DESIGN AND FABRICATION OF A PALM KERNEL CRUSHER

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A PROJECT SUBMITTED TO THE SCHOOL OF UNDERGRADUAUTE STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF BACHELOR OF ENGINEERING (B.Eng) IN MECHANICAL ENGINEERING, IN THE DEPARTMENT OF MECHANICAL ENGINEERING, COLLEGE OF ENGINEERING, COVENANT UNIVERSITY, OTA.

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ACCEPTANCE

This is to justify that this project work is accepted in partial fulfillment of the requirements for the award of the Bachelor of Engineering, B.Eng. in Mechanical Engineering in the Department of Mechanical Engineering, College of Engineering, Covenant University, Ota, Ogun State, Nigeria

Prof. Joshua Okeniyi ……………………………………………

Project Supervisor Signature and Date

DECLARATION

We, **Nottidge, David Enoabasi (17CM022802)** and **Unwan, Bethel Onyekachukwu (17CM022845),** declare that this project work was carried out by us under the supervision of Prof. Joshua Okeniyi of the department of Mechanical engineering, College of Engineering, Covenant University, Ota, Ogun state.

Nottidge, David Enoabasi ………………………………

Signature and date

Unwan, Bethel Onyekachukwu ………………………………

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CERTFIFICATION

This is to certify that the project titled “Design and Fabrication of Palm Kernel Crusher” is the original work carried out by NOTTIDGE, DAVID ENOABASI (17CM022802) and UNWAN, BETHEL ONYEKACHUKWU (17CM022845) in the Department of Mechanical Engineering, College of Engineering, Covenant University, Ota, Ogun State, Nigeria under the supervision of Prof. Joshua O. Okeniyi and Engr. Adelekan Damola. We have examined and found this work acceptable as part of the requirements for the award of Bachelor of Engineering (B.Eng) in Mechanical Engineering.

Prof. Joshua O. Okeniyi ………………………………
Supervisor Signature and Date

Prof. Joshua O. Okeniyi ………………………………
HOD Signature and Date

DEDICATION

This work is dedicated to God almighty from whom all life flows.

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Our thanks go first to the Lord most high; the giver of life, and without whom nothing can be done. It has been his grace and strength that has kept us through the five years of our sojourn at Covenant University.

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NOMENCLATURE

CPO – Crude Palm Oil

CPKO – crude palm kernel oil

Nm – Newton meter

GPa – Gigapascal

KN – Kilonewton

ABSTRACT

The need for a mechanized means of agricultural processing is on the rise in Nigeria, and palm kernel is a very useful raw material in a lot of industries – cosmetics, shampoo, and detergent production industries. Palm kernel possesses medicinal features that make it useful in herbs and medicines. Manual palm kernel processing involves using stones to crack individual kernels. This process is laborious, hazardous, and time-consuming. Thus, an efficient means of processing palm kernel is required. This work produced a mechanized means of palm kernel cracking. The palm kernel cracker makes use of centrifugal palm kernel cracking where an impeller impacts kernel seeds against the wall of the cracking chamber with sufficient force to crack the kernel. The fabrication processes used were simple and all the materials used were sourced within Nigeria. Maximum cracking efficiency and throughput capacity of 94.11% and 28.28 g/s were achieved at a shaft speed of 1105 rpm. While the minimum cracking efficiency and throughput capacity of 43.50 % and 23.50 g/s were achieved at a shaft speed of 551 rpm. Therefore, the fabricated palm kernel cracking machine provides an efficient means of cracking kernels.

Keywords: palm kernel. Cracking, centrifugal, impeller, mechanized.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

The oil palm (Elaeis guineensis) is a tree which according to popular belief can be traced back to the tropical rain forest region of West Africa. Its most prominent features include: a tall straight branchless trunk which has all its leaves concentered at the top (Mijinyawa & Omoikhoje, 2005). The first major concentration of palm trees was located in the highlands of the Fouta Djallon district of Guinea, about 10 -11°N (Gupta, 2015). The oil palm fruit has an edible seed which is referred to as palm kernel. There are varieties of products sourced from the plant, some of which include palm oil, palm kernel cake, palm kernel oil, palm kernel cake, fibre, palm wine (locally referred to as Tombo or Pammy in Nigeria), broom, fatty alcohol, wood plank and others (Ismail et al., 2015). Every part of the palm tree is useful, and no part needs to be condemned to waste. For millennia, palm oil processing has been carried out in Africa, the oil produced from this process is dark red in colour and has a taste that is considered as earthy, and savory-it is a major ingredient in a large proportion of the traditional West African dishes. (Poku, 2002).

The oil palm plant serves as a high yield source of edible and technical oils. The oil palm plant economic significance, and its fruits grow in bunches with weights ranging from 10 to 40 kg, and each fruit weighing 6 to 20 gm (Poku, 2002). The individual fruits consist of an external layer known as the exocarp, the palm oil is contained in a fibrous matrix known as the mesocarp (the pulp), a central nut made up of a shell known as the endocarp and the actual kernel containing an oil known as palm kernel oil which is quite distinct from palm oil and bears a resemblance to coconut oil (Poku, 2002).

Dura is a thick shelled variety of the palm kernel fruit with a thin mesocarp and is found to be the most recurring variety among the wild oil palm grooves of Central and West Africa. Cross breeding efforts-most especially between Dura and a shell-less variety known as Pisifera have resulted in the creation of a hybrid called Tenera. The Tenera hybrid is characterized by a significantly thicker mesocarp as well as a thinner shell (Poku, 2002). The Tenera hybrid possesses a higher amount of palm oil than its native counterpart the Dura, making it a preferred selection for planting and breeding programs (Poku, 2002).

The steps involved in the processing of the oil palm are harvesting, threshing, sterilization or cooking, fruit digestion, pulp pressing, oil clarification, oil drying, and oil packing (Ismail, 2010).

The processing of the oil palm fruit starts with harvesting the fruits from the palm tree. During harvesting, the bunch is plucked from the tree and allowed to fall to the ground under the action of the force of gravity. The fresh fruit from the field comes either in bunches or as loose fruit. After harvesting, the next step is threshing, threshing can be carried out manually by utilizing a rotating drum fitted with rotary beaters that remove the fruit from the bunch, allowing the spikelets to remain on the stem. After harvesting and threshing to remove the fruit from the stem the fruit needs to be sterilized. Sterilization or cooking is a process carried out on the loose oil palm fruits which leads to the expansion of the moisture in the nuts and the eventual separation of the kernel from the shell wall, the kernels are thus loosened within their shells (Ismail, 2010). Both sterilization and cooking involve the use of high-temperature wet-heat treatment, but cooking is distinct from sterilization in that while cooking involves the use of hot water, sterilization makes use of pressurized steam. On a local scale, sterilization simply involves boiling the already threshed palm kernel fruit in hot water, however in industrial palm oil processing, sterilization is carried out before threshing using pressurized steam; the steam softens the stem of the fruit and makes it easier to remove the fruit from the bunch by simply shaking it or tumbling it in the threshing machine. Some of the objectives of the sterilization process include enabling the solidification of the proteins that contain the oil-bearing cells which are systematically dispersed in it. The protein coagulation process facilitates the aggregation of the oil bearing cells so that they flow unconstrained when pressure is applied. Also, the fruit is cooked to etiolate the pulp structure, make it soft and enable the effortless removal of the fibrous material and its constituents during the digestion process (Ismail, 2010). After the sterilization process comes digestion; this is the process whereby the palm oil in the fruit is released by the fracture of the oil-bearing cells. Two techniques exist for the extraction of oil from the digested material. The dry method-which use mechanical presses, and the wet method which adopt hot water to drain out the oil (Ismail, 2010). The crude palm oil obtained from the press comprise of a mixture of palm oil, fibrous materials, and water in different proportions (Ismail, 2010). This crude palm oil is pumped to a continuous horizontal or vertical clarification tank for the separation of the oil.

Palm kernel processing to obtain palm kernel oil can be broken down into the following stages: nut and fiber separation, palm nut cracking, sorting of kernels from shell-kernel mixture, washing, sterilization, kernel pulverization and finally kernel oil extraction (Oyebanji et al., 2012).

The oil palm industry has been very productive over the years and every by-product of the oil palm is useful (Ismail, 2010). Furthermore, by conscientiously making use of the by-products of the oil palm through nutrient cycling, the negative environmental impacts of waste has been reduced. Thus, facilitating the actualization of the zero-waste policy (Ismail, 2010)

Generally, on an industrial scale, the palm oil processing in a palm oil mill will only involve the extraction of the crude palm oil and the kernel from the fruit of the oil palm. The crude palm oil can then be transported to a refinery where it will be processed into a different product. The kernel on the other hand is sent to a palm kernel nut cracking plant for the extraction of the crude palm kernel oil (Ismail, 2010). Some of the kernel can be processed into animal feedstock and would not need to be sent to the cracking plant.

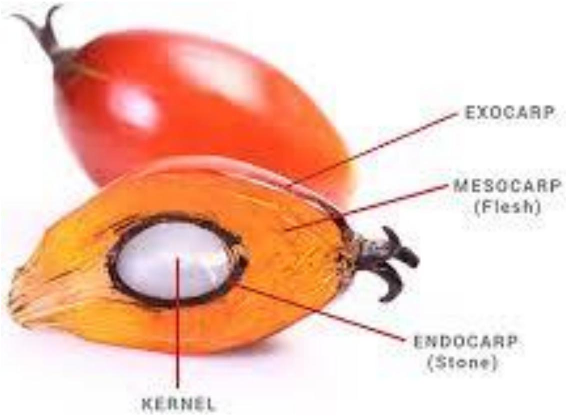


Figure 1. 1 Labelled Diagram of an Oil Palm Fruit

1.2 PALM KERNEL PROCESSING

The palm kernel fruit is the whitish part of the oil palm fruit, it is the part of the fruit found beneath the endocarp. The various parts of the oil palm fruit are shown in figure 1.1. The palm kernel fruit is a by-product of the palm oil mill, alongside the fibre left after the pressing of the oil palm fruit to obtain palm oil. The fibre is useful in the production of boiler fuels in electricity generation plants (Umani et al., 2020).

Nut and kernel processing is made up of four distinct stages: nut conditioning, nut cracking, shell and kernel separation and kernel drying (Umani et al., 2020). The cracking of the kernel shells and the separation of the kernels from the shell particles are distinct stages in the processing of the palm fruit that require significant advancement. This is to improve the quality and quantity of PKO (palm-kernel oil) available within Nigeria (Umani et al., 2020). Palm kernel cracking involves the application of an impact or crushing force to the hard palm kernel shell to expose the palm kernel fruit inside. The following factors influence the production of whole and fragmented kernels, as well as the size of the shell particles or the shells after cracking: moisture content, speed of cracking, feed rate and throughput capacity, and bulk density (Umani et al., 2020).

1.3 PROBLEM STATEMENT

The economic importance of palm kernel oil and its use in a variety of industries and products requires the hard palm kernel nuts to be cracked for the palm kernel oils to be extracted. The demand for palm kernel oil products is on the rise as ingredients in the production of non-hydrogenated margarine, with trans-free fats (Shimizu & Desrochers, 2012). Palm kernel oil is the yellowish oil used for frying purposes in a bulk of Nigerian cuisine and serves as a raw material in several industries such as cosmetics, detergent, and shampoo production industries. It also possesses some medicinal features that can be used in a variety of herbs and drugs within the pharmaceutical industry.

Furthermore, the palm kernel shell is useful as a biomass in energy production (Shimizu & Desrochers, 2012). It serves as an alternative aggregate in concrete production and the residue left after pressing of the palm kernel fruits known as Palm Kernel Meal (PKM) is a high fat, high protein source of feed for livestock (Olaoye & Adekanye, 2018).

With all these economic benefits, it is evident that the local production and processing of palm kernel and its by-products offers many advantages. Local production would serve as a source of livelihood for many rural farmers and with access to mechanized means of processing with reasonable accompanying cost, productivity and profitability would be increased. Palm kernel oil and the by-products of palm kernel processing are all very useful and with increased productivity, rural farmers would be able to reduce energy, time and cost spent on the palm kernel nut cracking.

The cracking of the palm kernel nut is the most important and highly delicate stage involved in the processing of Palm kernel oil. The quality of the palm kernel oil obtained largely depends on this stage (Olaoeye & Adekanye, 2018). Palm kernel nut cracking can be carried out by either traditional or mechanical means (Olaoye & Adekanye, 2018). The traditional and mechanical methods require that the palm kernels be thoroughly dry before the cracking can be done. The traditional method involves drying the nuts by placing them under the heat of the sun for days or placing the kernel nuts on a heated surface and cracking them one at a time using a hard stone. Thereafter the kernels are separated from the mixture of kernels, unbroken nuts, and dust by hand picking (Akusu et al., 2017).

The shortcomings of the manual palm kernel processing method include high labour intensity, time consuming, cumbersome, and is unable to meet up with the ever-growing demand in the industry (Oyebanji et al., 2012). Furthermore, it presents a risk to the individuals carrying out the procedure as fingers and other body parts can get injured in the cracking process. The limitations of the traditional method necessitate the need for alternate means of palm kernel nut cracking and separation. Mechanical cracking can be carried out in one of two ways, the first makes use of the shock which occurs as a result of the impact of the kernels against a hard object or surface, and the second involves applying mechanical pressure directly on the kernels to pulverize or cut through their shells (Oke, 2007). Based on these two principles the two kinds of nutcrackers identified in the palm oil mill are the roller cracker and the centrifugal impact cracker, while the roller utilizes the mechanical pressure principle and cracks the kernel nuts between two grooved rollers which are revolving in opposite directions, the centrifugal kernel cracker utilizes the principle of centrifugal force and throws the kernel nuts against a hard motionless surface (Oyebanji et al., 2012). One limitation of the roller crackers is the uniformity of the clearance between the rollers despite the size variation of the nuts which results in reduced efficiency (Oyebanji et al., 2012). Thus, the centrifugal cracking principle is more efficient in the cracking of the nuts. In centrifugal type cracking the nuts enter into a slot on a rotor which spins at a very high velocity, alternatively they are fed into a vessel (the cracking chamber) in which they collide with metal beaters spinning at high velocities which flap them against a cracking ring (Olaoeye & Adekanye, 2018). This work makes use of the centrifugal nut cracking machine as it is more efficient than the traditional method and overcomes the challenges encountered in the use of the roller cracker.

1.4 AIM AND OBJECTIVES OF THE STUDY

1.4.1 Aim

The work intends to produce a palm kernel nutcracker which is an improvement of a previous design, the nutcracker operates using the centrifugal cracking principle and saves the time and energy used in traditional cracking method, it has an appropriate efficiency and can be used in rural palm kernel processing plants for increased productivity.

1.4.2 Objectives of Study

The objectives of the study include:

- Model the palm kernel cracker using CAD software.
- Carry out analytical design analysis and calculation of parameters.
- Performance analysis for the fabricated palm kernel cracking machine.
- Economize the design production using locally sourced materials.

1.5 SCOPE AND LIMITATION

1.5.1 Scope Of Study

This study is concerned with the cracking of palm kernel nut shells and the subsequent sorting to obtain the kernel seeds, it includes increasing the productivity of the cracking stage to meet up with demand, reducing time and manual labour involved in the cracking process considering the effect of moisture on the cracking efficiency, finding ways to improve the throughput rate of the cracking machine, increasing the sorting efficiency. The study includes the traditional means of cracking and sorting palm kernels as well as the mechanized cracking methods.

