DESIGN AND FABRICATION OF AN IMPROVED PALM FRUIT DIGESTER

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CERTIFICATION

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DEDICATION

I dedicate this project to God Almighty for His divine guidance in all my academic endeavors. I also extend my heartfelt appreciation to my Parents Mr. Matthew Onwuegbuzie and Mrs. Onwuegbuzie and my siblings.

ACKNOWLEDGEMENT

As I bring this important chapter of my life to a close, I find myself filled with deep gratitude and emotion. This journey has been one of challenges, learning, growth, and transformation. Through it all, the unwavering hand of God Almighty has been my constant anchor. His grace, mercy, and strength have carried me farther than I could ever go on my own. For this, I give Him all the glory. To my incredible parents Mr. Onwuegbuzie and. Mrs.Onwuegbuzie, I owe more than words can express. Your sacrifices, love, and unwavering belief in me have been my greatest motivation. Through every high and low, your prayers and support gave me the strength to keep pushing. I am proud to be your child, and I thank God for blessing me with such amazing parents. My sincere appreciation goes to my project supervisor, Engr. Dr. O.I. Ihenyen, whose guidance, patience, and wisdom were instrumental throughout this work, your insightful contributions and steady encouragement helped shape the direction and quality of this project. I remain grateful for the opportunity to learn under your mentorship. A heartfelt thank you to my special group of friends, Aristotle, Bennett, Ebube and William you guys were the heartbeat of my university experience. From late-night class readings to long hours of shared study sessions, from jokes that eased the tension to deep conversations that reminded us why we started each of you played a part in making this journey rich with memories. You were my support system, my family away from home, and I am deeply thankful for every moment we shared ,to every other personmentioned I say a very big thank you.

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ABSTRACT

Due to the numerous challenges associated with conventional small-scale palm fruit digesters, such as low processing efficiency, poor hygiene, high material losses, and susceptibility to corrosion, the aim of this project was to design, fabricate, and evaluate an improved vertical palm fruit digester capable of enhancing performance and durability in small- to medium-scale palm oil processing.

The methodology adopted involved the design and construction of the digester using stainless steel to improve corrosion resistance and hygiene. Key components such as the digestion drum, shaft, and agitator were carefully fabricated and assembled to ensure efficient mixing and fruit maceration. Fresh palm fruit bunches were sourced, sterilized by boiling, and then processed in controlled batches of varying masses (7 kg, 9 kg, and 10 kg). The performance of the machine was evaluated based on digestion time, throughput capacity, and effectiveness of mesocarp breakdown, as well as the quality of sludge produced.

The results obtained showed that the developed digester was capable of processing a total of 36 kg of boiled palm fruit in 1020 seconds, with digestion time increasing proportionally with batch size. The machine achieved an average throughput of approximately 127 kg/hr, demonstrating improved efficiency compared to traditional small-scale digesters. Additionally, the digester produced well-macerated mesocarp and uniform sludge, indicating effective fruit breakdown and improved potential for oil extraction. The use of stainless steel also eliminated corrosion issues observed in mild steel designs, thereby enhancing durability and operational hygiene. The developed vertical palm fruit digester offers a significant improvement in efficiency, reliability, and product quality, making it a viable solution for small-scale palm oil processors seeking increased productivity and reduced operational losses.

CHAPTER ONE

INTRODUCTION

1.1 Background of study

Palm fruit digesters have evolved from manual, simple methods to more efficient, mechanized systems designed to optimize oil extraction from palm fruit. Early methods involved hand-pounding or simple presses, while modern digesters utilize steam-heated vessels, rotating shafts with beater arms, and various automated systems for breaking down the fruit and releasing oil.The project focuses on the fabrication of a shredder machine powered by a diesel engine specifically tailored to meet the need of small scale farmers in regions where electricity supply is unreliable and unavailable.The choice of diesel engine ensures that the machine remains off- grid areas thereby increasing it's accessibility and practicality for rural farmers (Mustayen et al, 2022). Most traditional or manually operated digesters which has been used for a significant amount of time in the past are usually inefficient, contains high fibre contents, Sometimes Leads to poor oil yeilds and increased workload compared to the advanced ones of today.These limitations highlight the need for locally adaptable, Affordable and efficient small-scale digester designs that can drastically improve oil recovery, reduce energy input and support sustainable rural processing. Digestion as in the case of the study mainly entails releasing the palm oil in the fruit through the rupture or breaking down of the oil-bearing cells in which such machines are designed to reduce the volume of waste making it easier to handle, compost and recycle (IMS Kumar & D Kumar 2015, Adil BM et al 2020) . 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. Pounding, or digesting the fruit at high temperature, helps to reduce the viscosity of the oil, destroys the fruits❼outer covering (exocarp), and completes the disruption of the oil cells already begun in the sterilization phase, digesting not only helps improve the production efficiency, but also helps reduce the oil residue in palm cake, and prevent damage to palm oil press machine.To address these issues, some researchers (Akinoso et al. 2016) have advocated for the use of modular and locally sourced components that can be easily repaired or replaced.

Horizontal and vertical ones are the two common types of digesting machine for palm oil production. The earliest digesting equipment used in palm oil processing is the horizontal masher, and it is widely used in mini palm oil processing plant and small scale oil mill. Vertical digester is an advanced design and it is more preferred in medium and large palm oil.

Today, many products can be made from palm oil which ranges from edible to non - edible usage as well as medicinal products. The edible usage include the production of margarine and palm oil for cooking, the non include production of soaps, detergents, candles, cosmetics, rubber processing, lubricants and glycerol while the medicinal usage include treatment of cancer, diuretic and liniment. The oil palm fruit from the species Elaeis guineensis is the source pof palm oil a globally traded vegetable oil, the fruit is reddish, about the size of a plum and grows in large bunches .Palm oil is used in a wide range of food and industrial products, and its production is a major part of the economy in many tropical countries. The extraction of palm oil involves several key processes, including sterilization, threshing, digestion, clarification, and purification.

1.2. Problem statement

Although digestion is a pivotal step in palm oil extraction, many small-scale producers continue to rely on inefficient and outdated equipment that fails to deliver satisfactory oil yields. The absence of affordable and effective digester units contributes to incomplete cell rupture, oil retention in fibers, and increased energy demands in downstream clarification stages. Furthermore, the lack of thermal control and consistent mechanical agitation leads to uneven digestion, resulting in emulsification and contamination of the oil. These issues compromise both the economic viability and the quality of production in rural settings. There is therefore a pressing need to design and fabricate a small-scale digester that is efficient, easy to operate, energy-conscious, and suitable for use by local palm oil processors. Such a system would improve oil extraction rates, reduce processing time, and enhance the livelihoods of smallholder farmers.

1.3 Aim and objectives

1.3.1. aim

To design and fabricate an improved small-scale digester for palm oil processing

1.3.2. Objective

1. To review existing digester technologies and identify limitations in small-scale applications.

2. To design a compact and cost-effective digester suitable for small-scale palm oil processing.

3. To select appropriate materials and components using locally available resources.

4. To fabricate a working prototype of the digester and evaluate its performance.

5. To assess oil yield, mash consistency, and operational feasibility of the developed unit.

1.4. Significance of study

The fabrication of a small-scale palm oil digester holds major importance across technical, economic, social, and environmental domains especially in palm oil-producing regions where smallholder farmers dominate the supply chain.The fabrication of a small-scale palm oil digester is not just a mechanical innovation—it is a strategic tool for transforming palm oil production at the grassroots level. Its significance lies in Boosting production efficiency, Empowering rural farmers, Creating jobs, Reducing poverty and Promoting sustainable practices.

