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Design and Fabrication of a Cassava Peeling Machine

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Abstract: - *This project work is on the design and fabrication of a cassava peeling machine. It is aimed at providing a base for the commercial production of a cassava peeling machine, using locally available raw materials at a relatively low cost. The successful fabrication of a cassava peeling machine is one of the major, if not the major, challenge in cassava processing. This work is intended to help solve some of the problems hindering a successful design and fabrication of a cassava peeling machine.*

Keywords: *Cassava, Peeling, Manual, Chemical, Steaming and Mechanical.*

Introduction

Cassava has become one of the prominent crops that are required to be provided for both local consumption and export promotion. In 2004, a policy was initiated by the federal government of Nigeria to produce bread with cassava and wheat flour in the ratio of 1:9 in Nigerian bakery industry. Apart from human consumption, cassava is also used for animal feed and alcohol production (Cork J.H 1987).

There is an ever increasing global demand for cassava chips and pellets, particularly in China and Brazil. Cassava can therefore be referred to as a multipurpose crop for man and livestock.

Cassava starch is an ingredient in the manufacture of dyes, drugs, chemicals, carpets and in the coagulation of rubber latex (Odigboh, 1983).

Since 1930, Nigeria has surpassed Brazil as the world's leading producer of cassava with an estimated annual production of 26 million tons from an estimated area of 1.7 million hectares of land (FAO, 1991). Other major producers of cassava are Congo DR, Thailand, Indonesia, China, India, Malaysia, Malawi, Togo and Tanzania (Odigboh, 1983).

Cassava processing thus deserves serious attention in order to meet the local and international demand for cassava products. The unit operations involved in the processing of cassava includes peeling, grating, boiling/parboiling, drying, milling, sieving, extrusion and frying. Several processes for the above mentioned operations have been mechanized successfully, however, cassava peeling remains a serious global challenge to design engineers involved in cassava processing. Research efforts in this area have resulted in the production of several prototypes with relatively low peeling efficiencies and quality performance. This as a result of the different size and irregular shapes of cassava tubers.

The size of a cassava tuber depends on the variety and fertility of the soil. The cassava tuber can be divided into three regions. They are:-

I. The periderm: - This is the uttermost layer, which is brown in colour and consists mainly of dead cells, which covers the surface of the tuber.
II. The cortern: - This lies below the periderm. It is usually about 1.5 – 2.5mm thick and white in colour.
III. The central portion of the tuber: - This makes up the greater bulk of the cassava tuber and is composed essentially of stored starch.

In cassava peeling operation both the periderm and the cortern are removed as waste, and the central portion of the tuber left as the desired output.

There are several methods of peeling cassava, which have been adopted. They include manual, chemical, steaming and mechanical methods. Each has its own advantages and disadvantages.

Manual Method

The manual method of peeling cassava is primitive and cumbersome. It is carried out by hand peeling of cassava using sharp edged object like the knife.

Chemical Method

Chemical method is often adopted in the industries, factories and food processing companies. It involves chemical actions and thermal shock, which leads to softening and loosening of the skin using caustic soda (NaOH). The disadvantages of this method of peeling cassava include:-

a. Cost of acquiring caustic soda.
b. The difficulty in controlling the penetration of chemical into the cassava tuber.
c. The difficulty in the removal of chemical traces as it may be poisonous.

Steaming Method

The tubers are subjected to high steam pressure over a short period of time to avoid partial cooking (or eventual cooking). The disadvantage is that the tubers could be subjected beyond the time required, which will lead to cooking.

Mechanical Method

This includes mechanized means of peeling, aimed at peeling a large number or a batch at a time. Many mechanisms have been devised for this purpose. This includes the continuous process, abrasive belt conveyors and batch abrasion types among others.

These methods of feeling have not been yielded the desired results. Hence, the continued research in this area. An extensive literature research was conducted to determine the state of the art in cassava processing. This project is intended to join the so many researches in this area to solve the problem of cassava peeling and to serve as a base for the commercial production and utilization of cassava peeling machines, Kawano (2000) and Hillocks (2002).