1.5.2 Limitations

It is not concerned with the extraction of the nuts from the surrounding pulp (from which the dark red liquid-palm oil, is obtained) or the extraction of Palm Kernel Oil (PKO) from the kernels. Some of other limitations include:

- The materials in use are limited to those that can be locally sourced to reduce the effort involved in maintenance and replication of the design.
- The throughput capacity of the machine produced is smaller in comparison to industrial grade machines
- The machine makes use of an electric motor and is subject to the constraints of power supply which is a major issue in Nigeria.

1.6 JUSTIFICATION OF THE STUDY

The palm kernel industry is still very well known in third world countries, this is due to the reliance of several companies on palm kernel oil as a raw material for their products. In the early sixties, Nigeria was one of the world's largest exporters of palm kernel based commodities- exporting about 400.000 metric tons an estimated 65% of the world trade at that time (Oke, 2007) In the seventies, there was a significant reduction in Nigeria's palm kernel product from 65% to 15% as a result of the crude oil boom. The high dependence of several industries – oil, soap, vegetable and body cream industries – on palm kernel oil emphasizes the need for an efficient palm kernel processing machine – one which would also restore the palm kernel production in an effort to satisfy industrial demand as it constantly rises (Oke, 2007). Furthermore, the palm kernel oil extracted from the kernels after the nuts have been cracked find uses in applications such as: enterprises dealing with nourishment and nutrition, makeup and cleanser producing enterprises, oil processing ventures, and pharmaceuticals (Ibikunle et al., 2018).

In this study, emphasis is laid on the simplicity of the cracking machine design, its affordability, components consisting of locally sourced materials and ease of operation. All these are necessary to make the machine accessible to rural farmers and communities where palm kernel nut cracking is still carried out by traditional means, the shortcomings of which have been earlier addressed.

1.7 SIGNIFICANCE OF THE STUDY

The purpose of this research is to offer viable solutions to the issues encountered when traditional means are used in the cracking and sorting of palm kernel. The perks of this machine include:

- Ease of use
- Ease of maintenance
- Low maintenance cost
- Low production cost making it affordable to rural farmers and local palm kernel processing plants.
- Compact size making it portable
- Simple technology
- Easy to construct

CHAPTER TWO

LITERATURE REVIEW

2.1 THEORITICAL FRAMEWORK

This section provides a comprehensive review of the different machines created to optimize the palm kernel cracker and sorter. This indicate the various materials in existence for various palm kernel cracking methods (such as centrifugal, rolling, and impact), and sorting methods like traditional hand-picking method, hydro-cyclone sorting, and mechanical separation. Palm kernel cracking and sorting methods can be classified as traditional and mechanized methods.

In Nigeria, palm kernel is relevant in a myriad of applications. The palm kernel oil is used as the typical frying oil in most of Nigerian cuisine, and as an ingredient in the cosmetic and soap industry he(Shimizu & Desrochers, 2012 & Oke, 2007). The use of palm kernel shells as fuel in boilers can be found in the work of Nnaemeka et al., (2018) and as an alternate aggregate in the manufacturing of concrete (Edmund et al., 2014). As a result of the widespread applications of palm kernel and its by-products, an efficient and economic means of cracking and sorting the palm kernel nuts is necessary. Traditionally this processing is carried out by placing individual nuts on a hard surface and using a hard object with sufficient force to crack the nut open. Thereafter, the palm kernel fruit is separated from the shells manually. The mechanized means have resolved a lot of the shortcomings encountered in the traditional processing methods; however, a lot of these solutions are expensive and require considerable effort to maintain and implement.

The information gathered in this chapter all led to the improvement of the performance of the palm kernel cracking machine.

2.2 HISTORY OF NUT CRACKING DEVICES

Nutshells that were too hard for teeth to split were presumably smashed by stones. Pitted stones used for breaking nuts have been discovered in many locations of the United States and Europe, and the sites date to the Archaic Period, which lasted between 4,000 and 8,000 years ago. When it was time for the nuts to fall, these nomadic peoples would camp near the nut trees. Whole kernels were consumed, while pulverized kernels were used to produce flour and nut butter.

The first wooden nutcrackers were simply two pieces of wood fastened together by a leather strap or metal hinge. The oldest known metal nutcracker is on display at a museum in Tarent, Italy, and dates from the third or fourth century B.C. A bronze Roman nutcracker dating between 200 B.C. and 200 A.D. is on display at the Leavenworth Nutcracker Museum. After being buried for nearly 1800 years, it was discovered in 1960. Brass nutcrackers are believed to have existed in the 14th and 15th centuries, while iron lever nutcrackers are featured in the Ironworks Museum in Rouen, France, with some dating back to the 13th century. These metal nutcrackers were originally hand-crafted, but following ages saw casting being used. The United States was famed for its cast-iron items, while England became known for its brass manufacture and several nutcracker forms (Nutcracker Museum, 2022).

The early inventions of the nutcracker employed the lever working principle. The lever working principle involves a rod pair pivoting about a fixed point (fulcrum). One end of both rods is made rigid to effectively clasp and crack whatever object is in between when a sufficient load is applied. It bears similarity to a plier and can only crack a few nuts at a time. It is also very labour-intensive as it is a manually operated device.

2.3 THE NEED FOR A PALM KERNEL CRACKING AND SORTING MACHINE

A variety of chemical, traditional and mechanical processes have been utilized in the extraction of oil from seeds (Ismail et al., 2015). The extraction of palm kernel oil from the palm kernel seeds is a very important step in palm kernel production. While lots of effort have been put into mechanizing the palm oil production operation, palm kernel oil production is significantly less mechanized. The first step of this production process is the sorting of the palm kernel seeds from the palm kernel shells which can only occur after the nuts have been cracked. Thus, the palm nut cracking operation is a very important step that determines the quality of the palm kernel oil obtained (Ismail et al., 2015).

According to Ismail et al., (2015), cracking is achieved traditionally by breaking the individual nuts between two stones, the magnitude of force applied is usually based on experience, while sorting is done by placing the mixture of nuts and fibre in the woven basket and rocking it back and forth to enable the lower density fibre to move above the higher density nuts, once the fibre are packed out of the basket the nuts and fibre are effectively separated. Ismail et al., (2015) opines that the problem with this method is the amount of time it takes and the danger of inadvertently hitting the operator’s fingers with the stone. Also, the need for further sorting because of the fibre is still present in the nuts. This necessitates a mechanised or automated means of cracking and sorting of the palm kernel.

Ibrahim et al., (2016) explains that for a period of about fifty to sixty years, numerous techniques have been used for cracking of palm kernel. These techniques have largely involved cracking the nuts by using stones or tossing the nuts against a rock with enough force to crack the nuts. Some of the challenges with these techniques include increased time-consumption, low-output per unit time, and the arduous nature of these techniques etc. Despite all the challenges involved in the native techniques of cracking of palm kernel nuts, there has been a persistent rise in the demand for palm kernel nuts, this is because palm kernels are useful in the production of cream, soaps, and cooking oil (the processed form of palm kernel oil), and other important commodities. Furthermore, the increasing population drives for larger demand of palm kernel and palm kernel-based products (Ibrahim et al., 2016). Thus, researchers are compelled to devise more efficient, less time-consuming, and less-hazardous means of separating palm kernel nut from its shell. (Ibrahim et al., 2016).

The traditional means of cracking and separating palm kernel is the manual method, which is a popular business endeavour among the local youth and aged women in rural Nigerian communities (Oke, 2007). This manual method is "labour-intensive, time consuming, cumbersome and is very slow to meet the demand of growing industry".

2.4 PALM KERNELS CRACKING METHODS

Typically, there are two methods employed in the cracking of palm kernel fruits and separating the same from their shells: the manual/traditional method and the mechanical method (John et al., 2020).

The traditional palm kernel cracking method is the most adopted cracking method in Nigeria. The traditional cracking method can be stone cracking method or mortar – pestle method [see Udo et al., (2015)]. Udo et al., (2015) further asserts that these techniques of manual palm kernel processing are among the most primitive and straight forward methods of palm kernel cracking in rural areas. Within Nigeria traditional cracking methods are still widely used. In the stone arrangement technique kernel cracking is carried out by making use of the impact principle. For this to occur, a few nuts – usually about 6 – are placed on a flat stone and then another stone acting as a hammer cracks them. Labourers, mostly the women and children in the rural areas, used this method. This method is "crude and has slow kernel recovery. In addition, the method is uneconomical, labor intensive and sometimes hazardous to the operator." Furthermore, the output may reach 50 kg of kernel per worker in a single working day, this implies that the method is not fast enough to satisfy the demand for palm kernel be it at the local or international level (Udo et al., 2015).

Typically, there are two mechanical techniques used in palm kernel cracking. The first involves the use of the impact caused by the hurling of the palm kernel against a hard object, while the second involves directly applying mechanical pressure to the palm kernel nut to pulverize, shear or cut through the hard shell (John et al., 2020). The work of John et al., (2020) indicates that the nutcrackers usually used in the palm oil mill are classified as: centrifugal crackers and roller crackers. In the roller crackers, there is a fixed clearance between the rollers which is used in cracking the nuts of different sizes, thus, the efficiency of the machines is greatly reduced. On the other hand, the centrifugal cracker utilizes the centrifugal force principle in hurling the palm kernels against a hard surface which is stationary. As a result of this hurling action, a shock is produced which shears through the shell (John et al., 2020).

2.5 METHODS OF SORTING PALM KERNEL

A study carried out by Akusu et al., (2017) highlighted five palm kernel shell separation methods employed in some communities in Rivers state namely: "traditional handpicking, clay-water bath (kaolin), mechanical dry separation, pneumatic and hydro-cyclone separations."

2.5.1 Traditional Hand-Picking Method

This technique involves separating the kernels manually by hand-picking. The kernels are first cracked using a stone, this yields the cracked mixture containing the shells, kernels, uncracked nuts, and dust.

2.5.2 Clay Water Bath (Kaolin) Method

Here, a clay solution with relative density of about 1:12 is utilized. When the mixture of cracked shells and kernels is placed in this solution; the denser shells sink to the bottom of the clay-water bath, while the less dense kernels float (Oguoma et al., 1993). After this, the floating kernels are then scooped off from the water-clay solution and then are washed and dried in the sun.

2.5.3 Mechanical Separation Method

Here, the cracker and nut separator are jointly built, the process is semi-automated such that the time consumed for cracking the nuts and separating the kernels is significantly reduced. Akusu et al., (2017) states that this is the kind of mechanical separation used at the Nigerian Institute for oil Palm research (NIFOR).

2.5.4 Pneumatic Palm Kernel Separator (Dry Method)

The separation here is done on the basis of difference in shape between the kernels and the shells. This separation system consists of a vibrating table and a winnowing column. Kernels are separated from the shells by dry forced air or induced draught. In the study of Akusu et al., (2017) two hundred kilograms of uncracked palm kernels fed into a pneumatic separator was cracked. Thereafter, the transporting of the cracked mixture through a winnowing column where the kernels and shells separated by using an induced draught process.

2.5.5 Hydro-Cyclone Method (Wet Method)

This method utilizes both water and air in separate sections enclosed within the same chamber. It shares a similarity with the kaolin method in that they are both operate using density differences. The uncracked palm kernels are cracked inside the system. The water section of the hydro-cyclone is responsible for separating the nuts from the shells and the section filled with air is responsible for drying the wet separated kernels before they are emptied into a bucket and bagged.

Akusu et al., (2017) performed experiments to determine the separation efficiency of each of these five methods. A performance analysis of the methods was carried out by determining the weight of the kernel recovered and calculating their separation efficiency. The results indicated that the hand-picking method and clay water method had average separation efficiency of 53 % and 60 % respectively. No significant difference ($P>0.05$) exists in their separation efficiencies (Akusu et al., 2017). However, the mechanical method had an average separation efficiency of 74 %, making it significantly higher than the hand-picking and clay-bath (kaolin) method. The study by (Akusu et al., 2017) showed that the methods with the highest efficiency were the hydro-cyclone and pneumatic methods with average efficiencies of 96 % and 90 % respectively.

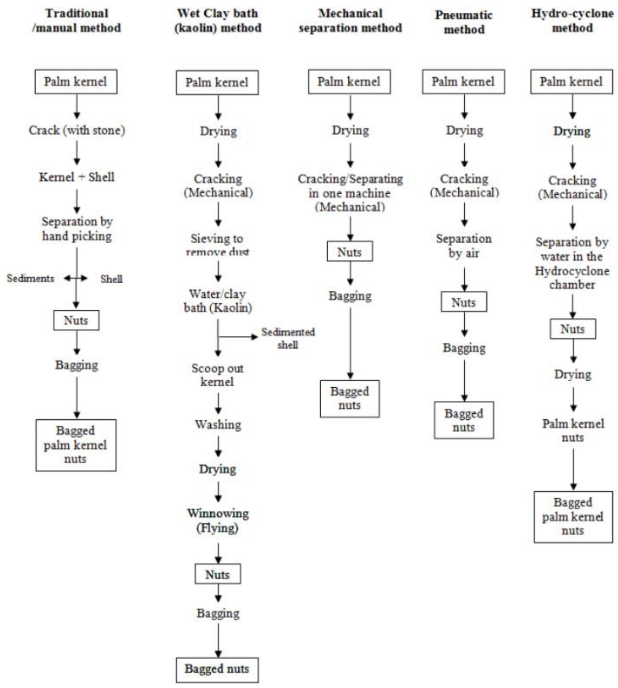


Figure 2. 1: Process Outline for the Different Palm Kernel Sorting Methods

Figure 2.1 summarizes the various steps involved in the sorting of the palm kernel in the form of a flow chart

2.6 DEVELOPMENT OF PALM KERNEL PROCESSING MACHINES OVER THE YEARS

A lot of work on palm kernel cracking has been carried out over the years by various authors; this section highlights some of these previous works, makes comparisons between them and draws relevant inferences.

Oyebanji et al., (2012) carried out a study in which they compared the performance of two palm kernel nut cracking machines: the vertical palm kernel nut cracking machine and the centrifugal impact approach nut cracking machine. In their work, they ascertained that various factors determine the design of the palm kernel cracking machine. Some of these factors include the velocity with which palm kernel nuts head towards the cracking chamber wall, the rotational speed of the rotor, difference in palm kernel nut properties such as size, shape, weight, the gap between the rotor and the cracking chamber wall, and the palm kernel nut feed rate. The results of their experiments indicated that "the efficiency of the vertical centrifugal cracking machine is 71.3 %" while the efficiency of the impact approach centrifugal palm kernel cracking machine is 50.38 %." From these results, Oyebanji et al., (2012) concluded that neither of the machines were as such efficient. They further stated that though the vertical centrifugal machine had a higher efficiency, it had a lower operating speed than the impact approach centrifugal cracker. They finally concluded that both machines required improvements to improve their performance and recommended possible areas of improvement.

