the design of a cassava attrition peeling machine did not take account of moisture content, and the age of cassava tubers. The peeling efficiency of a cassava attrition peeling machine increases as the moisture content of the tubers increases [13]. Another important parameter in increasing the performance of a cassava attrition peeling machine is the mass of peel. The mass of peel is the total mass of the peel with minimal flesh loss. The ratio of the mass of peel to total mass of cassava tuber is the percentage peeling weight (ppw). The percentage by weight of peel has a range of 10.6 – 21.5%. Other varying results recorded by researchers are 16.3 % and 17.35 – 24.09% [14], [15]. There is thus a need to establish a fixed value of percentage peeling weight in the evaluation of the performance parameters of a cassava peeling machine.

Achieving an extremely high percentage of efficiency in mechanized cassava peeling is a challenge yet manual peeling is taken to be the most efficient though greatly subjected to drudgery, time consuming and low output. Generally, most of the efforts in research has been to developing machines using abrasive drums and the attrition principle. Research shows that peeling efficiency, flesh loss, throughput and specific energy consumption of the peeler are important parameters to improving a mechanized peeling machine. The ratio of the total mass of the peeled cassava to the loaded cassava is expressed as the efficiency. The amount of useful flesh that goes with the peel is expressed as the flesh loss. The quantity of cassava that is peeled and discharged by the machine per time is the throughput. The quantity of energy consumed by the machine to peel a unit mass of cassava is the specific energy consumption. Thus a machine with maximum efficiency and throughput with minimum flesh loss and minimum specific energy consumption is required. For this reason, a machine with a different peeling mechanism other than a rigid knife edge and existing attrition methods is required [17].

2. Methodology
The model involves an introduction of the cassava tubers into the system through the hopper made of mild steel. The cassava tubers then enter the peeling zone/chamber with the aid of the auger which translates the cassava tubers through the rotating brushes, this is the metering system. The peeling chamber consists of the peeling tools which are brushes that are uniformly fixed about
throughout the curved surface area of the two rotating shafts. The forward motion of the cassava tubers is guided by the auger/conveyor, gravitational potential energy and the rotating brushes that are inclined at a selected angle. The rotating brushes are abrasive and their effect on the cassava tubers provide the necessary shear forces to peel off the tubers.

2.1. Assumptions in the Development of the Model

The complexity of the model has to be reduced to manageable level. The assumptions are simplified by reducing the numbers of parameters. The assumptions include;

(i) The cage length is 600 mm
(ii) Tuber weight is between 0.5 kg to 5.0 kg
(iii) The tubers come into the peeling chamber one at a time
(iv) The tubers are subjected to linear motion by the auger in the peel chamber
(v) The cassava tubers are approximately cylindrical in shape (the cassava tubers are already cut into smaller sizes hence the natural bends in a cassava tuber are eliminated)
(vi) The mild steel brushes are quasi-knives hence the theories applicable to the design of peeling knives for cassava tubers are applicable
(vii) The minimum mass flow rate of the cassava tuber is expected to be 1kg/min.

An equation was developed that shows a linear relationship between the force per unit length of a knife edge, F (N mm⁻¹) to penetrate into the body of a cassava root and its average diameter as [6]:

\[ F = 0.977 + 0.008803 \frac{d}{g_{1832}} \]  

(2.1)

2.2. Volume of the Introductory Sector

The introductory sector is the effective volume to be occupied by the cassava tuber as it is about to enter the peeling zone from the hopper. For a sector/hopper that is frustum in geometry, it was stated that the volume of the introductory sector is expressed mathematically as [18];

\[ N = \frac{\pi h_3}{3} \left( \frac{R_s^2 + R_s r_s + r_s^2}{\pi r_s^2 h_t} \right) \]  

(2.2)

Where,

\( N \) = Volume of an introductory sector in mm³
\( h_3 \) = Height of the sector in mm
\( R_s \) = Big radius of the sector or half of the diagonal for an inscribed square in mm
\( r_s \) = Small radius of the sector: this equivalent to half the diagonal of an inscribed square in mm
\( h_t \) = Height of a cassava tuber in mm
\( r_t \) = Radius of the tuber in mm

For the model,

\( h_3 = 150 \) mm
\( R_s = 150 \) m
\( r_s = 75 \) mm
\( h_t = 50 \) mm
\( r_t = 50 \) mm

Hence when these values are put into the equation (2.2),

\[ N = \left[ \frac{\pi \times 150}{3} \left( \frac{150^2 + 150 \times 75 + 75^2}{\pi \times 50^2 \times 50} \right) \right] \]

\[ N = 15.75 \text{ mm}^3 \]

