DESIGN AND FABRICATION OF AN IMPROVED CLARIFIER FOR PALM OIL PROCESSING

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CERTIFICATION

This is to certify that this project was carried out by IDEMUDIA ISOKEN EMMANUEL of the Department of Production Engineering, Faculty of Engineering, University of Benin, Benin City, Edo state. For the award of Bachelor of Engineering (B.ENG), under the supervision of Engr. Dr. O. I. Ihenyen.

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DEDICATION

I dedicate this project to God Almighty for His divine guidance in all my academic endeavours. I also extend my heartfelt appreciation to my Parents Mr. Egbe and Mrs. Joy Idemudia 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. Egbe and Mrs. Joy Idemudia, 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 Mrs. Comfort Omogbeme, Mr murphy Omogbeme and his wife Mrs Ruth Omogbeme and My Uncle Chief Matthew Onyenye I appreciate you all for your support. I also want to appreciate my special group of friends, Gold, Blessed, Ochuwa 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. And to every other person not mentioned I say a very big thank you

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The global edible oil market is a multi-billion-dollar industry, with palm oil dominating a significant share due to its high yield per hectare, versatility, and economic viability. Originating from West Africa, the oil palm (Elaeis guineensis) has become a staple crop in tropical regions worldwide, particularly in Southeast Asia, which now accounts for the largest share of global production. However, West Africa, especially Nigeria, remains a significant producer, with oil palm cultivation deeply embedded in its agricultural heritage and rural economy.

The production of palm oil in Africa dates back to the pre-industrial revolution era and before the advent of colonization in the continent. During this period, the oil was traditionally produced by the use of rudimentary tools. Palm oil is utilized in a variety of goods, including packaged goods, fast food, and cosmetics (Kavuma & Barakagira,2024). Nigeria, a country richly endowed with vast oil palm plantations, holds a significant historical position a major producer and exporter of palm oil with oil palm being the major export before the crude oil boom, Nigeria was the world's largest producer (Ajani et al, 2012; Greenpeace, 2012) but today it's production accounts for less than 2% of global total while up to 90 percent of global production occurs in South-East Asia alone, in Indonesia, Malaysia and Thailand.(Institute for Public Policy Analysis (IPPA), 2010; Ofosu-Budu and Sarpong, 2013).

Despite the historical success of the oil palm industry in Nigeria, the sector is still facing a lot of problems with one of the main issues being the level of the processing technology that is till rudimentary, tedious and inefficient especially at small scale production level. To address these issues my group come to a conclusion that the design and fabrication of an improved clarifier for small scale palm oil production as the viable solution. The design of the machine is such that it solves one of the problems in the most critical stages of the oil palm production process (The clarification stage), the problem being the low quality of the end product.

The project focuses on the design and fabrication of an improved clarifier for small scale oil palm production which would be powered by diesel, specifically tailored to meet the needs of small scale farmers who lack access to top level oil palm technology.

1.2 Problem Statement:

In Nigeria predominantly in small and medium scale oil palm processing outfits, there is a continuous reliance on inefficient, labour-intensive and time consuming clarification methods that result in low-quality crude palm oil. Consequently, local producers are unable to consistently meet domestic and international standards, limiting their competitiveness, income generation, and overall development of the local palm oil chain.

1.3 Aim and Objectives:

1.3.1 Aim:

To design and fabricate a cost-effective, efficient, and user-friendly clarifier for palm oil processing that significantly improves the quality and yield of palm oil for small and medium-scale processing facilities.

1.3.2 Objectives:

1. To conduct a thorough literature review on existing palm oil clarification technologies, relevant separation principles (e.g., centrifugal, sedimentation, filtration), and material science suitable for food-grade applications to inform optimal design parameters.

(Specific, Measurable – through comprehensive review report, Achievable, Relevant, Time-bound – by end of initial research phase).

