Design and Performance Evaluation of a Double Action Cassava Grating Machine

Oriaku E.C, Agulanna C.N, Ossai E.N, Odenigbo J.O, and Adizue U.L

Engineering Research, Development and Production (ERDP) Department, Projects Development Institute, (PRODA) Emene, Enugu.

Corresponding Author: Oriaku E.C

Abstract
The transformation of cassava from a low profile into an industrial raw material, coupled with the revolutionary policies of the Federal Government of Nigeria have resulted in a surge in the demand for cassava and cassava-based products locally and for export. The processing of cassava follows immediately after harvesting and involves peeling, grating, dewatering, sieving etc. A double action Cassava grating machine was designed, developed and its performance evaluated. Cassava tubers sorted into 10kg, 20kg, 30kg and 40kg sourced locally were used in the experiment and the data collected were analysed. Results showed that for a total of 100kg of sample tested, the average feed and grating time were 1.46 and 2.00 minutes respectively. The average feed and grating rates were 20.16 and 12.18 kg/min respectively. The average mass-loss, partially grated and completely grated were 1.43kg, 1.48kg and 22.09kg with an average grating efficiency of 86.23% and collection efficiency of 92.60%. These results indicate that cassava grating with large throughput can be done satisfactorily by the designed machine. It is believed that this machine would aid cassava processors who are currently finding it difficult to respond positively to the increase in demand as a single machine can serve multiple customers with increased throughput when compared to other available grating machines.

Keywords: double action, cassava pulp, feed rate, grating rate, collection efficiency, grating efficiency

INTRODUCTION
Cassava, (Manihot esculenta, crantz) is a tuberous starchy root crop of the family Euphorbiaceae (Kochlar, 1981). It is a popular crop worldwide known for drought tolerance and for thriving well on marginal soils, a cheap source of calories intake in human diet and a source of carbohydrate in animal feed (Kordylas, 2002). It is believed to be originally native of South America. It grows well in areas with annual rainfall of 500-5000mm and full sun, but it is susceptible to cold weather and frost (Agodzo and Owusu, 2002). Nigeria is by far the highest producer of the crop in the world with production level estimated at 49 million tons per year (Uthman, 2011). Processing cassava into finished or semi-finished products often involves all or some of the following operations, depending on the desired end-products; peeling, washing, grating, chipping, dewatering, fermentation, pulverizing, sieving, pelletizing, and drying/frying. Up till now, most of these operations are still being done manually, and they are generally labour intensive, arduous in nature, time consuming and unsuitable for large scale production (Adetan et al., 2003; Quaye et al., 2009), due to their low output capacity among other negative attributes.

Oyesola (1981) reported that, the traditional method of grating involves placing of the local grater, which is made of perforated metal sheet on the table where it is convenient for effective use and brushes cassava tuber on the sheet metal. The cassava turns into pulp and drop into container that is being used to collect the grated pulp cassava. Adejumo (1995) in his design used a wooden grater in which the cassava forced into a hopper is rubbed against the grater which is being electrically powered. Enhanced quantity of cassava can be grated using this method. However the durability of grating is low because of its wooden nature. Ndaliman (2006) described a pedal operated cassava grinder which is powered by human efforts applied to pedal. The grinder pulverizes the cassava tubers into paste which can pass through a wine sieve. The effective performance of the design was at 60%.

Ndaliman (2008) also designed a single action grater. The machine assembly is powered mechanically or manually in case of electricity failure. Apart from faster grating rate, it required less time involvement. The grating drum is made of metallic pipe that carries a perforated plate which served as the grater. Though, its efficiencies (sample weights of 2.0kg of Cassava) were found to be 91.95% (electrical), and 92.4% (manual). However, it’s throughput with time may not meet the market demand. This study was carried out in order to produce a machine that can handle large volumes of cassava or other tubers especially on site and it is limited to freshly harvested tubers with moisture content in the range of 68.2 - 77.8% wet basis.
MATERIALS AND METHOD
Description of the Designed Double Action Grating Machine:
The design drawing and photograph of the double action grater is shown in appendix. The machine consist of the following components namely: (1) Double inlet hopper (two in one), (2) Double inlet channels, (3) Two grating barrels, (4) Two transmission shafts, (5) Double groove V-pulley, (6) Flat pulley, (7) Bearings, (8) Electric motor, (9) Structural framework, (10) Keys and key sits, (11) Adapters, (12) Loading platform, (13) Self loading plate, (14) Adjuster metal strips, (15) Flat abrasive plates, (16) Rivets, (17) Bolts and nuts, (18) V-belt, (19) Flat belt and (20) Metal hinges. The machine has an overall length of 1600mm, width of 590mm and a height of 1330mm. The large trapezoidal hopper has a top area of 600x1010mm, base 440x1000mm, and height of 420mm. The grating barrels have diameter of 270mm and a length of 370mm. And the structural frame was made with 75mm thick angle iron of top length 910mm, base length 1170mm, slant length 800mm, width of 600mm and height of 800mm.

