DESIGN AND CONSTRUCTION OF CASSAVA WASHING MACHINE

By

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MINNA

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BEING A PROJECT REPORT SUBMITTED IN PARIAL FULFILMENT OF REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING (B.ENG) DEGREE IN AGRICULTURAL ENGINEERING IN SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE

JANUARY,2001

CERTIFICATION

This is to certify that this project work was carried out by Akande F.B. in the department of Agricultural Engineering, Federal University of Technology, Minna

.... 22.01.2001 ....

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(Project Supervisor)

.... 16/1/2001 ....

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(Head of Department)

DEDICATION

This work is humbly dedicated to Almighty God who has been with me throughout the degree programme years and to my Parents Mr. and mrs. John B.A. Eesu

ACKNOWLEDGEMENT

I sincerely express my gratitude to the Lord Jesus Christ for the grace granted unto me in the cause of my degree programme and to my parents Mr. and Mrs. John B. Akande Eesu for their moral and financial support throughout my study.

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My appreciation will be incomplete if my gratitude is not extended to these people, Mr. Sunday Olaleye, Mr. Yakub, Muritala Yusuf and finally I appreciate the effort of my friends and classmates in the persons of Oluwaseyi, Munir, Sammex, Gbolabo, Chinedu, Lanre, Gbenga, Edemu, Nester, Babatunde and also to those who their names could not be mentioned for their support towards the success of this project.

ABSTRACT

The processing of cassava tubers which is an important staple food for about 800million people and raw material for most industries has been mechanized that is use of machine has been incorporated in each unit operation of the cassava tuber processes. But it was noticed that of all the unit operations involved in processing of cassava tubers, the design and construction of machine for washing unit operation of cassava tuber has not been put into consideration and this unit operation is important because it gives the cassava tubers a good quality end product. So, in this project, the design, construction and performance test of cassava washing machine was carried out in which the total cost of the machine amounted to N7346.00k. The performance of the washer shows that the machine has 99% washing efficiency with average output capacity of 160kg/hr and the machine can wash 3.5kg of cassava tuber in 1 min unlike the local method of washing cassava tuber that will only wash the same quantity in 2 mins. It is therefore recommended that the machine can be used for washing operation of cassava tuber and can be constructed to one's desired capacity.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 CASSAVA VARIETIES

Cassava "manihot esculenta Crantz" is a dicotyledonous perennial plant belonging to the botanical family, euphorbiaceae. It is a starchy root crop that is grown almost entirely in the hotter low level tropics. The crop is also known under a variety of names according to the region in which it is cultivated, such as manioc, tapioca and mendioca in English speaking, French speaking and Spanish speaking countries respectively.

The total amount of cyanogenic glycosides in cassava roots are often used to group cassava cultivators into two major groups:

1. The bitter varieties in which the cyanogenic glycosides are distributed throughout the tuber and are at "high" level.
2. The sweet varieties in which the cyanogenic glycosides are confined mainly in the peels and are at a "low" level.

1.2 CASSAVA PRODUCTION

Cassava is grown mainly in the equatorial belt bounded by latitudes 30° N and S and is restricted to zones less than 2000m above sea level, receiving an annual rainfall of 200 – 2000 mm Asiedu, (1984). Within this region, according to Mayhew and Penny, (1988), cassava grows best in warm areas with an annual rainfall of 750 – 1300 mm.

Cassava is an important staple food for about 800 million people. The annual per capital consumption of cassava is greatest in Africa where consumption exceeds 3000kg/ person/

year and in Latin America, where the average per capital consumption is about 35 kg/year in which the global cassava production and consumption projected for 1985 and 1990 are 78809 and 124987 and 88715 and 135513 (figures in 100 tonnes) respectively.

1.3 CASSAVA UTILIZATION

For utilization of cassava, the fresh peeled cassava tuber is eaten as a vegetable after boiling or roasting. In some West Africa countries, the boiled cassava are pounded with boiled plantain called "Fufu" which is consumed with vegetable and meat soup. Cassava tuber can also be sliced, dried and ground into flour. Actually, the main form in which cassava is eaten in West Africa is a fried or roasted granular product, prepared from peeled, washed, grated and fermented cassava roots known as "gari". "Chickwangue" is another Africa food product, prepared by soaking the cassava tubers in water for 2-7 days until it softens, after which the roots are peeled and mashed. The fibres are removed and the resulting paste of pulp is wrapped in palm or banana leaves and then steamed for consumption. Other food products made from cassava include beer, biscuits and cakes.

Pallets and chips processed from cassava tubers are sources of energy in animal feeds. The chips are produced from fresh cassava roots, washed, peeled and cut into slices of 3-6 cm long. The slices are then dried on large concrete surface in the open air.

Also cassava is an important raw material for the non-food industries. This is because, the low amylose and high amylopectin content of cassava give it the necessary viscosity for high quality adhesives which are used in the paper and textile industries. Cassava starch is also used for the production of dextrins, which are utilized in glues. Another industrial product made from cassava is ethyl – alcohol (ethanol).

1.4 CASSAVA PROCESSING

After harvesting, cassava roots are susceptible to spoilage and without any preservation techniques, the roots can only be stored for about 48 hours before they begin to deteriorate Asiedu, (1984). Therefore, the roots must be processed as soon as possible after harvest to arrest any subsequent deterioration. The factors that can also favour the processing of cassava is that, the processed products are easier to store than raw cassava, that is, less storage space is needed with a long period of storage of the processed cassava products without less of it's nutritional value compared to freshly stored cassava tuber. Processing is therefore, undertaken primarily to detoxify the cassava product to improve its palatability and to convert it into a storable form.

Garri is considered to be the most popular form in which cassava is consumed in West Africa Asiedu, (1984). Cassava is processed into gari the following ways the harvested roots are peeled, washed and then grated. The resulting pulp is put into a bag and subjected to pressure for extraction of liquid from it. After pressing, the bag is left for 2-4 days during the pulp ferments. Most of the liquid from the cassava pulp is expressed from the bag during this period. The fermented pulp is then removed from the bag, sieved and fried in wide, shallow metal pans, until it is dry.

Also cassava flour known as "lafun" which is consumed in West Africa is processed from peeled, washed, sliced, soaked, dried and ground cassava tuber. Furthermore, the cassava starch used in paper and textile industries is produced from the peeled and washed tuber before further processing.

Figure 1.0 is a comprehensive flowchart for the production of various cassava products from cassava tubers.

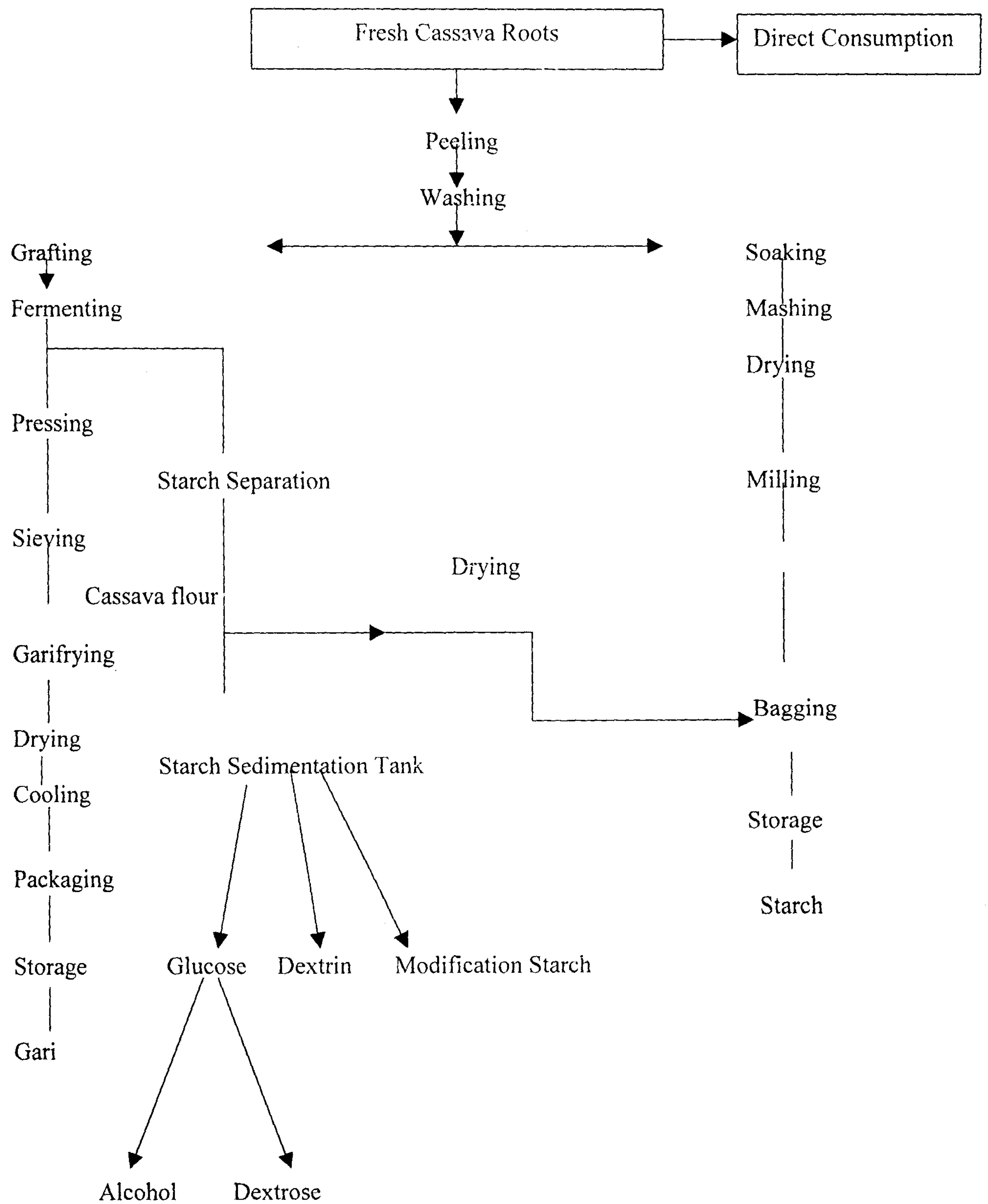


Fig. 1.0 A Comprehensive Flow-Chart for Cassava Tuber Processing.