2. To conceptualize and design the machine's components (e.g., separation chamber, heating system, inlet/outlet mechanisms, sludge removal system) and overall architecture using Computer-Aided Design (CAD) software, ensuring ease of operation, maintenance, and scalability. (Specific, Measurable – CAD models and technical drawings, Achievable, Relevant, Time-bound – by end of design phase).
3. To select appropriate, locally available, and food-grade materials (e.g., stainless steel for contact parts, mild steel for frame) and cost-effective manufacturing processes (e.g., welding, cutting, bending) that ensure durability, hygiene, and affordability of the clarifier. (Specific, Measurable – material specification list, Achievable, Relevant, Time-bound – integrated with design phase).
4. To fabricate the individual components of the clarifier according to the designed specifications and assemble the machine, adhering to safety standards and engineering best practices. (Specific, Measurable – functional prototype, Achievable, Relevant, Time-bound – by end of fabrication phase).
5. To test and evaluate the machine's performance against key design specifications, specifically measuring the reduction in moisture content, suspended solids, and oil loss in the effluent, while also assessing throughput and operational stability using actual crude palm oil samples. (Specific, Measurable – quantitative performance data against defined metrics, Achievable, Relevant, Time-bound – during testing phase).

1.4 Scope of the Project:

This project focuses on the design and fabrication of a pilot-scale improved clarifier for crude palm oil (CPO), specifically targeting the separation of oil from water and suspended solid impurities. The scope includes:

1. **Design**: Conceptualization, detailed engineering design, and simulation of the clarifier's main components including the oil-water-sludge separation chamber, heating system for viscosity reduction, CPO inlet, purified oil outlet, and sludge/water outlet. The design will prioritize simplicity, ease of manufacturing, energy efficiency, and user safety.
2. **Fabrication**: Construction of a functional prototype of the clarifier using readily available materials and manufacturing techniques within the local context. This involves material procurement, cutting, welding, assembly, and finishing.
3. **Functionality**: The machine will be designed to process pre-pressed crude palm oil to reduce its moisture content and suspended solid impurities to acceptable levels for enhanced quality and extended shelf life.
4. **Operational Parameters**: The design will account for typical operational parameters such as CPO temperature (e.g., 80-95°C), flow rate, and residence time to optimize separation efficiency.
5. **Performance Evaluation**: Testing will focus on quantifying the reduction in moisture and suspended solids in the clarified oil, as well as estimating oil losses in the discharged effluent. Throughput capacity will also be evaluated.

1.5 Significance of the Project:

The "Design and Fabrication of an Improved Clarifier for Palm Oil Processing" project holds substantial significance across several dimensions:

1.5.1 Economic Significance:

1. Increased Income for Processors: By significantly improving palm oil quality (lower moisture, less impurities) and increasing oil recovery (reduced losses in sludge), local small and medium-scale processors can command higher prices for their product and increase their overall yield. This directly translates to enhanced profitability and better livelihoods.
2. Reduced Operational Costs: While initial investment is required, the improved efficiency and reduced losses can lead to a lower effective cost per liter of oil produced compared to inefficient traditional methods, improving cost-effectiveness for local businesses.
3. Market Competitiveness: Higher quality palm oil allows local producers to compete more effectively with industrially processed oil, potentially opening up new market opportunities and reducing reliance on imports.
4. Job Creation: The adoption of improved technology can stimulate local manufacturing and maintenance capabilities, creating skilled and semi-skilled jobs in design, fabrication, installation, and repair.

1.5.2 Environmental Significance:

1. Reduced Waste and Pollution: More efficient oil recovery means less oil is lost into the effluent, reducing the environmental burden of palm oil mill effluent (POME), which can be a significant pollutant if not properly treated.
2. Sustainable Resource Utilization: Maximizing oil extraction from the palm fruit contributes to more sustainable use of agricultural resources.
3. Technological Significance:

4. Innovation in Local Manufacturing: This project demonstrates the feasibility of designing and fabricating effective agricultural processing machinery using local expertise and resources, fostering a culture of innovation and self-reliance in engineering.
5. Knowledge Transfer: The project serves as a practical application of engineering principles, providing valuable experience in design, fabrication, and performance testing, which can be transferred to future projects and benefit subsequent generations of engineers.
6. Foundation for Future Development: The successful design and fabrication of this clarifier can serve as a prototype and a benchmark for the development of other locally appropriate agricultural processing technologies, stimulating further research and development in the sector

