DESIGN AND FABRICATION OF AN IMPROVED PALM FRUIT DIGESTER

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SUPERVISED BY ENGR. PROF. R. EBHOJAIYE

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CERTIFICATION

This is to certify that this project work was carried out by EJEOMOH EFETOBORE OMOKHOJE, with Matriculation Number ENG2002654, of the Department of Production Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria.

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DEDICATION

I solemnly dedicate this project to The Almighty God for His grace and guidance that has sustained me throughout my entire academic run and shall continue to do so in all aspects of life.

I would also like to dedicate this work to my loving and supporting family, whose unwavering love, sacrifices and encouragements carried me all through till where I am now. Your support means everything to me.

ACKNOWLEDGEMENT

Firstly, I would like to thank God almighty for His grace, blessings, protection and guidance throughout the course of this project.

I also want to express deep appreciation to my family, your love and support means the world to me. To my parents and siblings, thank you for your continuous and constant encouragement and also for giving me the strength to continue and pull through amidst any and all obstacles. I truly appreciate you all.

A very special thank you to my project supervisor, Prof. R. Ebhojaiye, thank you very much sir for taking the time to guide and teach me. I am genuinely grateful for your patience, support and wisdom throughout this process.

Thank you all.

ABSTRACT

Despite the availability of palm fruit digesters in Nigeria, many of them remain inefficient due to outdated designs, poor material choices that increases the susceptibility to corrosion, and poor hygiene, as a result the aim of this project is to design and fabricate an improved vertical palm fruit digester with enhanced efficiency, hygiene and durability, suitable for small to medium-scale processing, specifically but not limited to South-South Nigeria.

To address these challenges, the improved digester incorporates stainless steel for fabrication material to prevent rust and contamination. The digester employs a vertical chamber with an optimized shaft and angled beater arms to ensure thorough maceration of the palm fruit without damaging the nuts. Material selection, fabrication, and performance testing, which involved sourcing of fresh palm fruit bunches that were sterilized by boiling (increasing the efficiency of maceration) and then digested in controlled batches of varying masses (7kg, 9kg, 10kg and lastly 10kg. Total of 36kg) led to the gathering of data for improved results.

The performance of the digester was evaluated based on digestion time, throughput capacity, effectiveness of maceration and the quality of sludge produced. The results gathered indicated that the improved digester was capable of processing a total of 36kg boiled palm fruit in 1020 seconds, with the digestion time increasing proportionally with the size of palm fruit batch. The digester achieved an average throughput of 127kg/hr, which demonstrates improved efficiency compared to traditional small-scale digesters. The use of stainless steel eradicates the issue of corrosion seen in mild steel designs, therefore enhancing durability and preventing contamination. The fabricated vertical palm fruit digester offers a significant improvement in efficiency (approximately 95%), durability and product quality making it a preferable choice for small-scale palm oil processing.

TABLE OF CONTENTSi

TABLE OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Palm oil production is a vital part of the agricultural economy in Nigeria, particularly in the southern states like Edo, where oil palm (Elaeis guineensis) grows naturally and in cultivated plantations. The process of extracting oil from the fruit involves multiple stages, among which digestion, where the fruit's mesocarp is broken down, is one of the most crucial. Traditionally, palm fruit digestion has relied heavily on manual labor and rudimentary heating and crushing methods. These methods are not only slow but inefficient and often unhygienic.

In rural settings around Benin City and beyond, the need for improved, semi -automated, and cleaner digesters is growing. Small-scale farmers and local processors face challenges with outdated digesters, especially those fabricated from mild steel. These tend to rust after repeated exposure to heat and moisture, reducing the quality of palm oil and compromising health standards. Another challenge is the heating method, mostly firewood, which is less efficient, polluting, and costly over time.

This project explores the design and fabrication of a palm fruit digester optimized for medium-scale processors, incorporating stainless steel for the internal chamber, an improved shaft design with angled blades for efficient mashing of the palm fruit and the use of a diesel-powered prime mover. This improvement is to be made based on findings from previously designed and fabricated digesters which used traditional heating method with firewood as the major heat source and the use of mild steel for fabrication which over time, due to prolonged exposure to extreme heat, was found to rust and risks contamination of the palm fruit. This has to be completely avoided because the finished product is meant for consumption and contamination might lead to health complications which is nowhere near the desired goal of clean palm fruit digestion.

1.2 Statement of the Problem

Despite the availability of palm fruit digesters in Nigeria, many of them remain inefficient due to outdated design and poor material choices. Local fabricators often use mild steel for internal chambers, which quickly rusts after repeated exposure to high heat and oil. This affects both machine durability and oil quality. Additionally, many digesters rely on firewood, which not only release harmful emissions but is also thermally inefficient.

Processors in Edo State have particularly voiced concerns about:

i. Poor oil extraction due to incomplete digestion of fruit pulp.
ii. High maintenance cost from corroded components.
iii. Excessive smoke and labor intensity associated with firewood heating.

There is, therefore, a clear need for an improved palm fruit digester that addresses these shortcomings.

1.3 Aim and Objectives of the Study

The aim of this project is to design and fabricate an improved palm fruit digester with enhanced efficiency, hygiene, and durability, suitable for medium-scale processing in South-South Nigeria.

The specific objectives include:

i. Designing a palm fruit digester using stainless steel for internal components to prevent rust and improve hygiene.
ii. Ensuring efficient mesocarp digestion without damaging the palm nut.
iii. Testing the digester's performance in terms of efficiency and throughput capacity.
iv. Reducing physical labor associated with traditional palm oil processing.

1.4 Scope of the Study

This project covers the design, material selection, fabrication, and testing of an improved palm fruit digester.

i. Focus is placed on small to medium-scale processors common around Benin City.
ii. Only the digestion phase of palm oil processing is considered.
iii. Stainless steel is used strictly for parts in contact with the palm fruit to prevent contamination.

This scope ensures a tight focus on improving the core function of digestion while prioritizing performance and safety.

1.5 Justification and Relevance of the Study

The palm oil industry is central to Nigeria's agricultural economy, with demand for cleaner, faster, and safer processing methods on the rise. In Benin City and other parts of Edo State, smallholder processors form the backbone of local production. However, they often struggle with outdated digesters that compromise oil quality and increase production costs.

Introducing an improved digester that utilizes stainless steel reduces the risks of contamination and improves longevity.

This project responds directly to these needs. The resulting machine offers a practical solution that students, engineers, and local fabricators can reproduce or improve upon. By grounding this work in the realities of local processing environments, especially within and around the University of Benin, the project contributes to indigenous technology development and energy efficiency.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Palm oil production is a key economic activity in many parts of West Africa, particularly Nigeria, where small and medium-scale processors form the backbone of the industry. The digestion stage is critical in the oil extraction process as it involves macerating the palm fruit mesocarp to release crude oil. A well-functioning digester significantly enhances oil yield and quality while reducing processing time. This chapter examines existing literature on palm fruit digesters, their classifications, operational mechanisms, and the challenges they present. The review highlights areas where past designs have fallen short and suggests potential improvements relevant to the local processing environment.

2.2 The Palm Fruit

The palm fruit, obtained from the oil palm tree (Elaeis guineensis), is a small, oval-shaped drupe typically reddish-orange in color. A single palm tree contains up to 2,000 fruits and it is known to contain high amount of beta-carotene. Each fruit is about 3.5 cm long and 2 cm wide, and weighs about 3.5 g (M. M. Urugo, T. A. Teka, P. G. Teshome et al., 2021). It comprises three main parts: the pericarp (mesocarp) which contains the oil-rich pulp, the endocarp (hard shell), and the kernel inside the shell, which also yields oil. The mesocarp provides crude palm oil

(CPO), while the kernel yields palm kernel oil (PKO) and is used in various industrial and food applications.

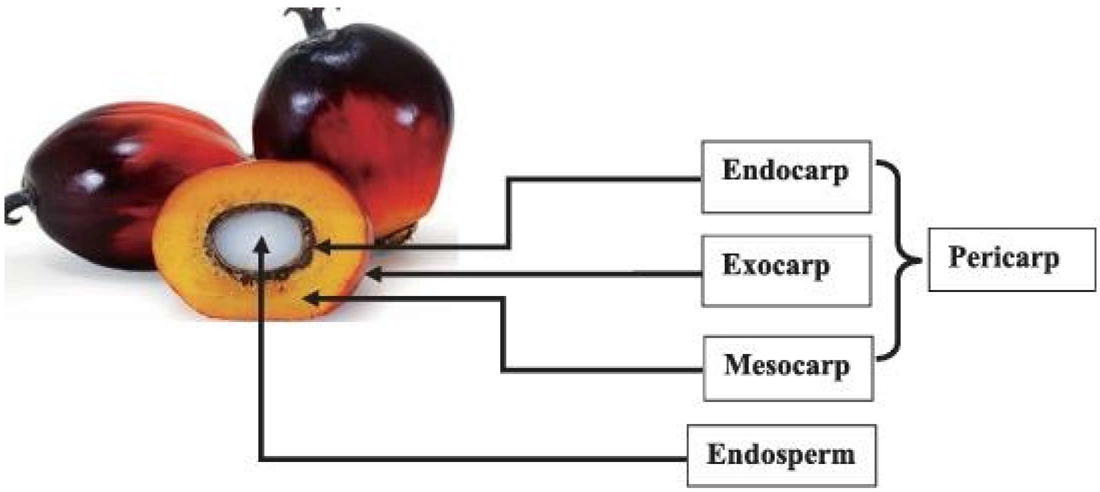


Fig. 1. Cross Section of a Palm Fruit

2.3 Overview of Palm Oil Processing

Palm oil is extracted both from the fleshy part of palm fruit, known as mesocarp, and from palm seed kernel called endosperm. Extraction of the oil from both parts of the plant requires different unit operations until the crude palm oil is obtained. Detailed palm oil processing steps are elaborated as follows:

2.3.1 Extraction of oil from palm flesh (Mesocarp)

Mesocarp of palm fruit contains 56-70% oil while the fruit fully ripe. Oil winning process involves reception of fresh fruit bunches from the plantations, sterilizing and threshing bunches to free the palm fruit, mashing the fruit and pressing out the crude palm oil. Detail extraction process indicated on the flow chart under Fig. 2.

2.3.1.1 Threshing (removal of fruit from the bunches)

The fresh fruit bunch consists of fruit embedded in spikelets growing on a main stem. Manual threshing is achieved by cutting the fruit-laden spikelets from the bunch stem with an axe or machete and separating the fruit from the spikelets by hand.

