

**DESIGN AND FABRICATION OF AN IMPROVED PALM OIL CLARIFIER**



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**EDO STATE, NIGERIA.**

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**OCTOBER 2025.**

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**CERTIFICATION**

This is to certify that this research work was carried out by **ODEH MARTINS ELOGHOSA (ENG2006318)** of the Department of Industrial Engineering, Faculty of Engineering, University of Benin, Benin City.

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## **DEDICATION**

I dedicate this report to the glory of God Almighty, whose divine guidance and wisdom have been my constant source of inspiration and strength throughout my academic journey.

## **ACKNOWLEDGEMENT**

I acknowledge Almighty God, whose grace, strength, and guidance made the successful completion of this project possible.

I also wish to express my heartfelt gratitude to my Parents Mr. Ernest Odeh and Mrs. Charity Odeh and siblings Abigail Odeh, Elizabeth Odeh and Ebenezer Odeh, for their unwavering love, support, and words of encouragement.

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## ABSTRACT

The palm oil industry continues to suffer from the limitations of traditional clarification methods, which result in significant oil losses, poor product quality, and low throughput, particularly among small-scale rural processors who lack access to mechanized systems. This project aimed to design and fabricate an improved small-scale palm oil clarifier that addresses these shortcomings through enhanced chamber geometry, controlled heating, and appropriate material selection. Specifically, the work sought to evaluate existing clarification technologies, design a compact multi-chamber unit, select thermally and chemically resistant materials, develop an integrated heating system, and validate the prototype through performance testing.

The clarifier was fabricated using 304H stainless steel, chosen for its superior corrosion resistance, thermal stability at elevated temperatures, and suitability for hygienic food-grade processing. The design incorporated a cylindrical crude palm oil tank, a settling tank, and a dryer unit all of which was interconnected to facilitate gravity-driven phase separation and residual moisture removal. A gas-fired burner was integrated to maintain the mixture within the optimal clarification temperature range of 85–90°C, reducing oil viscosity and promoting separation of oil, water, and sludge. Design calculations covering tank volume (116.29 litres per batch), heat energy requirements (approximately 15.3 MJ), surface area, and settling time using Stokes' law were all carried out to ensure the system was dimensionally and thermally appropriate for a small-scale processing scenario involving up to 200 litres per day.

Performance tests conducted on 1st and 3rd November 2025 yielded oil recovery rates of 91.30% and 91.54% respectively, both of which fall within the 90–95% benchmark typically reported for larger automated industrial clarifiers and represent a marked improvement over the 74.24% efficiency documented in comparable small-scale prototype studies. The total fabrication cost of ₦1,137,000 confirms that high-performance clarification equipment can be produced at an accessible cost for small-scale processors. These findings demonstrate that thoughtful engineering design, when grounded in local material availability and the practical realities of rural processing environments, can deliver results competitive with far more capital-intensive systems, offering a viable pathway to reduced oil losses, improved livelihoods, and stronger agricultural productivity across small-scale palm oil communities in Nigeria and similar regions.

## TABLE OF CONTENTS

CERTIFICATION .....	iii
DEDICATION .....	iv
ACKNOWLEDGEMENT .....	v
ABSTRACT .....	vi
CHAPTER ONE: INTRODUCTION .....	1
1.1 Background of the Study .....	1
1.2 Historical Background of Clarifiers in Palm Oil Processing.....	3
1.3 Problem Statement.....	4
1.4 Aim and Objectives .....	5
1.4.1 Aim .....	5
1.4.2 Objectives .....	5
1.5 Scope of the Study .....	6
CHAPTER 2: LITERATURE REVIEW .....	7
2.1 Brief history of palm oil .....	7
2.2 What is Palm Oil Processing? .....	9
2.2.1 Bunch Reception .....	10
2.2.2 Sterilization.....	10
2.2.3 Threshing .....	11
2.2.4 Digestion.....	11
2.2.5 Clarification .....	11
2.2.6 Purification and Drying .....	12
2.2.7 Storage.....	12
2.2.8 Kernel Recovery (Optional) .....	12
2.3 Clarification .....	13
Types of Palm Oil Clarifiers.....	14
2.4 Components of a Small-Scale Palm Oil Clarifier.....	16
2.5 Projects and Research on Palm Oil Clarification .....	18
Operating Parameters in Clarification .....	18
2.5.1 Recent Clarifier Design Studies for Palm Oil Processing .....	18
2.6 Gaps in the Existing Literature .....	20
CHAPTER THREE METHODOLOGY .....	21
3.1 Consideration.....	21
3.2 Design calculations.....	21

3.2.1 Determination of the volume and capacity .....	21
3.2.2 Volume per day .....	22
3.2.3 Determination of the clarifier capacity .....	23
3.2.4 Volume of the clarification tank .....	23
3.2.5 Heating requirement. ....	24
3.2.6 Heat transfer calculations .....	25
3.2.7 Determination of settling time .....	27
3.3 Material Selection requirement for the Clarifier .....	28
3.3.1 Factors Affecting Materials Selection .....	28
3.4 Parts and Assembly Drawings .....	30
3.5 Materials used in the fabrication. ....	30
3.5.1 Stainless Steel .....	31
3.6 Manufacturing process .....	35
3.6.1 Body of the Clarifier .....	<b>Error! Bookmark not defined.</b>
3.6.2 Fire Chamber .....	<b>Error! Bookmark not defined.</b>
3.6.3 Crude oil tank .....	<b>Error! Bookmark not defined.</b>
3.6.4 Settling tank .....	<b>Error! Bookmark not defined.</b>
3.6.5 Dryer .....	37
3.6.6 Chimney .....	38
CHAPTER 4 PERFORMANCE TESTING, RESULTS AND DISCUSSION .....	39
4.1 Performance Evaluation .....	39
4.1.1 Materials and Equipment .....	39
4.1.2 Experimental Procedure .....	40
4.1.3 Performance Evaluation Metric .....	41
4.2 Discussion of Results .....	43
4.3 Bills of Engineering Quantity .....	46
4.3.1 Material Cost .....	46
4.3.2 Fabrication Cost .....	47
4.3.3 Procurement Cost .....	48
CHAPTER FIVE .....	49
CONCLUSION AND RECOMMENDATIONS .....	49
5.1 Conclusion .....	49
5.2 Recommendation .....	50
REFERENCES .....	51



## CHAPTER ONE: INTRODUCTION

### 1.1 Background of the Study

Palm oil plays a major role in the Nigerian economy, especially in rural communities where it is processed mostly by small-scale producers. Despite the availability of palm fruit, the tools used for processing—especially during clarification—are often outdated, slow, and produce low-quality oil. Clarification is the stage where oil is separated from water and solid residues, and when done poorly, it affects the purity, shelf life, and value of the oil.

While large factories use advanced machines to clarify oil efficiently, these systems are too expensive and complex for small processors. Most rural producers still rely on manual settling or boiling methods, which are time-consuming and less effective. The palm oil demand has risen in recent years due to various reasons, one of the major reasons is the discovery of using plant based oils in biodiesel production, Plant-based oils are among the most common and effective raw materials for producing biodiesel. These oils are primarily composed of triglycerides, which can be chemically converted into fatty acid methyl esters (**FAME**) which is the chemical name for **biodiesel**, through a process called **transesterification**. Global demand has fueled a continuous evolution in processing technologies to maximize yield, improve quality, and reduce environmental impact. The oil palm is an exceptional product as even the palm kernels are recovered and further processed into cakes and oils, these products are useful in the cosmetic industry and agricultural industry as feeds for livestock. Although this topic is geared toward palm oil

processing, the FFB of an oil palm virtually has no waste. The palm oil is extracted from the mesocarp of the oil palm fruit (*Elaeis guineensis*), palm oil plays a pivotal role in the economies of many tropical countries, particularly in West Africa and Southeast Asia (Corley & Tinker, 2015). In Nigeria, palm oil production is a crucial agricultural activity, supporting millions of rural livelihoods and contributing significantly to food security and national income.

The processing of palm oil involves a series of mechanical and thermal operations, including sterilization, threshing, digestion, clarification, and purification. Among these stages, clarification is a vital process that separates crude palm oil from water and fibrous solids (Owolarafe et al., 2007). Proper clarification ensures not only a higher yield of oil but also better quality by removing impurities that affect the color, shelf life, and chemical stability of the product (Adeosun et al., 2014). Clarifiers are specialized equipment used in this separation process. In large-scale industrial operations, clarification is often achieved through decanter centrifuges, which employ high-speed rotation to separate oil from aqueous and solid phases (Hartley, 1988). However, these machines are costly, energy-intensive, and unsuitable for smallholder and rural processors. As a result, traditional methods such as gravity settling tanks are still widely used in small-scale settings (Nwannewuihe et al., 2013). To address these limitations, there is a growing interest in designing small-scale clarifiers that are efficient, affordable, and adapted to local conditions. In particular, innovations in material selection, heating mechanisms, and agitation systems (such as the inclusion of a stirrer rod) have the potential to enhance the performance of traditional clarifiers. A well-designed clarifier must ensure consistent

heating to maintain oil fluidity, effective mechanical separation of phases, and durability under repeated use in rural environments.

## **1.2 Historical Background of Clarifiers in Palm Oil Processing**

The process of clarifying palm oil has evolved from basic traditional methods to more mechanized systems over the past century (Hartley, 1988). In early palm oil production, clarification was achieved through natural settling. Crude oil extracted from digested fruit was poured into shallow basins or pots and left undisturbed for several hours or days, allowing gravity to separate the oil from water and sediment (Nwannewuihe et al., 2013).

Although simple, this method was time-consuming, imprecise, and often resulted in oil loss or contamination (Akinoso et al., 2010). As the demand for palm oil increased, especially during the colonial and post-colonial industrial periods, efforts were made to mechanize the clarification process (Owolarafe et al., 2007). Settling tanks with heating jackets were introduced to maintain the temperature of the oil-water mixture, reducing viscosity and improving phase separation. Later, large-scale mills adopted decanter centrifuges and high-speed separators, which significantly improved efficiency and oil recovery. However, these advanced systems remain beyond the reach of most smallholder producers due to their high cost, technical complexity, and maintenance demands. Consequently, many rural processors still use traditional clarifiers that lack temperature control, are prone to sludge build-up, and do not allow for mechanical stirring. Several studies (Abubakar et al., 2021; Onwuka et al., 2019) have identified the need for improved small-scale clarifiers.