2.3 Power Consumption Determination

The total power required for the cassava attrition peeler, \( P_T \) is a sum of the power consumed by the peeling mechanisms (brush shafts and the auger shafts) at no load, \( P_1 \), the power at maximum load of tubers, \( P_2 \).
\[ P_T = P_1 + P_2 \]  \hspace{1cm} (2.3)
\[ P_1 = (T_1 - T_2) \nu \times n \]  \hspace{1cm} (2.4)
\[ P_2 = n_s CF \frac{L_s}{L_b} \nu \]  \hspace{1cm} (2.5)

Where,
- \( n = 2 \) for the number of chains used,
- \( n_s \) is the number of shafts carrying the brush, \( 2 \)
- \( L_s \) is the length of the peeling shaft carrying the brushes, \( 600 \text{mm} \)
- \( L_b \) is the thickness of each brush as a knife edge, \( 2.0 \text{mm} \) [6]
- \( C \) is circumference of each shaft, \( \pi 22 \text{mm} \)
- \( F \) is the force per unit mm exerted by each brush, \( 1.85 \text{Nm}^{-1} \)

From equation (2.4) \( P_1 \) is computed as:
\[ P_1 = 202.5 \times 0.79 \times 2 = 320 \text{W} \]

From equation (2.5) \( P_2 \) is computed as:
\[ P_2 = 0.0605 \text{W} \]

The total power required \( P_T \) from equation (2.3) is computed as:
\[ P_T = 320 \text{W} + 0.0605 \text{W} = 335.5 \text{W} = 0.320 \text{kW} \]

Therefore using an excess factor of safety of 2.2, the required power becomes 0.7458 kW (1hp).

This means that a motor of 1hp is sufficient to power the cassava peeling attrition machine. The applied force from the 1hp electric motor is found from equation (2.6) where \( k \) is the number of shafts and is equal to 3 as shown below:
\[ F_{app} = \frac{P_T}{\nu} \]  \hspace{1cm} (2.6)

The applied force is computed from equation (2.6) and is obtained as \( F_{app} = 315 \text{N} \)

2.4 Shaft Design

The computed values for the shear stress and bending moment at the shaft is obtained as:
\[ V = -31.5 \text{N} \text{ and } M_D = -33.1 \text{Nm} \]

\( M_D \) is equivalent to the maximum bending moment, \( M_b \) in the shafts. The torsional moment acting on the shaft is obtained from equation (2.7)
\[ Q = \frac{60P}{2\pi N} \]  \hspace{1cm} (2.7)

The value computed for the torque from equation (2.7) is \( Q = 28.5 \text{Nm} \). This value is the value of the maximum twisting moment, \( M_T \) on all the shafts.

2.5 Selection of the diameter for the shaft

The diameter, \( d \) of each of the shaft was determined using Equation (2.8) [19]; it is also the ASME code for determining the standard diameter of a shaft.
\[ d = \left[ \frac{16}{\pi \tau} \left( \sqrt{(K_b M_b)^2 + (K_f M_f)^2} \right) \right]^{\frac{1}{3}} \]  \hspace{1cm} (2.8)

Where,
- \( K_b \) is the shock and fatigue factor for bending (2)
- \( K_f \) is the combined shock and fatigue factor for twisting (1.5)
- \( M_b \) is the maximum bending moment in the shaft (-33.1Nm)
- \( M_f \) is the maximum twisting moment in the shaft
- \( \tau \) is the allowable shear stress for steel shafts with key ways, 42MPa

The computed value for \( d \) from equation (2.8) is 21.2mm. Therefore the diameter, \( d \) of the shaft is 22mm.
2.6 Determination of chain length

The length of the chain mounted on the three sprockets of equal diameter and equal centre distances is computed as shown in (2.9)

\[
L = \sqrt{a^2 - \left(\frac{D_b - D_a}{2}\right)^2} + \sqrt{b^2 - \left(\frac{D_c - D_a}{2}\right)^2} + \sqrt{c^2 - \left(\frac{D_a - D_b}{2}\right)^2} + \left[2\pi - \cos^{-1}\left(\frac{D_a - D_b}{2c}\right)\right] - \\
\left[2\pi - \cos^{-1}\left(\frac{D_a - D_c}{2b}\right)\right] - \left[2\pi - \cos^{-1}\left(\frac{a^2 + b^2 - c^2}{2c}\right)\right] \frac{3d_a}{2}
\]

(2.9)