2.3.1.2 Sterilization of bunches

Sterilization is a means of using high temperature wet-heat treatment of loose fruit by pressurized steam. It is critical for the final oil quality and strippability of the fruits. Sterilization inactivates lipolytic enzymes in the fruit mesocarp and prevents buildup of free fatty acids (FFA). In addition, it also softens the fruit mesocarp for digestion, facilitates release of oil, and conditions nuts to minimize kernel breakage. Moreover, gums and resins in the oil can cause foaming of oil during frying, heat from hot water treatment of the palm seed hydrolyzes gums, resins, starch and coagulates proteins (M. M. Urugo, T. A. Teka, P. G. Teshome et al., 2021).

2.3.1.3 Digestion of the fruit

Digestion is the process of releasing the palm oil in the fruit through rupturing or breaking of the oil-bearing cells. The digester commonly used consists of a steam-heated cylindrical vessel fitted with a central rotating shaft carrying a number of beater (stirring) arms. Through the action of the rotating beater arms the fruit is pounded. Digesting the fruit at high temperature, helps to reduce the viscosity of the oil, destroys the fruits' outer covering (exocarp), and completes the disruption of the oil cells already begun in the sterilization phase.

2.3.1.4 Pulp pressing (Extracting the palm oil)

There are two distinct methods of extracting oil from the digested material. One system uses mechanical presses and is called the 'dry' method. The other called as 'wet' method uses hot water to leach out the oil. In the 'dry' method extraction is achieved by squeezing the oil out of a mixture of oil, moisture, fiber and nuts by applying mechanical pressure on the digested mash. Presser may be designed for batch (small amounts of material operated upon for a time period) or continuous operations. After pressing the nut separated and collected for further extraction, oil from the kernel and extracted crude palm oil will be subjected to refining process to improve color and flavor by removing products of hydrolysis and oxidation. Furthermore, the oil can be fractionated to solid and liquid phase by controlled cooling, crystallization and filtering through thermomechanical means. The liquid fraction (olein) is used for cooking purpose.

2.3.2 Extraction of oil from palm kernel (Endosperm)

Extraction of oil from the palm kernel is generally differing from palm flesh oil extraction. Likewise extraction of oil from other oilseed requires milling of the kernel. The stages in this process comprise grinding the kernels into small particles, heating (cooking), and the oil finally being extracted by using extraction solvent such as petroleum ether and ethyl ether (M. M. Urugo, T. A. Teka, P. G. Teshome et al., 2021).

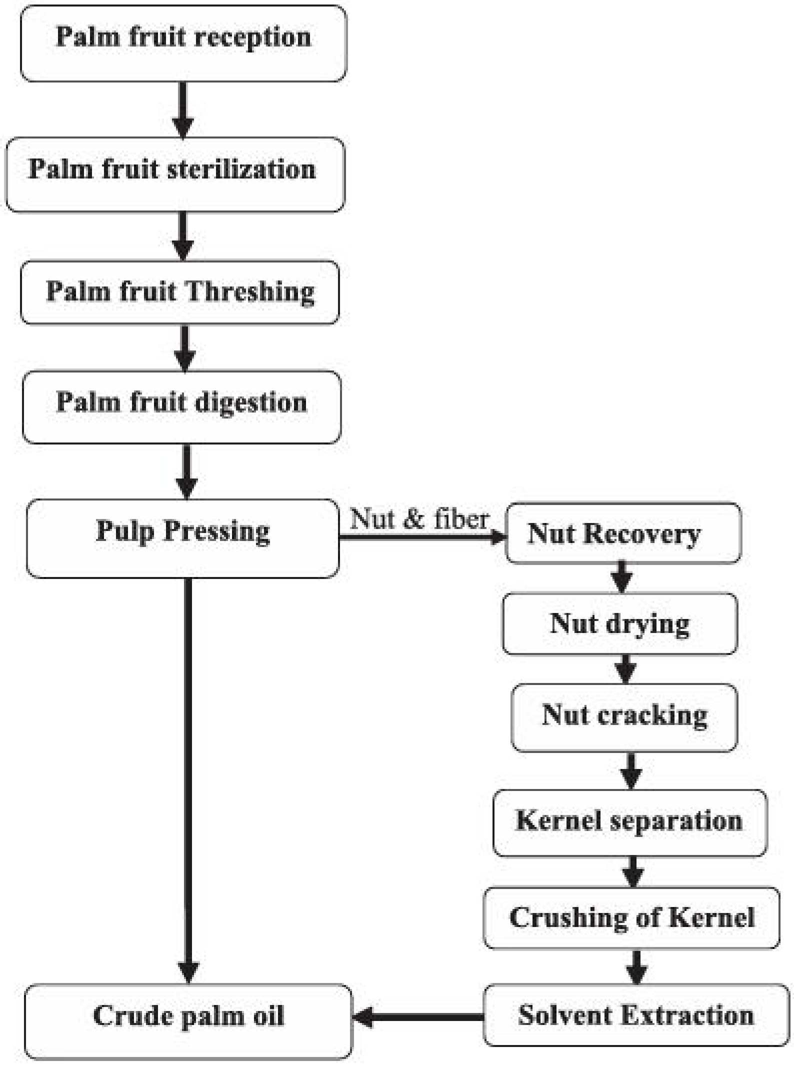


Fig. 2. Flow chart of Crude Palm Oil Processing

2.4 Historical Development of Palm Fruit Digesting Machines

The development of palm fruit digesting machines has evolved alongside the growth of palm oil as a major agricultural product, particularly in West Africa. Traditionally, palm fruits were processed manually using wooden mortars and pestles, a labor-intensive and inefficient method that yielded inconsistent oil quality and volume (FAO, 2010).

As palm oil production scaled up in the mid-20th century, especially in countries like Nigeria and Malaysia, there was a push to mechanize the digestion process. Early mechanical digesters were often vertical drums powered manually or with diesel engines. These designs featured a rotating shaft with paddles or arms to macerate the mesocarp. Though a step forward, these early models had uneven mashing action and were hard to clean, often leading to contamination (Okechukwu et al., 2017).

Over time, horizontal digesters were introduced, offering better fruit turnover and easier maintenance. Innovations such as integrated digester-press units emerged in the 1990s to improve efficiency in large-scale mills (Eka, 2010). However, these machines were often too expensive and complex for small- and medium-scale farmers.

In recent years, focus has shifted toward localized fabrication of affordable digesters suited for rural use. Emphasis has been placed on improving materials (e.g., switching from rust-prone mild steel to food-grade stainless steel), optimizing shaft design, and introducing alternative heat sources like compressed natural gas (CNG) to replace firewood or diesel. These innovations aim to improve oil yield, hygiene, and machine durability while remaining accessible to processors in places like Edo State, Nigeria.

2.5 Classification of Palm Fruit Digesters

Palm fruit digesters can be broadly classified based on orientation, power source, and level of automation:

2.5.1 Manual Digesters

These digesters are simple, non-mechanized systems such as mortars and pestles or modified steel drums, where palm fruits are pounded manually. While affordable and suitable for very small-scale processing, they are labor-intensive and produce inconsistent results.

2.5.2 Mechanized Digesters

Mechanized digesters are powered either electrically, mechanically, or by combustion engines. They can be further categorized as follows:

i. Vertical Digesters: These use a vertical chamber where the rotating shaft moves vertically or around a central axis. Common in early semi-industrial settings, they have poor mixing efficiency and are difficult to clean.

ii. Horizontal Digesters: These use a horizontally aligned chamber where a rotating shaft fitted with beater arms macerates the fruits. Horizontal types offer better mixing and digestion uniformity and are easier to maintain.

iii. Integrated Digester-Press Units: In these systems, digestion and pressing occur in the same chamber. While efficient, they are expensive and complex, making them less suitable for small-scale processors.

2.6 Digester Shaft Mechanism and Its Role in Palm Fruit Digestion

The digester shaft plays a central role in the mechanical digestion process. It is the primary rotating component that drives the motion of the beater arms, which physically tear and mash the palm fruits to extract the mesocarp. The efficiency of palm fruit digestion depends greatly on the design and operation of this shaft.

A well-designed shaft rotates at an optimal speed, usually between 100–150 rpm, to ensure that the mesocarp is thoroughly broken down without cracking the palm nut. This balance is crucial for maintaining high oil yield and preserving kernel quality. The arrangement of the beater arms along the shaft also influences performance. Spiral or staggered configurations are preferred because they improve fruit movement and prevent clumping inside the chamber (Okechukwu et al., 2017).

Material selection further affects shaft efficiency. While mild steel is common for cost reasons, it tends to rust under high moisture and heat, contaminating the oil and reducing machine lifespan. Replacing this with stainless steel improves hygiene, durability, and thermal tolerance (Akinoso and Raji, 2011).

The shaft's diameter and structural rigidity are also important. A thicker shaft better resists bending and ensures smoother, more consistent rotation under heavy loads. If torque transmission is poor or if the shaft is undersized, the machine may experience stalling or failure during operation (Olaoye, 2014).

Thus, optimizing the shaft mechanism in digesters offers a practical and direct way to improve the digestion process, oil quality, and machine durability.

2.7 Review of Existing Digester Designs

Various studies and engineering efforts have been made to design digesters that meet the needs of different scales of processors:

i. Ojomo and Adegbulugbe (1991) developed a vertical digester powered by a diesel engine, which suffered from uneven maceration and high energy consumption.

ii. Oke and Omolehin (2004) tested a horizontal digester with inclined beaters driven by a chain-and-sprocket mechanism. Although oil recovery was improved, the mild steel chamber showed signs of rusting after a few months of use, contaminating the oil and requiring frequent maintenance.