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of Palm Oil Processing and the Role of Clarification

Palm oil, extracted from the mesocarp of the oil palm fruit (Elaeis guineensis), is one of the most widely consumed vegetable oils globally, renowned for its versatility in both food and non-food industries (Basiron, 2007). The processing of Fresh Fruit Bunches (FFB) into crude palm oil (CPO) involves a series of sequential operations: sterilization, threshing, digestion, pressing, clarification, and purification (Ohimain et al., 2012). Among these stages, clarification is a critical step that directly influences the quality, market value, and shelf life of the final palm oil product.

Crude palm oil, as it emerges from the pressing stage, is not pure oil. It is typically a complex emulsion comprising approximately 30-50% water, 1-5% suspended solids (e.g., fiber, sand, dirt, non-oil solids), and the remaining percentage being oil (Chong, 1980; Bakar et al., 2008). The presence of these impurities, particularly water and suspended solids, significantly compromises the oil's quality. High moisture content promotes hydrolysis, leading to increased Free Fatty Acid (FFA) levels and accelerated rancidity, while suspended solids can cause sedimentation, equipment fouling, and undesirable appearance (Ohimain et al., 2013a). The primary objective of clarification, therefore, is to separate the oil from these non-oil components, thereby enhancing its purity, stability, and suitability for further refining or direct consumption.

2.2 Principles of Separation in Palm Oil Clarification

The separation of oil from water and solids in CPO is fundamentally based on differences in density. Palm oil has a lower density (approximately 0.9 kg/L) than water (1.0 kg/L) and most suspended solids, which are denser than water. This density differential forms the basis for various separation technologies. Effective clarification is often enhanced by reducing the viscosity of the CPO, which facilitates the movement of oil droplets through the aqueous phase and the settling of solids. Heating the CPO to temperatures typically between 85-95°C is a common practice to achieve this viscosity reduction and to break down the oil-in-water emulsion (MPOB, 2010; Abang Zaidel et al., 2017).

Several principles are employed in clarifier design:

2.2.1 Gravity Settling (Sedimentation and Creaming)

Gravity settling is the most basic and widely applied principle, particularly in small-scale palm oil processing. When CPO is held quiescently, denser particles and water settle due to gravity (sedimentation), while lighter oil droplets rise to the surface (creaming). The rate of settling or creaming is governed by Stokes' Law, which states that the terminal velocity of a particle in a fluid is directly proportional to the square of its diameter and the density difference between the particle and the fluid, and inversely proportional to the fluid's viscosity (Geankoplis, 2003). In the context of palm oil, heat is applied to reduce the viscosity of the CPO, thereby increasing the settling/creaming velocities. Prolonged retention time in settling tanks allows for more complete separation.

2.2.3 Centrifugal Separation

Centrifugal separation accelerates the gravitational process by subjecting the fluid mixture to a high centrifugal force, which can be thousands of times greater than gravity. This enhanced force significantly reduces the time required for separation and achieves a higher degree of purity (Coulson & Richardson's Chemical Engineering Volume 2 1999). This principle is employed in decanters (for solid-liquid separation) and disk stack centrifuges (for liquid-liquid and fine solid separation). Industrial palm oil mills extensively use centrifuges for high-efficiency clarification and sludge separation (MPOB, 2010).

2.2.4 Filtration

Filtration involves passing the CPO through a porous medium to physically remove suspended solid particles. Filter presses, vibrating screens, and more advanced membrane technologies fall under this category. While effective for solids removal, filtration alone is often insufficient for separating emulsified water (Kemper & Nienaber, 2004).

2.2.5 Emulsion Breaking

CPO often forms a stable oil-in-water emulsion due to the presence of surface-active agents (e.g., phospholipids, proteins) and fine solids. Breaking this emulsion is crucial for efficient clarification. Methods include:

1. **Heating**: Reduces viscosity and kinetic energy of oil droplets, allowing them to coalesce.
2. **Dilution with hot water**: Increases the density difference between oil and the continuous phase, and washes away some impurities.
3. **Chemical demulsifiers**: Though less common in raw palm oil clarification, specific chemicals can destabilize emulsions.

