DESIGN, CONSTRUCTION AND TESTING OF CASSAVA PELLETIZING MACHINE

This project is on the design, construction and testing of a cassava pelletizing machine. The machine processes cassava mash by extrusion into cylindrical form of about 2-3cm length and 9mm diameter called pellets. The machine is made of these major components: hopper, barrel, auger conveyor and a circular die plate. The hopper is made of a stainless steel 1mm thick cut from a flat metal sheet. The sides if the hopper is joined by electric arc welding while the barrel is a cylindrical hollow shaft. This barrel is welded to the already fabricated hopper at its base, with the base of the hopper coinciding with an opening in one end of the barrel and the other end welded to an already perforated die plate. The auger conveyor is an intricate part of the machine made of a shaft wound round with a 20mm rod joined by arc welding with honcon electrode. A helical auger is mounted on a shaft which is supported on bearings so that the shaft rotates freely in the stationary cylindrical barrel. Cassava mash is introduced into auger through the inlet gate of the barrel. The auger conveys the mash to the die and builds up pressure for its extrusion. Pressure resulting from rotating auger forces the mash through the perforations in the die, compressing and forming it into pellets. Experiments were conducted to compare the moisture content of the pellets and that of the unpelletized cassava mash using the oven method and also to determine the production rate and efficiency of the machine.

Experimental results revealed that the pellets had a moisture content of 16.49% (d.b) and cassava mash 75.20% (d.b). The results also indicated that the pellets have more durability than the cassava mash since high moisture content have been found to decay mash faster hence the need for pelletizing. Furthermore, the production rate and efficiency of the machine were found to be 63.86g/min and 81.27% respectively. Though the performance of the machine is satisfactory, I recommend that a force feed mechanism be introduced to avoid caking of the mash especially while operating on large quantity and also the noice level minimized.

CHAPTER ONE

1.0 INTRODUCTION

Cassava is a perennial crop and is widely grown in Africa and South America. It has an estimated height of 2metres when fully grown and has great potentials to germinate in not very fertile soils which could be impossible for other cops to grow. The roots of a fully grown cassava plant are rich in starch and the percentage of carbohydrate present in its dried state is higher than other staple crops. However, it possesses very low percentage of protein (Food and Agriculture Organization FOA, 2004a). A substance called cyanogen glycosides is present in cassava in its raw form making it poisonous. Also present, is an enzyme called linamarase which is responsible for changing the poisonous glycosides to hydrogen cyanide (HCN), this occurs when the plant cell bursts open when processed or eaten. Cassava is of two categorise, sweet and bitter. The latter has greater cyanide content than the former; though it is not in all cases the former (sweet) have low cyanide content present in it. The range of cyanide is between 10 to 450 mg/kg of fresh root and is greatly reduced in its processing hence making it safe for consumption when transformed into a variety of food and non food products (FAO, 2004b).

1.1 Problem Statement

Cassava is very perishable, therefore the need for its processing immediately after harvest to minimize wastage. The limitations in its processing are high cost of transportation, inadequate supply of tubers annually, low output in small-scale processing and inadequate and inefficient processing equipment amongst others. Over the years, there have been some locally produced pelletizing machines for processing cassava by compaction process but this work is focussing on the use of extrusion process in order to achieve greater efficiency, minimize waste and improve on the ease of operation of the machine.

1.2 **Justification of the machine**

Over the years the existing machines used for various processing of cassava are very expensive and as such difficult for peasant farmers to afford, thus is one of the focus here is its construction at reduced cost. The products produced by the machine such as cassava chips, pellets have considerable export potentials hence the need for its manufacture to boost the nation's revenue. More so, for export purposes, cassava tubers are processed into raw cassava chips, but because of environmental concerns, over 90% of cassava chips that are exported to the European Union (EU) enter as pellets (Ugoamadi, 2012a).

The operation of giving a plastic material a structure by forcing it through a die via an extrusion process is called Pelletizing. When raw cassava chips is compressed putting in mind relevant operational parameters, it results in the formation of an unfermented dried cassava products called cassava pellet. This product is estimated to be 3cm long and is used greatly in feeding farm animals. The product is now greatly accepted because of its durability and portability when packaged. This makes handling, storage and transporting convenient hence exporting is achieved Ugoamadi, (2012b).

Furthermore, this project emphasizes on the use of available resources (cassava) which is in line with the national policy and forecast on industrialization. It supports the long term forecast of the Federal Institute of Industrial Research Oshodi (FIIRO) to investigate the actualization of commercializing cassava processing.

Consequently, it agrees with the goal of the Raw Materials Research and Development Council (RMRDC) to encourage and enhance the use of local raw materials and technology for industrial development. The design will bring down the cost of production to a minimum in order to make it available to the end users, mostly rural farmers at a reduced price. This is achieved through reduction of the complexity of the design while at the same time maintaining high design efficiency and aesthetics.

1.3 Aim and objectives

The aim of this project is to design, fabricate and test cassava pelletizing machine based on extrusion process.

The specific objectives are to:

1. Develop cassava pelletizing machine at a reduced cost.
2. Determine the efficiency and rate of production of the machine.
3. Compare the moisture content of the extruded material (pellets) and that of cassava mash.

1.4 Scope of the Research

The project covers the Design, Fabrication and Testing of a Cassava Pelletizing Machine. The test is limited to:

1. Testing the efficiency and production rate of the machine.

2. Comparing the moisture content of the extruded material (pellets) and that of the cassava mash.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Cassava Production in Nigeria and the rest of the World

The struggle for national food security and sustainable and virile market expansion policies call for viable processing options that will guarantee food and industrial raw materials, and at the same time provide employment opportunities for rural labour force to carry out the processing tasks. The tasks, according to (Odigboh 2000), include timeliness and efficiency of processing, packaging and preservation of agricultural (processed) products. With high labour demand, a teaming population of over 120 million and an annual agricultural growth rate of about 7%, introduction of efficient, sustainable and cost effective mechanization technology is imperative.

World production of cassava, Nigeria in 1982, was rated sixth in the world with a production rate of 6.8million tonnes/annum. Through cassava multiplication

(IFAD-Assisted Root and Tuber Expansion Project), Her annual production output increased between 1982 and 1996 from 12.4 million to 33 million tonnes, equivalent to an increase of over 300%.The production level heightened to 36.75 million tonnes/annum in 2000. This is because of the conducive environment the Nigerian cassava production sector witnessed. Cassava production in Nigeria is estimated top in the world when compared with that of other countries like Brazil, Indonesia and Thailand. The figure 2.1 shows the world leading producers of cassava and the corresponding amount produced while

figure 2.2 shows the picture of a typical cassava tuber.

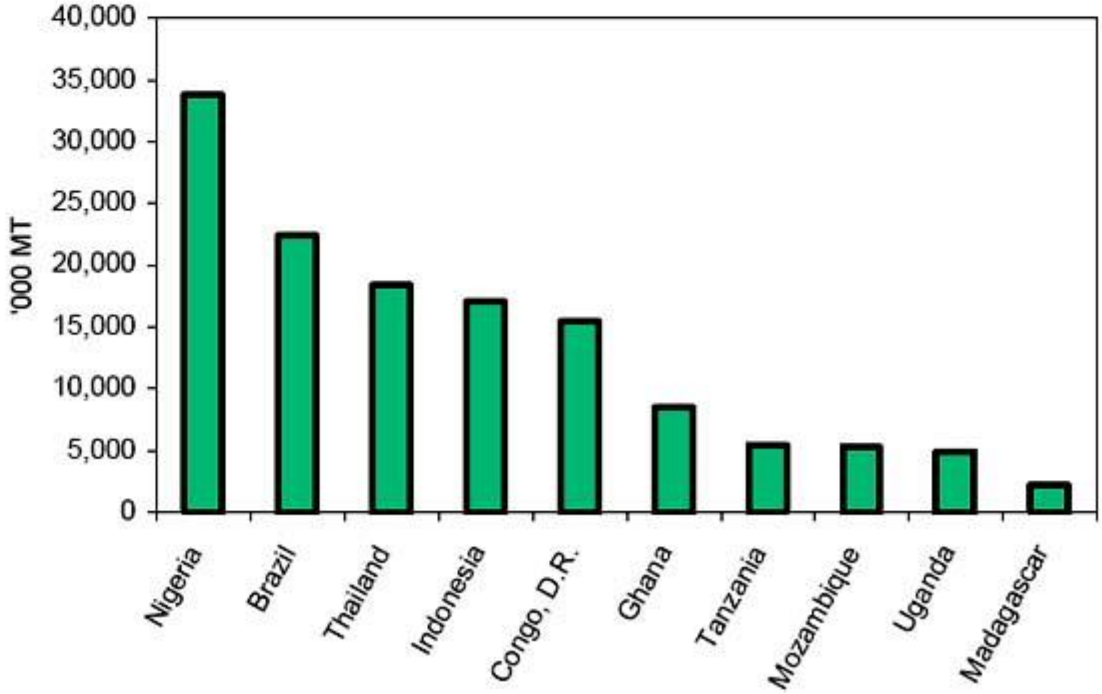


Figure 2.1: Leading World Producers of Cassava

Source: FAO, 2004.

Figure 2.2 Picture of a cassava tuber

Source: International Institute of Tropical Agriculture IITA, 2004

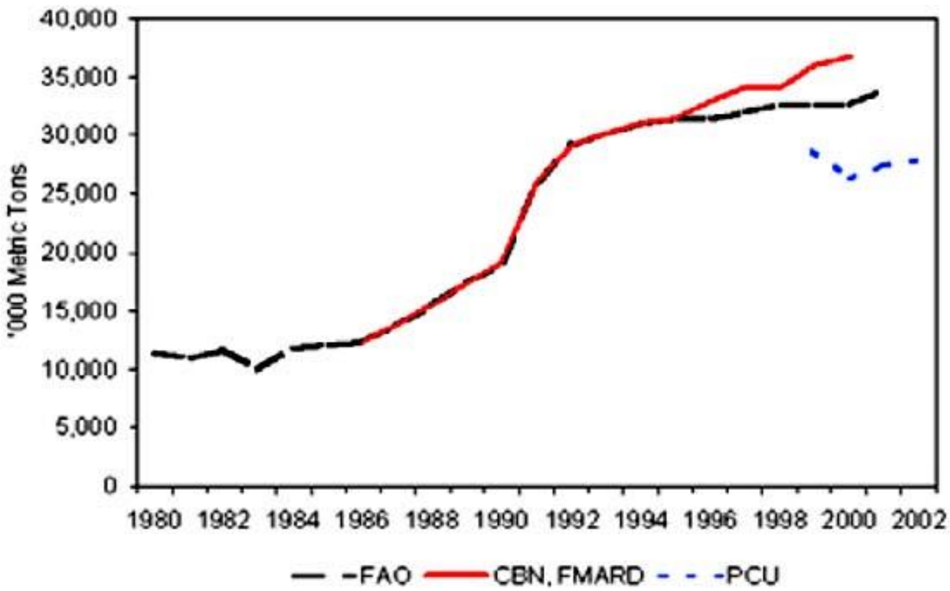


Figure 2.3 Cassava Production 1980-2002

Source: FAO, 2004

From the graph in figure 2.3, between 1996 to 2002 three categories of evaluations were established for cassava production in Nigeria. In 2002, an estimated 34 million tonnes of cassava was produced in Nigeria as discovered by the Food and Agriculture Organization of the United Nations (FAO) in Rome (FAO, 2004c). Report by the Central Bank of Nigeria agrees with that of FAO data on the path of cassava production until 1996 and increased drastically in 2000 to an estimated value of 37 million tones (Federal Ministry of Agriculture and Natural Resources FMANR, 1997; Central Bank of Nigeria CBN, 1998). In 2002, 28million tonnes of cassava were produced as discovered by the Project Coordinating Unit PCU (PCU, 2003).The statistical data provided by PCU are information gathered and compiled at the state level by the Agricultural Development Programme ADP offices. In the same year also, cassava production recorded a greater output as compared to other various crops in Nigeria. Comparing its output with that of other crops in Nigeria gave these statistics: that yam, sorghum, millet and rice had a production rate of 27 million tonnes, 7 million tonnes, 6 million tonnes and 5 million tonnes respectively

(FAO, 2004d). There have been a great deal of consistency on the increase of the production of cassava since 1980 but between 1988 to 1992 an additional increase was recorded because of the introduction of new species by IITA. By comparing the cassava production rate between the year 1999 to 2002 within the zones in the country, that is: North Central , South South, South West and South East zone, recorded an estimate of over 7 million tones, over 6 million tonnes and less than 6 million tonnes by the last two zones respectively. An estimated 2 and 0.14 million tonnes was recorded for the North West and North East respectively which is small as compared to other zones of the Federation.