1.5 Scope of study

This study focuses on the design, construction, and performance evaluation of a small-scale digester intended for use in palm oil processing. The research covers the mechanical and thermal design aspects, material selection, fabrication processes, and field testing of the unit. The digester is expected to handle sterilized fruitlets and prepare them for oil separation through standard clarification methods. However, the study does . In palm oil processing, digesters play a crucial role in releasing oil from the fruit by breaking down the oil-bearing cells. They are typically steam-heated cylindrical vessels equipped with rotating beaters that pound the fruit, reducing the oil's viscosity, destroying the exocarp, and completing the rupture of oil cells. This process enhances oil extraction efficiency.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The digester❼s history reflects contributions from various regions, particularly West Africa and and innovations by colonial engineers, plantation companies, and research institutions. Several researchers and engineers have contributed to the development of palm fruit digesters .Palm Kernel oil is a vital commodity in Nigerian economy with reference to its role as a source of farm income and food requirement. In addition to providing direct and indirect employment for about four (4) million people, palm kernel oil contributes about 70% of the country❼s national consumption requirement of vegetable oils (Poku, 2002, Nzeka, 2014). However, over the past 40years, the Nigerian palm oil industry has undergone dramatic changes, recording slow growth in domestic production and losing its export share in the world market. Furthermore, there has been a growing competition from imports in the face of rising domestic demand. These factors have heightened concerns with regards to the survival of the palm oil industry in Nigeria (Babatunde and Okoli, 1998, Shamsudin et al; 1998, FAO, 002, Shri Dewi et al, 2011).Palm kernel oil is clear, white, and rich in lauric acid, used in soap, cosmetics, and food processing.

Palm kernel oil production has been a target for small and large scale investors, and tofollow the trend and encourage mass and qualitative production of the oil by local oil-Palm farmers as well as supplement governments❼efforts towards increment of local contents (in terms of machinery and equipment) , there is the need to & sign and construct a palm kernel oil extracting machine that will reduce the problems of crude, time and energy consuming, uneconomical and laborious traditional methods of the palm kernel oil production. At present machinery manufacturing of palm kernel oil is a recent development in sub-Sahara Africa, and until recently it has not been possible to develop the sophisticated machines required to improve on traditional methods. The palm kernel oil is a common domestic and cash crop in Nigeria. The extraction of oil from the hard pam kernel is more difficult and less efficient than from the pulpy flesh(AkpobiandOniah,2009,JimohandOlukunle,2013). Mechanizing the palm kernel oil extraction process world reduce waste and improve efficiency and output, and thus encourage rural development by generating wealth and promoting self-employment (Olayiwola, 1998).

Extraction of palm kernel oil into edible oil or for commercial purposes is done using various methods which may be grouped into three categories according to their degree of complexity. These are the traditional, solvent and mechanical extraction methods (S vakumaran et al,1985, Koya and Faborode, 2005, Owolarafe and Oui, 2011). The traditional method is used in rural areas of many developing countries. The oil-bearing material is ground and then heated in boiling water. The liberated oil floats to the surface and is collected. The solvent extraction method is a chemical extraction method, and is very expensive and complex for small-scale extraction. In the mechanical method such as the screw press, a rotating screw forces the oil-bearing material down the length of the cylindrical pressing cage. Increasing pressure squeezes oil out through perforations in the sides of the cage. The cake emerges from the end of the press (Gbadamosi, 2006).

2.1.1 The palm fruit

The palm fruit is the fruit of the oil palm tree (Elaeis guineensis), a tropical plant native to West and Central Africa but now widely cultivated in Southeast Asia, Latin America, and other tropical regions.

It is primarily valued for its oil-rich mesocarp and kernel, from which palm oil and palm kernel oil are extracted.

2.1.2 Structure of the Palm Fruit

Each palm fruit is oval or spherical, measuring about 2–5 cm in length, and grows in large bunches weighing 10–50 kg.

I. Exocarp (Outer Skin)

The outermost layer of the fruit. It has a Deep orange to reddish-brown when ripe.and a texture which is Smooth and thin. It Protects the inner layers from mechanical damage and water loss.

II. Mesocarp (Pulp)

The middle fleshy layer, thick and oily. Which is Rich in crude palm oil (CPO) — a reddish oil due to high β-carotene (vitamin A precursor). It Contains 40–50% oil by weight. It acts as the main source of palm oil used for cooking, industrial, and cosmetic purposes.

III. Endocarp (Shell)

Hard, woody layer surrounding the kernel, Known as the palm nut shell.It Protects the kernel inside.

Function: Important for determining fruit type:

Dura: Thick shell (2–8 mm)

Tenera: Thin shell (1–3 mm)

Pisifera: Shell-less

IV. Kernel (Seed)

Found inside the shell and Contains palm kernel oil (PKO) and palm kernel cake (residue after oil extraction).It has an Oil content of (45–55)%

2.2 Palm Oil Production Process Overview

Palm oil production, whether undertaken by large-scale industrial mills or traditional rural processors, involves a series of core mechanical, thermal, and separation operations designed to extract high-quality oil from the mesocarp of the oil palm fruit (Elaeis guineensis).

The standard process flow can be summarized as follows:

Fruit Reception and Harvesting: Fresh fruit bunches (FFB) are harvested from mature oil palms and transported promptly to the mill, minimizing spoilage and excessive free fatty acid formation.

Sterilization: Fruit bunches are sterilized—commonly by steaming at elevated pressure—for 45–60 minutes. This process softens the fruits, kills microorganisms, and facilitates easy separation of fruits from the bunch stalk and mesocarp loosening for subsequent digestion.

Threshing: The sterilized bunches are mechanically threshed to separate individual fruits from the bunches. The main machinery is a rotary drum or spike-type thresher.

Digestion: Sterilized fruits are transferred to the digester for mechanical maceration—commonly using rotating shafts with paddles or beaters—where the mesocarp is ruptured and oil cells released. This is the critical stage addressed by this present study.

Pressing & Extraction: The digested mash is pressed (using screw presses or hydraulic systems) to extract crude palm oil (CPO). Pressing separates the oil, water, and solids (fiber, kernels).

Clarification: The extracted oil is diluted with water, settled, and filtered to remove solids and impurities. A multi-stage settling tank system is used, followed by filtration and drying.

Palm Kernel Recovery:

After pressing, the remaining cake (fiber and nuts) goes through mechanical separation to recover palm kernels, which can be further processed into palm kernel oil and cake by-products.

Refining (industrial scale); Crude palm oil may be refined to remove gums, free fatty acids, pigments, and odors if destined for high-value markets or export. At rural or SME level, simple boiling and decanting are common.

Packaging and Distribution: Oil is packaged into drums or containers suitable for transport, retail, or industrial use, with careful attention to cleanliness and moisture control.

2.3 Application of Palm fruit Digesters

The main application of a palm fruit digester is in the palm oil extraction process. It is a crucial piece of machinery used to prepare the sterilized palm fruit for efficient oil pressing.

Here are the key applications and functions:

1. Primary Function (Conditioning for Oil Extraction)

Rupture Oil-Bearing Cells: The core purpose is to pound and mash the palm fruit (the mesocarp pulp) to rupture the oil-bearing cells. This releases the crude palm oil, making it easier to extract in the subsequent pressing stage.

Create a Mash (Pulp): It pounds the fruit into a uniform, soft mash or pulp, which is the optimal consistency for the oil press machine.

Loosen Fiber from Nut: The mechanical action helps to loosen the fruit's outer covering (monocarp) from the inner palm nut.

2. Enhancing Efficiency

Increase Oil Yield: By breaking down the fruit and releasing the oil, the digester significantly improves the overall efficiency of oil extraction, leading to a higher yield of palm oil.

Reduce Residual Oil: The thorough mashing process helps lower the oil content remaining in the final press cake (fibre and nut), thus reducing waste.

Protect the Press Machine: By properly softening and conditioning the fruit, it reduces the strain and potential damage to the palm oil screw press machine.