2.3 Existing Palm Oil Clarification Technologies and Their Limitations

2.3.1 Traditional and Artisanal Methods

In many palm oil-producing regions, particularly among smallholder farmers and small-scale processors in Nigeria, traditional clarification methods are still prevalent. These often involve:

1. **Open Tank Settling and Skimming**: CPO is heated in large open tanks, typically over an open fire, and allowed to settle for several hours or overnight. The clear oil layer is then manually skimmed off the top.

Limitations:

1. **Low Efficiency and High Oil Loss**: Incomplete separation due to the slow gravitational process and stable emulsions. Significant amounts of oil remain entrapped in the sludge and wastewater (Ohimain et al., 2012; Izah & Ohimain, 2013). Oil losses can be as high as 10-15%.
2. **Poor Product Quality**: High residual moisture and impurities (e.g., sand, fiber) in the clarified oil, leading to high FFA development, reduced shelf life, and inferior appearance (Agbaire, 2012). This limits market access and value.
3. **Time and Labour Intensive**: Requires long settling times (hours to days) and manual labour for skimming, reducing overall throughput.
4. **Hygiene Issues**: Open tanks are susceptible to contamination from dust, insects, and other environmental factors.
5. **Energy Inefficiency**: Direct heating methods can be inefficient and lead to localized burning of oil, affecting quality.

2.3.3 Semi-Mechanized and Small-Scale Improvements

Attempts to improve traditional methods have led to the development of semi-mechanized clarifiers for small-scale operations. These often incorporate features like:

1. **Improved Settling Tanks with Heating Coils**: Tanks with indirect heating systems (e.g., steam coils) offer better temperature control and prevent localized burning.
2. **Multi-Chambered Clarifiers**: Some designs feature multiple compartments for sequential settling or a combination of settling and screening to improve separation efficiency. Research has shown that even simple two-chamber prototype clarifiers can achieve significant efficiency improvements. A prototype developed by ResearchGate (2025) achieved a clarifier efficiency of 74.24% at 85°C.
3. **Manual/Mechanical Skimmers**: More refined skimming mechanisms can improve oil recovery compared to crude manual methods.

While these improvements offer marginal advantages, they often still suffer from low throughput, reliance on extended settling times, and incomplete removal of fine impurities compared to industrial standards.

2.3.4 Industrial-Scale Clarification Systems

Large commercial palm oil mills employ sophisticated and highly efficient clarification systems:

1. **Continuous Clarifiers/Settling Tanks**: These are often large, heated tanks (typically at 90-95°C) designed for continuous flow, allowing for the gravitational separation of oil, water, and sludge. They are often equipped with automatic skimming devices and sludge discharge systems. While offering continuous operation, they still rely on density differences and can have significant footprints.

2. **Centrifugal Separators**: As discussed in Section 3.2.2, centrifugal purifiers (disk stack centrifuges) are widely used for polishing the CPO, significantly reducing moisture and suspended solids to meet stringent quality specifications (e.g., moisture $< 0.25\%$, impurities $< 0.01\%$). They offer high throughput and superior separation.

2.3.5 Limitations for Small-Scale Processors:

The primary barrier to adoption of centrifugal clarifiers for small and medium-scale processors is their exorbitant capital cost, high energy consumption, complex operational requirements, and the need for specialized maintenance and spare parts. This makes them economically unfeasible for most local Nigerian processors.

1. **Vacuum Dryers**: Often used in conjunction with centrifuges, vacuum dryers reduce the moisture content of palm oil to very low levels (e.g., $< 0.1\%$) by evaporating water under vacuum, preventing oxidation and enhancing shelf life.

Limitations: High capital and operational costs, suitable only for large-scale operations.

1. **Membrane Filtration**: Emerging technologies involve the use of microfiltration (MF), ultrafiltration (UF), and nanofiltration (NF) membranes for palm oil clarification, particularly for treating palm oil mill effluent (POME) and potentially for direct oil purification.

