KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF ENGINEERING

FACULTY OF MECHANICAL AND AGRICULTURAL ENGINEERING

DEPARTMENT OF AGRICULTURAL ENGINEERING

PROJECT REPORT ON:

THE DESIGN, CONSTRUCTION AND TESTING OF A MANGO JUICE EXTRACTOR

REPORT SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL ENGINEERING IN PARTIAL FUFILMENT OF THE REQUIREMENTS FOR THE BACHERLOR OF SCIENCE (HONS) IN AGRICULTURAL ENGINEERING

BY

ODEH – AGBOZO KWABENA BOAKYE

INDEX NUMBER: 4855010

SUPERVISORS:

PROF. E. MENSAH

DR. GEORGE. Y. OBENG

DECLARATION

I Odeh – Agbozo Kwabena Boakye, declare that I personally undertook this project and it has not been produced anywhere for award of a degree except other peoples work which have been dully acknowledged.

....   …………………………………

ODEH – AGBOZO KWABENA BOAKYE   DATE

....   …………………………………

PROF. EBENEZER MENSAH   DATE

(SUPERVISOR)

……………………………………………….   …………………………………

DR. GEORGE YAW OBENG   DATE

(SUPERVISOR)

DEDICATION

I dedicate this dissertation to my late father, counselor and friend Odeh –Agbozo Kwame Isaac.

ACKNOWLEDGEMENT

I am very grateful to the Lord Almighty for making me reach this far. I will like to express my profound gratitude to my supervisors, Prof. Ebenezer Mensah and Dr. G. Y. Obeng for their constructive criticisms and correction that has enabled me to complete this work successfully.

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ABSTRACT

The Food and Agricultural Organization (FAO) describes the loss of foods in the post-harvest system as not new since it has always been a problem for humankind. Post-harvest losses of fruits and vegetables are more severe in developing countries than in well developed countries. The recent rapid increasing populations in the poorest countries in which there is already food scarcity requires ways and means to conserve mankind's food supply in order to alleviate hunger and malnutrition. This project is focused on the design, construction and testing of mango juice extractor. The design consists of major components like the screw conveyor, a motor, frame, hopper, extraction chamber, juice outlet, waste outlet, perforated drum and bearings. The project was carried out by constructing the machine in the Agricultural Engineering workshop based on theoretical design work. Materials for the construction of the juice extractor were obtained locally. The major material used is stainless steel because the food safety aspect of the machine was taken into consideration. After construction, the machine was tested using the Keitt variety of mango. This is due to its large size, relatively low fiber content and firm juicy flesh. The machine was found to be easy to operate, repair and maintain and this makes it suitable for local production. It operates on a 2.5 horse power single phase motor, an efficiency of 60%, and an extraction loss percentage of 11.1% and a production output of 17.8 liters per hour. Therefore, the machine is very efficient. The capacity of the machine was determined, the efficiency of the machine at different speeds was found out and the optimum operating speed of the machine was ascertained.

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CHAPTER 1
INTRODUCTION

1.0 Background

Mango is a fleshy stone fruit belonging to the genus *Mangifera*, consisting of numerous tropical fruiting trees in the flowering plant family Anacardiaceae. The mango is native to South Asia, from where it has been distributed worldwide to become one of the most cultivated fruits in the tropics. While other *Mangifera* species, for example, horse mango, *M. foetida* are also grown on a more localized basis, *Mangifera indica* – the 'common mango' or 'Indian mango' is the only mango tree commonly cultivated in many tropical and subtropical regions. It is the national fruit of India, Pakistan and the Philippines, and the national tree of Bangladesh. (Bompard, 1993)

African Mango, or *Irvingia gabonensis*, is a variety of mango that grows in Central and West Africa. It also goes by other names such as wild mango, bush mango, or dika nut. Mango can be grown on a wide range of soils. It can be grown on alluvial to lateritic soils except in black cotton soils having poor drainage. It grows well in soils which are slightly acidic. However, it prefers a well-drained, sandy-loam to deep loamy or alluvial soils. The mango varieties under cultivation in the country are of seedling origin and are the result of open pollination arisen as chance seedlings. Varietal improvement in mango has been attempted both by selection of promising types from the indigenous ones and through controlled hybridization. A large number of varieties are available inside the state. (SUVADRA, 2012)

Mangoes are an important part of the diets in certain parts of the world. The edible portion of the fruit varies from 55 to 75 percent of the mango fruit depending upon the variety. Most of the mangoes can be characterized as having a high sugar content (15-20%) and a low acid content (0.2-0.5%), which would account for mango's sweet, pleasant characteristics. Nutritionally, mangoes are a good source of vitamins A, C, and fiber. (USDA, 1975)

As with many fruits, the edible fleshly portion or pulp of mango fruit is enjoyed to the extent of commercialization. A wide variety of processed products include canned whole or sliced mango pulp in brine or in syrup, mango juice, nectar, jam, sauce, chutney and pickle (Singh, 1960; Vandrendriessche, 1976). Over 60 varieties of mango are identifiable. (Opeke, 1982)

Mangoes are processed into purée for re-manufacturing into products such as nectar, juice, squash, jam, jelly and dehydrated products. The purée can be preserved by chemical means, or frozen, or canned and stored in barrels. This allows a supply of raw materials during the remainder of the year when fresh mangoes are not available.

Chemical storage also provides a more economical means of storage compared with the cost of storing the finished products, except for those which are dehydrated, and provides for more orderly processing during peak availability of fresh mangoes.

Mangoes can be processed into purée from whole or peeled fruit. Because of the time and cost of peeling, this step is best avoided but with some varieties it may be necessary to avoid off-flavors which may be present in the skin. The most common way of removing the skin is hand-peeling with knives but this is time-consuming and expensive. Steam and lye peeling have been accomplished for some varieties. (FAO, 1995)

Mango processing has become increasingly important in Kenya and represents an important food source. In addition, demand for the fruit is high and mangoes can provide small farmers with a valuable source of income. However, there are strict quarantine regulations and an export ban is imposed on any fruit affected by fruit flies, so excluding farmers from a profitable market (BFED, 2003)

1.1 Problem Statement

The Food and Agricultural Organization (FAO) describes the loss of foods in the post-harvest system as not new since it has always been a problem for humankind. Post-harvest losses of fruits and vegetables are more severe in developing countries than in well developed countries. The recent rapid increasing populations in the poorest countries in which there is already food scarcity requires ways and means to conserve mankind's food supply in order to alleviate hunger and malnutrition. Meanwhile, some individuals have been drawing attention to the problem of post-harvest losses for many years. Estimates of production losses in developing countries are hard to tell, but some researchers put losses as high as 50 percent, or half of what is grown (FAO, 1980). Reduction in this wastage, if economically can be avoided, would be of great significance to growers and consumers alike.

Ghana, a developing country with agriculture as the main stay of the economy, faces postharvest losses especially in highly perishable crops. Postharvest diseases and poor postharvest handling practices can be major causes of postharvest losses. This remains a serious challenge facing the country as it still struggles with developmental issues most importantly in the agricultural sector. Mangoes are among those that are affected and sometimes results in substantial losses. (SAEED, 2012)

Mango processing presents many problems as far as industrialization and market expansion is concerned. Due to the perishable nature, the farmers records abundant wastage during the production season and extreme scarcity during the off season. Processing the fruit into the form that can easily be stored, preserved, packaged, transported or consumed is crucial to having the product all the year round. Besides, mango juice can be consumed freshly, processed into dry powder, mixed or blended with other juice to make fruit jams, or evaporated to concentrates. These products have a lot of potential in food and beverage industries for export and foreign exchange earnings.

