DESIGN, DEVELOPMENT AND PERFORMANCE EVALUATION OF A FRUIT JUICE EXTRACTION MACHINE

BY

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DECLARATION

I hereby declare that this dissertation titled "**Design, Development and Performance Evaluation of a Fruit Juice Extraction Machine"** was done by myself in the Department of Mechanical Engineering, Ahmadu Bello University Zaria, under the supervision of Dr. D.S. Yawas and Dr. M. Dauda. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this work has been presented for another degree or diploma in any institution.

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CERTIFICATION

This dissertation titled "**Design, Development and Performance Evaluation of a Fruit Juice Extraction Machine"** meets the requirements governing the award of degree of Masters of Science in Mechanical Engineering of the Ahmadu Bello University Zaria, and was approved for its contribution to knowledge and literary presentation.

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DEDICATION

To my parents, Chief and Mrs. T.G. Boih, and to the Most High God who is the custodian of all grace.

ACKNOWLEDGEMENTS

My gratitude goes to Almighty God for His guidance, protection and provision towards the success of this work.

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ABSTRACT

This research centers on the design, development and testing of a motorized juice extractor fabricated using locally-available materials. The machine is made essentially of two basic compartments: the chopping compartment and the juice extracting compartment. Other components include feeding hoppers, top cover, auger conveyor housed in a cylindrical barrel, juice sieve, juice collector, waste outlet, transmission belt, main frame, pulleys and bearings. In operation, fruits introduced into the chopping compartment via the first hopper are chopped/sliced and passed into the extracting compartment via a second hopper. The auger conveys, crushes, presses and squeezes the fruits to extract the juice. The juice extracted is filtered through the juice sieve into juice collector while the residual waste is discharged through waste outlet. When tested for freshly harvested pineapple, ginger and orange fruits, results show that the average juice yield for pineapple, orange and ginger were respectively 74 %, 72 % and 34 %; juice extraction efficiencies were respectively 84 %, 80 % and 71 %; and juice extraction losses were respectively 18 %, 16 % and 9 % at optimum machine speed of 335 rpm for pineapple and oranges, and 476 rpm for ginger. Powered by a 3hp electric motor, the machine has a capacity to process 30 litres/hr of oranges, 32 litres/hr of pineapples and 24 litres/hr of ginger and the machine costs of about ₦54,600, hence it is affordable for small-scale farmers.

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NOMENCLATURE

A_p	-	Pressing area (m^2)
D_m	-	Mean thread diameter
E_L	-	Extraction losses
F	-	Feed rate
F_C	-	Centrifugal force
g	-	Acceleration due to gravity (m/s^2)
J_E	-	Extraction efficiency
J_Y	-	Juice yield
ls	-	Length of shaft with blades
P	-	Power (Watts)
P_e	-	Power required for extraction (kW)
P_r	-	Pressure developed by auger
Q_e	-	Theoretical capacity of extractor
Q_{vc}	-	Volumetric capacity of extractor (litrs/hr)
S	-	Extraction speed
S_n	-	Number of blades on shaft
St	-	Spacing of blades

T	-	Torque transmitted by shaft
v	-	Inlet velocity of material (m/s)
W_e	-	Load lifted by auger (N)
W_{FS}	-	Weight of feed sample
W_{JE}	-	Weight of juice extracted
W_{RW}	-	Weight of residual waste
δ_a	-	Allowable stress
δ_o	-	Yield stress for stainless steel
$\propto$	-	Tapering angle
θ_n	-	Lift angle
μ	-	Coefficient of friction
Π	-	A constant (3.142)
ρ_g	-	Density of ginger (Kg/m^3)
ρ_o	-	Density of orange (Kg/m^3)
ρ_p	-	Density of pineapple (Kg/m^3)
□	-	Filling fac

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Before the discovery of crude oil in commercial quantity in the 1970s, agriculture was the mainstay and sustaining source of the Nigerian economy. The agricultural sector contributed immensely to the gross domestic product (GDP) of the nation. The discovery of oil and the boom that resulted from the exploitation of crude oil in the 70's inflicted a big blow on the agricultural sector as all attention was shifted to oil, leading to the neglect of this vital sector (Fasanya *et al.*, 2013). Various programmes such as Operation Feed the Nation (OFN) of 1976 and the Green Revolution of 1979 were embarked upon to ensure that there is enough food for the ever-growing population of Nigeria. This agricultural potential was what Nigeria exploited in the pre-independence and the post-independence period prior to 1975, which gave it its leadership position internationally in the production and export of agricultural products (CBN, 2004). Well over 50 % of the country's total export earnings came from the agricultural sector prior to the 1970s (CBN, 2004; Ndubisi *et al.*, 2013). Furthermore, the agricultural sector accounted for about 50 % of the GDP and employed about 72 % of the labour force on average between 1960 and 1970 (CBN, 2004; Fasanya *et al.*, 2013).

In developed countries like the USA, Germany, France, Italy, Canada and Great Britain etc., the productivity of the Agricultural sector is always on the increase. These achievements results from their high level of mechanization. However, mechanization has been difficult in Nigeria because of the high cost of imported machines and equipment and lack of indigenously designed, developed and built technologically advanced agricultural machines (Ekerete, 2000).

From the foregoing discussion, it became paramount to research, conceptualize, develop, design and produce low cost, durable and efficient machines to meet the basic needs. Such laudable developments will no doubt increase the mechanization of food production and processing in Nigeria. This will consequently lead to increase in both quantity and quality of agricultural products available locally and for export.

1.2 Statement of the Problem

Fruits are seasonal and therefore are not available in sufficient quantities throughout the year because it is difficult to store them in their natural form. The major problem is the high perishing rate of fresh fruits especially in the Sub-Saharan region (Olaniyan, 2010). A study carried out on fruits indicated that the losses were up to 30 % during the rainy season (Ndubisi *et al.,* 2013). This problem leads to scarcity as well as high cost of fresh fruits during the off-season. This has made it necessary for continuous research in ways to preservation of fruits. Extraction of the liquid content (juice) has been found to be one of the best methods for fruits preservation. Some fruit juices can take months or even years before they expire depending on how well they were preserved and packaged (Abulude *et al.,* 2007). In many areas they are plentiful but seasonal, thus expensive. An extractor from locally available materials is therefore necessary to effectively and efficiently extract juice from various fruit at a low cost so as to encourage fruit juice consumption for a healthy life. It is also desirable for longer preservation of the fruit.

1.3 The Present work

The present work is on the design, development and performance evaluation of a juice extractor with emphasis on high extract yield, simplicity in operation and maintenance, cost and hygiene using locally available materials.

1.4 Aim and Objectives

The aim of this work is to design, develop and carry out performance evaluation of a fruit juice extraction machine. The specific objectives are to:

i. Carry out the design analysis of the juice extractor.
ii. Construct the extractor and assemble it.
iii. Determine the optimum operating factors for the machine (extraction speed S and feed rate F).
iv. Evaluate the performance of the extractor (juice yield, extraction efficiency and extraction losses).
v. Evaluate the production capacity of the juice extraction machine.

1.5 Significance of the study

The dietetic value of well packaged fruit juice is far more than bottled drinks such as Pepsi, Coca-cola etc (Simmonds, 2000). If fruits juice could be substituted for this synthetic preparation, then it will prove a boom to the consumer as well as fruit farmer.

This project is very important in that it will encourage the commercial production of fruits and therefore help to boost the agricultural sector of the economy. It will help to beat down the cost of fruit juice which can adequately serve as a substitute to bottled drinks. As a result, the consumption of fruits will increase thereby improving the health of the common man. Juice will no longer be seen as a luxury for the high class.

The cost of importation of foreign extractors which tends to reduce the country's GDP will be greatly reduced.

1.6 Justification

Although successes have been recorded so far in the design and development of juices extractors, emphasis is always on such fruits that contain large quantity of liquid herein referred to as soft fruits like oranges, pineapple etc. There is the need for work to be done on the possibility of designing and developing a machine that can extract juice from both soft and hard fruits. Examples of such hard fruit are ginger, carrot, etc. This extractor is developed to assist small scale fruit farmers in the rural communities with a view to minimizing fruit spoilage.

1.7 Scope of study

The scopes of this project work are:

i. To efficiently and effectively develop a means of extracting juice from multiple fruits with emphasis on pineapple, ginger and orange fruits.
ii. To design and construct the prototype of the juice extracting machine.
iii. To test the fabricated prototype and evaluate its performance.

Meanwhile, preparation of fruits prior to extraction is very paramount. The preparation of fruit may just be washing with clean water for some fruits, but others may include peeling, removal of seeds (as is the case of cashew fruit). Peeling methods include manual peeling with knife and the use of suitable peeling machines.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter is a review of the literature that are pertinent to the studies carried out in this work. It also specifically considers some relevant concepts such as fruit juice extraction, agricultural fruits used for juice extraction, nutritional value of fruits and the principal methods of juice extraction from fruits.

2.2 Nutritional value of fruits

Fruits are one of the most important foods to mankind and its usefulness can be traced back to the early man ages when it serves as the foremost source of food for man during which he engaged in hunting and gathering so as to survive from age to age. These fruits contain vitamins, enzymes, minerals; natural sugars and cellulose (Davidson *et al.*, 1975). The nutrients contained in fruit juice can be absorbed within minutes. It has low calories and so fresh fruits juice should be included in any weight lose plan to provide abundant vitamin and mineral nourishment with little calories.

It has been estimated that over 70 % of cancer cases is attributed to diet. Several studies have shown that a diet high in fruits (especially Ginger fruits) protect against cancer which may be due to the high level of antioxidant these fruits contain. These antioxidants are compound found in the juice and skin of fruits which help to protect the body against free radicals and therefore may also have a role to play in preventing heart related diseases, ageing and cancer (Steinmtz and Potter, 1991). There are many different antioxidant; they include the vitamin A, C and E, the minerals manganese, selenium, zinc, copper etc.

(Davidson *et al.,* 1975). Vitamin C is required in the production of collagen, the substrate that give structure to muscles, veins, arteries, bones and cartilage. It helps to heal wounds and aids in iron absorption.

Fruit juice also contain Foliate, a B-group found imperatively consumed by women of child bearing age to help reduce the number of babies born with "spinal bifida". Fruit juices also contain Potassium in significant quantity which help to maintain fluid balance in the body and is also important for cell structure and nerve transmission. A recent scientific study shows that most men suffering from hypertension who ate food rich in potassium were found to have 60 % less chance of having stroke (Davidson *et al.*, 1975).

Drinking of fruit juice with a meal helps the body to absorb more iron from plant food especially to those segments of the population that is iron deficient. The high content of fruit sugar in grape fruits promotes secretion of bile and combats formation of gallstone and acid deposits (Steinmetz and Potter, 1991).

In spite of its extensive use and its obvious benefits to man, fruits have been viewed as a sort of luxury. Historically, this may be attributed to the fact that they are available only in seasons as fresh produce. Even today, fruits juices are considered by many to be a luxury and are far more commonly included in the diet of people from developed nations like USA. Fruit juice extraction is the process of squeezing the liquid content out of fresh fruits, to ease effective storage and prevent unnecessary wastage. The stages involve cutting, crushing, squeezing, pulping and pressing. Extraction can be done manually or mechanically depending on the volume of fruits to be processed. Fruit juice can be obtained from many types of fruit e.g. pineapple, apple, orange, ginger, cashew etc. This transformation of locally produced fruit helps to enhance profitable farming system in various parts of Nigeria (Ndubisi *et al.*, 2013). However, the processing facilities required for this transformation are inadequate and when they exist, they are usually imported with the attendant problems of maintenance and inadequate supply of raw materials in large quantities to keep the machine running efficiently (Akhigbe, 1989). Fruits processing should make the fruit safe for future consumption and maintain quality i.e flavor, odour, appearance and nutritional values. Fruits from which the juice is to be extracted must be fully ripe since this is when their sugar content and flavor are at optimal peak (Ameine and Gruess, 1972). As a result of this, fruits should be processed as near as to the harvest point so as to reduce transportation of fruits over long distance before processing. This will give fresher fruits and thus better quality of extracted juice.

2.3 Fruit juice extraction

Fruit juice extraction involves the process of crushing, squeezing and pressing of whole fruit in order to obtain the juice and reduce the bulkiness of the fruit to liquid and pulp. According to Abulude *et al* (2007), the various processes involved in fruit processing (Figure 2.1) include: sorting, washing, pressing, slicing, crushing and extraction, addition of additives, homogenization, pasteurization (heat treatment), packaging and storage.

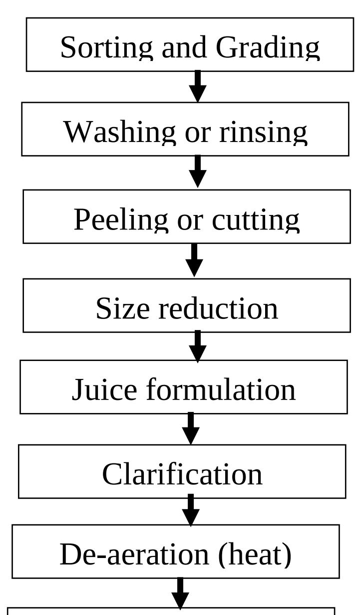


Figure 2.1: Flow chart for juice processing

There are two principal methods of juice extraction from fruits. In the first method, the fruits are crushed and pressed continuously in a single operation. In the second method, fruits are sliced into smaller pieces and then processed by a suitable pressing machine to extract the juice. The common types of juice extraction machines include: simple juicers, manual juicers and continuous juicers. Automatic juicers are sub-divided into centrifugal juicers and masticating juicers (Jackson, 1998).

Juice extraction industries have advanced rapidly in developed nations like United Kingdom, USA, etc. This development has enabled the use of juice extractors ranging from household type to the fully automatic juice lines which can produce liters of juice daily. Majority of our homes, hotels, food and marketing centers etc. use juice extractors of various designs and sizes.

2.3.1 Efficiency of extraction

Efficiency of extraction process is a function of yield of juice obtained and time taken to obtain it. It depends on the following factors: Viscosity of juice to be removed; resistance of the formation of solid phase of pulp; porosity of pulp and pressure or force applied. These factors are dependent on the physical characteristics of the pulp to be extracted and are subject to change in the course of extraction (Simmonds, 2000).

2.3.2 Traditional method of fruit juice extraction

In most local communities in the world, especially under-developed world, juice extraction from fruit has been found to be unique. This involves crushing and pulping with mortar and pestle or blender and then sieving through muslin cloth or plastic sieve (Adewumi and Ukwenya, 2012)

The merits include (Adewumi and Ukwenya, 2012):

i. The method requires no special skill
ii. Cost of extraction is low
iii. It requires no electricity for its operation

The demerits include (Adewumi and Ukwenya, 2012):

i. The volume that can be extracted is low. Hence, efficiency is low
ii. It is time wasting
iii. It requires high amount of human energy to perform the operation
iv. The process is hygienically poor

2.4 Agricultural fruits available for juice extraction

2.4.1 Ginger rhizome

Ginger (*Zingiber officinale Roscoe)* belongs to the plant family of *Zingiber Raceae*. It is an erect herbaceous plant which produces underground tuberous stems or rhizomes characterized by its strong essence. It is cultivated vegetatively as an annual crop in tropical regions to yield the fleshing underground rhizomes. Its importance as a spice is underscored by the fact that it is now grown on a commercial sale in many countries of the world.

Ginger is cultivated extensively in India, Nigeria, Jamaica, Sierra-Leone, Indonesia, China, Fizi and Australia, with India producing about 50 % of the world's production (Ajav and Ogunlade, 2014).

The cultivation of ginger in Nigeria started seriously around 1927, and today ginger is commonly grown in Kafanchan, Kagoro, Kachia, Zonkwa, Jaba and Kubacha areas of Kaduna state. Hence the state is today referred to as the traditional homes of ginger production in Nigeria and has placed the country on the world map as one of the major producers of ginger (Ajav and Ogunlade, 2014).

The economic importance of ginger cannot be over-emphasized as it has a higher market value per unit weight than most agricultural commodities and therefore very important both for export and domestic consumption. The main market outlet for ginger is the food, perfumery and pharmaceutical industries with the food having the highest share of ginger market. Researchers have shown that ginger is very effective in the treatment of cancer. Studies also showed that ginger reduces all symptoms associated with motion sickness including dizziness, nausea and vomiting. When swallowed, it acts as a stimulating tonic and is known to be very effective in alleviating symptoms of gastro intestinal distress and also contain very potent anti-inflammatory compounds called ginger oil which reduces level of rheumatoid when consumed (Ajav and Ogunlade, 2014).

Unlike citrus which will give out its juice on mere compression, ginger is a very hard fruit and has little quantity of liquid content; therefore there is the need to have the ginger split into pieces prior to juice extraction. Although these splitting can be done manually by hand with the use of knife, however it consumes a lot of energy and time.