Ibikunle et al., (2018) developed and carried out performance evaluation of a palm nut cracker. In their design, (Ibikunle et al., 2018) made use of the vertical centrifugal machine. This was a deviation from the conventional impact approach centrifugal cracker. They justified their decision to use this approach by referring to the work of Oyebanji et al., (2012) which indicated that the vertical centrifugal machine is the more efficient of the two. Their palm kernel nut cracker design included five units; the in-feed unit made up of the hopper, the cracking unit made up of the cracking drum/cracking chamber, the driving unit which included an electric motor, pulley and v-belt assembly, and finally, a driven unit consisting of a rotating shaft to which the hammers are attached. The shaft and hammers are driven by the v-belt and pulley assembly that are connected to the electric motor.

Ismail et al., (2015) designed a palm kernel cracking and sorting machine that also worked on the centrifugal cracking approach employed in previous works. The machine thus developed had five major units namely: the in-feed, cracking, discharge outlet, sorting, and driven units. The hopper in their design was inclined at an angle of 60 °. Ismail et al., (2015) gave reasons for this inclination which include to make sure the hopper was kept free of debris during the machine operation, to allow the kernels fall freely through the hopper, and finally to prevent the clogging up of kernels at the throat of the hopper. The hopper was connected to the cracking chamber by means of an in-feed elbow which included the elbow itself as well as a hollow tube. The in-feed elbow was a half-parabolic tube which prevented the back flow of kernels when the kernels encountered the high-speed rotation of the impeller in the cracking chamber. Furthermore, the in-feed elbow was inclined at 10 ° to the horizontal to make sure that the free-falling kernels being fed into the cracking chamber gained enough velocity before encountering the impeller in the cracking chamber. The inclination of the in-feed elbow also helped to prevent any clogging up of kernels at the cracking chamber entrance and increase the cracking efficiency of the machine. Both the in-feed elbow and hopper were made of mild steel. The cracking chamber designed by Ismail et al., (2015) in their cracking and sorting machine possessed impeller tube and blades at its core. The tube carried the blades and facilitated their rotary motion, cracking was accomplished by the action of the impeller blades which acted on the kernels striking the kernels against the cracking chamber walls. The discharge unit of the cracking and sorting machine was located directly below the cracking chamber. The design of the discharge opening was such that several cracked kernels could pass through it per unit time, this prevented the clogging up of kernels at the entrance and improved the sorting efficiency. The sorting unit of the machine consisted of a rectangular mesh with uniform rectangular grooves. The grooves had a diameter of 10 mm which is less than the average size of the kernels than the average diameter of the kernel seeds – this was done to prevent the kernels from passing through the grooves as they flowed along the sorting route. The sorting mechanism used in the machine was the same one employed in Oke (2007). It was based on the difference in the dynamic angle of repose between the shells and the kernel seeds on a particular material. The rectangular mesh was made of mild steel and inclined at an angle of 20 °; which is less than the dynamic angle of repose of shells on mild steel, the palm kernel seeds however have a dynamic angle of repose of 20 °. Therefore, the kernel seeds will move with a higher velocity than their shell counterparts while flowing along the sorting route, and would avoid being ejected through the grooves, the shells on the other hand are ejected from the grooves. An electric motor drives a shaft by means of a pulley-belt system, the shaft carries the impeller blades which slam the kernels against the walls of the cracking chamber. The vibratory action necessary for sorting is provided by the vibration of the electric motor. The machine had a whole kernel recovery of 70 %, an optimum shelling-sorting efficiency of 90 %, an effective shelling-sorting rate of 2.08 nuts per second, and a throughput capacity of 59 kg/h. It was found that the shelling-sorting efficiency of the machine increased as the kernel size increased, and in another analysis, it was concluded that a stronger relationship existed between the shelling-sorting efficiency and the moisture level of the nuts that is the drier the nuts the higher the shelling-sorting efficiency. Furthermore, the operation of the machine indicated that kernel feed rate was another variable that largely affected the shelling-sorting efficiency of the machine. Here, the best performance and worst performances were attained using feed rates of 2 nuts per second and 8 nuts per second respectively.

Oke (2007) developed a palm kernel cracking and sorting machine that made use of the centrifugal principle. The cracking chamber of the machine consisted of three blades evenly distributed such that each was at an angle of 120 ° and a clearance of 15 mm existed between the blades and the walls of the cracking chamber. The blades of the cracking chamber were removable to allow for ease of maintenance and replacement in the incident that failure occurred due to wear of the blades after extended use. The blades were made from high carbon steel to give it sufficient strength to effectively crack the palm kernels. The sorting mechanism used in the machine separated the kernels by employing the difference in the dynamic angle of repose between the shells and the kernel seeds on a particular material. The separating unit included a camshaft, returning spring and separating tray; the sorting tray was positioned such that it made an angle of 20 º with the horizontal – this angle is less than the dynamic angle of repose of the kernel shells on mild steel but greater than the dynamic angle of repose of the kernel seeds on mild steel. This allowed the kernel seeds to roll of the tray while the shells fell through the grooves. The sorting tray had two sections. The first section is the shell screener and the second, the kernel screener. The first section was made up of 10 mm rods distributed evenly within the tray such that a 9 mm spacing was maintained between subsequent rods; this spacing was chosen because it was less than the empirically determined size of the kernels but was large enough for the shells to pass through. The second section was made up of a tray with 16 mm holes punched through; this size was chosen because of the average sizes of kernels as observed from experiment and it functioned to sort the broken kernel seeds from the whole kernel seeds. The sorting tray was made to vibrate using three camshafts driven by a 4 hp electric motor and three returning springs. The 4 hp electric motor acted as the prime mover for the machine and was responsible for driving both the cracking and sorting units. A system of two pulleys and a belt served to transmit the power from the electric motor, the rotational speed of the electric motor was 2500 rpm. Oke (2007) carried out tests on their fabricated machine; the results indicated that the throughput capacity was 95 nuts per sec and the machine's performance efficiency 98 %.

Olatunde et al., (2019) developed a palm kernel cracking machine very similar to that of Oke (2007) in design and operation, their machine however focused on the cracking of the palm kernel shells and did not sort the shells from the kernels after cracking. As usual the machine consisted of the hopper or in-feed unit, cracking chamber, discharge unit and the driving unit. The cracking hammers were three in number and arranged radially with 120º between them [See Oke (2007);]. The same centrifugal principle was applied to crack the kernels. The tests carried out on the machine revealed that loading the kernel cracker with palm kernel less than 1000 kg in mass per time would cause split loss and uncracked palm kernel loss as the machine operates. The percentage of both these losses encountered was found to reduce as the mass of palm kernel input to the machine is increased at a given time during the machine's operation. At maximum performance, the results showed that the machine gave a "throughput capacity of

401.4 kg/hr, cracking efficiency of 95.6 %, split losses of 9.3 % and un- cracked losses of 6.2 %" [See Olatunde et al., (2019);].

John et al., (2020) did some relevant work on palm kernel cracking and separation. The machine designed in the study applied some of the basic principles already utilized in previous works. [See Olatunde et al., (2019) and Oke (2007)]. As such it had a hopper for in-feed, a cracking chamber with rotating hammers which cracked the palm kernel by centrifugal action and so on. The separation of the kernels from the shells was also based on the difference in the angle of repose of the kernel seeds and the shells on a given material. The hammers had a rotational speed of 2500 rpm. Though the basic principles applied in (John et al., 2020) were largely the same as those applied in previous works; the separation unit was an improvement on previous designs to increase the sorting efficiency of the machine. In this machine, the separation unit consisted of two screens instead of the regular single screen used in other designs. The first screen had groove sizes of 12 mm thus cracked shells and kernels with sizes less than 12 mm will not be retained. The second screen had groove sizes of 10 mm. The tests were carried out on the machine using 2400 rpm as the maximum rotational speed, and 800 rpm as the minimum. The results indicated that a proportional relationship existed between the number of cracked palm kernel nuts and the shaft rotational speed such that an increase in the shaft rotational speed resulted in an increase in the number of cracked palm kernel nuts. Furthermore, it was also observed that at a rotational speed of 800 rpm, 2.75 % of the palm kernel nuts were partially cracked – this figure reduced to 1.75 % at a rotational speed of 2400 rpm. At a rotational speed of 1600 rpm, the lowest fraction of un-broken kernels was observed (1.5 %) and the largest number of broken nuts (3.25 %) was observed at the maximum speed of rotation of the shaft (2400 rpm).

CHAPTER 3

MATERIALS AND METHODOLOGY

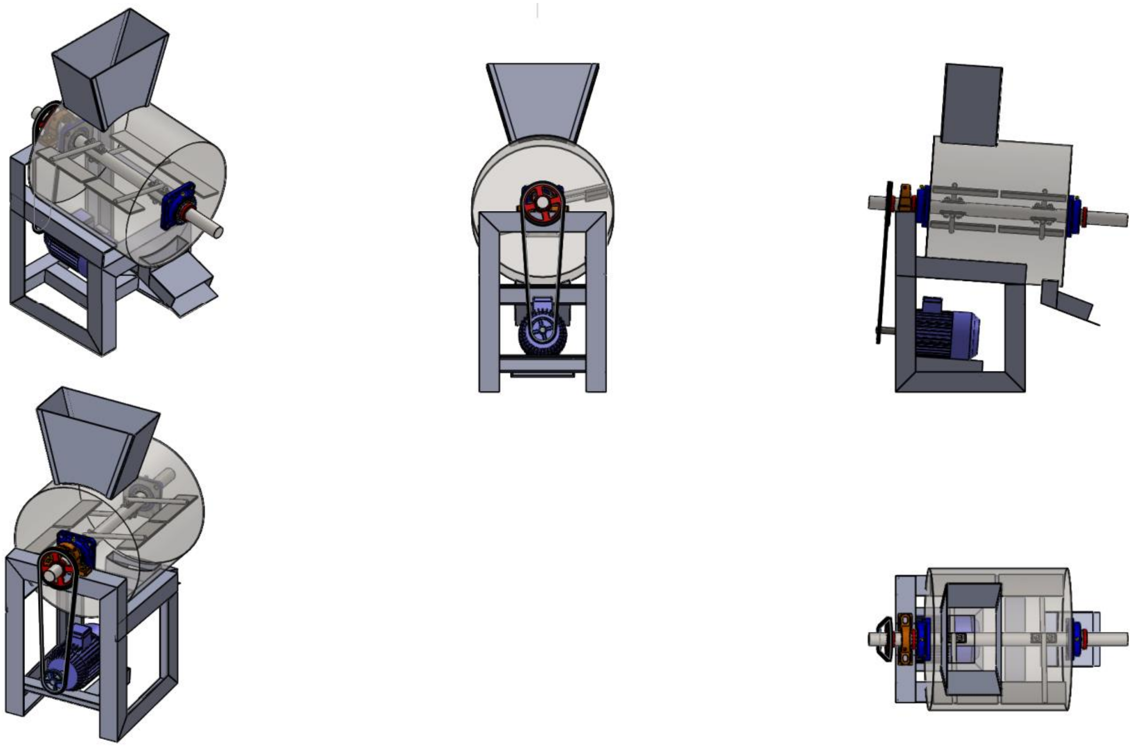
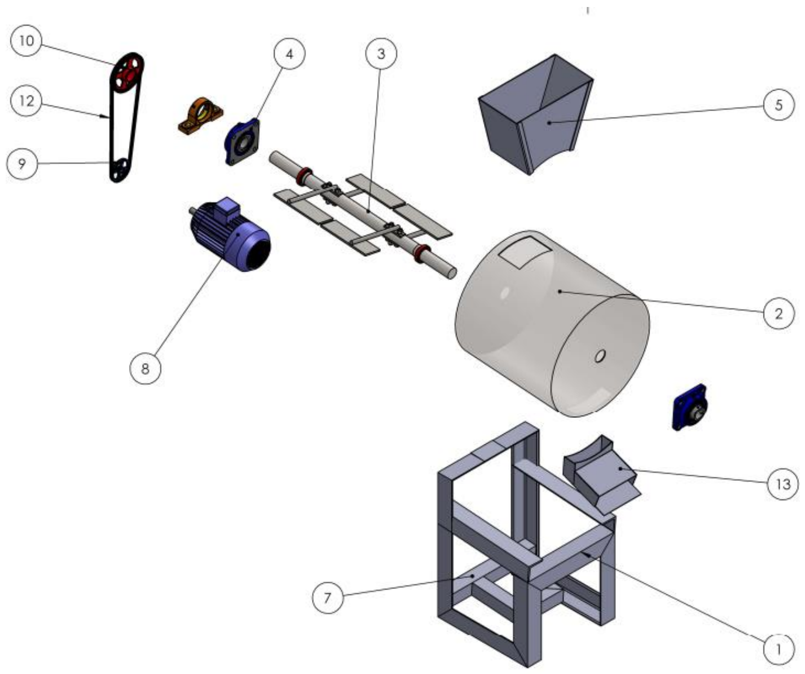


Figure 3. 1 Complete Orthographic View of the Palm Kernel Cracking Machine



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Supporting Frame		1
2	Cracking Drum		1
3	Shaft assembly		1
4	5967K88	BEARING,FLNG MNT,1-1/2" SHFT,STL	2
5	In-feed hopper		1
6	Pillow block housing-		1
7	Motor Support Frame		1
8	Electric Motor Assembly-		1
9	Motor pulley	Motor pulley	1
10	Shaft pulley-		1
11	Motor shaft		1
12	Belt2-4^Palm kernel Crakcing Machine		1
13	Sorting Unit		1

Figure 3. 2 Exploded View and Bill of Materials of the Machine

Machine Parts:

- Cracking Drum
- Shaft
- Shaft Sleeve
- Hammer
- Radial cylindrical roller bearing
- Pillow block bearing
- Hopper
- Electric Motor
- Pulley
- Belt
- Cracker drum side cover
- Cracker drum top cover
- Cracker frame

3.2 MACHINE DESCRIPTION

The palm kernel cracking and sorting machine consists of a hollow drum made from galvanized steel. It is supported by a frame made from angle iron (2.5 x 2.5 in). The frame supports both the cracking drum and the electric motor. The electric motor is connected to the shaft by means of a belt and pulley mechanism, thus the electric motor acts as the prime mover of the machine. The rotation of the electric motor is transferred to the shaft by the means of the belt and pulley mechanism. Thus, the shaft is rotated, and the hammers (four in number) rotate and exert an impact force on the incoming palm kernel fruits and smash them against the walls of the cracking chamber with sufficient force to crack the shells. The palm kernel cracking and sorting machine is made up of five important units; these units include: the feeding unit, cracking unit, discharge outlet, sorting unit and the driving unit (Ismail et al., 2015).