The wooden barrel has perforated stainless steel sheet metal wrapped around it and held permanently with rivets. The perforations are very rough so as to provide the required abrasiveness for grating. The perforations are carried out on the surface area of the sheet stainless metal before wrapping round the wooden barrel. The transmission shaft and adapters are coupled to the wooden barrel to form one rotating unit. This grating unit is the grating barrel. The grating barrel is carried on two bearings. Through these bearing, the grating barrel is mounted on a rigid and robust structural frame work. There are two grating barrels on this machine rotating in opposite directions. The grating barrels are mounted close to one another but separated by a thick wooden trapezoidal plate which divides the large inlet hopper into two separate partitions, thus, forming two different cassava tuber inlet channels to the grating points. The greater part of both sides of the trapezoidal wooden plate, are also covered with perforated stainless sheet metal to increase the abrasive requirement for good grating. Both ends of the grating barrels have extended shafts so as to accommodate the transmission pulleys and bearings.

There are two pulleys used, namely; double groove V-pulley and flat pulley. The flat pulley has a crossed flat belt so as to achieve both barrels rotating in opposite directions. Both pulleys on the grating barrels are connected to the ones on the electric motor through belts. The two grating barrels are driven by one electric motor. The adjusting metal strips are used to maintain the critical gap requirement between the rotating barrel and trapezoidal plate. The peeled cassava tubers are loaded on the loading platform before they are distributed to enter the two grating inlet channels during grating operations. The tubers drop by gravity on the self loading plates inclined at a critical angle from which they roll unaided direct to the grating points. All the components of this machine are systematically assembled and are carried by a robust structural frame work. The hinges are used to connect the inlet hopper to the structural frame work in one direction for easy access to the grating barrels.

Principle of Operation
The electric motor provides the primary rotary motion required to power the machine. The motion and torque from the electric motor are transmitted to the grating barrels via pulleys, shafts and bearings. The two grating barrels rotate in opposite directions. The peeled cassava tubers drop from the loading platform and reach the grating points by gravity via the inclined self loading plates. The grated pulp drop through the critical gaps between the grating barrels and the trapezoidal plates through the inclined exit channels into the receiver. The inclined pulp exit channels (chute) are in opposite directions.

Design Considerations
The considerations in designing this machine is to achieve very high throughput in cassava grating, reduce grating time to the barest minimum, reduce the high labour requirement of the traditional manual and single action grating machine. Also to achieve economic viability; using this double action cassava grating machine.

Design principles
The design principles adopted for this machine are as follows

- The gravitational dropping of the peeled cassava tubers from the loading platform to the grating point and exist of the pulp to the receiver
- The continuous abrasive force (frictional force) delivered to the tubers by the rough surfaces of the rotating barrels which are achieved by the rotating actions of the pulleys, bearings, belts and shafts.

The dropping of the cassava tubers to the grating points by gravitational force \( F_g \) is given by (Ryder and Bennet, 1982)

\[
F_g = mg
\]  

Where, \( F_g \) = force due to gravity, \( m \) = mass of cassava tuber, \( g \) = acceleration due to gravity.

The abrasive (frictional) force \( F_f \) is given by the equation (Nelkon and parker 1984)

\[
F_f = \mu R
\]  

For friction on an incline plane

\[
F_f = \mu R = \frac{mg \tan \theta}{\mu g \cos \theta} = \tan \theta
\]

Where, \( F_f \) = frictional force,
\( \mu \) = coefficient of friction
\( \theta \) = angle of friction, and
\[ R = \text{normal reaction} \]

**Pulley arrangement on the designed machine**

![Diagram of pulley arrangement](image)

The centrifugal force experienced by the pulleys is given by (Hannah and Stephens, 1984)

\[ F_c = M\alpha = M\omega^2 \quad r = \frac{M\omega^2}{r} \quad (4) \]

Where \( F_c \) = centrifugal force, \( M \) = mass of belt, \( \omega \) = angular velocity, \( r \) = radius of pulley, \( v \) = linear velocity of belt.