3. Integration with Heat/Steam

Heat Application: The digester is typically a heated, cylindrical vessel, often with the injection of hot steam (around 90-95°C).

Softening and Viscosity Reduction: This heat softens the fruit further, completes the disruption of oil cells (a process started during sterilization), and reduces the oil's viscosity, all of which facilitate easier and greater oil expulsion. In the overall palm oil mill process, the digester is positioned after the fruit bunches have been sterilized and the individual fruits have been separated (threshed), and it operates immediately before the crude palm oil is extracted by the screw press machine.

2.4 Types of digesters

In the fundamental technological development, engineering designs encouraged the construction of different proto type of digester which aids in the production of more digestible mashy fruit.They are classified into Manual digester and Motorized digester.

I. Manual Digesters
II. Motorised Digesters

I. Manual digesters are built with different shapes and patterns. These is a ways a handle which is used to turn the palm fruit in the barrel the shaft of the digester is designed and welded onto with flanges of barrel depending on the size of the barrel used. The operation is efficient but very slow and involve a lot of human effort for high production. This method of operation can not go on for industrial use because of its low production rate. Above all human effort tends to dominate the whole operation manual digesters are mostly common in industrial African villages and communities where there is no rural electrification.

ii. Motorised Digesters

Motorized digesters consist of a machine with a power driver pulley from the electric motor. The source of power transmission is belt from the driver (i.e) elector motor pulley to the driven digester pulley. The pulley is keyed to the shaft which is supported on two ball bearings located on each end of the shaft. The type of shaft used is the step shaft with the flanges welded unto the bigger correctional part of the shaft. The shaft assembly and flanges are enclosed in a barrel which is usually cylindrical, and the barrel internal surface is about 2cm ∽5cm depending on the verities of palm fruit intended for digestion.

2.4.1 Types of motorised digesters

Horizontal types of the motorized digester are classified depending on the axis of mounting of the barrel and shaft. The horizontal digester are designed with shaft and barrel parirel to the horizontal axis and will incorporate an electric motor that will generate power to the system that will enable the system to function accordingly the vertical digester are this type which the axis are built at right angle to the horizontal axis, the shaft and barrel are positioned in a vertical direction to work effectively. Most designers prefers this type of vertically mounted system because of it high efficiency and easy construction and even good out put in terms of digestion.Motorized digesters for palm oil processing come in various types, each with its own design and operational characteristics. Here are some common types:

I. Vertical Digesters : These digesters have a vertical orientation, which allows for efficient steam injection and hot water circulation. They are often used in large-scale palm oil processing plants.They are cylindrical tanks, often made of steel, used for various industrial processes like palm oil processing. They are characterized by a vertical orientation and are commonly found in industries required for digestion of organic matter.

II. Horizontal Digesters : These digesters have a horizontal orientation, which can be beneficial for certain types of palm fruit processing. They may be more suitable for smaller-scale operations.

2.5. Role of digesters in palm fruit oil processing

Digesters are designed to break down sterilized palm fruits before pressing. According to Owolarafe and Faborode (2006), effective digestion ensures a higher percentage of oil is released during the pressing stage. Inadequate digestion often leads to high oil losses in the fiber and nuts

I. Breaking Down the Fruit Mesocarp

Digesters use mechanical agitation and heat to break down the fleshy mesocarp (the oily part) of the palm fruit. This process loosens the oil from the fiber and makes the oil more accessible for extraction in the next stage.

II. Sterilizing the Fruit Further

Although palm fruits are typically pre-sterilized, digesters apply additional heat (usually with steam) which helps to Soften the fruit further, Kill remaining enzymes or microbes, Prevent fermentation or oil deterioration

III. Detaching Nuts from the Mesocarp

Digesters help separate the palm kernel nuts (seeds) from the mesocarp and fiber. This makes it easier to separate the nuts for kernel oil extraction later.

IV. Enhancing Oil Yield

By breaking down the cells and softening the pulp, digesters improve the efficiency of the oil press or expeller, resulting in a higher oil yield.

V. Preconditioning for Pressing

Digesters act as a pre-treatment stage before pressing. The processed mash that exits the digester is in the ideal condition (hot, soft, and broken down) for the oil press to extract maximum crude palm oil.

2.6 Recent advancement / existing research on the palm fruit digester

Recent advancements in palm fruit digesters focus on improving efficiency, reducing nut breakage, and minimizing oil loss through innovative designs like kernel-free systems, integrated machines, and vertical digesters. Locally sourced materials and dimensional analysis modeling enhance accessibility and performance prediction. However, challenges like nut breakage and oil loss driving research toward sustainable solutions like biogas production and smart technology integration. For detailed specifications or purchasing, manufacturers like those on Alibaba offer digesters with capacities of Digester. The Buckingham Pi theorem has been used to derive dimensionless parameters for predicting digester efficiency and throughput. A 2023 study reported R^2 values for both throughput and efficiency, indicating reliable predictive models for operational performance. Studies indicate that decreasing motor speed increases digestion efficiency but reduces throughput, while higher speeds boost throughput at the cost of efficiency.

Optimal balance is critical for practical applications and proper steaming before digestion is crucial. Insufficient steaming time reduces oil yield, while extended steaming enhances extraction efficiency. Stainless steel is preferred for digester construction due to its high corrosion resistance and durability under elevated temperatures and pressures. Mild steel and aluminum are also considered but are less resistant to corrosion.

Research has explored anaerobic digestion of palm oil mill effluent (POME) and empty fruit bunches to produce biogas, reducing environmental impact Biogas Production Enhancement by Co-Digestion of Technology Innovation and Business Model of Palm Oil Miniplant (2024). A coupled liquid and solid-state anaerobic digestion process achieved a methane yield of 60.9 m^3/ton of waste, with optimal conditions at a 30-day hydraulic retention time and specific organic loading rates. In Indonesia, biogas plants using POME have reduced by up to 91% and produced 55% methane content, offering economic and environmental benefits. Mechanical and alkaline pretreatment of EFB improves biogas yield by up to 90%. Optimal EFB:POME ratios (0.25–0.4:1) enhance methane production, with thermophilic conditions yielding up to 340 ml CH_4/g VS. Exploratory research on hydrogen production from EFB using gasification methods (direct, indirect, and supercritical water gasification) shows promise but faces challenges in scaling up due to reactor design and safety issues. Studies indicate that decreasing motor speed increases digestion efficiency but reduces throughput, while higher speeds boost throughput at the cost of efficiency. Optimal balance is critical for practical applications. Development and Testing of a Kernel-Free Digester.

2.7 Limitations and challenges

Palm fruit digester technology faces challenges related to nut breakage, low efficiency of traditional systems, high costs, oil loss, environmental impact, mechanical issues, lack of nut-pulp separation, energy demands, and scalability. While innovations like integrated digester-separator systems, vertical digesters, and anaerobic co-digestion show promise, their commercial adoption is limited by cost, complexity, and lack of infrastructure. Future efforts should focus on affordable, locally adaptable solutions that minimize environmental impact and cater to small-scale processors.

In the aspect of for the scalability and adaptation to local needs Most advanced digester technologies are designed for large-scale mills, leaving small-scale processors with limited options tailored to their needs. The lack of customizable, affordable solutions hinders adoption in rural areas. Consideration on the high cost and accessibility such as motorized vertical digesters, are often too expensive for small-scale processors. The cost of equipment, maintenance, and energy requirements (e.g., electric motors or diesel engines) poses a barrier, particularly in developing nations.

Traditional and semi-mechanized digestion methods, such as manual pounding or basic horizontal digesters, are labor-intensive, time-consuming, and less efficient. These methods often result in incomplete digestion, leaving oil trapped in the mesocarp, which reduces overall yield. In regions like Nigeria, where many processors rely on traditional methods, low throughput and high labor costs hinder scalability and profitability. For instance, manual digestion using pestle and mortar is slow and physically demanding, limiting production capacity. Modern vertical digesters with higher capacities (e.g., 740 kg/h and 92.31% efficiency) have been developed to address this, but their adoption is limited by cost and accessibility.