1.5 PROBLEM DEFINITION

Before processing of fresh cassava tubers after peeling, washing of the tubers must be carried out as it has an important effect on the quality of any end product of the processed cassava tuber. This means that to get a high quality of gari, lafun, starch etc. the peeled cassava tubers have to be washed to remove contaminants from the surfaces of the peeled tubers, which occur during the peeling operation.

Washing operation is also known to be cumbersome and time consuming. Therefore, the need for a washing machine, which will help in washing of cassava tubers after peeling prior to, further processing of the tubers.

1.6 PROJECT OBJECTIVES

One major technology required in processing of cassava tubers, which has not been fully mechanized, is cassava washing machine. Traditionally, washing of cassava tubers is carried out by putting the peeled cassava tubers into a basin containing water and washing with bare hands. This method is tedious and time consuming, hence there is a need for a cassava washing machine so as to have complete processing equipment for cassava tubers processing.

Consequently, the objectives of this project are to: -

1. To design and construct a cassava washing machine.
2. To carry out a performance test of the cassava washing machines.

CHAPTER TWO

LITERATURE REVIEW

2.1 THE NEED FOR CLEANING OF AGRICULTURAL PRODUCTS

The cleaning of any agricultural produce after harvest is the first step that should be taken prior to further processing.

A variety of equipment is available for cleaning of seeds ranging from simple to complex and highly sophisticated equipment. All agricultural product cleaning equipment work on the basis of some physical properties of the product such as size (length, width, thickness, diameter etc.), shape, weight, surface texture, colour, affinity for liquids, electric conductivity etc.

Therefore cleaning of crop can be accomplished by using any simple equipment or a combination of machines taking into consideration one or a combination of the properties mentioned above.

Satisfactory removal of foreign matter requires a specific sequence for removing a certain portion of the contaminating material. However, according to Kachru (1989), the choice of machine or sequence for removing contaminating material will depend upon: -

a. Kind of seed being cleaned,

b. Nature of foreign matter,

c. Quantity of each in the total material

d. Desired quality standards

2.2 CLEANING PRINCIPLES & PROCEDURES

Cleaning of crops can be classified into: -

1. Wet cleaning
2. Dry cleaning

Dry Cleaning: - is used for crops that are smaller, have greater mechanical strength and posses lower moisture content for example grains, nuts.

Dry cleaning usually involves smaller, cheaper equipment than wet cleaning. However, additional capital expenditure may be necessary to prevent creation of dust removed during dry cleaning.

The main types of equipment used for dry cleaning of agricultural products are: -

1. Air Clarifier
2. Magnetic Separator
3. Separator based on screening of food
4. Physical Separator.

Wet Cleaning: - This is more effective than dry cleaning for the removal of soil from crops and it causes less damage to food than the dry cleaning.

The effectiveness of wet cleaning is determined by the availability of clean water or the cleaning liquid which help in removal of foreign matter (dirts, dust, lighter particles etc.) from the crops.

The different principles used in the washing operation according to Henderson and Perry (1980), are as follows: -

1. Soaking in still or moving water or other fluid: - Soaking in still or moving water or other fluids is effective only if dirt, to other surfaces undesirable is present in small quantities and is loosely attached to the product. This method is frequently used in connection with other methods such as a pre-.cleaning.

2. Water Sprayers: - Water sprayers that vary from low – pressure wide angle to high – pressure directed jets are very effective in cleaning since they physically remove firmly attached pieces of dirts from agricultural products and agitate the mass of product, particularly if it is carried in a water bath. Sprayers are suitable for most products, but the intensity and type of spray distribution must be carefully selected. It is evident that high – pressure concentrated spray for cleaning potatoes would be destructive to celery or lettuce.

   Flood washing is done by a large quantity of water moving at a moderate to high speed over the product.

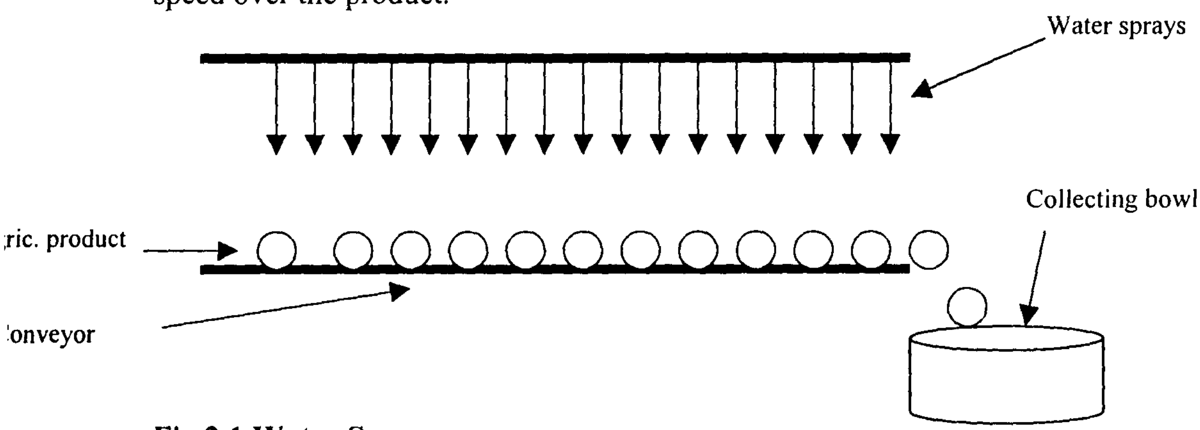


Fig 2.1 Water Sprayer

3. Rotary Drum Cleaner: - This washer is the most commonly used commercial washing device because of simplicity, high capacity, thorough cleaning and minimum damage to the product. It may be used in a bath of water or with spray nozzles or both. A rotary type washer is shown in Fig 2.2 The performance as based upon dirt removal is dependent upon the rotary speed, the roughness or amount of corrugation on the product is retained in the washer. Auxilliary aid such as spray nozzles may be used to facilitate the job. The washing time is controlled by the pitch of the drum.

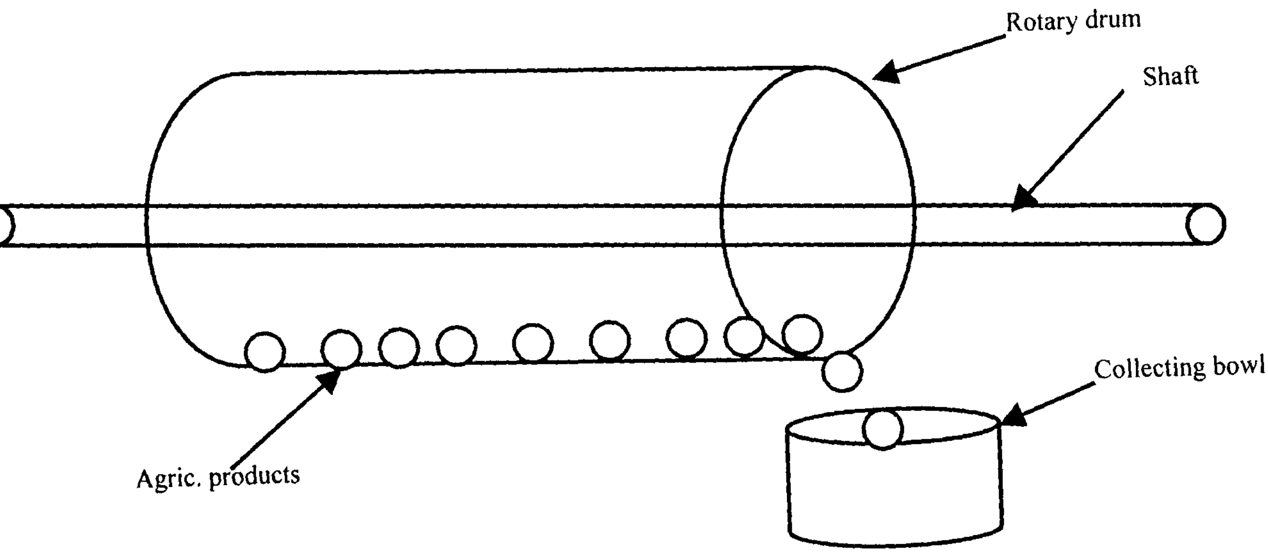


Fig 2.2 Rotary Drum Cleaner

4. Brush Washer: - Rotating brushes are frequently used and are highly effective in cleaning agricultural products. They are particularly effective for removing soils and for removing spray residues. Washing time is controlled by the relatives motion of the brushes, which moves the products through a definite path and to some extent by the flow of water, if the brushes are operating in a water bath. The

brushes are made of fibre, rubber, sponge or other material and may have to be replaced frequently. This must be considered in evaluating this type of washer.

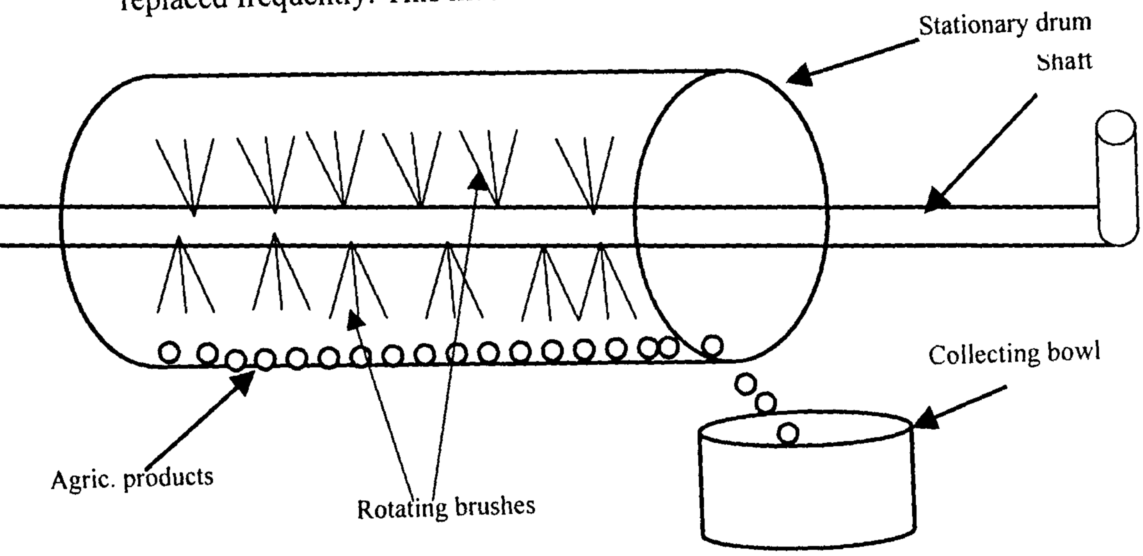


Fig 2.3 A Rotating Brush Washer

5. Shuffle or Shaker Washer: - These washers employ a vigorous re Shaft motion to carry out the washing of the products. Since the motion is reciprocating, the washer must be ruggedly constructed and carefully maintained to minimize interruptions resulting from mechanical failure. Although this type of washer is more complicated mechanically and more expensive than some of Collecting bowl it is recommended for the more difficult cleaning jobs. Although effective because of its vigorous action, it is obviously unsuited for products that can easily be damaged.