Recent innovations have explored the integration of thermostatic heating systems, corrosion-resistant materials, and mechanical agitation into small clarifier designs. The inclusion of a stirrer rod, in particular, helps prevent the accumulation of solids at the base, facilitates uniform heating, and improves separation efficiency. Nonetheless, there remains a research and design gap in developing such systems using locally available materials and fabrication techniques suitable for rural applications. As clarifier designs continue to improve, the heating mechanism must remain simple enough for rural farmers to operate and maintain without requiring technical expertise.

### **1.3 Problem Statement**

Despite the central role of clarification in palm oil processing, most small-scale producers continue to use inefficient and outdated clarifiers that result in significant oil losses, poor product quality, and low throughput (Njeshu et al., 2025). These conventional systems often lack adequate heating mechanisms, are constructed from substandard materials prone to corrosion, and do not include any means for mechanical agitation. The absence of temperature control leads to high viscosity and emulsion formation, while stagnant operation allows sludge to accumulate and interfere with oil separation. Research has further established that poor tank geometry and uncontrolled retention time significantly worsen separation efficiency, design considerations that are almost entirely absent from the

improvised systems used by rural processors (MPOB, 2023). Moreover, the manual nature of current clarification methods places additional labour burdens on processors and prolongs processing time.

To curb these problems, this project aimed to design and fabricate an improved small-scale palm oil clarifier that is affordable, easy to operate, and efficient. The improved design includes a controlled gas-fired heating system to maintain optimal clarification temperatures, a conical tank geometry to facilitate sludge settlement, and 304H stainless steel construction to ensure durability and hygiene. The goal is to create a solution that suits local needs while improving oil quality and reducing processing time.

## **1.4 Aim and Objectives**

### **1.4.1 Aim**

To design and fabricate a small-scale clarifier for palm oil processing that incorporates improved materials, a more efficient heating system, and a stirrer rod mechanism to enhance oil separation efficiency and reduce losses.

### **1.4.2 Objectives**

1. To evaluate existing clarification technologies and identify limitations in small-scale applications.
2. To design a compact clarifier unit equipped with a stirrer rod and turning mechanism.

3. To select corrosion-resistant and thermally efficient materials suitable for rural conditions.
4. To develop and integrate a heating system that maintains consistent operational temperature.
5. To fabricate and test the prototype for oil yield, thermal performance, and ease of operation.

### **1.5 Scope of the Study**

This project is limited to the design and fabrication of a small-scale clarifier unit intended for use in palm oil processing at the rural or cooperative level. The study will focus on the selection of suitable materials, development of a heating mechanism, and the integration of a stirrer rod with a mechanical turning system. The fabricated unit will be evaluated in terms of oil recovery efficiency, separation quality, ease of use, and operational safety.

## **CHAPTER 2: LITERATURE REVIEW**

### **2.1 Brief history of palm oil**

The origin of palm oil processing dates back thousands of years, particularly in West Africa, where the oil palm tree (*Elaeis guineensis*) is native. Archaeological evidence from West Africa, especially in present day Nigeria and Ghana indicates that palm oil has been used for both domestic and commercial purposes since as early as 3000 BCE (Sridhar & AdeOluwa, 2009). Traditional communities extracted oil from palm fruits using rudimentary techniques involving boiling and hand pressing, primarily for cooking, medicinal applications, and as a base for traditional soaps and cosmetics.

Early processing was highly labor-intensive and followed seasonal harvesting patterns. The typical method involved boiling the fruit bunches to soften the mesocarp, manually separating the fruits, and then pounding or squeezing them to release the oil. Water was used to wash the mixture, and the oil was skimmed off the surface after natural settling. Though crude, these methods laid the foundation for future technological developments. With the advent of the trans-Atlantic trade in the 15th century, palm oil became a valuable commodity for European traders. By the 18th and 19th centuries, it had become a critical export product, particularly in British colonial territories in West Africa, where it was known as "red gold" (Martin, 1988). Palm oil was highly sought after for use in soap production, lubricants for machinery during the Industrial Revolution, and as a raw material in various industries.

The colonial period saw the first efforts to mechanize palm oil processing. Colonial administrations and European firms introduced mechanical screw presses, iron boiling tanks, and improved clarification techniques to increase oil extraction efficiency and reduce manual labor (Hartley, 1988). These efforts, however, were mostly limited to larger plantations and colonial enterprises, leaving smallholders to continue using traditional methods.

In the post-colonial era, particularly from the 1960s onward, governments and research institutes in countries like Nigeria, Malaysia, and Indonesia began investing in palm oil research and technology development. Institutions such as the Nigerian Institute for Oil Palm Research (NIFOR) and the Malaysian Palm Oil Board (MPOB) have played pivotal roles in advancing processing techniques and promoting the use of improved cultivars, modern mills, and small-scale processing equipment.

Today, palm oil processing ranges from highly mechanized industrial mills to artisanal, village-level operations. While large-scale processing employs automated systems such as sterilizers, digesters, screw presses, and decanter centrifuges, small-scale processors are increasingly adopting semi-mechanized equipment that bridges traditional methods and modern efficiency. The evolution of palm oil processing reflects a continuous adaptation to social, economic, and technological developments, underscoring its central role in the livelihoods and economies of tropical regions. In the early stages of fruit formation, the oil content of the fruit is very low. As the fruit approaches maturity the formation of oil increases rapidly to about 50 percent of mesocarp weigh. In a fresh ripe, un-bruised fruit the free fatty acid (FFA) content of the oil is below 0.3 percent. However, in the ripe fruit

the exocarp becomes soft and is more easily attacked by lipolytic enzymes, especially at the base when the fruit becomes detached from the bunch. The enzymatic attack results in an increase in the FFA of the oil through hydrolysis. Research has shown that if the fruit is bruised, the FFA in the damaged part of the fruit increases rapidly to 60 percent in an hour. There is therefore great variation in the composition and quality within the bunch, depending on how much the bunch has been bruised. The importance of palm oil cannot be underestimated as it has various uses

## **2.2 What is Palm Oil Processing?**

Palm oil processing is a structured sequence of mechanical and thermal steps designed to convert fresh fruit bunches (FFB) into crude palm oil (CPO) with minimal losses and impurities. According to Basiron (2007), the efficiency and quality of palm oil production depend heavily on the design and execution of each processing stage.

While large-scale mills adopt fully mechanized and automated systems, smallholder producers who account for over 40% of global palm oil output often rely on traditional or semi-mechanical approaches (Oboh & Musa, 2018; Wahid et al., 2013). The primary processing stages include **bunch reception, sterilization, threshing, digestion, clarification, purification**, and optionally **kernel recovery and effluent management**. Each of these stages not only determines the yield and quality of palm oil but also affects the efficiency of equipment such as **decanter centrifuges**, especially at the clarification stage.

### **2.2.1 Bunch Reception**

Bunch reception is the first stage of palm oil processing, where harvested fresh fruit bunches (FFBs) are received, checked, and weighed. Prompt handling at this stage is vital to prevent deterioration of oil quality. If bunches are left too long before processing, enzyme activity can increase free fatty acid (FFA) levels, which reduces the oil's shelf life and commercial value.

This stage involves:

- i.** Checking the bunches for ripeness and rot.
- ii.** Separating under-ripe or overripe bunches.
- iii.** Quickly transferring them for sterilization.

Proper reception ensures the raw material remains in good condition and sets the stage for high oil yield and quality.

### **2.2.2 Sterilization**

Sterilization involves steaming the FFBs at high pressure (100°C to 130°C) to soften the fruit and deactivate enzymes that degrade oil quality. It also helps in loosening the fruits from the bunch and reducing microbial activity.

Efficient sterilization improves oil recovery by softening the mesocarp and making it easier to extract oil in later stages. Poor sterilization, however, results in hard fruit, more fiber contamination, and lower separation efficiency during clarification.

### **2.2.3 Threshing**

Threshing separates sterilized fruits from the bunch stalk. In small farms, this is done manually, while larger mills use mechanical threshers.

Manual threshing is slower and may leave some fruits behind, reducing oil yield. Mechanical systems improve efficiency but must be carefully adjusted to avoid breaking the fruits, which can affect oil quality.

### **2.2.4 Digestion**

Digestion breaks down the soft pulp of the fruits to release crude palm oil. This is done using a digester with rotating paddles that stir and crush the fruit at high temperatures (around 80°C to 100°C).

Proper digestion helps release more oil and prepares the slurry for easier separation during clarification. Poor digestion results in low oil output and more solid residues in the slurry.

### **2.2.5 Clarification**

**Clarification** is the process of separating crude palm oil (CPO) from water and suspended solids (e.g., fibers, nut shells, sand) after the fruits have been digested. The output from digestion (called *press liquor* or *oil mash*) is a three-phase mixture:

- Oil (lighter phase)

- Water (medium phase)
- Solids (heavier phase)

Clarification aims to isolate the oil from this mixture to obtain a cleaner, more stable product for storage, sale, or refining. According to Wahid et al. (2013), **efficient clarification is essential** to ensure high oil recovery, low losses, and a product with acceptable levels of moisture and impurities.

### **2.2.6 Purification and Drying**

After clarification, the oil is filtered to remove fine particles and then dried to reduce moisture content to less than 0.1%. This is important to prevent spoilage during storage.

### **2.2.7 Storage**

Once purified and dried, the oil is stored in tanks or drums. Large mills use heated storage tanks to maintain the oil at about 50°C, preventing solidification and spoilage. In small-scale settings, oil is often stored in used drums at room temperature, which may pose contamination risks if not well managed.

### **2.2.8 Kernel Recovery (Optional)**

After oil extraction, the nuts are separated from the fiber and cracked to obtain palm kernel oil (PKO). Although not part of the main oil stream, kernel recovery improves economic returns and supports waste reduction. The shells and leftover fiber can also be used as fuel or organic fertilizer, contributing to sustainable processing.

## **2.3 Clarification**

### **2.3.1 Definition of Clarification in Palm Oil Processing**

Clarification is the process of separating oil from the mixture of oil, water, and solid particles that comes out after digestion. The main aim is to collect clean crude palm oil and remove as much water and dirt as possible. This helps to increase the amount of oil produced and improve its quality.

In traditional palm oil processing, clarification is done by leaving the mixture in a big tank for a few hours. The oil floats to the top, while the heavier solids and water settle at the bottom. The oil at the top is then collected. This method is cheap and easy to use, but it takes a long time and often leaves oil trapped in the sludge, leading to losses. It also doesn't remove very fine particles or oil that is mixed with water (called emulsions) very well.

To improve this, many modern processors now use machines called **decanter centrifuges**. These machines spin the mixture very fast, and the spinning force helps to quickly separate the oil, water, and solids. Decanters are faster and more efficient than using tanks. They also help recover more oil and reduce waste. Researchers like Abubakar et al. (2021) and Onwuka et al. (2019) have shown that using decanters can improve oil production, especially in small-scale or rural setups.