2.4.2 Pineapple fruit

Pineapple fruit (*Ananas Comosus*) is highly perishable in its natural state after harvest and is vulnerable to spoilage by mechanical damage, chemical deterioration and environmental effects. Pineapple never becomes any ripened than it was when harvested, though a fully ripe pineapple can bruise and rot quickly. It should be used within two days of harvest when kept at room temperature. However, it can span for a period of seven days when properly stored in a fridge. Fresh pineapple is low in calories. Nonetheless, it is a store house of several unique health promoting compounds, minerals, minerals and vitamins that are essential for optimum health. Pineapple contains a proteolytic enzyme, bromelain, which breaks down protein. Bromelain also has anti-inflamatory, anti-clothing and anti-cancer properties. Studies have shown that consumption of pineapple regulary helps fight against arthritis, indigestion and worm infestation. Though it contain small amount of vitamin A but is very rich in B complex. Thus, it is highly essential to process the freshly harvested fruit into juice which can be consumed fresh or processed further into healthy beverages (Badmus and Adeyemi, 2004).

2.4.3 Orange fruit

Orange (*citrus sinensis*) is a dominant member of a large botanical family known as citrus. Other members of the family are tangerine (*citrus reticulata*), grape fruit (*citrus paradisi*), lemon (citrus limon) and lime fruit (*citrus aurantifoiia*). Orange is an economic crop in Nigeria and had long been planted in Lagos, Imo, Oyo and Benue states. The orange fruit is stored well on the tree and the ripe fruit utilized either as fresh fruit, processed into juice or frangrant peel. With a density of about 734 kg/m^3, orange fruit is a rich source of vitamin- C (Olaniyan, 2010)

2.5 Review of previous works

After an extensive search for information relevant to the scope of study, it was discovered that a number of locally fabricated fruit juice extractors have been developed.

Jackson (1988) worked on an electrically powered juice pulping machine. It consists of an auger-sieve combination mounted on top of an aluminum frame, a handle for manual operation and produces juice free of seed and skin. The fruit press consists of a crusher mounted on top with components like screw-thread, slated cage and a crusher. The machine is a lever operated press that grinds and crushes in one operation with an output of about 25 litres of juice per hour when operated by one person.

Adewumi (1999) designed, fabricated and tested a fruit juice extractor for citrus. The machine has a power requirement of 1.17 kW and is operated by a 1420 rpm electric motor. The extraction capacity and extraction efficiency of the machine were determined to evaluate the performance of the machine. The machine has an average juice extraction capacity of 5.11 and 2.79 kg/hr for orange and grape respectively. It equally has an extraction efficiency of 78.78 and 75.66 % for orange and grape respectively. For orange juice extraction, the extraction capacity of the machine was found to be 280 % of the manual extraction method and 304 % of the value obtained using the domestic extraction cup. For grape juice extraction, the extraction capacity of the machine was 220 % of the manual extraction method and 180 % of the value obtained using the extraction cup. The machine was further modified and the tapered auger was replaced with a straight auger. The modifications resulted in an increase in the juice extraction efficiency of the machine from 78.9 to 89.2% and juice extraction capacity from 5.1 to 15.8 kg/h for sweet orange. The fruits were reduced to uniform sizes and the effect of fruit size (thickness) and shaft speeds were studied with respect to machine juice extraction efficiency and capacity using regression analysis. Fruit thickness of 20, 40, and 60 mm and shaft speeds of 300, 400, 500 and 600 rpm were used for the test. Juice extraction efficiency and capacity showed very strong quadratic relationships with speed for the 3 sizes of pineapple and orange fruits studied. The exception was apple of 60 mm thickness which exhibited a very strong linear relationship be-tween shaft speed and machine capacity. The relationships among various parameters were established and the optimum speeds for peak performance of the machine at various fruit thicknesses were also recommended

Badmus and Adeyemi (2004) designed and fabricated a small scale whole pineapple fruit juice extractor. The machine consists of beater blades and a shaft in conjunction with a powered screw pressing mechanism. The machine successfully processed 12 kg of ripe pineapple fruit into 8 L of pineapple juice.

Ishiwu and Oluka (2004) developed and carried out performance evaluation of a juice extractor as a function of its extraction efficiency. The extractor consisted of a screw jack, frame, connecting screw rod, pressing mechanism, interlock, feeding pot, receiving pot and discharge mechanism. Performance tests revealed a juice yield, extraction efficiency and extraction loss of 76, 83 and 3 %, respectively

Kailappan *et al.* (2005) fabricated and evaluated a tomato seed extractor having a capacity of 180 kg of fruits/h. With a unit cost of $190, the extractor has a seed extraction efficiency of 98.8 %. Compared with manual seed extraction method, the extractor has a saving time and saving cost of 96.6 and 89.6 % respectively.

Olaniyan (2010) designed and constructed a small scale orange juice extractor using locally available construction materials. The essential components of the machine included feeding hopper, top cover, worm shaft, juice sieve, juice collector, waste outlet, transmission belt, main frame, pulleys and bearings. In operation, the worm shaft conveys, crushes, presses and squeezes the fruit to extract the juice. The juice extracted is filtered through the juice sieve into juice collector while the residual waste is discharged through waste outlet. Result showed that the average juice yield and juice extraction efficiency were 41.6 and 57.4 %, respectively. Powered by a 2 hp electric motor, the machine has a capacity of 14 kg/h. With a machine cost of about $100, it is affordable for small-scale citrus farmers in the rural communities.

Adewumi and Ukwenya (2012) designed and fabricated an extractor for the juice and pulp of mango fruit. The machine is made up of a main frame, the hopper, anger, extraction unit, shaft, juice outlet, belt and pulley, bearing, top cover and the machine frame. The shaft of the auger has a diameter of 18 mm. The auger has a pitch of 8.8 cm. The extractor requires a power 1.42 hp, and the production cost of the extractor is less than fifty thousand Naira (N50, 000. 00). Juice extraction efficiency, juice extraction capacity and thorough-put of the machine were determined at a speed of 300, 600 and 900 rpm. The highest juice extraction efficiency of 76 % was recorded at shaft speed of 300 rpm. The highest juice extraction capacity of 26.67 Lh^{-1} was recorded at shaft speed of 900 rpm. Also, highest thorough-put value of 14.36 g/s was recorded at shaft speed of 900 rpm. The study established linear relationships between shaft speed and juice extraction efficiency, juice extraction capacity and thorough-put of the machine.

Sylvester and Abugh (2012) designed and constructed an orange juice extractor. The machine has a diameter of 160 mm and a height of 350 mm. The juice extraction is achieved by means of small sharpened blades on a shaft which rotates with the aid of the bevel drive. The rotation is achieved by turning the handle. The machine is designed with ease of operation and high efficiency, and combine the extraction and beating often by macerating. It consists of two main parts – a goblet and a manually operated mechanical unit. The manually operated mechanical unit consists of a pair of bevel gear casings, two bearings and two shafts. It has a handle welded to the horizontal shaft. Small sharpened blades were made and fixed onto the impeller shaft. A bearing was then fixed underneath and a shaft passed through. A dynamic seal was put between shaft, bearing and the goblet to prevent leakage. The machine extracted about 180-220 oranges per hour into orange juice when performance test was carried out.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter describes in detail the design considerations, analysis, choice of materials, construction, operation and the experimental procedure required to test the fruit juice extractor for ginger, pineapple and orange.

3.2 Description of the Motorized Juice Extractor

Figure 3.1 shows the sectional view of the motorized juice extractor. It consists of two feeding hoppers, chopping shaft with spikes, screw conveyor housed in a cylindrical barrel, cake outlet, juice outlet and main frame.

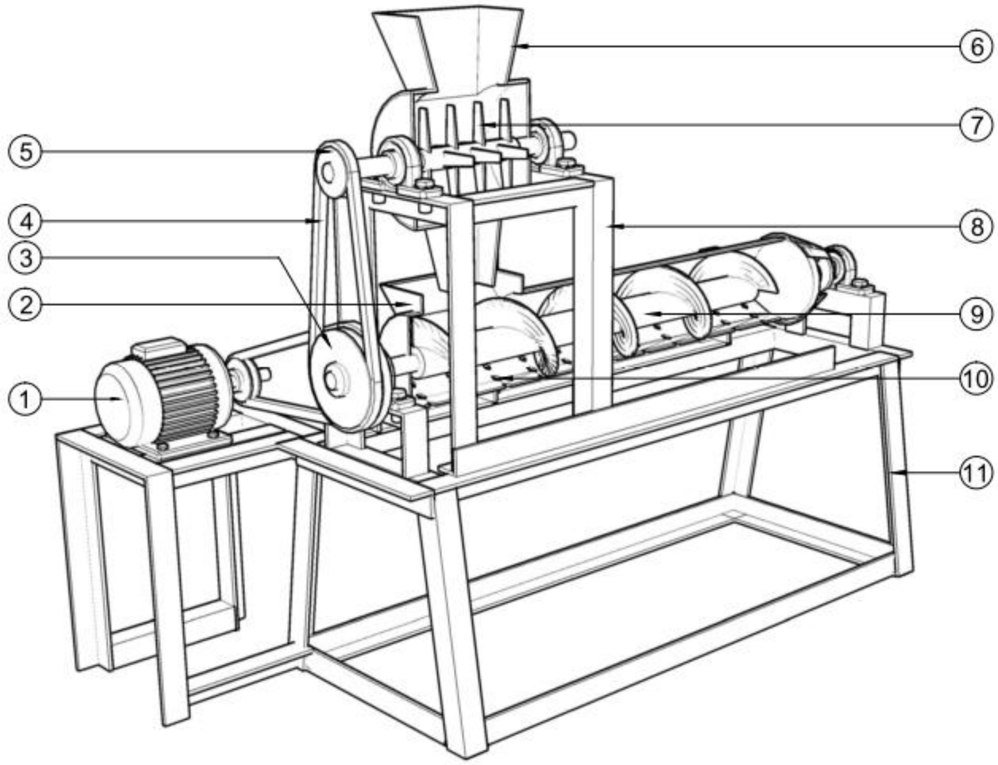


Figure 3.1: Sectional view of the motorized juice extractor

1 – Electric motor; 2 – Second hopper; 3 – Pulley; 4 – V-belt; 5 – pulley; 6 – First hopper; 7 – blades (knives); 8 – Chopping unit frame; 9 – Auger conveyor; 10 – Perforations; 11 – Main frame.

3.3 Assembly and Working Principle of the Motorized Juice Extractor

The motorized juice extractor was designed and fabricated in the Mechanical Engineering Workshop, Ahmadu Bello University Zaria, and assembled as shown in Figure (3.1).

The machine is so constructed that it will remain steady on the ground while in operation.

It consists of two feeding hoppers, chopping unit with spikes on shaft, screw (auger) conveyor housed in a cylindrical barrel, waste outlet, juice outlet and main frame. The juice extractor is designed to work on the principle of chopping, crushing and squeezing, and is made up of six units which include: main frame, feed hoppers, chopping unit, juice extraction unit, collecting unit and power transmission unit (Figure 3.1).

The main frame is made up of angle iron having an angle cross-section. The main frame forms a rectangular shape and supports and holds the machine components and gives it a compact design and a sturdy outlook.

The first hopper is mounted on top of the chopping compartment and the second hopper is mounted on top of the juice extraction barrel. The feed hoppers are trapezoidal in shape and inclined vertically in order to enable mass flow of feed into the chopping and extraction chambers of the machine. The hoppers have rectangular upper and base openings and are made of stainless steel sheet.

Below the second hopper base and mounted on the tool frame, is the barrel like juice extraction unit that formed a conveyor housing where juice extraction takes place. Through this housing runs a diameter tapered shaft from one end to the other with a tapered screw rolled around it. The shaft and screw assembly known as auger (screw) conveyor receives power via the speed reduction pulley assembly and runs in a journal bearing. The screw conveyor and housing provide the shear and compressive forces needed to crush the fruit and squeeze out the juice.

The screw conveyor is housed in a cylindrical barrel at a clearance of 2 mm between the screw diameter and the inside diameter of the barrel. In operation, fruits are introduced in the machine through the first feeding hopper. They are chopped and sliced in the chopping unit by means of the blades (knives) on the shaft and then passed into the cylindrical barrel via the second hopper, where they are crushed on their way into the barrel. The machine convey, crushes, grinds and presses the fruit inside the cylindrical barrel with the aid of the screw conveyor until juice is pressed out of the fruit. The juice extracted is drained through the perforation provided at the bottom of the cylindrical barrel. The residual cake is discharged at the cake outlet which houses a cone with a little clearance between the cylindrical barrel and the cone.

The flow chart below simplifies the operational sequence of the designed juice extractor.

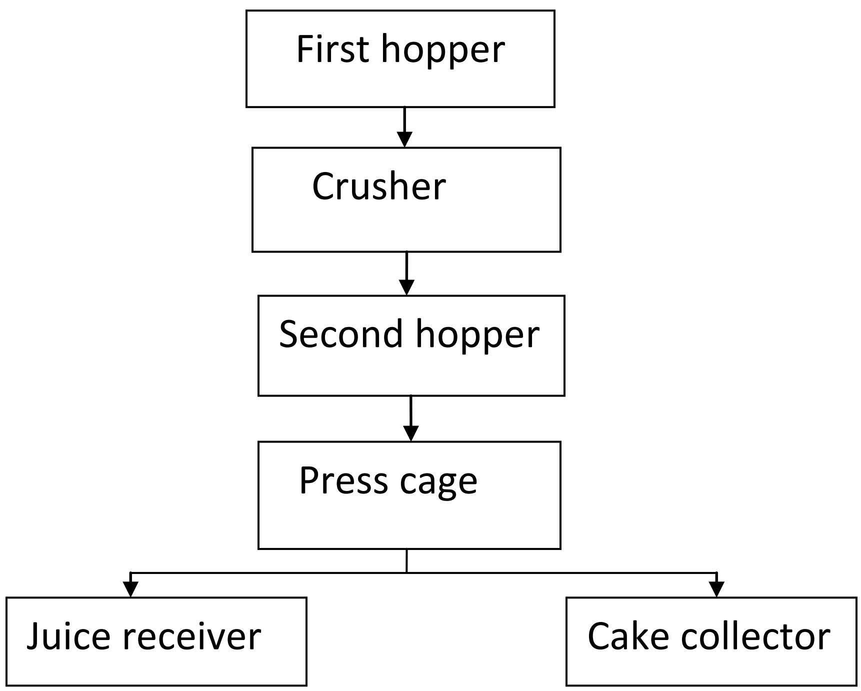


Figure 3.2: Flow chart showing the operational sequence of the designed juice extractor

3.4 Design Considerations/Specifications

The following assumptions were made during the design of the machine components:

i. Expected capacity of the extractor for pineapple, orange and ginger is respectively 60, 50 and 40 liters of juice per hour

ii. Density of orange, pineapple and ginger is respectively 734, 700 and 920 kg/m^3

iii. Density of mild steel = 7840 kg/m^3

iv. Power of electric motor = 3 hp

v. Selected length of shaft = 700 mm

vi. Coefficient of friction for stainless steel = 0.58

vii. Acceleration due to gravity, g = 9.81g/m^2

viii. Motor speed = 1440 rpm

ix. Maximum weight of shaft pulley = 40 N

x. Electric motor efficiency = 85 %

xi. Allowable shear stress of mild steel = 55 x 106 N/mm^2 for shaft without keyway (Khurmi and Gupta, 2005)

xii. Combined shock and fatigue factor applied to bending moment, kb = 1.5 (Khurmi and Gupta, 2005) Combined shock and fatigue factor applied to torsional moment, kt = 1.0 (Khurmi and Gupta, 2005)

xiii. Selected speed of shaft = 96 rpm

xiv. Filling factor = 0.9

xv. Coefficient of friction between belt and pulley = 0.52

xvi. Selected diameter of motor pulley = 65mm

3.4.1 Materials Selection

The following properties were considered in selecting the materials needed for the construction of the extractor:

i. Physical properties such as size, shape, density etc.

ii. Mechanical properties which include; strength, toughness, stiffness, fatigue, hardness and wear resistance

iii. Chemical properties: this includes resistance to oxidation and all forms of corrosion since the machine is to be used in processing food.

iv. Material availability: the materials used were selected based on their availability such that they can be obtained from the market with ease.

v. Cost of materials: materials used can be made available at a cheaper price to peasant farmers

vi. Cost of maintenance: replaceable parts were not welded to the machine frame in order to allow for easy replacement of parts.

vii. Strength of material: to avoid operational failure, the strength of the materials used was ascertained. These were determined by establishing data and formulae. Based on the data and formulae applied, the strength and size of parts such as auger, power of electric motor required, size of bearing and thickness of the sieve materials were determined.

viii. Durability and Hygiene: the machine will come in contact with easily oxidized food (liquid substance). It is therefore necessary to ensure all these parts coming in contact with the juice be made of stainless steel of appropriate strength. The use of stainless steel material for constructing the auger, shaft with blades, feed hoppers and juice collector will enhance the durability of the machine because of its corrosive resistance. However, for construction of the proto-type, ordinary mild steel was used but painted to reduce corrosion.

3.4.2 Description of the components of the juice extractor

3.4.2.1 Feed hoppers

The feed hopper is essentially the part of the machine through which the fruit is fed into the machine. The hopper acts as a container and at the same time helps in gradually introducing the fruits into the chopping and juice-extracting compartments. The hoppers are trapezoidal in shape in order to accommodate enough fruits and gradually introduce portions of the fruits by gravity into the chopping and extracting compartments. They are constructed from 2 mm thick stainless steel plate, and are two in number. The first is welded to the chopping compartment and the second is welded to the barrel of the machine to introduce chopped fruits into the extraction compartment of the machine.