DESIGN ANALYSIS

The following were identified as needed to be determined in order to analyze completely the component parts of the machine.

i. Estimation of power required by the machine.
ii. Determination of approximate length of the belt.
iii. Determination of load on shaft pulley and belt tensions.
iv. Determination of load on the peeling drum.
v. Determination of minimum shaft diameter.
vi. Determination of the weight of the peeling drum

According to Eugene and Theodore (1996), mass of the drum m is given by,

$m = \rho V$ ………. (1)

Where ρ is the density of the material and V the volume.

But,

V = (Length x width x thickness) + (2 x circumference x thickness)

$V = (L \times \pi D_d \times t_p) + (2 \times \pi D_d \times t_p)$

$V = \pi D_d t_p (L + 2)$

Hence equation (1) becomes

$m = \rho \times \pi D_d t_p (L + 2)$ ……………… (2)

Weight of the drum is given by,

$W = mg$

Substituting equation (2) gives

$W = \pi \rho D_d t_p g (L + 2)$ ……………….. (3)

Estimation of Power Required by the Machine

The force F required to crush out the cassava peel by the drum of mass m having a tangential acceleration a is given by:

$F = ma$ …………… (4)

From the equation of motion:

$v = u + at$

Therefore,

$a = \frac{v+u}{t}$ …………… (5)

Since the drum is turning at an average constant speed by the time the peeling begins, the initial speed *u* is zero. Hence equation (5) reduces to:

$a = \frac{v}{t}$ …………... *(6)*

Substituting equation (6) into (4), gives

$F = \frac{mv}{t}$ ……….. *(7)*

We know that speed, *v* in terms of angular speed, *N* is given by:

$v = \frac{2\pi rN}{60}$ ………. *(8)*

Where r is the radius of the peeling drum.

Therefore, equation (7) becomes:

$F = \frac{m \times 2\pi rN}{60t}$

For one seconds, the force becomes:

$F = m\frac{2\pi rN}{60}$ ……… *(9)*

This is the load per second on the peeling drum as the peeling is in progress. The torque, T due to this load is given by:

$T = Fr$ …………. *(10)*

Substituting equation (9) from (10)

$T = \frac{2\pi r 2mN}{60}$ ………… *(11)*

The power P required to drive this torque is given by:

$P = T\omega$ ………. *(12)*

Where ω is the angular speed, which is given by:

$\omega = \frac{2\pi N}{60}$

Therefore, equation (12) becomes:

$P = T\frac{2\pi N}{60}$ ……………. *(13)*

Substituting equation (11) into (13), gives

$P = m\left(\frac{2\pi N}{60}\right)^2$ …… (14)

Determination of Approximate length of Belt

For our analysis, it is assumed that the centre distance *c* between the shaft pulley and motor pulley is given by:

$C \geq \left(\frac{D+d}{2}\right) + d$ ……….. *(15)*

Where *D* is the shaft pulley diameter and *d*, is the motor pulley diameter.

The approximate length of the belt is given by the sum of the arc length of the major arc AOB, length BC, arc length of the minor arc CO_2E and length EA.

$\Rightarrow L = Arc\ AB + BC + Arc\ CE + EA$ ………………. *(16)*

But,

$Arc\ AB = Q_L \frac{D}{2}$ ……….. *(17)*

$Arc\ CE = Q_s \frac{d}{2}$ ……….. *(18)*

Considering triangle O_1O_2F in the figure above,

$Sin\alpha = \frac{FO1}{O1O2}$ ………… *(19)*

But,

$\overline{FO_1} = \overline{BO_1} - \overline{BF}$ …………. *(20)*

Also,

$\overline{BF} = CO_2$ (opposite side of a parallelogram)