CHAPTER THREE

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 1.082N/mm^2.

This value was obtained using the formula

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

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:

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

$F_R = mg$ (3.8)

$m = F_R/g$ (3.9)

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

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:

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

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,

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

With the bending moment on the digester arm determined by:

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

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:

$$\boldsymbol{e}^{\Theta\mu} \tag{3.14}$$

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

Using the values of $\Theta_{\mathbf{1}}$, and $\Theta_{\mathbf{2}}$: from equations (3.20) and (3.21), we determine the pulley that the load carrying capacity of the design:

i. Using $\Theta_{\mathbf{1}}$:

$\boldsymbol{e}^{\Theta\mu} = e^{0.3 \, x \, 2.58} = 2.16$

ii. Using $\Theta_{\mathbf{2}}$:

$\boldsymbol{e}^{\Theta\mu} = e^{0.3 \, x \, 3.70} = 3.03$

Hence, using equation (3.18):

$$T_1/T_2 = \boldsymbol{e}^{\Theta\mu}$$

$T_1/T_2 = 2.16$

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

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

I. The smaller diameter is 1/3 of the larger pulley diameter

II. 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:

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

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

$$T_1 = F_b \; x \; b \; x \; t \; x \; N_b \qquad (3.24)$$

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:

$$M_t = (T_1 - T_2)R \quad (3.31)$$

In designing the shaft, the following assumptions were made

I. The weight of the shaft is negligible

II. Length of the shaft = 720mm

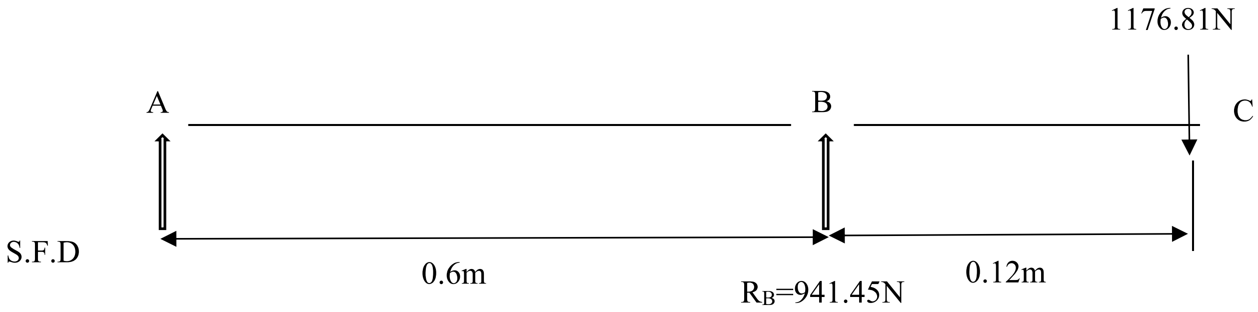

Figure 3.1: Shaft showing forces acting on it

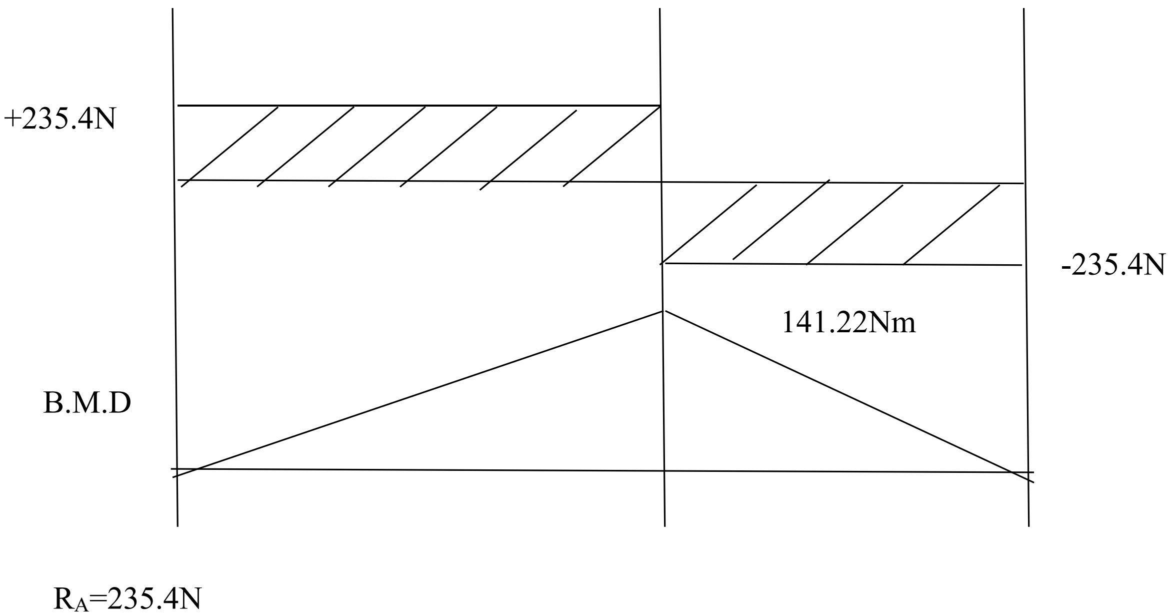

Figure 3.2: Shear force and bending moment diagram of the drive shaft in a static position

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

$$M_b = (T_1 + T_2)\ BC \tag{3.32}$$

$$M_b = (804.4 + 372.41)\ 0.12$$

$$M_b = 141.22Nm$$

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:

$$P_d = T\omega \qquad (3.33)$$

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,

$$P_m = P_d + P_f \qquad (3.34)$$

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, stainless steel was ultimately chosen for the fabrication of the digester. Stainless steel is an alloy steel that contains a minimum of about 10.5% chromium, along with varying amounts of nickel, molybdenum, manganese, silicon, and carbon, depending on the grade. The chromium content enables the formation of a thin, protective oxide layer on the surface, which prevents corrosion and enhances durability.

Materials used in the construction of a palm fruit digester must be capable of withstanding high temperatures, continuous mechanical agitation, moisture, and organic acids released during the digestion process. Stainless steel effectively meets these requirements, making it a more suitable material than mild steel for this application.

One of the primary reasons for selecting stainless steel over mild steel is its excellent corrosion resistance. During operation, the digester is constantly exposed to heat, water, and acidic components from palm fruits. Mild steel, which has low resistance to corrosion, was previously observed to rust—especially at the base near the heat source. Stainless steel, however, resists rusting and chemical degradation, thereby significantly increasing the lifespan of the equipment.

In addition, stainless steel offers high strength and durability, enabling it to withstand the mechanical stresses generated by the rotating shaft and agitator arms within the digester. It maintains its structural integrity under heavy loads and continuous operation, reducing the risk of failure.

Stainless steel also has good thermal resistance, allowing it to perform efficiently at elevated temperatures without losing its mechanical properties. This is particularly important in a digester, where heat is applied to soften the palm fruits and aid oil extraction.

Another important advantage is its hygienic and non-contaminating nature. Since palm oil is a consumable product, it is essential that the processing equipment does not introduce impurities. Stainless steel has a smooth, non-porous surface that prevents contamination, does not react with the oil, and is easy to clean and maintain . Furthermore, stainless steel exhibits good weldability, formability, and machinability, making it suitable for fabrication into the cylindrical shape and internal components of the digester. Although it may require more precision during machining compared to mild steel, the long-term benefits outweigh the initial fabrication challenges. It also demonstrates excellent resistance to wear, creep, and fatigue, ensuring reliable performance over extended periods of operation. Unlike mild steel, it does not require frequent repainting or protective coatings, thereby reducing maintenance costs and downtime.