A sorting screen is frequently included in the unit so that dirt, pieces of leaves, stems and product fragments are washed away from the material However the best washing procedure usually utilizes two or more of the washing devices described above.

2.3 EXISTING WASHING MACHINES

In the course of research on this project the following types of washing equipment used for agricultural products were identified.

1. The melon washer:- The melon washer found in existence was developed by the National Centre for Agricultural Mechanization (NCAM), Ilorin. The NCAM melon washer which is manually operated consist of a water trough, a stationery perforated drum which is semi-immersed inside a water trough and a shaft with brushes and spikes attached to it, which passes through the stationery perforated drum where the main melon washing process takes place (washing chamber) through the rotation of the shaft. The decayed melon pod is fed in to washing chamber through an hopper situated on top of the stationery perforated drum. A frame and stand made up of angle iron was used to hold the entire system in a static position for easy operation.

The working principle of NCAM melon washer is the brush washing principle. That is a rotating assembly of brushes with spikes are passed through a stationery perforated drum wholly immensed in a water trough. The melon is fed in to the stationery perforated drum through an hopper with water already inside the water trough. The water in the trough passes through the perforated holes in the stationery drum. The spikes help in loosening the decayed melon pod which the brushes are used to wash the melon by rubbing the melon pod against the wall of the perforated drum. This rubbing action is possible because the clearance of the brushes and spikes from the wall of the cylinder are made so small as to help to increase the efficiency of the washer. The washed melon seeds are discharged from the washer by raising one of the ends of the perforated drum up for the washed melon seed to be collected at the other open end of the drum, while the water is discharged through the water at the bottom of the water trough.

2. The potato tuber washer:- The potato washing equipment being discussed in this work was developed by the International Potato Centre (CIP) in Peru. According to intermediate technology publications (source) and United Nations Development Fund for Women (UNIFEM), 1993, the CIP manually operated potato washer is constructed from a 250 liters (55 gallons) of oil drum, cut length wise and paddle wells equipped with brushes are fixed on to an axle with wooden dowels. A handle is fixed to the axle in order to rotate the paddles and so agitate the potatoes.

The washer has a capacity of 25 kg of potatoes per batch and requires 150 liters of water per batch. After a few minutes the drum is turned on it's side to empty the potatoes and dirty water discharged.

2.4 PREVIOUS METHOD OF WASHING CASSAVA

By the research made by post harvest technology research group in the faculty of technology, Obafemi Awolowo university Ile-Ife in April 1998, it was noticed that during the processing of cassava tubers sufficient attention was not paid to the importance of washing in Garri processing. Many of the places visited wash the peeled tubers using little quantity of water which easily get muddy within a short time and is still used even in it's muddy state. This is seen to be unhygienic.

At other places the local cassava tuber washer they use consist of a washing trough made of raised side on cemented floor, but the top layer of the trough needed to be plastered annually to restore the damage made by the corrosive action of hydrocyanic acid from cassava. While some other local centers use plastic bowls in washing the cassava tubers. For now the practice of washing peeled tubers in plastic bowl is encouraged because such bowls are cheap and can be easily lifted.

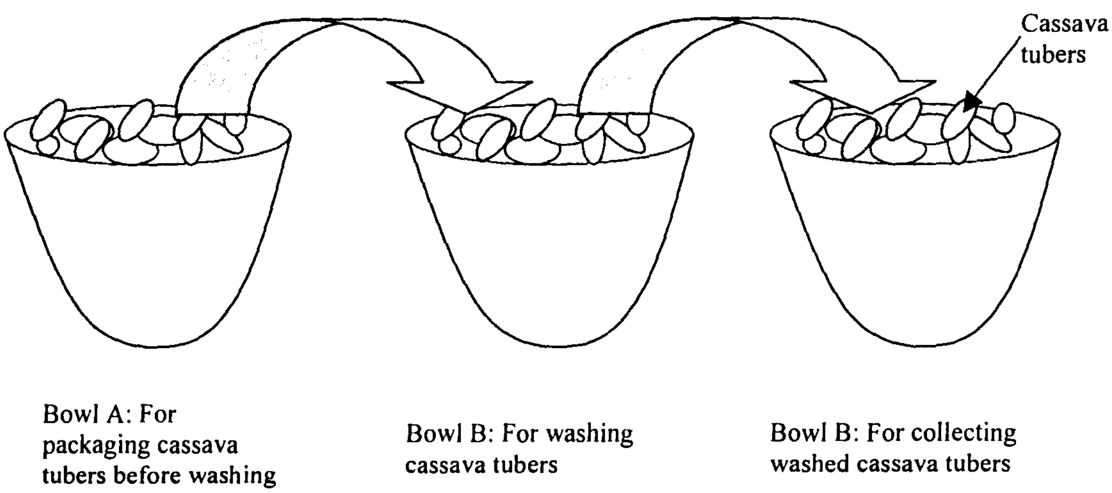


Fig 2.4 Local Method Of Washing Cassava Tubers

Actually different types of machines have been designed and constructed by Professor E.U. Odigboh for production and processing of cassava tubers starting from cassava planter up to the gari fryer, but was observed that the machine for washing unit operation of cassava tuber has not been put into consideration which is very important because this unit operation helps in having a good quality end product of any cassava tuber

Therefore there is a need for a cassava washing machine, so that the entire unit operations for processing cassava tuber may be mechanized.

Hence in the design of cassava washing machine the principles of wet cleaning using the rotating drum washer and the rotating brushes which earlier discussed shall be considered.

CHAPTER THREE

3.0 THE DESIGN OF A CASSAVA WASHER

3.1 PREAMBLES

The most widely used traditional method of cleaving cassava is hand washing in a bowl or basin of water with sponge while a mechanized method is by washing in a rotary drum or stationary drum with rotating brushes. These methods are referred to as wet cleaning.

The material to be processed is fed into rotary or stationary drum. The rotation or movement of cassava tubers with the rotary drum or the stationary drum along with the rotary drum or the stationary drum containing water on the rotary tuber facilities the loosening of soil particles and unpeeled residues from the tuber surfaces. This results in inefficient cleaving of the cassava tubers.

3.2 THE DESIGN CONSIDERATIONS

The following factors were considered during the design of the design of the cassava washer

(a) The cassava tubers to be washed are already pealed

(b) All cassava tubers have irregular oblong shape with average geometric mean diameter of 7.00cm

(c) The dirts in the harvested cassava tuber are soils from the field and unpealed residues.

(d) The pealed cassava tuber to be washed could be whole or cut tubers depending on what it is to be used for

(e) The cleaning of cassava tuber the help of a rotary brush in a rotary perforated drum immersed inside a water trough is practicable

(f) The perforation of rotary drum allow easy movement of water from the water trough into, for cassava tuber to have contact with the water.

(g) That the reaction of water as a universal solvent on the surfaces of the tuber loosens the soil particles and unpeeled residues from the surfaces of the tuber which depend on the length of time the material is retained in the washer.

(h) That the brushes create a rubbing action on the surfaces of the tubers for easy removal of the dirts.

3.3 DESIGN CALCULATIONS

Assumptions

The following assumptions were made in this design:

The length of the rotary perforated cylinder = 580mm

The length of the perforated cylinder = 50mm

The diameter of the rotary perforated cylinder = 250mm

The length of the water trough = 680mm

The diameter of the water trough = 350mm

The density of cassava = for 100kg of cassava tubers the density = 501kg/m^3 Baderinwa, (2000)

The time of washing = 5mins

The speed of machine = 90rpm

3.3.1 THE CAPACITY OF HE MACHINE

The total volume of the rotary perforated cylinder is given by

$$V_{TR} = \pi r^2 L$$

Where r = radius of the rotary perforated cylinder = 125mm

L = length of the rotary perforated cylinder = 580mm

$$V_{TR} = \pi(125)^2 \ x \ 580$$
$$= 2847068.42 mm^3$$
$$28.5 cm^3$$

Assuming that ½ of the volume of the rotary perforated cylinder would be filled with cassava tubers during the washing, then the capacity of the machine V_c would be

V_c =1/2 x 28.5cm^2 = 14.25cm^2

3.3.2 ENERGY REQUIREMENT

The energy required operating the cassava washer E_R is calculated thus,

E_R = Average human minimum power (kW) x time designed for washing (hr)

Where average human minimum power = 0.08kW (human factor in engineering design)

Time designed for washing = 5 minutes = 0.083hr

$$\therefore E_R = 0.08 \ x \ 0.083 = 6.664 \ x \ 10^{-3} kWh$$
$$= 23099.4 J$$

3.3.4 DESIGN OF CYLINDERS

Water Trough Dimensions

The total volume of the cylinderical trough is

$V_{TW} = \pi r^2 L$

where

$r = radius\ of\ the\ water\ trough = 175mm$

$L = length\ of\ the\ water\ trough = 680mm$

$\therefore V_{TW} = \pi(175)^2\ x\ 680$

$0.0654m^3$

the circumference of the circular section of the water trough is

$C_{WT} = 2\pi r = \pi D$

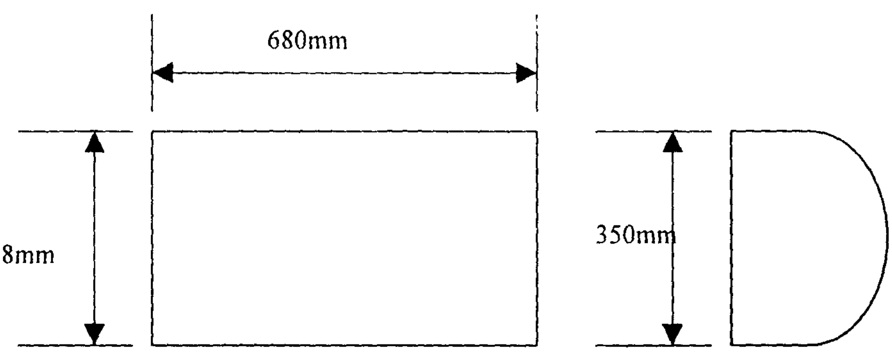
$where\ d = diameter\ oif\ the\ circularsection\ of\ th\ \ wstertrough = 350mm$