Therefore, equation (20) becomes,

$FO_1 = BO_1 - CO_2$

$\overline{FO_1} = \frac{D}{2} - \frac{d}{2}$

$\overline{FO_1} = \frac{1}{2}(D - d)$ ………… *(21)*

and,

$\overline{O_1O_2} = c$ ……………… *(22)*

Substituting equation (21) and (22) into equation (19) gives,

$Sin\alpha = \frac{D-d}{2c}$

$\alpha = sin^{-1}\left(\frac{D-d}{2c}\right)$ ……… *(23)*

Also, from Pythagoras theorem,

$O_1O_2^{\ 2} = FO_1^{\ 2} + FO_2^{\ 2}$

Therefore,

$\overline{FO_2} = \sqrt{O1O2^{\ 2} + FO1^2}$

$\overline{FO_2} = \sqrt{c^2 - (\frac{D-d}{2c})^{\ 2}}$

$\overline{FO_2} = \frac{1}{2}\sqrt{[4c^2 - (D-d)^2]}$

But,

$BC = FO_2$ (opposite side of a parallelogram)

Therefore,

$\overline{BC} = \frac{1}{2}\sqrt{[4c^2 - (D-d)^2]}$ ………… *(24)*

Since the drum is symmetrical about section O_1O_2, then

$\overline{AE} = BC$

Therefore,

$\overline{AE} = \frac{1}{2}\sqrt{[4c^2 - (D-d)^2]}$ ……… *(25)*

Substituting equation (17), (18), (24) and (25) into equation (16) gives the approximate length of the belt as,

$L = Q_L\frac{D}{2} + \frac{1}{2}\sqrt{[4c^2 - (D-d)^2]} + Q_s\frac{d}{2} + \frac{1}{2}\sqrt{[4c^2 - (D-d)^2]}$

Therefore,

$L = \sqrt{[4c^2 - (D-d)^2]} + \frac{1}{2}(Q_LD + Q_s d)$ ………… *(26)*

The contact angle of the pulleys, Q_L and Q_s, in radians can be determined in terms of pulley diameters. From the figure above,

$Q_L = \pi + 2\alpha$ …………… *(27)*

$Q_s = \pi - 2\alpha$ …………….. *(28)*

Substituting equation (23) into equation (27) and (28) gives,

$Q_L = \pi + 2Sin^{-1}(\frac{D-d}{2c})$ …………… *(29)*

$Q_s = \pi - 2\ Sin^{-1}(\frac{D-d}{2c})$ …………… *(30)*

Substituting equation (29) and (30) into equation (26) gives,

$L = \sqrt{[4c^2 - (D-d)^2]} + \frac{1}{2}[D\ [= \pi + 2Sin^{-1}(\frac{D-d}{2c})] + d\ [\pi - 2\ Sin^{-1}(\frac{D-d}{2c})]]$

Therefore,

$L = \sqrt{[4c^2 - (D-d)^2]} + \frac{\pi}{2}(D + d) + (D - d)\ Sin^{-1}(\frac{D-d}{2c})$ ………… *(31)*

Shaft Design

The shaft of the machine carries a pulley that receives power from an electric motor via a v-belt, the peeling drum and two bearings.

The minimum shaft diameter needed to avoid failure of the shaft is calculated thus:-

Torque on the Shaft

$T_A = \frac{60P}{2\pi N_A}$ …………… *(32)*

Where P is the power delivered to the pulley by the motor, and N_A is the speed of the rotation of the pulley, which can be determined from the speed ratio of the shaft and the motor as thus:-

$\frac{N_A}{N_M} = \frac{d}{D}$

$N_A = \frac{N_M d}{D}$ ………….. *(33)*

Where N_M is the motor speed, d is the motor pulley diameter, and D is the shaft pulley diameter.