Farmers in Ghana do not utilize the mango fruit to the optimum after harvesting because of poor postharvest practices. Therefore, it is important to produce a machine that can aid in the extraction of mango juice in an efficient way so that this can be done on an industrial basis to boost income for farmers.

1.2 Objective

The main objective of this project is to design, construct and test a mango juice extraction machine.

1.2.1 Specific Objectives

The specific objectives of this project are to:

- Determine the capacity of the machine.
- Find out the efficiency of the machine at different speeds.
- Ascertain the optimum operating speed of the machine.

1.3 Justification

Every year, there is wastage of the mango fruit after harvesting. This reduces the value of the fruit because it is not processed on large scale into other marketable forms. Processing is one of the most effective solutions to reduce the wastages. *Mangifera indica* is a perishable fruit that needs good post harvesting practices to produce optimum income yield. Processing of the fruit into forms that will attract maximum yield is important. Therefore, this project is aimed at producing a machine that can aid in the production of mango juice. This machine will aid in the processing of mango into juice that can be sold on other markets, hence providing a greater amount of income for the farmer.

CHAPTER 2
LITERATURE REVIEW

2.0 The Mango Fruit

2.0.1 History

Mango belongs to family Anacardiaceae and the genus *Mangifera*. There are several species of genus *Mangifera* that bear edible fruit. The majority of trees that are commonly known as mango belong to the specie, *Mangifera indica*. *Mangifera* originates from tropical Asia, with larger number of species found in Borneo, Java, Sumatra, and the Malay Peninsula. The most-cultivated *Mangifera* species, *M. indica* (mango), originates from India and Myanmar (Bally, 2006). Mango has turned out be naturalized, adapted and is cultivated throughout the tropics and subtropics. Its spread and naturalization have occurred in line with the spread of human populations, and as such, mango plays a significant role in the diet and cuisine of many diverse cultures. There are over 1,000 named mango varieties throughout the world, which is an indication of their value to humankind (Bally, 2006).

2.0.2 The tree

Mangifera is a perennial, evergreen, and branching tree which can grow to a height of 30-40 m tall. The trees can flower after 5-7 years but grafted and propagated trees which are generally smaller can flower after 3-4 years (Ploetz et al, 1994). Mango can grow on a wide range of soils (optimal pH 5.5–7.5.) and are relatively tolerant to drought. They are also tolerant to low temperatures (0 °C - frost), optimum growth temperatures (24–27 °C) and a wide range of rainfall (annual 400–3600 mm) conditions (Bally, 2006).

The canopy is normally oval, elongated or dome shaped. The juvenile period of seedling trees can range from 3 to 7 years. The root system consists of long, vigorous taproot and abundant surface feeder roots. (The Mango, 2nd Edition).

Its adaptation throughout the world makes its existence evident in Ghana especially in the northern part of Ghana where rainfall is once a year followed by a period of drought and the mango flourishes very well in these regions. Even though the mango trees are all over Ghana, commercial productions are found in two typical agro ecological zones. They are the Northern Ghana around Tamale and Southern Ghana around Greater Accra, Eastern and Volta Regions (FAO, 2009).

Ghana has immense comparative advantage for the cultivation of mango because most of the lands of the coastal savannah, northern Ashanti, the transitional zones of Ashanti and Brong Ahafo regions, the northern Volta region, and the whole of Northern, Upper East and Upper West regions are suitable for mango production that meet international quality specification. These areas have abundant moisture and hot temperatures that are favorable for large-scale production of mango. As a tree crop that flourishes best in areas of moderate rainfall and high light intensity, the savannah areas are the most excellent for mango. GNA further highlighted that agronomists have argued that, Ghana with a better comparative advantage in Africa with regards to precipitation, soil and proximity could become an important producer within a few years if the nation pays attention to that industry (GNA, 2008).

2.0.3 The flowers

Mango flowers are born on terminal inflorescences (panicles) that are broadly conical and can be put up to 60cm long on some varieties. Inflorescences usually have primary, secondary and tertiary pubescent, cymose branches that are pale green to pink or red and bear hundreds of flowers. The mango has two flower forms, hermaphrodite and male, with both forms occurring on the same inflorescence. The ratio of hermaphrodite to male flowers on an inflorescence varies with variety and season and is influenced by the temperature during inflorescence development.

2.0.4 Uses of mango

2.0.4.1 Nutritional and health benefits

Mangos are an extremely nutritious and contain carbohydrates, proteins, fats, minerals, vitamins: vitamin A (beta carotene), B1, B2, and vitamin C (ascorbic acid) (Bally, 2006).These nutrients no doubt play a crucial role in human nutrition thus the health of the individual. For instance, deficiency in vitamin A can lead to reversible night blindness and keratinization of normal mucous tissue of the eye, lungs skin and other ectodermic tissues. Lack of vitamin B1 can cause *beriberi* (edema and heart hypertrophy). Again deficient in vitamin C which is a vitamin for humans and primates results in scurvy (Van Camp et al., 2009). Mangos also make important seasonal contributions to the diet of many countries in the tropics especially African countries that primarily have a starch (carbohydrates)-based diet. Ripe mangos fruits are rich sources of vitamin A and are used to treat vitamin A deficiencies such as night blindness. Also drinks made from the infusion of fresh mango leaves has been used to treat diabetes and dried mango seed ground into powder is used to treat diarrhea. Diarrhea and throat disorders are treated by bubbling the bark extracts mixed with water (Bally, 2006). Some other uses of the mango includes its use in agro forestry and environmental practices such as livestock shelter, home gardens, fence post, wind breaks and animal foods. Other uses include: flavorings

in which its puree is used to give flavor to many foods such as drinks, ice cream, wines, teas etc., honey (from its nectar), making leaf vegetables from boiled young leaves and used for tannin/dye (Martin et al.1998).

2.0.5 Processing of Mango

According to GNA (2008), the major producing countries of mangos include India, Mexico, Pakistan, Brazil, Indonesia, China, Haiti, the Philippines, Madagascar and Tanzania. The production of mango globally currently stands at about 25 million tons of fresh fruits and 290,000-processed mango pulp, puree and juice. Africa out of this produces only 2.5 million tons (about 10%) of fresh fruits and 11 per cent of processed mango. Ghana's current

Production is reported to have increased from about 1,200 tons in 2007 to about 2,000 in 2008. The varieties of mangoes that are grown in Ghana include Kent, Keitt, Palmer, Haden, Tommy Atkins, Irwin, Sensation, Julie, and the local variety (GEPC, 2005).

Mangoes are processed at two stages of maturity. Green fruit is used to make chutney, pickles, curries and dehydrated products. The green fruit should be freshly picked from the tree. Fruit that is bruised, damaged, or that has prematurely fallen to the ground should not be used. Ripe mangoes are processed as canned and frozen slices, purée, juices, nectar and various dried products. Mangoes are processed into many other products for home use and by cottage industry. (FAO, 1995)

Mango, which is a highly demanding economic crop on the international market was left rotten on farms in Ghana annually because the country did not have processing plants for mango. Mango has huge export earnings that could enhance Ghana's Gross Domestic Product. Ghana could add value to its mango, and package the fruit well for export. (GNA, 2012)

The mango processing presents many problems as far as industrialization and market expansion is concerned. The trees are alternate bearing and the fruit has a short storage life;

these factors make it difficult to process the crop in a continuous and regular way. The large number of varieties with their various attributes and deficiencies affects the quality and uniformity of processed products.