$\therefore C_{WT} = \pi\ x\ 1099.56mm$

then, the halve of the circumference of the circular sectionm of the water trough

$= \frac{1099.56}{2} = 549.78mm$

$= 0.550m$



Now, the material volume of the water trough V_{mw} using a galvanized sheet of 16 gauge

V_{mw} = surface area x thickness

= length x breadth x thickness

= length x breadth x thickness

where length = 680mm

breadth = 549.78mm (length of curved section)

thickness = 680 x 549.8 x 1.5

= 560775.6mm^2

=0.000561m^3

$\therefore$ Total material volume for the two halves of the trough = 2 x 5.61 x 10^{-4}m^3

Assuming steel material is used for the cylinder,

$\therefore$ Weight of the water trough W_t is given by $W_t = \rho_s V_{mw} g$

Where ρ_s = density of the steel material; = 7850kg/m^3

V_{mw} = volume of the material = 1.22 x 10^{-3}

G = acceleration due to gravity = 9.81 m/s^2

W_t = 7850 x 1.22 x 10 x 9.81

= 86.40N

Rotary Perforated Cylinder Dimensions

The total volume of the rotary perforated cylinder is

$$V_{TR} = \pi r^2 L$$

where r = radoius of the rotary perforated cylinder = 125mm

$V_{TR} = \pi(125)^2 \ x\ 580$

$= 2847068.342mm^3 = 0.028m^3$

the circuimference of the circular sectioon of the rotary perforated cylinder is

$C_{RP} = 2\pi r = D\pi$

where

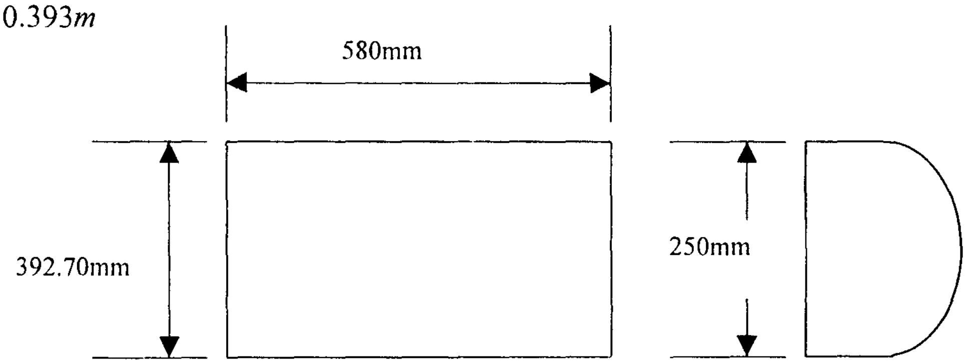
$D = diameter\ of\ thedis\tan ce\ circularsec tion\ of\ theroad\ perforated\ cylinder$

$\therefore C_{RP} = \pi\ x\ 250 = 785.398mm$

then, the halve of the circumference of the circular section of rotary perforated cylinder

$= \frac{785.398}{2} = 0.393m$

diagram



Now, the material volume of the rotary perforated cylinder V_{TR}; using a galzvanized sheet hauge 16

V_{rw} = surfacve area x a thickness

= lenght x breadth x thickness

where

length = 580mm

breadth = 392.70mm (length of curved section)

thickness = 1.5mm (for 16 guage sheet)

$\therefore V_{rw} = 580\ x\ 2.70\ x\ 1.5$

$\therefore V_{rw} = 580 \times 2.70 \times 1.5$

$= 341649mm^3$

$= 0.000342m^3$

$\therefore$ total material volume for the two halves of the rotary cylinder

$= 2 \times 3.42 \times 10^{-4}m^3$

$= 6.84 \times 10^{-4}m^3$

assuming steel material is used for the cylinder

$\therefore$ weight of the rotary perforated cylinder $W_p = \rho_s V_{rw} g$

where

ρ_s = density of steel material = $7850kg/m^3$

$= V_{rw}$ = accelaration due to gravity = $9.81m/s^2$

$\therefore W_p = 7850 \times 6.84 \times 10^{-4} \times 9.81$

= 52.67N (when it is not yet peforated)

3.3.5 SHAFT DESIGN

Load On The Shaft: the load acting on the shaft are the weight of the cassava tubes and the weight of the rotary perforated cylinder

The Weight of The Cassava Tubers

Assumingthe casava tubers occupied ½ of the total volume of the rotary perforated drum, that is ½ of V_{TR}. And the density of 100kg of cassava tubers is $501kg/m^3$ (Baderinwa, 2000)

Now given that $V_{TR} = 0.028m^3$

$\therefore$ the volume of the cassava

$= \frac{1}{2} \times -.028$

$0.014m^3$

since 100kg of cassava gives $501kg/m^3$

thjen the volume of the cassava tuber $V_o = 100kg/501kg \times m^3 = 0.1996m^3$

therefore the mass of the cassava tuber rotary perforated drum

$=(0.014 \times 100) /0.1996 = 7.014kg$

then the weight of the casava tuber $W_{CT} = 7.014 \times 9.81$

$W_{CT} = 68.81N$

Now , the total weight W on the shaft

$W = W_p + W_{CT}$

$=52.67 + 68.81$

$= 121.48N$

The assuming the loads on the shaft are uniformly distributed loads W/unit length

there fore, total ditributed load carried by the shaft = q

$q = W/l$

where

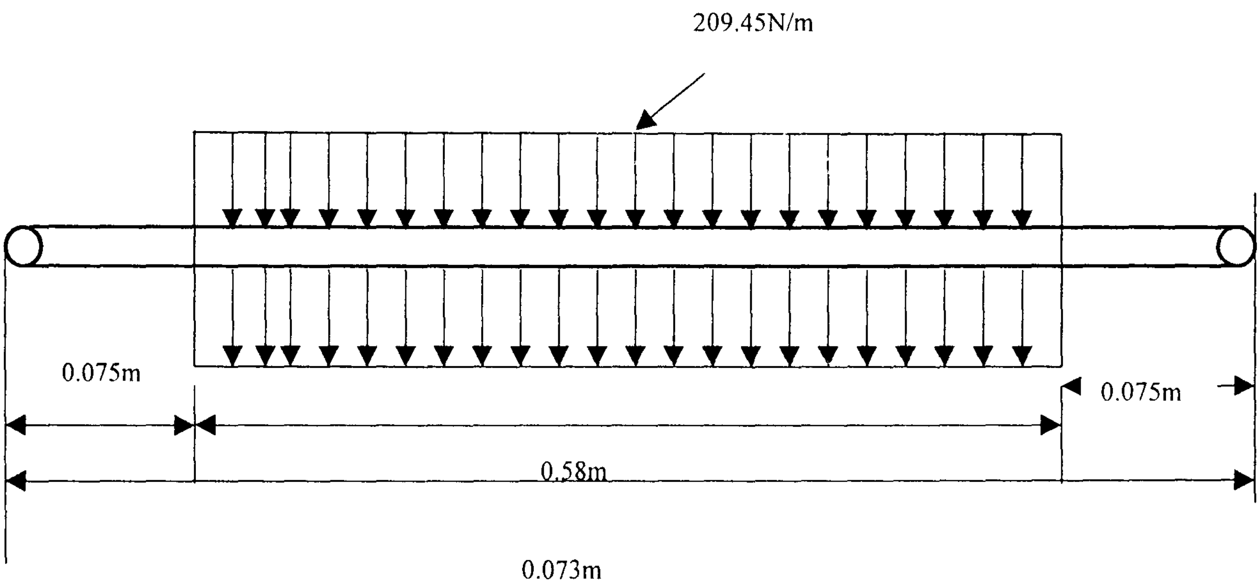
W = summation of the loads

L = the unit length of the loads

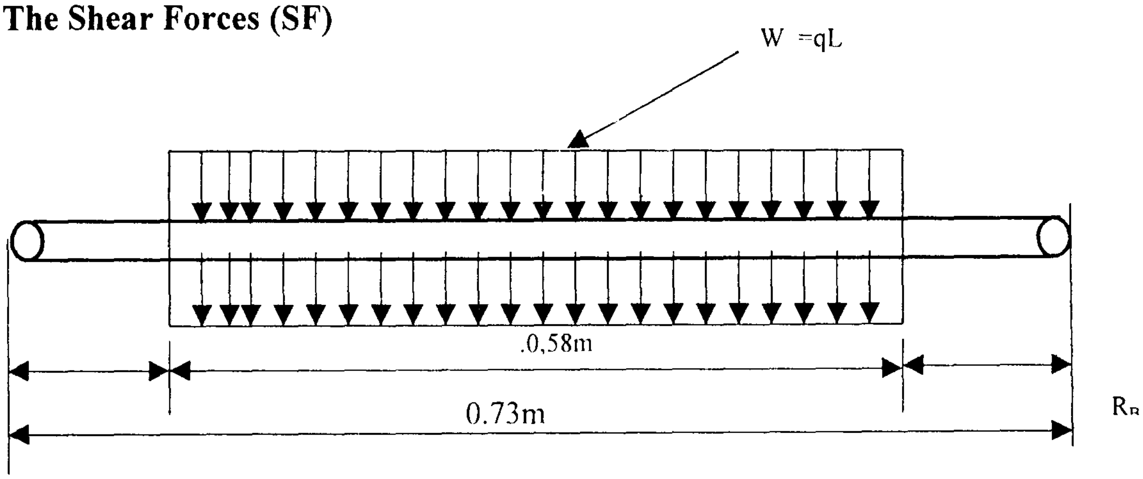
$\therefore$ total distributed load carried by shaft