3.4.2.2 The chopping compartment

The chopping compartment of the machine comprises the shaft with blades (knives) housed in a drum-like steel casing into which slicing of the fruits takes place. In operation, fruits from the first hopper are gradually introduced into the chopping unit; they are sliced by the knife blades on the shaft into smaller sizes and then moved by the machine into the extracting compartment via the second hopper.

3.4.2.3 Extracting compartment

The extracting compartment of the machine comprises the cylindrical barrel which houses a screw conveyor, and the pulley with bearing. The screw shaft is supported by the bearings at both ends as shown in Fig. 1. The auger (screw) conveyor and the barrel were both fabricated from stainless steel, and the pulley, fabricated from mild-steel is mounted on the screw shaft (made of stainless steel) with the main function of transmitting the rotary power (torque) from the electric motor to the juice extracting machine through the V-belt connection. The V-belts provide a means of changing speed.

3.4.2.4 The frame and stand

The frame and the stand, fabricated from angle iron bar are the parts of the machine that provide supports for both the juice extractor and the electric motor as shown in Fig. 1. The frame also provides rigidity when the machine is in operation.

3.4.2.5 The outlet compartment

The outlet compartment comprises two major outlets: the juice outlet and the cake outlet. The juice outlets are perforations drilled below the cylindrical barrel unto which a sieve made of stainless steel for juice collection attached. The cake outlet is joined to the posterior end of the barrel, and the two outlets are designed to discharge the extracted fruit juice and the fruit residue (or fruit cake) simultaneously.

3.4.2.6 The power unit

The power unit consists of a 3 hp single-phase electric motor with belts and pulleys and a gear box arrangement for speed variation. The motor powers the machine via v-belts, pulleys and gear box arrangement, and is mounted on a seating located at the base of the tool frame. The belt receives power from a pulley mounted on the motor shaft.

3.5 Design theories

3.5.1 Power requirement of the chopping unit

Power required for splitting the fruits can be calculated using the equation given by Hannah and Hillier, (1988) as:

$$P_c = F_c \times V \qquad (3.1)$$

Where:

P_c = power (watts)

F_c = Centrifugal force (N)

V = Velocity of the shaft with blades

The average shear force for orange was assumed to be 90 N

Assuming the centrifugal force of the shaft to be greater than the shear force (F_s) by 25 %

25 % of 90 N = 22.5 N

Therefore F_s = 90 + 22.5 = 112.5 N

3.5.2 Peripheral speed of the shaft with blades:

A shaft is a rotating member, usually of circular cross section (either solid or hollow) transmitting power. It is supported by bearings and supports gears, sprockets, wheels, rotors, etc. and is subjected to torsion and to transverse or axial loads, acting singly or in combination. The peripheral speed of the shaft with blades is given by Bhandari (2004) as:

$$V = \frac{\pi D n}{60} \quad (3.2)$$

Where:

D = diameter of blades

n = speed of shaft with blades

3.5.3 Design of the number of blades on the shaft.

The number of blades on the shaft is determined using the expression adapted from Adebayo *et al* (2014) as:

$$S_n = 2 \times \frac{l_s}{s_t} \quad (3.3)$$

Where:

S_n = the number of blades on the shaft

l_s = length of the shaft with blades

S_t = the desired thickness of lump (spacing of blades).

3.5.4 Volume of the feed hoppers

The feed hoppers are trapezoidal in shape in order to accommodate enough fruits and gradually introduce portions of the fruits by gravity into the chopping and extracting compartments. The volume of hopper can be calculated using the expression below:

$$V = \left\{\frac{1}{2}(A + B)\ D\right\} \times C \quad (3.4)$$

Where:

V = volume of hopper

D = height of hopper

C = width of upper end

A = upper length of hopper

B = lower length

3.5.5 Design of the screw conveyor of the extraction unit

The screw conveyor is the main component of the extraction unit and its shaft is acted upon by weights of the pulley and screw thread. In operation, the screw conveyor conveys, crushes, presses and squeezes the chopped fruit lumps for juice extraction. Therefore in order to safeguard against bending and torsional stresses, the diameter of the shaft was determined from the equation given by Khurmi and Gupta (2008) as:

$$d_s{}^3 = \frac{16}{\pi\delta_0}\sqrt{(k_b m_b)^2 + (k_t m_t)^2} \tag{3.5}$$

Where:

d = diameter of the shaft in *m*

δ_0 = allowable shear stress (55 x 106 N/m^2 for shaft without keyway)

K_b = combined shock and fatigue factor applied to bending moment

K_t = combined shock and fatigue factor applied to torsional moment

K_b = 1.5 and K_t = 1.0 (for load applied gradually)

M_b = maximum bending moment kNm

M_t = maximum torsional moment kNm

3.5.6 Design of the load that can be lifted by the auger

The load that can be lifted by the screw was determined from the equation given by Hall *et al* (2002) as:

$$W_e = T \frac{\frac{Dm\tan\theta}{2} + \frac{\mu}{\cos\alpha}}{(1-\mu\tan\theta\cos\alpha)} \qquad (3.6a)$$

$$\alpha = \tan^{-1}(\tan\theta_n \mathrm{Cos}\theta) \qquad (3.6b)$$

Where:

W_e = load that can be lifted by the screw (kW)

T = torque transmitted by the screw shaft

D_m = mean thread diameter

μ = coefficient of friction

θ_n = thread (lift) angle

$\propto$ = tapering angle

3.5.7 Design of the pressing area and pressure developed by the auger

The pressing area and the pressure developed by the auger were determined from equations (3.7) and (3.8) respectively given by Hall *et al* (2002) as:

$$A_p = \pi D_m nh \tag{3.7}$$

$$P_r = \frac{W_s}{A_p} \tag{3.8}$$

Where:

P_r = pressure developed by the auger

h = screw depth at the maximum pressure (discharged end);

n = number of threads.

3.5.8 Design of the pressure on the barrel

The pressure to be withstood by the barrel was determined from the equation (Ryder, 1985):

$$P_b = \frac{2t\,\delta_a}{D_i} \tag{3.9a}$$

Where:

P_b = pressure on the barrel

t = thickness of the barrel

D_i = the inside diameter of the barrel

δ_a = allowable stress, and ($\delta_a = 0.27\delta_o$) (3.9b)

δ_o = the yield stress for stainless steel

3.5.9 Design of the first pitch of the decreasing pitch auger

Auger flighting design considerations and nomenclature are presented in EP389.1 (ASAE, 1993). This engineering practice states that the pitch of the flighting should be between 0.9 and 1.5 times the outside diameter of the flighting. Therefore, the first pitch of the decreasing pitch auger is given by equation (*10)*, (*ASAE*, 1993) as:

$$P_s = 1.4D_s \qquad (3.10)$$

Where P_s and D_s are respectively the pitch and outside diameter of the auger

3.5.10 Design of the pitches of the decreasing pitch auger

The auger was designed to have pitches of decreasing order. In determination of the pitches, iteration method was used. A value was assumed for the first pitch (P(x)) in order to obtain a value for the inlet velocity (v) and then evaluate the remaining six pitches using iteration. The summation of the seven pitches must not be greater than the total length of the auger (0.7m). The auger was designed using a method by Jones and Kisher (1995) in: Gbabo *et al* (2013) as:

$$P(X_n) = \frac{4vD_sL}{\frac{\pi}{4}(D_s^2 - d_s^2)N} \qquad (3.11)$$

Where:

$P(X_n)$ = n^{th} pitch (m)

v = inlet velocity of fruit (m/s)

D_s = outside diameter of auger (110 mm)

d_s = inner diameter of auger (40 mm)

L = Length of auger (700 mm)

N = speed in rev/min of the screw shaft (365 rpm)

3.5.11 Design of the theoretical capacity of the extractor

The theoretical capacity of the extractor was determined using a modified form of equation given by Onwualu *et al* (2006) as:

$$Q_e = 60\times \frac{\pi}{4}(D_s^2 - d_s^2)P_sN_s\varphi \qquad (3.12)$$

Where:

Q_e = theoretical capacity of the extractor in *kg/hr*

D_s = diameter of the screw of auger *m*

d_s = base diameter of the screw shaft in *m*

P_s = pitch of auger in *m*

N_s = rotational speed of auger in *rpm*

φ = filling factor

3.5.12 Design of the volumetric capacity of the machine

The volumetric capacity of the machine is given by Onwuala *et al* (2006) as:

$$Q_{vc} = \frac{Q_e}{\rho} \qquad (3.13)$$

Where:

Q_e = the theoretical capacity of the extractor

ρ = the density of fruit in kg/m^3

3.5.13 Design of the power requirement for extraction

The power requirement of the machine for extraction can be calculated using the equation adapted from Hall *et al* (2002) as:

$$P_e = 4.5 \times Q_{vc} \times l_s \times \rho \times g \times F \qquad (3.14)$$

Where:

P_e = power requirement for extraction

Q_{vc} = volumetric capacity

l_s = length of screw shaft

ρ = density of the material

g = acceleration due to gravity

F = the material factor.

Therefore, the total power requirement is the sum of the power required for chopping and that required for extraction:

$$P_t = P_c + P_e \qquad (3.15)$$

Where:

P_t is the total power requirement of the machine.

The power of the electric motor to drive the system can be estimated from the equation given by Onwuala et al., (2006) as:

$$P_m = \frac{Pt}{\acute{\eta}} \quad (3.16)$$

Where:

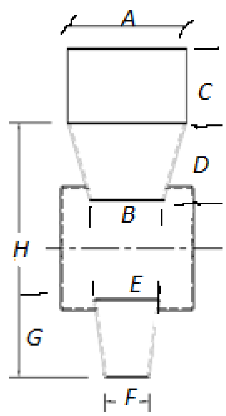
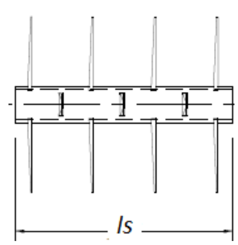
P_m = power of the prime mover and

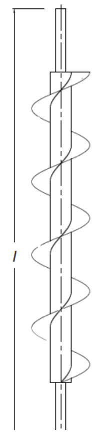
$\acute{\eta}$ = the drive efficiency.

3.6 Design Calculations

Table 3.1: Design calculations for the motorized juice extractor

Initial Data	*Calculation and Sketches*	*Results*
$\pi = 3.142$ $n = 500$ rpm $D = 0.3$ m	***Peripheral speed of the shaft with blades*** *From equation (3.2)* $V = \frac{\pi D n}{60}$ $V = \frac{3.142 \times 0.3 \times 500}{60}$	$V = 7.86$ m/s
$F_s = 90$ N	***Centrifugal force of the shaft with blades*** $F_c = F_s + 25\%$ of F_s $F_c = F_s + 22.5N$ $F_c = (90 + 22.5)N$	$F_c = 122.5$ N

F_c = 90 N V = 7.9 m/s	***Power requirement of the Chopping unit*** *From equation (3.1),* $P = F_c \times V$ $P = 112.5 \times 7.9$	P_c =0.89 kW
A = 300 mm B = 140 mm C = 300 mm D = 200 mm E = 180 mm F =110 mm G = 140 mm	***Volume of the upper and lower hopper*** *From equation (3.4),* $V_{upper} = \left\{\frac{1}{2}(A+B)\ D\right\} \times C$ $V_{upper} = \left\{\frac{1}{2}(300+140)\ 200\right\} \times 300$  $V_{lower} = \left\{\frac{1}{2}(E+F)\ G\right\} \times I$ $V_{lower} = \left\{\frac{1}{2}(180+110)\ 140\right\} \times 150$	V_{upper} = 44 mm^3 V_{lower} =20.3 mm^3
l_s = 145 mm S_t = 37 mm	***Number of blades on the shaft*** *From equation (3.3),*  $S_n = 2 \times \frac{ls}{St}$ $S_n = 2 \times \frac{145}{37}$	S_n = 8

T = 60Nm $\pi = 3.142$ δ_0 = 55 x 106 N/m^2 K_b = 1.5 K_t = 1.0 M_b = 0.01998 kNm M_t = 0.0247 kNm	***Screw conveyor of the extracting unit*** *From equation (3.5),* $d_s{}^3 = \frac{16}{\pi\delta_0}\sqrt{(k_b m_b)^2 + (k_t m_t)^2}$ $d_s{}^3 = \frac{16}{\pi\delta_0}\sqrt{(k_b m_b)^2 + (k_t m_t)^2}$ 	d_s = 20 mm
$\Theta = 3^0$ $\Theta_n = 15^0$	***Tapering angle*** *From equation (3.6b)* $\alpha = tan^{-1}\ (tan\theta_n Cos\theta)$ $\alpha = tan^{-1}\ (tan15^0 cos3^0)$	$\alpha = 14.98^0$
T = 60 Nm $\mu = 0.58$ $\Theta_n = 15^0$ $\Theta = 3^0$ $D_m = 0.09\ m$ $\alpha = 14.98^0$	***Load that can be lifted by the auger*** *From equation (3.6a),* $W_e = \frac{T \left(\frac{Dmtan\Theta}{2} + \frac{\mu}{cos\alpha} \right)}{(1-\mu tan\Theta cos\alpha)}$ $W_e = \frac{60 \left(\frac{0.09 \times 0.052}{2} + \frac{0.58}{0.966} \right)}{(1-0.58 \times 0.052 \times 0.966)}$	W_e = 13 kW
D_m = 90 mm *h =3 mm*	***Pressing area*** *From equation (3.7),*	A_p= 4241.7 mm^2

$\pi = 3.142$ $n = 5$	$A_p = \pi D_m nh$ $A_p = 3.142 \times 90 \times 5 \times 3$	
$A_p = 7069.5\ mm^2$ $W_e = 2.01\ kW$	***Pressure developed by the auger*** *From equation (3.8),* $P_r = \frac{We}{Ap}$ $P_r = \frac{13 \times 1000}{4241.7}$	$P_r = 3.06\ N/mm^2$
$\delta_0 = 200\ N/m^2$	***Allowable stress for barrel*** *From equation (3.9b),* $\delta_a = 0.27\delta_0$ $\delta_a = 0.27 \times 200$	$\delta_a = 54\ N/m^2$
$Di = 42\ mm$ $t = 12\ mm$ $\delta_a = 54\ N/m^2$	***Pressure on the barrel*** *From equation (9a),* $P_b = \frac{2t\delta a}{Di}$ $P_b = \frac{2 \times 12 \times 54}{42}$	$P_b = 30.86\ N/m^2$
$D_s = 110\ mm$	***First Pitch of decreasing pitch auger*** *From equation (3.10)* $P_s = 1.4 \times D_s$ $P_s = 1.4 \times 110$	$P_s = 154\ mm$

$P(X_1)=0.15$ m $L=0.7$ m $D_s=0.11$ m $d_s=0.04$ m $N=335$ rpm $\Pi = 3.142$	***Inlet velocity of material*** *From equation (3.11),* $v = \frac{P(X_1)\times\frac{\pi}{4}(D_s^2 - d_s^2)N}{4DL}$ $v = \frac{0.15\times\frac{3.142}{4}(0.11^2 - 0.04^2)335}{4 \times 0.11 \times 0.7}$	$v = 1.34$ m/s
$L_2 = 0.7 - 0.15 = 0.55$ m *Similarly,* $L_3 = 0.55 - 0.117 = 0.43$ m $L_4 = 0.43 - 0.09 = 0.34$ m $L_5 = 0.34 - 0.07 = 0.26$ m $L_6 = 0.26 - 0.05 = 0.211$ $L_7 = 0.21 - 0.04 = 0.166$	***Pitches of the decreasing pitch auger*** *From equation (3.11)* $P(X_2) = \frac{4vDL_2}{\frac{\pi}{4}(D_s - d_s)N}$ $P(X_2) = \frac{4\times1.34\times0.11(0.55)}{\frac{\pi}{4}(0.11^2 - 0.04^2)335}$	$P(X_2) = 0.117$ m $P(X_3) = 0.092$ m $P(X_4) = 0.073$ m $P(X_5) = 0.057$ m $P(X_6) = 0.045$ m $P(X_7) = 0.035$ m

$D_s = 0.11$ m $d_s = 0.04$ m $P_s = 0.15$ m $N_s = 335$ rpm □ = 0.9 $\Pi = 3.142$	***Theoretical capacity of the extractor*** *From equation (3.12),* $Q_e = 60\times \frac{\pi}{4}(D_s^2 - d_s^2) P_s N_s$ □ $Q_e = 60\times \frac{3.142}{4}(0.11^2 - 0.04^2)\times 0.15\times 335\times 0.9$	$Q_e = 22.4$ kg/hr
$Q_e = 22.4$ kg/hr ρ = 734 kg/m^3 (orange)	***Volumetric capacity of the machine*** *From equation (3.13),* $Q_{vc(o)} = \frac{Q_e}{\rho}$ $Q_{vc(o)} = \frac{22.4}{734}$	$Q_{vc(o)}$ = 0.030 m^3/hr = 30 litres/hr
P = 700 kg/m^3 pineapple $\rho = 920$kg/m^3 (ginger)	$Q_{vc(p)} = \frac{Q_e}{\rho}$ $Q_{vc(p)} = \frac{22.4}{700}$ $Q_{vc(g)} = \frac{Q_e}{\rho}$ $Q_{vc(g)} = \frac{22.4}{920}$	$Q_{vc(p)}$ = 0.032 m^3/hr = 32 litres/hr $Q_{vc(g)}$ = 0.024 m^3/hr = 24 litres/hr
$Q_{vc} = 0.03$ m^3/hr $l_s = 934$ mm $g = 9.81$ m/s^2 $F = 0.5$ $\rho = 734$ kg/m^3	***Power required for extraction*** *From equation (3.14),* $P_e = 4.5\times Q_{vc}\times l_s\times \rho\times g\times F$ $P_e = 4.5\times 0.03\times 0.934\times 734\times 9.81\times 0.5$	$P_e = 0.454$ kW

N_1 =40 rpm N_2 = 25 rpm	***Angular velocities of extraction and chopping pulleys*** *From equation (3.15)* $\omega = \frac{2\pi N}{60}$	$\omega 1 = 35.1$ rad/s $\omega = 52.4\ rad/s$
r_1 =0.08 m r_2 = 0.06 m Wp_1 = 40 N W_{p2} =25 N l_{ss} = 0.36 m	***Power required for driving the two pulleys*** *From equation (3.16)* $P_{p1} = T_1\omega$ $T_1 = W_{p1}r_1$ $P_{p2} = T_2\omega$ $T_2 = W_{p2}r_2$	 P_{p1} = 0.112 kW P_{p2} = 0.072 kW
D = 0.11 m D = 0.04 m ρ = 734 kg/m^3 g = 9.81 m/s^2 N = 335 rpm P = 0.15 m F = 0.5; l = 0.7 m	***Power required for driving the two shafts*** *From equation (3.17),* $P_{s1} = \frac{(D2-d2)\rho gNPfl}{8000}$ $P_{s1} = \frac{(0.0121-0.002)\times 734\times 9.81\times 625\times 0.15\times 0.5\times 0.7}{8000}$	 P_{s1} = 0.298 kW P_{s2} = 0.34 kW
  P_c =12.5 kW P_e =80.7 kW	 ***Total power requirement of the juice extractor*** *From equation (3.18),* $P_t = P_c + P_e + Pp1 + Pp2 + Ps1 + Ps2$ P_t = 0.89+0.45+0.112+0.072+0.32+0.34	 P_t = 2.186 kW
  P_t =2.186 kW	***Required electric motor capacity*** *1 hp = 0.746 kW*	 P_t = 3 hp

	$2.186\ kW = \frac{2.186}{0.746}$	

3.7 Construction Processes

The design specification gives particular and quantitative information about the machine to be constructed and takes certain factors such as ease of fabrication into consideration.