Where,
- \(L\) = length of the chain
- \(D_a\) = diameter of sprocket A, 60mm
- \(D_b\) = diameter of sprocket B, 60mm
- \(D_c\) = diameter of sprocket C, 60mm
- \(a\) = center distance between sprockets B and C, 65mm
- \(b\) = center distance between sprockets A and C, 65mm
- \(c\) = center distance between sprockets A and B, 65mm

The parameters above are substituted into the equation (2.9) and the computed value of \(L\) is:

\(L = 585 \text{ mm} + 86.7\pi\text{mm} = 857.3\text{mm}\)

2.7 Conveyor Shaft Design

The conveyor shaft is an auger and its capacity depends on the screw diameter and pitch, loading efficiency of the cross sectional area of the screw, and the speed of the screw [20]. For a continuous screw the capacity is expressed as:

\[
Q = 60 \times \left(\frac{\pi}{4}\right) \times D^2 \times S \times n \times \Psi \times \rho \times C
\]

(2.10)

Where,
- \(Q\) = Capacity of a screw conveyor, kg/h
- \(\rho\) = Bulk density of the material, kg/m, 1300 kg/m³ [6]
- \(D\) = Nominal diameter of screw in m, 0.022m
- \(S\) = Screw pitch in m, 0.044m
- \(N\) = revolutions per minute of the screw, 250rpm
- \(\Psi\) = Loading efficiency of the screw, 0.15 for abrasive materials
- \(C\) = Factor to take into account for the inclination of the conveyor, 1.2

C is determined based on the angle of inclination of the screw conveyor with the horizontal. For an inclined conveyor of 10 degrees \(C = 1.5\)

The diameter of the shaft is 0.022m

From equation (2.10), the capacity of the screw conveyor, \(Q\) is computed as:

\(Q = 58.7 \text{kg/h}\)

3. Results and Discussions

The peel efficiency of the cassava peeling attrition machine is computed from equation (3.1) [17]:

\[
P_e = \frac{kB_eM_e[0.977 + 0.365(t - 1.098)]}{c_e\pi r_1^2 Lp(\pi r_2 + 1)}
\]

(3.1)

Where,
$M_c$ = Moisture content of the cassava peel, varies from 45% to 70% [6]  
$B_r$ = Brush speed, 0.79 m/s  
$k$ = constant, taken as 1  
$t$ = thickness of the cassava peel, 1.20 mm - 4.1 mm  
$C_v$ = Speed of the conveyor shaft, 0.79 m/s  
$L_t$ = Length of the cassava tuber, 0.05 m  
$\rho$ = density of the cassava tuber, 1300 kg/m$^3$  
$r_1$ = Big radius of the introductory sector, 0.0755 m  
$r_2$ = Small radius of the introductory sector, 0.05 m  

From equation (3.2) the peeling efficiency is computed in terms of moisture content and peel thickness as:

$$P_e = M_c (1.12 + 0.07t)$$  \hspace{1cm} (3.2)

For a maximum moisture content $M_c$ of 70% and maximum thickness $t$ of 4.15 mm the peeling efficiency is computed as:

$$P_e = 78.4\%$$

Thus the peel efficiency of the machine will be tested for varying moisture contents and peel thickness of the cassava tubers. The cassava peeling attrition machine was tested after fabrication and its performance was evaluated on parameters such as percentage of peel, throughput capacity, force per unit length exerted by the attrition brushes as a function of cassava diameters, and the peel efficiency as a function of brush/conveyor speed and variable moisture content only.

### 3.1 Throughput capacity and Percentage of peel for the modified cassava peeling attrition machine

The peel efficiency of the cassava peeling machine is deduced from the data in Table 3.1. Mathematically the percentage of peel is determined as the ratio of the average mass of peeled cassava tubers to the average mass of the fresh tubers that were loaded into the hopper before entering the peel chamber.

#### Table 3.1. Data obtained at cassava loadings of 4.5 kg to 5 kg into the peel chamber

| Peeling Duration (min) | Mass of fresh tubers $W_1$ (kg) | Peeled Tubers $W_2$ (kg) | Mass of Unpeeled Tubers $W_3$ (kg) |
|------------------------|---------------------------------|--------------------------|-----------------------------------|
| 5                      | 5                               | 3.8                      | 1.2                               |
| 4                      | 4.5                             | 3.50                     | 1.0                               |
| 5                      | 4.8                             | 3.50                     | 1.3                               |
| 3                      | 4.0                             | 3.0                      | 1.0                               |
| 8                      | 5.0                             | 4.8                      | 0.2                               |
| Total time = 25 mins   |                                 |                          |                                   |
| Total                  | 23.3                            | 18.6                     | 4.7                               |
| Average                | 4.6                             | 3.72                     | 0.94                              |