Limitations: High initial cost of membranes, susceptibility to fouling by oil and solids, and technical complexity still limit their widespread application in primary CPO clarification, especially for small-scale operations.

2.4 Factors Affecting Palm Oil Quality Post-Press

Several factors, particularly those related to the clarification stage, significantly influence the final quality of palm oil:

1. **Moisture Content**: High moisture content promotes enzymatic hydrolysis (catalyzed by lipases) and microbial activity, leading to rapid increase in FFA, which is a key indicator of oil degradation (Agbaire, 2012). It also affects storage stability.
2. **Impurities (Suspended Solids)**: Fibers, sand, and other particulate matter contribute to a higher impurity level, which can cause sedimentation during storage, affect appearance, and foul downstream processing equipment.
3. **Free Fatty Acid (FFA) Content**: FFA is formed by the hydrolysis of triglycerides. While some FFA can form due to bruising of fresh fruit bunches and delayed processing, significant increases often occur during inefficient clarification and storage due to high moisture and presence of lipases (Ohimain et al., 2012a; Okechalu et al., 2011). Lower FFA is indicative of higher quality oil.
4. **Temperature during Clarification**: Optimal temperature (85-95°C) is crucial. Too low a temperature results in high viscosity and poor separation, while excessively high temperatures or prolonged heating can lead to oil degradation (oxidation, burning) and increased FFA.
5. **Residence Time**: Sufficient residence time in the clarifier is essential for effective separation based on gravitational principles. Insufficient time leads to incomplete separation.
6. **Emulsion Stability**: The stability of the oil-water emulsion in CPO dictates the difficulty of separation. Factors like the presence of phospholipids, proteins, and fine particles contribute to emulsion stability (Choo et al., 1996).

2.5 The Nigerian Palm Oil Sector: Challenges and Opportunities

Historically, Nigeria was a leading global producer and exporter of palm oil (Helleiner, 1966; Konfrontasi, 2024). However, its position has significantly declined, largely due to neglect of smallholder farmers, aging plantations, and insufficient investment in modern processing technologies. Today, Nigeria is a net importer of palm oil, despite having vast suitable land for cultivation.

A significant portion (around 80%) of Nigeria's palm oil production comes from dispersed smallholder farmers and artisanal processors. These producers face a multitude of challenges:

1. **Inefficient Processing Facilities**: Outdated and rudimentary processing equipment, particularly for clarification, leads to low oil extraction rates and poor overall efficiency.
2. **Low Product Quality**: The poor quality of CPO from traditional methods hinders market access and reduces competitiveness.
3. **Post-harvest Losses**: Significant losses occur at various stages, including during inefficient clarification, leading to reduced income.
4. **Limited Access to Modern Technology**: The high cost and complexity of industrial machinery make them inaccessible to small and medium-scale processors.
5. **Lack of Capital and Credit**: Limited financial resources impede investment in improved technologies.
6. **Inadequate Research and Development**: Insufficient efforts in optimizing infrastructure for value addition have hampered technological advancement.

Despite these challenges, there is immense potential for economic development and rural empowerment in the Nigerian palm oil sector. Studies have shown that increased use of modern processing methods by processors can lead to a significant increase in net returns. Improved processing efficiency, particularly in clarification, can directly translate to improved livelihoods for farmers and processors, leading to poverty alleviation and enhanced food security.

2.6 Gaps in Existing Literature and the Need for This Project

While extensive research exists on large-scale industrial palm oil clarification systems and the principles of separation, there remains a significant gap in the literature and practical application regarding affordable, efficient, and locally sustainable clarification solutions specifically designed for small and medium-scale palm oil processors in developing countries like Nigeria. Many studies highlight the limitations of traditional methods and the unaffordability of industrial ones, but fewer provide detailed design and fabrication methodologies for appropriate intermediate technologies that address this specific need.