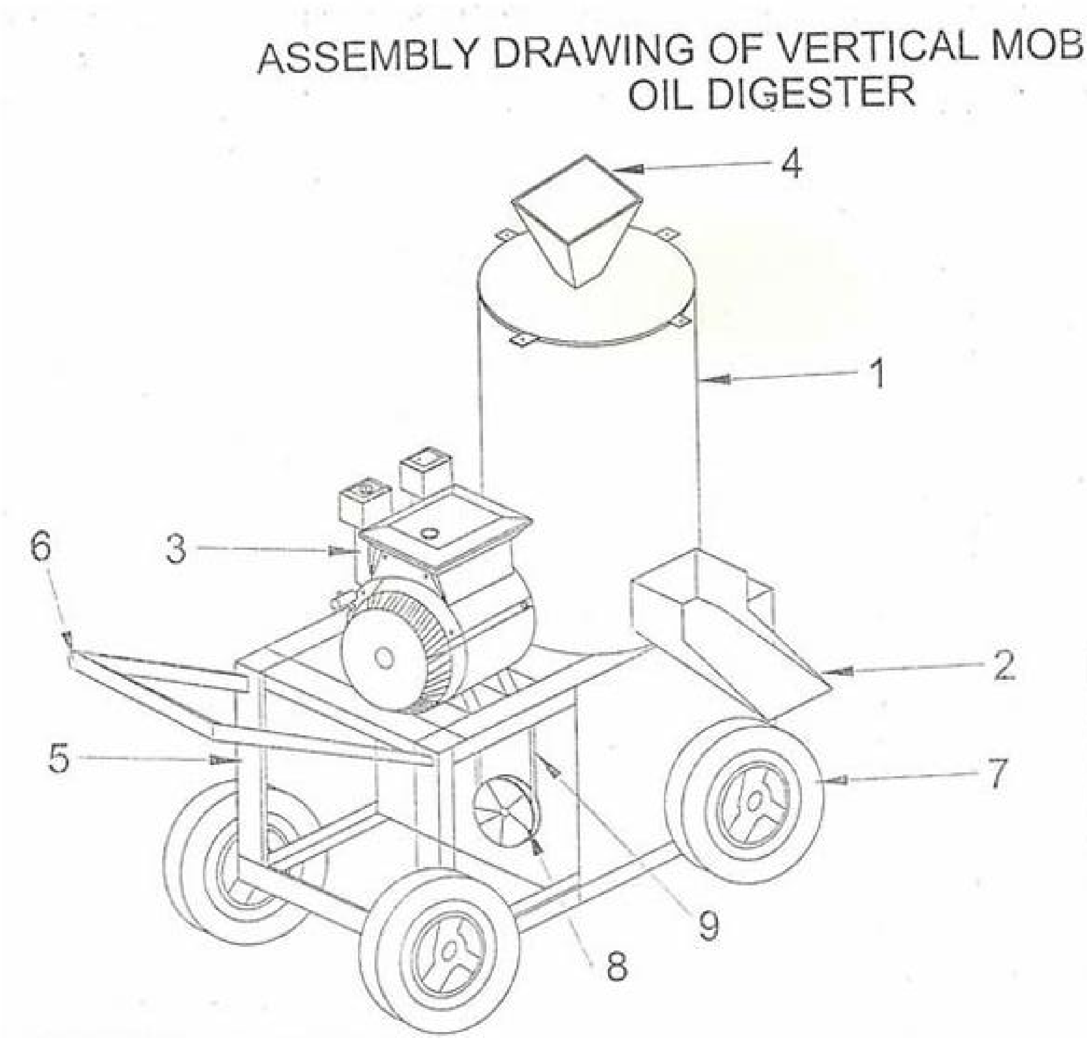
iii. Babatunde et al. (2012) designed a batch-type digester for small-scale processors. It was affordable and functional but still relied on firewood heating, which limited control over temperature and prolonged digestion time.

iv. Adeyemi et al. (2015) introduced a dual-purpose digester-press machine. While energy-efficient, the machine was relatively expensive to produce and not modular, reducing its adoption among smallholder farmers.

v. Ibrahim and Akinoso (2019) evaluated the thermal efficiency of different heating sources in digesters and found that uncontrolled firewood heating led to overheating and kernel cracking, resulting in oil loss and increased waste.

vi. Agba et al. (2020) tested stainless-steel modifications to beater arms and found that the oil contamination rate dropped significantly when stainless steel was used instead of mild steel.

These works show a common trend: a trade-off between cost, durability, and thermal efficiency. Most designs have focused either on affordability or on maximizing oil output, often at the expense of hygiene and sustainability.



S/N	DESCRIPTION
1	CYLINDRICAL CASING
2	DISCHARGE
3	INTERNAL COMBUSTION ENG
4	HOPPER
5	BASE STAND
6	HANDLE
7	TYRE
8	SHAFT PULLEY
9	VEE-BELT

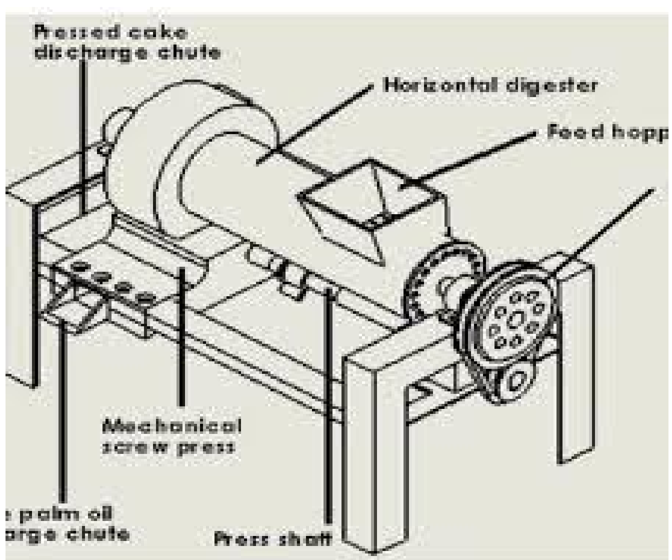


Fig. 3. Vertical and Horizontal Palm Fruit Digesters

2.8 Problems with Past Digesters

From the literature, the following limitations are commonly observed in existing digesters:

i. Corrosion and Contamination: Use of mild steel for the digestion chamber leads to rusting due to constant exposure to heat and moisture, which results in contamination of palm oil and shortens equipment lifespan.

ii. Inefficient Heating Systems: Many digesters depend on firewood or diesel-based burners. These are not only inefficient and polluting but also difficult to regulate, leading to inconsistent heating that affects digestion quality.

iii. Palm Nut Damage: Poorly designed beater arms or improper heat application often leads to cracking of the kernel, which contaminates the oil with shell fragments and affects further processing.

iv. Labor-Intensive Maintenance: Digesters with poorly arranged or fixed beater systems are difficult to clean and maintain, especially when using materials that accumulate residue.

CHAPTER 3

METHODOLOGY

3.1 Design Preliminaries

In designing the machine, the target is small-scale farmers who desire to add value to their products enabling them to supply both retailers and meet personal consumption needs. The following factors were considered:

I. Cost: since the design is considered for small-scale farmers, it was made to be affordable.

II. Load capacity: the design aimed to process 2 palm fruit bunches, each weighing approximately 8-12 kilograms, every hour.

Ill. Material properties: The material used for this project was mild steel then later upgraded to stainless steel for improved performance, which is painted to increase its corrosion resistance.

IV. Maintainability: The digester is simple, so it can be easily maintained, repaired or serviced.

3.2 Design Consideration

Having considered the primitive method of digestion and mechanized rotary action of the oil palm fruit digester, we were able to determine the appropriate design for this project considering the following factors:

I. Higher capacity compared to the traditional/primitive method of palm fruit digestion.

II. Reduction in drudgery associated with the traditional/primitive method.

III. The strength of the material should withstand the forces acting on the various components of the rotary palm fruit digester.

IV. Simplicity and complexity of the digester should suit the intended users and have no side effect on him and his environment.

V. The general configuration of the machine and the factors of safety administered for effectiveness and efficiency.

VI. The power ratings of the diesel engine to be used.

VII. The configuration and operation techniques of the machine when in operation.

VIII. Ease of operation, choice of material and machine affordability.

3.3 Design Calculations and Analysis

To calculate the power requirement of the palm fruit digester, the following parameters were considered;

3.3.1 Rupture Strength of a Single Palm Fruit

The power requirement calculations of the machine start from determining the rupture strength required for a single palm fruit that has been sterilized at 100 degrees Celsius under a pressure of 1 atm for 45 minutes.

According to American Society of Agricultural Engineers (ASAE, 2019), this value is $1.082 N/mm^2$.

This value was obtained using the formula

$$S_R = F_R/A_M \quad (3.1)$$

Where,

S_R = rupture strength

F_R= rupture force (N)

A_M = area of palm fruit mesocarp (mm^2)

3.3.2 Rupture Force of a Single Palm Fruit

The rupture force for a single palm fruit can be obtained from equation (3.1) by making F_R the subject formula:

$$F_R = S_R \times A_M \quad (3.2)$$

Assuming that the palm fruit is a sphere, the area is determined as follows:

$$A_M = 4\pi (r_m)^2 \quad (3.3)$$

Where,

r_m = approximate radius of deformation of fruit (mm)

Hence, A_M = 254.5mm^2. According to American Society of Agricultural Engineers (ASAE, 2019). So, from equation (3.2), the value for the rupture force for a single palm fruit is:

$$F_R = S_R \times A_M$$

$$F_R = 275.37N$$

3.3.3 Torque Transmitted Per Digester Arm

According to American Society of Agricultural Engineers (ASAE, 2019), the relationship is expressed by the given equation:

$$T_d = F_R \times L_d \quad (3.4)$$

Where, L_d = length of digester arm

So, $T_d = 60.581Nm$

Hence, Total torque in the digester of 6 beater arms is given by

$T = T_d \times n$ (3.5)

Where,

n = number of digester arm

n = 6

So, the Total torque (T) transmitted in the digester is:

T= 363.48Nm

3.3.4 Angular Speed of the Shaft

According to American Society of Agricultural Engineers (ASAE, 2019), the relationship is expressed by the given equation:

$F_R = mw^2 L_d$ (3.6)

The required angular speed of the shaft (w) to support the beater arms of the digester is deduced as in equation (3.10) below:

$w = \sqrt{FR/_{mLd}}$ (3.7)

$F_R = mg$ (3.8)

$m = F_R/g$ (3.9)

$w = \sqrt{g/Ld}$ (3.10)

Hence, the required angular speed of the shaft is,

w = 8rad/sec

3.3.5 Diameter of Digester Arm

According to American Society of Agricultural Engineers (ASAE, 2019)

The diameter of a shaft subjected to bending and torsion is obtained from the formula (3.11) below:

$d^3 = 16/\pi S_{smax}\sqrt{(K_b M_b)^2 + (K_t M_t)^2}$ (3.11)

Where, S_{smax} = maximum allowable shear stress

K_b = combined shock and fatigue factors applied to the bending moment

K_t = combined shock and fatigue factors applied to the torsional moment

M_b = bending moment

M_t = torsional moment

But since the digester's arms are mainly subjected to bending moment, equation (3.12) reduces to,

$d^3 = 16/\pi\, S_{smax}\sqrt{(K_b M_b)^2}$ (3.12)

With the bending moment on the digester arm determined by:

$M_b = F_R \; x \; L_d$ (3.13)

M_b = 60.581Nm

According to ASME, bending stress for shafts without keyway is 55MN/m^2 and Kb = 2.0. Hence, making the relevant substitution, we get the shaft diameter as d = 25mm.