With respect to this work, fabrication involved the use of available tools, machines and technology to transform the design drawing in paper work to rigid components and assembly of the fruit juice extraction machine. The materials were selected based on the following requirements:

i. Rigidity
ii. Corrosion resistance
iii. Cost effectiveness
iv. Ease of fabrication and availability of equipment e.g. welding machine, hack saw, file etc.
v. Non reactivity to the juice to be extracted.

The requirements of relevant parts relating to function, stress condition and service life was considered by selecting suitable materials as described below:

i. The hopper: was constructed from 1 mm thick plate of stainless steel because of non-reactivity to juice.

ii. **The barrel:** was constructed from stainless steel of 4 mm thick for rigidity, resistance to corrosion and non-reactivity to juice compared with mild steel.

iii. **The frame**: was made from angle iron of 2 mm thick to provide rigidity, strength and ease of fabrication.

3.7.3 Fabrication of the Machine Components

The hopper was fabricated from a standard length of 1 mm thick stainless steel. Four pieces of dimension 2 mm × 40 mm were cut from the stainless steel plate and welded together to form the hopper. The shaft with blades in the chopping unit was fabricated from stainless steel rod of diameter 24 mm and length 145 mm. A stainless steel plate of thickness 2 mm was welded spirally round the extraction shaft to form a screw system of uniform pitch. The main frame was made from angle iron of 4mm thickness and dimension 6200 mm × 20 mm × 20 mm and welded together. Fabrication process included marking out, machining, cutting, joining, drilling and fitting.

The fabrication process of the components is detailed in the table below:

Table 3.2: Fabrication process for the motorized juice extractor

S/N	***Component***	***Material used***	***Procedure***	***Tools used***
1	*Hoppers*	*Stainless steel*	*The work piece was cut into four pieces of required dimensions and welded to form the hoppers (drawing number 8)*	*Hammer, arc welding and grinding machines*
2	*Spikes on shaft*	*Stainless steel*	*The spikes were cut from the work piece and welded on the shaft after machining to required dimensions (see drawing number 7)*	*Milling machine, welding machine and grinding machine*

3	*Cylindrical barrel*	*Stainless steel*	*A hollow pipe of required diameter and thickness was cut and used.*	*Drilling machine, filing machine, and milling machine*
4	*Auger conveyor*	*Stainless steel*	*The work piece was made into an helix of five circular discs and welded together to form the screw blade in an helical form*	*Arc welding machine, grinding machine, hammer, electric cutter and hand saw*
5	*Juice sieve*	*Stainless steel mesh*	*The work piece was cut to the required dimensions and fastened below the perforations on the cylindrical barrel*	*Center punch, drilling machine*
6	*Main frame and electric motor stand*	*Mild steel angle iron*	*The work piece was cut to the required dimensions and welded together to form the main frame and electric motor stand*	*Power hacksaw, welding machine*
7	*The top cover*	*Stainless steel*	*The work piece was cut to the dimensions and then hinged on top of the first hopper to form the top cover.*	*Hand saw, electric cutter, hammer and arc welding machine*

3.8 Performance evaluation of the motorized juice extractor

After fabrication, the performance evaluation of the motorized juice extractor was carried out to determine the optimum juice extracting parameters for the machine. The extracting parameters considered are:

i. **Operating factors:** This included feed rate (F) at three levels (F_1 = 2.5, F_2 = 3.0, and F_3 = 3.5 kg/min) and extraction speed (S) at five levels (S_1 = 96, S_2 = 208, S_3 = 335, S_4 = 476, and S_5 = 632 rpm).

ii. **Performance parameters:** This included juice yield, J_Y (%), juice extraction efficiency, J_E (%) and extraction losses, E_L (%).

3.8.1 Test procedure

Bulk quantities of freshly harvested pineapple, orange and ginger were purchased from a local store in Zaria, Kaduna State. The fruits were washed, cleaned and damaged ones discarded. The undamaged ones were weighed into three portions of 2.5, 3.0 and 3.5 kg each for juice extraction. The machine was set into operation by the power source and known weights of each fruits were fed into the chopping unit via the first hopper where they were sliced into lumps by the machine, and then delivered by gravity into the extraction unit via the second hopper. In the extraction unit, the auger (screw conveyor) crushed, squeezed and pressed the lumps thus extracting the juice from the fruits. After extraction, the mass of fruits fed into the machine, mass of juice extracted, mass of residual waste (chaff) and juice constant of the fruits (in decimal) were recorded. The mass of juice in chaff was determined using the method of ASAE (1993), which involved oven drying the chaff at 130 ^oC until a constant weight was reached. Each experiment was replicated thrice for pineapple, orange and ginger. The test was carried out at different extraction speeds with the aid of v-belts and pulleys. The performance evaluation of the motorized juice extractor was carried out using the following expressions given by Olaniyan and Oje (2011):

$$J_Y = \frac{100W_{JE}}{W_{JE} + W_{RW}}\% \quad (3.17)$$

$$J_E = \frac{100W_{JE}\%}{xW_{FS}} \quad (3.18)$$

$$E_L = \frac{100[W_{FS} - (W_{JE} + W_{RW})]\%}{W_{FS}} \quad (3.19)$$

Where:

W_{JE} = Juice extracted (kg)

W_{RW} = Residual waste/dry chaff (kg)

W_{FS} = Feed sample (kg)

J_Y = Juice yield (%)

J_E = Extraction efficiency (%)

E_L = Extraction loss (%)

The juice constant was obtained from the ratio of sum of masses of juice extracted and juice in chaff to the mass of fruit fed in.

$$x = \frac{(w_{JE} + w_{JC})}{w_{FS}} \quad (3.20)$$

Where:

x = Juice constant of fruit (decimal)

W_{JC} = Juice in the chaff

The juice constant (x) for pineapple, orange and ginger were determined to be 0.77, 0.84 and 0.90 respectively, and applied in equation (3.18) to calculate the juice extraction efficiencies for pineapple, orange and ginger as shown below:

$$J_Y = \frac{100W_{JE}}{W_{JE} + W_{RW}} \%$$

For F1:

$$J_Y = \frac{100 \times 2.44}{2.44 + 0.77} = 76.01 \%$$

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

$$J_E = \frac{100 \times 2.44}{0.73 \times 3.3} = 95.8 \%$$

$$E_L = \frac{100\ [W_{FS} - (W_{JE} + W_{RW})]}{W_{FS}} \%$$

$$E_L = \frac{100\ [3.5 - (2.44 + 0.92)]}{3.5} = 3.9 \%$$

3.9 Cost Analysis of the Juice Extractor

An important factor in design and construction is the cost of production. The purpose of fabrication would not be achieved if at the end of production, the produced machine is not affordable by the targeted customers. This factor has been duly considered resulting to the choice of relatively cheap and reliable materials as summarized below:

Table 3.3: Material cost of the fruit juice extractor

S/N	*Material*	*Specifications*	*Quantity*	*Unit cost (₦)*	*Total cost (₦)*
1	*Mild steel angle iron*	*50×50 mm, standard length*	*4*	*1500*	*6000*
2	*Stainless steel rod*	*ϕ 20 mm*	*1*	*3500*	*3500*
3	*Stainless steel rod*	*ϕ 24 mm*	*1*	*2500*	*2500*
4	*Cast iron Pulley*	*ϕ 110 mm*	*1*	*1250*	*2500*
5	*Cast iron pulley*	*ϕ 160 mm*	*1*	*700*	*700*
6	*Cast iron ball bearing*	*ϕ 20 mm*	*1*	*1500*	*1500*
7	*Cast iron ball bearing*	*ϕ 20 mm*	*1*	*1500*	*1500*
8	*Stainless steel plate*	*2 mm thickness, ¼*	*2*	*1500*	*1500*

		standard size			
9	*Stainless steel mesh*	*1 mm thickness, ¼ standard size*	*1*	*800*	*800*
10	*Bolt and Nuts*	*M12*	*10*	*40*	*400*
11	*V-belt*	*B65*	*2*	*150*	*300*
12	*Electric motor*	*3 hp*	*1*	*15,000*	*15,000*

Table 3.4: Labour and overhead cost

S/N	*Type of labour*	*Amount (₦)*
1	*Cost of fabrication and assembly*	*10,000*
2	*Cost of transportation and miscellaneous*	*3000*
3	*Total labour cost*	*13,000*

Grand total cost of the motorized juice extractor = ₦ 41,600 + ₦ 13000 = ₦ 54,600

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Results

The results of the tests carried out on the motorized juice extractor for pineapple fruits, orange fruits and ginger are shown in Figures 4.1 to 4.9 and Tables A1 to A6.

4.1.1 Machine performance results using pineapple fruits

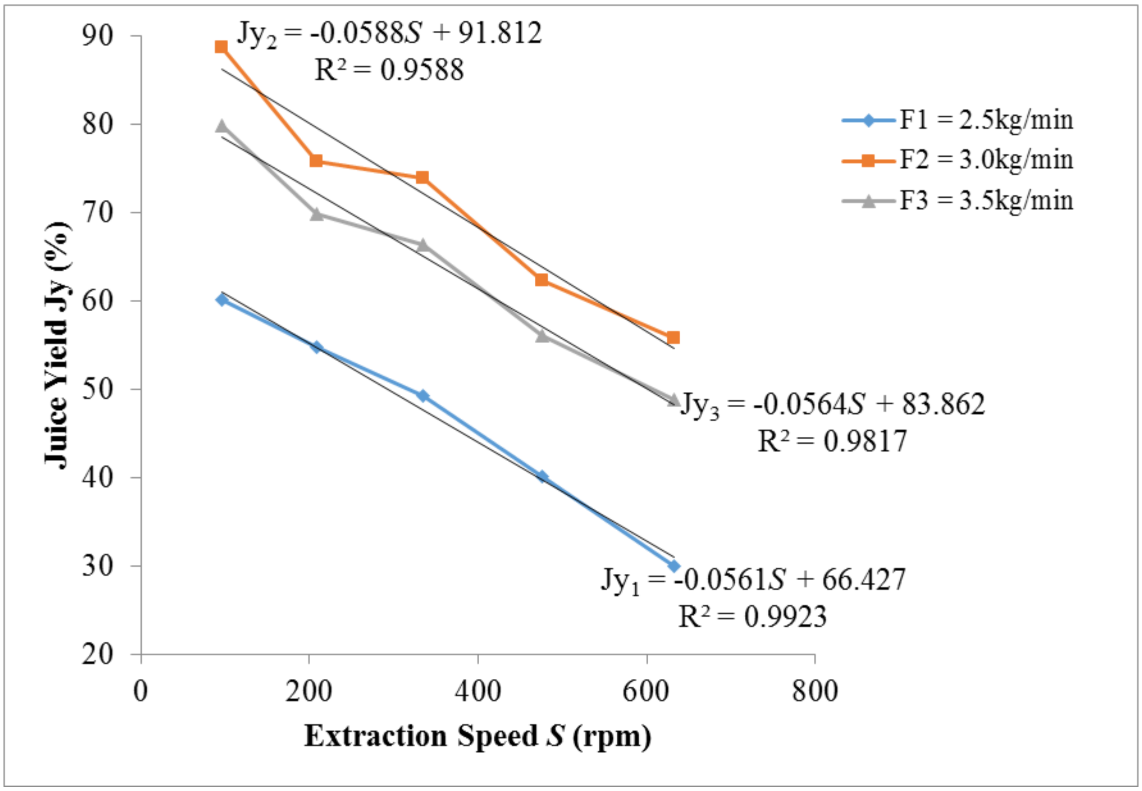


Figure 4.1: Variation of Juice yield versus juice extraction speed and feed rate for pineapple fruits

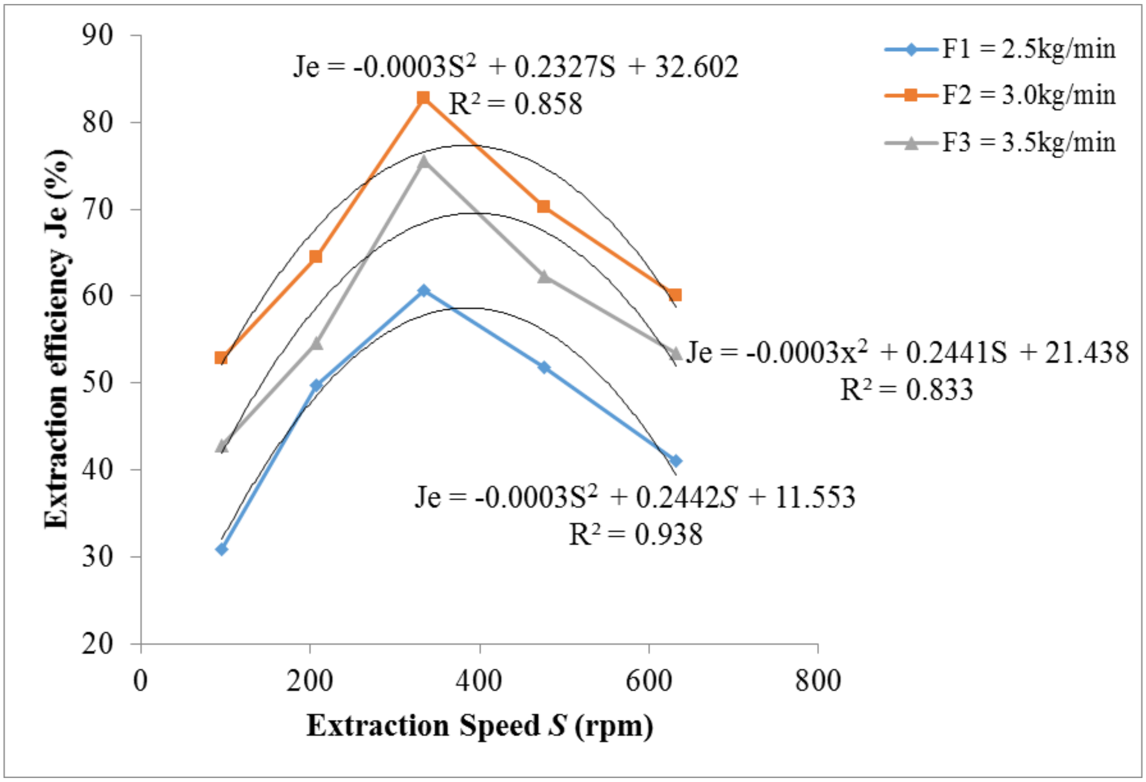


Figure 4.2: Variation of extraction efficiency versus juice extraction speed for pineapple fruits