The lack of simple, reliable methods for determining the stage of maturity of varieties for processing also affects the quality of the finished products. Many of the processed products require peeled or peeled and sliced fruit. The lack of mechanized equipment for the peeling of ripe mangoes is a serious bottleneck for increasing the production of these products.

A significant problem in developing mechanized equipment is the large number of varieties available and their different sizes and shapes. The cost of processed mango products is also too expensive for the general population in the areas where most mangoes are grown. There is, however, a considerable export potential to developed countries but in these countries the processed mango products must compete with established processed fruits of high quality and relatively low cost. (FAO, 1995)

Mangoes expected to be harvested from more than 4,000 acres of land in parts of the Northern Region stand the risk of going bad due to the lack of local and foreign processing companies to buy the produce. Strenuous efforts being made by the Export Development and Agricultural Investment Fund (EDAIF) to attract prospective processors to buy and process the mango into juice for local consumption and for export is also not yielding any results. (Doudu, 2013)

CHAPTER 3
MATERIALS AND METHODS

3.0 Materials

The materials used in the construction of the mango juice extractor were all obtained locally.

Some materials used in the construction are listed as follows:

- Stainless steel sheets
- Stainless steel rods
- Stainless steel mesh
- Mild steel angle iron
- Pillow bearing
- Cast iron pulley
- Bolts and nuts
- Welding electrodes
- Cutting disc
- Grinding disc

3.1 Concept

A machine was designed for small scale mango juice extraction. In operation, the screw conveyor conveys and the screw blade presses the mango fruits against a drum perforated on the inside. The extraction chamber consists of a perforated cylindrical drum which houses a uniform diameter and equal-pitch screw conveyor. The perforated drum is essentially a cylindrical drum on which series of perforated holes were drilled in an orderly manner. The perforations are roughened in the internal surface of the drum to form an abrasive surface for tearing the fruit mesocarp and enhance the flow of juice. In operation, as the shaft rotates at its required speed, the screw blades press the mango fruits against the roughened/abrasive drum surface in such a way that the mango mesocarp is softened. The extraction is actually achieved by the action of the screw blades in pressing the macerated mesocarp against the roughened/abrasive internal surface of the perforated cylindrical drum along the line of travel. More extraction takes place at the far end of the drum when the outlet valve of the pulp remains shut. The pulp that has been conveyed to that end is pressed by the rotating action of the auger against the wall. The juice extracted drops on the collector and is drained through the juice channel into the juice outlet from where it is collected while the residual waste is collected at the waste outlet. The machine consists of the following major components: hopper, extraction chamber, juice outlet, waste outlet, frame, electric motor and motor stand. Other components included screw shaft, the juice collector and the top cover.

3.2 Theoretical Design factors

In designing the machine, design consideration included: high juice yield, high extraction efficiency, low extraction loss and cost of construction materials. Other considerations included the auger speed, capacity of the machine, total power requirement and the inlet velocity of the material. Consideration was also made for a strong main frame to ensure structural stability and strong support for the machine.

3.2.1 Shaft speed of the juice extractor

Length of shaft (L) = 0.6604m

Diameter of Shaft (D) = 0.03m

Moment of Inertia (I) = $39.97 \times 10^{-9} m^4$

According to the American Society of Mechanical Engineers (ASME) code for the design of transmission shafts, the maximum permissible working stress in tension or compression may be taken as 112MPa for shafts without allowance for keyways and 84Mpa for shafts with allowance for keyways (A Textbook on machine design by R. S. Khurmi and J. K.Gupta) .

Modulus of elasticity (E) = 84MPa

Weight per meter = 5.51kg/m

Shaft mass (m) = 5.51kg/m x 0.6604m = 3.63kg

C_q = Stiffness coefficient

N_c = Critical Speed

$$C_q = \frac{3EIL}{a^2.b^2}$$

Where C_q = Stiffness coefficient

$$a = \pi r^2$$

$$= \pi(0.03^2)$$

$$= 0.00282743348m^2$$

$$b = Length\ of\ shaft = 0.6604$$

$$C_q = \frac{3(84 \times 10^6)(39.76 \times 10^{-9})(0.6604)}{(0.002)^2.(0.6604)^2}$$

$$C_q = 1897820.3N/m$$

$$N_C = \sqrt{\frac{C_q}{m}}$$

$$N_C = \sqrt{\frac{1897820.3}{3.63}}$$

$$N_C = 723rpm$$

Applying a safety factor of 25%, the actual speed $= \frac{75}{100} \times 723rpm$

$$= 542rpm.$$

3.2.2 Design capacity of the juice extractor

The capacity of a screw conveyor depends on the screw diameter, screw pitch, speed of the screw and the loading efficiency of the cross sectional area of the screw. The capacity of a screw conveyor with a continuous screw: (Akowuah, 2012)

$$C_s = \frac{\pi}{4}(D^2 - d^2) \times P_a \times N$$

Where,

C_s = Capacity processed, m^3/s

P_a = Average Screw Pitch = 0.0762m

N = Shaft Speed = 542rpm

D = Outer diameter of shaft = 26 inches = 0.6604m

d = Inner diameter of shaft = 0m

Therefore,

$$C_s = (0.6604^2) \times 0.0762 \times \frac{542}{60}$$

$$= 0.3m^3/s$$

$$\therefore \textit{the volumetric flow rate} = 0.3m^3/s$$

$$\text{Density of mango } (\rho) = 978\text{kg}/m^3$$

$$\textit{then the Mass flow rate} = \textit{volumetric flow rate } \times \textit{density of mango}$$

$$= \frac{0.3m^3}{s} \times \frac{978\text{kg}}{m^3}$$

$$= \frac{293.5999kg}{s}$$

$$= 8.155555 \times 10^{-5} t/h$$

3.2.3 Driving power of the loaded screw conveyor

The driving power of the loaded screw conveyor is given by:

$$P = P_H + P_N + P_{st}$$

Where,

P_H = Power necessary for the progress of the material (kilowatt)

P_N = Driving power of the screw conveyor at no load (kilowatt)

P_{st} = Power requirement for the inclination of the conveyor (kilowatt)

3.2.3.1 Power necessary for the progress of the material, P_H:

For a length L of the screw conveyor (feeder), the power P_H in kilo watts is the product of the mass flow rate of the material by the length L and an artificial friction coefficient λ, also called the progress resistance coefficient.

$$P_H = I_m.L.\ \lambda.g / 3600 \text{ (kilowatt)}$$

$$= I_m.L.\ \lambda / 367 \text{ (kilowatt)}$$

Where,

I_m = Mass flow rate in t/hr

λ = Progress resistance coefficient = 2

Drive power of the screw conveyor at no load =P_N:

This power requirement is very low and is proportional to the nominal diameter and length of the screw.

$$P_N = D.L / 20 \text{ (Kilowatt)}$$

Where,

D = Nominal diameter of screw in meter = 0.6604m

L = Length of screw conveyor in meter

$$P_N = \frac{(0.03)(0.6604)}{20}$$

$$= 0.001KW$$

3.2.3.2Power due to inclination: P_{st}

This power requirement will be the product of the mass flow rate by the height H and the acceleration due to gravity g.