### **2.3.2 Importance of Clarification**

- i. Increases the oil recovery rate
- ii. Reduces impurities and free fatty acids (FFAs)
- iii. Produces oil suitable for long-term storage and consumption
- iv. Minimizes waste and pollution from palm oil mill effluent (POME)

## **2.4 Types of Palm Oil Clarifiers**

### **2.4.1 Sedimentation Tanks**

The simplest and oldest form of clarification used especially at the smallholder level. Crude oil from the press is poured into an open or closed tank and allowed to stand undisturbed. Over time, the oil rises to the top, even though the process is slow, and impurities settle at the bottom. Despite its affordability and ease of construction, this method is inefficient and prone to substantial oil loss, particularly when dealing with emulsified water or fine solids that resist separation by gravity alone.

### **2.4.2 Vertical Settling Clarifier**

This is a more advanced variation, which uses a cylindrical tank equipped with heating coils and controlled inlet and outlet channels. The digested and screened oil-water mixture enters from the top and settles as it descends through the heated zone, while clarified oil is skimmed off from the upper region and sludge is removed at the base. Heating assists in

reducing viscosity and breaking emulsions, thus speeding separation compared to traditional settling methods.

### **2.4.3 Horizontal clarifiers**

This offers an even more refined approach. These elongated settling tanks often incorporate flow-control mechanisms and scraping systems, enabling quasi-continuous operation. Their design distributes the oil through multiple compartments or channels, allowing better sludge management and improved phase separation. While more effective than vertical units, horizontal clarifiers require precise fabrication and larger space, making them less common in small-scale operations.

### **2.4.4 Decanter Centrifuges**

In industrial facilities, represent the most efficient clarification technology available. Operating at high rotational speeds, they use centrifugal force to accelerate phase separation. The heavier solids and water are forced to the outer wall of the bowl, while the lighter oil accumulates near the center and is diverted for collection. Decanters can operate continuously, handle high throughput, and yield high oil recovery with minimal residual moisture. However, their cost, technical complexity, and energy demands make them impractical for rural small-scale processing.

### 2.4.5 Improved Mechanical Clarifiers

It is designed specifically for small-scale use. These hybrid systems maintain the general principles of gravity clarification but enhance performance by incorporating insulated tanks, thermostatic heating (often via gas burners or electric elements), and mechanical agitation through stirrer rods or paddles. By keeping mash temperature around 85–90 °C, reducing viscosity, and breaking emulsions, these systems substantially elevate oil recovery efficiency. Some designs even include dual chambers or coalescing plates to further improve separation without resorting to full-scale centrifuges.

### 2.5 Components of a Small-Scale Palm Oil Clarifier

The design and construction of a small-scale clarifier typically incorporate the following components:

1. **Clarification Chamber:** This is the main body or tank where crude oil is introduced and separation occurs. It may be cylindrical or rectangular, depending on the design.
2. **Heating System:** To reduce oil viscosity and facilitate separation, heat is applied. This may involve steam coils, electric heaters, or gas-fired burners. CNG (Compressed Natural Gas) has become a preferred fuel due to efficiency and low emissions (Adepoju et al., 2019).
3. **Stirrer Rod and Agitation Mechanism:** A rotating stirrer breaks up emulsions and distributes heat evenly. Some designs include manual or motor-driven turning systems with gear mechanisms to ease operation.

4. **Oil Outlet:** Located at the top of the chamber to collect the floating oil after separation.
5. **Sludge and Water Discharge:** Positioned at the bottom to remove settled solids and wastewater.
6. **Insulation Layer:** Thermal insulation helps retain heat and maintain consistent temperature throughout the clarification process.
7. **Support Frame and Control Valves:** Structural frame holds the chamber in place. Valves control the inlet, outlet, and pressure.

These components are selected based on cost, material availability, and ease of maintenance, particularly in rural settings where technical support may be limited.

## 2.6 Projects and Research on Palm Oil Clarification

### 2.6.1 Operating Parameters in Clarification

Clarification performance is influenced by three main variables:

1. **Temperature:** Liquor heated between 85°C–90°C produces the lowest residual solids and highest oil yield (MPOB, 2023).
2. **Dilution ratio:** Diluting the press liquor with hot water (e.g., 1:1 ratio) improves phase separation but increases mill effluent (Nurulhuda, 2016).
3. **Agitation:** Mild agitation (mechanical or manual) prevents stratification and reduces settling time without disrupting the oil phase (Njeshu et al., 2025).

### 2.6.2 Recent Clarifier Design Studies for Palm Oil Processing

#### 1. Small-Scale Dual Chamber Clarifier Design

Njeshu et al. (2025) developed a two-chamber clarifier for small-scale processors in Cameroon. The system integrates a heated metal settling chamber (85°C), a conical sludge base, and a second chamber for final oil draw-off. The prototype achieved 74.24% clarification efficiency and a 16.33% oil extraction rate when processing 120 liters per batch. It was fabricated using mild steel for cost-effectiveness and was reported to reduce oil loss in sludge by approximately 30% compared to traditional static tanks.

#### 2. Clarification Tank Simulation Study

The Malaysian Palm Oil Board (MPOB, 2023) developed a simulation protocol for clarification tanks, guiding appropriate tank geometry, inlet velocity control, and baffle

placement to reduce short-circuiting and re-entrainment risks. Recommendations include: 3-hour retention time, a temperature of 85°C, and a conical base angle of 45°–60°. This simulation informs geometry optimization even in small-scale contexts, where trial-and-error fabrication is not feasible.

### **3. Evaporation-Based Clarification Concept**

An innovative technique tested by Sivasothy and Batumalai (2013) involves pre-evaporation of dilution water to reduce wastewater and aid phase separation. The system couples multiple-effect evaporators with a settling compartment. Although economically strenuous for rural mills, it influenced the understanding of dilution-water minimization and thermal integration for better oil-sludge separation.

### **4. Practical Parameter Optimization**

Nurulhuda (2016) conducted experiments on the influence of temperature, impeller types, and settling times on CPO separation efficiency in laboratory-scale clarifiers. Findings indicated that agitation at low speed (100–120 rpm) enhanced phase stratification without disturbing solids—and settling time reduced significantly from 120 min to 80 min when operated at 90°C.

### **5. Adoption Barriers and Economic Context**

According to Dennis and Nwadiolu (2018), adoption of modern clarifiers in rural Nigeria is extremely low (0% in some surveyed regions) because of cost, unfamiliarity with operation, lack of local fabrication expertise, and poor spare-part availability. Their study emphasizes

that successful technology deployments in palm oil milling must balance innovation with ease of maintenance and locally accessible materials.

## **2.7 Gaps in the Existing Literature**

Despite increasing technical interest in clarifier design, gaps remain in the following areas:

1. Limited studies on clarifiers specifically designed and field-tested for small-scale farm-level use, with most research focusing on industrial systems or stopping at laboratory-level optimization (Njeshu et al., 2025).
2. Absence of long-term durability assessments under rural operating conditions, particularly regarding corrosion resistance and performance over repeated heating cycles (Njeshu et al., 2025).
3. CFD-based geometry and flow optimization has not been extended to compact clarifiers below 500-litre capacity, leaving small-scale designs largely unguided by simulation (Mohammad Fauzi et al., 2021).
4. Practical and low-cost desludging mechanisms for sludge removal, reuse, or disposal remain largely unaddressed in small-scale clarifier literature (Njeshu et al., 2025).

The current study addresses these gaps by designing and fabricating a low-cost, thermally efficient, and mechanically optimized clarifier suitable for small-to-medium-scale processors using locally available materials.

## **CHAPTER THREE**

### **METHODOLOGY**

#### **3.1 Consideration**

This study considered a small-scale farmer who cultivates Tenera species of palm tree on a plot of farmland measuring 50ft by 100ft. It is estimated that the farmer will be able to plant 6 palm trees on the plot of farmland using the standard spacing for planting oil palm (9m by 9m by 9m) and harvest an average of 60 fresh fruit bunches at maturity. A fresh fruit bunch is estimated to weigh about 10kg.

#### **3.2 Design calculations**

This is concerned with the evaluation of the various data necessary for the fabrication of the clarifier. This data generally revolves around the clarifier's size, the heating requirements, settling time and separation efficiency.

##### **3.2.1 Determination of the volume and capacity**

Firstly, we established how much CPO the farm produces at maturity. To estimate the amount of oil that can be extracted from 600kg of FFB at maturity, this can be calculated by the formula:

$$\text{Volume of oil} = \text{Weight of FFB} \times \text{OER} \times (1 \div \text{Density of palm oil}) \dots\dots\dots 3.1$$

Where:

**OER** = oil extraction rate in (23-25% palm oil can be achieved from good quality Tenera)

Weight of FFB = 600kg

Density of palm oil = 0.89kg/l

Volume of oil =  $600 \times 0.23 \times (1 \div 0.89) = 155.056$  Liters

### 3.2.2 Volume per day

To calculate the required clarifier volume per day, we considered several factors including the volume of the crude oil tank, the volume of crude palm oil to be processed in each batch, the volume of water and sludge as CPO contains a mixture of oil, water and sludge.

This can be calculated using the formula.

$$V_t = V_{cpo} + (V_{cpo} \times \%ws) \dots\dots\dots 3.2$$

Where:

$V_t$  = Total volume per day

$V_{cpo}$  = Volume of crude palm oil, 155.056

$\%ws$  = Percentage of water and sludge, 25%

$$V_t = 155.056 + (155.056 \times 0.25)$$

$V_t = 193.82$  liters

### **3.2.3 Determination of the clarifier capacity**

Daily palm oil production (volume per day) = 193.82 liters per day

Number of batches per day = 2 batches

Volume per batch =  $193.82 \div 2 = 96.91$  liters

### **3.2.4 Volume of the clarification tank**

This is the most crucial factor to consider when designing of a palm oil clarifier. The clarifier must be large enough to allow for the efficient separation of oil from the water and sludge. To determine the volume of the clarification tank, we need to consider:

1. Extra volume for safety and efficiency: To ensure the clarifier operates efficiently, and to accommodate fluctuations in input volume, add an additional safety margin to the volume.
2. Clarifier Design: The shape of the tank (e.g. cylindrical, rectangular) might affect the settling process. A wider base facilitates faster settling.
3. Total volume needed for processing and separation already calculated (96.91 litres per batch)
4. Required volume of CO and sludge/water separation = 96.91 litres per batch

Additional safety margin = 20%

=  $96.91 \times 1.2$

= 116.292 litres.