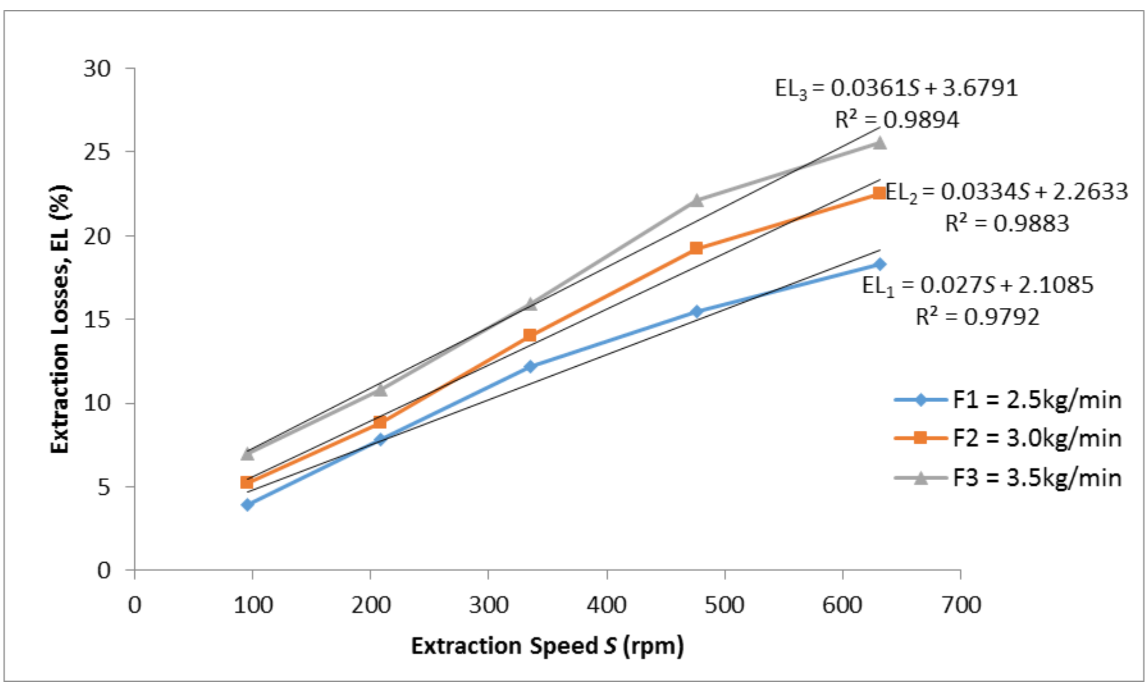


Figure 4.3: Variation of extraction losses versus juice extraction speed and feed rate for pineapple fruits

4.1.2 Machine performance results using orange fruits

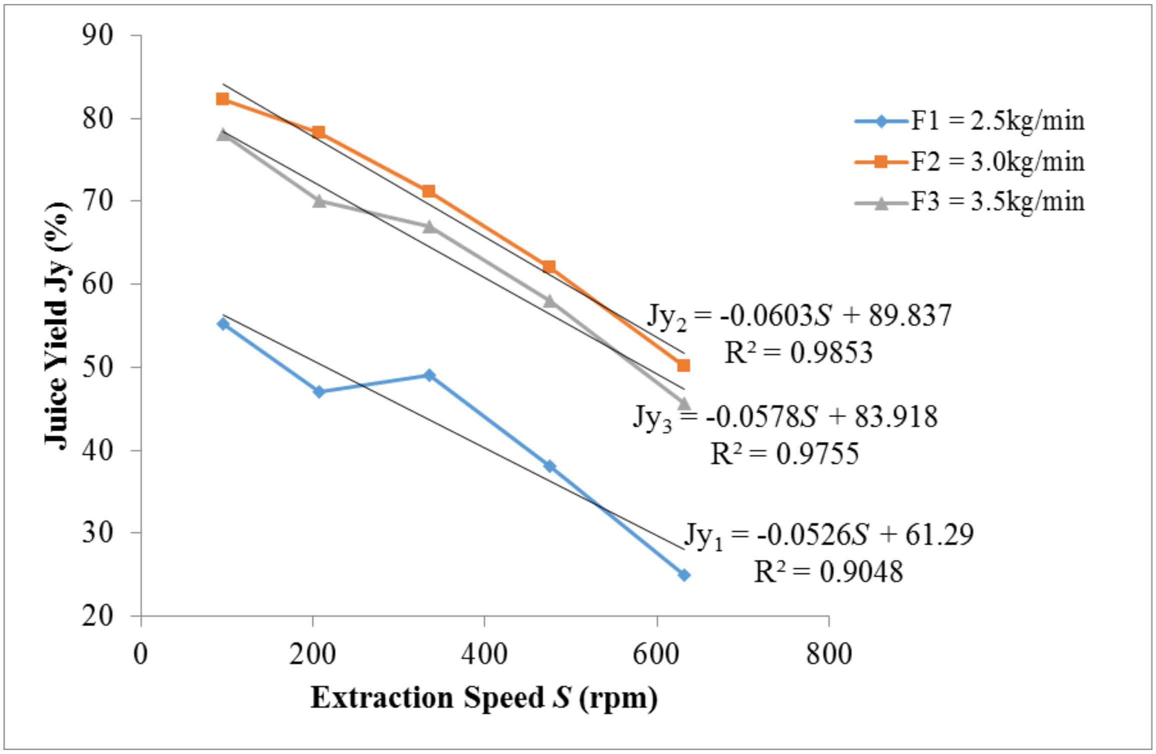


Fig 4.4: Variation of Juice yield versus extraction speed and feed rate for orange fruits

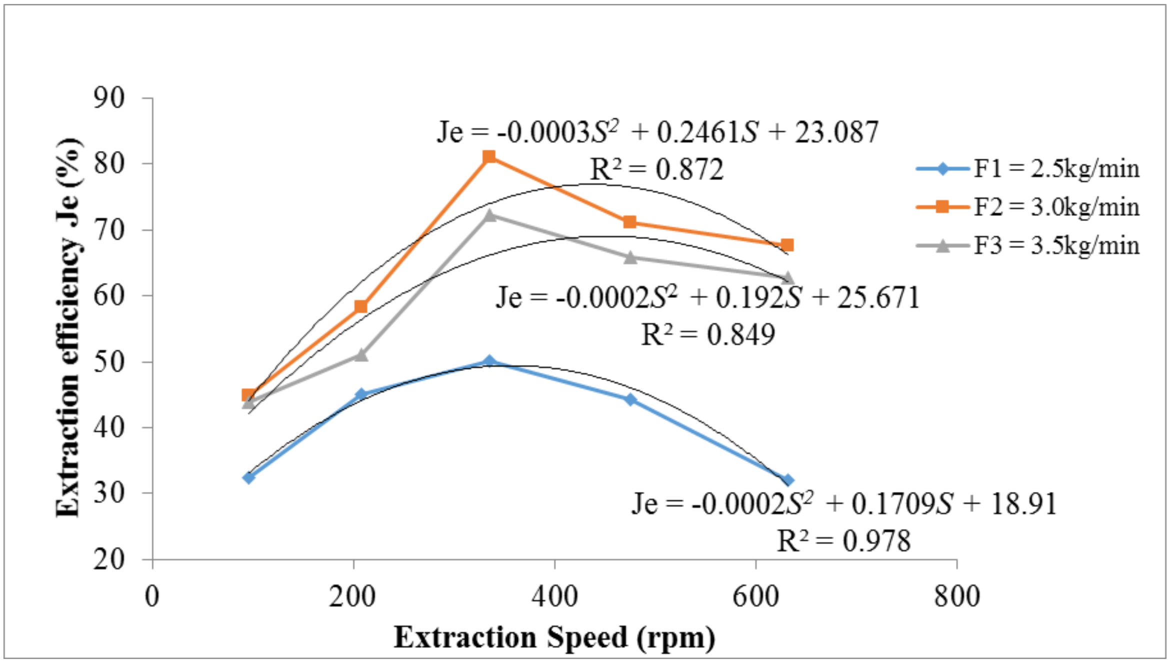


Fig 4.5: Variation of juice extraction efficiency versus juice extraction speed and feed rate for orange fruits

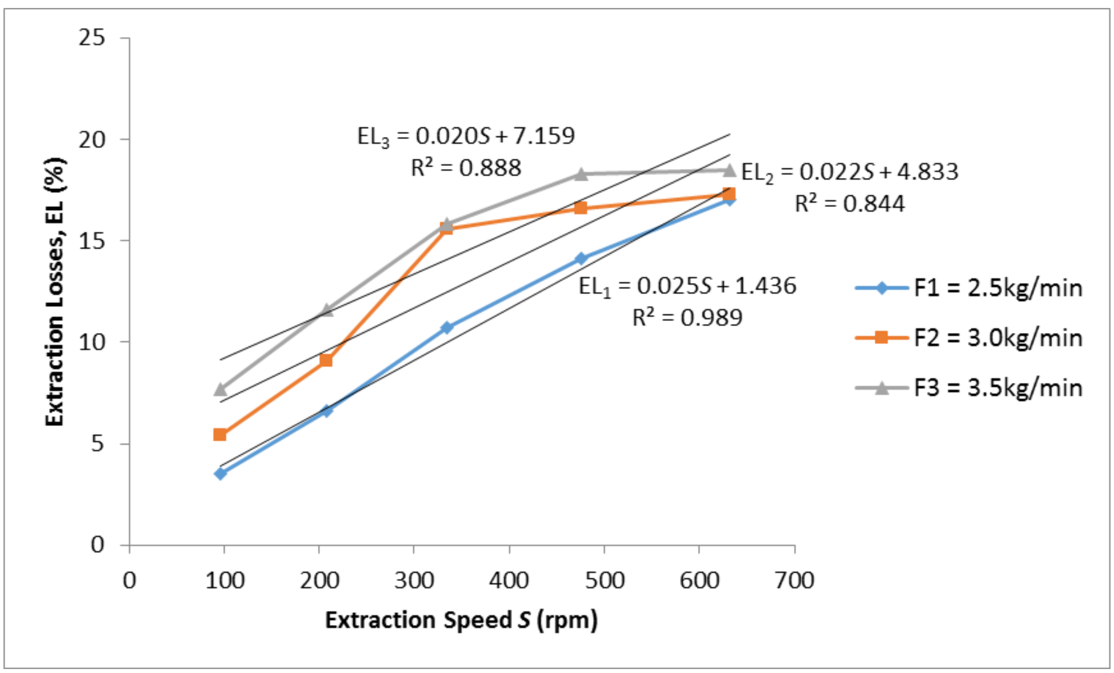


Fig. 4.6: Variation of juice extraction losses versus juice extraction speed & feed rate for orange fruits

4.1.3 Machine performance results using ginger

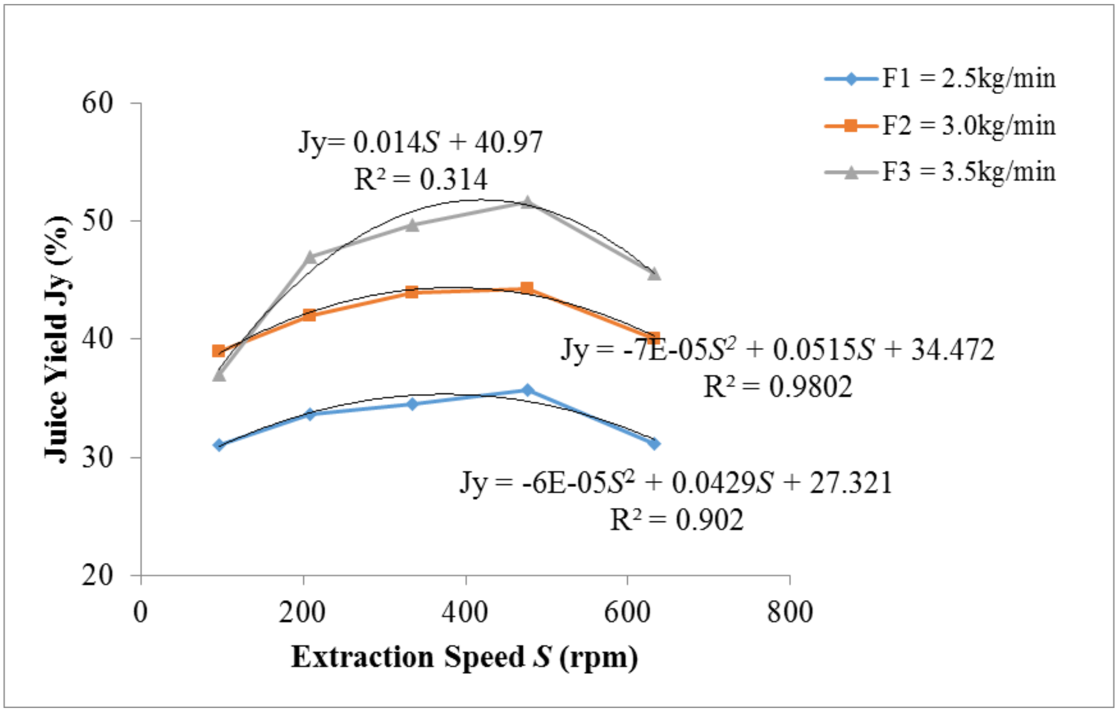


Fig. 4.7: Variation of juice yield versus juice extraction speed and feed rate for ginger

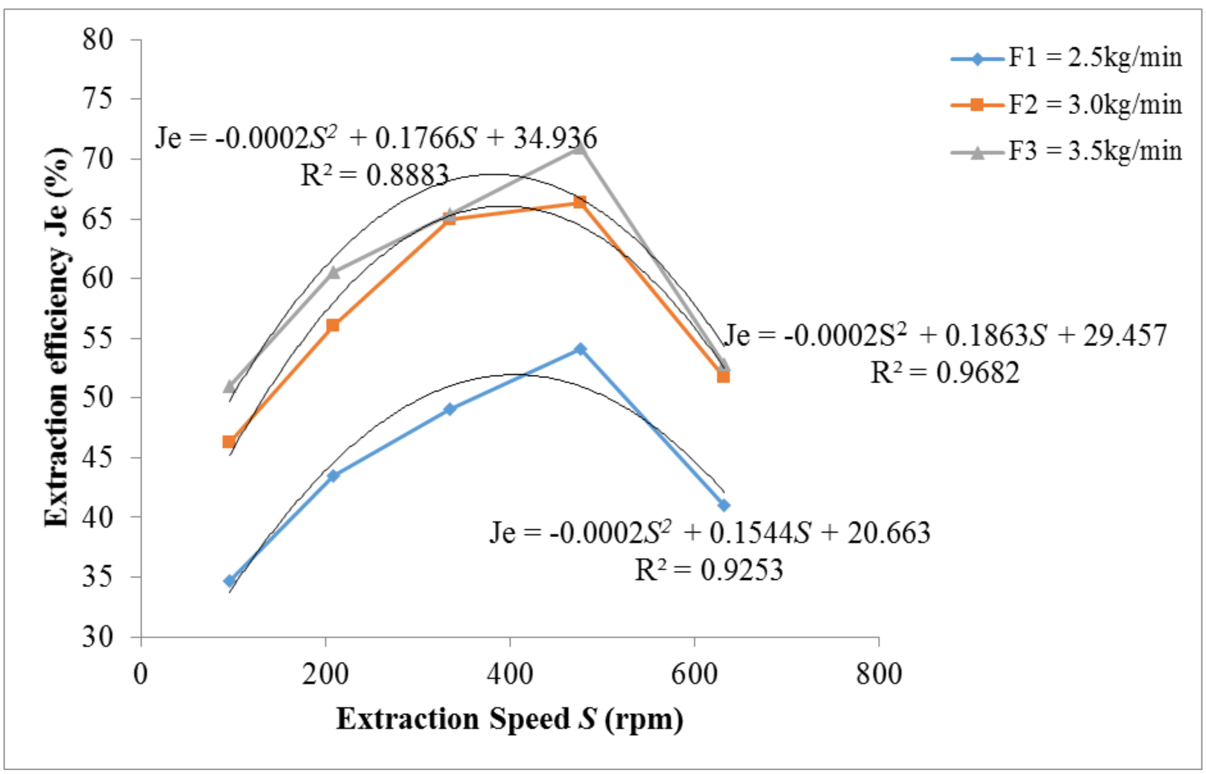


Fig. 4.8: Variation of juice extraction efficiency versus extraction speed & feed rate for ginger

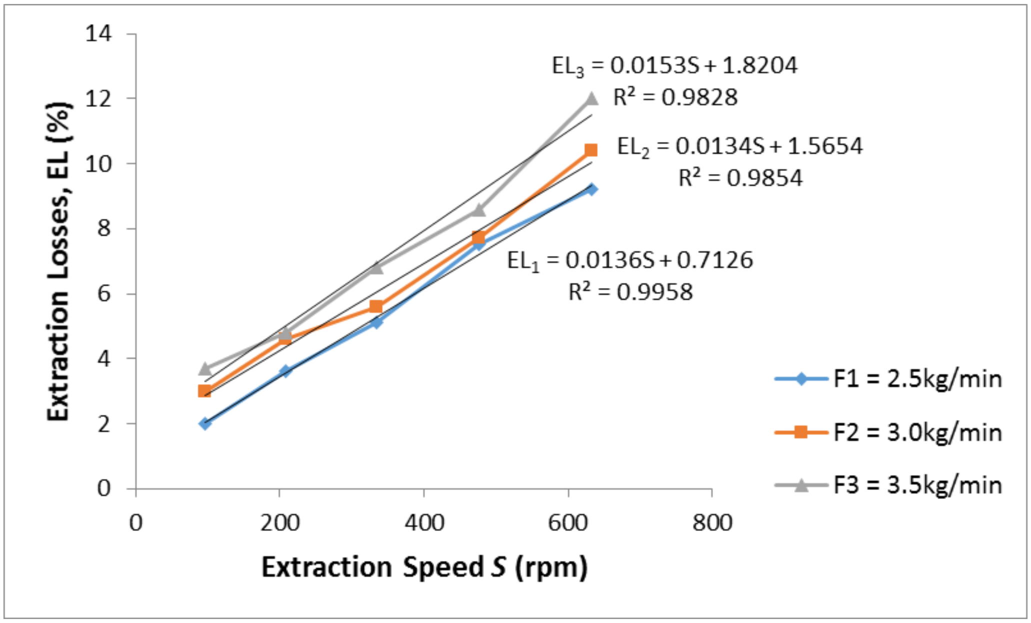


Fig. 4.9: Variation of juice extraction losses versus juice extraction speed and feed rate for ginger

4.2 Discussion of results

4.2.1: Juice yield (J_Y)

The results show that the optimum feed of the machine for both pineapple and orange fruits is F_2 (3.0 kg/min) and that for ginger is F_3 (3.5 kg/min) as shown in Figures 4.1, 4.4 and 4.7 respectively. More juice was yielded from pineapple fruits followed closely by orange fruits than ginger. This is may be due to the fact that pineapple and orange fruits are more succulent in nature compared to ginger. As a result, more juice was extracted at each operating speed from pineapple and orange fruits with the aid of the fabricated juice extractor than obtained from ginger.