Table 2.1 Cassava Production by Zone 2000-2002 (tonnes)

Region	2000	2001	2002

South West	4 993 380	5 663 614	5 883 805
South South	6 268 114	6 533 944	6 321 674
South East	5 384 130	5 542 412	5 846 310
North West	2 435 211	2 395 543	2 340 000
North Central	7 116 920	7 243 970	7 405 640
North East	165 344	141 533	140 620
Total	26 363 099	27 521 016	27 938 049

Source: PCU, 2003.

On further study of the production rate per individual recorded 2002 reveals that: North Central, South East, South South, South West, North West and North East with 0.72, 0.56, 0.47, 0.34, 0.10 and 0.01 tonnes per individual respectively. Consequently, 0.32 tonnes per individual was recorded as the Gross per capita (IITA, 2004a).

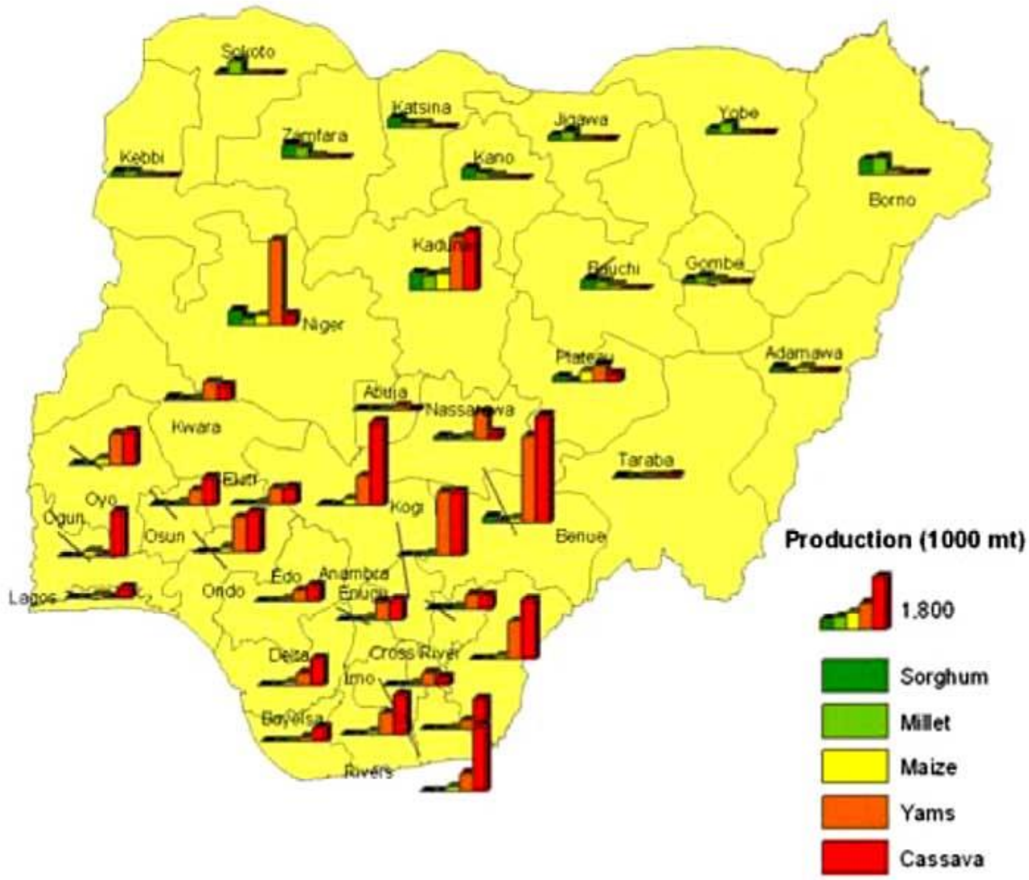


Figure 2.4 Crop Productions by State 2002

Source: IITA, 2012.

According to IITA, 2004a statistics reveals that some states lead the pack in terms of cassava production in their zone: Benue and Kogi state for North Central, Cross River, Akwa Ibom, Rivers and Delta for South South. Ogun, Ondo and Oyo for South West and Enugu and Imo for South East Zone. Interestingly, Kaduna State from the North West records a competitive cassava production value of approximately 2 million tonnes annually with states in the southern region as against the North East zone with relatively small amount produced. Practically, countries involved in heavy production of cassava have less demand for wheat flour. For instance, in the production of wheat flour bread some percentage of cassava flour is added, 2% in Brazil and 10% in Nigeria

(IITA, 2004b). The scope of expanding the consumption of cassava in Nigeria, particularly within the food processing sub-sector, is determined by the development of efficient processing technologies and market system, to assure of steady supply of high quality products, appropriate pricing and specifications required for domestic and export markets. It should therefore be clear to any discerning mind that it is not the continuous expansion of cassava production that will earn Nigeria the targeted US$5 billion but the introduction of appropriate processing technologies. Moisture content removal in processing cassava root is responsible for the products durability, transportability and portability. Cyanide content is also removed in its processing thus ensuring safety in consumption of its food products. In Nigeria, small and medium scale industries utilize the raw material from processed cassava (IITA, 2004c).

Among the identified products obtained from cassava processing and their area of application include the following:

i. Food Industry - fermented and unfermented Cassava flour, Gari, snacks
ii. Textile Industry - Starch
iii. Animal Feed - Pellets (Livestock feeds)
iv. Paper - Adhesive and particle board
v. Pharmaceuticals - Syrups and tablets
vi. Alcohol – Ethanol

About 55% of Nigeria's root and tubers are consumed locally which means that the remaining percentages have great industrial and export potentials. There is also tremendous potential for investments in the processing for local and international markets for cassava (IITA, 2004d).

2.2 Methods of Processing Cassava

Cassava are always required healthy free from pest attack, therefore it is expected that the materials used in its processing should be in the right condition. In order to achieve good quality of the product, the cassava processing should be carried out not more than 48hours from its time of harvest. Care must be taken to process cassava in a clean environment to prevent contamination. The methods described below are among the methods of processing cassava as established by (FAO, 2004e) and (Oduntan, 2010).

2.2.1 Peeling

This is a process carried out after its harvest. It involves the removal of the scalp of the tuber either manually with a knife or by mechanical means. Research has shown that practically it takes an average of one hour for a lady to peel an average of 23kg of the root. After this operation 30% of its weight is lost when manual peeling is adopted. Although some peeling machines have been invented in the past but general acceptability has been low especially on the part of peasant farmers for reasons that the machines are expensive and produces too much waste in operation. Often, the tubers are harvested in the morning and the peeling process begins immediately and finished quickly especially when more hands get involved. The fleshy part of the tuber is then washed properly to remove dirt and the buried in water into a container before rasping takes place.

For large scale production, the entire tuber is processed. Washing here involves both the removal of dirt and the removal of its pericap. If the tuber is very ripe, the pericap removal is done easily leaving behind the fleshy cortex where starch can be processed further.

2.2.2 Chipping

The bitter cassava variety possesses higher hydrogen cyanide than the sweet type, therefore its root soaked in water much longer between 2 to 4 days for proper expelling of the cyanide in order to keep the product safe for consumption. Chipping can be done manually or with chipping equipment.

2.2.3 Grating and Rasping

The crushing of the cell wall of the cassava tuber is essential in order to expose its starch granules. This process can be achieved either by mechanical or biochemical means. The latter is a traditional means where the already soaked cassava tuber gets fermented after some days and then smashed to a pulp from where the starch is then extracted. The extracted starch gotten from this procedure is of less quality compared with that of the other method. Mechanical action on the other hand, involves cutting the tubers in slice and then rasping, grating or crushing them, converting the flesh to a pulp. Thereafter, the pulp form of the tuber is then thoroughly squeezed to liberate the starch granules.

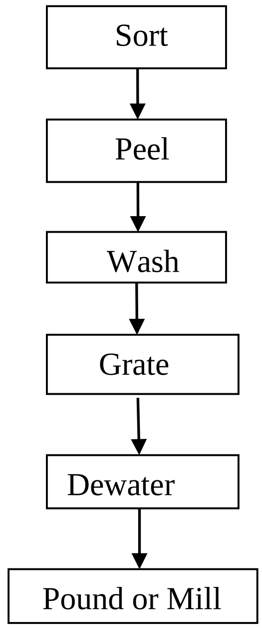
Cassava grating and rasping is one of its processing operations. Years back the operation was considered stressful as it was done with bare hands but in recent time there exists good motorized machine used for its operation.

2.2.4 Drying

Drying is one of the methods employed in preserving and storing the cassava chip. The period of drying should be not more than 48hours after its harvest. However, it is important to minimize the drying time of the chip because in most cases they get infected by insects when drying. The drying time can be reduced by producing chips to be dried in large flat sheets such that there is greater surface area for the escape of moisture. The moisture content of the chip before drying is estimated between 65%-75% but approximately between 12%- 15% after drying. The most common method of drying is sun drying.

2.2.5 Making Cassava Flour

Cassava flour is powder like in nature. Its particles are so refined and can be achieved conventionally by the use of mortar and pestle where the cassava chip is pounded into fine particles. Cassava flour can be stored throughout the year if properly preserved. The flow chart is shown in figure 2.5



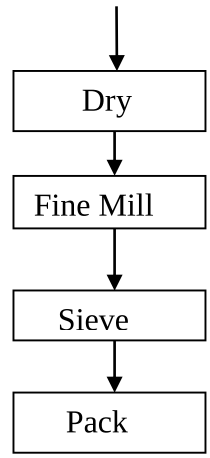
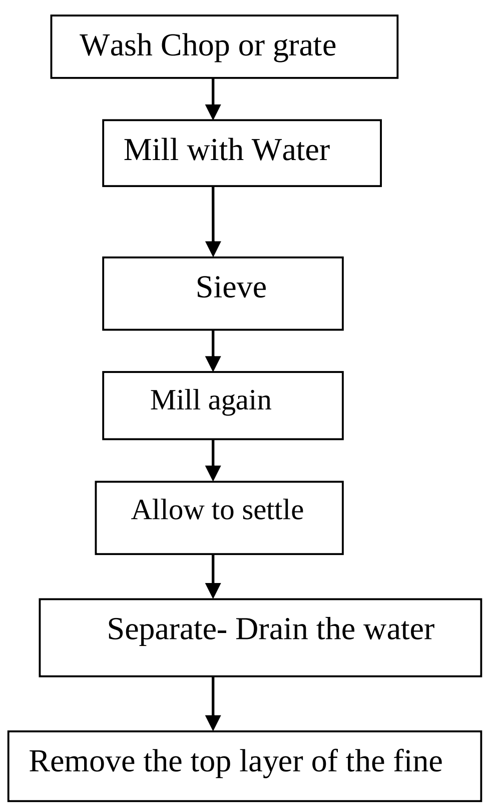


Figure 2.5: Basic steps for making cassava flour:

Source: Oduntan, 2010

2.2.6 Making Starch

Starch is a product of cassava. It is locally used for foods such as biscuits, bread e.tc. It is also used for non-food applications such as in papermaking and in the textile industry.



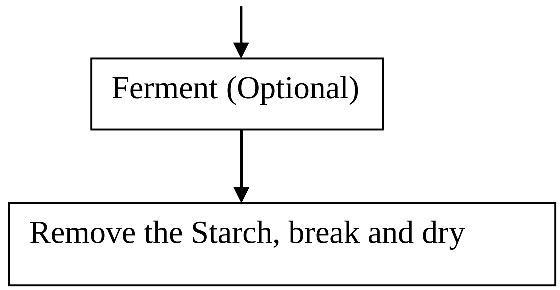


Figure 2.6 Basic Steps for making starch

Source : Oduntan, 2010.

2.2.7 Cassava Flour and Starch

In the production of cassava flour, the starch granules must be completely removed from its tuber. The granules are bonded together along with other elements (proteins, fats, soluble carbohydrate e.t.c.) in the protoplasm of the cell. (proteins, soluble carbohydrates, fats and so on). This separation can be achieved by filtration process in their liquid state.