3.3.6 Load Carrying Capacity of the Pulley

The load carrying capacity of a pair of pulleys is determined by the relation:

$$e^{\theta\mu} \tag{3.14}$$

For the choice of the value of which pulley's to use, we use the smaller value θ that returns the smaller value of $e^{\theta\mu}$.

Using the values of θ_1, and θ_2: from equations (3.20) and (3.21), we determine the pulley that the load carrying capacity of the design:

i. Using θ_1:

$$e^{\theta\mu} = e^{0.3\ x\ 2.58} = 2.16$$

ii. Using θ_2:

$$e^{\theta\mu} = e^{0.3\ x\ 3.70} = 3.03$$

Hence, using equation (3.18):

$$T_1/T_2 = e^{\theta\mu}$$

$$T_1/T_2 = 2.16$$

$$T_1 = 2.16\ T_2 \tag{3.15}$$

Therefore, for the palm fruit digester, power to be transmitted by the belt is equals

$$Pa = 2544.23W = 2.544KW$$

Referencing a belt selection table, the maximum power that can be transmitted by a belt at a pulley ratio of 2:1 is 1.7 kW.

Hence, the number of belts (N_b) $= 2.544/2.3$ = 1.1

So the number of belts required equals 1.

3.3.7 Selection of Pulleys and Determination of Their Speeds

Power is transferred from a driving shaft to a driven shaft using a pulley and belt system.

The relationship expression provided by Kurmi and Gupta (2005) is utilized to calculate the transmission speed.

The equation (3.16) below is used to determine the transmitted speed:

$$N_1D_1 = N_2D_2 \qquad (3.16)$$

Where:

N_1 = Speed of motor shaft = 850rpm

D_1 = Diameter of driver pulley = 180mm

N_2= Speed of Digester shaft = 480pm

D_2 = Diameter of driven

Hence,

$D_2 = 850\ x\ 180/480$ = 320mm

3.3.8 Designs for Belt

The belt is required for the transmission of the required power. The total power transmitted by a belt drive is a function of the belt tensions and belt speed. According to American Society of Agricultural Engineers (ASAE, 2019), the relationship is expressed by the given equation:

Power (P_m) = $(T_1 - T_2)V$ (3.17)

Where,

T_1= belt tension on the tight side

T_2 = belt tension on the slack side

V = belt speed (m/s)

The equation (3.18) below gives a relationship between T_1, T_2, and the angle of wrap of the belt around the pulley,

$T_1/T_2 = e^{\theta\mu}$ (3.18)

Where,

μ = coefficient of friction between pulley and belt

θ = angle of wrap i.e. angles of contact of the belt on the pulley

3.3.9 Determination of Angle of Wrap

According to American Society of Agricultural Engineers (ASAE, 2019), the angle of wrap for an open loop belt may be determined using equation (3.13)

$Sin\,\beta = (R - r)/c$ (3.19)

Hence β = 15.96°

$\theta_1 = 180° - 2\beta = 180° - 2\sin^{-1}(R - r)/c$ (3.20)

$\theta_1 = 180 - 2(15.96)$

θ_1 = 148.08 = 2.58 rad

$\theta_2 = 180° + 2\beta = 180° - 2 \sin^{-1}(R - r)/c$

$\theta_2 = 180 + 2(15.96) = 211.92 = 3.70$ rad (3.21)

Where, C = distance between pulley centers

This C is selected based on the assumption that

1. The smaller diameter is 1/3 of the larger pulley diameter
2. The difference between the pulley diameters.

As such, the difference between the two pulleys is (320 - 180) mm = 140mm

And C = 400mm

3.3.10 Length of Belt

According to American Society of Agricultural Engineers (ASAE, 2019), the length of the belt is determined by the equation:

$$L = \pi(r_1 + r_2) + 2C + \frac{(r_1+r_2)^2}{C} \quad (3.22)$$

Hence, L = 0.6549m

3.3.11 Velocity of Belt

According to American Society of Agricultural Engineers (ASAE, 2019), the velocity of the belt is determined using the formula:

$$V = \frac{\pi D_1 N_1}{60} \quad (3.23)$$

3.3.12 Determination of T_1 an T_2 of belt

The maximum and minimum tension of the belt can be determined using equation (3.17):

Power (P_m) = $(T_1 - T_2)V$ $2544.2 = (T_1 - T_2)\, 5.89$

So by substituting the values of Pm and V into the above equation:

T_1 = 372.41N and T_2 = 804.40N

3.3.13 Determination of Belt Width

The width of the belt can be obtained from the equation

$$T_1 = F_b\, x\, b\, x\, t\, x\, N_b \quad (3.24)$$

Where,

F_b = tensile strength of belt = 2.7MN/m^2

b = width of belt

t = belt thickness = 12mm (standard value)

N_b = number of belts

Hence substituting values into equation (3.24) we have

b = 25mm

3.3.14 Shaft Loading

The solid shaft is chosen for the digester to satisfy the strength and rigidity requirements. When the shaft is transmitting power under various operating and loading conditions, shafts are usually subjected to torsion, bending and axial loads. (Allen et al, 2002)

I. **Maximum shear stress:** the maximum shear stress for a circular shaft is given by;

$$Tmax = 16M_t/\pi d^3 \quad (3.25)$$

II. **Bending stress:** the bending stress (S) is given by;

$$S_b = 32M_b/\pi d^3 \quad (3.26)$$

III. **Axial loading:** tensile or compression stress is given by

$$S_a = 4f_a/\pi d^2 \quad (3.27)$$

IV. **Combined torsion and bending:** the maximum shear stress theory is used for shafts subjected to twisting and bending. This is given by

$$S_{smax} = \sqrt{{\delta_b}^2 + 4\tau^2} \quad (3.28)$$

$$S_{smax} = 16/\pi d^3 \sqrt{{M_b}^2 + {M_t}^2} \quad (3.29)$$

When fatigue and combined shock factor is applied to bending (K_b) and torsional moment (K_t) equation (3.29) becomes,

$$S_{smax} = 16/\pi d^3 \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad (3.30)$$

In a belt drive machine such as a palm fruit digester, the torsional moment is given by the relation:

$$M_t = (T_1 - T_2)R \tag{3.31}$$

In designing the shaft, the following assumptions were made

I. The weight of the shaft is negligible

II. Length of the shaft = 720mm

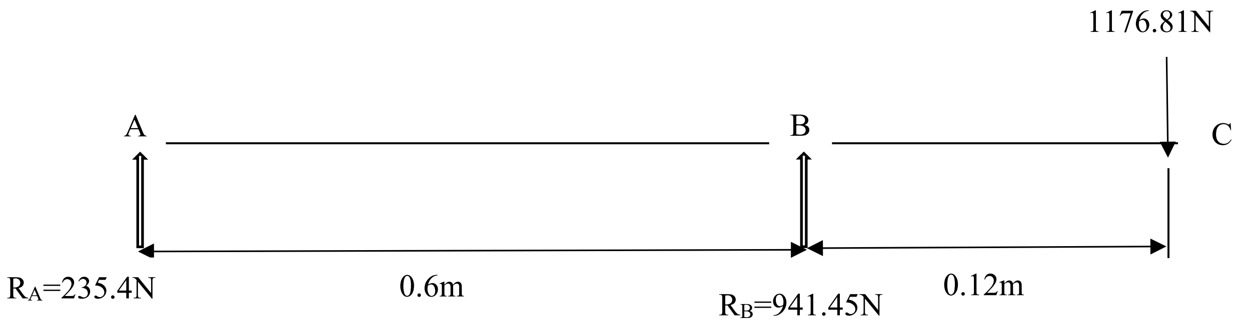


Figure 3.1: Shaft showing forces acting on it

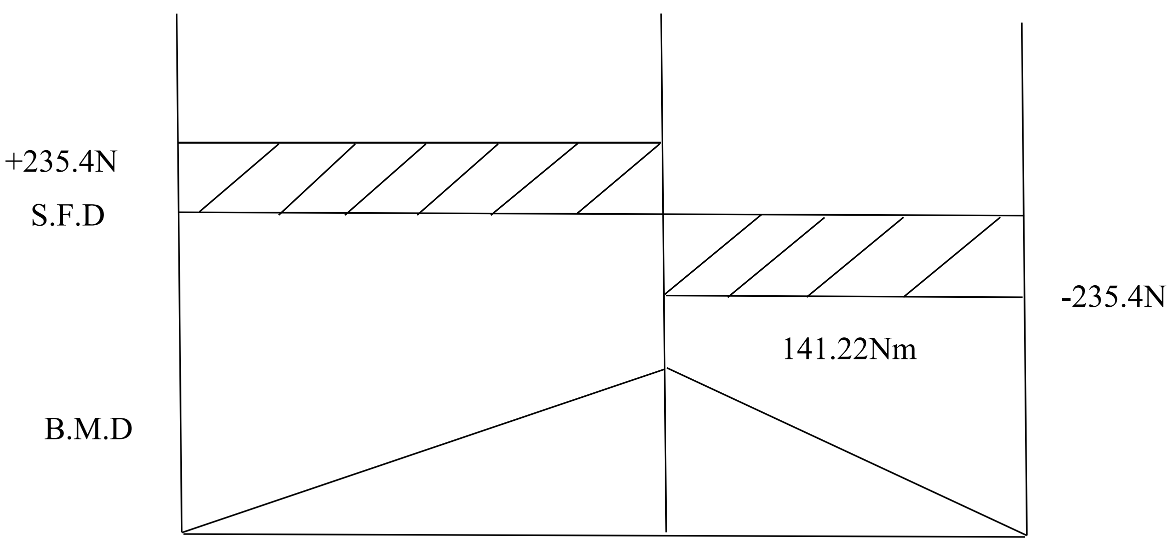


Figure 3.2: Shear force and bending moment diagram of the drive shaft in a static position

To determine the reactions R_A and R_B at points A and B which are the support, moment is taken about point B.