CHAPTER THREE

METHODOLOGY

3.1 Consideration

We considered a small-scale farmer who cultivates Tenera specie of palm tree on a plot of farmland measuring 50ft by 100ft. It is estimated that the famer 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

Existing small-scale clarifiers and its critical components were examined along with their mode of operations. A sketch of the small-scale palm oil clarifier was made as shown in figure 3.1 below, detailed design analysis was carried out for all the critical components, and a working drawing (detailed, parts, and exploded) was generated.

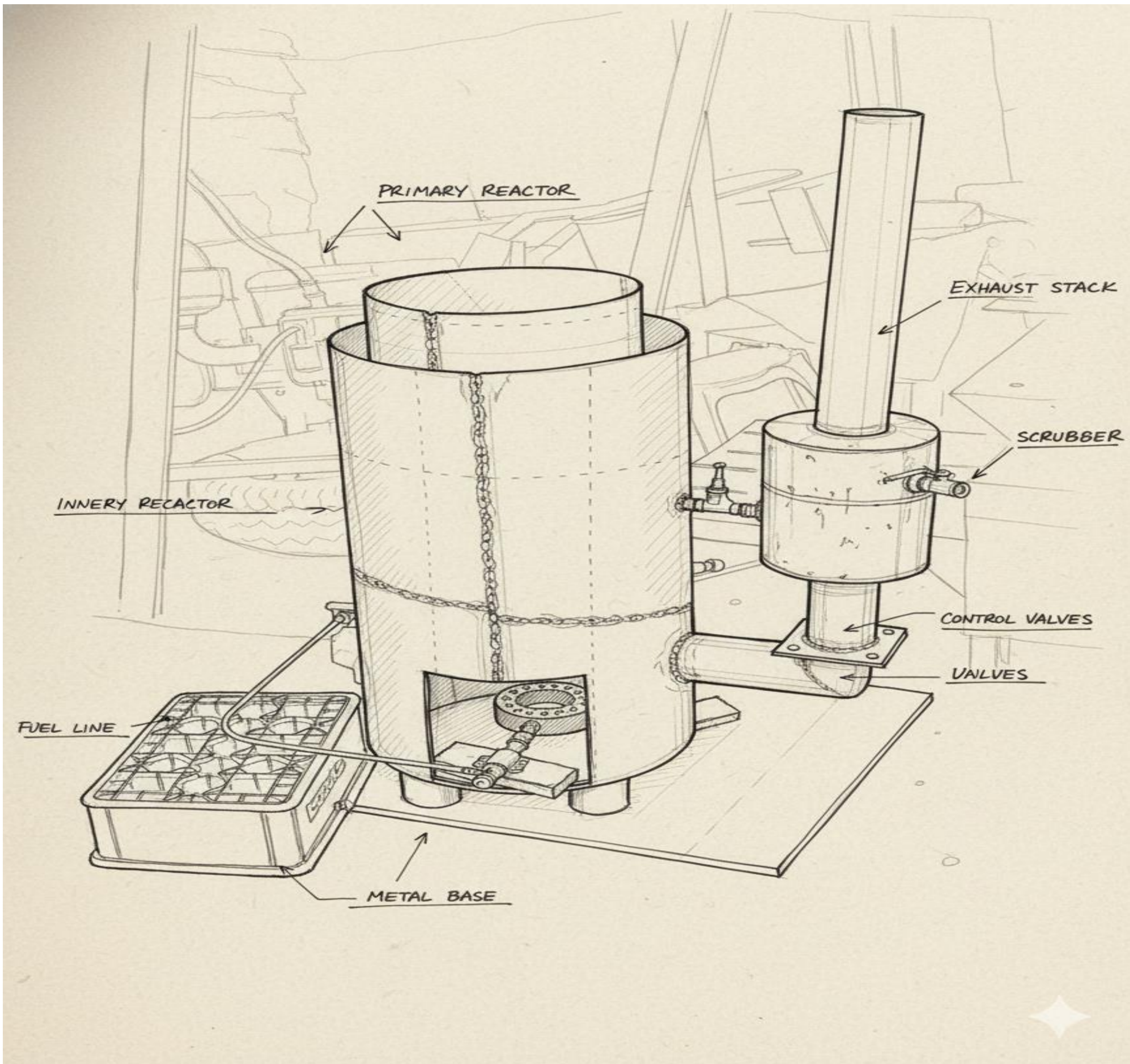

FIG 3.1 Isometric Drawing of the Small Scale Clarifier

3.2.1 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 clarifiers size, the heating requirements, settling time and separation efficiency.