In conclusion, stainless steel was selected over mild steel for the construction of the digester due to its superior corrosion resistance, strength, thermal stability, hygienic properties, and durability. These advantages make it a higher-grade material and a more appropriate choice for ensuring efficient, safe, and long-lasting operation of the palm fruit digester.

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

3.7 Parts and Assembly Drawings

The part list, assembly drawings, and part drawings are found in the appendices section of the report.

CHAPTER FOUR

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.

4.1.1 Performance Evaluation of the Palm Fruit Digester

The performance of the developed palm fruit digester was evaluated using four separate test runs with varying masses of boiled palm fruit. The results obtained from Table 4.1 provide a basis for assessing the efficiency, throughput capacity, and operational effectiveness of the machine.

From the results, it was observed that digestion time increases proportionally with the mass of the palm fruit. Specifically, 7 kg of fruit required 180 seconds, 9 kg required 240 seconds, while 10 kg required 300 seconds. This indicates a relatively linear relationship between load and digestion time, suggesting that the machine operates with consistent efficiency across different batch sizes without significant performance loss. The total mass processed was 36 kg within a cumulative digestion time of 1020 seconds (17 minutes) This throughput demonstrates a significant improvement in processing capacity when compared to traditional small-scale/manual digesters, which typically exhibit lower processing rates due to inefficiencies in mixing and fruit breakdown.

4.1.2 Evaluation Based on Digestion Efficiency and Product Yield

The effectiveness of a palm fruit digester is not only determined by processing time but also by the quality of digestion, which directly influences the yield of

- Oil-bearing mesocarp (pulp)
- Sludge (mixture of oil, water, and fine solids)

During the operation of the developed digester, it was observed that:

- The mesocarp was thoroughly macerated, indicating effective breakdown of the palm fruit structure.

. There was minimal presence of un-digested or partially digested nuts, which is a key indicator of high digestion efficiency.

. The sludge obtained was uniform and well-mixed, which is essential for efficient downstream oil extraction.

Efficient digestion increases the surface area of the mesocarp, thereby enhancing oil release during subsequent clarification and pressing stages. Compared to conventional small-scale digesters, which often leave a significant portion of mesocarp attached to the nuts, the developed digester shows a notable reduction in oil loss.

4 1.3 Performance Improvement Over Conventional Small-Scale Digesters

The improved performance of the developed digester can be attributed to several design and material enhancements:

Material Upgrade (Use of Stainless Steel):

The use of stainless-steel minimized contamination and corrosion, ensuring cleaner processing conditions and longer equipment lifespan.

. Efficient Agitation Mechanism:

The uniform digestion times across repeated 10 kg tests (300 s each) demonstrate operational consistency and reliability, unlike traditional digesters that often produce variable results.

. Enhanced Heat Retention and Distribution:

Proper heat interaction with the digestion chamber contributed to effective softening of the fruits, improving mesocarp separation.

. Improved Hygiene and Product Quality:

Stainless steel construction ensured that the sludge and mesocarp remained uncontaminated, thereby improving the quality of crude palm oil extracted.

4.1.4 Conclusion of Performance Evaluation

Based on the results obtained, the developed palm fruit digester exhibits:

High throughput capacity (~127 kg/hr)

Consistent and predictable digestion time

Efficient mesocarp breakdown

Improved sludge formation for oil extraction

Reduced material loss and higher oil recovery potential

Overall, the machine demonstrates a significant improvement over traditional small-scale digesters in terms of efficiency, durability, hygiene, and productivity. These improvements make it highly suitable for small- to medium-scale palm oil processing operations.

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

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

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

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

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

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

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

$$= 95.5\%$$

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 3rd and 5th 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	Metal sheet	2	80,000	160,000
2	5hp diesel engine	1	250,000	250,000
3	Pillow bearing	2	10,000	20,000
4	Mechanical gearbox	1	25,000	25,000
5	Angle bar	1	26,000	26,000
6	Electrode (pack)	5	15,000	75,000
7	Belt	1	1,000	1,000
Total				**557,000**

4.4.2 Production Cost

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

S/N	Description	Price (₦)
1	Fabrication workshop service	30,000
2	Transportation	20,000
3	Miscellaneous	30,000
	Total	**80,000**