$$P_{st} = I_m.H.g / 3600$$

Where g = 9.81

$$= \frac{l_m(H)(9.81)}{3600}$$

$$= \frac{l_m H}{367}$$

3.2.3.3Total power requirement:

The total power requirement is the sum total of the above items

$$P = (I_m (\lambda.L + H) / 367) + (D.L /20) \text{ (Kilowatt)}$$

$$P = \left[(8.155552778 \times 10^{-5})\left(\frac{(0.381) + ((2)(0.6604))}{367}\right)\right] + \left[\frac{(0.03)(0.6604)}{20}\right]$$

=0.09kW

3.2.4 Design of screw conveyor

The screw conveyor is the main component and most functional unit of the extraction chamber. The screw IS designed to have equal pitch steps. This is to ensure the efficient compression of the fruit against the perforated surface to produce juice. The screw pitch was designed using the expression in the equation below as:

$$P_S = \frac{4VDL}{\frac{\pi}{4}(D^2 - d^2)N}$$

Where,

Ps = screw pitch,

V = inlet velocity of raw material,

D = outside diameter of screw,

d = is the inside diameter of screw,

L = length of the screw shaft,

N = shaft speed.

Given,

Ps = 0.0762m

V =?

D = 0.03m

d = 0

L = 0.6604m

N=542rpm

Therefore from,

$$P_{S}=\frac{4VDL}{\frac{\pi}{4}(D^2-d^2)N}$$

$$V = \frac{(P_s)(\frac{\pi}{4})(D^2 - d^2)N}{4DL}$$

$$V = \frac{(0.0762\text{m})\left(\frac{\pi}{4}\right)(0.03^2)\left(\frac{542}{60}\right)}{4(0.03)(0.6604\text{m})}$$