3.2.1.1 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:

Volume of oil = Weight of FFB × OER× (1÷Density of palm oil) ……………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 × 0.23 × (1 ÷ 0.89) = 155.056 Litres

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.

Vt = Vcpo + (Vcpo + %ws) ……………3.2

Where:

Vt = Total volume per day

Vcpo = Volume of crude palm oil, 155.056

%ws = Percentage of water and sludge, 25%

Vt = 155.056 + (155.056 × 0.25)

Vt = 193.82 litres

3.2.3 Determination of the clarifier capacity

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

Number of batches per day = 2 batches

Volume per batch = 193.82 litres = 96.91 litre

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:

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.

Clarifier Design: The shape of the tank (e.g. cylindrical, rectangular) might affect the settling process. A wider base facilitates faster settling.

Total volume needed for processing and separation already calculated (96.91 litres per batch)

Required volume of CO and sludge/water separation = 96.91 litres per batch

Additional safety margin = 20%

$= 96.91 \times (1 \div 0.2)$

$= 96.91 \times 1.2$

= 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 VCPO = 116.292 litres

Initial temperature of CPO (T initial) = 20°C

Final temperature of CPO (T final) = 90°C

Density of CPO (ρ) = 0.89kg/L

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

Converting volume to mass

$$\text{Density} = \frac{\text{mass}}{\text{Volume}} \quad \ldots\ldots\ldots\ldots\ldots\ldots 3.3$$

Mass (m) = V × p

= 116.292 Litre × 0.89kg/L

=103.499kg

The energy required can then be calculated using the formula:

Q= m x c× (T final - T initial)

= 103.499 x 1848 × (80)

= 15301292.16 joules

3.2.6 Heat transfer calculations

This can be calculated using the formula:

$Q = U \times A \times \Delta T$……………………………….3.4

Where:

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

U= Overall heat transfer coefficient (in w/m2°C)

A = Surface area of the heat exchanger or heating element in contact with the palm oil (in m2)

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

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

$= \frac{15301292.16}{2 \times 3600}$

= 2125.18 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,

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

Where:

T initial = Starting temperature of the CPO

T final = Temperature after heating

T medium = The temperature of the heating medium which needs to be higher than T final.

$\Delta T = 100°C - \left(\frac{20°C+90°C}{2}\right)$

ΔT = 100°C - 55°C

ΔT= 45°C

Surface area (A)

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

Where U= 250w/ m2°C

$A = \frac{2125}{250 \times 45}$

A = 0.19m2

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:

$V = \frac{2gr^2(e\rho - ef)}{9\mu}$…………………………..3.8

Where:

V= settling velocity (m/s)

g = the acceleration due to gravity (9.81m/s2)

r = the radius of the particle (m)

eρ = the density of the particle (kg/L)

ef = the density of the fluid (kg/m3)

μ= 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 x10m/s

Settling time can be calculated by:

$$t = \frac{h}{v} \text{.................................3.9}$$

where:

h = The height of the crude palm oil tank

v = The settling velocity

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

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

t = 134.97537seconds

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 is discussed below.

3.3.1 Factors Affecting Materials Selection

(a) Availability and cost:

These vary continually for materials, and as the change is toward favourable or unfavourable 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 member's 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 aluminium is 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:

Stainless Steel sheet

Stainless Steel pipe

Bolts and nuts

Ball valve

Tap

3.5.1 Stainless steel

Stainless steel is a corrosion and heat resistant iron-based alloy. Stainless steel properties include durability, a high level of hygiene, easy maintenance and aesthetic qualities. Consequently, it's an important metal for many industries, particularly construction, medical, food and manufacturing.