The torque T_C acting at C must be equal to that at A for equilibrium of the shaft. Hence,

$T_C = \frac{60P}{2\pi N_A}$ …………….. *(34)*

Loads on the Shafts

At A

The belt tension ratio is given by,

$\frac{T_1}{T_2} = e^{\mu\theta}$ ………………. (35)

Where θ is the contact angle at the small pulley, which can be determine from the equation (30), μ is the coefficient of friction between the pulley and belt, which is read from data on catalogues, and T_1 and T_2 are the belt tensions on the tight and slack side respectively.
If $e^{\mu\theta}$ is represented as k, then equation (35) can be rewritten as,
$T_1 = k\,T_2$ ………….. (36)
The vertical load, F_A on the shaft is the bending load and is given by,
$F_A = T_1 + T_2$
Substituting equation (36) gives,
$F_A = T_2\,(k + 1)$ …………….. (37)
The driving load F_d is given by,
$F_d = T_1 - T_2$
Substituting equation (36) gives,
$F_d = kT_2 - T_2$

Therefore,
$F_d = T_2\,(k - 1)$ ……………… (38)
The driving load, in terms of the torque, is given by,
$F_d = \frac{T_A}{D/2}$ …………………. (39)
Combining equation (38) and (39) gives,
$T_2\,(k - 1) = \frac{2T_A}{D}$
Therefore,
$T_2 = \frac{2T_A}{D(k-1)}$ …………….. (40)
Substituting equation (40) into equation (37) gives the vertical load as,
$T_2 = \frac{2T_A(k+1)}{D(k-1)}$
Since k = $e^{\mu\theta}$
$F_A = \frac{2T_A\,(e^{\mu\theta}+1)}{D(e^{\mu\theta}-1)}$ …………… (41)
At C,
The vertical load F_{VC} on the drum as a result of friction is the tangential load between it and the cassava, and is given by,
$F_{VC} = \frac{2T_c}{Dd}$ ………… (42)
The total load F_C on the drum is given by,
$F_C = F_{VC} + W$ …………………. (43)
Where W is the weight of the drum, and can be determined using equation (14). Hence, substituting equations (14) and (42) into equation (43) gives,
$F_C = \frac{2T_C}{Dd} + \pi\rho D_d tg\,(l + 2)$ ……. (44)

MATERIAL SELECTION

Material selection is of utmost importance to ensure that the components to be fabricated have the desired performance requirements. Since different components of the cassava peeling machine would be subjected to varying forms and the degree of stresses strains, torque and frictional effect, the material with the appropriate engineering properties was chosen.

Material Selection Criteria

The materials to be used for fabrication were selected after a careful study of the desired physical, mechanical and chemical and even aesthetic characteristics of a number of proposed materials. For this project, due economical considerations and availability of raw materials, high and medium carbon steel was mostly used for body parts and chuck materials while cast iron was chosen for the pulley, Khurmi and Gupta (2004).

Machine Frame

The machine frame supports the other parts of the cassava peeler machine, as well as providing balance. It is subjected to the direct weight or load of other members of the machine (hence compressive forces) and also to torque and vibration from the peeling drum and motor. The desired material should be of high rigidity, hardness, adequate toughness and posses' good machining characteristics. For this purpose, angular high carbon steel rods were chosen.

Peeling Drum

The peeling drum was made of medium high carbon steel sheet. The drum is to be punched or punctured from one side leaving the spiky. It rotates (powered by an electric motor) hence generate torque. Though hardness of the drum is desired because of the intended penetration and abrasion (of the tuber), the ductility of the drum material should be adequate to retain a rigid shape (cylindrical) when in use.

Body

The body covers the moving part of the machine. In addition to aesthetics, it also provides support and balance for the chuck and handle. Medium carbon steel was used because of its machineability, hardness and rigidity.

Pulley

The pulley, attached to the shaft through the peeling drum, should rigid, hard and machinable. Cast iron was chosen for this purpose as the pulley would be subjected to tension forces from the belt as well as torque and speed variations from the motor.

Chuck and Bearing

Corrosion resistance high carbon steel rods were used as chuck materials because of the chemical inertness of the metal to cassava. In addition, the material has to be machinable and withstand the reaction (shearing force) generated when abrasion occurs between the peeling drum and the cassava, as well as withstand the generated torque.

Springs and Belt

Springs chosen were compressive type springs with adequate stiffness to hold the tuber in position firmly without crushing it. Manufactured vulcanized belt with adequate tension were used.