= 209.45N/m

the free body diagram of force on shaft is shown below



The Shear Forces (SF)



The total weight on the shaft W will be:

W = qL

Where

Q = total distributd load carried along by the shaft = 209.45N/m

L = the unit length of the loads on the shaft = 0.58m

$\therefore W = 209.45 \times 0.58$

$= 121.48N$

the reactions at the two supports can be calculated from:

$W = R_A + R_B$ (equilibrium law which states that upward reaction equal to downward reactions)

i.e. $W - R_A + R_B = 0$

Also $R_A = R_B$ (because the loads on the shaft act at its centre)

So $W = R_A + R_B$

$W = 2R_A$

Or $W = 2R_B$

$\therefore R_A = W/2$

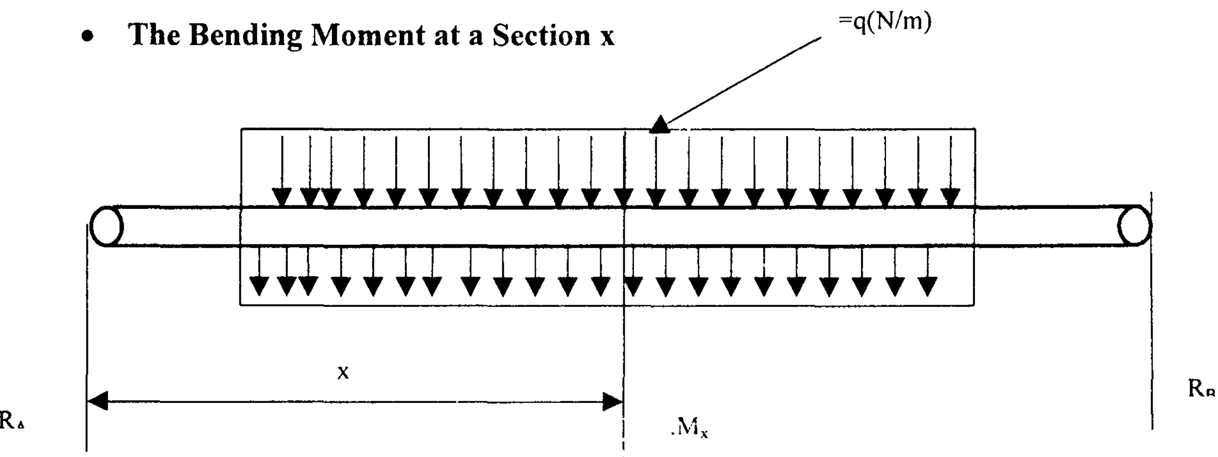
$=121.48/2$

$= 60.74N$

since $R_A = R_B$

$\therefore R_B = 60,74N$

- each vlaues of shear forces (SF) for the wo supports are ±60.74N with zero value at centre.
- **The Bending Moment at a Section x**



So the bending moment at any section z is

$$M_x = R_A x - q(x-0.075)\frac{(x-0.075)}{2}$$

$$R_A x - q\frac{(x-0.075)^2}{2} \quad . \quad x \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

To check differentiating M_x *with respect to x gives*

$$\frac{dM_x}{dx} = R_A - q\frac{(x-0.075)}{2}(2)$$

$$= R_A - q(x-0.075) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$\therefore$ *the second differential is*

$$\frac{d^2 M_x}{dx^2} = -q(\max.\textit{bending moment})$$

Now equating

$$\frac{dM_x}{dx} = 0$$

$$\Rightarrow R_A = q(x-0.075)$$

$$R_A = qx - q(0.075)$$

$$\Rightarrow qx = R_A - q(0.075)$$

$$\therefore x = \frac{R_A + q(0.075)}{q}$$

Substituting the value of R_A *and q*

$$\Rightarrow x = \frac{60.74 + 209.45(0.075)}{209.45}$$

$$= 0.3650m$$

Hence $x = 0.3650m$

The bending moment M_x from equation (1)

$$M_x = R_A x - \frac{q}{2}(x - 0.075)^2$$
$$= 60.74(0.365) - \frac{209.45}{2}(0.365 - 0.075)^2$$
$$= 13.3628$$
$$\therefore M_x = 13.4N$$

Torsional Moment On The Shaft

The torsional moment acting on the shaft can be determined from this equation

$$M_t = \frac{9550\ x\ Kw}{rev/\min} Nm\ (from\ Schaum's\ series, 1982)$$
$$where$$
$$k_w = average\ human\ \min nimum\ power = 0.08k_w$$
$$rev/\min = speed = 90rpm$$
$$\therefore M_t = \frac{9550 x\ 0.08}{90} = 8.5Nm$$

Determination Of The Shaft Diameter

For solid shaft having little or no axial loading, the equatioon below ca be used

$$d^3 = \frac{16}{\pi\rho_s}\sqrt{(k_b M_b)^2 + (k_t M_t)^2}\ \ (Schaum's\ series, 1982)$$

where d = diameter of the shaft (m)

ρ_s = allowable shear stress = 55 x 10^{-6}N/m^2 (which is for shaft without key way; ASME code for commercial steel shafting)

For a rotating shaft with load suddenly applied (minor shock) k_b and k_t are

k_b = combined shock and fatigue factor applied to bending moment = 1.5 to 2.0

$\therefore$ k_b = 2.0 (selected)

k_t = combined shock andf fatigue factor applied to tensional moment = 1.0 to 2.0

$\therefore$ k_t = 1.5 (selected)

M_b = Maximum bending moment = 13.4 Nm

M_t = torsional moment = 8.5Nm

Hence, the shaft diameter d, becomes

$$d = \left[\frac{16}{55 \, x \, 10^6 \, x \, \pi} \sqrt{(2.0 \, x \, 13.4)^2 + (1.5 \, x \, 8.5)^2} \right]^{1/3}$$

$= 0.01401m$

$\therefore$ The diameter of the shaft = 14.0mm

However, for the purpose of safety, the diameter of the shaft chosen for the construction of the cassava washing machine is greater than the calculated diameter 14.00mm so that the shaft can withstand any additional loads on it

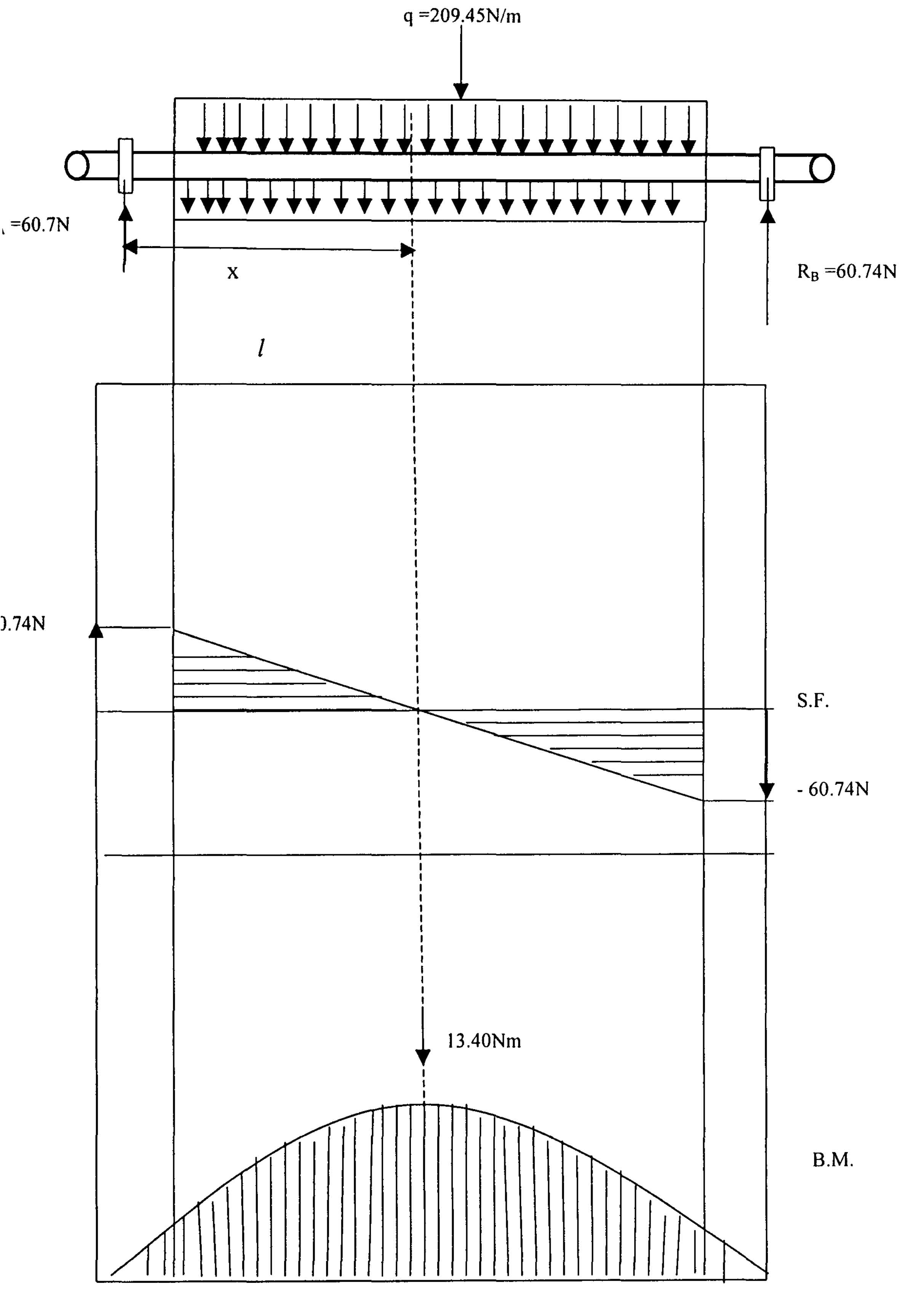


Fig 3.1 The Shear Force And Bending Moment Diagram

3.3.6 DESIGN OF BEARING

The Bearing Size Selection

The selected design life for agricualtural equipment is between 3,000 – 6,000 (from the marks standard handbook, (1997) Table) the equipment radial load; p is calculated from this equation

P = XR + YT [from Mark's standard handbook: (1997)]