Bill of quantity = Production cost + material cost

Bill of quantity = 80,000+557,000

= #637,000

CHAPTER FIVE

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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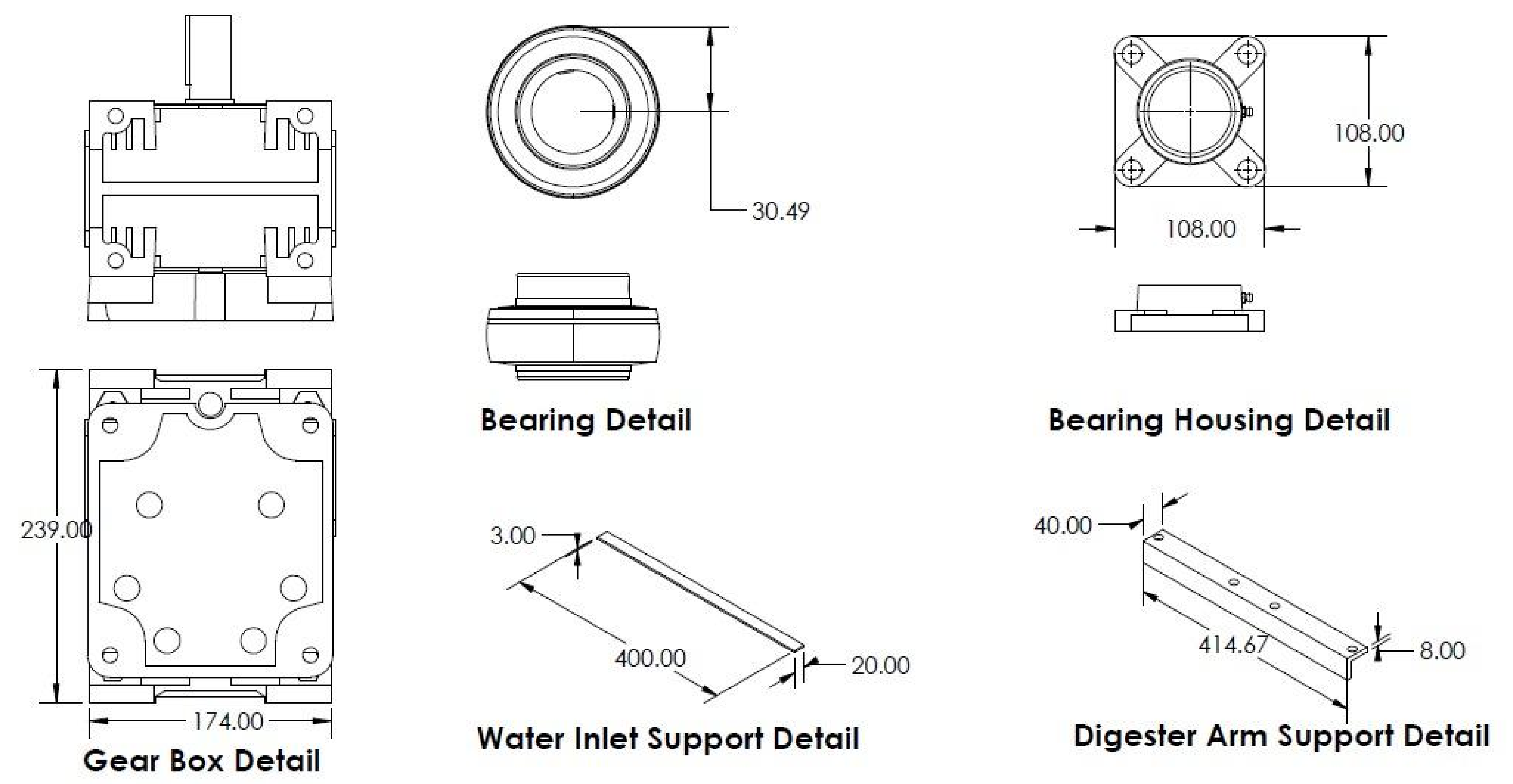
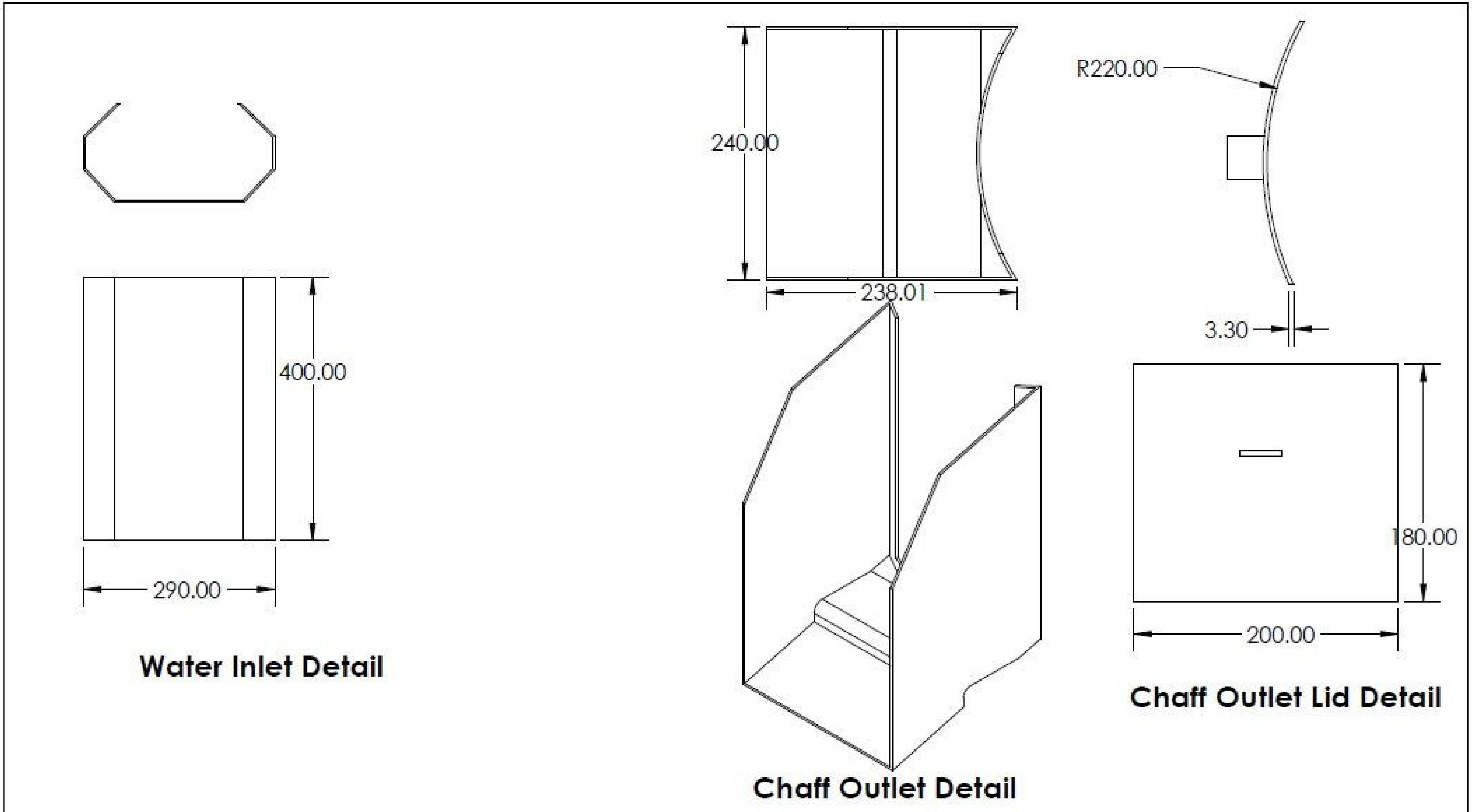
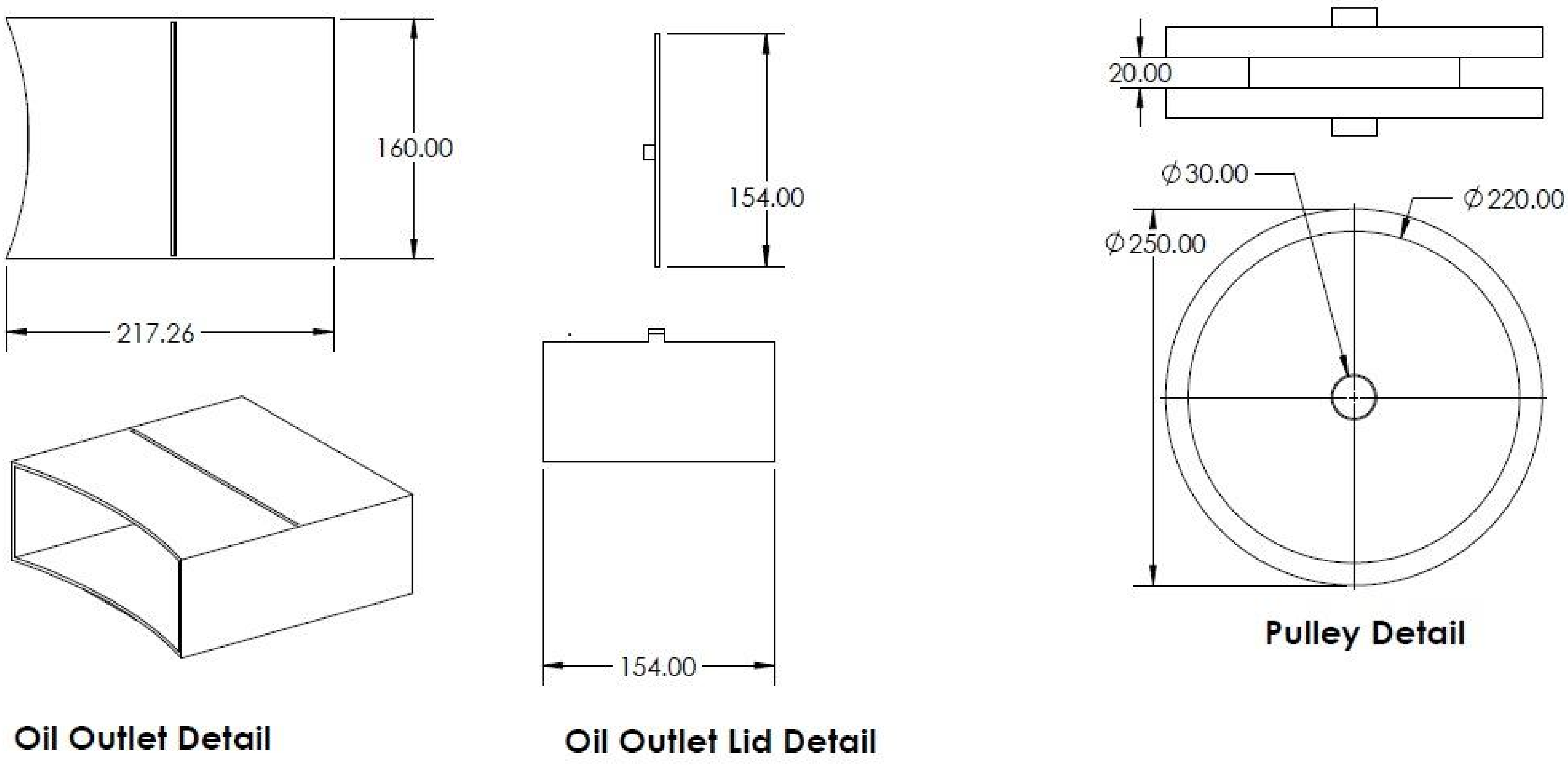