$$V = 0.006m/$$

3.2.5 CONCEPTUAL DESIGN

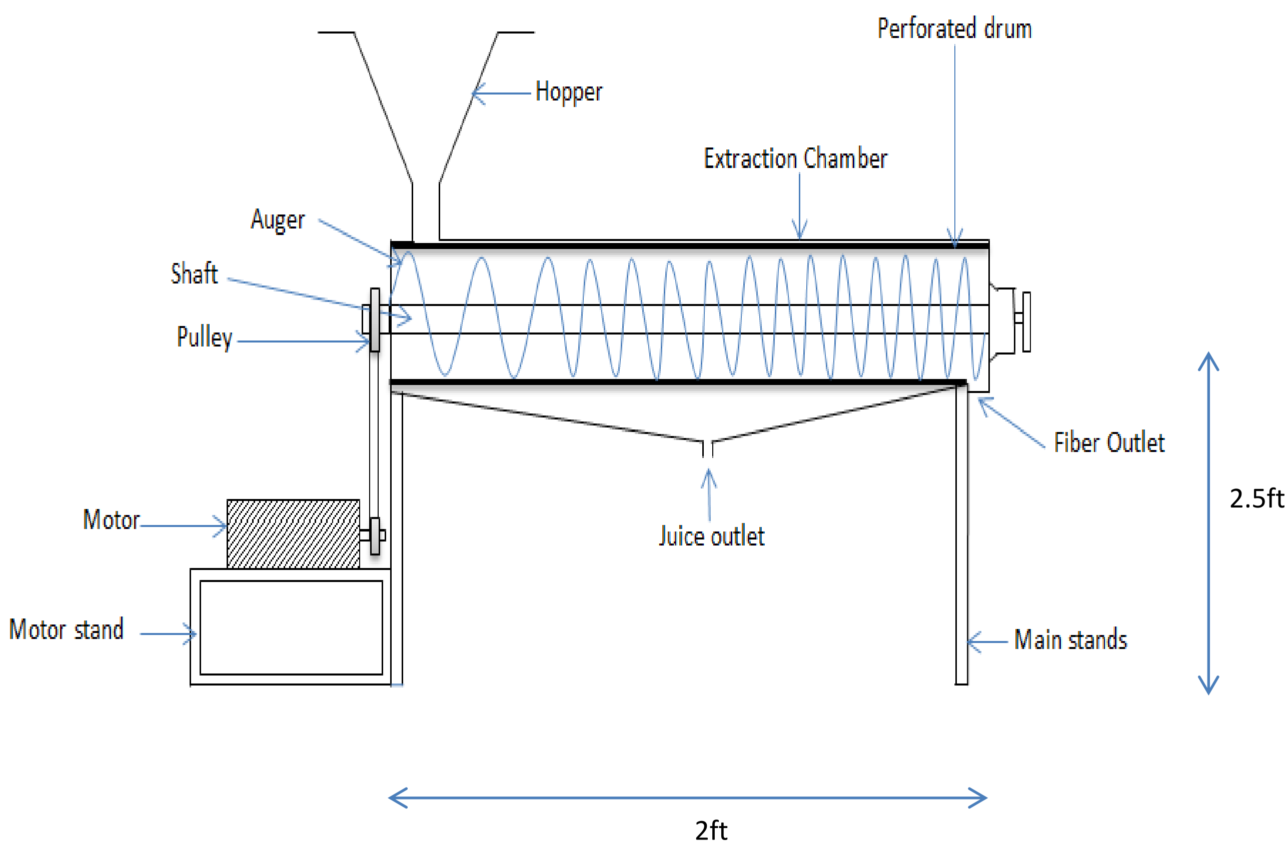

FIGURE 1: Outline of Juice Extractor

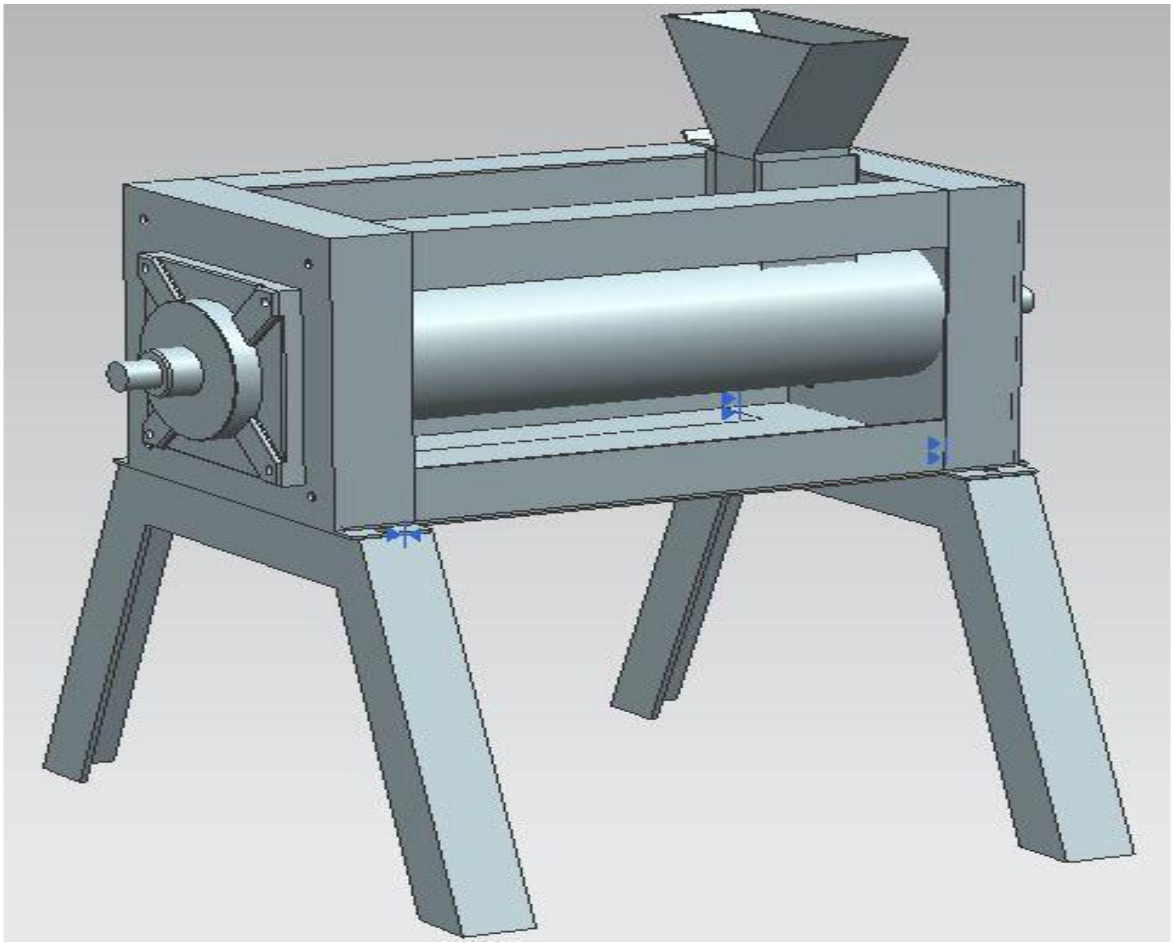

FIGURE 2 – Design of Mango juice extractor

3.2.6 ASSEMBLY DRAWINGS

All the assembly drawings were not drawn to scale and the units are in millimeters.