The stages involved in the production of starch are stated below:

1. **Preparation and extraction:** This involves primarily the washing and peeling of the roots. They are then rasped so that the cells are broken and the granules removed by filtration to extract the cassava product and prevent the attack of foreign materials.
2. **Purification:** Involves introduction of clean water into the starch granules obtained in the previous stage. The next operation is the sedimentation and the washing of the starch in tanks and on flour tables, silting, centrifuging, etc.
3. **Centrifuging and drying:** By placing in a centrifuge and Sun drying.
4. **Finishing:** Grinding, bolting and other finishing operations.

These stages are important in the production of all type of starch. The filtration operation involved in cassava processing is done without difficulty because of the presence of little foreign materials. But with other cereals, the separation of the pericarp from the grain, and the grinding of the seed are extremely labour intensive (FAO, 2004f).

2.3 Importance of Quick Processing

Quick processing is very important in the processing of cassava as soon as they are harvested. This is in a bid to reduce the attack of enzymes on cassava during the various stages of processing thereby reducing the quality of product produced. This therefore requires a well planned arrangement of the transportation of the cassava roots to the place where it is to be processed. Though the procedure involved in the production of process looks simple but great care must be taken. The cassava roots are promptly received just as they are harvested as they cannot be kept unprocessed more than 48 hours from the time of harvest. Particle of stones present in cassava root could affect its rupturing process therefore it is essential to cut off the woody parts of the root before other processing operation begins.

2.4 Some Cassava Processing Technologies Developed By NCAM

The National Centre for Agricultural Mechanization (NCAM) Ilorin Kwara State has a mandate for research and development (R&D) on appropriate technologies in order to increase the quantity and quality of agricultural produce through design, development and evaluation of *home-grown, need-based* agro-technologies. The Centre also evaluates and tests imported technologies for the relevance of their application in Nigerian agriculture industry. Below are some of cassava processing technologies developed at the Centre:

NCAM Cassava Lifter:

This is equipment for uprooting cassava root shown in figure 2.6. It consists of a frame to which a footboard and immovable gripping jaws are attached and a lever (handle) which is hinged to the frame. The field capacity is 200 plant stand/man-hour. The use of this tool eliminates drudgery and tediousness involved in cassava root harvesting (IITA, 2005a)

Figure 2.7 NCAM Cassava Lifter

Source: IITA, 2005a

NCAM Cassava Peeling Tool:

The tool in figure 2.7 is used for removing the brown covering (pericarp) of cassava root. Its use is quite easier compared to the local method of using kitchen knife which is labour intensive. It consists of peeling blade and a handle which are made of steel. Root tuber loss is less than 0.4%. The tool peeling capacity is

6.5 tones/8 hr-days (IITA, 2005b).

Figure 2.8 NCAM Cassava Peeling Tool

Source: IITA, 2005b

NCAM Cassava Root Washer:

It comprises a horizontal cylindrical drum and an axial shaft on which cleaning brushes are spirally arranged as shown in figure 2.8. Cleaning water occupies lower half of the drum and the peeled cassava moved through the water by the brush paddles, thus ensuring complete washing of the root. The agitation is either by hand cranking of the axial shaft or mechanically through a belt transmission powered by about 3.5 kW engine. Capacity varies between 3 tonnes of root per hour

(hand cranking) to 8 tonnes per hour (engine powered) (IITA, 2005c).

Figure 2.9 NCAM Cassava Root Washers
Source: IITA, 2005c

NCAM Cassava Root Grater:

It comprises a grating drum, a recto-trapezoidal hopper of 50kg peeled cassava root capacity with a cover, drum housing with an outlet for grated cassava mash, and powered by a 6.5 kW (@ 2600 rpm) diesel engine via a two-way pulley transmission as shown in figure 2.9. It has a capacity of 6.5 tonnes/8 hr.-day

(IITA, 2005d)

Figure 2.10 NCAM Cassava Root Graters
Source: IITA, 2005d

NCAM Cassava Rasping Machine

It is made of stainless steel material with a capacity of 285kg/hr as shown in figure 2.11. Power rating of the machine is 5.5KW and occupies a space of 2 by 2m (IITA, 2005e).

Figure 2.11 NCAM Cassava Rasping Machine

Source: IITA, 2005e

NCAM Mechanical Chipper:

It consists of the hopper, the chipping disc, the frame, outlet and prime mover as shown in figure 2.11. The root to be chipped is placed in the hopper which falls by gravity into the chipping disc rotating at 500rpm. A minimum of 3.5 kW is required to power the chipping machine. It has a capacity of 200 kg of cassava root in one hour (IITA, 2005f)

Figure 2.12 NCAM Mechanical Chipper

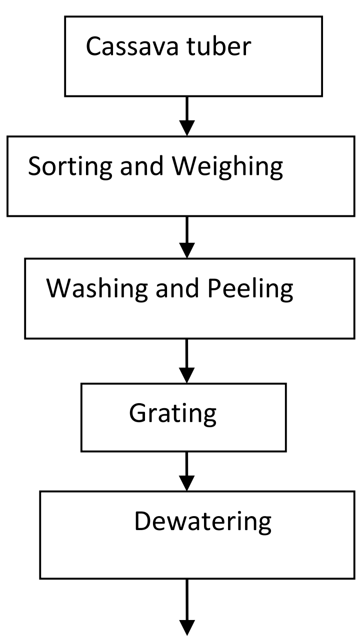
Source: IITA, 2005f

2.5 Cassava Pellets

When raw cassava chips is compressed putting in mind relevant operational parameters, it results in the formation of an unfermented dried cassava products called cassava pellet. This product is estimated to be 3cm long and is used greatly in feeding farm animals.

They can be produced from raw cassava root and cassava chips. The production of cassava pellets from raw cassava roots is shown in the flow chart shown in figure.2.13.

Cassava pellets are used in producing ethanol, glucose, flour, livestock feed, starch, biscuit, bread, adhesives etc (Ugoamadi, 2012a).



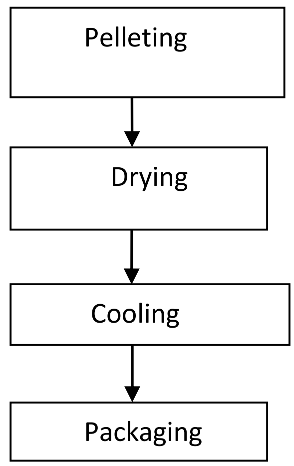
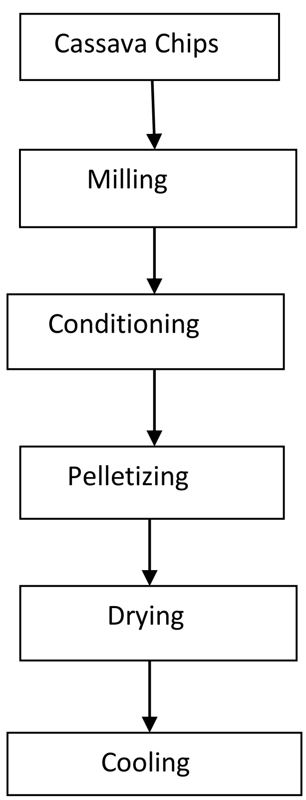


Figure 2.13: Flow diagram for the cassava pellets from raw cassava roots.

Source: Ugoamadi, 2012b



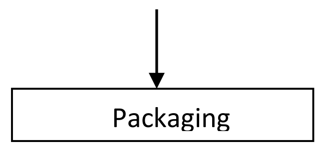


Figure 2.14: Flow diagram for the Cassava pellets from cassava chips.

Source: Ugoamadi, 2012c

The essential operations are as follows (Ugoamadi, 2012d):

Sorting and Weighing

This involves the separation of wholesome roots from deficient roots as well as other unwanted materials like lump of sand before weighing.

Washing and Peeling

This is the process of using clean water to wash away dirt from the tuber after which it is peeled and washed again to ensure that there is no dirt on it.

Chipping

The already washed and peeled tuber is ready for chipping. This can be done manually or with a chipping machine. The latter is faster and less tedious than the former. The chips produced with chipping machine have regular shapes and sizes compared to the manually produced type.

Drying

The method commonly used is the sun drying. Where the chips are spread exposed to the sun to be dried. The other is the artificial type employed majorly in a humid weather.

Cooling

The dried chips are spread out for proper cooling before they are packaged

Packaging

The cooled, dried chips are vacuum packaged in high density polyethylene bags for proper storage or distribution to consumers of the product.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Design Analysis and Calculations

An average tuber weight is between 4-7kg but specimen up to 40kg have been recorded (FAO, 2004g).

Water content in cassava mash is between 18- 22% w.b.; 530-635 kg/m^3, bulk density and

8.86 – 34.24MPa crushing strength (Oduntan 2010)

Density of steel is 7800kg/m^3 (Khurmi and Gupta, 2010)

3.1.1 Hopper Design

The hopper was designed on two important factors

1. The maximum volume of cassava the container can hold

2. The repose angle i.e. the slant height of the hopper makes with the vertical

According to FAO, 2004 an average cassava has a length of 50cm and width of 7.5cm diameter.

The base inlet through the hopper into the barrel is square shaped and its dimension carefully chosen with reference to the volume of cassava to be fed.

3.1.2 Volume of the Hopper

Therefore the volume of hopper is set at higher value than the volume of cassava.

Volume of hopper V_h was set as 8.0×10^6 mm^3

Base area of hopper A_1

The inlet or base dimension was set at 100mm × 100mm.

Therefore base area of hopper $A_1 = 100 \times 100 = 10,000mm^2$

Top area of hopper A_2

The length and breadth of the base hopper were multiplied by a factor of 3

Top length = 3 × 100 = 300mm

Top breadth = 3 × 100 = 300mm

Therefore top area of hopper $A_2 = 300 \times 300 = 90000mm^2$

Height of the hopper h

Since A_1, A_2 and V_h have been established, as follows

A_1 =10,000 mm^2

A_2 = 90,000 mm^2

V_h = 8.0 × 10^6 mm^3

Therefore the height of the hopper can be determined by using equation 3.1 for a based frustum.

$\boldsymbol{V_h = \frac{1}{3}h(A_1 + A_2 + \sqrt{A_1A_2})}$ (Ilori et al., 2003) 3.1

$$8.0 \times 10^6 = \frac{1}{3}h\left(10{,}000 + 90{,}000 + \sqrt{(10{,}000 \times 90{,}000)}\right)$$

$$8.0 \times 10^6 = 43333.33h$$

$$h = \frac{8.0 \times 10^6}{43333.33}$$

$$h = 184.62mm$$

$$h = 185mm \ \ was\ used$$

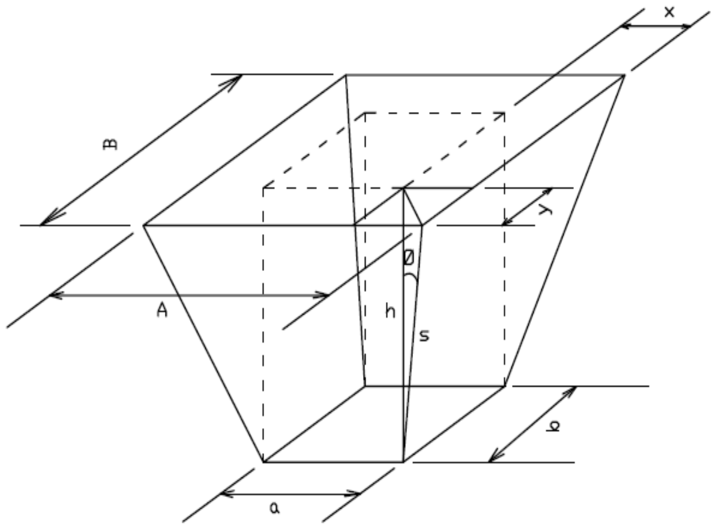


Figure 3.1: Schematic Diagram of the hopper

Angle of repose

a – entrance length =100mm

b –entrance breadth = 100mm

A – top length = 300mm

B – top breadth = 300mm

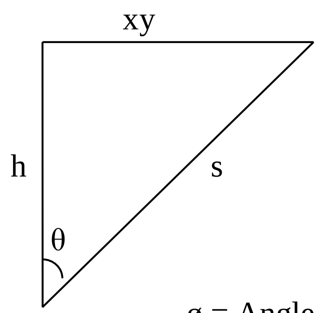
It can be inferred from figure 3.1 that

$$x = \frac{A \ - a}{2} = \ \frac{300 \ - 100}{2} = 100mm$$

$$y = \frac{B \ - b}{2} = \ \frac{300 \ - 100}{2} = 100mm$$

$$xy = \ \sqrt{x^2 + y^2} \ = \ \sqrt{100^2 + \ 100^2} \ = 141.4mm$$

but h = 185mm



ø = Angle of Repose

Figure. 3.2 An Enlarged View showing the angle of Repose and the slant Height

$$slant\ height = \sqrt{h^2 + xy^2}$$

$$slant\ height = \sqrt{185^2 + 141.4^2}$$

$$slant\ height = 233mm$$

$$235mm\ used$$

3.2 Volume of Barrel (Extrusion Chamber)

A hollow stainless steel pipe was chosen for the barrel. The dimension of the pipe are:

Outside diameter = 90mm

Inside diameter = 80mm

Thickness = 5mm

Length = 390 mm

The volume of the extrusion barrel could be computed using equation 3.2 given as:

$V = \pi R^2 L$ (Ilori et al., 2003) 3.2

Where V = volume of barrel

R = radius of barrel

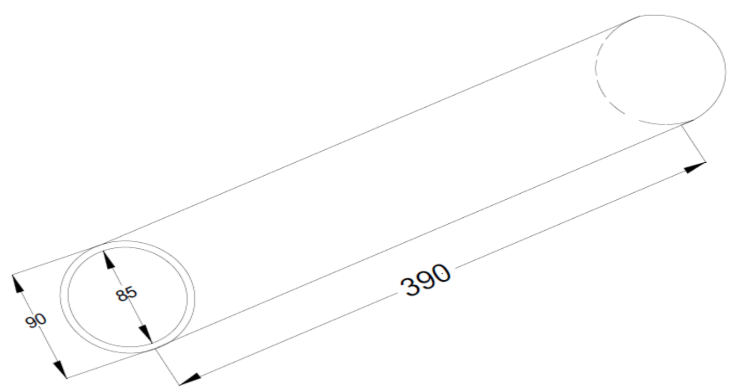
L = length of barrel

Radius of barrel used is half of the external diameter

$R = \frac{90}{2} = 45mm$

$$V_p = \pi \times 45^2 \times 390$$

$$V_P = 2.48 \times 10^6 \ mm^3$$



(Dimensions in mm)

Figure 3.3: A View of the Pipe used for the Barrel

3.2.1 Area of Cut-off Segment (A_s) from Barrel

$$\boldsymbol{A_S = \frac{1}{2} R^2 \left[\frac{\pi\theta}{180} - sin\theta\right]}$$ (Ilori et al., 2003) 3.3

Where A_s = Area of segment

θ = angle subtended at the centre by the sector of which the segment forms a part.

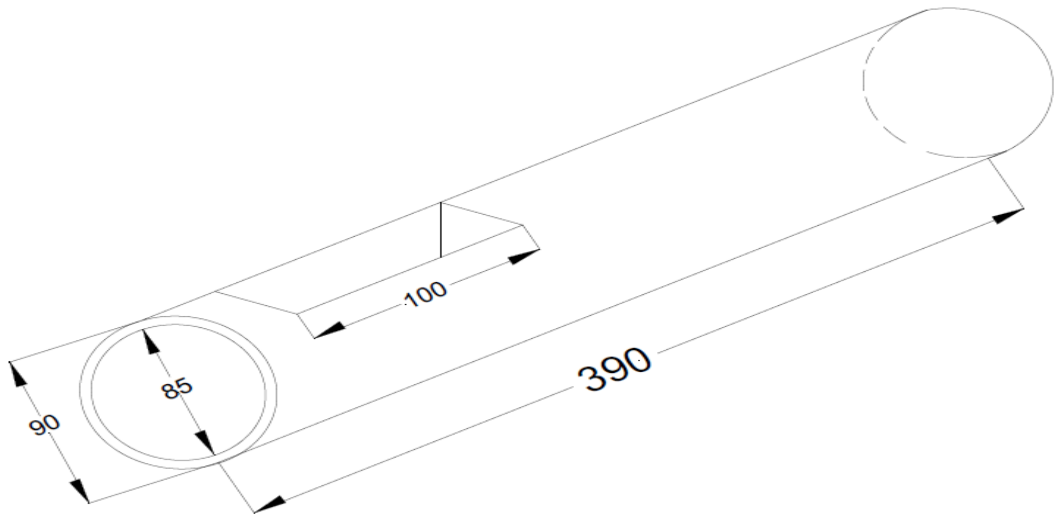


Figure 3.4 A pipe showing the cut off segment (Dimensions in mm)

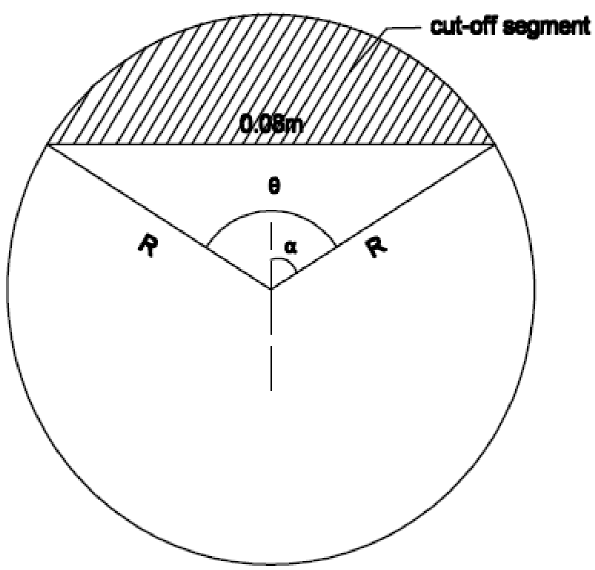


Figure 3.5 A View of the Cut Off Segment

From figure 3.5,

$$2\alpha = \theta$$

And $\frac{20}{R} = sin\alpha$

Where R is the radius of the outside diameter $R = \frac{90}{2} = 45mm$

$$\sin \propto = \frac{20}{45}$$

$\sin \propto = 0.4444$

$\propto = \sin^{-1} 0.4444$

$\propto = 26.4°$

θ = 2x 26.4

θ=52.8°

$$As = \frac{1}{2} \times 45^2 \left(\frac{\pi \times 52.8}{180} - \sin 52.8\right)$$

$$= 1012.5 \times (0.92153 - 0.79653)$$

A_s = 126.6 mm^2

Therefore As is approximately 127mm^2

3.2.2 Volume of Cut-off Part, V_s

V_s = Area of cut off segment (A_s) × length of barrel

V_s = 127 × 390

V_s = 49530 mm^3

3.2.3 Volume of Barrel, (Extrusion Chamber), V_c

$V_c = V_p - V_s$

$V_c = 2480000 - 49530$

$V_c = 2430470$

$V_c = 2.43 \times 10^6\ mm^3$

3.2.4 Volume occupied by the Auger Conveyor in the Extrusion Chamber

The maximum volume of cassava mash handled in the hopper:

Taking a sample of 10kg mass of cassava flour conditioned into mash with 2kg of water (Odutan, 2010). Then total mass of mash is 12kg

$$volume\ of mash = \frac{mass}{density}$$

$$volume\ of mash = \frac{12}{583} = 2.06\ \times 10^{-2}mm^3$$

Where 583kg/m^3 is the average bulk density of a cassava mash (Oduntan, 2010)

The length of the conveyor is to be set at 390mm to leave a clearance of 2mm from container 1mm on each side in order to prevent rubbing.

Volume occupied by auger conveyor = volume of extrusion chamber – volume of cassava mash

Volume occupied by auger conveyor = $2.43 \times 10^6 - 2.06 \times 10^{-2}$

Volume occupied by auger conveyor = $2.429\times 10^6 mm^3$

3.2.5 Determination of Capacity of Conveyor

The auger conveyor which is placed horizontal is designed with helices of uniform diameter of 90mm and pitch of 40mm. Therefore its capacity is computed using the expression:

$$Q = 60np\emptyset\gamma(D - d)\frac{\pi}{4} \qquad \text{(Kubota, 1995)} \qquad 3.4$$

Where Q = capacity of the conveyor

n = speed of the conveyor

Ø = output efficiency for horizontal auger

d = mean pitch diameter

γ = bulk density of feed

D = maximum pitch diameter

Spanns (1989) recommended the

Speed of auger = 450rpm;

Output efficiency for horizontal auger =1

Pitch = 40mm = 0.04m;

Diameter of auger = 0.06m

Diameter of shaft = 40mm =0.04m;

Bulk density of cassava mash between 530 kg/m^3 -635kgm^3; average (583 kg/m^3) with a moisture content of between 18 % - 22% w.b. (Oduntan, 2010)

Substituting values in the equation 3.4

$$60 \times 450 \times 1 \times 0.04 \times 583(0.06 - 0.04)\frac{\pi}{4}$$

= 9890.362

Q = 9.890362kg/hr

3.2.6 Determination of Power required (Pw) by Conveyor in the Barrel

The power, P required by the conveyor is computed using equation 3.5

P = 0.7353 C L Q (Kubota, 1995) 3.5

P = Power

C = Output coefficient for horizontal auger

L = Length of auger

Q = capacity of auger

Since the capacity of auger has been established as Q =9.890362kg/hr

P = 0.7353 × C × L × 9.890362

P = 0.7353 × 1 × 0.390 × 9.890362

P = 2.8362kW

3.2.7 Determination of Operating Pressure (Po) in the Barrel

The determination of the operating pressure in the extrusion barrel is computed using equation 3.6

$$Po = \frac{Pw}{Q}$$ (Nelkon, 1999) 3.6

Where

Po = Operating pressure

Pw = Extruding Power

Q = Capacity of auger

And Q in terms of volume:

$$\frac{Q}{\rho/_{3600}}$$

$$\frac{Q}{\rho} = \frac{9.890362}{583}$$

$$= 0.01696 m^3/s$$

Therefore (Po) Operating Pressure

$$Po = \frac{Pw}{Q} = \frac{2.8362}{0.01696}$$

=167.24kPa.

3.2.8 Determination of Thrust Force (W)

The trust force (W) moving the cassava mash inside the barrel could be computed using the expression 3.7

W = P×A (Nelkon, 1999) 3.7

P = Pressure in the barrel

A = (Area of extruder – Area of conveyor shaft)

$$A = \frac{\pi}{4}(0.06^2 - 0.04^2)$$

A = 0.000314m^2

W= P × A

= 167.24 × 0.000314

= 0.0525kN

3.2.9 Determination of Extrusion Pressure (Pe)

For a constant feed rate, speed of extrusion and material density, extrusion pressure varies with die size.

The die plate diameter = 90mm

Diameter of pellet hole =16mm

The extrusion pressure in respect to the pellets hole size is computed using:

$Pe = \frac{W}{A}$ (Nelkon, 1999)

Where

W = Thrust force

Pe = extrusion pressure

A = total area of pellet holes

A = $N \times \pi \frac{d^2}{4}$

Where

N = total number of holes

D = diameter of a single hole

Therefore $A = 4 \times \pi \times \frac{16^2}{4}$

$= 804.248mm^2$

$= 0.804248m^2$

Then extrusion pressure:

$$Pe = \frac{W}{A} = \frac{0.0525}{0.804248}$$

= 0.0653kPa

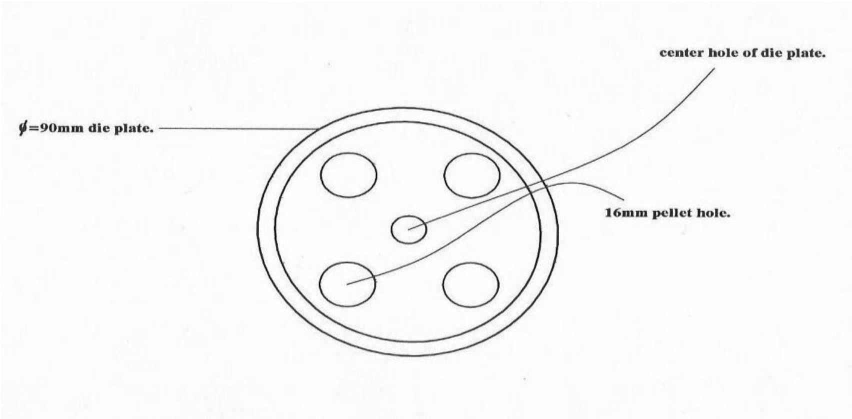


Figure 3.6: A section of the die plate and pellet holes

3.2.10 Radius of the Conveyor

The length of the conveyor is to be set at 0.39m to leave a clearance of 0.01m at both ends of the container in order to prevent rubbing.