In general, the juice yield of the machine for all the fruits tested decreases as the machine operating speed increases and vice-versa (Figures 4.1, 4.4 and 4.7). Similar observation was made by Adebayo *et al* (2014), Badmus and Adeyemi (2004) and Olaniyan (2010) for other juice extractors. At high speeds, there is reduction in juice extracted even from pineapple and orange despite the succulent nature of the fruits. This may be due to the losses arising from the vibrations of the machine at high operating speeds, causing splashing of juice to the walls of the machine, thus reducing the yield. This is in agreement with the observation of Adebayo *et al,* (2014). Hence a controlled speed should be maintained when operating the machine for juice extraction from fruits in order to obtain high yield of juice.

4.2.2: Extraction efficiency

Figures 4.2, 4.5 and 4.8 show respectively the juice extraction efficiencies of the machine when tested using pineapple, orange and ginger. It can be seen that the efficiency of extraction for pineapple and orange increased to a maximum value of 84 % and 82 % respectively at optimum operating speed of 335 rpm and optimum feed F_2 (3.0 kg/min), and then decreases at speeds beyond 335 rpm. For ginger, the optimum feed was found to be F_3 (3.5 kg/min), and the efficiency increased to a maximum at 71 % at optimum speed of 476 rpm. This may be due to the fact that ginger, being harder and less succulent than pineapple and orange is less efficient for juice extraction at low speeds. When little quantity of water was added to the fruit during the extraction processes, it enhanced the ease of juice extraction, reduced the roughages and at the same time increased the quality of juice extracted. At high speeds, fruits were not completely grinded and that may be responsible for the reduction of yield of juice extracted compared to when the machine was ran at a slow and steady speeds. Thus, performance tests show that the optimum extraction efficiency of the motorized juice extractor depends on the nature of fruit from which juice is to be extracted and the extraction speed of the machine. Similar observation was posited by Gbabo *et al* (2013) and Ndubisi *et al* (2013) for other juice extractors. The chopper has a role to play with regards to the sizes of fruit that passes down to the barrel where the fruit juice are finally extracted. The roughages increase with increasing speed while there is reduction in extraction time as the extraction speed increases.

4.2.3: Extraction losses (E_L)

Referring to Figures 4.3, 4.6 and 4.9, it can be seen that an increase in machine operating speed increases the extraction losses and vice versa. This may be because of losses arising from the splashing of the juice at the machine walls as a result of vibrations at high speeds. As a result, the volumes of juice extracted from all the fruits tested were minimal at the highest extraction speed of 632 rpm. Just like pineapple fruits, juice from succulent fruits should be extracted at a controllable speed in order to avoid much splashing of the juice at the machine outlet. Provision should be made for adjustable cone for the machine for proper discharge of the residual wastes from fruits arising from the screw conveyor, and thus reducing the volume of juice loss at high speeds.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

i. The design analysis of the fruit juice extraction machine was carried out and the machine successfully constructed, assembled and tested

ii. The optimum operating speed of the machine for juice extraction was found to be 335 rpm for orange and pineapple fruits, and 476 rpm for ginger, while the optimum feed was found to be F_2 (3.0 kg/min) for orange and pineapple, and F_3 (3.5 kg/min) for ginger

iii. The average juice extraction efficiency at optimum speed (S) and feed (F) for pineapple, orange and ginger were respectively 84 %, 80 % and 71 %; juice yield at optimum *S* and *F* for pineapple, orange and ginger were respectively 74 %, 72 % and 34 %; juice extraction losses for pineapple, orange and ginger were respectively 18 %, 16 % and 9 % at optimum *S* and *F*.

iv. The production capacity of the developed juice extractor was found to be about 30 litres/hr for orange, 32 litres/hr for pineapple and 24 litres/hr for ginger

v. With a machine cost of about ₦54,600, it is affordable for small-scale farmers in the rural communities.

5.2 Recommendations:

i. The length of the auger should be increased and should cover about 95 % of the shaft for proper juicing and easy ejection of seeds.

ii. The perforation of the inner cylinder should be increased in order to allow free flow of the extracted juice

iii. Pulping machine should be incorporated to separate the juice from the fruit pulp thereby avoiding blockage of the perforations

5.3 Contributions to knowledge

The following are some of the contributions to knowledge of this work:

i. The work has recast the drudgery of manual juice extraction method and the expensive importation of fruit juice extracting machines to Nigeria.

ii. The work has established that the efficiency of extraction of a juice extractor depends on the speed of extraction *S, (rpm)*, feed rate *F* (kg/min) and nature of fruit.

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APPENDIX A

PERFORMANCE RESULTS FOR THE MOTORIZED JUICE EXTRACTOR

Table A1: Juice extraction raw data measured for pineapple fruits

Extraction speed (rpm)	**Feed sample W_{FS} (kg)**	**Mass of juice extracted W_{JE} (kg)**	**Mass of juice in chaff (kg)**	**Mass of dry chaff W_{RW} (kg)**	**Extraction time (min)**
96	F_1	0.81	0.79	0.77	2.8
	F_2	0.96	0.94	0.97	
	F_3	1.18	1.14	1.05	
208	F_1	0.84	0.77	0.77	2.5
	F_2	0.97	0.93	0.98	
	F_3	1.2	1.15	1.02	
335	F_1	0.88	0.69	0.79	2.3

	F_2	1.19	0.68	0.96	
	F_3	0.73	0.51	0.42	
476	F_1	0.83	0.58	0.68	2.1
	F_2	1.12	0.59	0.87	
	F_3	1.31	0.90	0.91	
632	F_1	0.88	0.56	0.68	1.4
	F_2	0.27	0.58	0.86	
	F_3	1.39	0.80	0.92	
Manual juice extraction method	2.5 kg	1.26	0.65	0.97	10.55

F_1 = 2.5 kg/min

F_2 = 3.0 kg/min

F_3 = 3.5 kg/min

Table A2: Juice extraction raw data measured for orange fruits

Extraction speed (rpm)	**Feed sample W_{FS} (kg)**	**Mass of juice extracted W_{JE} (kg)**	**Mass of juice in chaff (kg)**	**Mass of dry chaff W_{RW} (kg)**	**Extraction time (min)**
96	F_1	0.79	0.77	0.75	3.1
	F_2	0.94	0.92	0.95	
	F_3	1.16	1.12	1.03	
208	F_1	0.82	0.75	0.75	2.9
	F_2	0.95	0.91	0.96	
	F_3	1.18	1.13	1.00	
335	F_1	0.89	0.71	0.80	2.0

	F_2 F_3	1.20 1.34	0.72 1.04	0.97 1.03	
476	F_1 F_2 F_3	0.79 1.10 1.29	0.56 0.59 0.89	0.69 0.83 0.89	1.7
632	F_1 F_2 F_3	0.81 1.14 1.32	0.55 0.59 0.58	0.68 0.82 0.87	1.5
Manual juice extraction method	2.5 kg	1.24	0.63	0.97	12.20

F_1 = 2.5 kg/min

F_2 = 3.0 kg/min

F_3 = 3.5 kg/min

Table A3: Juice extraction raw data measured for Ginger

Extraction speed (rpm)	**Feed sample W_{FS} (kg)**	**Mass of juice extracted W_{JE} (kg)**	**Mass of juice in chaff (kg)**	**Mass of dry chaff W_{RW} (kg)**	**Extraction time (min)**
96	F_1 F_2 F_3	0.76 0.91 1.13	0.74 0.89 1.09	0.76 0.96 1.04	4.3
208	F_1	0.79	0.72	0.76	4

	F_2 F_3	0.92 1.15	0.88 1.10	0.97 1.01	
335	F_1 F_2 F_3	0.83 1.14 1.28	0.68 0.69 0.98	0.78 0.95 1.01	3
476	F_1 F_2 F_3	0.82 1.13 1.27	0.64 0.65 0.92	0.76 0.90 0.95	2.5
632	F_1 F_2 F_3	0.85 1.14 1.30	0.63 0.62 0.89	0.77 0.87 0.92	1.5
Manual juice extraction method	2.5 kg	1.20	0.62	0.96	35.11

F_1 = 2.5 kg/min

F_2 = 3.0 kg/min

F_3 = 3.5 kg/min

Table A4: J_Y, J_E, and E_L for Pineapple fruit

Extraction speed (rpm)	**Feed rate (kg/min)**	**Juice yield J_Y (%)**	**Extraction efficiency J_E (%)**	**Extraction losses E_L (%)**
S_1 = 96	F_1	76.01	95.8	3.9

	F_2 F_3	84.02 88.6	93.6 92.0	5.2 7.0
S_2 = 208	F_1 F_2 F_3	70.7 72.8 75.8	90.5 85.7 85.1	7.8 8.8 11.8
S_3 = 335	F_1 F_2 F_3	68.9 64.4 60.2	82.7 78.7 75.6	12.2 14.0 14.9
S_4 = 476	F_1 F_2 F_3	59.3 59.0 56.1	70.2 64.8 62.3	15.5 17.2 17.9
S_5 = 632	F_1 F_2 F_3	52.7 51.8 51.1	60.0 54.3 53.4	18.3 18.5 19.2

F_1 = 2.5 kg/min

F_2 = 3.0 kg/min

F_3 = 3.5 kg/min

Table A5: J_Y, J_E, and E_L for Orange fruit

Extraction speed (rpm)	**Feed rate (kg/min)**	**Juice yield J_Y (%)**	**Extraction efficiency J_E (%)**	**Extraction losses E_L (%)**
$S_1 = 96$	F_1	85.7	93.0	3.5
	F_2	82.2	91.5	5.4
	F_3	81.7	90.7	5.7
$S_2 = 208$	F_1	80.0	89.9	6.6
	F_2	78.2	86.6	7.1
	F_3	76.0	85.7	9.6
$S_3 = 335$	F_1	73.8	84.3	10.7
	F_2	71.2	82.0	11.0
	F_3	70.8	81.6	13.8
$S_4 = 476$	F_1	65.0	80.4	14.1
	F_2	62.7	78.1	14.6
	F_3	62.0	77.0	16.7
$S_5 = 632$	F_1	53.4	76.0	17.0
	F_2	51.6	73.8	17.3
	F_3	50.2	72.7	19.8

F_1 = 2.5 kg/min

F_2 = 3.0 kg/min

F_3 = 3.5 kg/min

Table A6: J_Y, J_E, and E_L for Ginger

Extraction seed (rpm)	**Feed rate (kg/min)**	**Juice yield J_Y (%)**	**Extraction efficiency J_E (%)**	**Extraction losses E_L (%)**
S_1 = 96	F_1	56.3	71.0	2.0
	F_2	53.7	66.3	2.3
	F_3	51.1	66.1	3.7
S_2 = 208	F_1	51.8	65.4	3.6
	F_2	50.5	62.7	4.6
	F_3	49.9	61.5	4.8
S_3 = 335	F_1	45.7	60.5	5.1
	F_2	45.0	56.0	5.6
	F_3	44.3	55.5	6.8
S_4 = 476	F_1	39.9	54.9	7.5
	F_2	34.7	52.9	7.7
	F_3	30.6	52.0	8.6
S_5 = 632	F_1	27.1	52.8	9.2
	F_2	25.7	51.7	9.6
	F_3	25.1	51.5	12.0