3.2.1 The Feeding Unit

The cracking unit consists of a drum made from galvanized steel, it has a diameter and length of 450 mm and 440 mm respectively. The cracking drum is made from a rolled galvanized steel sheet of 3 mm thickness. Galvanized steel is used because of its corrosion-resistant nature thus the drum is protected from rapidly corroding in the presence of moisture in the palm kernel nuts. The drum is covered at both ends by circular flat plates made from the same material as the drum. Circular holes are cut out on both flat plates for the shaft to pass through to the ball bearings. Rectangular cut-outs of 200 x 100mm and 170 x 50mm were made on the drum for palm kernel feeding and palm kernel discharge respectively. Flanges were welded to the ends of the cracking chamber drum and the circular flat plates, the flanges had holes drilled through them to enable the circular flat plates to be bolted to the cracking drum. This was done to allow for easy disassembly if maintenance or inspection needs to be carried out. The body of the cracking chamber is hard enough to cause cracking of the palm kernels when they are hurled against the walls of the cracking chamber. Inside the cracking chamber is a Ø40 x 820 mm mild steel shaft, the shaft passes through two rectangular flange type universal bearings which are bolted to the cracking drum covers, these bearings support the shaft and prevent whirling and vibration when the shaft rotates at high speeds. Four cracking hammers are bolted to the shaft, each hammer consists of an iron rod welded to a plate of 6 mm thickness, each plate has dimensions of 50 x 190 mm, and the iron rods are Ø16 mm and 225 mm long. The hammers are fixed to the shaft by means of a fixture plate; the shaft is milled in two separate areas to accommodate the fixture plates. 10 mm diameter holes are drilled in the fixture plate. Holes with the same diameter are also drilled through the shaft to enable heat treated bolt to pass through the fixture plates and the shafts, thus effectively joining them. This design was implemented for ease of disassembly and maintenance of the hammers. The hammers rotate with the shaft and strike the palm kernels against the wall of the cracking chamber to crack them open. The cracking drum is inclined at an angle of 4 ^{o} to the horizontal, this facilitates the movement of the kernels from one end of the drum where the hopper opening is located to the other end where they get to the discharge outlet.

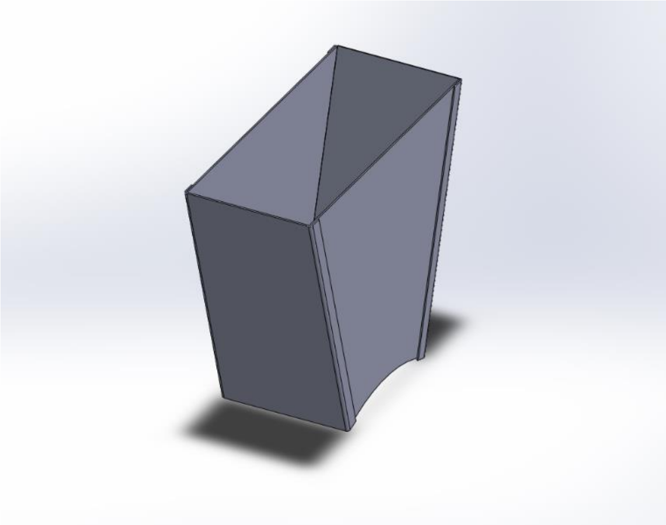


Figure 3. 3 In-Feed Hopper

3.2.2 The Cracking Unit

The cracking unit consists of a drum made from galvanized steel, it has a diameter and a length of 450 mm and 440 mm respectively. The cracking drum is made from a rolled galvanized steel sheet of 3 mm thickness. Galvanized steel is used because of its corrosion-resistant nature thus the drum is protected from rapidly corroding in the presence of moisture in the palm kernel nuts. The drum is covered at both ends by circular flat plates made from the same material as the drum. Circular holes are cut out on both flat plates for the shaft to pass through to the ball bearings, and rectangular cut-outs of 200 x 100 mm and 170 x 50 mm were made for palm kernel feeding and palm kernel discharge respectively. Flanges were welded to the ends of the cracking chamber drum and the circular flat plates, the flanges had holes drilled through them to enable the circular flat plates to be bolted to the cracking drum. This was done to allow for easy disassembly if maintenance or inspection needs to be carried out. The body of the cracking chamber is hard enough to cause cracking of the palm kernels when they are hurled against the walls of the cracking chamber. Inside the cracking chamber is a Ø40 x 820 mm mild steel shaft, the shaft passes through two rectangular flange type universal bearings which are bolted to the cracking drum covers, these bearings support the shaft and prevent whirling and vibration when the shaft rotates at high speeds. Four cracking hammers are bolted to the shaft, each hammer consists of an iron rod welded to a plate of 6 mm thickness, each plate has dimensions of 50 x 190 mm, and the iron rods are Ø16 mm and 225 mm long. The hammers are fixed to the shaft by means of a fixture plate; the shaft is milled in two separate areas to accommodate the fixture plates. 10mm diameter holes are drilled in the fixture plate. Holes with the same diameter are also drilled through the shaft to enable heat treated bolt to pass through the fixture plates and the shafts, thus effectively joining them. This design was implemented for ease of disassembly and maintenance of the hammers. The hammers rotate with the shaft and strike the palm kernels against the wall of the cracking chamber to crack them open. The cracking drum is inclined at an angle of 4 ^{o} to the horizontal, this facilitates the movement of the kernels from one end of the drum where the hopper opening is located to the other end where they get to the discharge outlet.

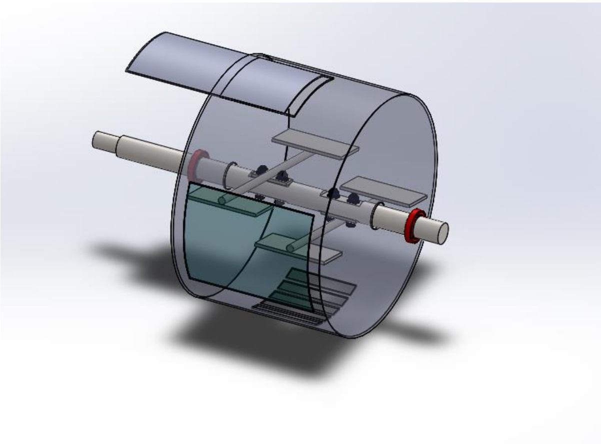


Figure 3. 4 The Cracking Unit

3.2.3 The Driving Unit

The driving unit is made up of a three hp electric motor, which acts as the prime mover, 2 two-way pulleys and a belt drive. The pulleys are of diameter 150 mm and 100 mm respectively. While the belt drive has specifications; V-belt (A60) spanning through a length of 1350 mm.

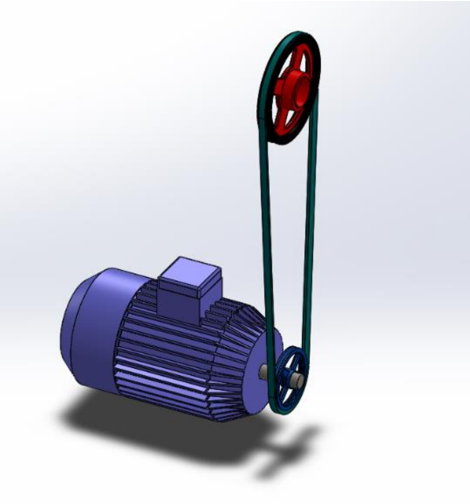


Figure 3. 5 The Driving Unit

3.2.4 Discharge Outlet

The cracked palm kernels are discharged through the bottom of the cracking chamber, they pass through an opening of 170 x 50 mm into the sorting unit. The design of the discharge opening is such that multiple cracked nuts can pass through it per unit time, this reduces the possibility of jam occurring at the discharge and increases the sorting efficiency.

3.2.5 The sorting Unit

The design concept of the sorting unit is as gotten from Ismail et al., (2015). The sorting unit consists of a rectangular metallic mesh with uniform rectangular grooves of diameter 10mm, and diameter 12 mm. This is to allow for shell particles of varying sizes to fall through the grooves and be effectively separated from the palm kernel seeds. The diameter of the mesh grooves is smaller than the average size of a palm kernel seed (15 mm diameter), therefore the kernel seeds do not pass through the grooves as they pass over the metallic mesh. The height width and length of the sorting unit are 70 x 174 x 500 mm respectively. The cracking unit functions as an agitated basket, this agitation is because of the vibration effect of the electric motor, this vibratory effect moves the sorting tray back and forth and to the left and right. It has empirically obtained from experimental procedures that the dynamic angle of repose of palm kernel seeds on mild steel is about 20 º - which is less than the dynamic angle of repose of shells on mild steel. This means the palm kernel seeds will move faster than the shells along the slope of the metallic groove, thus they would not be expelled through the grooves of the metallic mesh. The sorting tray is thus placed at an angle of 20 º to the horizontal, allowing the palm kernels seeds to slide freely over the rectangular grooves while the shells fall through them.

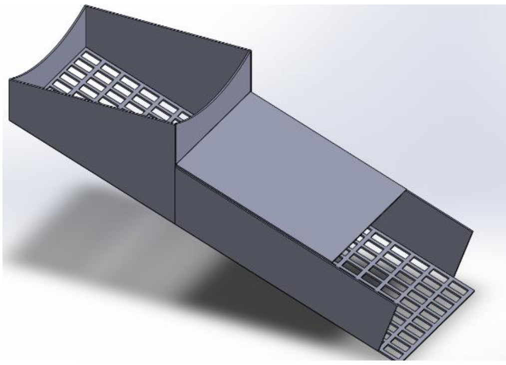


Figure 3. 6 The Sorting Unit

3.3 THE PRINCIPLE OF OPERATION

Palm kernels are fed into the machine through the hopper. The electrical energy is converted to mechanical energy by an electric motor; thus, it causes the rotation of the shaft and the hammers through the pulley system. The hammers moving with a given rotational speed impact the palm kernels and toss them against the walls of the cracking chamber thus cracking their shells because of the reaction force of the walls on the palm kernel shell. The cracked kernels fall through slots at the bottom of the cracking chamber to the sorting unit where the kernel seeds are separated from the shells by the vibration caused by the electric motor.

3.4 DESIGN ANALYSIS

3.4.1 The Cracking Unit

Following the law of conservation of kinetic energy:

Kinetic energy of kernels = impact energy of kernels on the cracking chamber wall

$\frac{1}{2}mv^2 \ = impact\ energy$ (1)

However, impact energy on the cracking wall = Work required to deform kernels

Work required to deform kernels = $\frac{F}{2} \times x$ (2)

Where:

F: force/load applied

x: distance travelled; specifically for this case, the deformation is e

Therefore, work needed $(W) = \frac{F}{2} \times e$

And we know $F = P\ x\ r$ (3)

Where:

P: impact load applied to kernels

r: ratio of stress due to impact to direct stress or ratio of deformation due to impact to the corresponding deformation

We know:

$$r = \frac{\sigma'}{\sigma} \times x \quad (4)$$

Where:

σ' = impact stress = $\frac{2P}{A}$ and $\sigma = \frac{P}{A}$ (5)

This implies, $r = 2, F = 2P$

Putting this into equation (2) gives: $W = \frac{2P}{2} \times e \ \rightarrow W = Pe$

From this we can see that: $\frac{1}{2}mv^2 = Pe$ (6)

From results of experiments, the product Pe (which is the energy of deformation) is given as 2.0015 Nm and 0.9012 Nm for Tenera and Dura nuts respectively (Ismail et al., 2015).

3.4.2 Hammer Design

For the Tenera Variety:

The average mass of a palm kernel fruit of the tenera variety is 8.5 g (=0.0085 kg) (Ismail et al., 2015)

Putting this in equation (6) gives:

$$\frac{1}{2}(0.0085)v^2 = Pe$$

$$\rightarrow v = \sqrt{\frac{2 \times 2.0015}{.0085}} = \frac{21.70\ m}{s}$$

However, linear velocity is the product of angular velocity and radius, that is; $v = \omega r$

The hammer radius is 0.16 m

Therefore, $\omega = \frac{v}{r}$ (7)

$$\omega = \frac{21.70}{.16} = \frac{135.625\ rad}{s}$$

To find linear speed; $\omega = \frac{2\pi N}{60}$ (8)

Making N the subject gives:

$$N = \frac{60\omega}{2\pi} = \frac{60 \times 135.625}{2\pi}$$

$$N = 1295.123\ rpm$$

For the Dura Variety:

The average mass of a palm kernel fruit of the dura variety is 7.66g (=0.00766 kg) (Ismail et al., 2015)

Putting this in equation (6) gives:

$$\frac{1}{2}(0.00766)v^2 = Pe$$

$$\rightarrow v = \sqrt{\frac{2 \times 0.9012}{.00766}} = \frac{15.34\, m}{s}$$

However, linear velocity is the product of angular velocity and radius, that is; $v = \omega r$

The hammer radius is 0.16 m

Therefore, $\omega = \frac{v}{r}$ (9)

$$\omega = \frac{15.34}{.16} = \frac{95.872 rad}{s}$$

To find linear speed; $\omega = \frac{2\pi N}{60}$ (10)

Making N the subject gives:

$$N = \frac{60\omega}{2\pi} = \frac{60 \times 95.872}{2\pi}$$

$$N = 915.509\, rpm$$

Thus:

Mean linear speed the machine needs = $\frac{1}{2}(21.70 + 15.34) = 18.52\, m/s$

Mean angular speed the machine needs = $\frac{1}{2}(135.625 + 95.872) = 115.749\, rad/s$

Mean rotational speed the machine needs = $\frac{1}{2}(1295.123 + 915.509) = 1105.316\, rpm$

3.4.3 V-Belt and Pulley Design

The smaller of the two pulleys is connected to the electric motor, while the larger is connected to the shaft. The ratio of pulley sizes; size of motor pulley to size of shaft pulley is 1.5:1. The formula used is:

$N_1 D_1 = N_2 D_2$ (11)

Where:

D_1 = Diameter of the Pulley for the shaft (mm)

D_2 = Diameter of the Pulley for the electric motor (mm)

N_1 = Rotational speed of the driven shaft (rpm)

N_2 = Rotational speed of the electric motor (rpm)

N_1 = unknown, N_2 = 1500 rpm, D_1= 150 mm, D_2 = 100 mm

After calculating, this gives N_1 = 1000 rpm

3.4.4 Determination of V-belt Length

The belt length was calculated by using the equation below:

$$L = 2C + 1.57(D_1 + D_2) + \frac{(D_1 - D_2)^2}{4C} \quad \text{(Khurmi, 2004)} \qquad (12)$$

Where:

C = center to center distance = 470 mm

L = Belt length

D_1 = Diameter of the Pulley for the shaft (mm)

D_2 = Diameter of the Pulley for the electric motor (mm)

$$L = 2(470) + 1.57(150 + 100) + \frac{(150 - 100)^2}{4 \times 200}$$

$$\boldsymbol{L = 1335.63\ mm = 1336\ mm}$$

3.4.5 Angle of Contact between belt and pulley

The coefficient of friction $\mu = 0.35$ (From Autodesk Inventor)

For an open belt $\sin\alpha = \frac{(R_1 - R_2)}{C}$ (Khurmi, 2004) (13)

$$\sin\alpha = \frac{(75 - 50)}{200} = 0.125$$

$$\alpha = sin^{-1}(0.125) = 7.18\,^{o}$$

Angle of contact or lap, $\theta = (180 - 2\alpha)\frac{\pi}{180}$ (14)

, $\theta = \left(180 - (2 \times 7.18)\right)\frac{\pi}{180} = 2.89\ rad$

3.4.6 Determination of Belt Tensions:

To determine the tension in the belt, the tight and slack sides of the belt need to be calculated for, using simultaneous equations: (Oluwole et al., 2014)

$$\mu\theta = 2.3log\frac{T_1}{T_2} \qquad (15)$$

$$P = (T_1 - T_2)v \qquad (16)$$

Where:

μ = the coefficient of friction, θ = angle of contact, T_1 = Tension on the tight side, T_2 = Tension on the slack side, P = electric motor power rating, v = peripheral velocity of the belt, this peripheral velocity is given as;

$$v = \frac{\pi DN}{60} \tag{17}$$

Let $\mu = 0.35$ and $\theta = 2.89$

Using equation (10) to find the ratio of the tight side to the slack side (Oluwole et al., 2014)

$$log\frac{T_1}{T_2} = \frac{\mu\ x\ \theta}{2.3} = \frac{0.35\ x\ 2.89}{2.3}$$

$$log\frac{T_1}{T_2} = 0.43978$$

$$\rightarrow \frac{T_1}{T_2} = 2.753 \tag{18}$$

Peripheral velocity of the belt, $v = \frac{\pi DN}{60}$ (Oluwole et al., 2014)

Substituting this gives: $v = \frac{\pi \times 0.1 \times 1500}{60} = 7.854\ m/s$

Putting v in (11) gives:

$$2238 = (T_1 - T_2)7.854$$

$$(T_1 - T_2) = 284.957 \text{ N} \tag{19}$$

Combining equations (18) and (19)

$$T_1 = 447.507\ N\ \ T_2 = 162.555\ N$$

3.4.7 Centrifugal Tension

$$T_C = mv^2 \tag{20}$$

Where:

T_C = Centrifugal Tension of the belt

m = mass of the belt per unit length = 0.060 kg/m

v = peripheral velocity of the belt = 7.854 m/s

$T_C = 0.060 \times 7.854^2$ = 3.701 N

3.4.7 Key Design

By using the diameter of the shaft as a guide, the size of the key; that is its height and width can be determined by employing the empirical design code relation for various kinds of keys.