Radius of conveyor $r_c = \sqrt{\frac{volume\ of\ conveyor}{\pi \times h}}$ (Khurmi and Gupta, 2010) 3.6

$$= \sqrt{\frac{2.429 \times 10^6}{\pi \times 390}} = 44.53mm$$

3.2.11 Determination of the Axial Force acting on the Mash

The two forces acting on the cassava mash are:

1. Centrifugal force of the conveyor in the container Fc
2. Weight of the conveyor itself. Wc

Axial force = Fc + Wc

$Centripetal\ force\ Fc = \frac{Mc \times V^2}{r_c} = M_c \times w^2 \times r$ (Kurmi and Gupta, 2010) 3.7

Where Mc = mass of conveyor = 11g (determined from a spring balance)

r_c = radius of conveyor

V = linear velocity; w = angular velocity

$$W_c = 11 \times 9.807 = 107.877N$$

Given a crushing strength of cassava mash 8.86MPa (Oduntan, 2010)

Also with the already calculated area, then Fc = Pressure × Area

Fc = $8.86 \times 10^6 \times 0.000314$

= 2782.04N

Axial force required (Fmax) = (2782.04 + 107.877)N

= 2889.917N

= 2.889917kN

$Therefore\ w = \sqrt{\frac{F_c}{m_c \times r_c}}$

$$w = \sqrt{\frac{2782.04}{11\ \times 0.04453}}$$

$$w = \sqrt{\frac{2782.04}{11\ \times 0.04453}}$$

w=74.72rad/s

$$w = \frac{74.72 \times 60}{2\pi} = 713.52\ rev/min$$

This is the velocity at which the shaft must rotate to give the required centrifugal force.

3.2.12 Determination of Screw Conveyor Torque

The Torque to convey and extrude may be calculated using equation 3.8

$Torque\ T = \frac{F \times P \times C}{2 \times \pi}$ (Kurmi and Gupta, 2010) 3.8

Where p = pitch of the screw = 0.054m

F = axial force required = 45382.477N

C = Conveyance efficiency =1.01

$$T = \frac{2889.917\ \times 0.054\ \times 1.01}{2\ \times\ \pi}$$

T = 25.0854Nm

3.3 Electric Motor Selection

The electric motor is selected based on the load it will handle.

The two important factors to be considered are:

1. The speed of the motor
2. The power of the motor

The speed of the motor is trivial as the speed of the motor can always be reduced or increased with the driven pulley to the required value.

Since the shaft speed required is 713.52 rpm, a motor with a speed of 1440rpm is a good choice.

3.4 Determining the Size of the Driven Pulley

Electric motor features:

Power = 1hp

Angular Speed = 1440 rpm

Diameter of pulley on motor spindle = 48mm =0.048m

From the relation

$$\frac{D_2}{D_1} = \frac{N_1}{N_2} \qquad \text{(Kurmi and Gupta, 2010)} \qquad 3.9$$

Where D_1 = Diameter of Driver (spindle) pulley

D_2 = Diameter of Driven pulley

N_1 = Angular speed of motor

N_2 = Angular speed of driven pulley

From eqn 3.10

$$D_2 = \frac{N_1 \times D_1}{N_2}$$

$$\frac{1440 \times 48}{713.52}$$

D_2 = 96.87mm; $D_2 = 96.87mm \approx 100mm\ used$

Minimum Electric Motor Power

$\boldsymbol{Power = force(load) \times linear\ velocity}$ **(**Kurmi and Gupta, 2010) 3.10

The force is equivalent to the sum of the weights of all the components driven by the motor

$$Screw\ conveyor\ shaft = 11kg = 11 \times 9.807 = 107.877N$$

$$Pulley = 6kg = 6 \times 9.807 = 58.842N$$

$$\text{Weight of cassava mash} = 12\text{kg} \times 9.807 = 117.684\text{N}$$

(From section 3.2.4 mass of cassava mash is 12kg)

Gravitational Acceleration, g $\cong 9.807\ m/s^2$

These weights were determined by a spring balance.

The weights add up to give 284.403N

But the already established angular speed w=74.72rad/s

$V = \omega R_2$

Where

V= Linear velocity

R_2 = radius of driven pulley on motor = 50mm

$$V = 74.72 \times 50 = 3736 mm/s$$

Therefore, according to equation 3.9

Power P = 284.403 × 3.736

P = 1062.53W

Therefore the best choice of electric motor must be the one with a minimum power rating of 1062.53W

A 2horse power motor will definitely serve since 2hp =1492W

3.5 Centre Distance between Pulleys, X

According to Ej song, 2008, the centre distance X between pulleys is given by

$$\boldsymbol{X = 2 \times \sqrt{(D_1 + D_2) \times D_1}} \qquad 3.11$$

$$X = 2 \times \sqrt{(48 + 100) \times 48}$$

X =168.57mm

3.6 Length of Belt Required

It is known that

$$\boldsymbol{L = \frac{\pi(D_1+D_2)}{2} + 2X + \frac{(D_1-D_2)^2}{4X}}$$ (Khurmi and Gupta, 2010) 3.12

Where

L = Length of Belt

X = centre distance between pulleys

D_1 and D_2 = diameter of driver and driven pulleys respectively

Therefore $L = \pi\frac{(48+100)}{2} + 2(168.57) + \frac{(48-100)^2}{4(168.57)}$

$$L = 232.48 + 337 + 4.01$$

$$L = 573.49mm \approx 575mm$$

3.7 Contact Angle between Belt and Pulleys, θ

According to Khurmi and Gupta, 2010, for an open belt drive

$$\boldsymbol{\sin\alpha = \frac{R_2-R_1}{x}}$$ 3.13

Where α is the angle between the centre between pulley and line parallel to belt

$$Sin \propto = \frac{50-24}{168.57}$$

$$Sin \propto = 0.15424$$

$$\propto = \sin^{-1}(0.15424)$$

$$\propto = 8.87°$$

Contact angle θ is given by

θ = (180 - 2α) **(**Khurmi and Gupta, 2010) 3.14

θ = (180 – 2 × 8.87);

θ = 162.26º

In Radian

$$\theta = 162.26 \times \frac{\pi}{180}$$

$\theta = 2.832rad$

3.8 Shaft Design

The shaft is subjected to both bending and torsional stresses.

Torque on the driving pulley, T is given as

$$\boldsymbol{T = \frac{P \times 60}{2\pi N}}$$ (Khurmi and Gupta, 2010) 3.15

Where p = power rating of the electric motor = 2hp = 1492W

N = speed of motor in rev/min =1400rpm

$$T = \frac{1492 \times 60}{2\pi \times 1440} = 9.89\text{Nm}$$

Since it is a belt drive

Then, torque or twisting moment on driving shaft T is given as

$$\boldsymbol{T = (T_1 - T_2)R_1}$$ **(**Khurmi and Gupta, 2010) 3.16

Where T_1 and T_2 = tension on tight and slack sides of belt respectively

R_1 = radius of the driving pulley

From eqn 3.16

$$\boldsymbol{T_1 - T_2} = \frac{T}{R1}$$

$$T_1 - T_2 = \frac{9.89}{0.024}$$

= 412.08N

Therefore, twisting moment on driven pulley

$$\boldsymbol{T_d = (T_1 - T_2)R_2}$$ **(**Khurmi and Gupta, 2010) 3.17

$$T_d = 412.08 \times 0.050 = 20.60Nm$$

3.8.1 Diameter of Shaft Required

To get the actual diameter of shaft required for the machine, the bending moment diagram of the shaft must be determined.

The actual value of T_1 and T_2 must also be determined

It has been shown that

$$T_1 - T_2 = 412.08N \qquad 3.18$$

And $\mathbf{2.3\log\left(\frac{T_1}{T_2}\right) = \mu\theta}$ **(**Khurmi and Gupta, 2010) 3.19

Where μ (coefficient of friction) for a leather belt = 2.5 **(**Khurmi and Gupta, 2010)

θ = 2.832rad

From eqn 3.19

$$2.3\log\frac{T_1}{T_2} = (0.25 \times 2.832) = 0.708$$

$\log\left(\frac{T_1}{T_2}\right) = 0.308$

Changing to indicial form

$$\frac{T_1}{T_2} = 10^{0.308}$$

$$\frac{T_1}{T_2} = 2.0324$$

And $T_1 = 2.0324T_2$ 3.20

Substituting for T_1 in equation 3.18

$$2.0324T_2 - T_2 = 412.08$$

$$1.0324T_2 = 412.08$$

$$T_2 = 399.15N$$

Therefore

$$T_1 - T_2 = 412.08N$$

$$T_1 = 412.08 + T_2$$

$$T_1 = 412.08 + 399.15$$

$$T_1 = 811.23N$$

3.8.2 Vertical Bending Moment on Shaft

Balancing the upward and the downward forces

∑ Upward forces = ∑Downward forces

$$R_{AV} + R_{DV} = 58.842 + (729.24 \times 0.39)$$

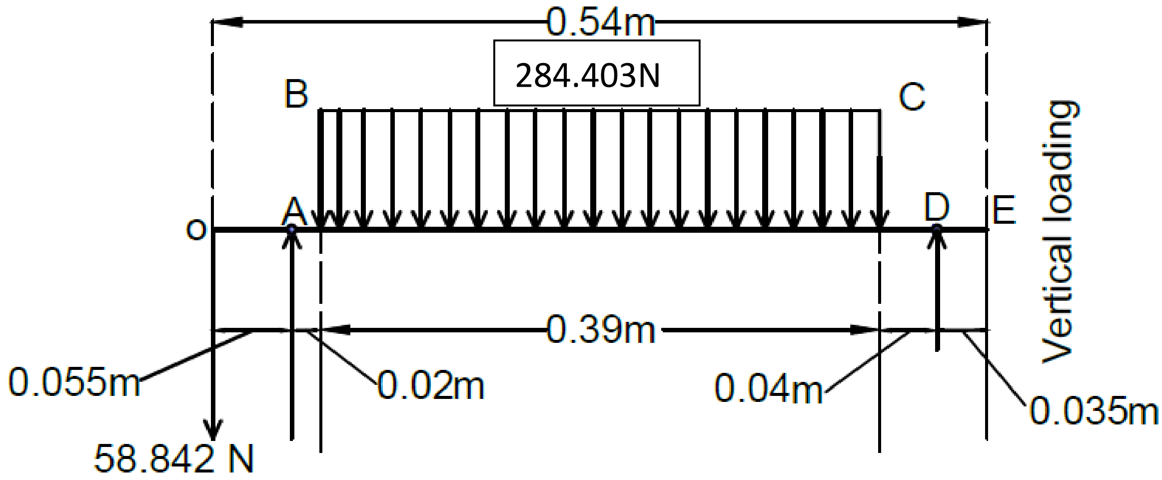


Figure 3.7 Vertical Loads on the Shaft

Where R_{AV} = Reaction as a result of bearing at point A

R_{DV} = Reaction as a result of bearing at point D

$$R_{AV} + R_{DV} = 58.842 + 284.403$$

$$\boldsymbol{R_{AV} + R_{DV} = 343.245} \qquad 3.21$$

Taking moment about point A

Clockwise Moment = Anticlockwise Moment

$284.403 \times 0.215 = R_{DV} \times 0.45 + 58.842 \times 0.055$

$$61.147 = 0.45R_{DV} + 3.236$$

$$57.911 = 0.45R_{DV}$$

$$R_{DV} = \frac{57.911}{0.45}$$

$$R_{DV} = 128.69N$$

Substitute for R_{DV} in eqn 3.20

$$R_{AV} + R_{DV} = 343.245$$

$R_{AV} = 343.245 - 128.69$

$R_{AV} = 214.56N$

3.8.3 Vertical Bending Moment Analysis (From Fig 3.7)

Bending moment is the sum of the areas under the shear force diagram

Convention used: subtract if area is above the shaft

Add if area is under shaft

1. Bending moment at point o = 0 (no applied Bending moment)
2. Bending moment at point A = 58.842 x 0.055 = 3.2363Nm (area under the shear force diagram between point o and A)
3. Bending moment at point B = M_A + area under the shear force diagram between point A and B