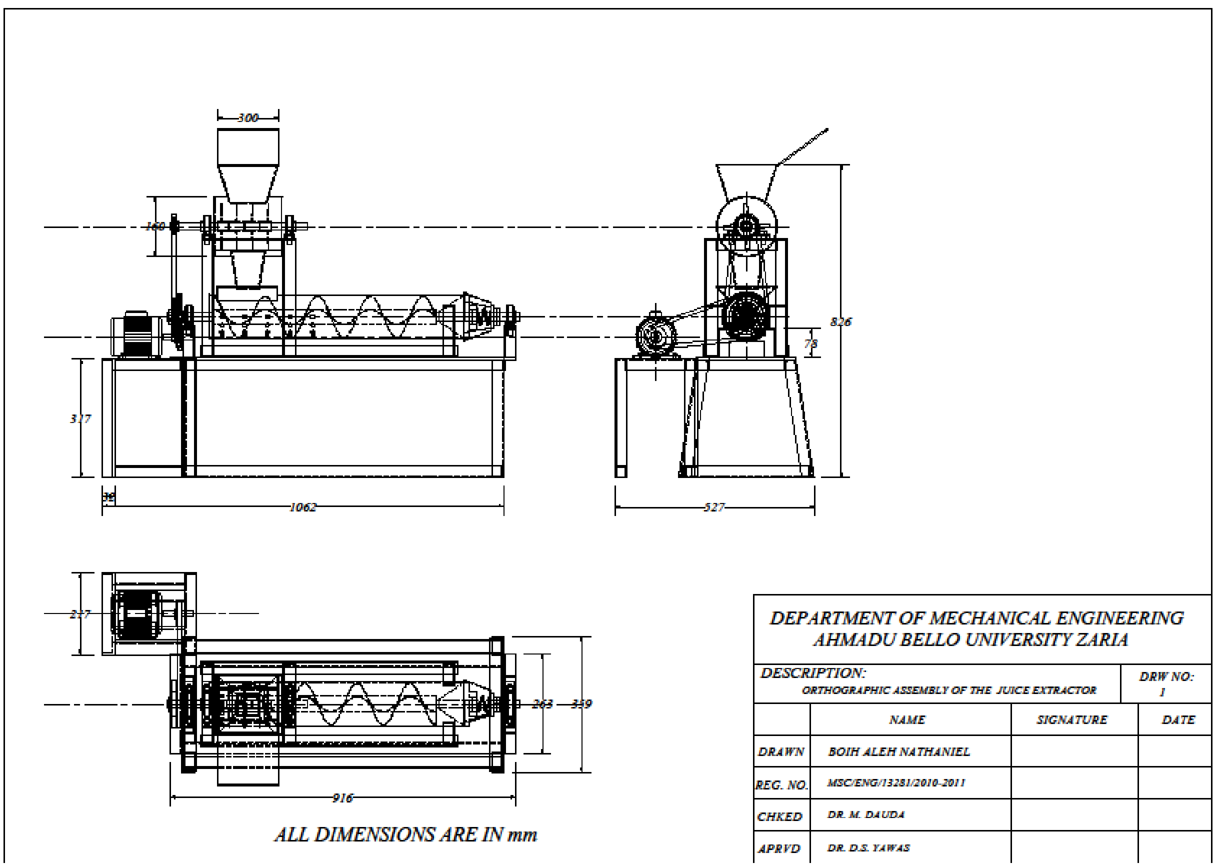
F_1 = 2.5 kg/min

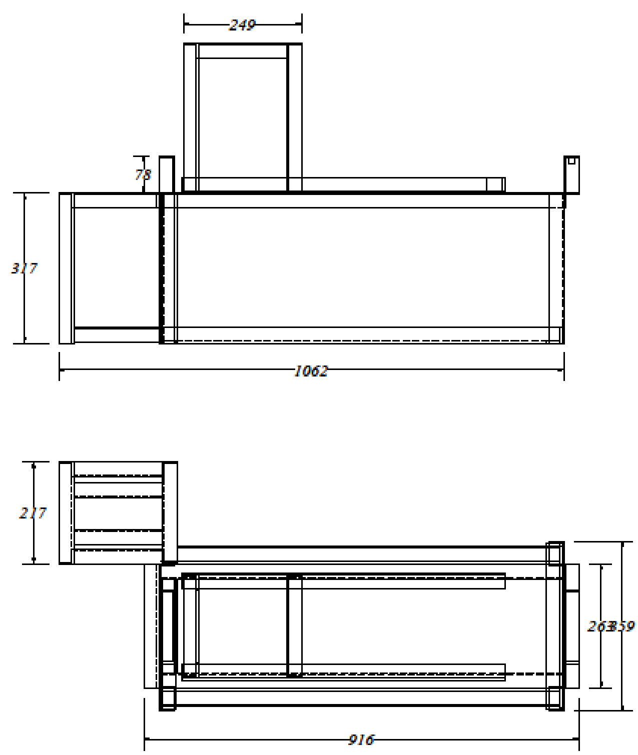
F_2 = 3.0 kg/min

F_3 = 3.5 kg/min

APPENDIX B

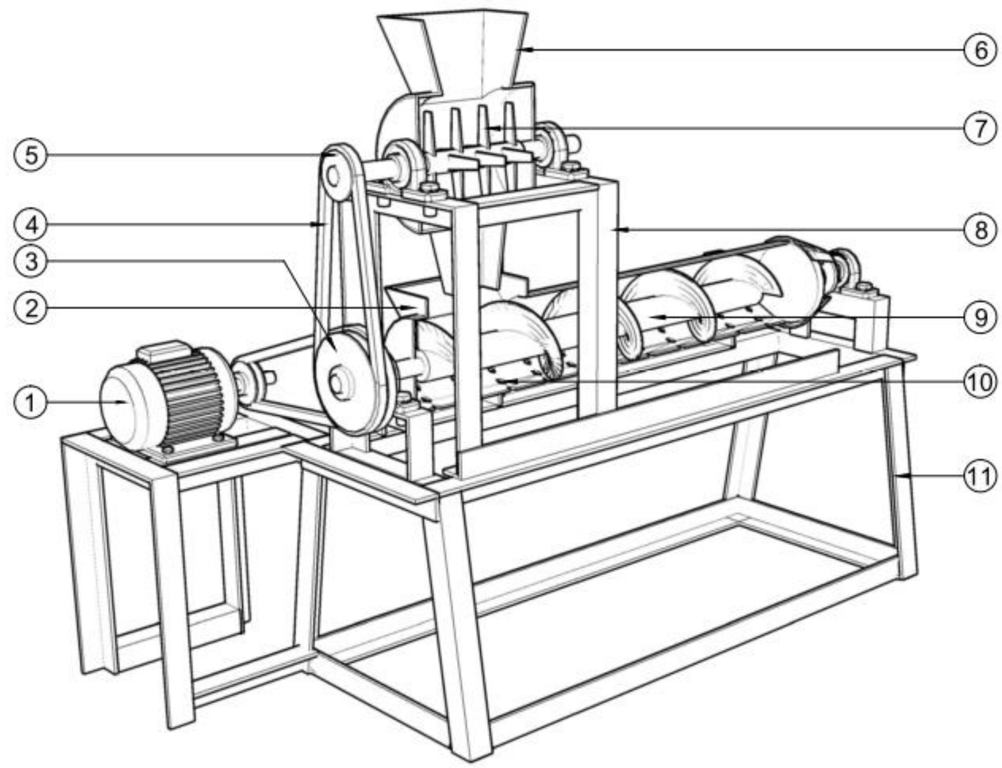
DRAWINGS OF THE MACHINE COMPONENTS





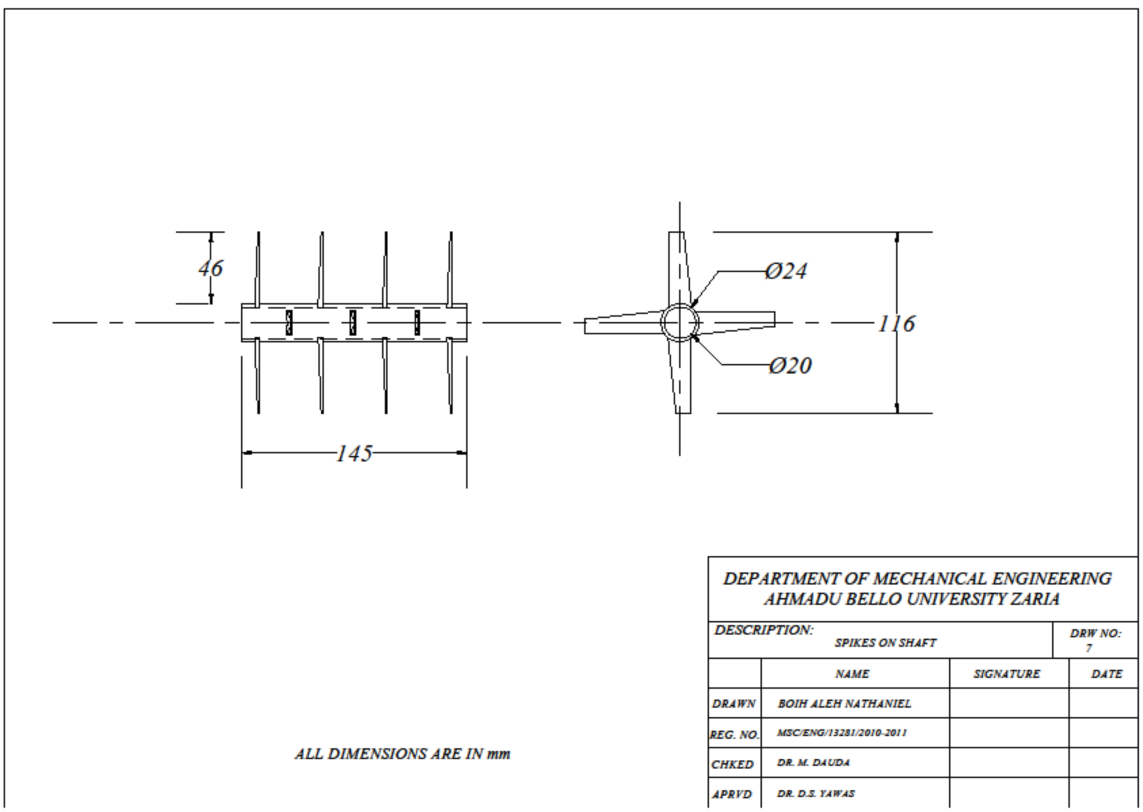
ALL DIMENSIONS ARE IN mm

DEPARTMENT OF MECHANICAL ENGINEERING AHMADU BELLO UNIVERSITY ZARIA			
DESCRIPTION: ORTHOGRAPHIC ASSEMBLY OF THE MAIN FRAME			DRW NO: 2
	NAME	SIGNATURE	DATE
DRAWN	BOIH ALEH NATHANIEL		
REG. NO.	MSC/ENG/13281/2010-2011		
CHKED	DR. M. DAUDA		
APRVD	DR. D.S. YAWAS		



Sectional view of the motorized juice extractor

1 – Electric motor; 2 – Second hopper; 3 – Pulley; 4 – V-belt; 5 – Bearing; 6 – First hopper; 7 – Spikes on shaft; 8 – Chopping unit frame; 9 – Auger conveyor; 10 – Perforations; 11 – Main frame.


46
Ø24
116
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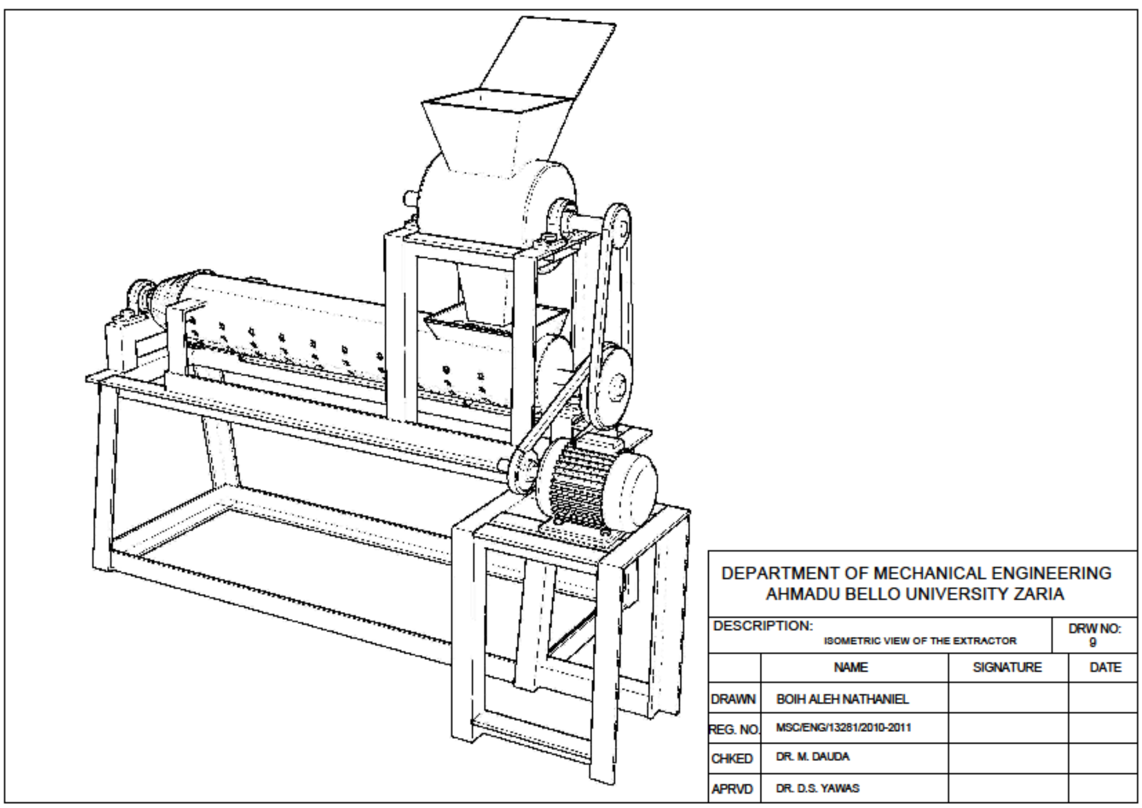
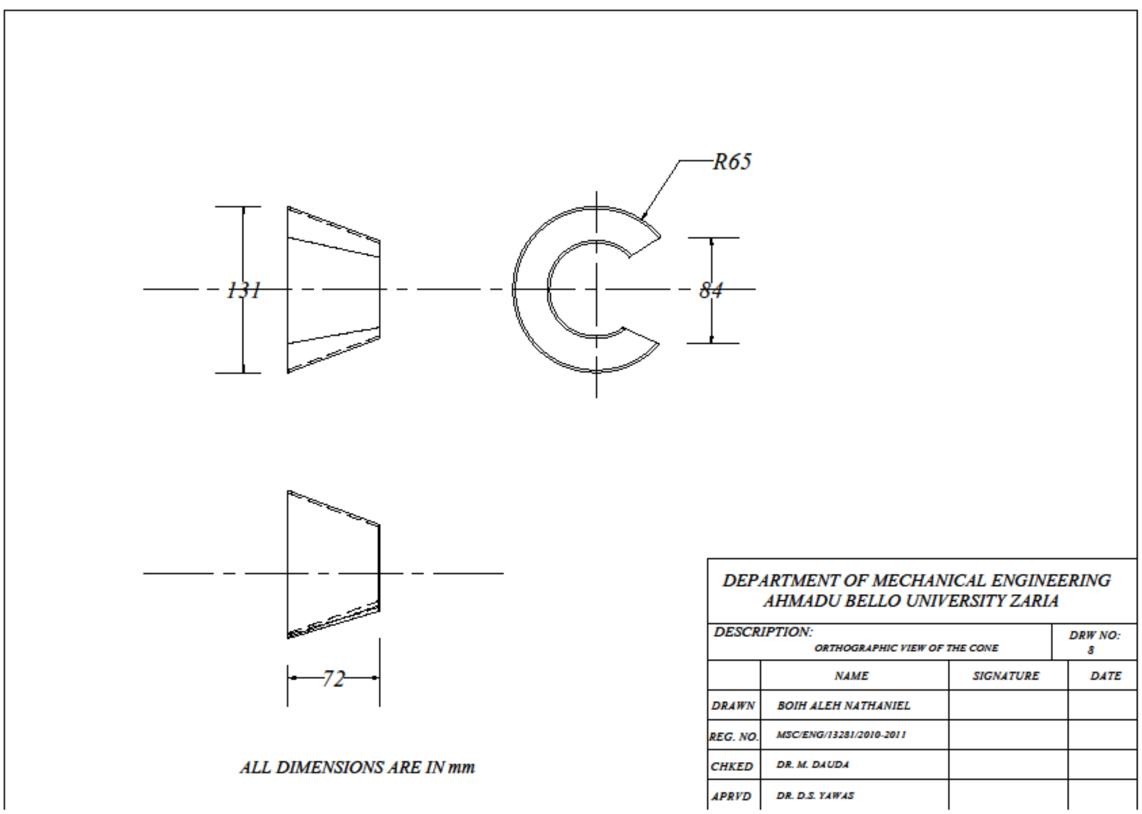
145
ALL DIMENSIONS ARE IN mm
DEPARTMENT OF MECHANICAL ENGINEERING
AHMADU BELLO UNIVERSITY ZARIA
DESCRIPTION:
SPIKES ON SHAFT
DRW NO:
7
NAME
SIGNATURE
DATE
DRAWN
BOIH ALEH NATHANIEL
REG. NO.
MSC/ENG/13281/2010-2011
CHKED
DR. M. DAUDA
APRVD
DR. D.S. YAWAS


DEPARTMENT OF MECHANICAL ENGINEERING
AHMADU BELLO UNIVERSITY ZARIA
DESCRIPTION:
ISOMETRIC VIEW OF THE EXTRACTOR
DRW NO:
9
NAME
SIGNATURE
DATE
DRAWN
BOIH ALEH NATHANIEL
REG. NO.
MSC/ENG/13281/2010-2011
CHKED
DR. M. DAUDA
APRVD
DR. D.S. YAWAS



R65
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84
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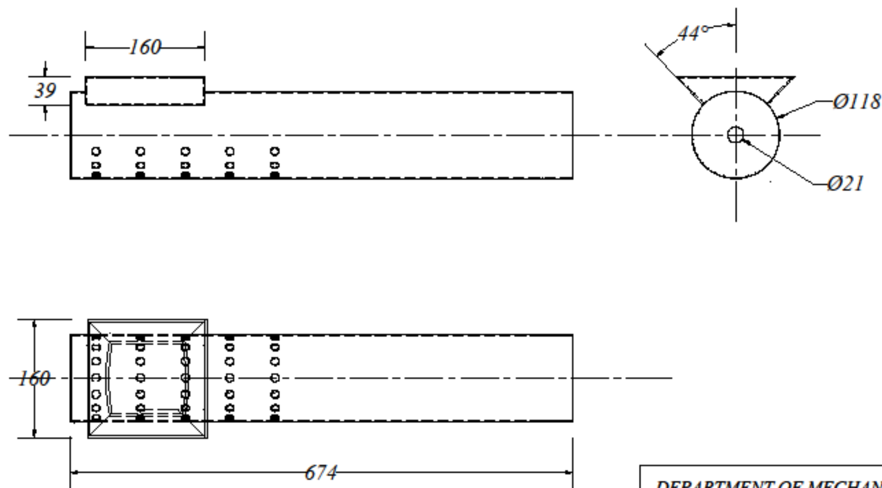
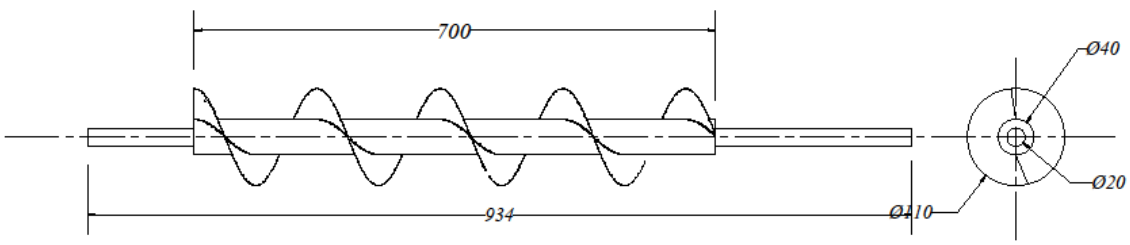
ALL DIMENSIONS ARE IN mm
DEPARTMENT OF MECHANICAL ENGINEERING
AHMADU BELLO UNIVERSITY ZARIA
DESCRIPTION:
ORTHOGRAPHIC VIEW OF THE CONE
DRW NO:
8
NAME
SIGNATURE
DATE
DRAWN
BOIH ALEH NATHANIEL
REG. NO.
MSC/ENG/13281/2010-2011
CHKED
DR. M. DAUDA
APRVD
DR. D.S. YAWAS



ALL DIMENSIONS ARE IN mm

DEPARTMENT OF MECHANICAL ENGINEERING AHMADU BELLO UNIVERSITY ZARIA			
DESCRIPTION: ORTHOGRAPHIC ASSEMBLY OF THE EXTRACTION UNIT			DRW NO: 4
	NAME	SIGNATURE	DATE
DRAWN	BOIH ALEH NATHANIEL		
REG. NO.	MSC/ENG/13281/2010-2011		
CHKED	DR. M. DAUDA		
APRVD	DR. D.S. YAWAS		