### 3.2.5 Heating requirement.

Energy required for heating the palm oil processing, especially for the clarification process, is crucial for ensuring the oil's proper separation from water and sludge. The primary aim is to heat the crude palm oil (CPO) to a temperature that allows for efficient separation, which typically ranges around 85°C - 90°C. Energy required to heat 116.292 litres of CPO for clarification.

Where:

Volume of CPO to be heated  $V_{CPO} = 116.292$  litres

Initial temperature of CPO ( $T_{initial}$ ) = 10°C

Final temperature of CPO ( $T_{final}$ ) = 90°C

Density of CPO ( $\rho$ ) = 0.89kg/L

Specific heat capacity of palm oil ( $c$ ) = 1848J/kg°C

Converting Volume to Mass

$$\text{Density} = \frac{\text{mass}}{\text{Volume}} \dots\dots\dots 3.3$$

$$\text{Mass (m)} = V \times \rho$$

$$= 116.292 \text{ Litre} \times 0.89\text{kg/L}$$

$$= 103.499\text{kg}$$

The energy required can then be calculated using the formula:

$$Q = m \times c \times (T_{\text{final}} - T_{\text{initial}})$$

$$= 103.499 \times 1848 \times (80)$$

$$= 15300051.84 \text{ joules}$$

### 3.2.6 Heat transfer calculations

This can be calculated using the formula:

$$Q = U \times A \times \Delta T \dots\dots\dots 3.4$$

Where:

Q = Rate of heat transfer (in watts, w, where 1w = 1j/s)

U = Overall heat transfer coefficient (in w/m<sup>2</sup>°C)

A = Surface area of the heat exchanger or heating element in contact with the palm oil (in m<sup>2</sup>)

ΔT = The temperature difference between the heating medium (e.g. steam or hot water) and the palm oil (in °C)

$$Q = \frac{\text{Energy Required (J)}}{\text{Time (s)}} \dots\dots\dots 3.5$$

$$= \frac{15300051.84}{2 \times 3600}$$

$$= 2125.01 \text{ watts (W)}$$

**Temperature difference (ΔT)**

This temperature difference drives the heat transfer process and is critical for determining the efficiency and effectiveness of the heating system.

For direct heating (if the heating medium is directly mixed with in contact with the CPO as in this case,

$$\Delta T = T_{\text{medium}} - \left( \frac{T_{\text{final}} + T_{\text{initial}}}{2} \right) \dots\dots\dots 3.6$$

Where:

$T_{\text{initial}}$  = Starting temperature of the CPO

$T_{\text{final}}$  = Temperature after heating

$T_{\text{medium}}$  = The temperature of the heating medium which needs to be higher than  $T_{\text{final}}$ .

$$\Delta T = 100^{\circ}\text{C} - \left( \frac{10^{\circ}\text{C} + 90^{\circ}\text{C}}{2} \right)$$

$$\Delta T = 100^{\circ}\text{C} - 50^{\circ}\text{C}$$

$$\Delta T = 50^{\circ}\text{C}$$

**Surface area (A)**

$$A = \frac{Q}{U\Delta T} \dots\dots\dots 3.7$$

Where  $U = 250\text{w}/\text{m}^2\text{C}$

$$A = \frac{2125}{250 \times 50}$$

$$A = 0.17\text{m}^2$$

### 3.2.7 Determination of settling time

The settling velocity ( $v$ ) of particles was estimated using Stoke's law, which is applicable to small, spherical particles under laminar flow conditions. The formula is given by:

$$V = \frac{2gr^2(e_p - e_f)}{9\mu} \dots\dots\dots 3.8$$

Where:

$V$  = settling velocity (m/s)

$g$  = the acceleration due to gravity ( $9.81\text{m/s}^2$ )

$r$  = the radius of the particle (m)

$e_p$  = the density of the particle (kg/L)

$e_f$  = the density of the fluid ( $\text{kg/m}^3$ )

$\mu$  = the dynamic viscosity of the fluid (pa.s)

$$V = \frac{2 \times 9.81 \times 50^2 (0.928 - 0.890)}{9 \times 0.01}$$

$$= 4.06 \times 10^{-3} \text{ m/s}$$

Settling time can be calculated by:

$$t = \frac{h}{v} \dots\dots\dots 3.9$$

where:

$h$  = the height of the crude palm oil tank

$v$  = the settling velocity

$$t = \frac{548\text{mm}}{4.06 \times 10^{-3} \text{m/s}}$$

$$= \frac{0.548\text{m}}{4.06 \times 10^{-3} \text{m/s}}$$

$$t = 134.97537 \text{seconds}$$

### **3.3 Material Selection requirement for the Clarifier**

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 prior to any calculations. Some of the more important economic factors and physical and mechanical properties that are involved in material and sometimes, process selection are discussed below.

#### **3.3.1 Factors Affecting Materials Selection**

##### **(a) Availability and cost:**

These vary continually for materials, and as the change is toward favorable or unfavorable conditions, designs will necessarily undergo corresponding alterations for economic reasons. In this, efforts had been made to select materials that will eventually make the product affordable since availability is ensured and the cost moderate.

##### **(b) Strength:**

This is an important property of materials used for machine members. Strength, as measured by the ultimate strength, is necessary to prevent failure of the member by rupture.

However, some steels have the desirable property of high ultimate strength coupled with low ductility, which may be undesirable in members subject to stress concentration (Ryder, 1985). To guard against permanent deformation of the member, the elastic limit should be considered in design. For ductile materials, the yield point may be used ordinarily instead of the elastic limit.

**(c) Rigidity:**

This is of importance in members whose deflection is limited. Rigidity depends upon the modulus of elasticity. It should be noted that all steels have practically the same value of the modulus of elasticity. It follows that a change from soft low-strength steel to hard high-strength steel will not materially alter the rigidity of the part.

It may also be noted that a member made of cast iron will generally be more rigid than a member of load carrying ability made of steel, since the larger size required for the cast iron members will more than compensate for its lower modulus of elasticity.

**(d) Resistance to fatigue:**

This should be the basis for the design of members that are subjected to cyclic loading. This property is measured by the endurance limit. If concentration of stress is present in the members, notch sensitivity and damping capacity should also be considered carefully. Controlled heat treatment should be applied to members that are subjected to fatigue in order to avoid harmful surface effects. In some cases, the strength of a member may be increased by grinding off a surface layer after heat treatment.

**(e) Hardness and ductility:**

These are important in many members. In bearing surfaces which have relative motion and which fluid lubrication does not exist, hardness is of importance to limit wear. Ductility is frequently desirable in order to relieve concentration of stress and it is effective in static loading but not in cyclic loading.

**(f) Weight:**

This is important especially in this project work. Lightweight materials like aluminum are used in conjunction with steel to reduce the total weight of the shaft.

**(g) Machinability:**

This is frequently a critical factor, for instance, for parts made by automatic machine tools. Often, an expensive material which is easily machined, is more economical than a lower-priced material which may be difficult to machine.

### **3.4 Parts and Assembly Drawings**

The part list, Assembly drawings, and Part drawings are found at the inner pockets of the back of the report.

### **3.5 Materials used in the fabrication.**

Materials used in the fabrication of the small-scale palm oil clarifier fit for farm use are as follows:

1. Stainless Steel sheet
2. Stainless Steel pipe

3. Bolts and nuts
4. Ball valve
5. Tap

### **3.5.1 Stainless Steel**

Stainless steel is one of the most widely used engineering materials in industrial and food-processing equipment due to its excellent corrosion resistance, mechanical strength, and hygienic properties. It is an iron-based alloy containing a minimum of about 10.5% chromium, which enables the formation of a thin passive oxide layer on the material surface. This chromium-rich passive film protects the metal from oxidation and corrosion by preventing direct contact between the underlying metal and the surrounding environment. As a result, stainless steel exhibits superior durability in environments where moisture, organic compounds, and elevated temperatures are present.

Recent studies have highlighted the importance of stainless steel in food and processing industries. For example, Stefano Rossi and colleagues demonstrated that austenitic stainless steels such as AISI 304 are widely used in food-handling and processing equipment because of their strong corrosion resistance, hygienic surface properties, and cost-effectiveness in industrial operations (Rossi et al., 2024). These characteristics make stainless steel particularly suitable for applications involving heated liquids and organic materials such as palm oil processing systems.

In addition to corrosion resistance, stainless steel also possesses favorable mechanical and thermal properties. The material has high tensile strength, good ductility, and the ability to retain its structural integrity under moderately high temperatures. These properties allow stainless steel components to withstand operational stresses and thermal cycling during industrial processes. Furthermore, advances in surface engineering and coating technologies have been shown to enhance the wear resistance and corrosion performance of stainless steel, improving its long-term reliability in demanding industrial environments (Singh et al., 2024).

Due to these characteristics, stainless steel has become the material of choice for many types of processing equipment, including storage tanks, piping systems, and clarification units used in agro-processing industries.

### **3.5.2 General properties of Stainless Steels**

Exhibiting a broad spectrum of strength and hardness, it also boasts high ductility, formability, high corrosion resistance, good creep resistance, good thermal conductivity, good machinability, and good weld ability.

### **3.5.3 Why Stainless Steel Was Used**

In this project, **AISI 304H stainless steel** was selected for the fabrication of the improved palm oil clarifier due to its superior combination of corrosion resistance, mechanical strength, thermal stability, and hygienic properties. Stainless steel grade 304H is a high-carbon modification of the conventional AISI 304 stainless steel and is specifically

designed to provide improved creep strength and structural stability at elevated temperatures. These characteristics make it particularly suitable for equipment operating under thermal conditions, such as heating vessels and processing units used in agro-industrial applications.

During palm oil clarification, the processing equipment is exposed to a mixture of oil, water, organic residues, and elevated temperatures. Such operating conditions can accelerate corrosion and material degradation in conventional carbon steels, leading to contamination of the processed oil and a reduction in equipment lifespan. Stainless steel provides an effective solution to this challenge because of the presence of chromium in its composition, which forms a thin passive oxide layer on the surface of the material. This protective film continuously regenerates when damaged, thereby preventing further oxidation and allowing the material to maintain its corrosion resistance even in aggressive chemical environments. Studies on stainless steels used in food-processing environments have shown that austenitic grades such as AISI 304 exhibit excellent resistance to corrosion caused by moisture, organic compounds, and industrial cleaning agents (Rossi et al., 2024).

Another important factor influencing the choice of stainless steel is its hygienic surface structure. Stainless steel surfaces are smooth and non-porous, which minimizes product adhesion and microbial accumulation. This property is particularly important in food and agro-processing equipment where contamination must be minimized in order to maintain product quality and safety standards.