   M_B = 3.2363 – 155.72×0.02 = 0.1219Nm

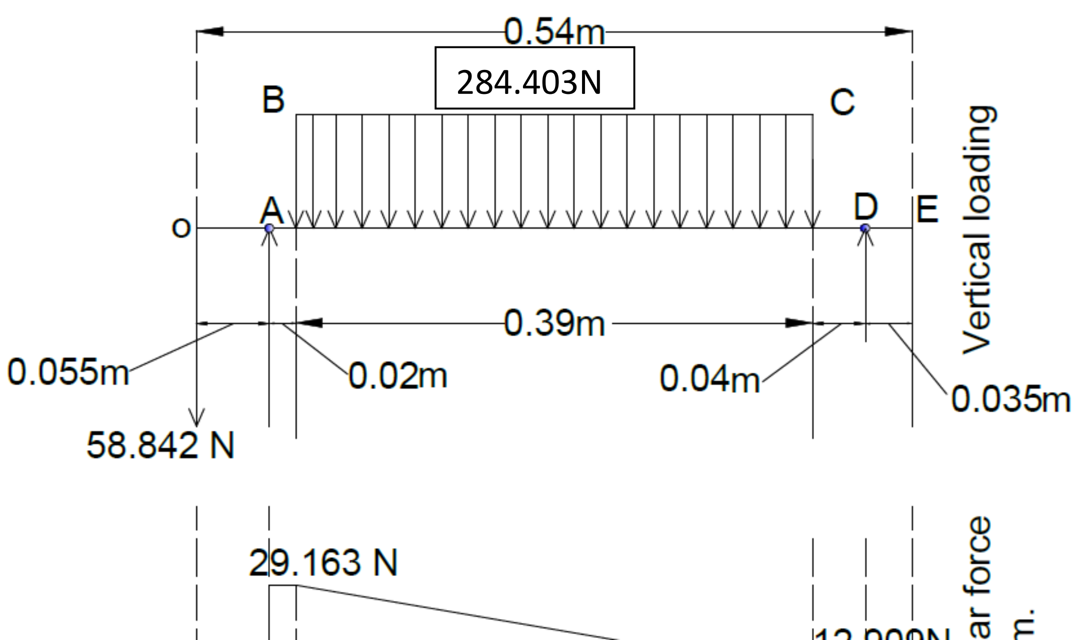
4. Bending moment at point C = Bending Moment at point B + area under the shear force diagram between B and C

   $M_c = 0.1219 - \frac{1}{2}(155.72 + 128.69) \times 0.39$

   $M_c = -5.338Nm$

5. Bending Moment at point D = Bending Moment at point C + area under the shear force diagram between point C and D

$$M_D = -5.338 - (-128.69) \times 0.04 = 0$$



155.72N

128.69N

-5.338Nm

3.8.4 Horizontal Bending Moment on Shaft

Horizontal load acting at point o = total tension on the belt

$= T_1 + T_2$

= 811.23 + 399.15

=1210.38N

Balancing the upward and the downward forces

∑ Upward forces = ∑Downward forces

$$\boldsymbol{R_{AH} + R_{DH} = 1210.38N} \quad 3.22$$

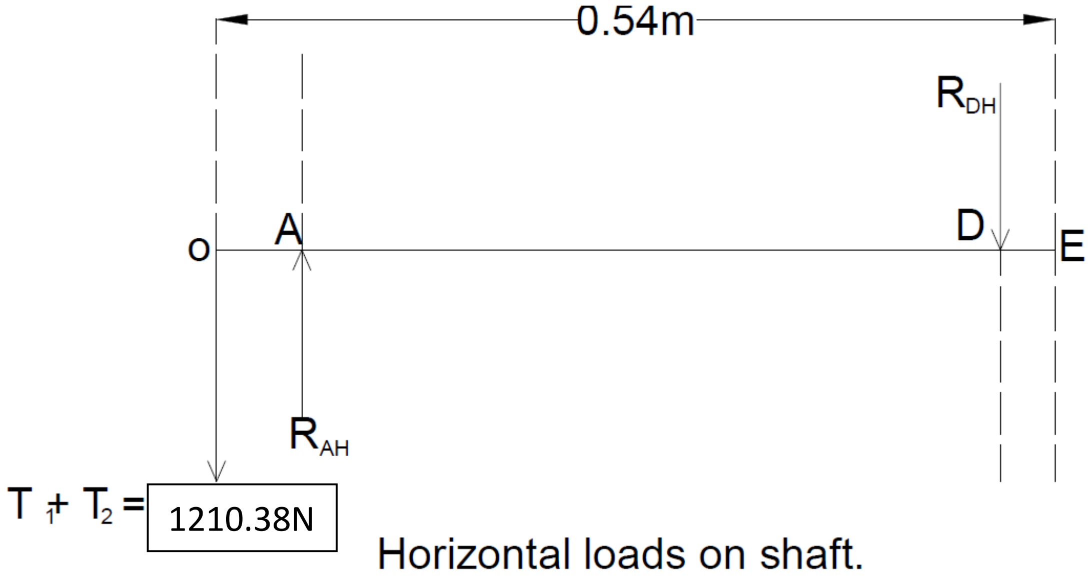


Figure 3.9 Horizontal Loads on Shaft

Where R_{AH}= Reaction as a result of bearing at point A

R_{DH}= Reaction as a result of bearing at point D

Taking moment about point D

Clockwise moment = Anticlockwise Moment

$R_{AH} \times 0.45 = 1210.38 \times 0.505$ (Fig. 3.9)

$R_{AH} = 1358.32N$

Substitute for R_{AH} in eqn 3.22

$$1358.32 + R_{DH} = 1210.38$$

$$R_{DH} = -147.94N$$

A negative value, means that reaction at D is acting downwards

3.8.5 Horizontal Bending Moment Analysis

From figure 3.9,

Bending moment is the sum of the areas under the shear force diagram

Convention used: subtract if area is above the shaft.

Add if area is under shaft

Bending moment at point o = 0 up to point P

Bending moment at point A = Area under the shear force diagram from O to A

= 1210.38 x 0.055 = 66.57Nm

Bending moment at point D = bending moment at point A – area under the shear force between point A and D.

Therefore bending moment at point D = 66.57 – (147.94 x 0.45) = 0Nm. This value is the same up to point E.

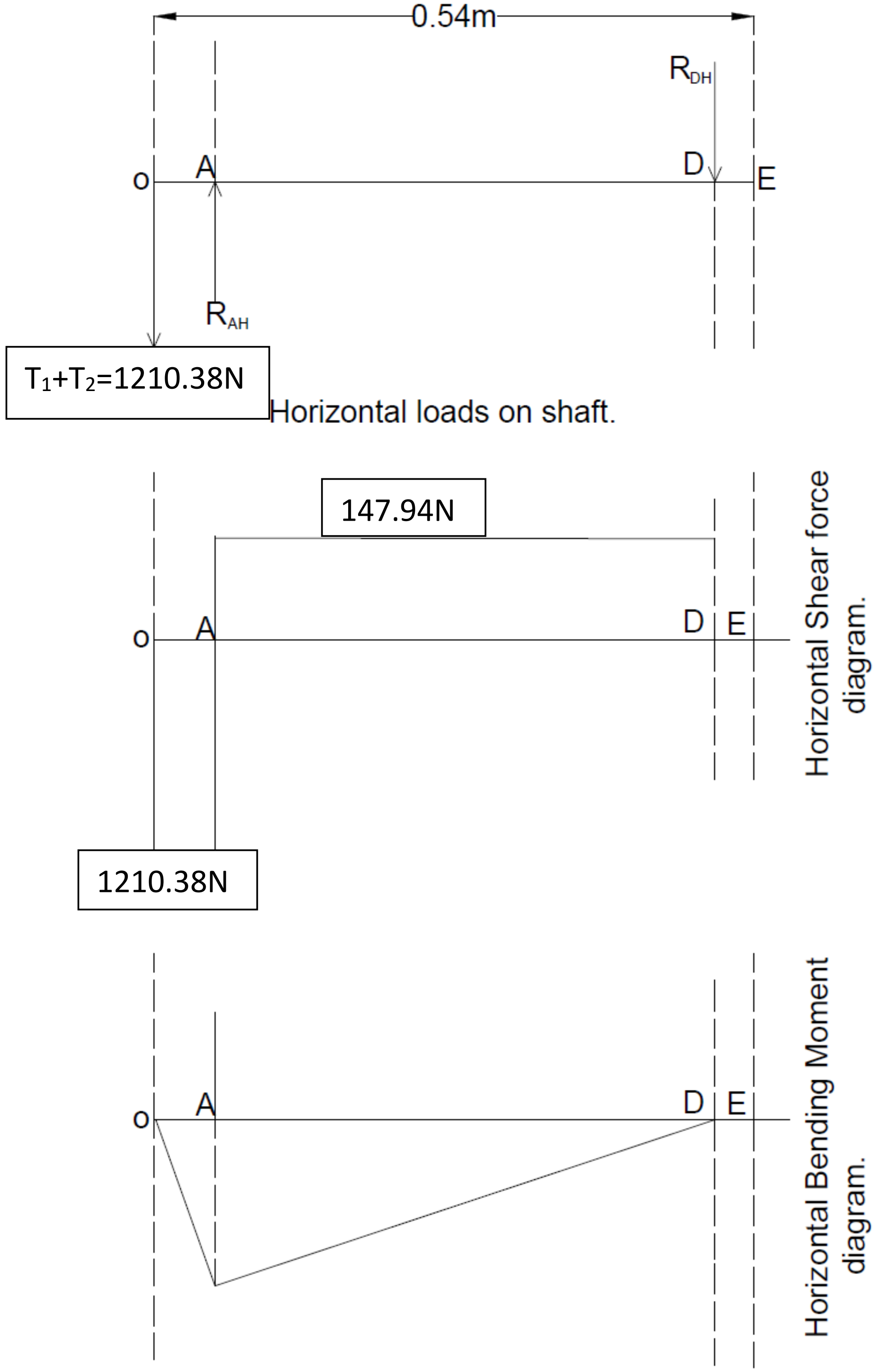


Figure 3.10 Horizontal Shear force and Bending Moment Diagram.

3.8.6 Resultant Bending Moment for Both Vertical and Horizontal Loading

It can be seen from both vertical and horizontal Bending moment diagrams that the resultant bending moment will occur at point A

Resultant Bending Moment, m at A

$$= \sqrt{{B_{AV}}^2 + {B_{AH}}^2}$$

Where $B_{AV} = vertical\ bending\ moment\ at\ point\ A$

$B_{AH} = horizontal\ bending\ moment\ at\ point\ A$

$= \sqrt{0.12^2 + 66.68^2}$

m = 66.68Nm

i.e Maximum Bending moment B.M at A = 66.68Nm

We can now find the minimum shaft diameter required

Equivalent twisting moment T_e is given as

$$\boldsymbol{T_e = \sqrt{(m^2 + {T_d}^2)} = \frac{\pi}{16} \times \tau \times d^3}$$ (Khurmi and Gupta, 2010) 3.23

Where

m= maximum bending moment

T_d = torque on driven shaft

τ = maximum allowable shear stress = 42MPa for shaft with allowance for key way **(**Khurmi and Gupta, 2010)

d = diameter of shaft

Making d the subject in eqn (3.23)

$$d = \left(\frac{16 \times \sqrt{m^2 + {T_d}^2}}{\pi \times \tau} \right)^{\frac{1}{3}}$$

Inserting values

$$d = \left(\frac{16 \times \sqrt{(66.68 \times 10^3)^2 + (20.60 \times 10^3)^2}}{\pi \times 42} \right)^{\frac{1}{3}}$$

$$d = 20.38mm$$

From Table 3.2 below, the closest size to this value is 25mm. Thus, a 25mm diameter shaft is chosen.

Table 3.2 Standard Sizes of Transmission Shafts

Type	**Size**
1	25mm to 60mm with 5mm steps

2	60mm to110mm with 10mm steps
3	110mm to140mm with 15mm steps
4	140mm to 500mm with 20mm steps

Source: Khurmi and Gupta, 2010

3.9 Operating Principle of the machine

The pelletizing machine comprises of a barrelled screw auger responsible for forcing the cassava mash through an end plate perforated symmetrically in four holes, for the extrusion of pellets.The machine makes possible the processing of cassava into pelletized form for the consumption of farm animals. An auger and a die are the fundamental components of the pelletizer. The pressure produced by the auger in pushing the cassava mash was absorbed by the die and its opening from which the pellets are forced out. The auger was made of mild steel shaft wound with steel rod by welding to form the screw auger conveyor. The entire set up was then mounted on bearings for ease of rotation in the stationary cylindrical barrel. Cassava mash was feed into hopper which leads to the auger; the inlet of the barrel. The mash was then conveyed with a force to die plate from where the extrusion takes place. Pressure built by the rotation of the auger forces the mash through the opening in the die; forming pellets.