$600R_A - 1116.81\ x\ 120 = 0$

$R_A = 235.36N$

The sum of upward forces = sum of downward forces

$R_A + R_B = 1176.81$

$R_B = 1176.81 - R_A$

$R_B = 1176.81 - 235.36$

$R_B = 941.45N$

Maximum bending moment occurs at point B, therefore

$$M_b = (T_1 + T_2)\ BC \qquad (3.32)$$

$M_b = (804.4 + 372.41)\ 0.12$

$M_b = 141.22Nm$

The torsional moment from equation (3.31) is

$M_t = (T_1 - T_2)R$

$M_t = (804.4 - 372.41)\ 0.16$

$M_t = 69.12Nm$

3.3.15 Determination of Shaft Diameter

According to the ASME code (Allen et al, 2002), the allowable stress for a shaft with a keyway is $40MN/m^2$, $K_b = 1.5$ and $K_t = 1.0$

From equation (3.11), the diameter of the shaft can be determined as follows

$d^3 = 16/\pi S_{smax}\sqrt{(K_b M_b)^2 + (K_t M_t)^2}$

Substituting values into the above expression, we have

$$d^3 = \frac{16}{\pi} x\ 40\ x\ 10^6 \sqrt{(1.5\ x\ 141.22)^2 + (1\ x\ 65.12)^2}$$

d= 0.030499m

d ~ 30mm

3.3.16 Required Power of the Digester

The power required by the digester was determined with the expression by Kurmi and Gupta (2005) which states that the power is the product of torque (T) and angular velocity (ω) as:

$$P_d = T\omega \tag{3.33}$$

Hence, P_d = 2544.43W

According to the ASME code (Allen et al, 2002), assuming 12% of power is used to overcome friction and a further 15% of power is required to overcome electrical losses in the system, therefore the required power for the machine is used,

$$P_m = P_d + P_f \tag{3.34}$$

Hence, the required power of the digester is,

$$P_m = P_d + 0.12P_d + 0.13P_d = 3231.415W$$

The engine purchased for the digester is rated at 5hp (3677.49W). This engine was selected because its capacity (3677.49 W) exceeds the required power (3231.415W), ensuring reliable operation.

3.4 Material Selection

One of the first steps in the design of any product is to select the material from which each part is to be made. A careful evaluation of the properties of the materials must then be made or looked into before any calculations. Some of the more important economic factors and physical and mechanical properties that are involved in material and sometimes, process selection is discussed below.

3.4.1 Factors Affecting Material Selection

I. Strength and Durability: The materials should possess sufficient strength to withstand the mechanical stresses during operation and have a long service life.

II. Corrosion Resistance: Given the exposure to acidic palm fruit pulp, materials resistant to corrosion, should be used for fabrication of the equipment.

III. Cost: Balancing performance with cost-effectiveness is crucial in material selection to ensure the digester remains economically viable.

IV. Availability: Accessibility to the chosen materials is essential for fabrication, especially in regions where certain materials may be scarce.

V. Fabrication Process Compatibility: Materials should be compatible with the fabrication processes involved, such as welding, casting, or machining.

VI. Environmental Impact: Considering the environmental impact of materials, including their recyclability and potential toxicity, is becoming increasingly important in material selection decisions.

3.4.2 Material Selected

After carefully evaluating all factors affecting the selection of material, mild steel was initially chosen. Mild steel is carbon steel typically with a maximum of 0.25% carbon, 0.4% - 0.7%

manganese, 0.1% - 0.5% silicon and some traces of other elements such as phosphorus (Ibhadode, 2001). Materials that are quickly assembled and capable of withstanding shifting loads are essential in the construction industry. Therefore, mild steel was thought the ideal material for frequent use. Insect damage cannot harm it, and although mild steel has a low level of corrosion resistance, it can be significantly increased by using a suitable surface protection agent on the exposed parts. Mild steel was used because of its desirable properties, Properties such as machinability, thermal conductivity and malleability crown it a choice material for the fabrication of the clarifier. They have good strength and can be bent, worked and can be welded into an endless variety of shapes. Exhibiting a broad spectrum of strength and hardness, it also boasts high ductility, formability, good creep resistance, good thermal conductivity, good machinability, and good weldability. Due to the low level of corrosion resistance, over time the previously fabricated parts were observed to corrode at the base closest to the heat source, this problem was overcome by opting for the use of stainless steel instead of mild steel. Below are some properties that show that stainless steel is a higher grade steel than mild steel and therefore a better material selection:

Property	**Stainless Steel**	**Mild Steel**
Corrosion Resistance	Excellent	Poor
Strength	Higher (varies by grade)	Moderate
Heat Resistance	Excellent	Moderate
Chemical Resistance	High	Low

Property	Stainless Steel	Mild Steel
Appearance	Bright, lustrous	Dull, rusts easily
Maintenance	Low	High
Cost	Higher initial	Lower initial
Durability	Very high	Moderate
Recyclability	100%	High but prone to degradation

Table 3.1: Stainless Steel Vs Mild Steel

3.5 Manufacturing Process.

The manufacturing process was a combination of fabrication and assembling.

3.5.1 Fabrication Process

The fabrication process involves using the selected materials and constructing the product based on the design and the desired dimension. The various methods used during the fabrication of the machine from start to finish include; measuring, marking, cutting, joining, drilling and finishing. This was done part by part before the assembly of each component.

I. Measurement: materials were measured according to the desired dimensions of the design.

II. Marking: all measured materials were marked in the main sheet or full material to give precise dimensions before cutting.

III. Cutting: marked materials are then cut into pieces.

IV. Joining: materials were joined together by electric arc welding for permanent joints and temporary joints by riveting.

V. Drilling: marked holes are then drilled to make holes for bolts.

VI. Finishing: any rough surface or sharp edge was ground to give a smooth and safe surface.

3.5.2 Fabrication of Each Component of the Digester

3.5.2.1 The Digester Chamber

The digester drum was fabricated using stainless steel. It is cylindrical and has a diameter of 440mm and a height of 757mm. The digester drum was fabricated by first using a plate rolling machine to roll the flat sheet of metal into a cylindrical shape, then it was welded using electric arc welding.

3.5.2.2 The Sludge Outlet

The sludge outlet was fabricated using stainless steel. It is a rectangular outlet with a dimension of 160mm by 80mm, and it extends out of the digester drum by 217mm. The sludge outlet has a cover of dimension 154mm by 90mm.

3.5.2.3 The Shaft Outlet

The shaft outlet was fabricated from stainless steel. Firstly, an opening of 416mm by 240mm was cut out of the digester drum (R220.00). Then it was extended from the digester drum by 238mm.

3.5.2.4 The Hopper

The hopper was fabricated from a stainless steel sheet with a dimension of 400mm by 290mm. It was curved to form an octagonal shape and also slandered to 45° to the horizontal.

3.5.2.5 Digester Stand

The digester stand was fabricated from mild steel bars. It has a height of 500mm and a square base of 480mm. The stand was constructed with four legs for proper balancing.

3.5.2.6 Rotating Digestion Shaft

The digestion shaft has an inner rod of radius 15mm and length 770mm, which connects the entire shaft to the gearbox and the bearing. Then it has an outer rod of radius 40mm and length 757mm, which holds the digestion blades. The digestion blades are welded to the outer rod, which has a dimension of 160mm in length by 50mm, which is welded at an angle of 45° to the outer shaft.

3.5.2.7 The Pulley System

The pulley which connects the digester to the diesel engine has a radius of 25m.

3.5.2.8 The Gearbox

The gearbox in this equipment was purchased from the local market and attached to the digester through electric arc welding. The bevel gear was a component of the gearbox system, equipped with a 125mm diameter pulley. The driver gear has 11 teeth, while the driven gear has 42 teeth. Using this gear arrangement, power was transferred to the stirrer shaft, resulting in a particular reduction ratio that raised torque while decreasing speed. The system efficiently employed the gear mechanism to customize power transmission for the intended use.

3.5.2.9 Diesel Engines

A 5hp diesel engine with a typical operating speed between 1500 and 3600 RPM, which provides an adaptable performance fit for the palm fruit digester was purchased from the local market to power the equipment. A belt is being used to connect the engine to the pulley system.

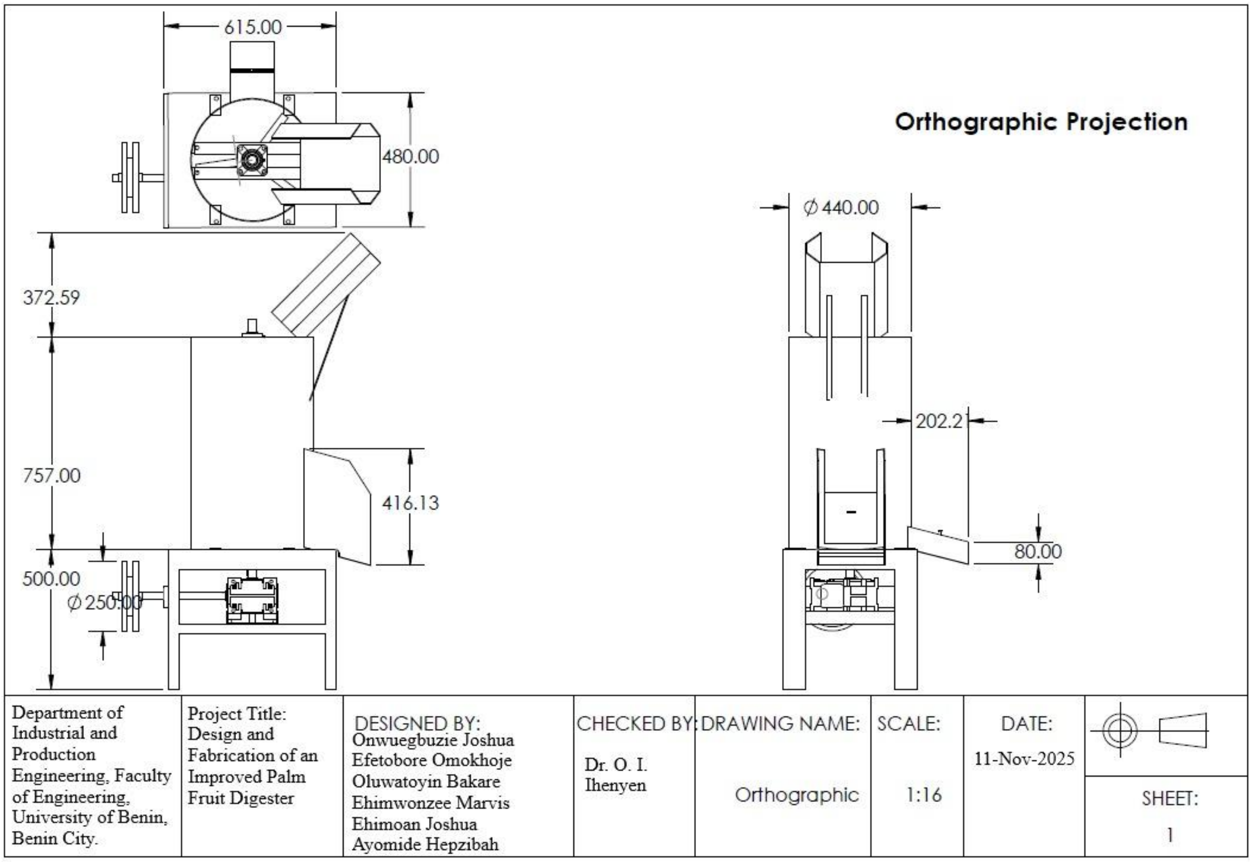
3.5.2.10 Bearing

In this design, a pillow bearing was used to connect the rotating shaft to the gearbox.