From a mechanical standpoint, AISI 304H stainless steel possesses favorable strength characteristics that enable it to withstand operational stresses during equipment operation. The material has a tensile strength of approximately **515 MPa** and a yield strength of about **205 MPa**, allowing it to resist deformation under load (Rossi et al., 2024). It also exhibits a **melting temperature range of approximately 1398–1454 °C**, indicating its ability to maintain structural integrity under high thermal conditions. Furthermore, stainless steel 304H can operate continuously at temperatures approaching **870 °C** without significant loss of mechanical performance, making it suitable for processing systems involving heated fluids and repeated thermal cycles.

In addition to its mechanical and thermal properties, AISI 304H stainless steel also possesses favorable physical characteristics that support its application in processing equipment. The material has a density of approximately **8.0 g/cm<sup>3</sup>**, which provides adequate structural rigidity while maintaining manageable fabrication weight. Its **thermal conductivity of about 16.2 W/m·K at 100 °C** allows efficient heat transfer and distribution within the clarifier vessel, thereby promoting uniform heating during the palm oil clarification process.

Stainless steel also offers excellent fabrication properties, including good weldability and formability. These characteristics allow the material to be easily shaped into various components such as cylindrical tanks, conical settling chambers, and piping systems required in the construction of clarification equipment. These fabrication advantages enable the production of durable and leak-proof processing units capable of operating under continuous industrial conditions.

Although stainless steel has a higher initial cost compared with mild steel, its long service life and reduced maintenance requirements make it economically advantageous over time. Its resistance to corrosion significantly reduces repair costs and equipment downtime, thereby improving operational efficiency.

Therefore, the use of **AISI 304H stainless steel** in the fabrication of the improved palm oil clarifier provides a reliable, hygienic, and durable material solution that supports efficient and safe palm oil processing operations.

### **3.6 Manufacturing process**

The various components of the small-scale palm oil clarifier were constructed and fabricated using the following procedures:

#### **3.6.2 Fire Chamber**

**Material:** 304H stainless steel sheet. **Dimensions:** Diameter: 600 mm Height: 500 mm

**Fabrication procedure:** A 3 mm thick stainless steel sheet was cut and rolled to form a cylinder. A diagonal cut was created at the top to produce the inclined mating surface. This was achieved by marking the cylinder at two diametrically opposite points measured from the top rim: the lowest cut height of 10 mm on one side and the highest cut height of 100 mm on the opposite side. The sheet was cut along the straight line connecting these marked points and the edge was dressed smooth. The difference in height across the diameter created the required inclined to surface for proper alignment when stacked with the settling tank. The fire chamber was then welded to the base of the clarifier body.

### **3.6.3 Crude Palm Oil Tank**

This is the compartment where the Crude Palm Oil and water is poured and set to boil after which more water can be added with the aid of the stirrer rod. Solid impurities called sludge will settle to the bottom of the tank leaving an almost pure palm oil at the top which will then flow through cuts made to the settling tank

**Material:** 304H stainless steel sheet.

**Dimensions:** Diameter: 500 mm, Height: 700 mm

**Fabrication procedure:** A 3 mm thick stainless steel sheet was cut to the developed length and width, rolled into a cylinder, and welded to form the tank. A diagonal cut was introduced at the base by marking the lowest cut height of 10 mm and the highest cut height of 100 mm from the bottom edge across the diameter. The cylinder was cut along the marked straight line and the edge finished smooth. The height difference between the lowest and highest points produced the inclined base surface. The crude oil tank was welded onto the settling tank, ensuring the inclined surfaces aligned properly for gravity drainage and stable stacking. . A 20 mm diameter opening was provided at the base and rod of 20mm with a valve attached was welded to the hole for sludge outlet

### **3.6.4 Settling Tank**

This is the compartment where the boiled palm oil settles

**Material:** 304H stainless steel sheet.

**Dimensions:** Diameter: 600 mm, Height: 600 mm

**Fabrication procedure:** A 3 mm thick stainless steel sheet was rolled and welded to form the cylindrical settling tank. A diagonal cut was made at the base using the same height-difference method: the lowest point was marked at 10 mm and the highest point at 100 mm from the bottom edge across the diameter. The cylinder was cut along the connecting straight line and the edge was smoothed. This height differential created the inclined base required for effective sludge collection and alignment with the fire chamber below. A 20 mm diameter opening was provided at the base and rod of 20mm with a valve attached was welded to the hole for sludge outlet. A second opening was created so the outlet rod from the CPO tank will pass through.

### 3.6.5 Dryer

This is the compartment where the pure palm oil is harvested from. The dryer with the aid of heat from the chimney helps to remove water to make the palm oil have a long storage time.

**Material:** The material used is Stainless steel (304H).

**Dimension:** Height: 220mm, Diameter: 200mm

**Fabrication procedure:** A 3mm thick sheet metal was cut to a length and width of 628mm by 220mm. It was rolled with a plate rolling machine and then welded to form a cylinder with a height of 220mm and a diameter of 200mm. A 3mm thick sheet metal was cut to two pieces to have a diameter of 200mm which was then welded to the top and bottom of the

cylinder. A 20mm hole was cut-out at 50mm from the top of the dryer and a ball valve was welded to it to serve as the pure palm oil outlet.

### **3.6.6 Chimney**

This is a vertical pipe which conducts smoke and combustion gases up from the fire chamber.

**Material:** The material used is Stainless steel pipe.

**Dimension:** Diameter: 100mm, Height: 830mm

**Fabrication procedure:** A hole of diameter 100mm was cut-out at 180mm from the bottom of the fire chamber. This was then extended to a height of 830mm with the use of 17 bolt and nut.

### **3.6.7 Stirrer Rod**

This is an agitation mechanism used to stir the mixture of CPO and water, it can also be used to add water to the mixture and get it to the height at which the almost pure palm oil will flow from the Crude Oil Tank to the Settling Tank

**Material:** The material used is Stainless steel pipe.

**Dimension:** Diameter: 40mm, Height: 680mm

**Fabrication procedure:** A cylindrical rod of 40mm diameter and 680mm height was cut and a metal funnel of appropriate size was attached to it.

## **CHAPTER 4**

### **PERFORMANCE TESTING, RESULTS AND DISCUSSION**

#### **4.1 Performance Evaluation**

To assess the operational effectiveness of the fabricated small-scale palm oil clarifier, a series of performance tests were conducted to quantify the oil recovery rate and evaluate the consistency of the clarification process. The tests were carried out on 1st and 3rd November 2025 using crude palm oil (CPO) obtained from a digester screw press. The performance evaluation methodology adopted in this study followed a similar approach to that employed by Njeshu et al. (2025), wherein prototype clarifiers are assessed based on measurable output parameters including oil yield, clarification efficiency, and process repeatability.

##### **4.1.1 Materials and Equipment Used**

The following materials and equipment were required for the performance evaluation:

1. The fabricated small-scale palm oil clarifier
2. 60 litres of Crude Palm Oil (CPO) sourced from a digester screw press
3. Calibrated measuring jars for volumetric measurement
4. Potable water for dilution and oil level adjustment
5. A detachable funnel for controlled water addition
6. Trained operators familiar with the clarifier's operational procedure

#### **4.1.2 Experimental Procedure**

The performance test was conducted in accordance with the following standardised procedure, developed to ensure reproducibility and accuracy of results across both test runs:

1. The gas cylinder valve was opened and the burner ignited to initiate heating.
2. Water was introduced into the crude oil tank up to approximately 40% of the marked tank capacity.
3. The water was allowed to preheat for a period of 20 to 30 minutes until the target temperature range of 85–90°C was approached.
4. A measured volume of 30 litres of CPO was obtained from the digester screw press and introduced into the crude oil tank.
5. The mixture was allowed to reach boiling point, facilitating initial phase separation between the oil, water, and sludge fractions.
6. Additional water was gradually introduced via the detachable funnel to raise the oil level within the crude oil tank, promoting overflow of the clarified oil into the settling tank through the designated outlet opening.
7. Water addition was carefully controlled to prevent water from entering the settling tank alongside the oil phase.
8. Once all clarified oil had transferred into the settling tank, additional water was introduced via the funnel to raise the oil level sufficiently to flow into the dryer/storage tank.
9. The oil was retained in the dryer/storage tank where residual moisture was removed through the heat conducted via the chimney, improving the oil's storage stability.

10. The recovered oil was then collected and its mass recorded for calculation of the oil recovery rate.

#### 4.1.3 Performance Evaluation Metric

The primary metric used to evaluate the performance of the clarifier was the **Oil Recovery Rate (ORR)**, defined as the ratio of the actual oil yield obtained from the clarifier to the potential oil content of the fresh fruit bunches (FFB) processed, expressed as a percentage. This is consistent with the evaluation approach used in comparable small-scale clarifier studies (Njeshu et al., 2025). The Oil Recovery Rate was calculated using the following expression:

$$\text{Oil Recovery Rate (\%)} = (\text{Actual Oil Yield} / \text{Potential Oil Content}) \times 100\%$$

The results of both test runs are presented in Table 4.1 below.