3.2.6.0 FRONT VIEW

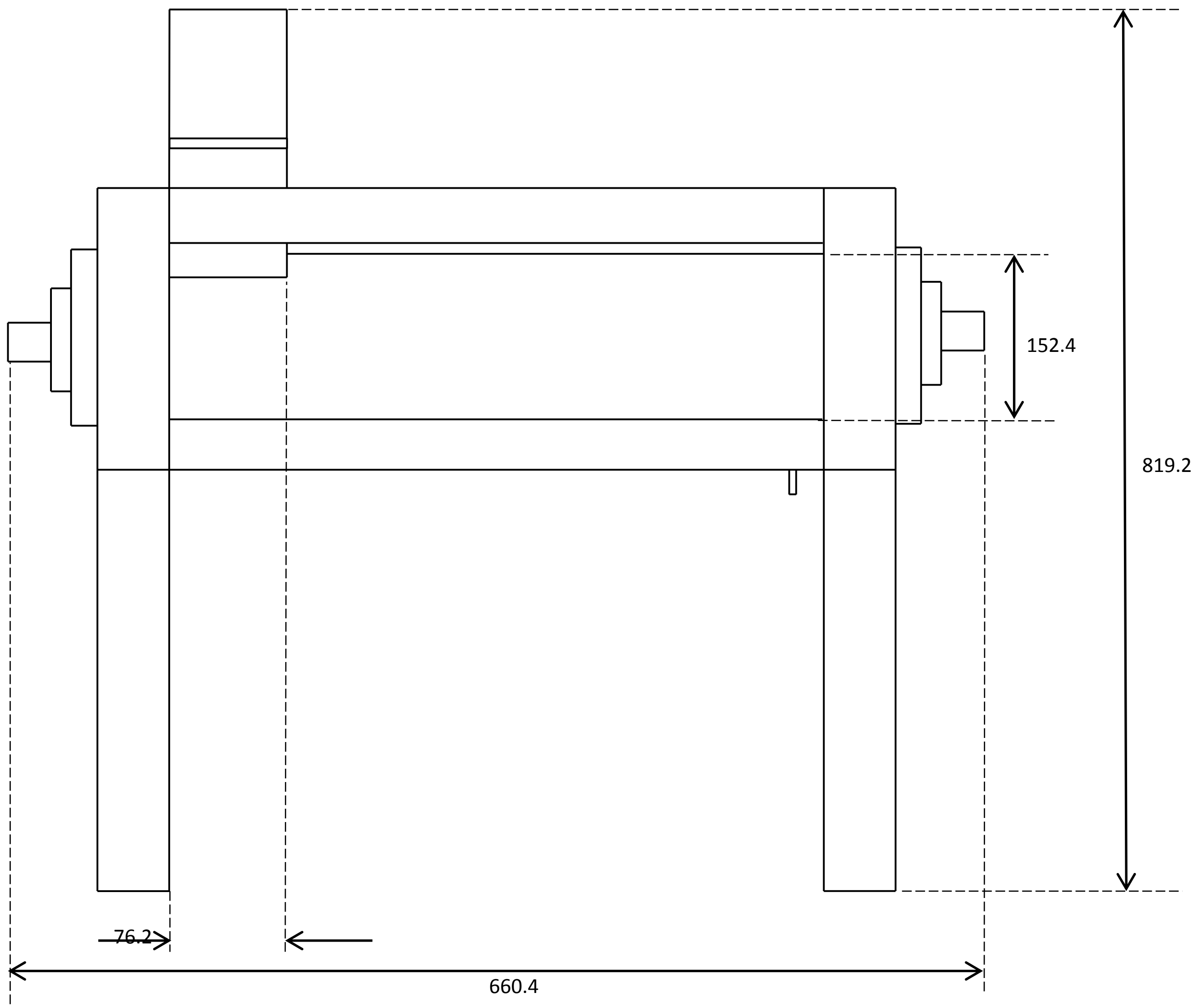

FIGURE 3 – Front view of extractor

3.2.6.1 SIDE VIEW

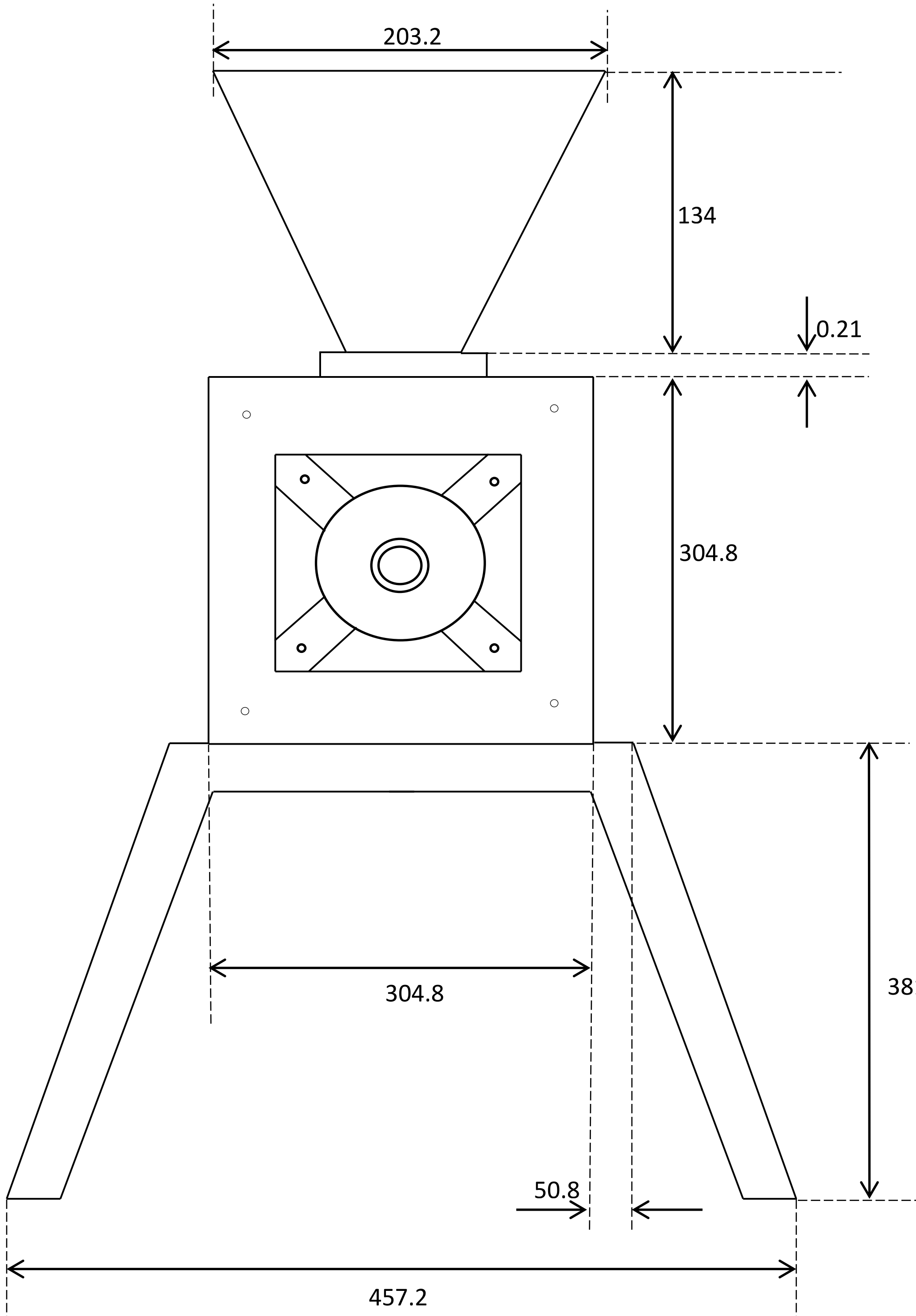

FIGURE 4 – Side view of extractor

3.2.6.2 TOP VIEW

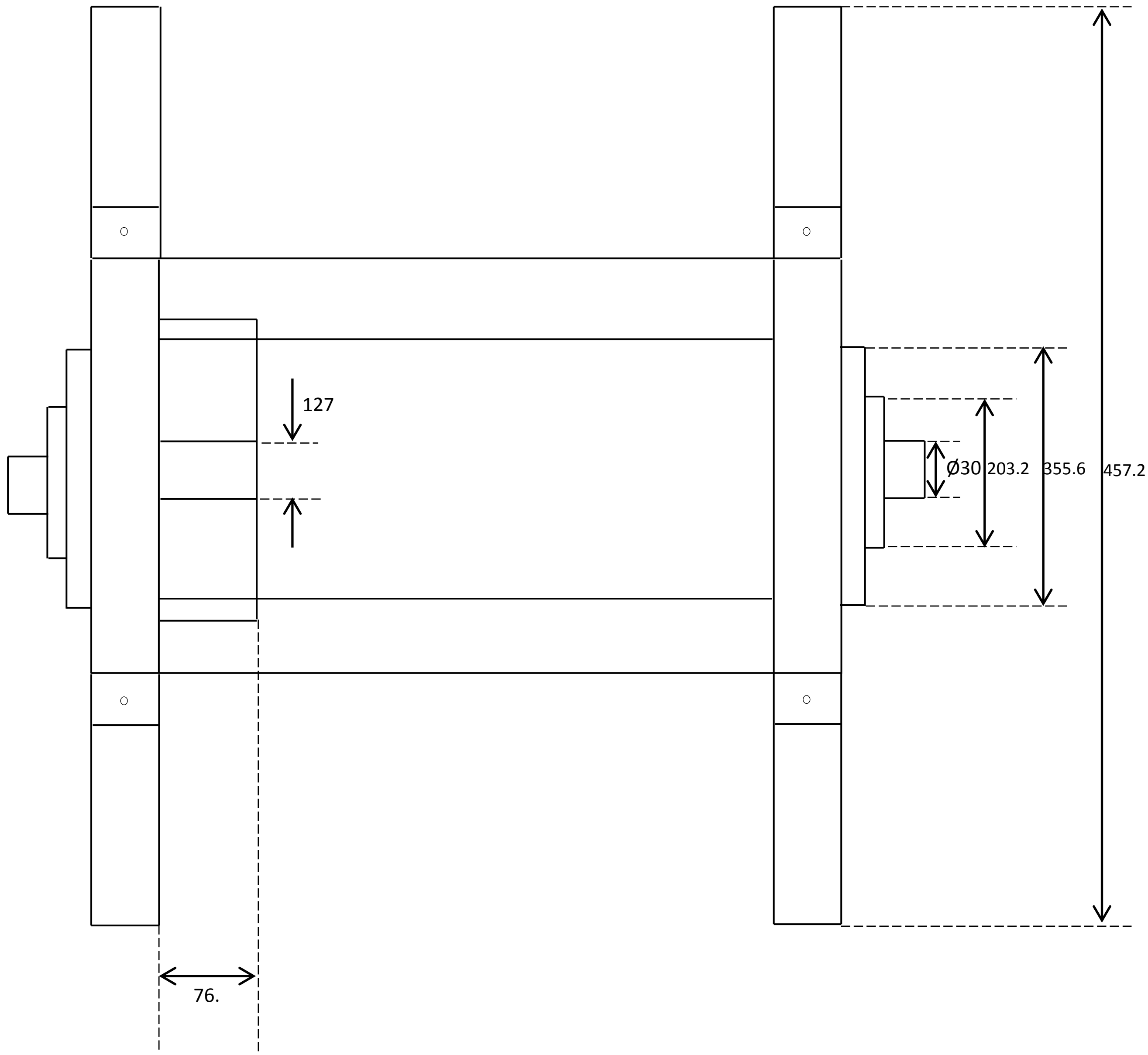

FIGURE 5 – Top view of extractor

3.2.7 MANUFACTURING PROCESS

The manufacturing process started by the fabrication of the perforated sieve and the framework of the machine. A stainless steel sheet of size 18 x 12 inches was cut. Holes were made on this sheet to create the rough perforating surface. The sheet was the n rolled with the perforated surface on the inside to a diameter of 6 inches and welding was done. Angle iron was used to create 2 plates to hold the perforated sieve in place and also, two stands to complete the framework of the machine. The screw auger was fabricated using stainless steel material of thickness 3mm and a shaft of diameter 30mm.

FIGURE 6: Framework of machine at its initial stage of construction

The shaft was machined and a keyway created on it using the lathe machine. Circular disks were cut and then welded to the shaft to form the auger. A base collector was made under the perforated sieve and a channel created through it for juice drainage. The base collector was slanted at an angle for easy juice flow during extraction. An outlet was created below the bearing. A gate was placed over the outlet to control the flow of substance out of it. A hopper of dimensions 3x3 inches was created and welded to the perforated sieve. A hole was then created to allow flow of material from the hopper to the auger. The machine was then assembled using bearing to hold the shaft at both end and the appropriate bolts and nuts were tightened to create a solid structure.