Department of Industrial and Production Engineering, Faculty of Engineering, University of Benin, Benin City.	Project Title: Design and Fabrication of an Improved Palm Fruit Digester	DESIGNED BY: Joshua Onwuegbuzie, Efotobore Omokhoje, Oluwatoyin Bakare, Ehimwonzee marvis, Ehimoan Joshua, Ayomide Hepzibah	CHECKED BY: Dr. O. I. Ihenyen	DRAWING NAME: Part Diag.	SCALE: N.T.S	DATE: 11-Nov-2025	SHEET: 8



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: Part Diag.	SCALE: N.T.S	DATE: 11-Nov-2025	SHEET: 7



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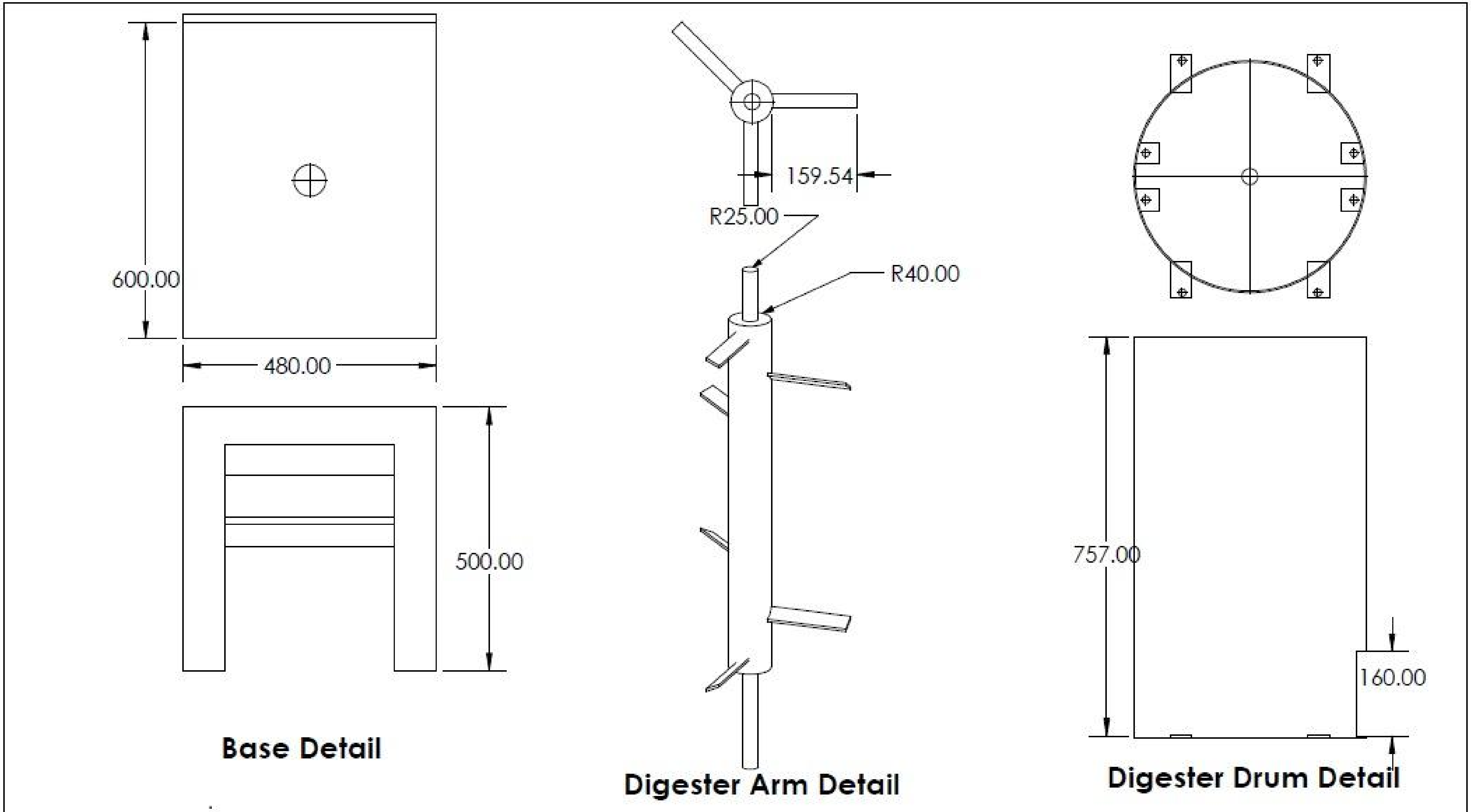
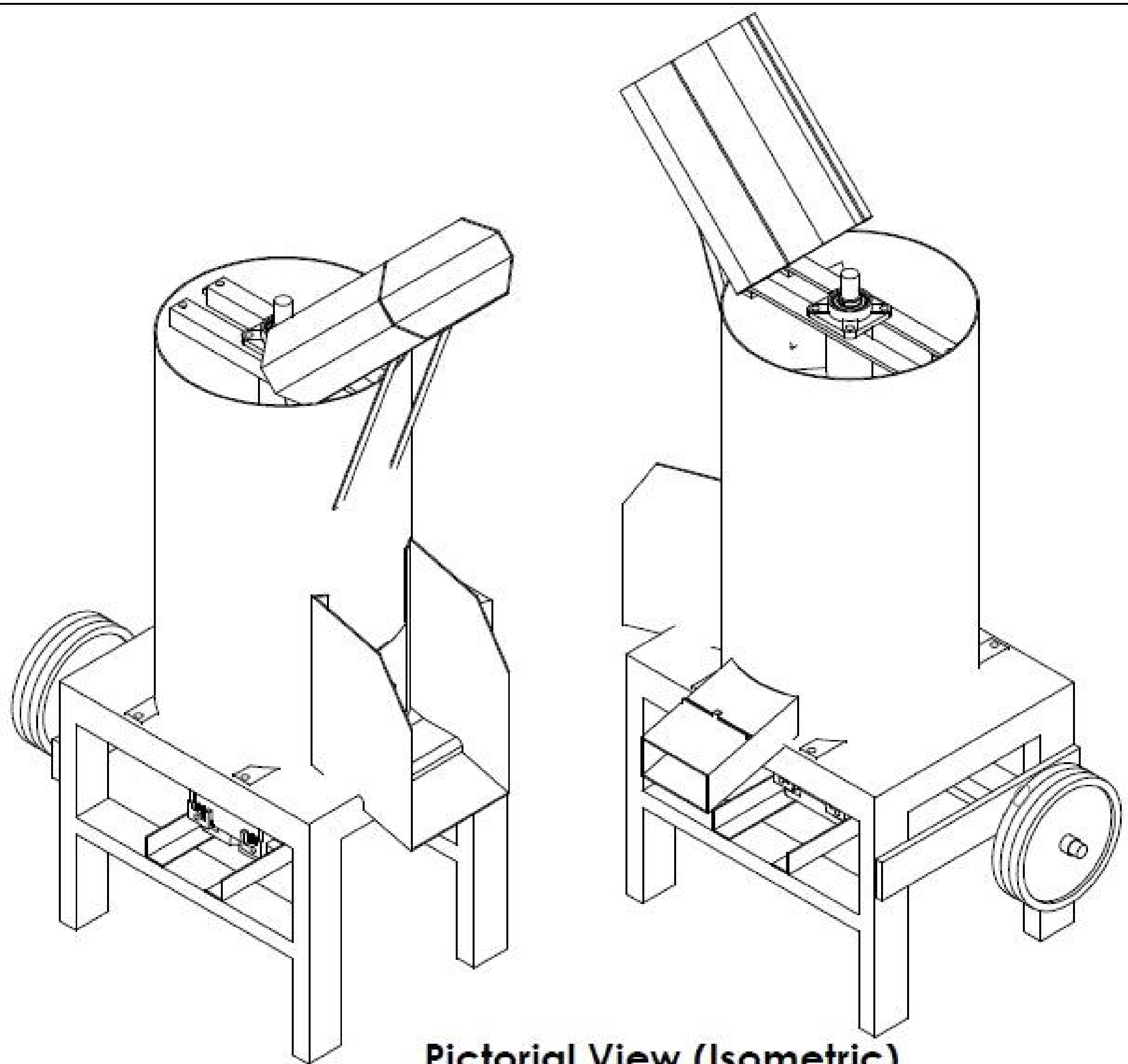
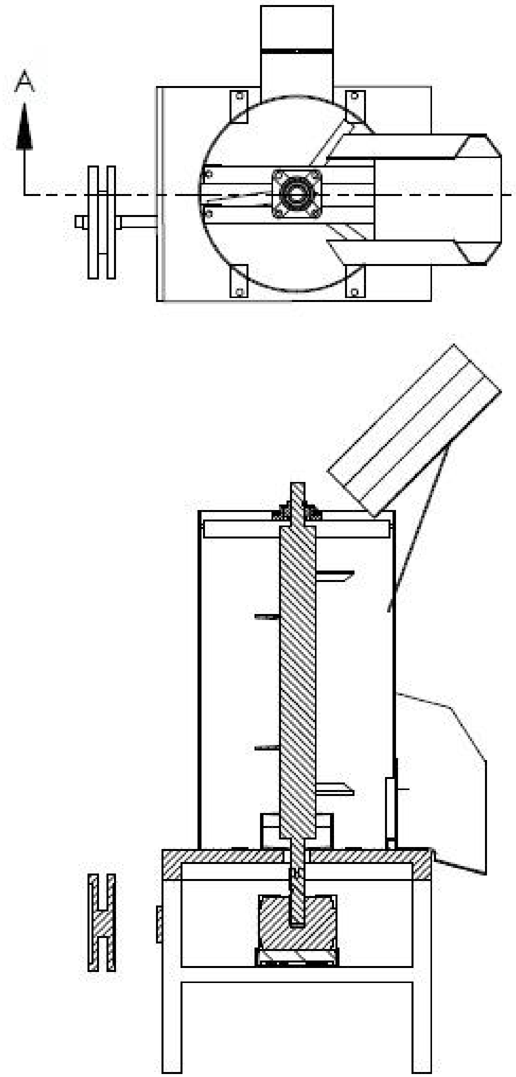