3.6 Working Principle

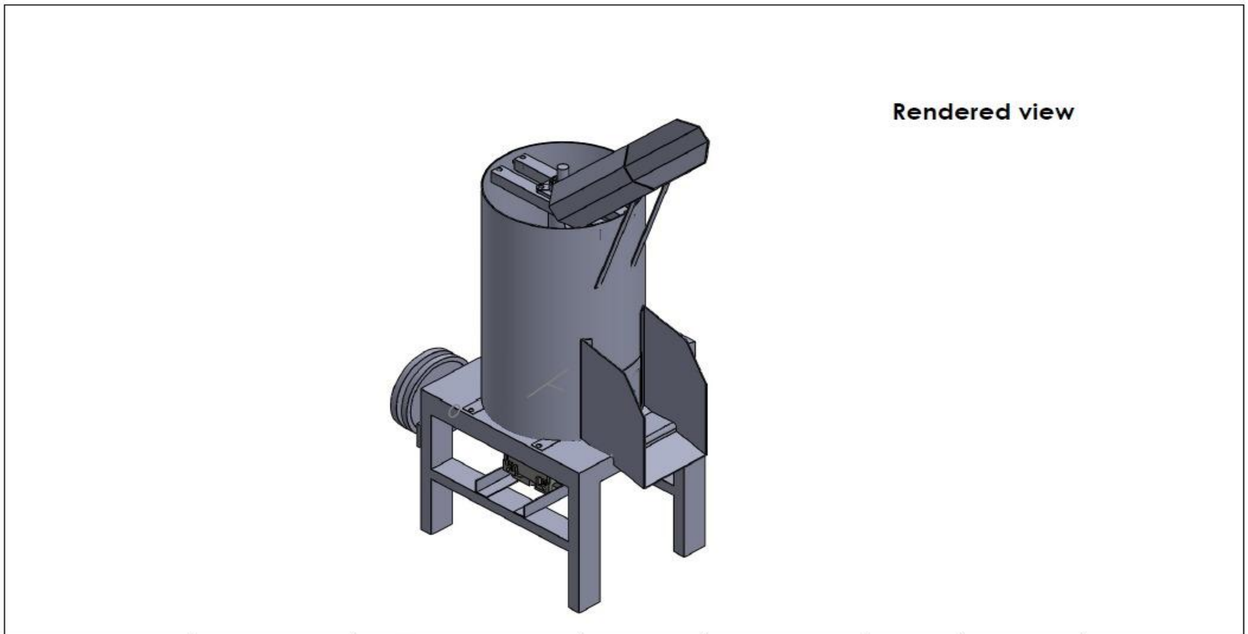
The vertical digester consists of the hopper, digesting chamber, bearings, main shaft, beaters arms, discharge end, bevel gear, and the prime mover. The vertical digester's barrel carries the hopper and the shaft assembly, which lies in the central position of the barrel. The shaft assembly is made up of a 50mm diameter x 500mm shaft with six beater arms that are arranged at a specific angle and distance and strongly welded to the shaft in the horizontal position. The digester works on the rotary impact principle. The machine shaft was designed to rotate at about 130 rpm, a safe speed for the maceration of the mesocarp from the hard nut and avoiding the breaking of the nuts. There is considerable friction between the digester drum and the macerate. On the other hand, within the macerate (nut-nut surface rubbing friction) and also as the beater arms stir up the macerate, its existence is recognizable in the difference in the extent of maceration when different quantities of fruits are put to work for some time; the more fruits, the better the extent of maceration. On entry through the hopper (parboiled oil palm fruits), the digester macerated the fruits for some minutes and automatically discharged the macerate through the exit end by gravity. The power or motion is supplied by a 5-hp diesel engine generating about 3.3 KW and running at about 2600 pm. The use of gears helps to regulate the power transmitted and improves the efficiency of the machine (Adah et al., 2015)

The following SolidWorks pictorial diagrams provide accurate dimensions, labels, and orthographic views illustrating the working principles and technical specifications of the



improved palm fruit digester:

Figure 3.3: Orthographic Projection



Department of Industrial and Production Engineering, Faculty of Engineering, University of Benin, Benin City.	Project Title: Design and Fabrication of an Improved Palm Fruit Digester	DESIGNED BY: Onwuegbuzie Joshua Efetobore Omokhoje Oluwatoyin Bakare Ehimwonzee Marvis Ehimoan Joshua Ayomide Hepzibah	CHECKED BY: Dr. O. I. Ihenyen	DRAWING NAME: Rendered	SCALE: 1:12	DATE: 11-Nov-2025	SHEET: 2

Figure 3.4: Rendered View

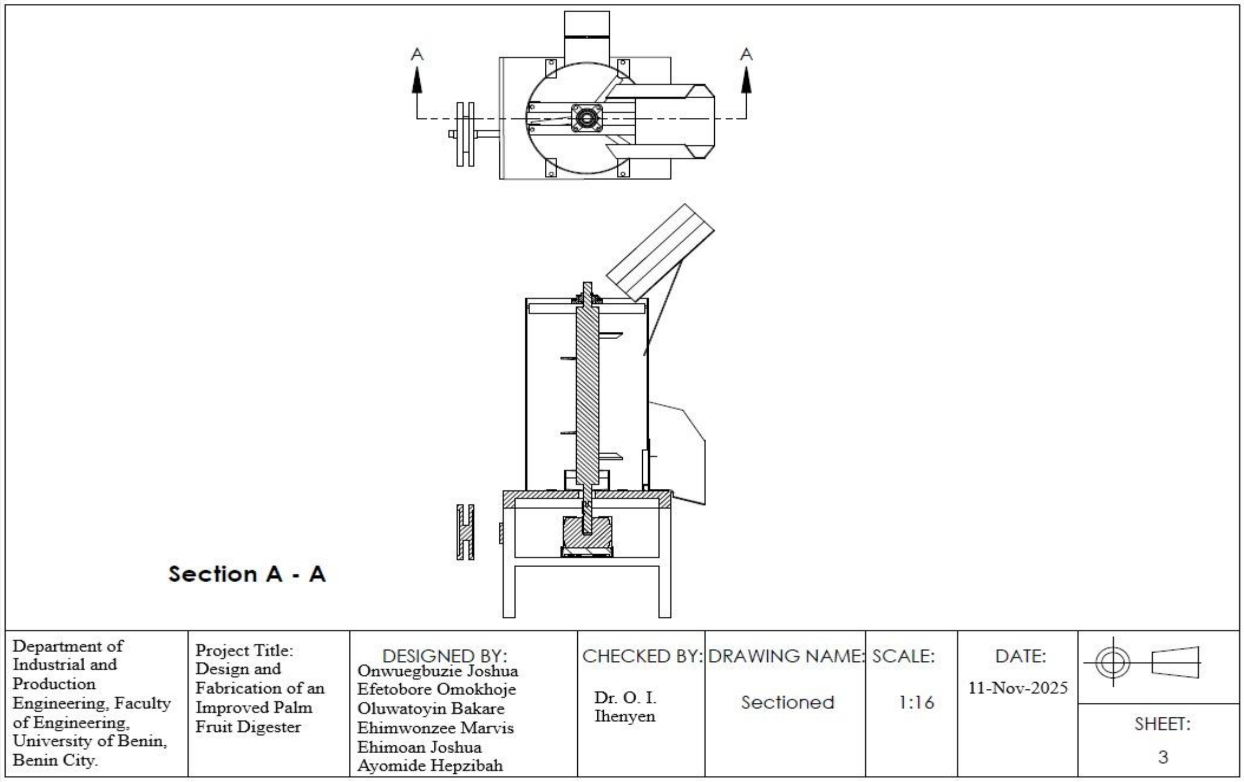


Figure 3.5: Sectioned Diagram

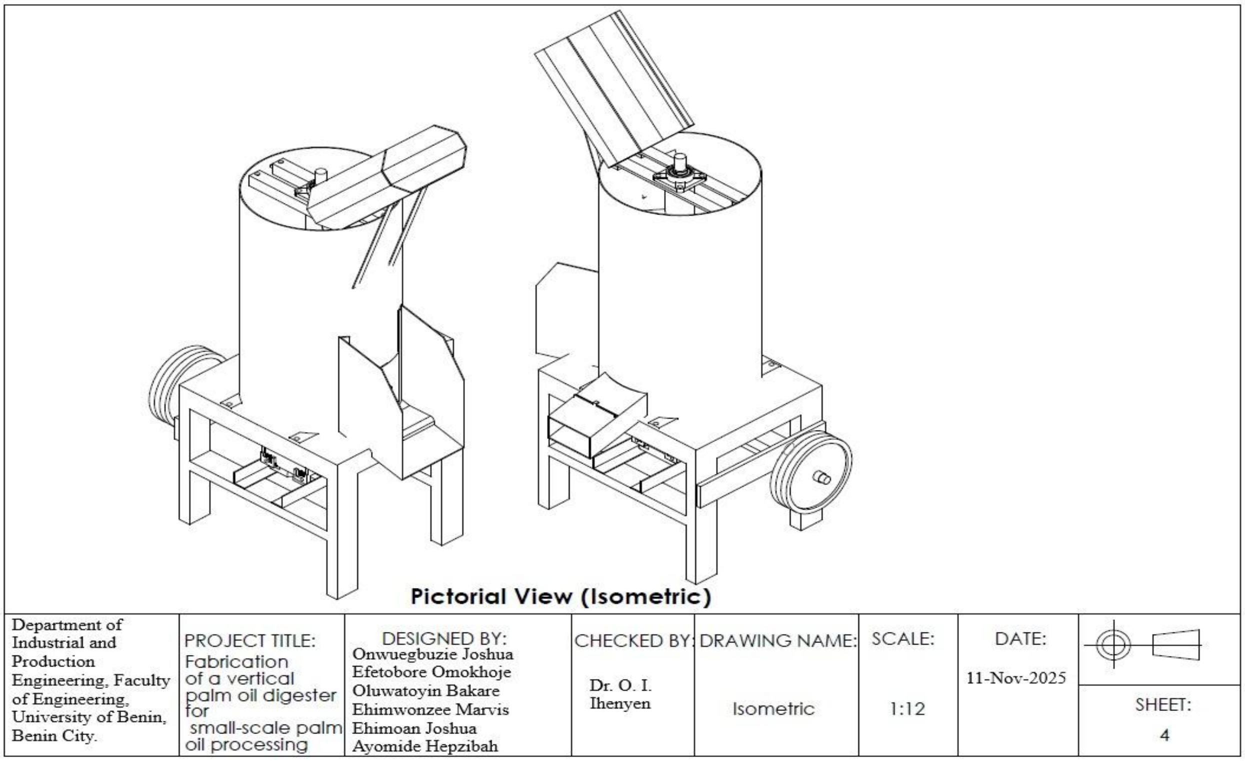


Figure 3.6: Pictorial View (Isometric)