The mango juice extraction machine was tested using freshly harvested Keitt variety of mango. This is due to its large size, relatively low fiber content and firm juicy flesh. The fruits were washed, cut and the peels, mesocarp and seeds were weighed for both big and small fruits.

FIGURE 7: Setup of juice extractor

This helped to determine the size range of fruits used for the experiment. Mangoes used for the test ranged from 0.32 – 0.58kg in weight.

Specific weights of 1.4kg were taken each time an input is to be made. The time for extraction, weight of extracted juice and mango pulp were then determined after extraction. This helped to calculate the various wastages at the various speeds, hence, the efficiency of the machine at various speeds. The time and amount of juice extracted per each speed were recorded. Different speeds ranging from 300rpm to 600rpm were used in the test of the machine with the help of a variable speed motor and a tachometer for speed measurement.

The criteria for testing and analysis of the results was based on the extraction efficiency (J_E) and extraction loss (E_L) in percentage using Tressler and Joslyn (1961) equation as in Badmus and Adeyemi (2004) and Olaniyan (2010) as:

$$J_E = \frac{100W_{JE}}{W_{FS}}\%$$

$$E_L = \frac{W_{FS} - W_{JE} + W_{RW}}{W_{FS}}\%$$

Where,

W_{JE}= Weight of juice extracted, g

W_{RW}=Residual waste, g

W_{FS}=Feed sample, g

The analyzed data was then represented in table and on graphs for clearer interpretation.

CHAPTER 4
RESULTS AND DISCUSSION

The results obtained after the testing of the machine was represented in a tabular manner and also, graphically. The extraction losses and machine efficiencies were also calculated.

MANGO WEIGHT(kg)	SPEED(rpm)	TIME(s)	FINE JUICE EXTRACT(kg)	MANGO PULP(kg)	WASTAGE(kg)	EFFICIENCY
1400	300	156	429.4	146.9	823.7	30.67142857
1400	400	145	625.7	395.4	378.9	44.69285714
1400	500	125	836.6	420.8	142.6	60
1400	600	150	769.7	450.4	179.9	54.97857143

Table 1: Results from juice extractor test

4.0 EFFICIENCY OF MACHINE

The results from the data collected after testing the machine indicated the various efficiencies of juice extraction at various speeds. The efficiencies were calculated using the equation

$$J_E = \frac{100W_{JE}}{W_{FS}}\%$$

Where,

J_E = extraction efficiency

W_{JE}= Weight of juice extracted, g

W_{FS}=Feed sample = 1400g

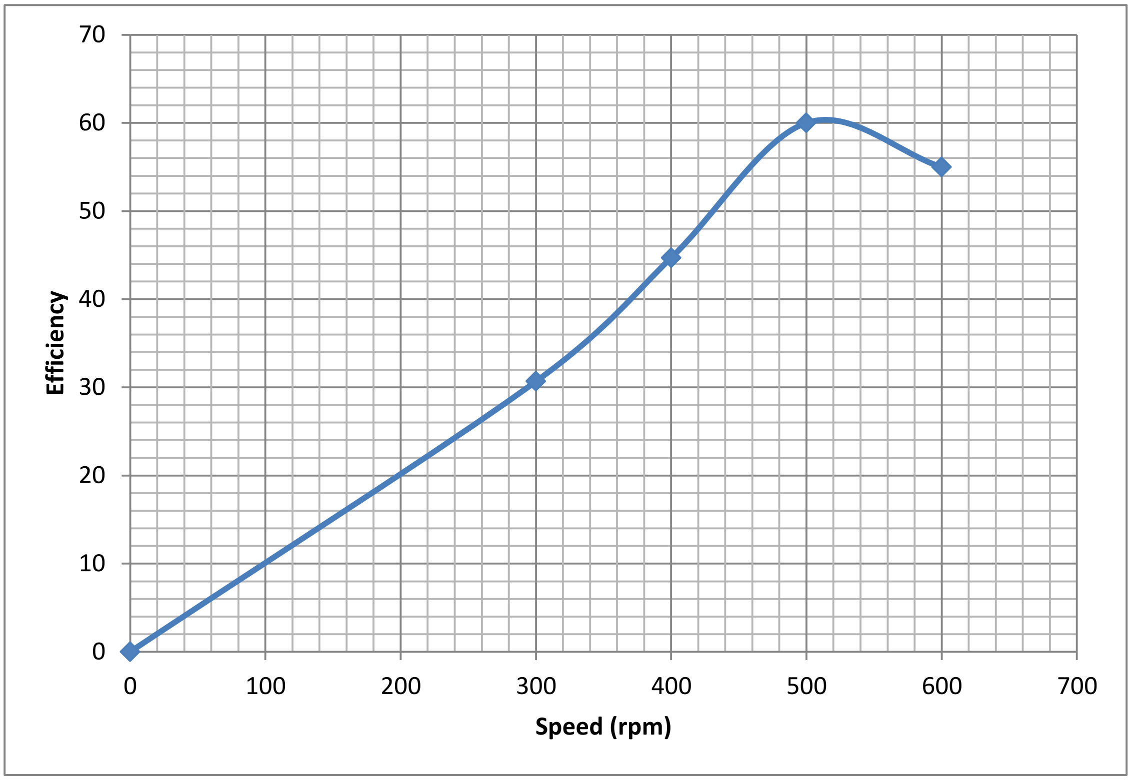

FIGURE 8: Graph of extraction speed against efficiency of machine

The loss percentages for each speed were also calculated as follows:

$$E_L = \frac{W_{FS} - W_{JE} + W_{RW}}{W_{FS}} \%$$

Where,

W_{JE}= Weight of juice extracted, g

W_{RW}=Residual waste, g

W_{FS}=Feed sample, g

The efficiency pattern showed that as the speed of the machine shaft was being increased, the efficiency increased to a speed of 500rpm where it started declining. As the speeds were changed, the efficiencies produced varied. This shows that, a change in speed directly affects the efficiency of the machine.

It was found out from the tests that the machine, when operating at 500rpm has the optimum efficiency of 60% as noted in Table 1. Also, it had an extraction loss percentage of 11.1%. This is an indication of the best speed to use in mango juice extraction using this machine. At speeds 300, 400 and 600rpm, the efficiencies were 31%, 45%, and 55% respectively. The machine efficiency increased as the speed increased, up to an optimum speed of 500rpm where the efficiency started declining. The lowest efficiency was recorded at a speed of 300rpm. This is due to the slow speed at which the shaft was turning. This made the fruits take a longer time to travel through the extraction chamber of the machine. Also, the centrifugal force developed in the machine that will drive the fruits to the outer edges of the auger to be pressed against the internal roughened surface of the perforated sieve for high juice extraction was inadequate. An object traveling in a circle behaves as if it is experiencing an outward force. This force, known as the centrifugal force, depends on the mass of the object, the speed of rotation, and the distance from the center. The greater the speed of the object, the greater the force: (UVPS, 2013)

The magnitude of this force increased as the speed was increased till 500rpm where the force was enough to aid juice extraction. At a speed of 600rpm, the centrifugal force produced is too high. Therefore, the fruits do not have adequate time to hit the surface of the perforated sieve for extraction. Also, due to the high speed, the fruits travel through the extraction chamber at a faster rate. When this happens, the traces of the original input are found coming out of the outlet. All these caused a decrease in the efficiency of the machine at speeds higher than 500rpm.