**Table 4.1: Performance Test Result**

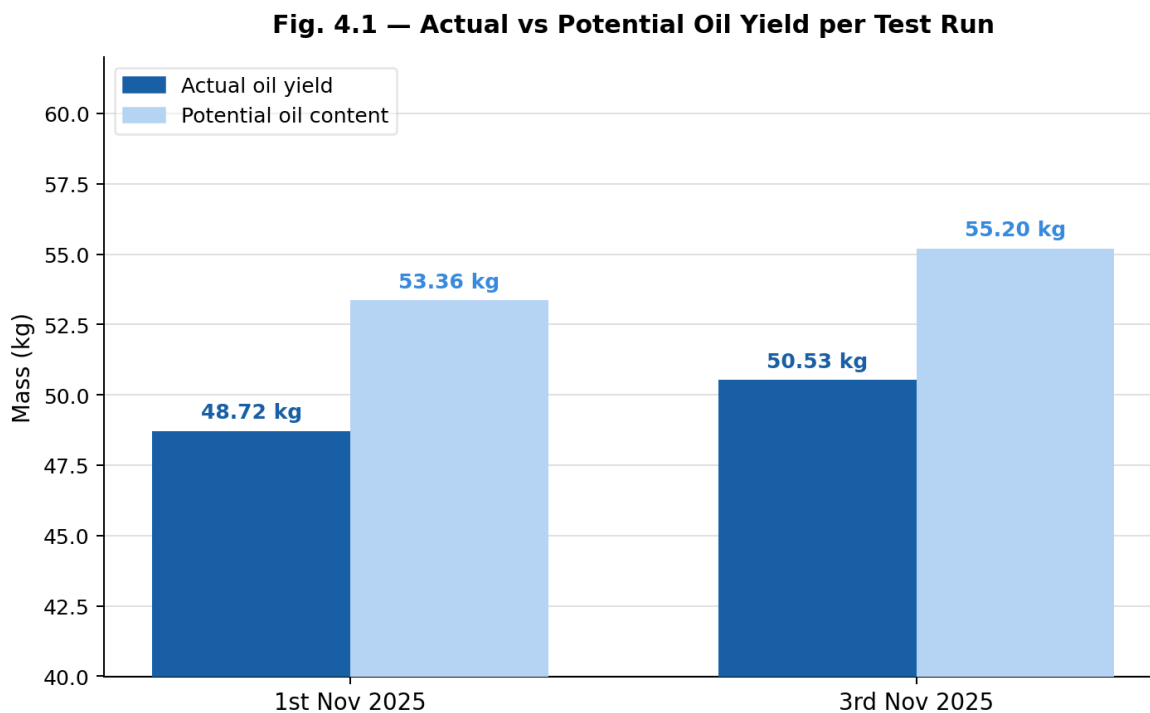
<b>DATE</b>	<b>MASS OF FFB PROCESSED (Kg)</b>	<b>ACTUAL OIL YIELD (Kg)</b>	<b>POTENTIAL OIL CONTENT (Kg)</b>
1 <sup>st</sup> November 2025	232	48.72	53.36
3 <sup>rd</sup> November 2025	240	50.53	55.20

The Oil Recovery Rate was then calculated by comparing the actual oil yield with the potential oil content of the FFB.

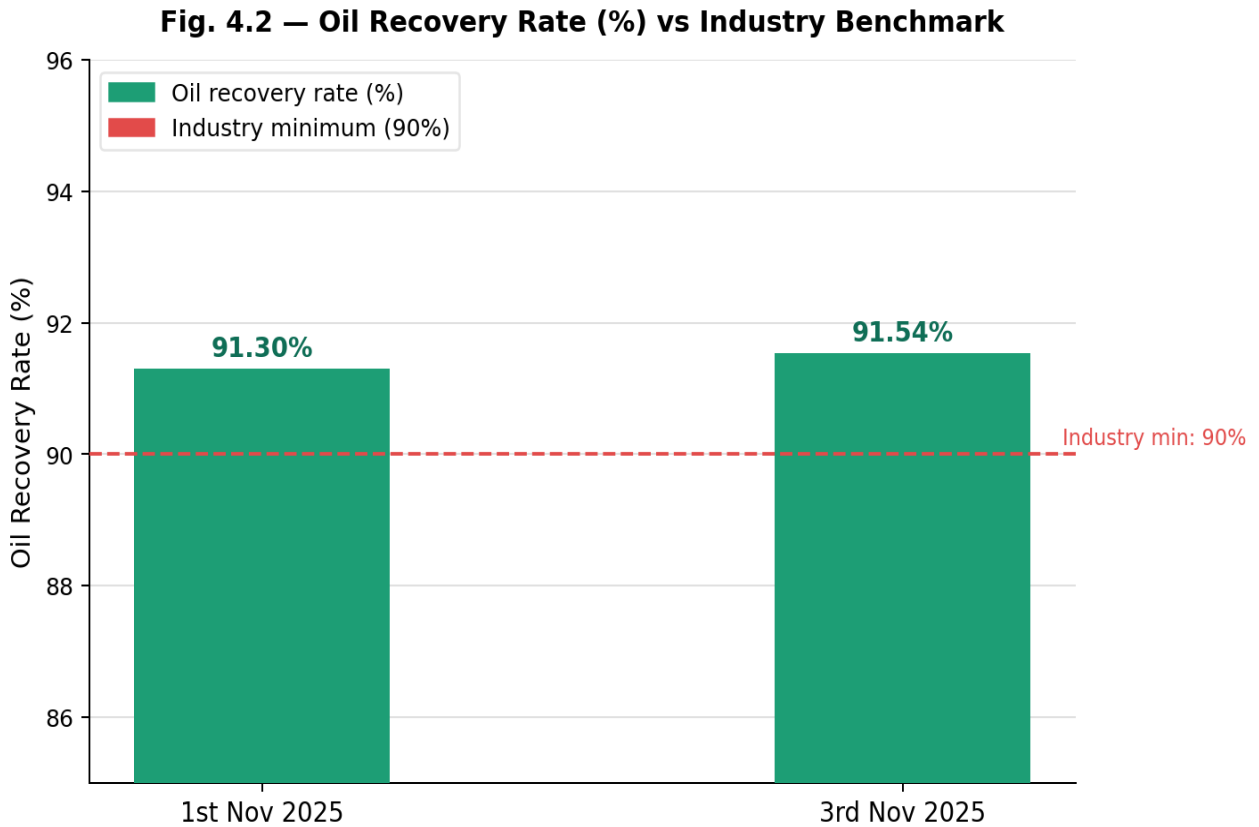
$$\text{Oil Recovery Rate (\%)} = \frac{\text{Actual oil yield}}{\text{potential oil yield}} \times 100\%$$

$$\text{Oil Recovery Rate (\%)} \text{ for 1<sup>st</sup> November 2025} = \frac{48.72}{53.36} \times 100\% = 91.30\%$$

$$\text{Oil Recovery Rate (\%)} \text{ for 3<sup>rd</sup> November 2025} = \frac{50.53}{55.20} \times 100\% = 91.54\%$$



**Fig. 4.1 Actual vs Potential Oil Yield per Test Run (kg)**



**Fig. 4.2 Oil Recovery Rate (%) Compared to Industry Benchmark**

#### **4.2 Discussion of Results**

The performance evaluation of the fabricated small-scale palm oil clarifier yielded oil recovery rates of 91.30% and 91.54% for the first and second test runs conducted on 1st and 3rd November 2025, respectively. These results demonstrate a high and consistent level of clarification efficiency, affirming the effectiveness of the design in separating crude palm oil from water and sludge under controlled thermal conditions.

The recovery rates obtained in this study compare favourably with those reported in similar works. Njeshu et al. (2025) reported a clarifier efficiency of 74.24% and an oil extraction rate of 16.33% for a two-chamber prototype clarifier tested at 85°C with a dilution ratio of 1:2. The superior recovery rates recorded in the present study may be attributed to the higher operating temperature range of 85–90°C employed during testing, the integrated dryer component which facilitated moisture removal, and the conical tank geometry which promoted efficient sludge settlement and minimised oil entrapment in the sludge phase.

The marginal difference between the two test runs (91.30% vs. 91.54%) indicates a high degree of operational consistency and process repeatability, which is an important indicator of the reliability of the fabricated equipment. Such consistency is critical for small-scale processors who require predictable output across multiple processing batches. Processing losses among small-scale processors in Africa can reach as high as 15% of total crude palm oil production (Njeshu et al., 2025), and the results of this study demonstrate that the developed clarifier is capable of substantially reducing such losses.

The recovered oil recovery rates of approximately 91% are also comparable to typical performance benchmarks for larger, more automated industrial clarification systems, which generally target recovery rates in the range of 90–95%. This suggests that the design objectives of the project to develop an affordable, efficient, and operable small-scale clarifier have been successfully achieved. The use of 304H stainless steel for the wetted components, combined with the gas-fired heating system, ensured stable thermal

performance throughout both test runs, maintaining the oil-water mixture within the optimal clarification temperature range.

These findings confirm that appropriate engineering design, when adapted to the constraints and material availability of rural processing environments, can yield performance outcomes that are competitive with more capital-intensive systems. The clarifier therefore presents a technically viable and economically accessible solution for small-scale palm oil processors in Nigeria and similar agricultural communities across sub-Saharan Africa.

### 4.3 Bills of Engineering Quantity

#### 4.3.1 Material Cost

A market survey was first carried out to determine the cost of materials required for the fabrication of a small-scale palm oil clarifier fit for farm use. The estimated prices are listed in the table 4.2 below

**Table 4.2 Material Cost**

S/N	DESCRIPTION	DIMENSION	UNIT	UNIT PRICE (₦)	TOTAL (₦)
1	Stainless Steel Sheet	3000 × 1500× 3mm	1	790,000	790,000
2	Stainless Steel Pipe	100 × 900× 7mm	1	50,000	50,000
3	Bolts and Nuts	17mm	4	2,000	8,000
4	Ball Valve	2 inch	3	10,000	30,000
5	Tap		1	3,000	3,000
6	Stainless Steel Welding Electrode	2.5mm	4	17,000	68,000
7	Burner		1	23,000	23,000
	Total Cost				972,000

### 4.3.2 Fabrication Cost

The Fabrication Cost is the cost of the process such as supervision, welding, plate rolling.

The table 4.3 below gives an estimate of the various cost incurred during the fabrication process.

**Table 4.3 Fabrication cost**

S/N	OPERATION	COST(₦)
1	Welding	45,000
2	Supervision	5,000
3	Plate Rolling	10,000
Total		60,000

### 4.3.3 Procurement Cost

Miscellaneous expenditure and other services such as transportation cost which cannot be determined directly will be listed under this heading. The procurement cost is listed in the table 4.4 below:

**Table 4.4 Procurement Cost**

S/N	DESCRIPTION	COST(₦)
1	Transport	30,000
2	Miscellaneous	25,000
3	Crude Palm Oil (CPO)	50,000
Total		105,000

**Bill of quantity = material cost + fabrication cost + procurement cost**

**=972,000+60, 000+105,000**

**= N1, 137,000**

In summary, it cost one million, one hundred and thirty-seven thousand naira (N1, 137,000) only to produce the small-scale palm oil clarifier.

## **CHAPTER FIVE CONCLUSION AND RECOMMENDATIONS**

### **5.1 Conclusion**

The aim of this project was to design and fabricate a small-scale palm oil clarifier suitable for farm-level use, with emphasis on affordability, ease of operation, and high oil recovery efficiency. This aim was successfully achieved through a systematic approach that encompassed design analysis, material selection, fabrication, and performance testing.

All five project objectives were met. Existing clarification technologies were evaluated and their limitations at the small-scale level identified. A compact clarifier unit incorporating a multi-chamber configuration was designed and fabricated using 304H stainless steel, selected for its superior corrosion resistance, thermal stability, and hygienic properties. A gas-fired heating system was integrated to maintain the optimal clarification temperature range of 85–90°C, and the design was validated through controlled performance tests.