Where

R = radial load

T = Axial load

x and y are radial and axial factors respectively

Estimation of axial Load, T

Axial load T = (weight of the shaft) + (weight on the shaft) + (weight of crack handle)

$\therefore$ weight of the shaft = mass x accelaration due to gravity

mass of shaft = 4.05kg

acceleration due to gravity = 9.81

weight of the shaft = 4.05 x 9.81 = 40N

$\therefore$ weight of the crank handle = 0.106kg

weight of the crank handlke = 0.106 x 9.81

= 1.04N

weight on shaft = 121.48N

$\therefore$ axial load, T = 4.0 + 1.04 + 121.48 = 162.524N

radial load = R = 0

x = 0.56, y = 1.4 (obtained from previous reference table)

$\therefore$ the equivqalent radial load, P

P = R x + YT

= 0.56 x 0 + 1.4 x 162.524

= 0 + 227.5336

P = 227.5

The Required Capacity of The Bearing

The required capacity: C_r of the bearing is calculated from this formula

$$C_r = P[L_{10}N]^{1/k} \text{ (From the previuos reference)}$$

where

$$P = equivalent\ capacity = 227.5$$
$$L = designed\ life = 6{,}000$$
$$N = rotating\ speed = 90rpm$$
$$Z = constant\ for\ ball\ bearing = 25.6$$
$$k = constant\ for\ ball\ bearing = 3$$
$$\therefore C_r = 227.5\frac{(6{,}000\ x\ 90)^{1/3}}{25.6} = 723.67$$
$$Therefore\ C_r = 723.67$$

So the first bore size having a capacity C greater than C_r = 15mm (from the previous reference table)

Then the speed limit,

d_n = bore(mm) x speed(r/min)

= 15 x 90

= 13350rpm

The Bearing Life Determination

The bearing rated life is calculated from this equation

$$L_{10} = \left(\frac{C}{P}\right)^k x\,10^6 \quad (\textit{from the same refernce})$$

where

L_{10} = *rated life*

C = *load rating (capacity)* = 723.67

P = *equivalent radial load* = 227.50

k = *constant for ball bearing* = 3

$$\therefore L_{10} = \left(\frac{723.67}{227.50}\right)^3 x\,10^6 = 32.20\,x\,10^6$$

To convert to hours

$$L_{10} = \frac{16700}{N}\left(\frac{C}{P}\right)^k \; (from\,the\,same\,reference\,book)$$

where

$N = rotary\ speed = 90rpm$

$$\left(\frac{C}{P}\right)^k = 32.20$$

$$\therefore L_{10}\ in\ hours = \frac{16700}{90}(32.20) = 5972.44\ hours$$

Therfore the claculated rated life of the bearings for the construction of cassava washing machine falls within the design life range of the bearings for any agricultural equipment which is between 3,000 and 6,000 hrs

3.3.7 FRAME DESIGN

The material selected for the frame is Angle Iron. The dimansions of the cassava washing machine are

Length of frame = 800mm

Height of frame = 700mm

Breadth of frame = 450mm

The weight acting on the frame are

Weight of the water trough = 86.40N

Weight of the water = 318.83N

Weight of the rotary perforated drum = 52.67N

Weight of the cassava tubers = 68.81N

Weight of the shaft = 40N

Therefore the total weight on the longer beams

= weight of the water troughs + weight of the water

= 86.40 + 318.83

=405.23/2 (for the two longer beams)

= 202.115N

The total weight on the shorter beam = weight of the rotary perforated drum + weigth of cassava tuber + eight of th shaft.

= 52.67 + 68.81 +40

=161.48/2 (for the two shorter beams)

= 80.74N

See figure 3.2 for the loads distribution on the frame

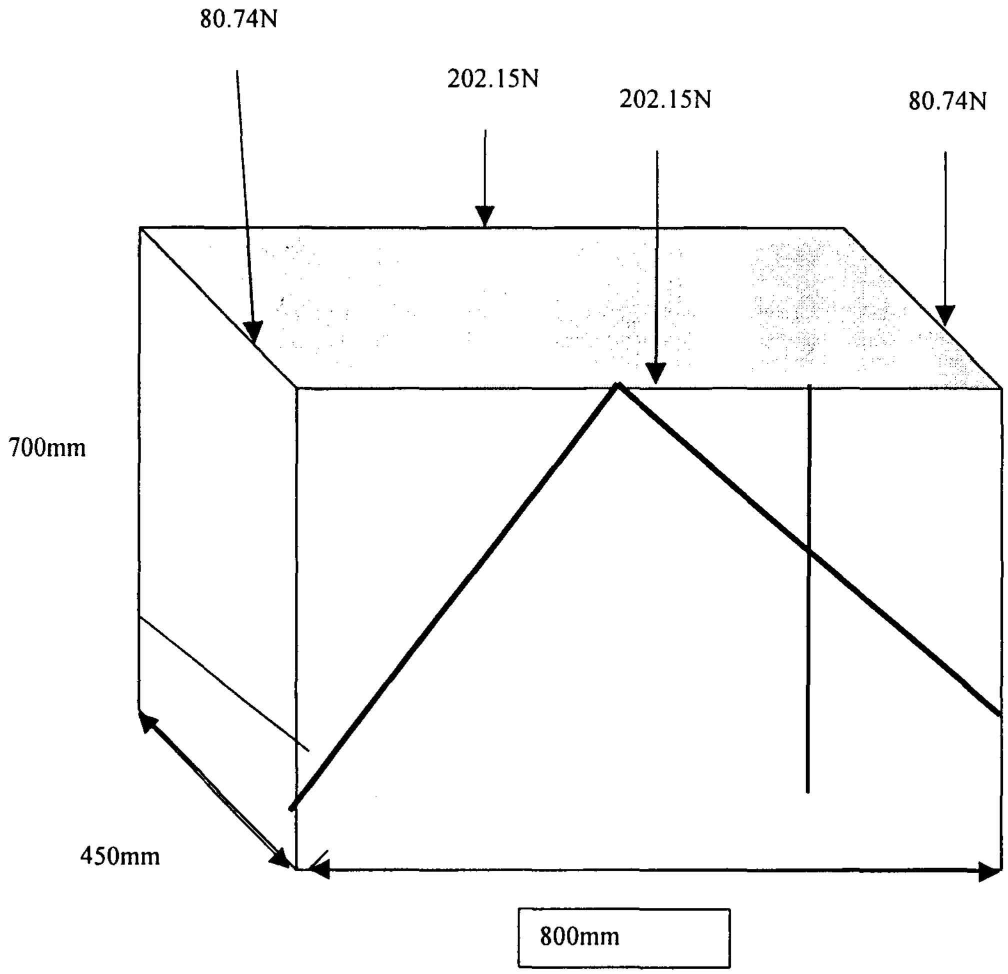
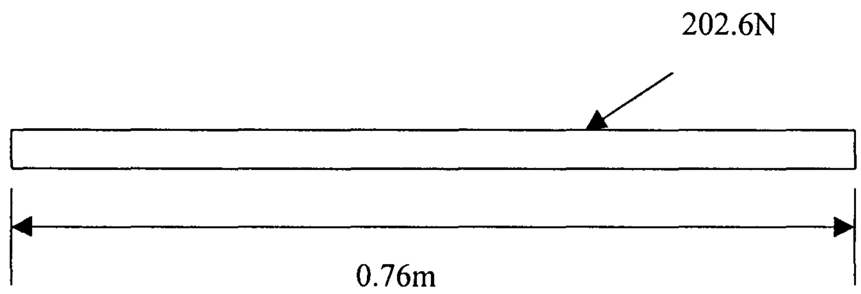