3.10 Construction and Assembling

For simplicity, the construction process has been divided into two main sections.

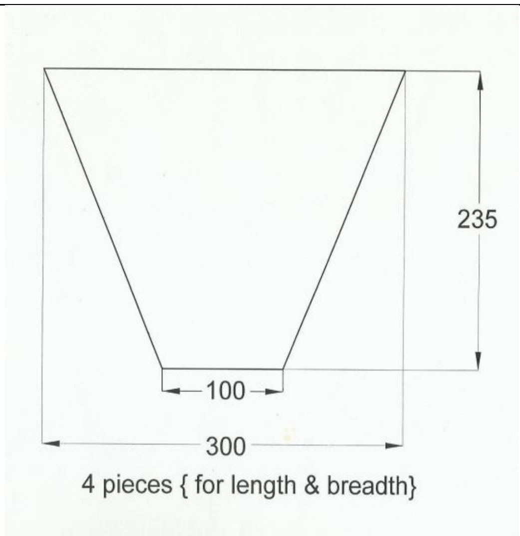
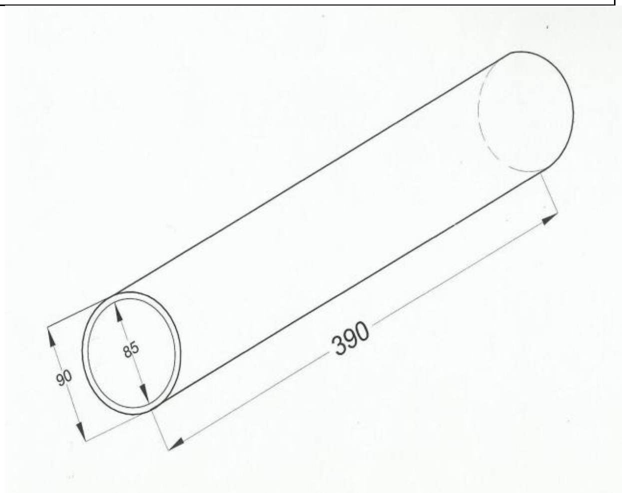
1.Cutting process

2.Joining process

Table 4.1 shows the detailed cutting process.

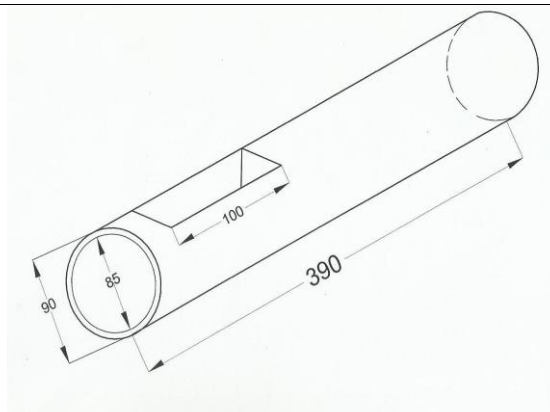
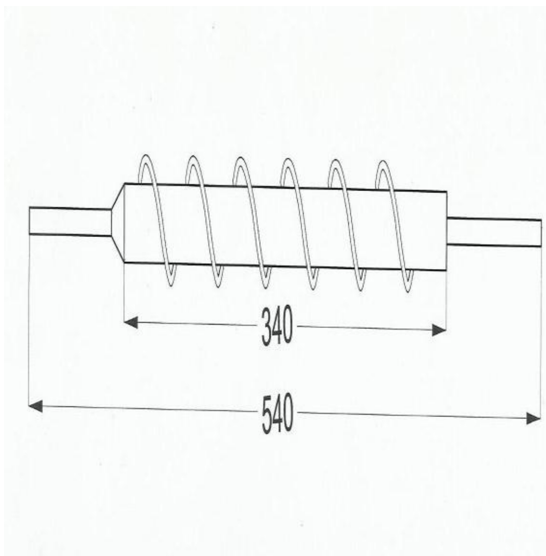
Table 3.3 Cutting Process Description

S/N	Description	Drawing (all dimenions in mm)

1	The frustum-shaped sides of the hopper were cut out to the required dimension from a stainless steel sheet 1mm thick (1m×1m.)	
2	A hollow stainless steel pipe (barrel) of outside diameter 90mm, inside diameter 80mm and length 390mm was selected bearing in mind the dimensions of the auger screw conveyor it is to house	

Cutting Process Description cont'd.

Cutting Process Description cont'd.

3	On one edge of the stainless steel pipe, the top was cut open with an hack saw to serve as the entrance into the barrel. The part cut off is exactly the square shaped dimension of the base area (100 ×100mm) of the hopper.	
4	The auger which is made of bright mild steel shaft on which was wound stainless steel 20mm rod to form the screw auger conveyor. Before this operation the pitch of the screw auger was marked on the shaft.	

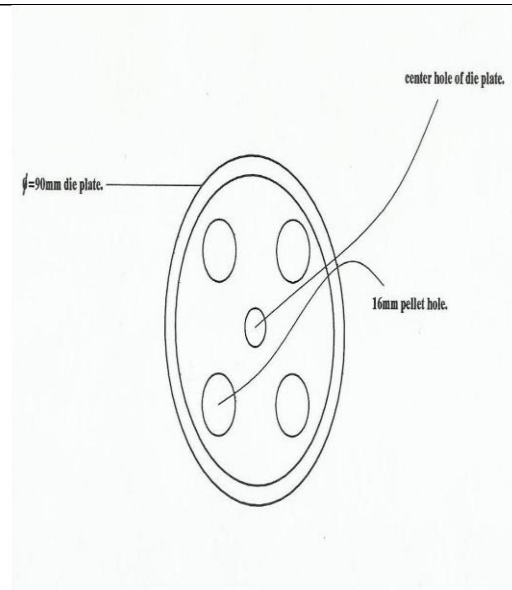
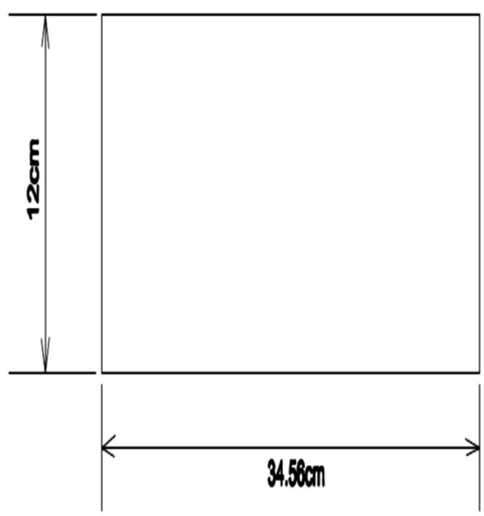
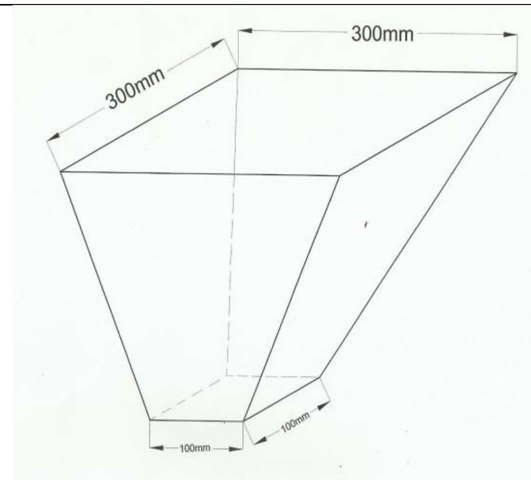
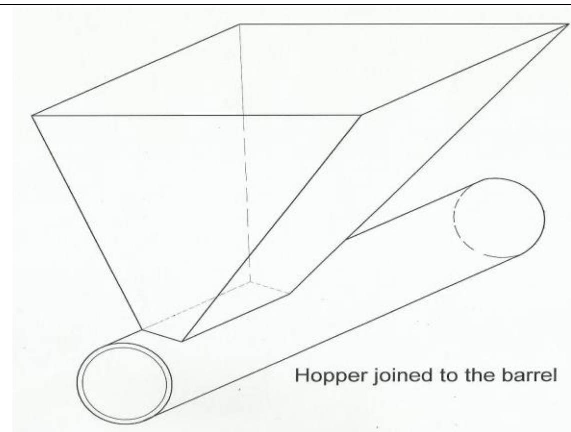
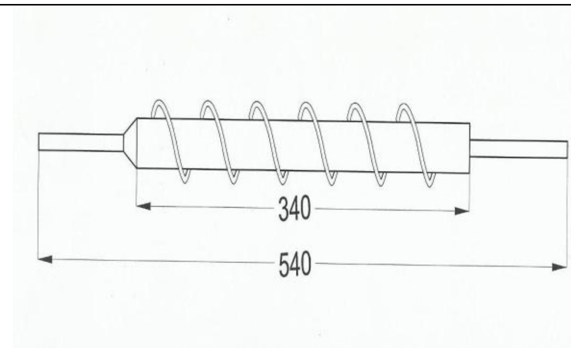
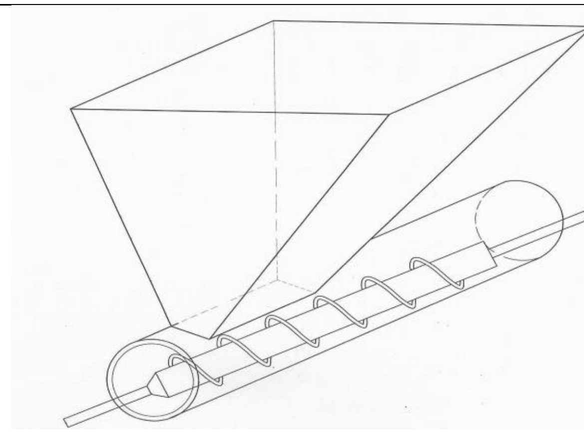
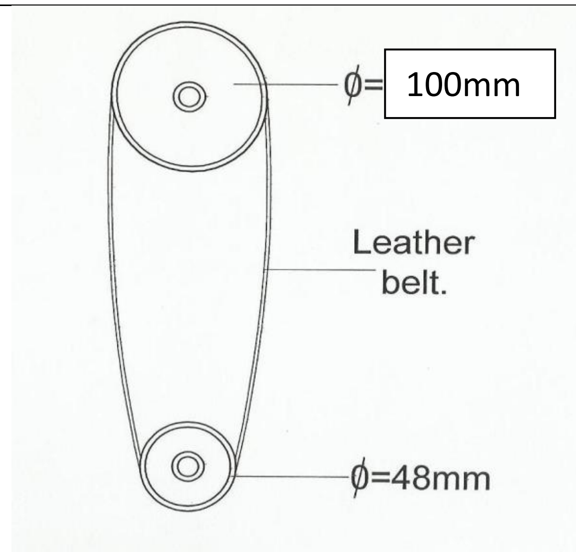
5	The Die is a circular mild steel plate 4mm thick and 90mm diameter turned out of a square plate on a lathe machine by tack welding a shaft at the center of the plate to facilitate the turning operation. The positioning of the 4 holes of the die were drawn symmetrically on a cardboard paper, later cut off and placed on the turned plate then centre punched and drilled to the required diameter.	
5	The frame stand on which the entire set up is placed is a rectangular stand made of angle iron with a steel metal sheet surface whose area is big enough to accommodate the entire set up .	

Table 3.4: Joining Process/ Assembling

1	The frustum shaped hopper is formed by joining the cut metal sheets by electric welding	
2	The above formed hopper was then welded to the open cavity of the steel pipe (barrel)	
3	The auger screw conveyor was formed by wounding round the shaft a 20mm rod on the marked off points indicated as the pitch of the screw. Arc welding process was used with a honcon electrode. After which the welded portion was grinded with the electric hand grinding machine.	

4.	The already formed auger screw conveyor was then fixed into the barrel supported by two bearings one each on the edge of the shaft to ensure easy rotation of the shaft in the barrel with an allowance of 1mm	
5	The flat belt pulley consists of an electric motor spindle attached to a small pulley 48mm diameter and big pulley 100mm diameter both connected with a leather belt 12.5mm thick and length 575mm, this was powered by 2 h.p. electric motor.	