Performance testing conducted on 1st and 3rd November 2025 yielded oil recovery rates of 91.30% and 91.54% respectively, which are consistent with industry benchmarks of 90–95% typically achieved by larger automated systems. These results represent a significant improvement over conventional small-scale settling methods and compare favourably with similar prototype clarifiers reported in the literature, such as the 74.24% efficiency recorded by Njeshu et al. (2025). The total fabrication cost of ₦1,137,000 demonstrates that high-performance clarification equipment can be produced at an accessible cost for small-scale processors.

In conclusion, the fabricated clarifier presents a technically sound, durable, and economically viable solution for improving palm oil processing outcomes at the rural and cooperative level, thereby contributing to enhanced livelihoods and agricultural productivity in Nigeria.

## **5.2 Recommendation**

The results from the performance test of the small-scale palm oil clarifier fit for farm use showing rates of 91.30% and 91.54% are quite promising. However, there are always opportunities to refine and improve the process. Here are some recommendations for further works which will increase cost of producing it but will enhance the efficiency of the palm oil. The following specific recommendations are proposed

1. Install sensors and automated control systems to precisely control temperature; time and other critical parameters, leading to more consistent results.
2. Enhance clarifier design to include features like better heat distribution systems, more efficient skimming mechanism, or optimized feed inlets and outlets.

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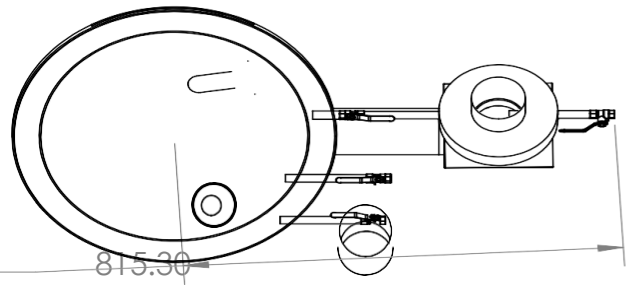
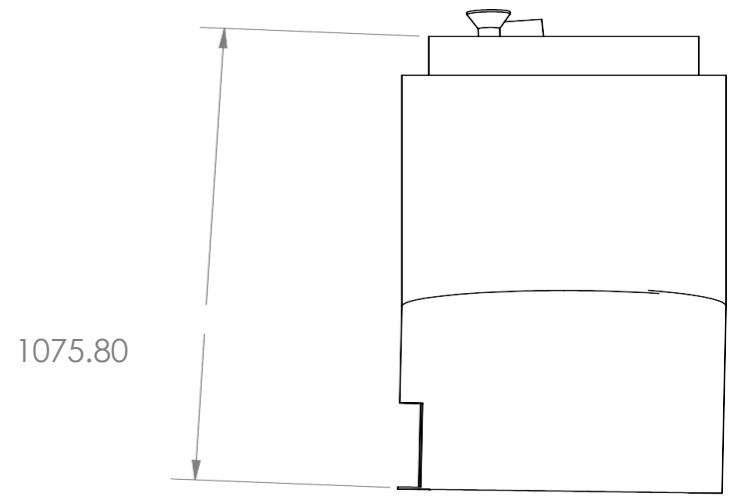
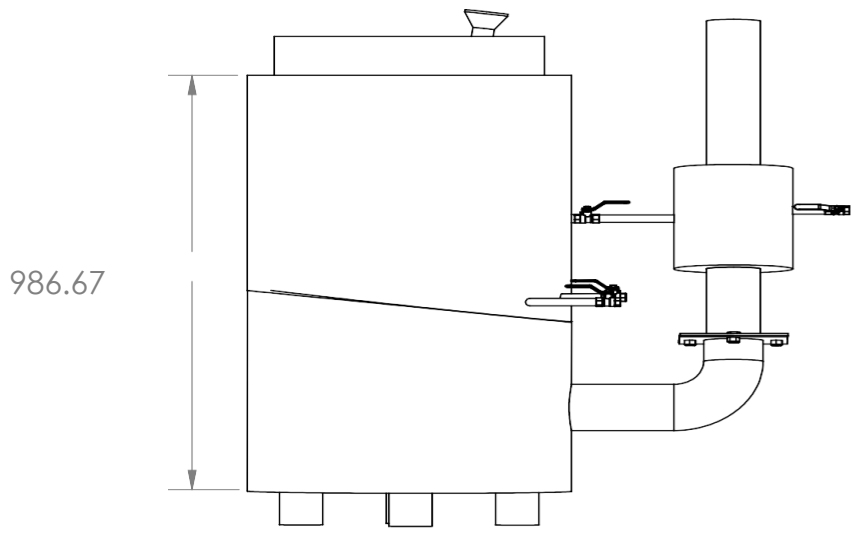
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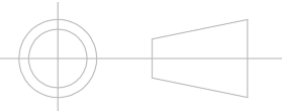
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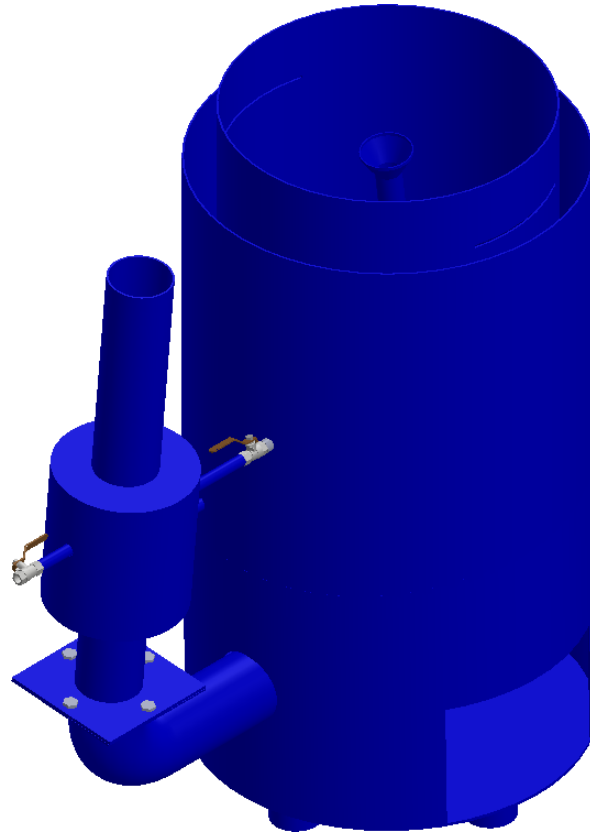
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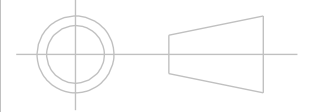


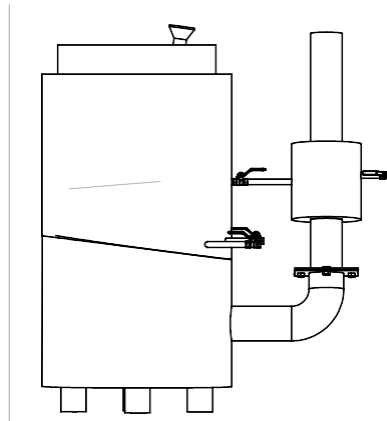
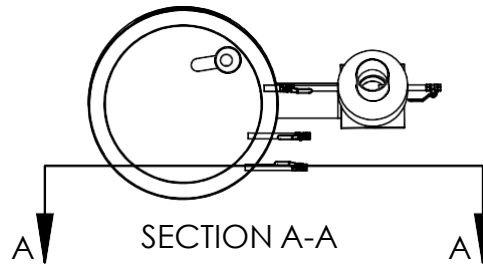
**ORTHOGRAPHIC PROJECTION**

Department of Agricultural, Industrial and Production Engineering, Faculty of Engineering, University of Benin, Benin City.	<b>PROJECT TITLE:</b> Design and Fabrication of an Improved Palm Oil Clarifier	<b>DESIGNED BY</b> Odeh Martins Idemudia Isoken Imoukhuede Benedict Osalpolor Marvellous Emmanuella Oghosa Emaku Peter	<b>CHECKED BY:</b> ENGR. DR. O. I. IHENYEN	<b>DRAWING NAME:</b> ORTHOGRAPHIC	<b>SCALE:</b> 1:14	<b>DATE:</b> 10-NOV-2025	 SHEET: 1
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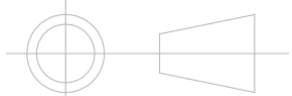


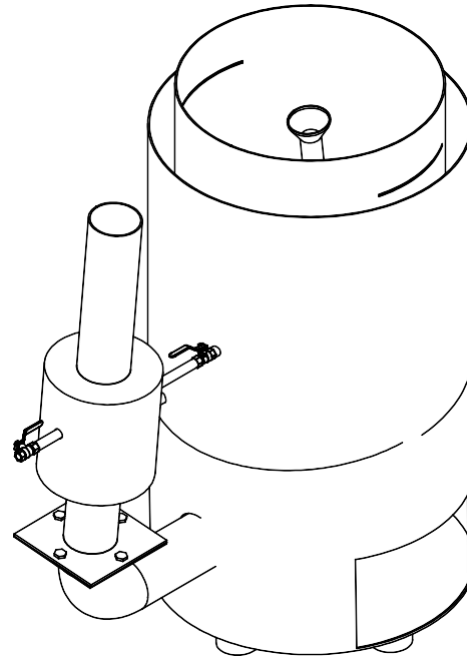
### RENDERED VIEW

Department of Agricultural, Industrial and Production Engineering, Faculty of Engineering, University of Benin, Benin City.	PROJECT TITLE: Design and Fabrication of an Improved Palm Oil Clarifier	DESIGNED BY Odeh Martins Idemudia Isoken Imoukhuede Benedict Osalpolor Marvellous Emmanuella Oghosa Emaku Peter	CHECKED BY: ENGR. DR. O. I. IHENYEN	DRAWING NAME: Rendered	SCALE: 1:14	DATE: 10-NOV-2025	
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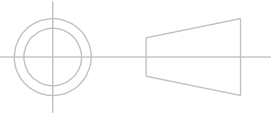