For key Width/diameter, b:

$$b = nd \tag{21}$$

Where:

n = ratio of key width to shaft diameter. n has a recommended value of 0.25

d = diameter of the shaft = 40 mm

Therefore:

$b = 0.25 \times 40 = 10\ mm$

$b = 10\ mm$

For depth/height of key:

$$h = mb \qquad (22)$$

Where:

m = ratio of key height to key width. m has a recommended value of 1.30

Therefore:

$b = 1.30 \times 10 = 13\ mm$

3.4.8 Shaft Design

The design of the palm kernel cracker includes a two-degree inclination of the cracking chamber, this degree of inclination would cause the forces acting on the shaft to have two components – one component acts perpendicular to the shaft and the other acts parallel to the

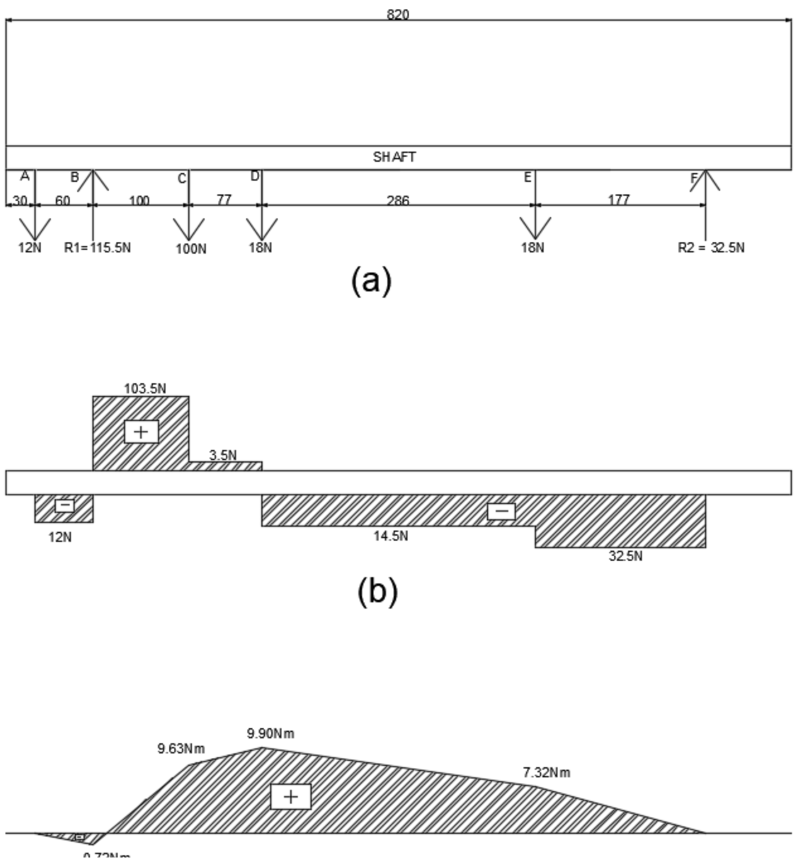


Figure 3. 7 (a) Free Body Diagram (b) Shear Force Diagram (c) Bending Moment Diagram

shaft. However, the component acting parallel to the shaft is very small and is considered negligible.

To find reactions R_1 and R_2

Conditions for static equilibrium:

$\Sigma F_y = 0$ (23)

This gives:

$R_1 + R_2 = 148\ N$ (24)

Taking moment about B:

$\Sigma M_B = 0$ (25)

$(12 \times 60) + (R_2 \times 640) - (100 \times 100) - (18 \times 177) - (18 \times 463) = 0$ (26)

This gives $R_2 = 32.5\ N$

And $R_1 = 148 - 32.5 = 115.5\ N$

Taking moment at A, $M_A = 0$

Taking moment at B, $M_B = (-12 \times 0.06) = -0.72\ Nm$

Taking moment at C, $M_C = (-12 \times 0.16) + (115.5 \times 0.1) = 9.63\ Nm$

Taking moment at D, $M_D = (-12 \times 0.273) + (115.5 \times 0.177) + (-100 \times 0.077) = 9.90\ Nm$

Taking moment at E, $M_E = (-12 \times 0.523) + (115.5 \times 0.463) + (-100 \times 0.363) + (-18 \times 0.286) = 7.32\ Nm$

Taking moment at F, $M_F = (-12 \times 0.700) + (115.5 \times 0.640) + (-100 \times 0.540) + (-18 \times 0.463) + (-18 \times .177) = 0\ Nm$

Torque on the impeller = $(T_1 - T_2) \times radius\ of\ pulley$

$T = (447.50 - 162.555) \times 0.075$ = 21.37 Nm

Maximum bending moment = 9.90 Nm

Equivalent Twisting moment $T_e = \sqrt{(T^2 + M^2)}$ (27)

$T_e = \sqrt{(21.37^2 + 9.90^2)} = 23.55\ Nm$

Calculating diameter of the shaft:

The Maximum Shear Stress Theory is used in calculating the diameter of the shaft, however, there are shock factors because the shaft experiences minor shocks during its operation as a result of the impact of the palm kernels during its operation.

The shock factors for Minor shocks are: $K_{sb} = 1.5, K_{st} = 1.5$

The diameter of the shaft is then given by

$$d = \sqrt[3]{\frac{32n}{\pi S_y}(\sqrt{(K_{sb} \times M)^2 + (K_{st} \times T^2)}} \quad (28)$$

Where:

n = factor of safety = 3, because of the uncertain stresses that might be encountered as the hammers come in contact with the palm kernels.

S_y = yield strength of shaft material = 250 MPa for mild steel

M = maximum bending moment

T = torque on the shaft

Substituting:

$$d = \sqrt[3]{\frac{32 \times 3}{\pi \times 250 \times 10^6}(\sqrt{(1.5 \times 9.90)^2 + (1.5 \times 21.37)^2}}$$

d = 0.01628 m = 16.28 mm

However, considering that the shaft will be milled flat at certain sections for the placement of the hammers, and holes drilled in it which would cause stress concentration at the holes; a 40mm diameter shaft was used in the design.

3.4.9 Hammer Force:

We know

$$P = T \times \omega \quad (29)$$

Where:

P = Power of the electric motor = 3 HP = 2238 W

T_i = Torque of electric motor

ω = rotational speed of the electric motor in rad/s

From (10): $\omega = \frac{2\pi N}{60}$

N = 1500 rpm

$\omega = \frac{2\pi \times 1500}{60}$ = 157.080 rad/s

Substituting in (29):

$$T = \frac{P}{\omega} = \frac{2238}{157.080} = 14.246\ Nm$$

From the torque value, the circumferential force acting on the belt can be calculated using the relation:

$$F_c = \frac{T}{r_i}$$

Where:

F_c = circumferential force acting on the belt

r_i = radius of driving or input pulley

Thus: $F_c = \frac{14.246}{0.05}$ = 284.951 Nm

This circumferential force should be equal to the difference between the tensions on the tight and slack side of the belt respectively, that is:

$$F_c = T_1 - T_2 \tag{30}$$

Substituting:

$T_1 = 447.507\ N\ \ T_2 = 162.555\ N$

$F_c = 447.507 - 162.555 = 284.952\ N$

This proves that the calculations are accurate.

The torque on the driven pulley is found from:

$T_o = F_c \times r_o$ where T_o and r_o are the Torque on the driven pulley and the radius of the driven pulley respectively.

$T_o = 284.951 \times 0.075 = 21.37\ Nm$

The torque on the shaft is 21.37 Nm, radius of the hammers from the center of rotation is 0.19 m.

Cracking force F = $\frac{T}{r}$ = $\frac{21.37}{0.19}$ = 112.47 N

3.4.10 Vibration Analysis:

The sorting unit of the palm kernel cracking machine requires some degree of vibration for the successful separation of the palm kernel seeds from the shells. The vibratory system of the palm kernel cracker falls under forced, damped vibrations

Taking $\omega_n = \sqrt{\frac{g}{\delta_{ST}}}$ (31)

Where:

ω_n = natural frequency of the vibration in rad/s

g = acceleration due to gravity = 9.81 m/s

δ_{ST} = amplitude of vibration required on the sorting tray = 5 mm = 0.005 m (Ismail et al., 2015)

$$\omega_n = \sqrt{\frac{9.81}{0.005}} = 44.29\ rad/s$$

r = $\frac{\omega}{\omega_n}$ (32)

r = $\frac{115.749}{44.29}$ = 2.61

The transmissibility of amplitude:

$$\frac{X}{Y} = \frac{1}{\sqrt{(1-r^2)^2 + (2\zeta r)^2}} \quad (33)$$

ζ = damping ratio = 2% = $\frac{2}{100} = 0.02$ for steels

Y = $\delta_{ST} = 0.005\ m$

r = 2.61

making X subject of formula:

$$X = \frac{0.005}{\sqrt{(1-2.61^2)^2 + (2 \times 0.02 \times 2.61)^2}}$$

X = $8.601 \times 10^{-4}\ m$

But $v = \omega X$ (34)

$v = 115.749 \times (8.601 \times 10^{-4}) = 0.0996\ m/s$

$a = \omega^2 X$ (35)

$a = 115.749^2 \times (8.601 \times 10^{-4}) = 11.523\ m/s^2$

We know, Force (F) = ma

The mass of the cracking chamber and the shaft with the hammers is 43.31 Kg

$F = 43.31 \times 11.523 = 499.06\ N$

This gives the amount of force required to produce the vibration needed for the sorting process.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 DESIGN DETAIL

The table 4.1 below includes the design details of the various machine elements that make up the palm kernel cracking machine. The force obtained at the hammers is 112.47N when the 3 HP electric motor is used at its maximum speed of 1500rpm. Considering the ratio of pulley diameters, this reduces the speed of rotation of the shaft to 1000rpm.

Table 4. 1 Design Detail of Machine Elements for the Palm Kernel Cracking Machine

S/N	Parameter	Value
Power Calculation		
1.	Velocity of the belt	7.854 m/s
2.	Angular speed of the impeller	104.72 rad/s
3.	Torque to rotate the impeller shaft	21.37 Nm
4.	Selected Power for the machine	2238 W
5.	Hammer force	112.47 N
Power Transmission		
1.	Driving Pulley Diameter	Ø100 mm
2.	Driven Pulley Diameter	Ø150 mm
3.	Belt length	1336 mm
4.	Selected belt	Standard V-Belt A50
5.	T_1 Tension on tight side of belt	447.50 N
6.	T_2 Tension on slack side of belt	162.56 N
7.	Angle of lap	2.89 rad/s
Shaft Diameter Calculation		
1.	Reaction at Bearing Point B	115.5 N
2.	Reaction at Bearing Point F	32.5 N

Plate 4.1 shows the fabricated palm kernel cracking machine. The angle of inclination of the cracking drum shown in the plate is 4 ^{o} to allow the palm kernels to slide down out of the discharge conduit. The shaft is also inclined at 4 ^{o}, it passes through the rectangular flange bearings on both cover plates, so it is perfectly aligned with the drum. The cracking hammers are welded perpendicularly to the shaft, a clearance exists between the cracking hammers and the cracking drum to prevent contact between them when the shaft is rotating at high speeds. Also, at high-speed rotation of the shaft, vibration occurs. The clearance between the cracking hammers and cracking drum must be enough to prevent any contact that would cause noise and be hazardous. The angle of inclination of the shaft affects the alignment of the belt, it is assembled perpendicular to the shaft axis and connects the driving pulley to the driven pulley. The electric motor is assembled parallel to the cracking drum. The hopper as well is inclined at 4 ^{o}. Kernels are fed through the hopper and after cracking by the cracking hammers flow down to the discharge conduit where the mixture of kernel seeds and cracked kernel shells are collected.

Plate 4.2 shows a mixture of the palm kernel seeds, their shells, damaged seeds, and uncracked palm kernels after processing by the palm kernel cracking machine. This mixture is obtained at the discharge conduit of the palm kernel cracking machine. The amount obtained depends on how many kernels were fed into the hopper of the cracking machine. The inclination of the palm kernel cracking machine means little, or no residue of the cracked mixture is left in the machine after its operation. During the machine's operation, there is a tendency for kernel seeds and shells to be flung back out of the hopper as they encounter the high rotational speed of the shaft and hammers. This could result in a safety hazard as the machine is in operation. To prevent this from occurring, a lid is provided for the in-feed opening on the drum. It is made from the material that was removed from the drum to create the opening. This lid has a bent iron rod welded to it. Iron bars have been welded under the hopper to allow the lid to slide open and close freely. The lid is opened to allow for in-feed of the kernels, and then closed during machine operation to prevent kernels from flying back out of the cracking drum.

Plate 4. 1 Fully Developed Model of the Palm Kernel Cracking Machine

Plate 4. 2 Mixture of palm kernel seeds, their shells, damaged seeds and uncracked palm kernels

Plate 4.3 shows the palm kernel seeds after they have been separated from the shells and uncracked kernels. It was observed that some of the palm kernel seeds had been damaged or broken by the palm kernel cracking machine, inspection revealed that this mostly occurred for seeds that had started to rot. The healthy seeds were emerged whole from the discharge conduit without any damage to the seeds. The occurrence of damaged seeds increased as the speed of rotation of the shaft increased. Palm kernel oil is gotten from the palm kernel seeds and so it is important that the seeds remain undamaged after the shells have been cracked. This would increase the quality of the oil that can be obtained from the palm kernel seeds.