FABRICATION

The manufacturing process used in the fabrication of the cassava peeling machine is such that the total cost of fabrication is reduce and also one that can make use of the available materials. The manufacturing process involved in this work includes, joining of metal parts by welding, cutting using hacksaw and hand cutting machine. Each component of the machine is fabricated separately before they are joined or welded together as the case may be. The following are the procedure of fabrication of each component of the machine and the final assembly, IITA (1997).

Peeling Drum and Shaft Assembly

This consists of the peeling drum, the shaft, the driven pulley and bearings. The bearings and the pulleys as a result of the fact that they are readily available in the market and the relative high cost of fabricating a new one, they are purchased from the market. A pulley of 169mm diameter groove and 23mm 'shaft hole' was selected based on what is available in the market and considering the speed reduction that is expected to be achieved. Two bearings of 67mm and 27mm external and internal diameters respectively were also purchased due to the same reason.

The peeling drum is made from a sheet of medium carbon steel metal. A sheet of dimension 565mm x 40mm was cut. The spikes on the drum were made by punching holes on the metal sheet from one side of the metal sheet so that the roughness produced on the other side of the metal sheet. The holes were punched very closed to each other so as to produce the roughness of the spikes enough to peel the cassava back. This sheet is then folded into a cylindrical shape and then welded along the edges where the sheet is joined using electric arc welding.

Also the circular end was made by cutting out the circular end from the medium carbon steel sheet. Holes of diameter 23mm were drilled in the center of the end and the edges welded to the drum at the both ends. These drum is now mounted on the shaft such that one end is 70mm from one end of the shaft opposite end of the drum is 120mm from the other end of the shaft and then welded firmly.

The bearing were mounted on the shaft such that they are 45mm each from both end of the peeling drum and then welded firmly to the shaft.

Finally the pulley is mounted on the lower arm of the shaft so that it is 15mm away from the bearing and with a bolt screwed firmly to the shaft.

Frame

Angular iron made of high carbon steel was used. Four lengths of 850mm each were cut to represents the legs of the frame for comfortable operation. Also six lengths, 1070mm each, were cut; two to support the legs, two for the top length and the remaining two support the peeling compartment. Six pieces of 970mm were cut; two for the width, two to support the legs at adjacent sides, and the other two to form support for the electric motor. These parts were carefully welded using electric arc welding machine.

Chuck and Handle Assembly

This part comprises of the cassava holder (chuck), the rail and handle. This was fabricated so that one can move the tuber to and fro abrasion line without exposure of the hands to the danger of coming in contact with the peeling drum. The chuck was made of high carbon steel rod, cut to dimension and pass through a hollow cylindrical pipe (one of which is spring-loaded). The spring is to aid firm grip of the chuck to the tuber. The chuck with the spring is connected to the handle. After their assembly, the two chucks ends were welded to the handle frame of the machine. Care was taken to ensure both chucks are horizontally aligned. Below each protruding ends of the chucks, light steel rods joins the chucks to the rails to permit horizontal motion. Bearings of 30mm diameter were used the rail construction.

TESTING

The machine having completed, in terms of the design and fabrication, was tested to verify if the efficiency of peeling is satisfactory. In fact, all the design concepts and calculated results were religiously followed and arrived at with little or no variations. Finally, the peeling machine was tested with approximately linear cassava. With continuous rotation of the handle, the tuber portion that comes in contact with the peeling drum was rapidly bruised off.