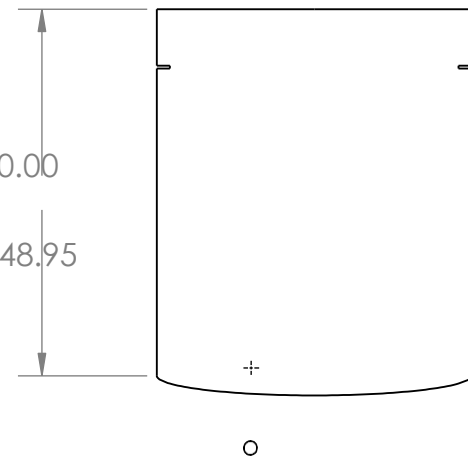
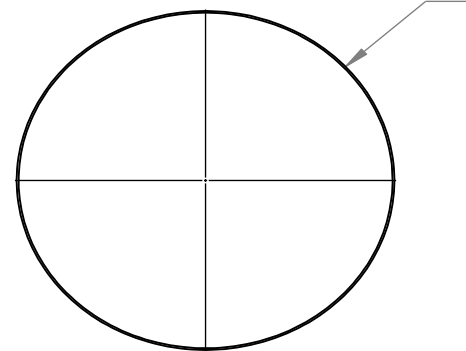
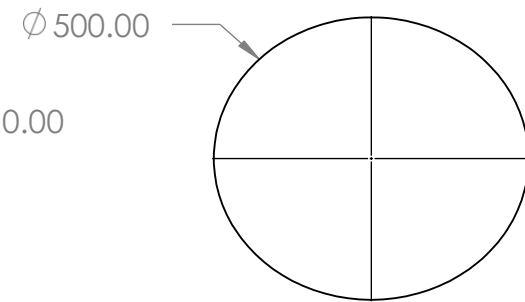
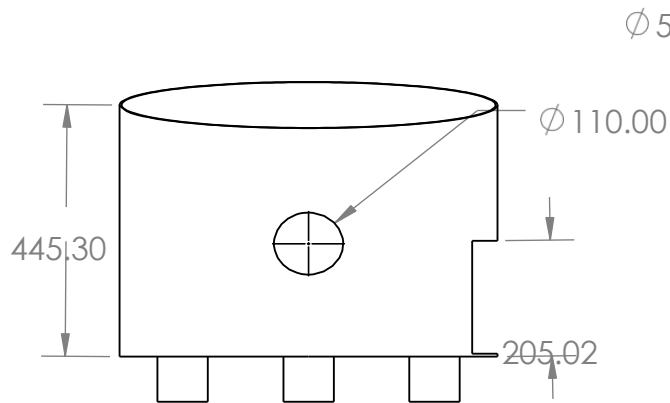
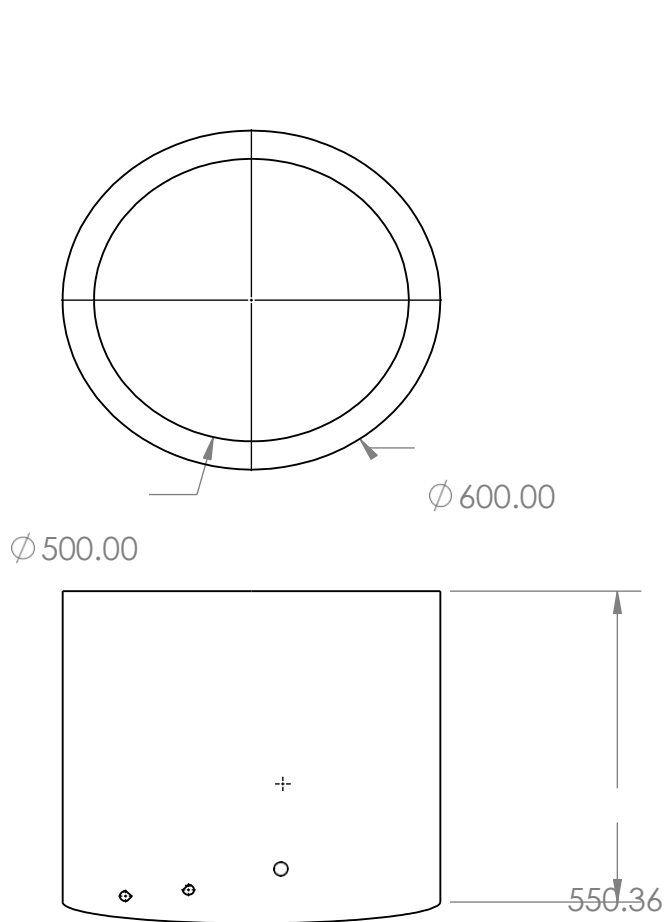
**SECTION A-A**

Department of Agricultural, Industrial and Production Engineering, Faculty of Engineering, University of Benin, Benin City.	<b>PROJECT TITLE:</b> Design and Fabrication of an Improved Palm Oil Clarifier	<b>DESIGNED BY</b> Odeh Martins Idemudia Isoken Imoukhuede Benedict Osalpolor Marvellous Emmanuella Oghosa Emaku Peter	<b>CHECKED BY:</b> ENGR. DR. O. I. IHENYEN	<b>DRAWING NAME:</b> Section Left View	<b>SCALE</b> : 1:14	<b>DATE:</b> 10-NOV-2025	 SHEET: 3
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### ISOMETRIC VIEW

Department of Agricultural, Industrial and Production Engineering, Faculty of Engineering, University of Benin, Benin City.	<b>PROJECT TITLE:</b> Design and Fabrication of an  Improved Palm Oil  Clarifier	<b>DESIGNED BY</b> Odeh Martins Idemudia Isoken Imoukhuede Benedict Osalpolor Marvellous Emmanuella Oghosa Emaku Peter	<b>CHECKED</b> BY: ENGR. DR. O. I. IHENYEN	<b>DRAWING NAME:</b> Isometric View	<b>SCALE</b> : 1:14	<b>DATE:</b> 10-NOV-2025	  SHEET: 4
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**Settling Tank Detail**

**Fire Chamber Detail**

**Crude Palm Oil Tank Detail**

Department of  
Agricultural, Industrial  
and Production  
Engineering, Faculty of  
Engineering, University  
of Benin, Benin City.

**PROJECT TITLE:**  
Design and  
Fabrication of an  
Improved Palm Oil  
Clarifier

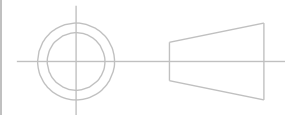
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Idemudia Isoken  
Imoukhuede Benedict  
Osalpolor Marvellous  
Emmanuella Oghosa  
Emaku Peter

**CHECKED**  
BY: ENGR.  
DR. O. I.  
IHENYEN

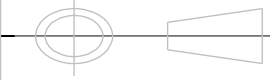
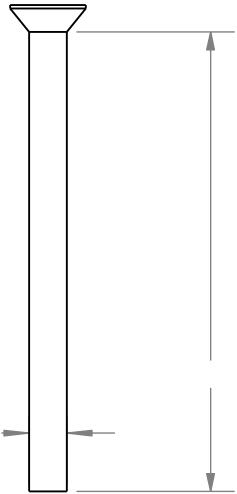
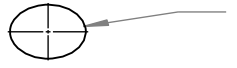
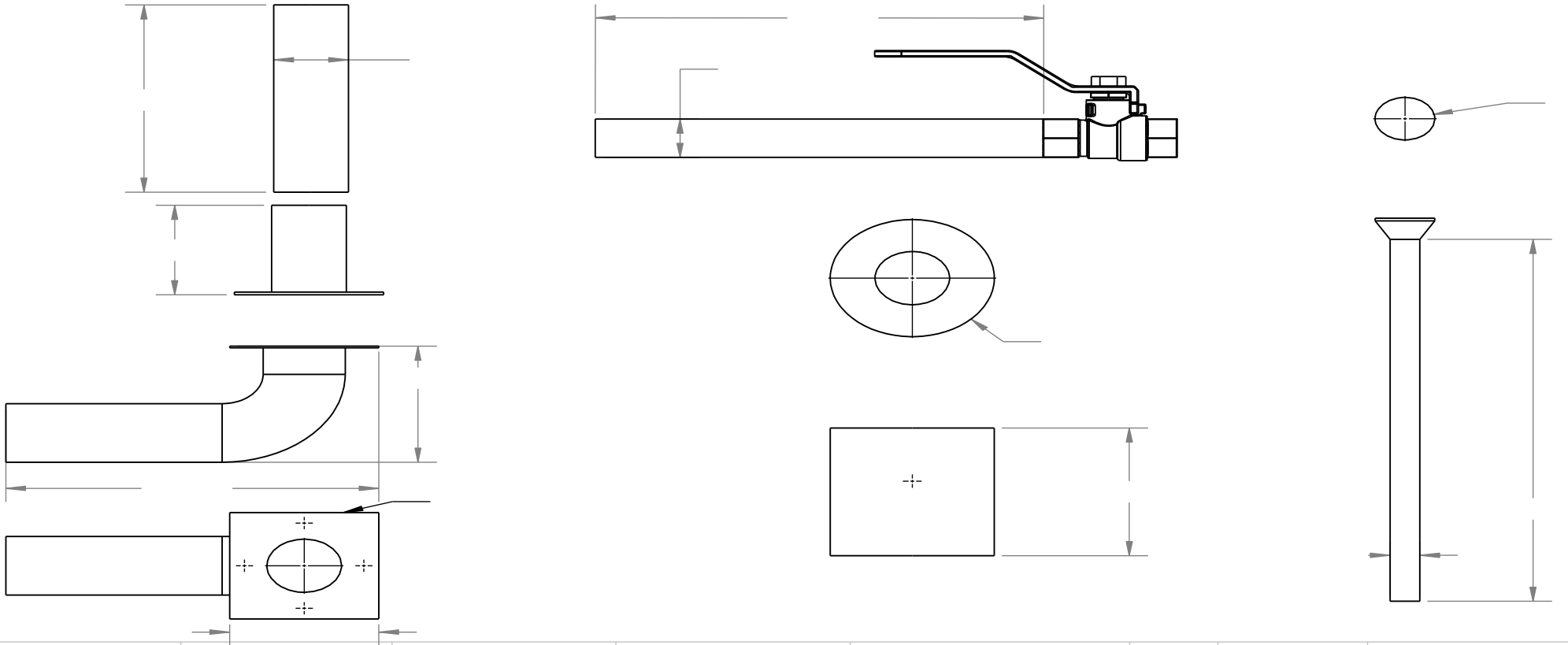
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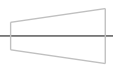
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10-NOV-2025



SHEET: 5



Department of Agricultural, Industrial and Production Engineering, Faculty of Engineering, University of Benin, Benin City.	<b>PROJECT TITLE:</b> Design and Fabrication of an Improved Palm Oil Clarifier	<b>DESIGNED BY</b> Odeh Martins Idemudia Isoken Imoukhuede Benedict Osalpolor Marvellous Emmanuella Oghosa Emaku Peter	<b>CHECKED BY:</b> ENGR. DR. O. I. IHENYEN	<b>DRAWING NAME:</b> Part Diagram	<b>SCALE:</b> N.T.S	<b>DATE:</b> 10-NOV-2025	  SHEET: 6
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