Plate 4. 3 Palm Kernel Seeds

Plate 4.4 shows the cracked palm kernel shells, the shells vary in size depending on the degree of fragmentation by the hammers of the palm kernel cracking machine. Generally, at higher speeds of shaft rotation, the degree of fragmentation of the shells increased. The increased centrifugal force of the hammers caused the shells to fragment more before emerging from the discharge conduit. Palm kernel shells are useful as fuel for boilers and as an alternative aggregate in concrete as stated in Chapter 2.

Plate 4. 5 Palm Kernel Shells

Plate 4.5 shows the uncracked palm kernels, that is kernels that emerged from the machine whole without any damage to their shells. This occurred at very low speeds of rotation of the shaft. It implies that the cracking force exerted by the hammers on the kernels was not enough to crack the kernels at a given speed of rotation of the shaft. Calculations concerning the cracking force of the hammers have been elucidated in Chapter 3. The cracking force needs to exceed the energy of deformation of the kernels for cracking of the shells to occur. As the shaft rotational speed increases, the number of uncracked palm kernels that emerge from the discharge conduit reduces.

Plate 4. 4 Uncracked Palm Kernel Seeds

In table 4.2 the construction details of the machine parts of the Palm Kernel cracking machine are shown. It depicts the methods by which the machine elements were fabricated, and the tools involved.

Table 4. 2 Construction Detail of the Machine Elements for the Palm Kernel Cracking Machine

S/N	Machine Part	Construction Detail	Tools Used
1.	Frame	Angle iron of size 50mm x 50mm x 6mm were cut and welded to form the shape shown in figure A1 of the working drawing.	Hacksaw, Arc welding machine, gauge 12 electrodes, hand grinding machine and hand cutting machine.
2.	Hopper	2mm mild steel sheet metal was cut and welded to form the shape shown in Figure A2 of the working drawing,	Metal sheet shearing machine, arc welding machine, gauge 12 electrode.
3.	Cracking hammers	$\emptyset 16\ mm$ iron rods were cut into four rods of 190mm length. 6mm thick mild steel metal sheet was then cut and welded at both ends of the rod to form the shape shown in figure A3 of the working drawing. Holes were then drilled in the fixture plate to allow for bolting to the milled face of the shaft.	Hand cutting machine, drilling machine, gauge 12 electrode, arc welding machine.
4.	Shaft	A long $\emptyset 40\ mm$ shaft was cut into 850mm length. A keyway was machined into the shaft of width 8mm and depth 5mm. Rectangular faces of 80 x 50mm were milled on opposite sides of the shaft. M10 holes were then drilled into the shaft and tapped.	Lathe machine, drilling machine, milling machine, vernier caliper

5.	Cracking Drum	A 3 mm thick galvanized steel sheet was cut and rolled to form a drum of $\emptyset 450mm \times 440mm$. An opening was cut into the drum to allow for in-feed through the hopper.	Rolling machine, arc welding machine, hand cutting machine, gauge 12 electrode.
6.	Pulleys	Two V-groove pulleys were machined on the Lathe machine, to get them to the proper bore size to fit on the electric motor and the driven shaft. The driving pulley had an external diameter of 100 mm and the driven pulley an external diameter of 150 mm.	Lathe machine and vernier caliper.
7.	Conveyor	A 2 mm thick sheet was cut and welded to form the shape shown in figure A7 the working drawing, it served to allow the cracked palm kernel shells and palm kernel seeds to come out of the machine.	Hand cutting machine, arc welding machine, gauge 12 electrode.
8.	Adapted parts	One pillow bearing of $\emptyset 40\ mm$ bore, two rectangular flange type universal bearings of $\emptyset 40\ mm$ bore, v-belt A50, 20 M10 bolts and nuts, 14 plain washers, 3HP electric motor.	

Table 4.3 shows the Cost Analysis for the fully developed Palm Kernel Cracking Machine

Table 4. 3 Cost Analysis for Palm Kernel Cracking Machine

S/N	DESCRIPTION	QUANTITY	RATE (₦)	AMOUNT (₦)
1.	Mild steel plate (1500 x 1220 x 2mm)	1	50,000	50,000
2.	Fabricated galvanized steel drum (Ø450 x 440 x 3mm)	1	40,000	40,000
3.	Shaft (Ø40 x 850)	1	24,000	24,000
4.	Bearing with pillow block housing. Size: p208.	1	5,000	5,000
5.	Rectangular flange type universal bearing. Size: UFC-208	2	7,500	15,000
6.	Mild steel plate (300 x 300 x 6mm thick)	1	10,000	10,000
7.	Electric motor (3HP)	1	80,000	80,000
8.	Pulleys (Ø100mm, Ø150mm)	2	8,000	16,000
9.	V belt (A50)	1	3,000	3,000
10.	M-10 x 60mm bolts and nuts	20	250	5,000
11.	Angle iron (2.5 x 2.5 x 0.25) 1m long	6	1,500	9,000
12.	Mild steel rod (Ø14 x 1000mm)	1	7,000	7,000
13.	Iron rod (Ø14 x 1000mm)	2	2,000	4,000
14.	Workmanship and Transportation			50,000
	Total			318,000

4.2 TESTING AND RESULTS

Tests carried out on the palm kernel cracker to obtain its performance; the following metrics of performance were considered:

i. Throughput capacity (kg/h): this is gotten by dividing the mass of nuts in the hopper infeed by the time it takes for the mixture of cracked nuts to leave the conveying chute totally (Shebayan, 2020). The throughput capacity is calculated using equation (36) below:

$$Throughput = \frac{M}{T}(kg/h) \tag{36}$$

Where:

M = total mass of palm kernel nuts in the hopper infeed (kg)

T = total time it takes the cracked mixture to completely leave the chute (h)

ii. Cracking Efficiency (ε_c): this is the percentage by mass of the total nut infeed that has been completely cracked by the machine before emerging from the conveying chute. It is calculated using equation (37) below:

$$\varepsilon_c = \frac{Mass\ of\ cracked\ palm\ kernel}{Mass\ of\ total\ nut\ infeed}$$

$$= \frac{M_{TN} - (M_{Uc} + M_{PC})}{M_{TN}} \times 100\% \tag{37}$$

iii. Percentage of Broken Nuts: this is the percentage by mass of the total nut feed whose palm kernel seeds have been damaged or cracked before emerging from the conveying chute.

$$PD(\%) = \frac{Mass\ of\ damaged\ or\ broken\ seeds}{Mass\ of\ total\ nut\ infeed}$$

$$= \frac{M_{BN}}{M_{TN}} \times 100\%$$

Where:

M_{TN} = Mass of the nut feed into the hopper (g)

M_{BN} = Mass of broken or damaged palm kernel seeds from the chute (g)

M_{UN} = Mass of the un-cracked nuts from the chute (g)

M_{PC} = Mass of the partially cracked nuts from the chute (g)

Table 4.4 shows the results for the performance tests that were conducted on the fully developed palm kernel nut cracking machine. The maximum speed of the shaft used in the test was 1105 rpm, while the minimum speed was 366 rpm. The speed of the shaft was varied using a frequency inverter which was set up to vary the frequency of electricity supply to the electric motor and as a result the speed with which the shaft rotated. The rotational speed of the electric motor increased as the frequency of electricity supply increased. It was observed that for every 10 Hz increase in frequency of electric supply, the rotational speed of the electric motor increased steadily by 185 rpm. The speed of the shaft was 366 rpm at 20 Hz and increased steadily to a maximum of 1105 rpm at 60 Hz. 200 palm kernel nuts were weighed using a digital weighing scale and then loaded into the cracking machine at the beginning of each experiment. After the nuts had been cracked and the cracked mixture had been discharged from the discharge conduit, the uncracked and partially cracked kernels were then separated from the kernel seeds. The mass of the uncracked and partially cracked kernels was measured and recorded in the table below. Also, the mass of the totally cracked palm kernels was measured and recorded. The cracking efficiency was then calculated using the formula shown in equation (37).

From the results obtained, it was observed that the percentage of the cracked palm kernel (i.e., the cracking efficiency) increased from 43.26% to 94.11% with an increase in the speed of revolution of the shaft from 551 rpm to 1105 rpm. Inversely, the mass of uncracked and partially cracked palm kernels reduced. From this relationship between the shaft speed and the cracking efficiency, it is evident that the shaft speed has a significant effect on the cracking force, calculations for the cracking force are shown in Furthermore, the highest cracking efficiency was recorded at the shaft speed of 1105 rpm while the shaft speed of 366 rpm resulted in no cracked palm kernels as the cracking force generated at the hammers was not sufficient to crack the palm kernel nuts. At a shaft speed of 551 rpm cracked palm kernels were observed at the discharge conduit which indicates that at this shaft speed the cracking force generated at the cracking hammers is sufficient to crack the shells of the palm kernel. The average mass of a single palm kernel from the sample tested = 3.0788g

Table 4. 4 Performance Test Results Showing Cracking Efficiency

Number of palm kernel nuts	Frequency of electricity supply (Hz)	Shaft speed (rpm)	Mass of palm kernels, M_{TN} (g)	Mass of uncracked + Mass of partially cracked (g)	Mass of cracked palm kernel (g)	Cracking efficiency, ε_c (%)
200	20	366	700	---	---	-----
200	30	551	705	400	305	43.26
200	40	736	630	120	510	80.95
200	50	921	619	60	559	90.31
200	60	1105	509	30	479	94.11

Table 4. 5 Performance Test Results Showing Throughput Capacity

Number of palm kernel nuts	Mass of palm kernels (g)	Shaft speed (rpm)	Cracking time (s)	Throughput (g/s)
200	700	366	--	--
200	705	551	30	23.50
200	630	736	26	24.23
200	619	921	23	26.91
200	509	1105	18	28.28

Table 4.5 shows the cracking time and the throughput capacity of the developed palm kernel cracking machine. From the results obtained, a decrease in the cracking time from 30 seconds to 19 seconds is observed as the shaft speed increases from 551 rpm to 1105 rpm. The throughput capacity of the machine showed a steady increase from 23.50 g/s to 28.28 g/s, as the speed of the shaft increased from 551 rpm to 1105 rpm.

Figure 4.2 shows the graph of the cracking efficiency of the palm kernel cracker against the speed of revolution of the shaft in rpm, the cracking efficiency increased with shaft speed and the highest cracking efficiency of the machine was observed to occur at a shaft speed of 1105 rpm. At a shaft speed of 366 rpm the cracking efficiency was 0 % as none of the kernels were cracked at this speed.

Figure 4.1 shows the graph of the throughput capacity of the palm kernel cracker in grams per second against the speed of revolution of the shaft. Throughput capacity increases as shaft speed increases and the machine had the highest throughput at the shaft speed of 1105 rpm. More kernels were cracked per unit time at higher shaft speeds due to the increased cracking force of the hammers. Also, the increased speed of rotation of the shaft causes the inclined cracking drum to vibrate more. This increased vibration is likely to cause the cracked kernels at the bottom of the drum to flow faster towards the discharge chute, thus increasing the throughput capacity.

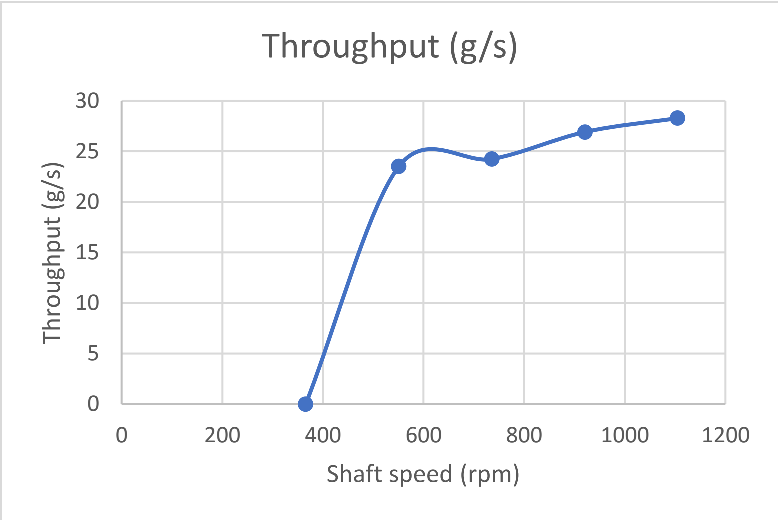


Figure 4. 1 Graph of Throughput (g/s) against Shaft Speed (rpm)

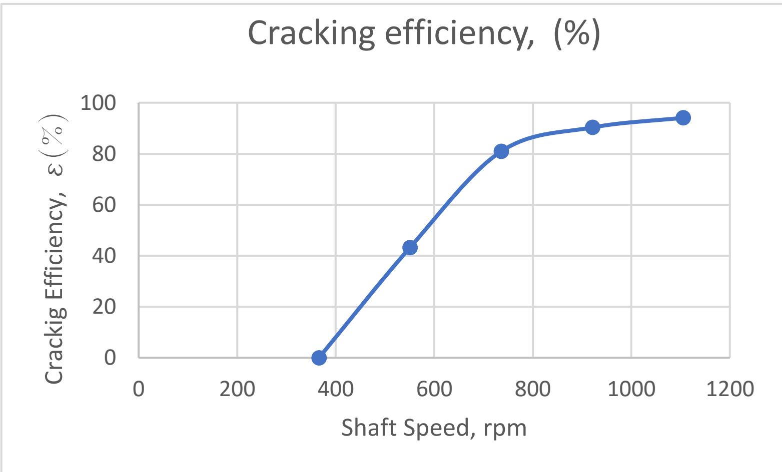


Figure 4. 2 Graph of Cracking Efficiency (%) against Shaft Speed (rpm)

4.3 SIMULATION RESULTS

Autodesk Inventor Professional 2023 was used to carry out Finite Element Analysis (FEA) on the assembly of the shaft and the cracking hammers [see figure A5]. It was a single point static analysis, as such only set of geometry was evaluated. Both the shaft and the cracking hammers were made of mild steel with a yield strength and ultimate tensile strength of 207 MPa and 345 MPa respectively.

The average element size represented as a fraction of the model diameter was 0.1. The minimum element size as a fraction of the average element size was 0.2.

Fig. 4.3 shows the operating conditions used in the analysis. A fixed constraint was placed at both ends of the shaft. A pin constraint was placed on the cylindrical face of the shaft. The torque of the electric motor acts on the cylindrical surface of the shaft in the clockwise direction as shown. Experiment results indicate that the strength required to crack a palm kernel nut is 1423.25 N/m^2 (Okoli, 1997). This 1423.25 N/m^2 stress was applied to the surface areas of the four cracking hammer as shown in figure 4.3.