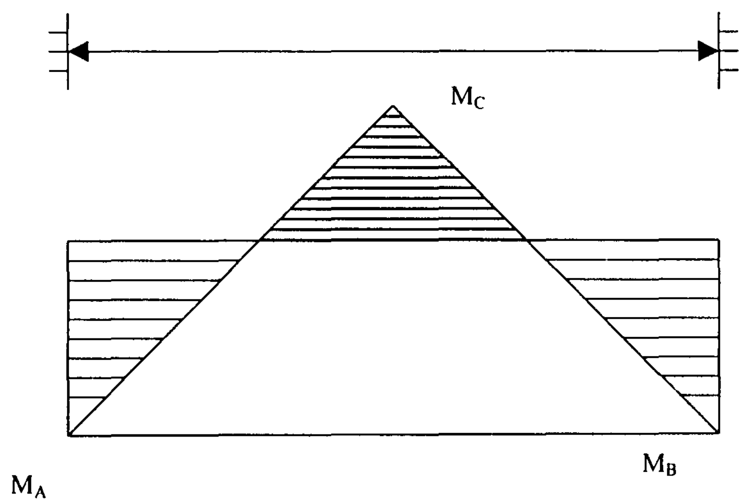
Fig 3.2 Load Distribution on The Frame

Determination of Sectional Modulus On The Longer Beams

The Free Body Diagram of One of the Longer Beams



The Bending Moment Diagram of The Section



$\therefore$ *The bending moment* $M_c = M_A = M_B$

$$M_{max} = \frac{PL}{8} = \frac{202.6 \; x \; 0.76}{8} = 19.25Nm$$

$\therefore$ *The Maximum bending moment at*

$C = 19.25Nm$

$\therefore$ *the sectional modulus,* Z

$$Z = \frac{M_{max}}{P_b}$$

where

P_b = *allowable bending stress of grade* 43 *steel* = $165N/mm$

$$Z = \frac{19.25 \; x \; 10^3}{165} = 117mm^3 = 0.12cm^3$$

The sectional modulus greater than $0.12cm^3$ *is used*

i.e. $\overline{Z} = 1.55cm^3$ *with dimensions* $40 \; x \; 40 \; 4mm$

(*from steel designer manual table*) *is used*

therefore the weight per unit length of the section $= 2.42kg/m$

the weight of the longer beam

$= 2.42 \; x \; 0.76 \; x \; 9.81 = 18.04N$

so the moment due to self weight

$$M_{sw} = \frac{PL}{8} = \frac{18.04 \; x \; 0.76}{8} = 1.714$$

$\therefore$ *Total bending moment* $\overline{M}$

$$\overline{M} = M_{max} + M_{sw} = 1.71 + 19.25 = 20.96Nm$$

so the actual ctual bending stress $= \frac{\overline{M}}{\overline{Z}}$

$$= \frac{20.96 \; x \; 10^3}{1.55 \; x \; 10^3}$$

$13.5N/mm^3$

since $13.5N/mm^2$ *is less than* $165N/mm^3$

then the section is okay

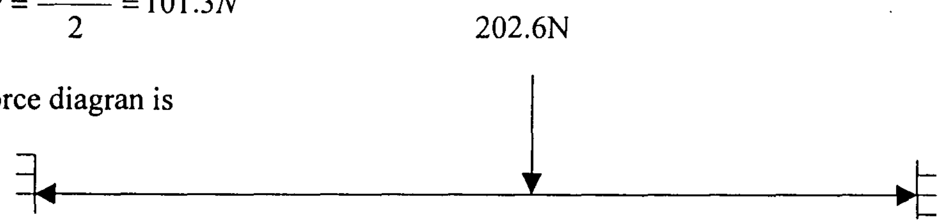
To Check for Shear

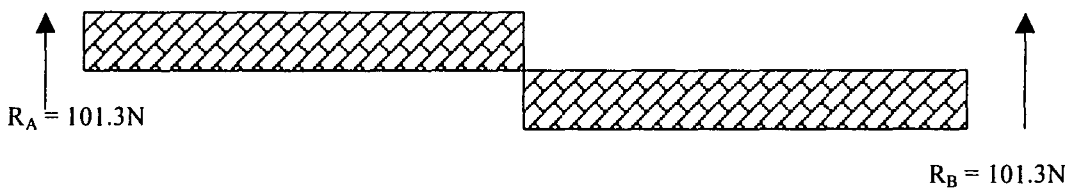
$$Actual\ shear\ force = \frac{\rho}{2}$$

$$where\ \rho\ is\ load = 202.6N$$

$$\therefore Shear\ force = \frac{202.6}{2} = 101.3N$$

that is shear force diagran is





$$Actual\ shear\ stress = \frac{Shear force}{Area\ of\ section}$$

$$where Area\ of\ section = 3.08cm^2\ (from\ the\ steel\ designers'\ manual\ table)$$

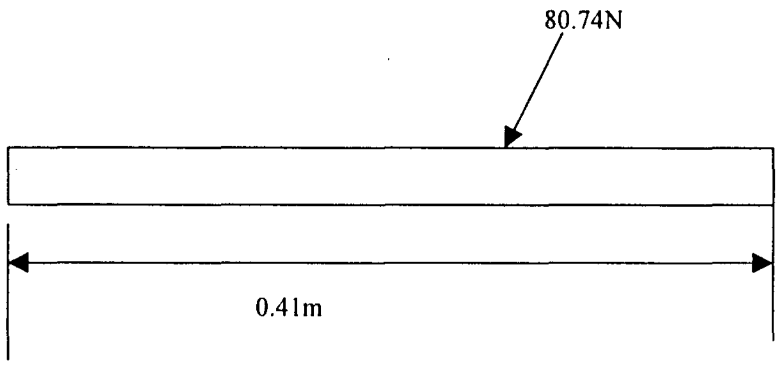
$$\therefore Actual\ shear\ stress = \frac{101.3}{3.08\ x\ 10^2} = 0.33N/mm$$

$$since\ 0.33N/mm\ is\ less\ than\ 100N/mm\ hence\ the\ section\ is\ okay$$

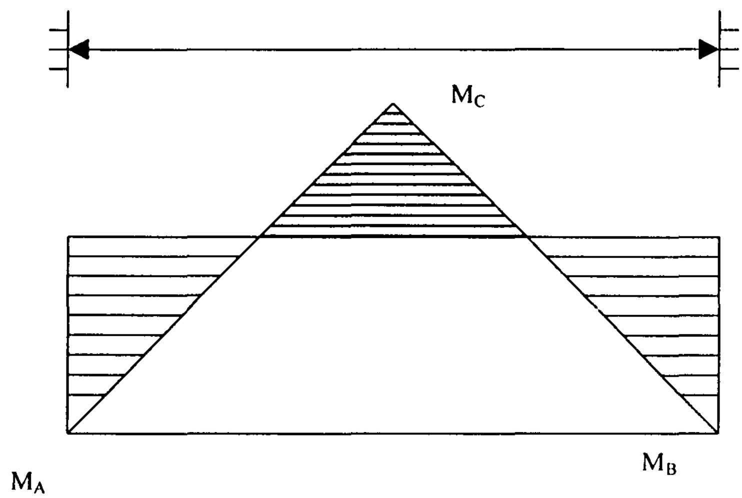
Determination Of The Sectional Modulus On the Shorter Beams

The free body diagram of one oif the shorter beam

The Free Body Diagram of The Section



The Bending Moment Diagram of the Section



$\therefore$ *The bending moment* $M_C = M_A = M_B$

$$M_{max} = \frac{PL}{8} = \frac{80.74\ x\ 0.41}{8} = 4.14Nm$$

$\therefore$ *The maximum bending moment at* $C = 4.14Nm$

$\therefore$ *The cross sectional modulus* : Z

$$Z = \frac{M_{max}}{P_b}$$

where

P_b = *allowable bending stress of grade* 43 *steel* $= 165N/mm$

$$\therefore Z = \frac{4.14\ x\ 10^3}{165}$$

$= 25.09mm^3$

$\therefore$ *the sectional modulus greater than* $0.025cm^3$ *is used*

i.e. $\overline{Z} = 1.55cm^3$ *with dimensions* $40\ x\ 40\ x\ 4mm$

(*from the steel desiners' manual Table* 3) *is used*

Therefore the wueight of the shorter beam

= 2.42 x 0.41 x 9.91

= 9.73N

So the moment due to self weight

=

$$M_{sw} = \frac{9.73\ x 0.41}{8} = 0.498 = 0.50Nm$$

$\therefore$ *Total bending moment* $\overline{M}$

$\overline{M} = M_{max} + M_{sw} = 0.5 + 4.14 = 4.64Nm$

So the actual bending stress $\frac{\overline{M}}{\overline{Z}} = \frac{4.64\ x 10^3}{1.55\ x\ 10^3} = 2.99 = 3.0N/mm^3$

Since $3.0N/mm^2$ *is less than* $165N/mm^3$ *then the section is OK*

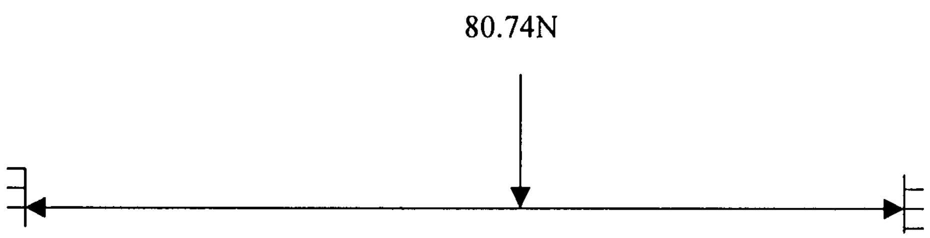
To check for shear

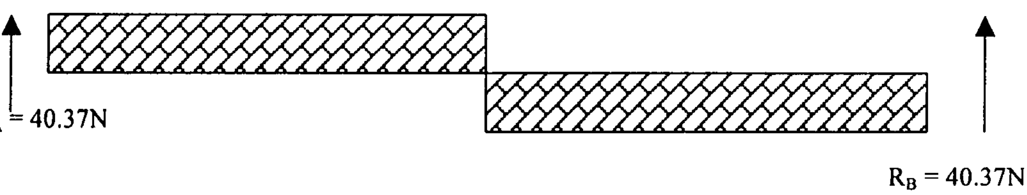
$$Actual\ shear\ force = \frac{\rho}{2}$$

$$where\ \rho\ is\ load = 80.74N$$

$$\therefore Shear\ force = \frac{80.74}{2} = 40.37N$$

that is the shear force diagram is





Actual shear stress

$$= \frac{Shear\ force}{Area\ of\ section}$$

where area of the section $= 3.08cm^2$ *(from the steel designers manual table)*

$$\therefore Actual\ shear\ stress = \frac{40.37}{3.08\ x\ 10^2} = 0.13N/mm$$

Since $0.13N/mm$ *is less than* $100N/mm$ *hence the section is O.K.*

CHAPTER FOUR

4.0 THE CONSTRUCTION, PERFORMANCE AND COST ANALYSIS OF MANUAL CASSAVA WASHER

4.1 CONSTRUCTION AND OPERATIONAL PRINCIPLES OF THE WASHER

4.1.1 Construction Of The Machine

The cassava washing machine is manually operated and consists of a water trough, a rotary perforated drum which is wholly inside the water trough, then a shaft with brushes attached to it passes through the rotary perforated drum where the main cassava washing operation takes place (washing chamber).

The washing of cassava tuber in the washer is carried out by feeding in the cassava into the rotary perforated drum water already inside the water trough. The feeding of cassava tuber is made easy with the way the construction of both the water trough and rotary perforated drum is made openable , in which, they are inform of semi-cylindrical shapes before closing them . Therefore, the breeding and off-loading of cassava tubers before and after washing operation respectively are made possible by construction.

The washing operation of the cassava tubers are carried out by the rotation of the perforated drum inside the water trough, through the cracking of the crack handle of the washer fitted to the shaft which aid the rotation of the perforated drum.

The water inside the water trough have contact with the cassava tubers insi9de the rotary drum through the perforated holes on the rotary drum. The dirty water is being drained out from the water trough through the outlet discharge (tap) located at the central bottom of the water trough.

4.1.1 Description and Construction of Each Component

1. Water Trough

This is a component that contains both the rotary perforated drum and water to use for washing operation. It has a dimension of 350mm. It serves the purpose of holding the water for washing operation. The component is constructed from a galvanized steel sheet of gauge 16. This was first cut into two rectangular shapes of the same sizes and then folded into a semi-cylindrical shapes. The bases of semi-circular shapes were also cut and welded to them. Then the galvanized sheet of semi-cylindrical shapes were now joined together to form a complete cylindrical shape with the aid of hinges and latches which are riveted to them for easy opening and closing of the completed cylinder.

2. Rotary Perforated Drum

This is the chamber where washing operation takes place which serves the purpose of containing the material to be washed and as well as help in washing the material by means of its rotation action. It has dimensions of 250mm diameter and length of 580mm.