The efficiency of the machine can be linked to the type of mango used. Mango of variety Keitt was used in the testing because of its large size, relatively low fiber content and firm juicy flesh. This produces more juice during extraction to other varieties of mango. The Francine variety of mango, which is also a common kind of mango in our region, but is not highly patronized as compared to the Keitt variety, will produce less juice during extraction. This is due to its Sweet, rich flavor, tender flesh with limited fibers. Its creamy nature will produce a paste hence making it difficult for juice extraction.

FIGURE 9: Keitt mango variety

Source: www.wikimedia.org

FIGURE 10: Francine mango variety

Source: Mango Postharvest Management Practices manual (2009), pp. 9.

The stage of ripening of the mango can also directly affect the amount of juice extracted from the fruit. The way fruits ripen is that there is commonly a ripening signal, a burst of ethylene production. Ethylene is a simple hydrocarbon gas that ripening fruits make and shed into the atmosphere. Sometimes a wound will cause rapid ethylene production. Thus picking a fruit will sometimes signal it to ripen. This ethylene signal causes developmental changes that result in fruit ripening.

New enzymes are made because of the ethylene signal. These include hydrolases to help break down chemicals inside the fruits, amylases to accelerate hydrolysis of starch into sugar, pectinases to catalyze degradation of pectin (the glue between cells), and so on. Ethylene apparently turns on the genes that are then transcribed and translated to make these enzymes. The enzymes then catalyze reactions to alter the characteristics of the fruit.

The action of the enzymes causes the ripening responses. Chlorophyll is broken down and sometimes new pigments are made so that the fruit skin changes color from green to red, yellow, or blue. Acids are broken down so that the fruit changes from sour to neutral. The degradation of starch by amylase produces sugar. This reduces the mealy (floury) quality and increases juiciness (by osmosis, a process we will study later). The breakdown of pectin, thanks to pectinase, between the fruit cells unglues them so they can slip past each other. That results in a softer fruit. (Koning, 1994)

The time taken to extract juice at varying speeds was also recorded. The lowest time for extraction was also recorded at a speed of 500rpm. This is a clear indication that juice extraction at this speed produces the juice in the shortest time and at the highest efficiency of the machine.

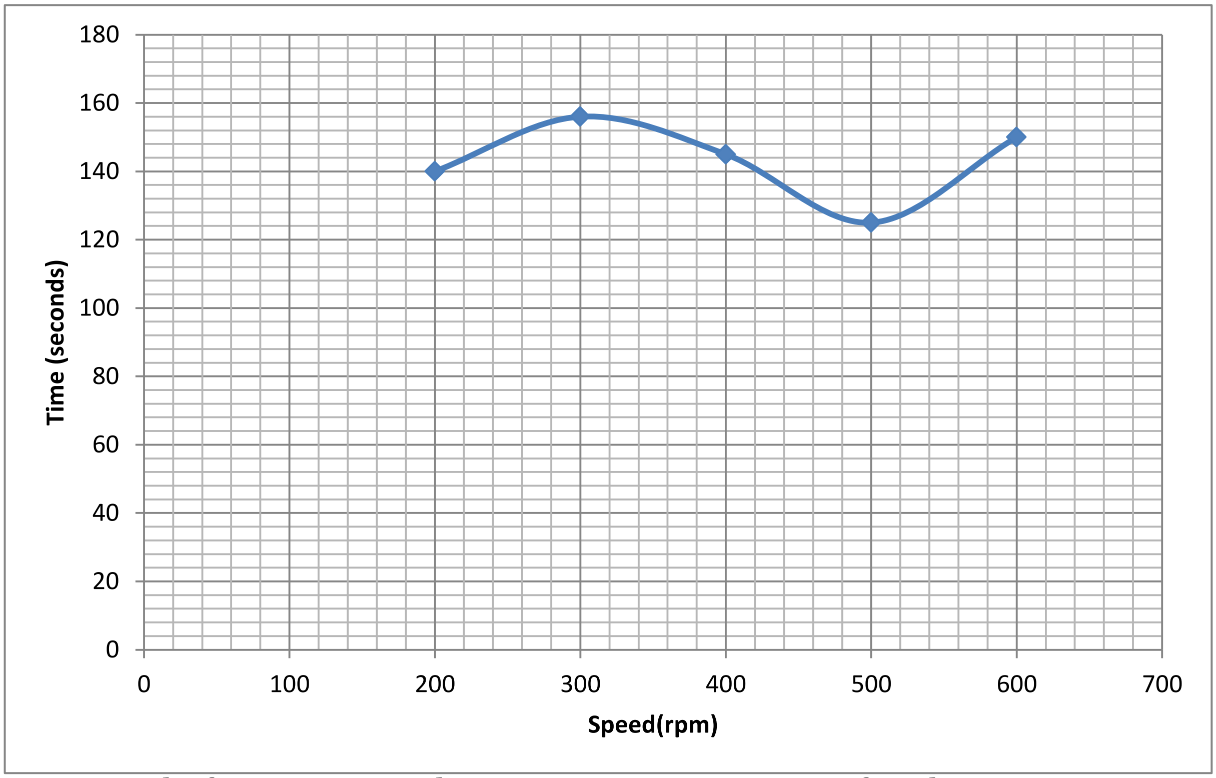

FIGURE 11: Graph of extraction speed against juice extraction time of machine

At speeds 200, 300, 400 and 600rpm, the times recorded were 140, 156,145 and 150. The speed time graph showed that the time for extraction increased from a speed of 200 to 300 and reduced to the least time of 125 second recorded at a speed of 500rpm. The time for extraction then increased as the speed increased to 600 and over.

4.1 CAPACITY OF MACHINE

A mass of 1.4kg of mango mesocarp was used during each test at the various speeds. At 500rpm, an input of 1.4kg of mango mesocarp produced juice equivalent to 620 milliliters within 125 seconds. Therefore, the machine has capacity of 40kg/h. The capacity of this machine has an effect on the amount of work that can be done in a day and how commercially the machine can be used. As machinery capacity increases, the number of hours required to complete an operation naturally declines. (William, 2013)

CHAPTER 5
CONCLUSION AND RECOMMENDATION

A machine that is used for the extraction of mango juice was designed, constructed and tested. All the materials needed in the construction were obtained locally. Therefore this machine can be produced easily in a local setting. The machine was found to be easy to operate, repair and maintain and this makes it suitable for local production. It operates on a 2.5 horse power single phase motor, a capacity of 40kg/h, efficiency of 60% and an extraction loss percentage of 11.1%. An improvement in the design of the screw conveyor of the can improve the efficiency of machine increasing its juice yield and reducing losses. The capacity of the machine was determined, the efficiency of the machine at different speeds was found out and the optimum operating speed of the machine was ascertained.

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APPENDIX

Shaft Diameter D (mm)	Moment of inertia I (m^4)	Weight per metre (kg/m)
20	7.85×10^{-9}	2.47
25	19.17×10^{-9}	3.85
30	39.76×10^{-9}	5.51
35	73.66×10^{-9}	7.99
40	125.66×10^{-9}	9.87
45	201.29×10^{-9}	13.00
50	306.79×10^{-9}	15.40
55	449.18×10^{-9}	18.70
60	636.17×10^{-9}	22.20
70	1178.59×10^{-9}	30.20

TABLE 2: Shaft diameters, Moment of Inertia and weight per meter

FIGURE 12: Speed reading using a Tachometer

FIGURE 13: Input of mango into machine