The velocity ratio between two pulleys transmitting torque is given as (Avallone and Baumeister, 1997);

\[ \frac{\omega_1}{\omega_2} = \frac{N_1}{N_2} = \frac{D_2}{D_1} \quad (5) \]

Where: \( \omega_1 \) = angular velocity of driver pulley \( \omega_2 \) = angular velocity of driven pulley \( D_1 \) = diameter of driver pulley \( D_2 \) = diameter of driven pulley \( N_1 \) = rpm of driver pulley \( N_2 \) = rpm of driven pulley \( \Theta \) = angle of lap between belt and pulley

**Rotational Torque (T):**

The value of torque developed by a rotational body is given as the product of the force causing the motion multiplied by the radius of rotation

\[ T = F_c \times r \quad (6) \]

**Work done by a torque**

If a constant torque \( T \) moves through an angle \( \Theta \)

\[ \text{Work done} = T \times \Theta \quad (7) \]

If the torque varies linearly from zero to a maximum value \( T \)

\[ \text{Work done} = \int_{T_1}^{T_2} T \times d\Theta \quad (8) \]

In general case where \( T = f(\Theta) \)

\[ \text{Work done} = \int f(\Theta) d\Theta \quad (9) \]

The power (P) developed by a torque \( T \) (N.M) moving at \( \omega \) rad/sec is

\[ P = T \omega = 2\pi NT \quad (10) \]

Where \( N \) is the speed in rev/min and

\[ \omega = \frac{2\pi N}{60} \quad (11) \]

**Tensions on Belt (T₁ and T₂)**

For belt transmission between two pulleys, the following equations by Hall et al., 1961 are used

\[ T_1/T_2 = e^{\Theta} \quad (12) \]

Also,

\[ \frac{T_1 - T_2}{T_2} = e^{\Theta} \quad (13) \]

And,

\[ T_c = \frac{mv^2}{3} \quad (14) \]

\[ T_1 = T_2/3 \quad i.e. \quad 3T_c = T_1 \quad (15) \]

The power transmitted with the belt is given as

\[ P = (T_1 - T_2) v \quad (16) \]

In this equation the power (P) is in watts, when \( T_1 \) and \( T_2 \) are in Newton and belt velocity is in metre per second.

**Belt Length (L):**

The belt length equation is given as (Avallone and Baumeister, 1997):

\[ L = 1.57(D_1 + D_2) + \frac{L^2 - D_1^2}{4} + 2C \quad \text{(Open belt)} \quad (17) \]

\[ L = 1.57(D_1 + D_2) + \frac{L^2 + D_1^2}{4} + 2C \quad \text{(Crossed belt)} \quad (18) \]

Where \( C \) = centre distance between two pulleys, \( D \) = Diameter of pulley

**Design of grating Shaft:** - The shaft with the forces acting on it is represented schematically.
Where, \( F_C = \) Centrifugal force, \( R_1 \) and \( R_2 \) are Bearing Reaction.

For ease of calculations, the uniformly distributed load is made a point load as shown below.

![Diagram of loads on shaft](image)

Fig 2a & b: Schematic representation of loads on shaft.

From the evaluation of the forces and determination of the bearing reactions, the maximum bending moments (\( M_{max} \)) for the shaft is evaluated. The shaft diameter (\( D \)) is calculated using the ASME code standard for shafting. The ASME code equation for shafting is given as

\[
D = \frac{2(\bar{F})}{(C_T \times M_{max})^2 + (C_T \times T)^2}^{\frac{1}{2}}
\]

(20)

For ASME code standard, \( \tau_d = 0.3\delta_y \) or \( 0.18\delta_y \).

NB: The smaller of the two values is chosen as \( \tau_d \).

The presence of key sit on the shaft reduces the value of \( \tau_d \) by 75%. For rotating shafts, \( C_m = 1.5 \), \( C_t = 1 \).

Where, \( D = \) Diameter of shaft, \( M_{max} = \) Maximum bending moment, \( \delta_y = \) Yield stress of shaft materials.

\[ \delta_y = \text{Ultimate stress of shaft material}, \quad \tau_d = \text{Allowable shear stress}, \quad C_m = \text{Moment factor} \]

**Sample Preparation**

Already harvested cassava tubers were purchased from Ogbete market in Enugu state. The samples were peeled and washed clean to remove dirt and any other foreign materials. Some samples were collected and used to determine the moisture content of the cassava tubers which is 70% wb. Samples of weight 10kg, 20kg, 30kg and 40kg were fed into the machine and the feed and grating times recorded. The cassava pulp (grated cassava) was collected through the discharge chute, and sorted into two units namely; partially and completely grated. They were weighed and the weights recorded. The experiment was repeated twice on each case and average values noted.

**RESULTS**

The results obtained from the experiment were recorded and shown in Table 1. The feed rate and grating rate were obtained as a function of time while the collection efficiency and grating efficiency were obtained in percentage as given below:

\[ K = \frac{a}{d} \times 100\% \]

(21)

\[ L = \frac{g}{a} \times 100\% \]

(22)

Where: \( K = \) collection efficiency (\%), \( L = \) grating efficiency (\%), \( d = \) collected mass of sample (kg), \( g = \) completely grated mass of sample (kg), \( a = \) mass feed of sample (kg).