The drum is also made from galvanized metal sheet of 16 gauge. This was cut into 2-rectanguar shapes of the same sizes and then ruled into smaller squares of 2cm by 2cm and each point of inter-section was punched for easy perforation. The ruled out metal sheet was perforated with drilling bits of 8mm diameter. The perforated holes area were then smoother with the use of hand-grinding machine, so as to eliminate the rough surfaces created in the course of the drilling action on it.

Then, the 2-perforated rectanglular shapes were folded into a semi-cylindrical shapes and then welded to their already cut semi-circular bases. The two perforated semi-cylindrical shapes were riveted together with the aid of hinges and latches for easy opening and closing, so as to form a complete perforated cylindrical shape/drum.

3. Shaft

The shaft has the length of 950mm with brushes attached to it, which carries the perforated drum and serves the main purpose of rotating both the brushes and the perforated drum. A mild steel shaft was used and reduced to the design specification requirements of length 950mm with the use of electric power saw and of diameter 250mm by the use of lathe machine

4. Brushes

They are flat cylindrical in shape, which help in creating a rubbing action on the surface of the cassava tubers so as to achieve high washing efficiency. The brushes were bought and fixed attached to the shaft. The brush sits are constructed using flat bar of 1.5inches. The brush sits are welded to the shaft, the brushes are fixed to it using bolts and nuts.

5. Frame

The frame and stands serves the purpose of holding the whole system in rigid position. They were constructed using angle from 40mm by 40mm dimension which were cut into different lengths according to design specifications and welded together to take the shape as indicated in the fig. 4.1

6. Screw-Plug Tap

The screw-plug tap was bought and fixed at the central position of the bottom of the water trough for easy discharging of the dirty water. After the washing operation. It was fixed by welding it to the perforated hole at central position of the trough which has the same diameter with the screw a plug tap

7. Bearing

Two bearings were bought according to design specifications and each was fixed to each end of the machine frame for easy rotation of the shaft when it is being passed through them.

4.2 PERFORMANCE TEST OF CASSAVA TUBER WASHER

4.2.1 Material and Test Procedure

The materials used for the test are peeled cassava tubers, water, weighing balance, stop water. Then the cassava washer was tested.

Test Procedure

The ergonomics experiment was carried out on hand pealing operation of the cassava tuber before the testing of the cassava washer itself. In which four were selected and the same quantity of cassava tuber were given to each person. The n the tubers were pealed and the time taken for each person to peal that same quantity of cassava tubers were taken. And the result of the ergonomic experiment are shown in Table 4.1 Then the testing of cassava washer was carried out immediately and it goes thus, the water trough of the washer was filled with water and certain quantity of cassava tubers were weighed and fed into the washer, then the washing operation was carried out until a desired cleanliness of the tuber was obtained at a specific time.

The cleanliness of the cassava tubers was observed usually and then the weight of the washed cassava tubers were determined and the number of the broken tubers noticed. The washing operation of the cassava tuber was repeated using the local method of washing cassava tubers.

4.2.2 RESULTS AND DISCUSSION OF THE TEST

Table 4.1 Anthropometric Data Collected and Parameters Determined During the **Ergonomic Experiment Carried Out On Cassava Hand-Peeling Operation**

S/No.	Name of the operator	Weight of unpeeled cassava tuber (kg)	Weight of the peeled cassava tuber (kg)	Time taken to peel (hr)	Output capacity of each operator (kg/hr)
1	Bose	16.50	13.00	1.05	15.70
2	Gbenga	16.50	11.55	1.03	15.97
3	Edemu	16.50	12.60	1.13	14.56
4	Chinedu	16.50	12.25	1.42	11.65
AVERAGE VALUES		16.50	12.35	1.17	14.47

TABLE: 4.2 THE DATA COLLECTED AND PARAMETER DETERMINED DURING THE TESTING OF CASSAVA WASHER

S/NO.	Weight of cassava input in batch (kg)	No.s of cassava tuber input	Time of washing operation (min)	Weight of the washed cassava tuber (kg)	Nos. Of broken cassava tuber	Output capacity (kg/hr)	Washing efficiency %)	Mechanical damage index
1	4.00	7	1.50	3.97	0	160	99.25	0
2	4.00	6	1.50	3.96	1	160	99.00	1:6
3	4.00	6	1.50	3.97	0	160	99.25	0
4	4.00	7	1.50	3.96	1	160	99.00	1:7

4.2.3. DISCUSSION OF THE RESULTS

The ergonomics experiment that was carried out on cassava hand peeling operation shows that an average human being has average output capacity of 14.47kg/hr for peeling cassava tubers.

It was found that all the unwashed all the unwashed cassava tuber fed into the washer was well washed with washing efficiency of 99.00% and of all the tubers fed into the washer only one or none of the tubers in each batch were broken with average output capacity of 160kg/hr. Also from the comparison made between the two methods of washing cassava tuber, it was found that the local method can washed 3.5kg of cassava tuber in 2 mins while the mechanized method will only use I minute to wash the same quantity of cassava tubers.

4.3 MATERIAL SELECTION AND COST ANALYSIS

4.3.1 Cost Analysis

The cost of the cassava washing machine can be classified into

1. Material cost
2. Labour cost
3. Overhead cost

Material Cost Analysis

The Table 4.3 below shows the material cost of the machine. Material cost is the cost of the material used for the construction of the part

Table: 4.3 THE COST OF THE MATERIALS

S/No.	Item description	Quantity	Unit price ₦ : k	Amount
1	Galvanized sheet (3.0 m^2) (gauge 16)	3.0m^2	2,500	2,500
2	Angle ioron (40mm x 40mm) 6m/length	12.0m	500	400
3	Brushes	4	100	400
4	25mm diameter shaft 6m/lngth	2	500	1000
5	25mm pillow bearing	2	500	1000
6	Latches	2	20	40
7	Hinges	4	20	80
8	Tap screw	1	200	200

The material cost = ₦720.00k

Labour Cost

20% of the total material cost amount to the labour cost of the machine

$$Labour\ Cost = 5720\ x \frac{20}{100} = 1144.00$$

Overhead Cost

10% of the total material cost of the material

$$\therefore Overhead \quad \cos t = 5720 \quad x \; \frac{10}{100} = N\,572\,.00$$

Total Cost of Fabrication

The total cost of the machine: T_C

T_c = material cost + labour cost + overhead cost

= 5720 + 1144 + 572 = 7436

Profit

The profit of the machine will be 10% of the total cost

Therefore

$$\Pr ofit = \frac{10}{100} x \; 7436 = 734.60$$

Price

The price of the machine will be the sum of ther total cost and the profit

$$\Pr ice = 7436 + 743.6 = 8179.60$$

CHAPTER FIVE

5.0 CONCLUSION AN DRECOMMENDATION

The design and construction of cassava washing machine has been carried out and the result from the test carried out on the machine shows that the machine has a washing efficiency of 99% with little or no breakage of the cassava tubers which has an output capacity of 160kg/hr.

Also the comparison made shows that the local method can wash 3.5 kg of cassava tuber in 2 minutes while the mechanized method can wash the same quantity of cassava tuber in 1 minute.

Therefore the machine can be effectively used for washing operation and also can be converted to motorized machine and be constructed to one's desired capacity for local and industrial purposes.

REFERENCES

Asiedu, J.J. (1984); A Technological Approach in Processing Tropical Crops. Macmillan, pp 1-20

Allens, H. Jr., Alfred R.H.,and Hermang. L. (1982); Shaum's Outline Series Of Theory and Problems Of Machine Design. Mc Graw Hill Inc., pp. 221—232

Baderinwa, O.A. (2000); Design and Construction Of Cassava Chip Dryer (Unpublished Project Report Submitted to the Department of Agricultural Engineering, University of Ilorin), pp 36

Constrado, (1983); Steel Designer Manual Fourth Edition. Grenada, pp 875-899

Eugene, A.A. (1997); Mark's Standard Handbook For Mechanical Engineers. Tenth Edition. Mc Graw Hill, pp 9751-9762

Henderson, S.M. and Perry, R.L. (1980); Agricultural Process Engineering 3rd Edition Av. Ub Go. Connecticut, Pp 162 – 165

Intermediate Technology Publication And United Nations Development Fund For Women (UNIFEM) (1993): Root crop processing. Food cycle technology source books

Kachru, R.P. (1989); Cleaning And Environmental Conditions For Effective Seed Storage. Macmillan, Pp 34-56

Mayhew, S. And Penny, A. (1988); Tropical An D Subtropical Foods. Macmilan, pp 110-114

Odigboh E.U. (1985); Mechanization Of Cassava Production And Processing: A Decade Of Design And Development. University Of Nigeria Press, Nsukka pp 19-45

Post Harvest Technology Research Group (1998); Appropriate Technology For Small Scale Gari Processing Faculty Of Technology, Obafemi Awolowo University Ile-Ife, pp 16-25, 31-32

Ryder, G.H. (1969); Strength Of Material 3rd Edition In S.I. Units. Macmillan , pp 71-85

APPENDIX

1. Washing efficiency (cleanliness)

$$washing \quad efficiency \quad = \frac{weight \quad of \ the \ washed \quad washed \quad cassava \quad tubers}{weight \quad of \ the \ cassava \quad tuber \quad fed \ \text{int} \ o \ thewasher} x \ 100 \ \%$$

2 Output capacity

$$Output \quad capacity \quad = \frac{weight \quad of \ the \ cassava \quad to \ be \ washed}{time \quad taken \quad to \ wash} kg \ / \ hr$$

3 Mechanical damage index

$$mechanical \ damage \ index = \frac{number \ of \ broken \ cassava \ tubers}{nuber \ of \ cassava \ tubers \ fed \ \text{int} \ o \ the \ washer}$$

4 The output capacity for each cassava hand peeling operator

$$he \ output \ capacity \ for \ each \ cassava \ hand \ peeling \ operator = \frac{weight \ of \ unpeeled \ cassava \ tubers}{time \ taken \ to \ peel} kg \ / \ hr$$

PLATES

Plate 1: The Hand Peeling Operation of a Cassava Tubers

Plate 2: The Peeled Cassava Tubers

PLATES

Plate 3: The Washing Operation of Peeled Cassava Tubers