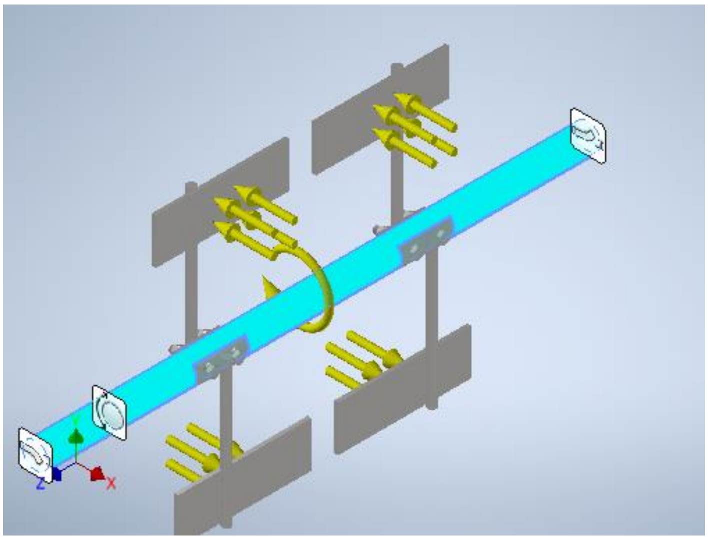


Figure 4. 3 Operating Conditions for the FEA

The simulation was run for varying speeds of shaft rotation, to reflect the change in the rotational speed, the torque on the shaft was varied accordingly using equation (29):

$P = T \times \omega$

Figures 4.4 to 4.7 below show the Von Mises stress for the different rotational speeds of the shaft. The maximum Von Mises stress at all the rotational speeds of the shaft was far below the ultimate tensile strength and yield strength of the shaft and cracking hammers. Therefore, the entire assembly is blue indicating that no part of it undergoes dangerously high stress that could cause failure during machine operation. The FEA analysis was not carried out for the 366 rpm rotational speed of the shaft as no kernels were cracked at that speed.

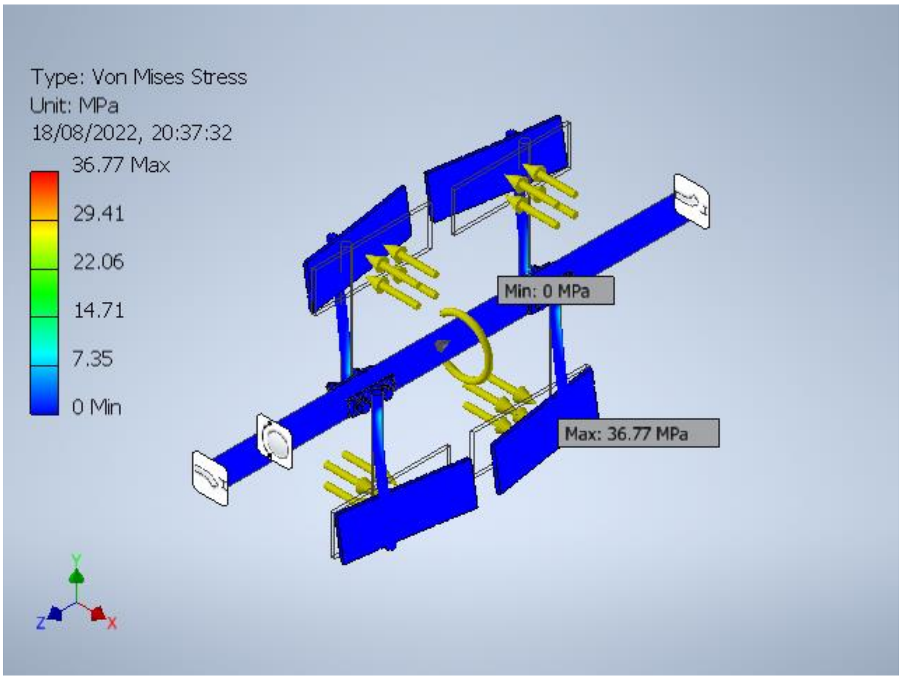


Figure 4. 4 Maximum and Minimum Von Mises Stress for 551 rpm

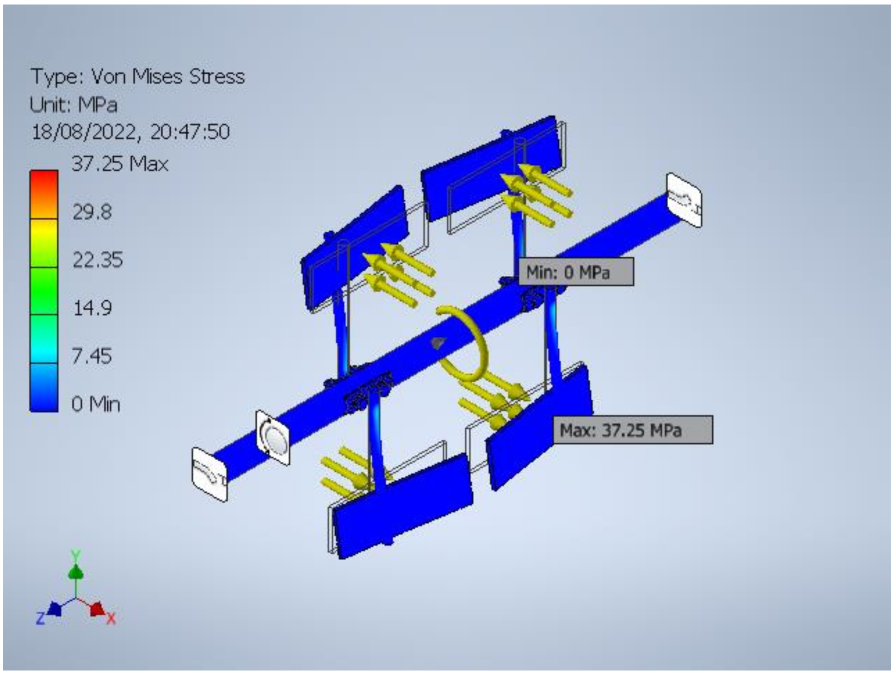


Figure 4. 5 Maximum and Minimum Von Mises Stress for 736 rpm

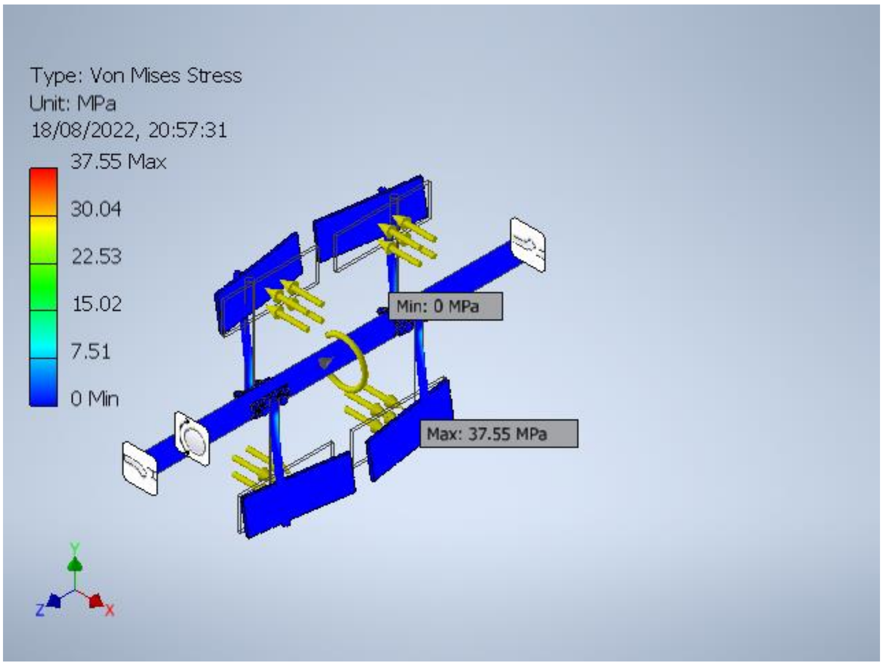


Figure 4. 6 Maximum and Minimum Von Mises Stress for 921 rpm

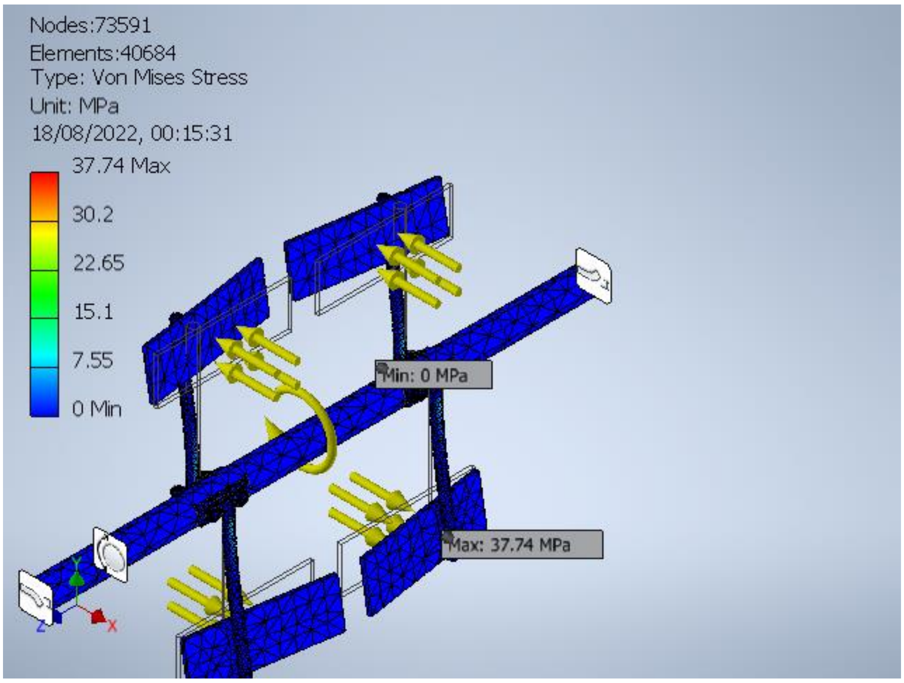


Figure 4. 7 Maximum and MInimum Von MIses Stress for 1102 rpm

Table 4.6 summarizes the maximum and minimum Von Mises stress at the various shaft speeds. The minimum Von Mises Stress remained constant at 0 MPa, while the maximum Von Mises stress increased as the shaft speed increased. The increase in the Von Mises stress with shaft speed occurs because as the shaft speed increases, the torque on the shaft reduces. This reduction in torque implies that the equivalent force on the shaft and hammers as a result of the impact of the palm kernels increases. This increased force then causes an increase in the induced stress.

Table 4. 6 Variation of Von Mises Stress with Shaft Speed

Shaft Speed (rpm)	Minimum Von Mises Stress (MPa)	Maximum Von Mises Stress (MPa)
551	0	36.77
736	0	37.25
921	0	37.55
1105	0	37.74

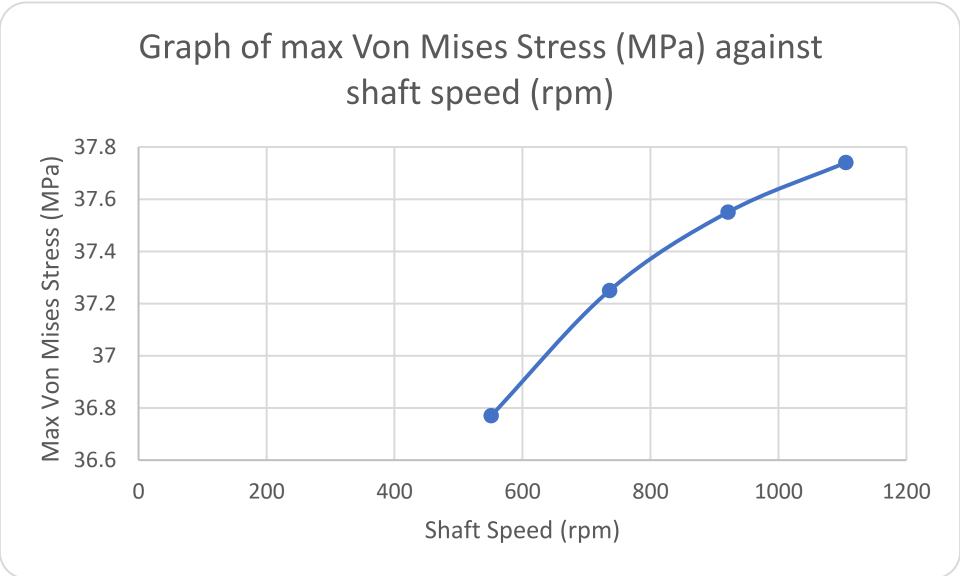


Figure 4. 8 Graph of max Von Mises Stress (MPa) against shaft speed (rpm)

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The palm kernel crushing machine was designed and fabricated as outlined in this work, the aim was to create a simple and effective design that eliminates the rigor and risk involved in manual palm kernel cracking and improve on the efficiency of previous works. It consists of a frame, cracking drum, hopper, cracking hammers, electric motor, v-belt and pulleys. All the materials used in the construction were locally sourced and required no extended procurement time. Minimum cracking efficiency and throughput capacity of 43.26 % and 23.50 g/s were attained at a shaft speed of 551 rpm. Maximum cracking efficiency and throughput capacity of 94.11 % and 28.28 g/s respectively were attained at a shaft speed of 1105 rpm. The cost of production is ₦318,000, however, with optimization of the production process and fewer reworks on components this cost can be reduced significantly.

5.2 RECOMMENDATION

The following recommendations are made for the developed palm kernel crushing machine:

1. Noise and vibrations should be reduced by using a thicker galvanized sheet for the cracking drum and adding dampers to the frame.
2. Wheels can be added to the machine to facilitate easy transportation of the machine.
3. The design should be optimized to reduce the weight of the machine.