The Efficiency of peeling of the machine was estimated using the ratio;

Thickness of tuber peeled by machine (t_a): ideal thickness to be peeled by machine (t_i)

Thus,

Efficiency = $\frac{t_a}{t_i}$ x 100 …………. (1)

From 3 samples, the efficiency was estimated as follows;

Sample 1

Diameter of the tuber before peeling = 52.11mm
Diameter of the tuber after peeling = 50.90mm
Thickness of tuber peeled by the machine (t_a) = 1.21mm
Ideal thickness to be peeled (t_i) = 2.00mm

Efficiency of peeler = $\frac{t_a}{t_i}$ x 100
= $\frac{1.21}{2.00}$ x 100 = 60.5%

Sample 2

Diameter of tuber before peeling = 58.44mm
Diameter of tuber after peeling = 54.10mm
Thickness of tuber peeled by the machine (t_a) = 1.17mm
Ideal thickness to be peeled (t_i) = 2.00mm

Efficiency of peeler = $\frac{t_a}{t_i}$ x 100
= $\frac{1.17}{2.00}$ x 100 = 58.5%

Sample 3

Diameter of tuber before peeling = 58.44mm
Diameter of tuber after peeling = 56.89mm
Thickness of tuber peeled by the machine (t_a) = 1.55mm
Ideal thickness to be peeled (t_i) = 2.00mm

Efficiency of peeler = $\frac{t_a}{t_i}$ x 100
= $\frac{1.55}{2.00}$ x 100 = 77.5%

Thus, Average Efficiency = $\frac{60.5+58.5+77.5}{3}$ = 65.5%

Hence the Efficiency of peeling of the machine is estimated at 65.5%.
Note; this efficiency is dependent on the operator as feeding of the tuber to the peeling drum is done manually.

PERFORMANCE

The ability of the machine to perform effectively determines the overall success of the project for high performance level. The machine is expected to peel a relatively linear tuber of 20-30mm length within 15-20sec. This was achieved with relative success with an efficiency of 65.5% at 4-5kg/min during its operation. These results vary as the loading and peeling periods is dependent on the operator.

MAINTENANCE

The simplicity of this design allows for minimum maintenance to be carried out on the machine, such as lubrication of the movable and rotating parts to prevent stiffness, removing cassava peels from the peeling drum at intervals. Regular inspection of the machine parts and belt should be carried out to ensure optimum machine life. The machine should also be used for what it is meant for and it should be kept in a place free from rain and harsh weather conditions.

CONCLUSIONS

At the end of an intensive literature research, construction and testing, a satisfactory cassava peeling machine with efficiency of 65.5% was fabricated using the available raw materials and techniques. The approximately linear tuber was loaded by hand and then conveyed by rail to the peeling drum.

The overall performance of the machine is more efficient compared to already existing ones. The cost of production and maintenance is relatively cheap. Hence, the machine will be welcomed by industries given its performance, affordability and simplicity.

Although some of the persistent problem(s) associated with previous models of the cassava peeling machine, particularly that of the varying shapes of the tuber, were not fully solved. This was taken care of by resizing the tubers to fairly linear dimensions. Various workable designs and models have been theoretically examined for further development. These could not be practically embarked on due to capital and time constrains.

RECOMMENDATIONS

At the end of this project work and research, we came up with what may be the most effective method of peeling cassava. The means of peeling cassava will be a method in which the cassava will be fixed in position but rotates about its axis while the peeling tool moves along the length of the cassava. This method employs the principle of turning using the lathe machine. Due to time constraints and finance, we are not able to make further research on this method. It is recommended that further research work be encourage towards this line.

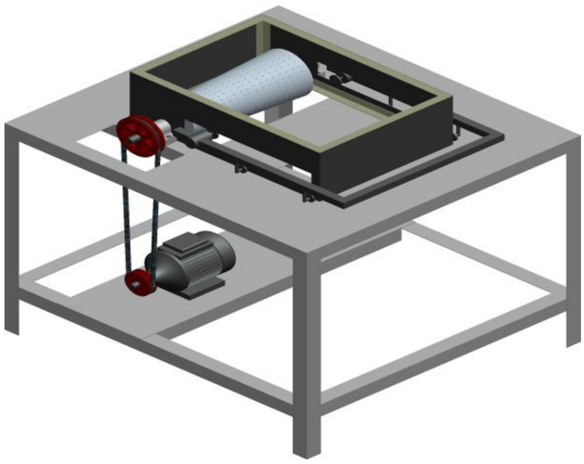

Fig.1.Cassava Peeling Machine.

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