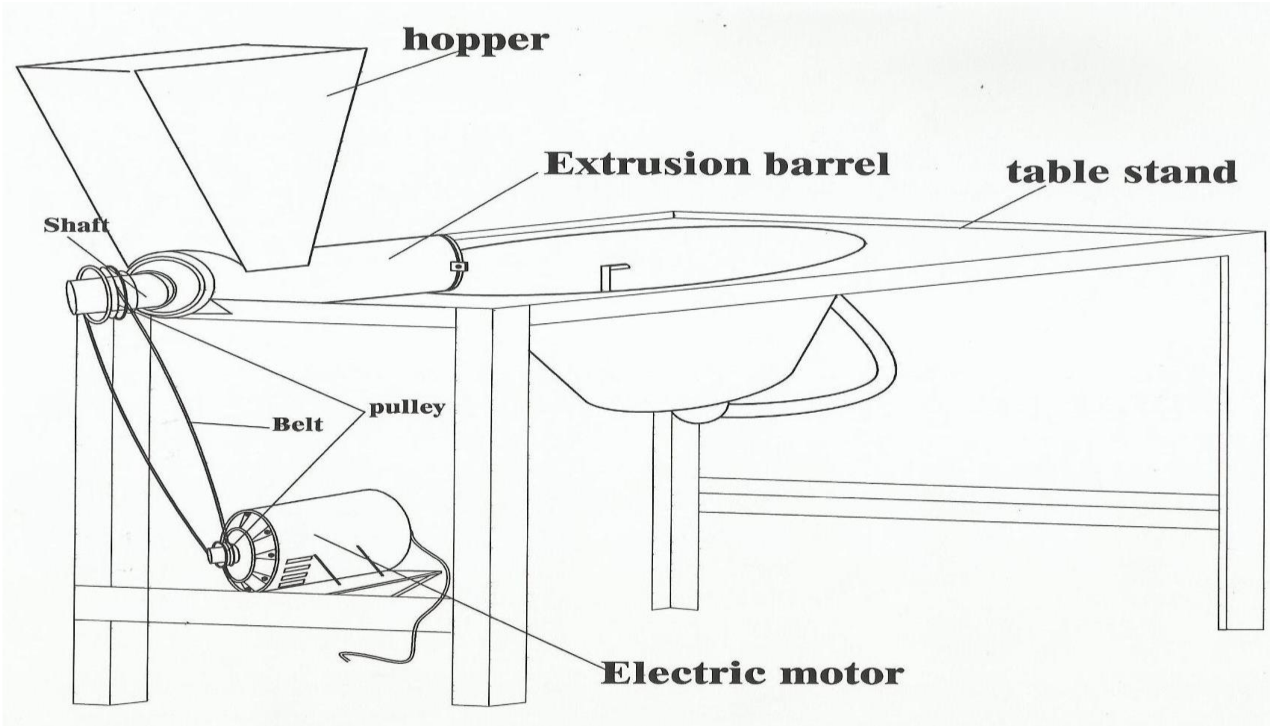


Figure 3.11 Schematic Drawing of the Assembled Pelletizing Machine

3.11 Material Selection

Considering the fact that cassava produce (pellet) is consumable, great care has been taken to properly select the material that will have contact with the cassava mash during and after it extrusion. More-so, cassava in its raw state contains hydrogen cyanide (HCN) which is acidic in nature and could corrode the parts of the machine it make contact with therefore, the material selection is of top priority so that it does not fail. Choosing the material used for the construction of the cassava pelletizing machine, therefore has been based on the following criteria:

1. Availability of the material
2. Suitability of the material for the working condition in service. This further depends on the physical, chemical and mechanical properties of the materials.

3. The cost of the material
4. Durability of the material

The machine is divided into two main parts:

1. The core parts of the machine: these are the parts that have direct contact with the cassava. These parts are critical and can affect the cassava pellets if not carefully selected. Table 4.6 shows the list of these parts and the material used

   They include:

   Hopper

   Screw conveyor shaft

   Barrel

   Die plate

   Table surface (that receives the pellets)

2. Supporting parts**:** These parts are used to run and give support to the machine but do not have direct contact with the cassava mash. Although they are meant to support and drive the machine, they still require very important design calculations and considerations before being chosen.

3. These parts include:

   Electric motor

   Pulley

   Belt

   Machine guide

Mounting frame

Table 3.5 Lists of Parts and Material Used

S/N	PART	MATERIAL USED	REASON(S)
1	Hopper	Stainless steel (austenitic stainless steels, E308L)	Resists oxidation and corrosion attack from most corrosive media. It is widely recommended for domestic use.
2	Barrel	Stainless steel (austenitic stainless steels, E308L)	Same as above
3	Auger screw conveyor shaft	Bright mild steel	High strength and rigidity. Resists oxidation and corrosion attack from most corrosive media.
4	Die plate	Mild steel	High strength and rigidity. Resists oxidation and corrosion attack from most corrosive media.
5	Mounting frame	Mild steel angle iron	High rigidity and high load bearing capacity

CHAPTER FOUR

4.0 TEST, RESULTS AND DISCUSSIONS

4.1. Experiment to Compare the Moisture Content of the Cassava Mash and the Pelletized Cassava.

Materials/Apparatus Used

Materials/Apparatus used include:

1. Weighing pan
2. Stove
3. Stainless Pot
4. 10 kg samples of dried cassava flour (determined by weighing).

4.1.1 Method of Determining the Moisture Content of the Cassava Mash (by the Oven Method).

Cassava tubers were obtained from a local farm in Suleja Niger state. The tubers were washed, peeled with knife, grated and dried into cassava flour. A Sample of dried cassava flour of mass 550kg was conditioned by adding water weighing 100g. This was mixed thoroughly for 10minutes. The weight of the stainless steel pot used in heating up the wet mash was weighed and noted. The wet mash and bowl was weighed before heating. The set up was heated for some hours and weighed intermittently. Heating stopped when there was no variation in weight. It was then allowed to cool and the weight noted. This experiment was repeated two more times and the average weight of water and wet mash was computed. The moisture content of the wet cassava mash was then determined by the oven method ASAE (1990). The final weight was taken when the products had been cooled and the moisture content determined as a ratio of weight of water to weight of wet mash expressed in percentage.

$$moisture\ content = \frac{weight\ of\ water}{weight\ of\ dry\ mash} \times 100\% \quad (d.b)$$

4.1.2 Method of Determining the Moisture Content of the Pellets (by the Oven Method)

The same sample of dried cassava flour of mass 550g was conditioned by adding water 100g mass. This was mixed thoroughly for about 10minutes. The mixture was then fed into the already washed and dried pelletizing machine. After the mash had been entirely extruded into pellet, the pellet was then placed into the stainless steel pot of known mass and weighed. It was then heated and the set up weighed intermittently. Heating stopped where there was no variation in weight and allowed to cool noting its weight.

4.1.3 Calculations

Weight of stainless pot = W_1= 10g

Weight of mash and pot before heating = W_2 = 643g

Weight of mash and pot after heating = W_3 = 368g

Weight of mash = $W_2 – W_1$ = 633g

Weight of water = $W_2 – W_3$ = 275g

Weight of pellets before heating = W_4 = 447g

Weight of pellets after heating = W_5 = 384g

Table 4.1: Experimental values recorded for cassava mash

Operation	**Experiment 1**	**Experiment 2**	**Experiment 3**	**Average value**
Weight of mash and pot before heating(g) **W_2**	638	642	648	643
Weight of mash and pot after heating(g) **W_3**	367	371	364	367

Therefore applying the formula:

$$moisture\ content = \frac{weight\ of\ water}{weight\ of\ dry\ mash} \times 100\% \quad (d.b) \qquad \textbf{4.2}$$

$$moisture\ content = \frac{avg.value\ of\ W_2 - avg.value\ of\ W_3}{avg.value\ of\ W_2} \times 100\% \qquad \textbf{4.3}$$

$$moisture\ content = \frac{643 - 367}{367} \times 100\%$$

$$moisture\ content = 75.20\%\ (d.b)$$

Table 4.2: Experimental values recorded for pellets

Operation	**Experiment 1**	**Experiment 2**	**Experiment 3**	**Average value**
Weight of	440	446	448	445

Pellet and pot before heating(g) W_4				
Weight of pellet and pot after heating(g) W_5	382	387	378	382

$$moisture\ content = \frac{weight\ of\ water}{weight\ of dry\ pellet} \times 100\%\ \ (d.b)$$

$$moisture\ content = \frac{avg.value\ of\ W_4 - avg.value\ of\ W_5}{avg.value\ of\ W_4} \times 100\%$$

$$moisture\ content = \frac{445 - 382}{382} \times 100\%$$

$$moisture\ content = 16.49\%\ (d.b)$$

4.3 Test on the machine

Table 4.3 Production rate and efficiency of the machine

Weight of cassava mash (input)	Operation	Time1 (min)	Time 2 (min)	Time 3 (min)	Average time (min)	Weight of cassava pellets (output)

550g	Feed the hopper with cassava mash	1.8 3.0 1.2 2.0	447g
	Pelleting the mash by extrusion Process	3.0 2.5 3.5 3.0	
	Total average time taken	7mins.	

Weight of cassava mash (input) = 550g

Weight of cassava pellets (output) = 447g

The efficiency of the machine with the expression

$$\varepsilon = \frac{output}{input} \times 100\%$$

$$\varepsilon = \frac{447}{550} \times 100\%$$

$$\varepsilon = 81.27\%$$

Production rate of the cassava pelletizing machine

$$production\, rate = \frac{weight\ of\ pellets\ (g)}{total\ processing\ time\ (min)}$$

$$production\, rate = \frac{447g}{7\ (min)}$$

$$production\ rate = 63.86\ g/min$$

4.4 Costing

Table 4.4 shows the cost of materials used. The total expenditure was N30, 770.00 (Thirty thousand, seven hundred and seventy naira only)

Table 4.4 Bill of Engineering Measurement and Evaluation (BEME)

QTY	**MATERIAL USED (Description)**	**Quantity**	**Unit Price**	**COST (N)**
1	Stainless steel 1mm thick (1mm x1mm)	½ sheet	4,000.00	4,000.00
2	Stainless steel pipe outside diameter 90mm, inside diameter 85mm and length 390mm	1 unit	2,000.00	2,000.00
3	Stainless steel 20mm rod used to wound the shaft to make the auger	1 unit	1,250	1,250.00

4	Circular die plate 4mm thick and 90mm diameter	1 unit	400	400
5	Bearing	2 unit	500	1000.00
6	Angle iron support (frame)	1 unit ½ length	3,000.00	3,000.00
7	Pulley with 48mm diameter driving and 100mm diameter driven pulley.	2 unit	300	600.00
8	Belt with 2.5 coefficient of friction and lenght 575mm	1 unit	300	300.00
9	Electric Motor (1440rpm, 2hp)	1 unit	15,000.00	15,000.00
10	Bolts and nuts 5mm and 10mm	12 units	10.00	220.00
11	Miscellaneous	3,000	3,000	3,000
		GRAND TOTAL		**₦30,770.00**

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The designed and fabricated cassava pelletizing machine on testing recorded an efficiency and production rate of 81.27% and 63.86g/min respectively operating at a speed 1440rpm through an extrusion process with a pellet hole (die hole) of diameter 16mm. This is a good performance rate. It also recorded a moisture content of 16.49% (d. b) for the pellet

(i.e. the extruded material) as compared to a moisture content of 75.20% (d. b) for the cassava mash before extrusion under the same conditions. This implies that the durability of a cassava pellet is far higher since it has very reduced moisture content than that of a cassava mash because moisture content is one of the factors on which the durability of the mash depends upon.

5.2 Recommandations

Haven tested and considered the performance of the machine, it is obvious there is room for improvement. I therefore recommend the following:

1. That a force feed mechanism be introduced for more efficient operation as its absence could make the mash become cake like especially when working on a very large quantity.
2. That the noise level be reduced by reducing the frequency of vibration.
3. Relevant research institute in the country should take up project such as this to modify and commercialize them in order to save our ever increasing perishing farm produce.

5.3 Contributions to knowledge

This research work has contributed to knowledge in the following aspects:

(i) Development of a cassava pelletizing machine from locally available materials.

(ii) Production of cassava pellets for preservation for a longer period before usage and easy packaging.

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