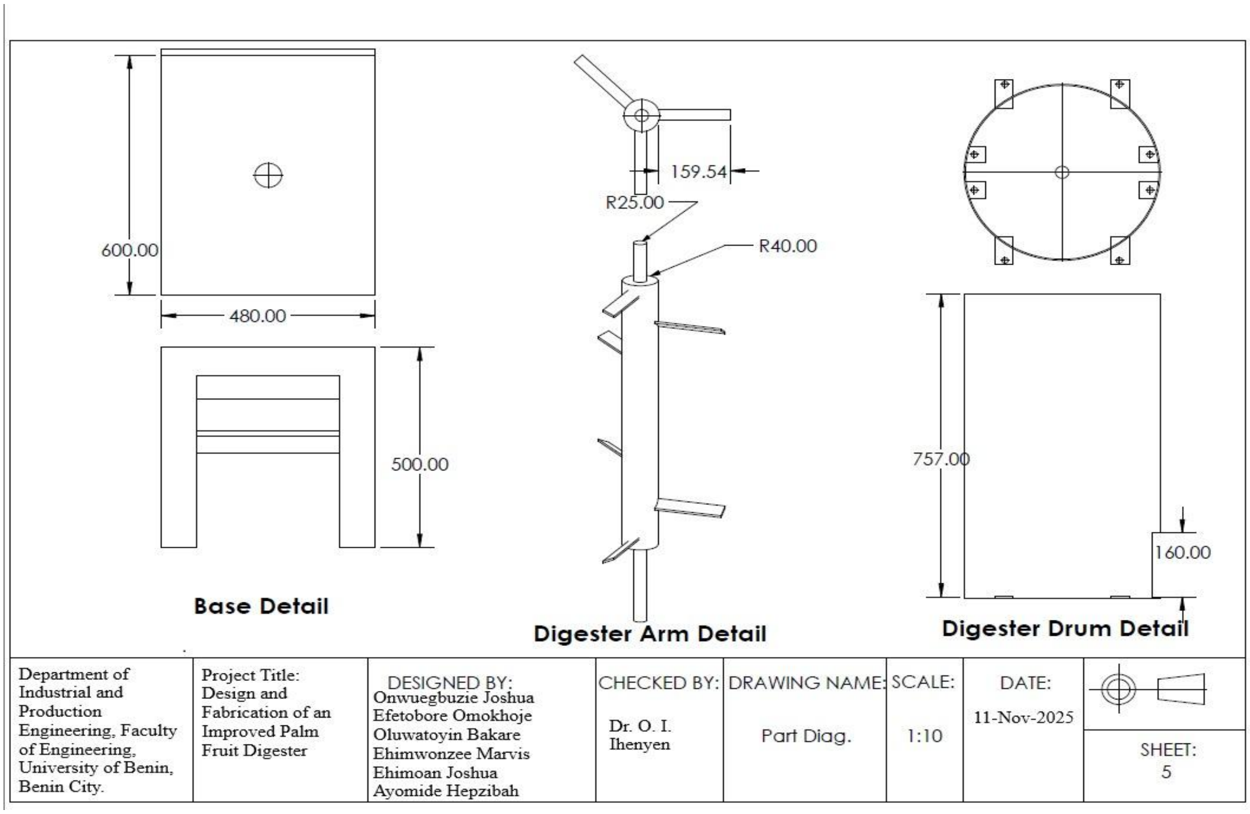


Figure 3.7: Parts Diagram

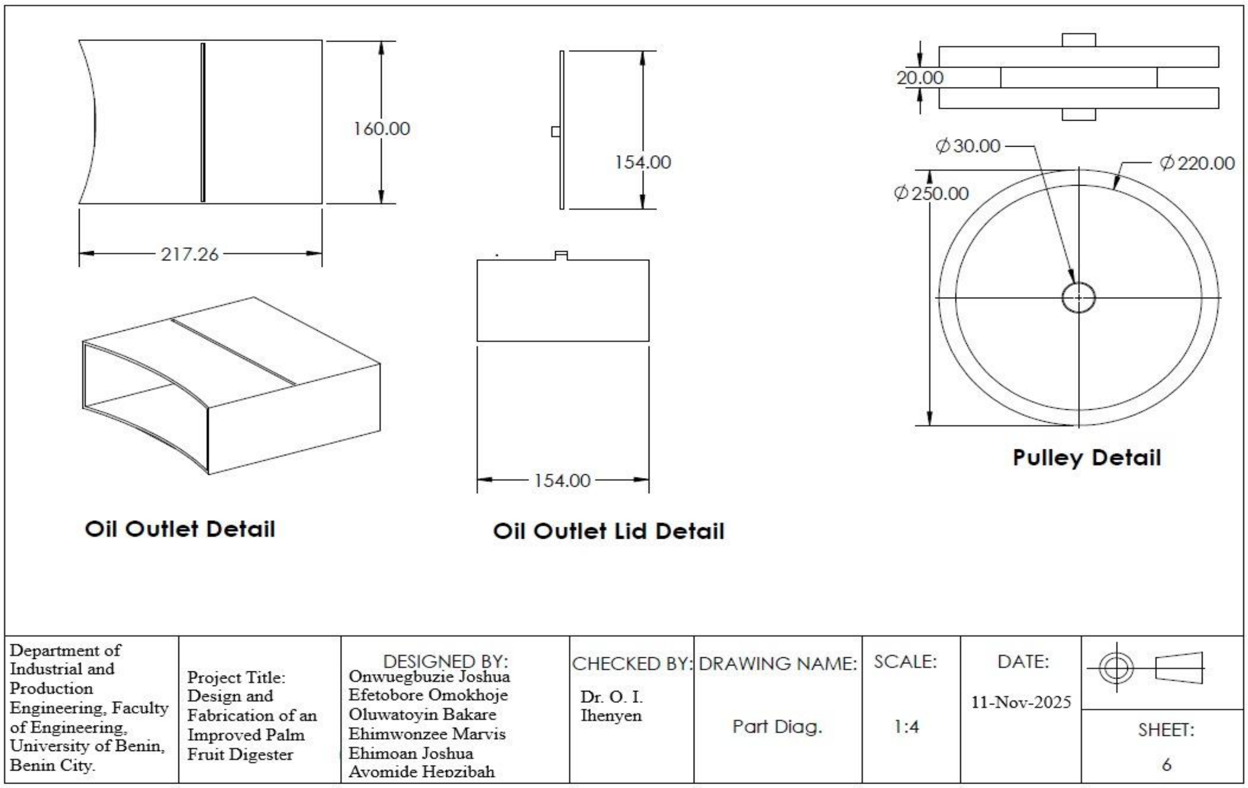


Figure 3.8: Parts Diagram

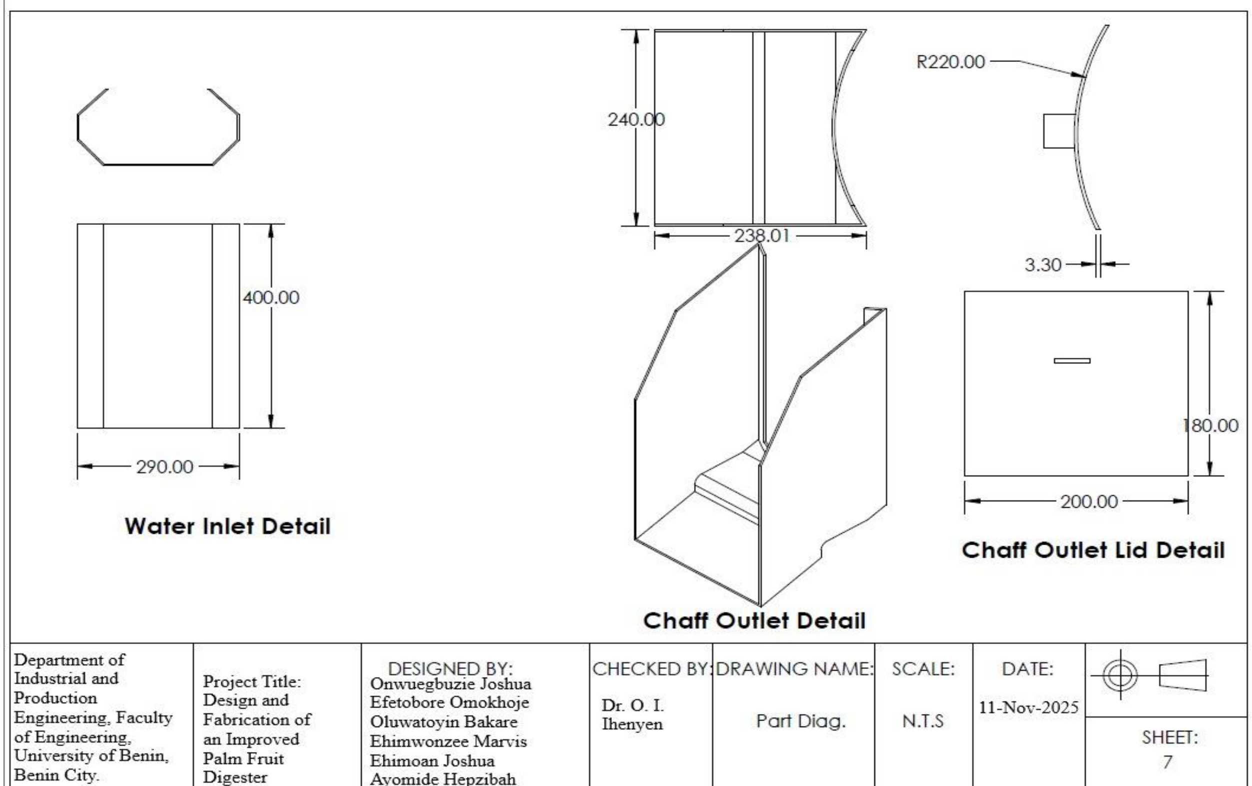


Figure 3.9: Parts Diagram

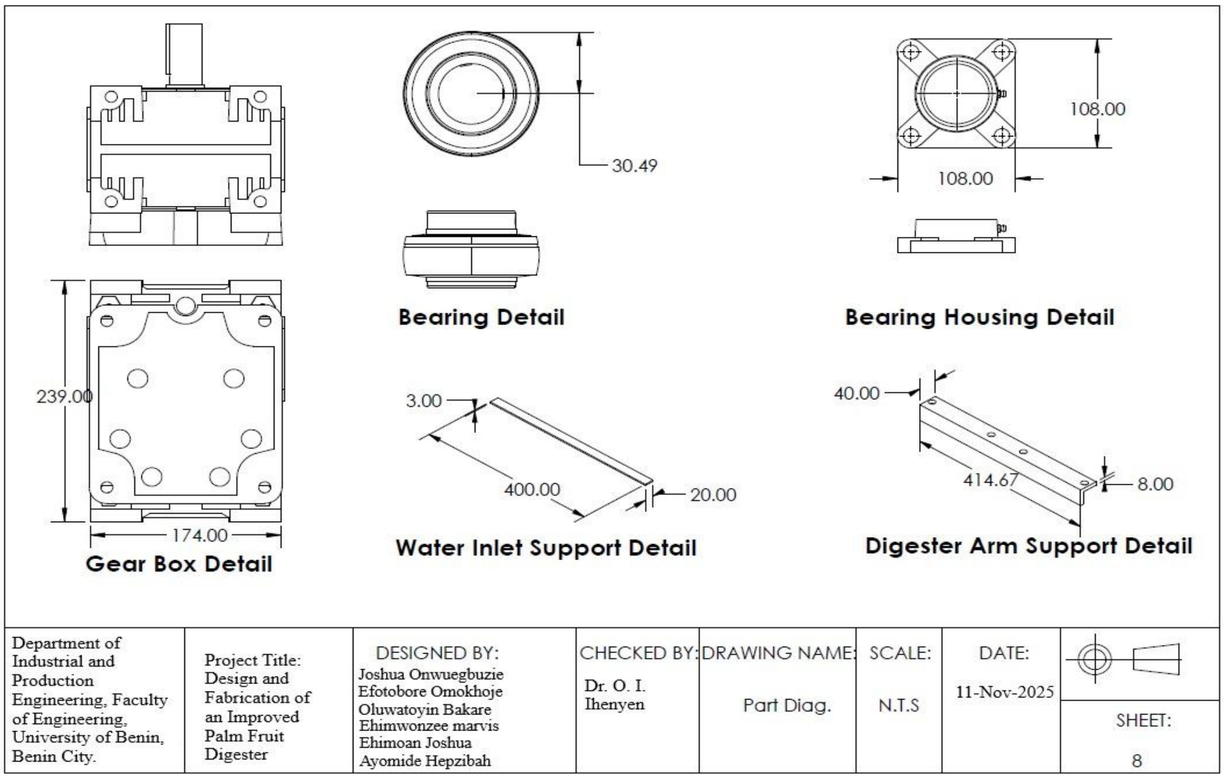


Figure 3.10: Parts Diagram

Figures 3.3 – 3.10: SolidWorks Pictorial Diagrams

CHAPTER 4

RESULT ANALYSIS AND DISCUSSION

4.1 Performance Test

Three fresh palm fruit bunches of about 12 kilograms each were sourced from a local market (Uselu market) in Benin, Edo State, Nigeria. The fruits were removed from the bunch (the fruits weighed 10 kilograms after being removed from the bunch) washed and cleansed for dirt and other impurities before being boiled for approximately 50 minutes. The mass of the palm fruit after boiling was weighed to be 12 kilograms. After proper assembly and installation of the digester machine, the digestion drum was carefully inspected, washed and cleaned to prevent any health hazards. The palm fruits were weighed using a spring-mass weighing scale.

The total weight of the three bunches was approximately 36 kilograms and was split into 4 parts, 7 kilograms, 9 kilograms, 10 kilograms and 10 kilograms. Each part was digested one at a time, and the following results were obtained;

Table 4.1: Measurement of the mass of boiled palm fruit and time taken to digest.

Test	Mass of boiled palm fruit (kg)	Approximate time taken to digest (s)
1	7	180
2	9	240
3	10	300
4	10	300
Total	**36**	**1020**

From Table 4.1 it is observed that the approximate time taken for the palm fruit to digest increases with an increase in the quantity of palm fruit.

4.2 Error Testing

Table 4.2: Measurement of the mass of boiled palm fruit, the weight of digested, the mass of digested palm fruit and the mass of undigested palm fruit

Table 4.2 shows the weight of properly digested and undigested palm fruit.

Test	**Mass of boiled palm fruit (kg)**	**Mass of digested palm fruit (kg)**	**Mass of undigested palm fruit (kg)**
1	7	6.7	0.3
2	9	8.7	0.3
3	10	9.5	0.5
4	10	9.5	0.5
5	36	34.4	1.6

From Table 4.2 we can deduce the efficiency of digestion.

Mass of palm fruit (input): 36 kilograms

Mass of properly digested palm fruit: 34.4 kilograms

Mass of undigested palm fruit: 1.6 kilograms

$$Efficiency\ =\ (mass\ of\ digested\ fruit/mass\ of\ total\ boiled\ fruit)\ x100$$

$$Efficiency\ of\ test\ 1\text{:}\ \frac{6.7}{7}\ x\ 100 = 95.7\%$$

$$Efficiency\ of\ test\ 2: \frac{8.7}{9}\ x\ 100 = 96.6\%$$

$$Efficiency\ of\ test\ 3: \frac{9.5}{10}\ x\ 100 = 95\%$$

$$Efficiency\ of\ test\ 4: \frac{9.5}{10}\ x\ 100 = 95\%$$

$$The\ average\ efficiency\ of\ digestion\ = \frac{95.7 + 96.6\ +\ 95.0 + 95.0}{4} = \ 95.5\%$$

From the result above, it is concluded that the efficiency of digestion is 95.5%.

4.3 Discussion of Result

The testing was carried out on the 1st of November, 2025, to evaluate the efficiency of the machine in carrying out the digestion of palm fruit. It was discovered that the machine has a very high efficiency of about 95.5%. This testing was done with carefully selected palm fruits, in which no bad or spoilt fruit was allowed into the machine to get an accurate value. Meanwhile, in realistic situations, the farmers may not have the time to sort out the palm fruit, therefore there may be situations of more undigested fruits than proposed in the testing.

Some factors that cause an increase in the number of undigested fruits, therefore reducing the efficiency of the machine include;

I. Spoilt fruit: when the fruit is spoilt, it will not be properly digested, no matter how much force is exerted on it.

II. Uncooked fruit: when uncooked fruits find their way into the digester, they will not be properly digested

III. Semi-cooked fruit: when the fruit is not properly cooked, it takes longer time to digest.