Department of Industrial and Production Engineering, Faculty of Engineering, University of Benin, Benin City.	Project Title: Design and Fabrication of an Improved Palm Fruit Digester	DESIGNED BY: Onwuegbuzie Joshua, Efetobore Omokhoje, Oluwatoyin Bakare, Ehimwonzee Marvis, Ehimoan Joshua, Ayomide Hepzibah	CHECKED BY: Dr. O. I. Ihenyen	DRAWING NAME: Part Diag.	SCALE: 1:10	DATE: 11-Nov-2025	SHEET: 5



Pictorial View (Isometric)

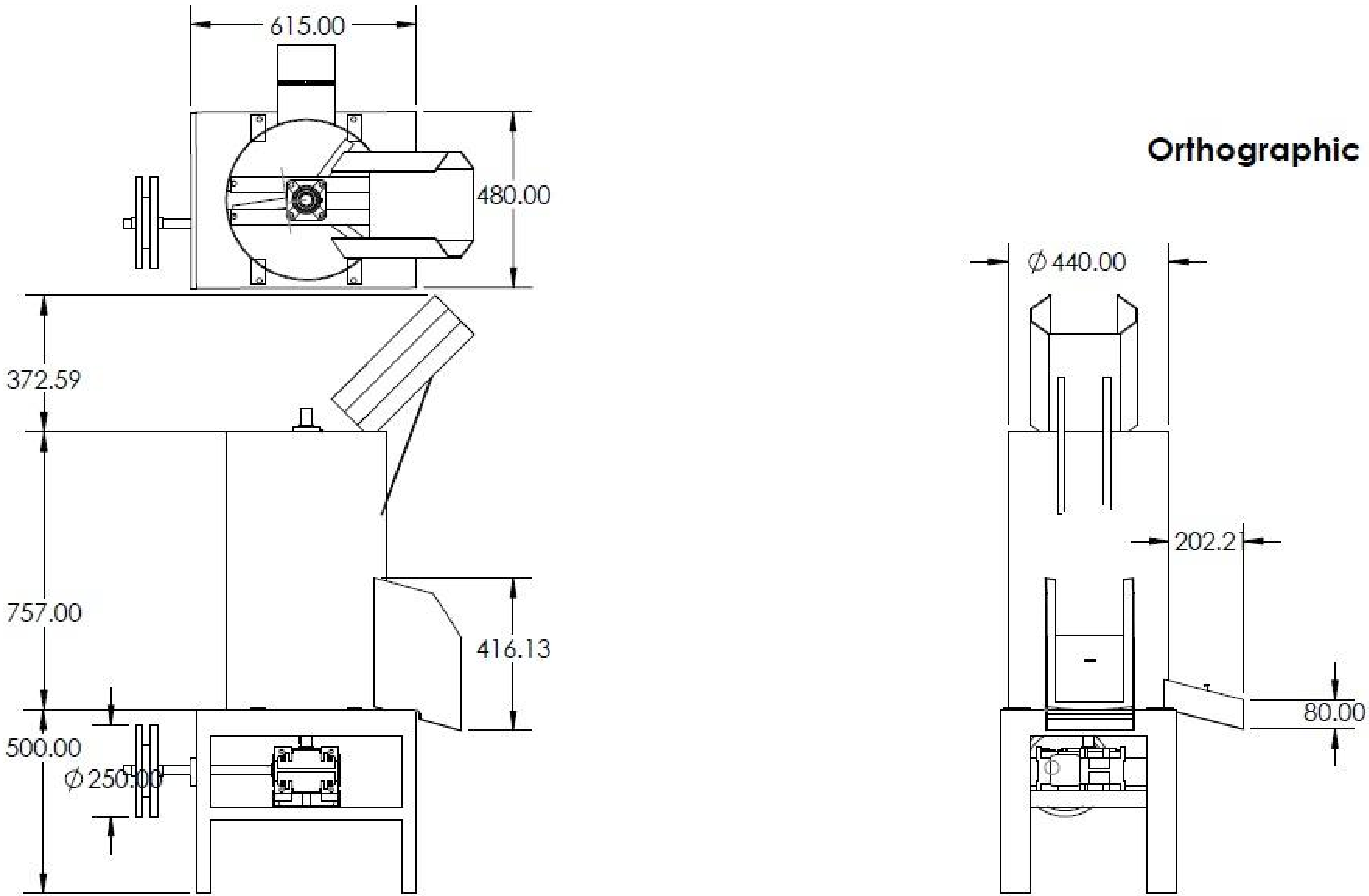
Department of Industrial and Production Engineering, Faculty of Engineering, University of Benin, Benin City.	PROJECT TITLE: Fabrication of a vertical palm oil digester for small-scale palm oil processing	DESIGNED BY: Onwuegbuzie Joshua, Efetobore Omokhoje, Oluwatoyin Bakare, Ehimwonzee Marvis, Ehimoan Joshua, Ayomide Hepzibah	CHECKED BY: Dr. O. I. Ihenyen	DRAWING NAME: Isometric	SCALE: 1:12	DATE: 11-Nov-2025	SHEET: 4



Section A - A

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: Sectioned	SCALE: 1:16	DATE: 11-Nov-2025	SHEET: 3

Orthographic Projection



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