**Table 1: data obtained from the designed machine test**

<table>
<thead>
<tr>
<th>S/N</th>
<th>feed time, b (min)</th>
<th>b/c</th>
<th>Collected pulp, d (kg)</th>
<th>Total losses, e (kg)</th>
<th>Partially grated, f (kg)</th>
<th>Completely grated, g (kg)</th>
<th>Feed rate, h (kg/min)</th>
<th>Grating rate, j/a (kg/min)</th>
<th>Collection efficiency, K (%)</th>
<th>Grating efficiency, L (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>0.38</td>
<td>1.05</td>
<td>8.55</td>
<td>1.45</td>
<td>0.80</td>
<td>7.75</td>
<td>26.32</td>
<td>9.52</td>
<td>85.50</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>0.83</td>
<td>1.46</td>
<td>18.65</td>
<td>1.35</td>
<td>1.30</td>
<td>17.35</td>
<td>24.10</td>
<td>13.70</td>
<td>93.25</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>2.00</td>
<td>2.47</td>
<td>28.60</td>
<td>1.40</td>
<td>1.50</td>
<td>27.10</td>
<td>15.00</td>
<td>12.16</td>
<td>95.33</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>2.63</td>
<td>3.00</td>
<td>38.45</td>
<td>1.55</td>
<td>2.30</td>
<td>36.15</td>
<td>15.21</td>
<td>13.33</td>
<td>96.13</td>
</tr>
</tbody>
</table>

Average grating efficiency = 86.23%, Average collection efficiency = 92.60%

(Source: Oriaku et al., 2014)

The plots above show the trend of the feed time and grating time with respect to the weight of samples. Both showed linear relationships (as shown in fig 5), indicating that they both increased with increase weights of samples.
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Their best fit mathematical model equations are given below.

\[ Y_f = 0.0686x + 0.28 \]  
\[ (R^2 = 0.9744) \]  
\[ Y_g = 0.0792x - 0.52 \]  
\[ (R^2 = 0.9729) \]  

(23)  
(24)

Fig 5 shows the combined plot of feed and grating times versus weight of samples. They are similar in trend. From the plot, it is clear that grating time is higher than feed time because feed occurs before grating.

Fig 6 shows that the grating efficiency had a quadratic relationship with weighted sample. It shows increase as more samples of materials are fed into the machine, the higher the rate of grating. The 30kg and
40kg samples have almost the same percentage grating efficiency.

Fig 7 shows a combined plot of both grating and collection efficiencies. Collection efficiency shows continuous increases as sample are feed into the machine. Also, both showed increase as weight of samples increased. Both exhibited quadratic behaviour. The equations and $R^2$ values indicate so. However, for Grating Efficiency of 30kg and 40kg samples appear to have the same value.

$$Y_c = -0.0174x^2 + 1.2084x + 75.373$$  
($R^2 = 0.9864$)  
(25)

$$Y_g = -0.023x^2 + 1.5731x + 64.178$$  
($R^2 = 0.9979$)  
(26)

From the plot above, in fig 8 it is observed that the collection and grating efficiencies have a quadratic relationship with respect to feed time. It implies that as the feed time increased, the efficiency also increased. And their best lines of fit model are as shown below.

$$Y_c = -3.7662x^2 + 15.279x + 81.309$$  
($R^2 = 0.8979$)  
(27)

$$Y_g = -5.1049x^2 + 20.313x + 71.576$$  
($R^2 = 0.9362$)  
(28)

The plot in fig 9 it shows that mass of grated and completely grated with respect to weight of sample are linearly related. And they both increased closely as the weight of sample is increased. This implies that as more samples is introduced, the higher the quantity completely grated and masses loss or partially grated reduces. It is a clear indication that the designed machine is very efficient. More so, their best lines of fits are shown below.

$$Y_{nc} = 0.9963x - 1.35$$  
(29)

$$Y_{cg} = 0.9495x - 1.65$$  
($R^2 = 0.9998$)  
(30)
CONCLUSION

From the results of the experiment carried out for the weighed samples of 10kg, 20kg, 30kg and 40kg, the average feed rate of the double action cassava grater was found to be 20.16 kg/min; which implies an input capacity of 1209.60kg/hr. more so, a grating rate of 12.18kg/min, i.e. a throughput capacity of 730.8kg/hr. The average mass loss, partially grated and completely graded were found to be 1.43kg, 1.48kg and 22.09kg respectively; which indicates effective grating and waste is drastically reduced (average sample of 25 kg) with an average grating efficiency of 86.23%.

REFERENCES


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APPENDIX

Pictorial view of side with belt drive mechanism covered with a metal sheet casing.
Orthographic drawings.