The percentage of peel is expressed as:

$$\% \text{ of Peel} = \frac{W_2}{W_1} \times 100\%$$  \hspace{1cm} (3.3)

$$\% \text{ of Peel} = \frac{3.72}{4.6} \times 100\% = 80.9\%$$

The throughput capacity, TPC is expressed as:
TPC = \frac{\text{Total mass of peeled cassava (kg)}}{\text{Time taken (hr)}} \quad (3.4)

Where TPC is computed as \frac{18.6 \text{ kg}}{0.388 \text{ hr}} = 47.9 \text{ kg/hr}

Plate I: A front view of the modified cassava attrition peeling machine

Plate II: A view of the contra rotating brush shafts and the conveyor shaft

3.2 Peel force exerted by the brush with cassava tuber diameters of 5mm to 100mm

The force per unit length that is exerted by each brush varies on the diameter of each cassava tuber. The cassava tubers of size 5mm to 100mm is selected and values of forces per unit length are computed from Equation (2.1). The values obtained from equation (2.1) are shown in Table 3.2.
Table 3.2: Data obtained for force per unit length being exerted by the brushes on cassava tubers of diameters 5mm to 100mm

| Diameter (mm) | Force exerted per unit length (N/mm⁻¹) |
|--------------|---------------------------------------|
| 5            | 1.021                                 |
| 10           | 1.065                                 |
| 15           | 1.109                                 |
| 20           | 1.153                                 |
| 25           | 1.197                                 |
| 30           | 1.281                                 |
| 35           | 1.285                                 |
| 40           | 1.329                                 |
| 45           | 1.373                                 |
| 50           | 1.417                                 |
| 55           | 1.461                                 |
| 60           | 1.505                                 |
| 65           | 1.549                                 |
| 70           | 1.593                                 |
| 75           | 1.637                                 |
| 80           | 1.681                                 |
| 85           | 1.725                                 |
| 90           | 1.769                                 |
| 95           | 1.813                                 |
| 100          | 1.8573                                |

A graph showing a plot of force exerted per unit length of the cassava tuber from a brush is shown in Figure 3.1.

**Figure 3.1:** Relationship between force per unit length exerted by a peel brush on freshly harvested cassava tubers of diameters 5mm to 100mm

It is hereby deduced that there is a linear relationship between the force required to peel a freshly harvested cassava tuber and the diameters. Thus the bigger the size of a cassava tuber, the larger the force required by each brush to peel this means there is a dependence on a higher speed from the electric motor.
3.4. Peeling efficiency of the cassava peeling and attrition machine as a function of moisture content and conveyor/brush speed

The peeling efficiency of the machine is seen to be affected by different moisture content and conveyor/shaft speed as it was computed from equation (3.2). The computed values are shown in Table 4.3.

**Table 3.3**: Values obtained for peeling efficiency for moisture contents (MC) at 45% to 70% and Brush speed of 50rpm to 250rpm

| Conveyor/Brush Speed (rpm) | 45%MC | 50%MC | 55%MC | 60%MC | 65%MC | 70%MC |
|----------------------------|-------|-------|-------|-------|-------|-------|
| 50                         | 50    | 60    | 66    | 70    | 75    | 77    |
| 100                        | 45    | 53    | 60    | 65    | 70    | 76    |
| 150                        | 40    | 47    | 50    | 55    | 60    | 65    |
| 200                        | 35    | 40    | 42    | 50    | 54    | 58    |
| 250                        | 33    | 38    | 40    | 45    | 48    | 52    |

It is seen that the peeling efficiency is maximum at the lowest speed of 50rpm and at a high moisture content, which is 70%. Thus high moisture content and low brush/conveyor speed gives a high peel efficiency. The graph of the peel efficiency plotted against moisture contents and brush/conveyor speed is shown in Figure 3.2.

**Figure 3.2**: The graph of peel efficiency plotted against moisture contents of 45% - 70% and brush/conveyor speed of 50rpm – 250rpm

**Conclusions**

The cassava attrition peeling machine is a modified version of the design made by Ejovo et al (1988) which similarly had an inclined peeling chamber but has two shafts with brushes made of mild steel extending radially over its entire curved surface area instead of a single belt that was coated with abrasives. The modified cassava peeling attrition machine has a maximum peel efficiency of 80.9% at 70% moisture content and Throughput Capacity, TPC of 47.9kg/h at a maximum speed of 250rpm and powered by a 1hp electric motor.
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