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APPENDIX

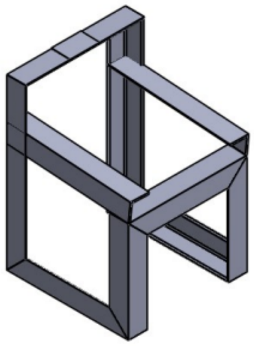

Figure A1: Frame

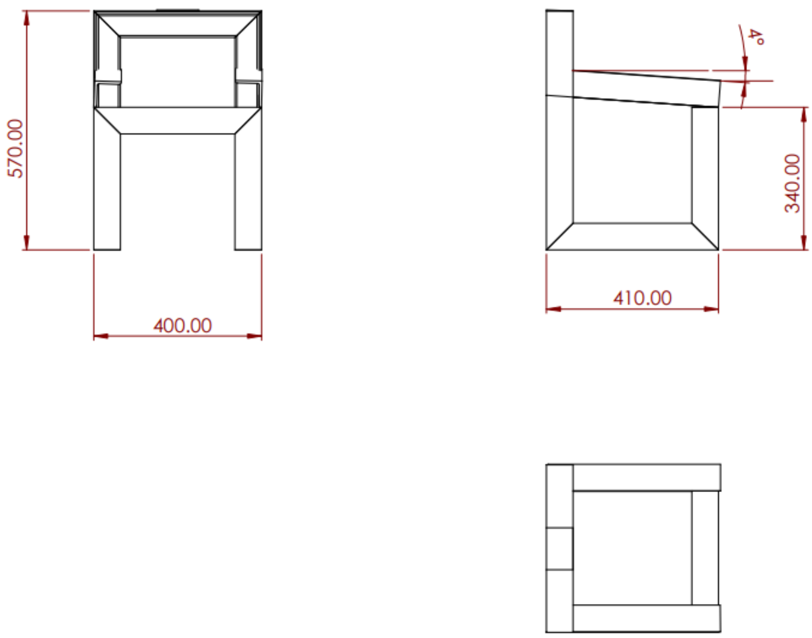

Figure A 1 Frame

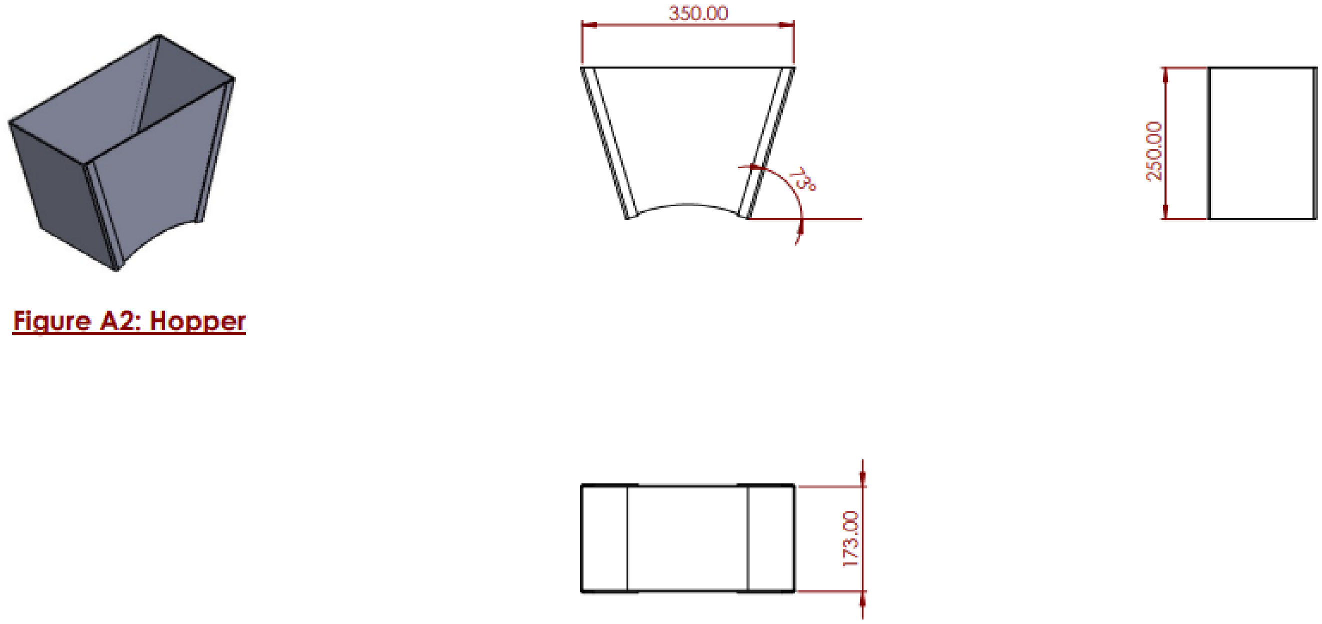

Figure A 2 Hopper

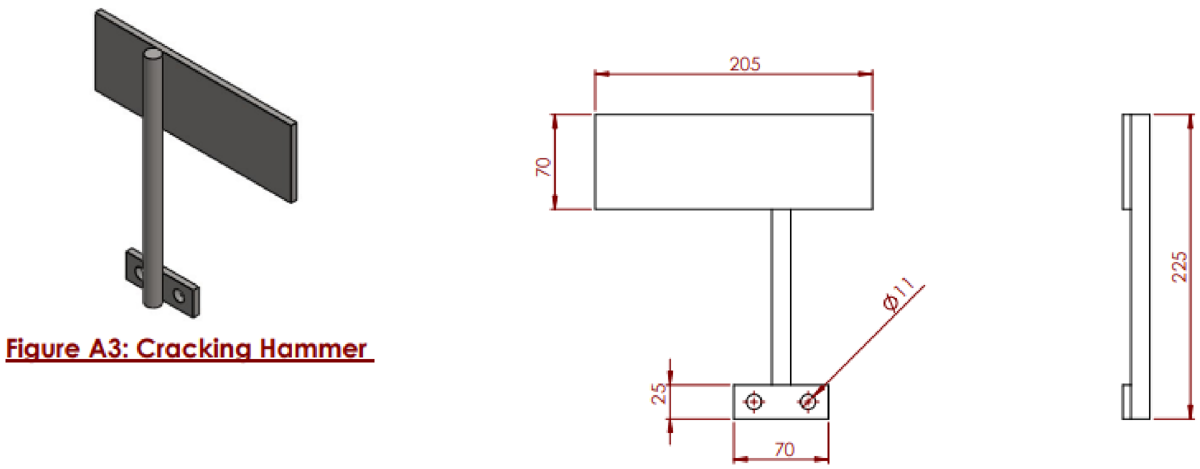

Figure A3: Cracking Hammer

Figure A 3 Cracking Hammer

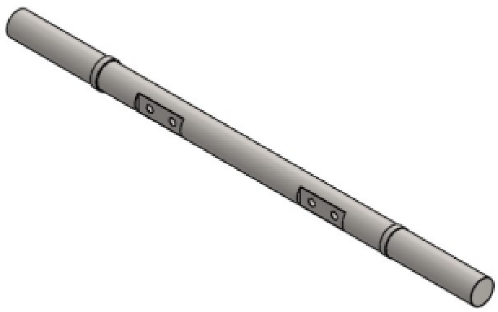

Figure A4: Shaft

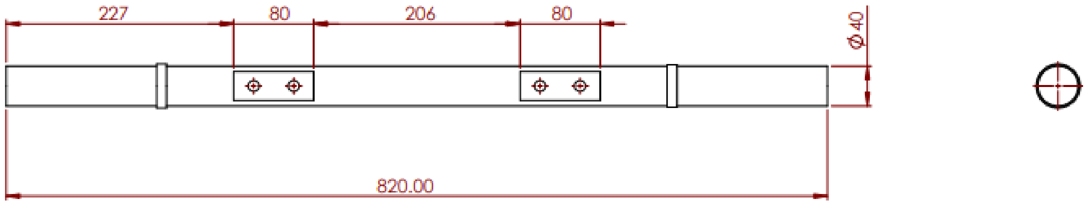

Figure A 4 Shaft

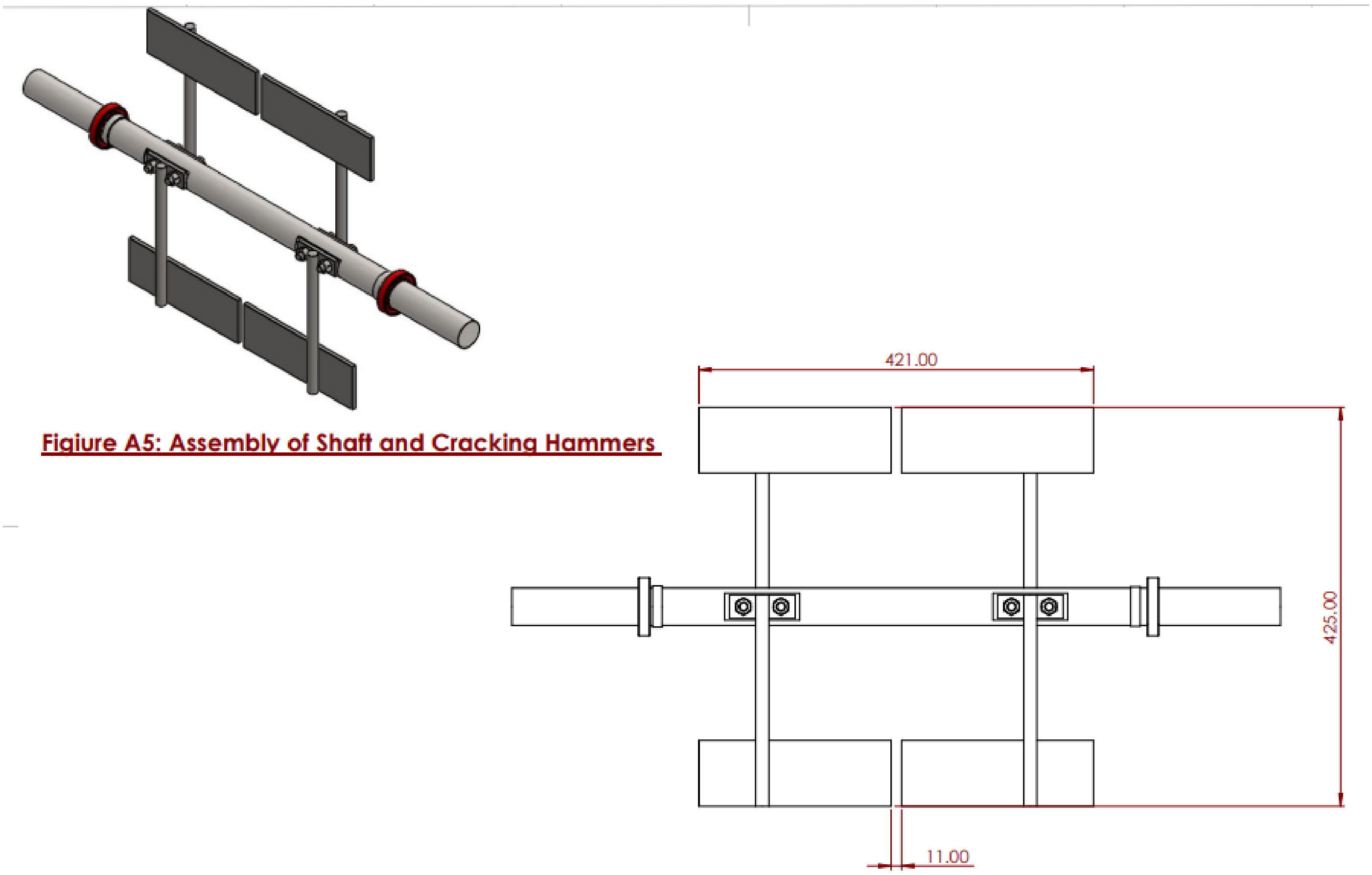

Figure A 5 Assembly of Shaft and Cracking Hammers

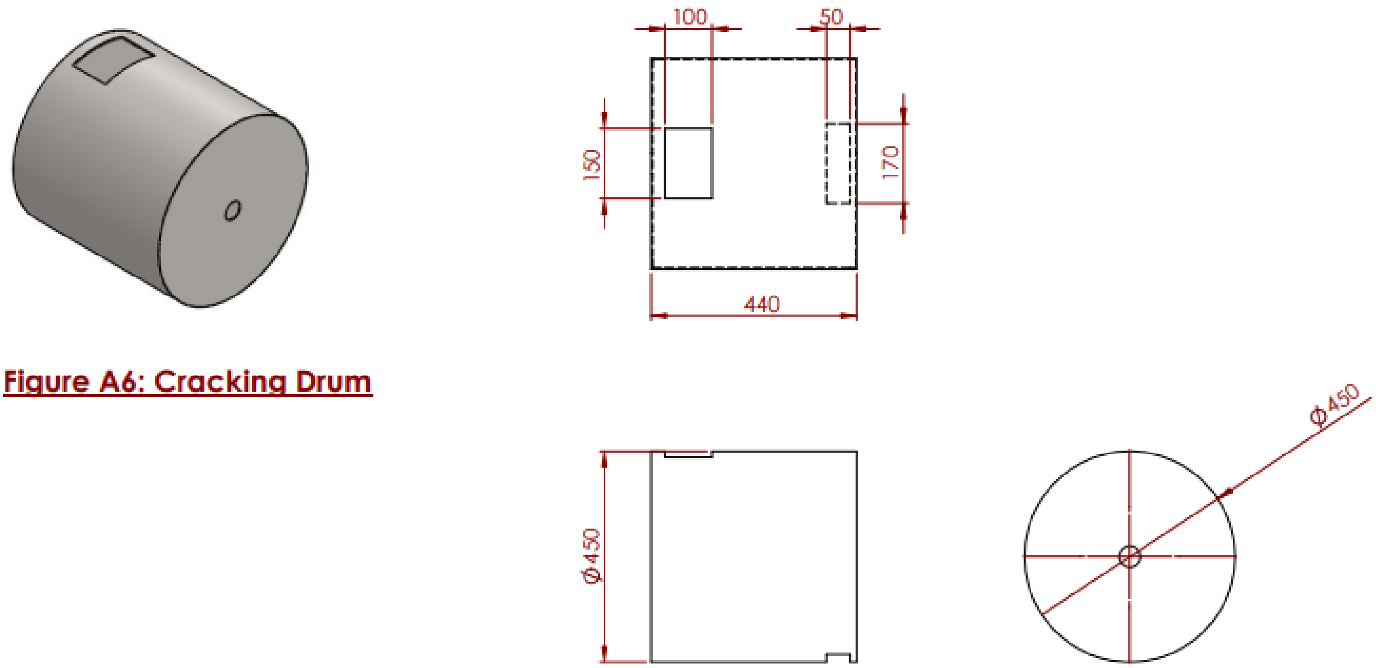

Figure A 6 Cracking Drum

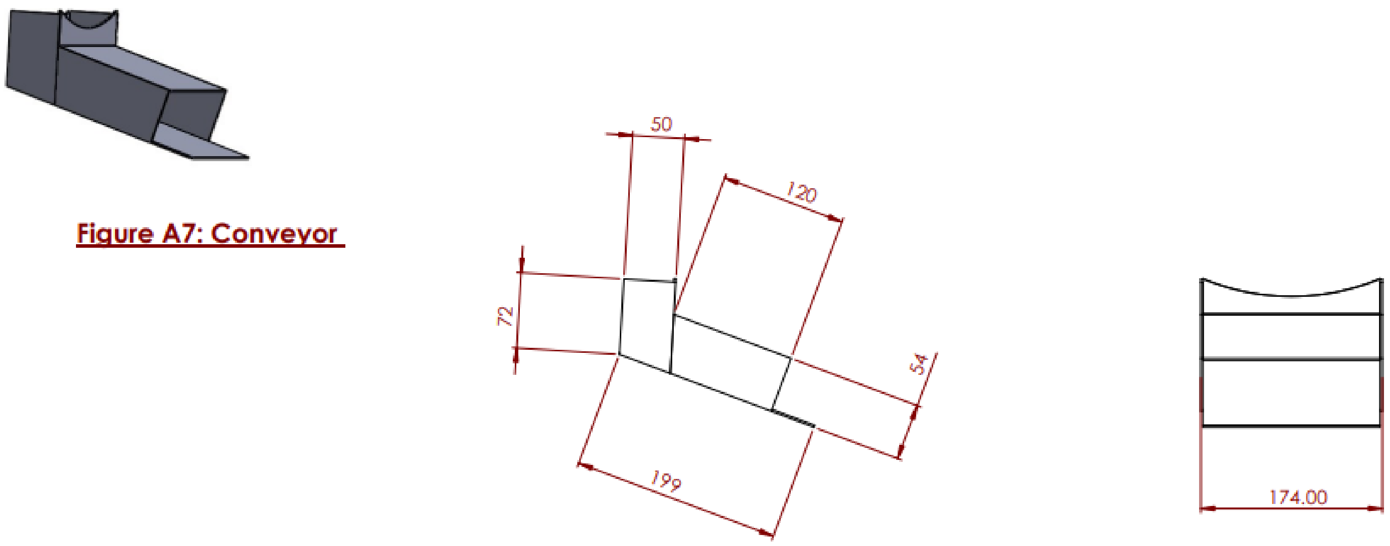

Figure A 7 Conveyor