ALL DIMENSIONS ARE IN mm

DEPARTMENT OF MECHANICAL ENGINEERING AHMADU BELLO UNIVERSITY ZARIA			
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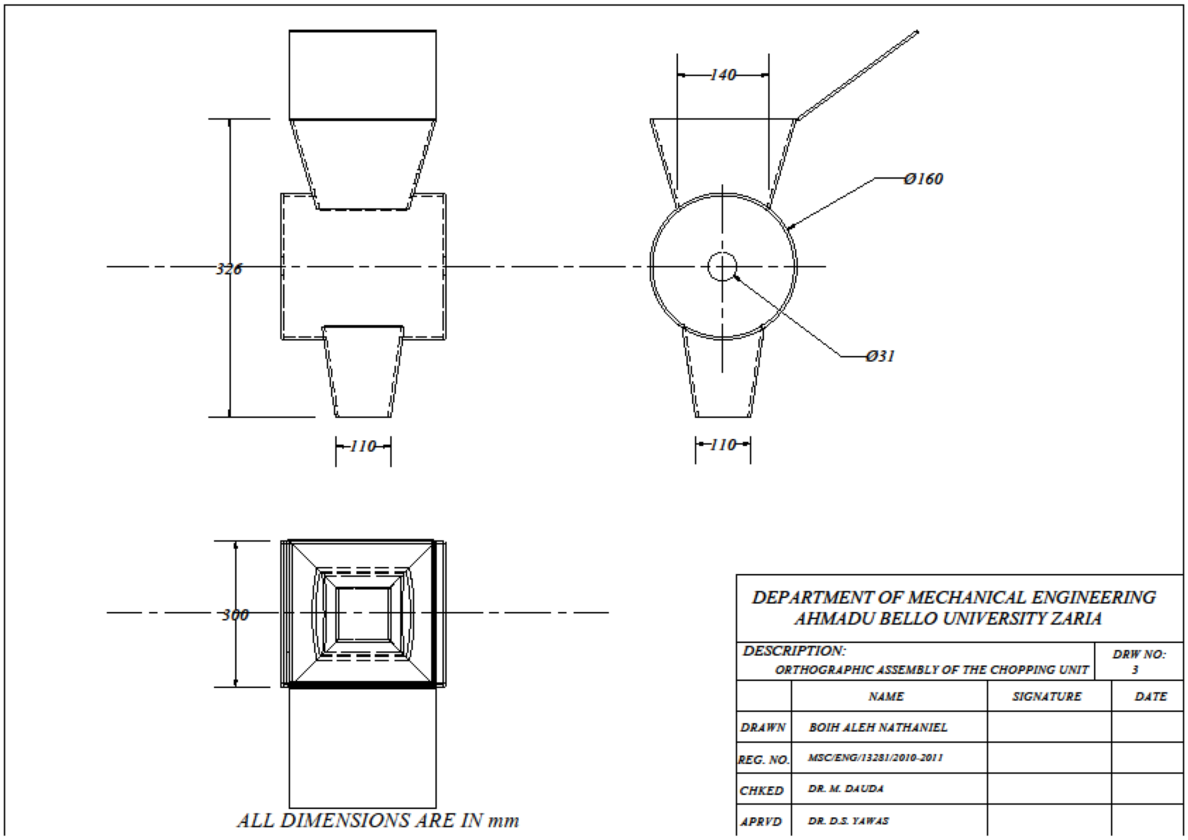
	NAME	SIGNATURE	DATE
DRAWN	BOIH ALEH NATHANIEL		
REG. NO.	MSC/ENG/13281/2010-2011		
CHKED	DR. M. DAUDA		
APRVD	DR. D.S. YAWAS		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Ø31
110
110
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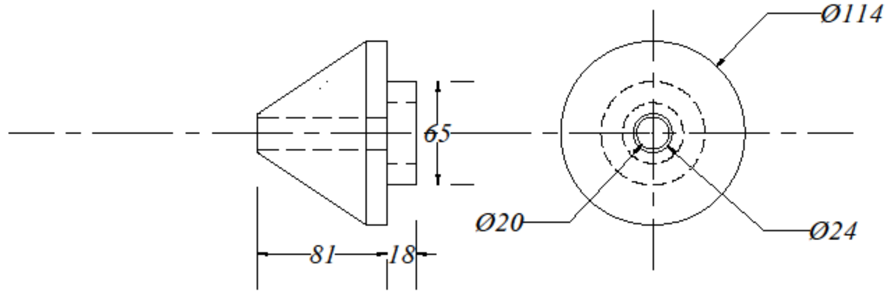
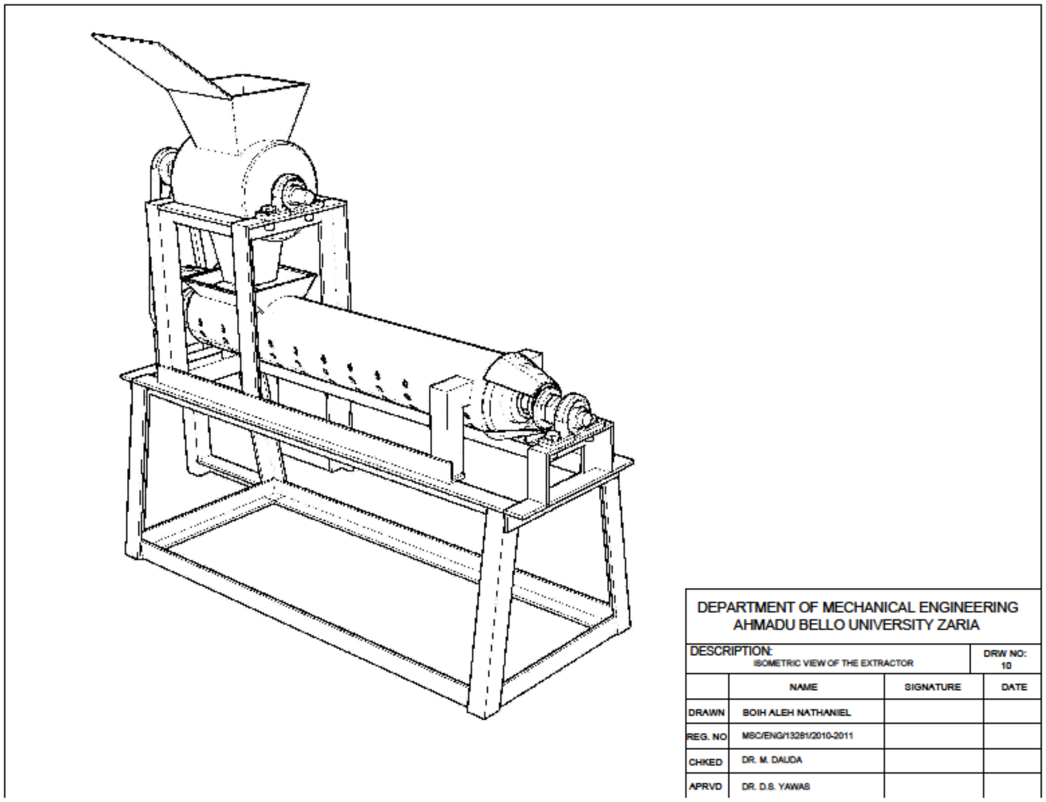
ALL DIMENSIONS ARE IN mm
DEPARTMENT OF MECHANICAL ENGINEERING
AHMADU BELLO UNIVERSITY ZARIA
DESCRIPTION:
ORTHOGRAPHIC ASSEMBLY OF THE CHOPPING UNIT
DRW NO:
3
NAME
SIGNATURE
DATE
DRAWN
BOIH ALEH NATHANIEL
REG. NO.
MSC/ENG/13281/2010-2011
CHKED
DR. M. DAUDA
APRVD
DR. D.S. YAWAS



ALL DIMENSIONS ARE IN mm

DEPARTMENT OF MECHANICAL ENGINEERING AHMADU BELLO UNIVERSITY ZARIA			
DESCRIPTION: CONE AND BARREL			DRW NO: 6
	NAME	SIGNATURE	DATE
DRAWN	BOIH ALEH NATHANIEL		
REG. NO.	MSC/ENG/13281/2010-2011		
CHKED	DR. M. DAUDA		
APRVD	DR. D.S. YAWAS		


DEPARTMENT OF MECHANICAL ENGINEERING
AHMADU BELLO UNIVERSITY ZARIA
DESCRIPTION:
ISOMETRIC VIEW OF THE EXTRACTOR
DRW NO:
10
NAME
SIGNATURE
DATE
DRAWN
BOIH ALEH NATHANIEL
REG. NO
MSC/ENG/13281/2010-2011
CHKED
DR. M. DAUDA
APRVD
DR. D.S. YAWAS

APPENDIX C

PHOTOGRAPHS OF THE JUICE EXTRACTOR

Plate C1: Photograph of the extractor on the rigid support

Plate C2: Photograph of the chopping compartment of the extractor

Plate C3: Photograph of the cylindrical barrel

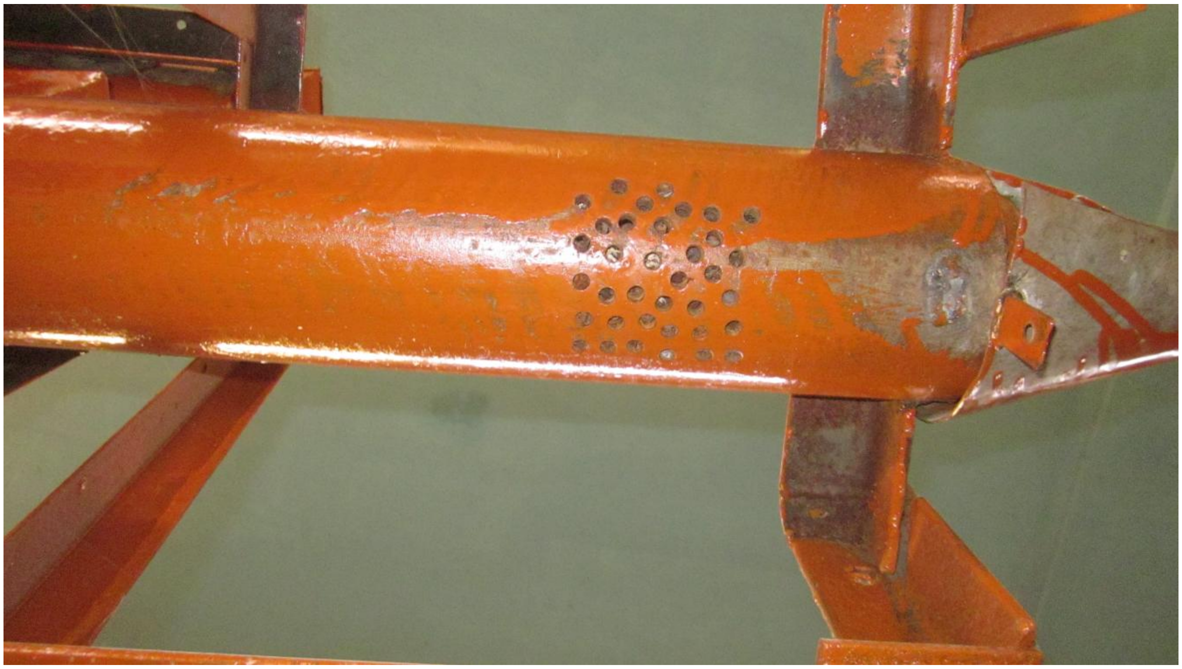


Plate C4: Photograph of perforations below the cylindrical barrel

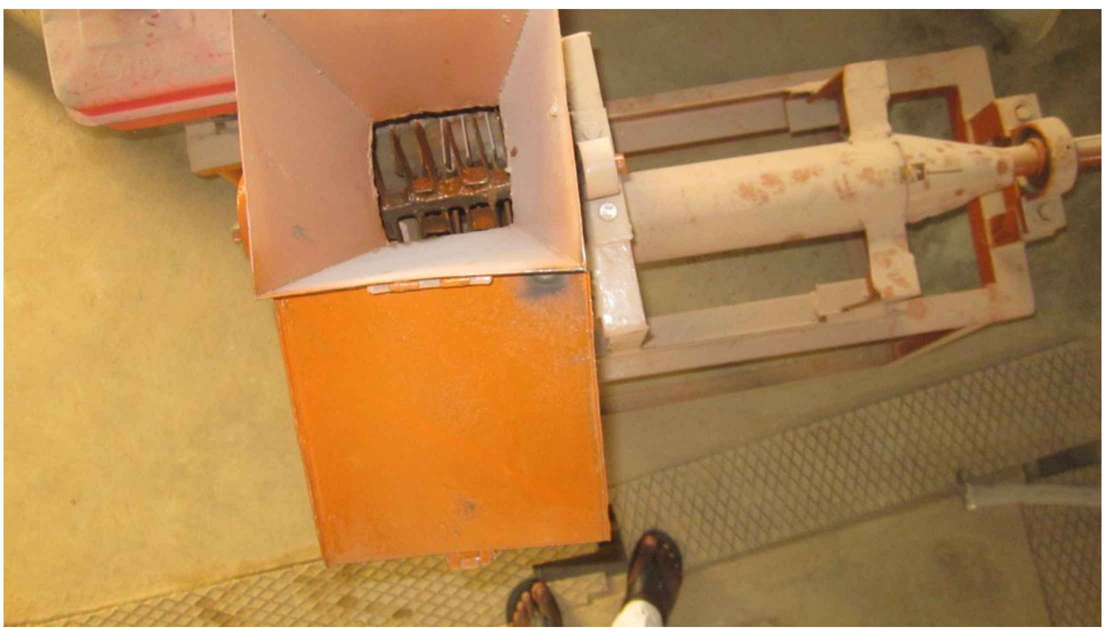


Plate C5: Photograph of the chopping unit showing spikes on shaft

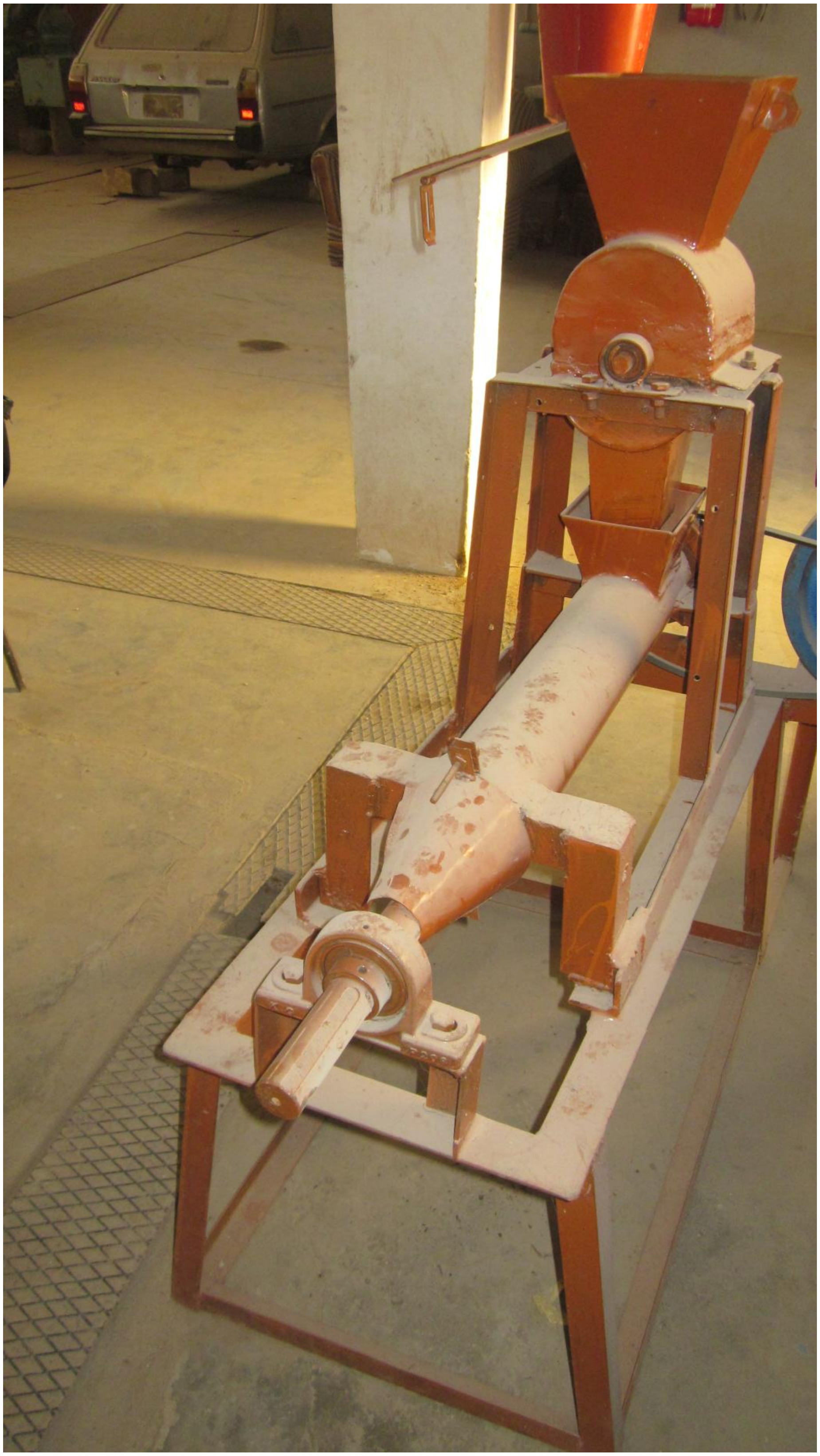


Plate C6: Photograph of front view of the juice extractor