4.4 Bills of Engineering Quantity

4.4.1 Material Cost

The table below shows the average cost of all materials used for the fabrication of the palm fruit digester

Table 4.3: Material cost

S/N	DESCRIPTION	QUANTITY	UNIT PRICE (₦)	TOTAL COST (₦)
1	Stainless Steel Sheet	1	530,000	530,000
2	5hp Diesel Engine	1	500,000	500,000
3	Pillow Bearing	2	10,000	20,000
4	Mechanical Gearbox	1	25,000	25,000
5	Angle Bar	1	30,000	30,000
6	Electrode (pack)	3	17,000	51,000
7	Belt	1	2,000	2,000
8	Palm Fruit Bunch	2	17,000	34,000
Total				**1,192,000**

4.4.2 Production Cost

The table below shows a summary of the cost of production incurred

Table 4.4: Cost of production and services

S/N	DESCRIPTION	TOTAL COST(₦)
1	Fabrication workshop service	45,000
2	Transportation	25,000
3	Miscellaneous	20,000
Total		**90,000**

Bill of quantity = Production cost + material cost

Bill of quantity = 90,000 + 1,192,000

= ₦1,282,000.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This project aimed to design and fabricate a model of a digester that is effective in the digestion and extraction of palm oil, easily affordable for small and medium-scale farmers, and also easy to operate. The test result revealed that the efficiency of digestion was 95.5%. After the design, fabrication and testing of the machine, the results obtained were favorable in terms of the output, cost, and ease of operation.

In conclusion, the fabrication of a vertical digester for palm oil processing offers a promising solution for enhancing efficiency and sustainability in the palm oil industry, by efficiently extracting oil from palm fruit bunches, this technology can contribute to increased productivity, reduced waste, and improved environmental practices. Additionally, the use of such equipment will support the nation's economy by generating foreign cash through the production of high-quality palm oil, which is one of the primary foundations of the economy.

With further research and development, vertical digesters have the potential to revolutionize palm oil processing, leading to a more sustainable and profitable future for the industry.

5.2 Recommendations

From the results obtained from the performance test, the average rate of digestion of 95.5% is quite promising. However, there is always room for improvement. Here are some recommendations for further work on the fabrication of the vertical digester;

I. Use of an electric motor in place of the diesel engine. When the supply of electricity in the farm is constant, this is a better alternative, as it is more cost-effective and also environmentally friendly. There is zero emission of exhaust gases, which helps to reduce harmful gases in the farm environment.

II. The digester can be connected to a water supply system that helps dispense water of desirable temperature into the digester to wash off the sludge from the shaft. This can help to reduce the stress of manual application of water into the digester, and also reduce labor.

III. The digester can be installed in a fixed position to keep its form. This installation can be done by setting it with cement and sand on the ground to keep it firm from movement during vibration, avoid unnecessary movement from one place to another and guard against theft.

In conclusion, the fabrication of a vertical digester for palm oil processing offers a promising solution for enhancing efficiency and sustainability in the palm oil industry, by efficiently extracting oil from palm fruit bunches, this technology can contribute to increased productivity, reduced waste, and improved environmental practices. With further research and development, vertical digesters have the potential to revolutionize palm oil processing, leading to a more sustainable and profitable future for the industry.

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