In comparison with aluminium, stainless steel is approximately three times heavier. It's completely (and infinitely) recyclable making it the green material of choice, particularly in meeting the sustainability requirements of the construction industry.

Stainless steel composition varies according to its intended use. Like steel itself, it's an alloy which always consists of different materials. For example, a minimum of 11% chromium is what makes steel corrosion-resistant and, therefore, 'stainless'. There are hundreds of different grades of stainless steel, each covered by national and international standards. These grades refer to the various mechanical and physical properties of stainless steel which are dependent upon the presence of elements such as chromium, nickel, molybdenum, titanium and niobium.

On contact with oxygen, a chromium oxide layer is formed on the surface of the steel. This passive layer protects the steel, giving it the unique ability to repair itself.

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

Stainless steel might have been chosen for certain applications in palm oil production due to factors such as cost-effectiveness, ease of fabrication, and suitability for specific non-corrosive or low-corrosive environments within the facility. Additionally, stainless steel may have been deemed sufficient for certain structural or non-contact components where the added expense of galvanized steel was not justified.

3.6 Manufacturing process

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

3.6.1 Body of the Clarifier

Material: The material used is stainless steel.

Construction:

(I) Dimension:

Height: 853mm

Diameter: 532mm

Fabrication procedure: A 3mm sheet metal was cut to a length and width of 1671mm by 853mm. It was then rolled with the aid of a plate rolling machine and then welded to form a cylinder with a height of 853mm and a diameter of 532mm.

3.6.2 Fire Chamber

This is the component of the clarifier were combustion takes place. By the nature of the design and expected performance, the fire chamber has to be moderately large enough to supply heat to the various parts of the clarifier.

Material: The material used is Stainless steel.

Construction:

(I) Dimensions:

diameter = 450mm

height = 304mm

(II) Fabrication procedure:

A 3mm thick sheet metal was cut to have a diameter of 532mm. This was then welded to a height of 304mm from the base of the body of the clarifier.

3.6.3 Crude oil tank

This is the compartment were water and crude palm oil is poured to boil. Soli impurities called sludge will settle to the bottom of the tank leaving an almost pure palm oil at the top which will then flow to the settling tank.

Material: The material used for the fire chamber is stainless steel.

Construction

(I) Dimension:

Height: 548mm

Diameter: 400mm

(II) Fabrication procedure:

A 3mm thick sheet metal was cut to a length and width of 1236 by 548mm, it was then rolled with a plate rolling machine and then welded to form a cylinder with a height of 548mm and diameter of 400mm. The cylinder was welded to the top of the fire chamber. A hole of diameter 51mm was cut-out at 498mm from the top of the tank and a 2-inch valve was welded to it to for sludge outlet.

3.6.4 Settling tank

This is the compartment where the boiled palm oil settles.

Material: The material used for the settling tank is mild steel.

Construction:

(I) Dimensions

Height: 448mm

Diameter: 132mm from the outer diameter of the crude oil tank.

(II) Fabrication procedure:

A 50mm diameter hole was cut out at 398mm from the top of the setting tank and a 2-inch valve was welded to the hole for sludge outlet.

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 mild steel.

Construction

(I) Dimension:

Height: 220mm

Diameter: 200mm

(II) 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 50mm 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.

Construction

(I) Dimension:

Diameter: 100mm

Height: 830mm

(II) 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.

CHAPTER FOUR

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 Njẹshu 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’s 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 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: 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 (Njẹshu et al., 2025). The Oil Recovery Rate was calculated using the following expression:

Oil Recovery Rate (%) = (Actual Oil Yield / Potential Oil Content) × 100%

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

Table 4.1: Performance Test Result

DATE	MASS OF FFB PROCESSED (Kg)	ACTUAL OIL YIELD (Kg)	POTENTIAL OIL CONTENET (Kg)
1st November 2025	232	48.72	53.36
3rd 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.

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

Oil Recovery Rate (%) for 1st April 2025 $= \frac{48.72}{55.36} \times 100\%$ = 91.30%

Oil Recovery Rate (%) for 3rd April 2025 $= \frac{50.53}{55.20} \times 100\%$ = 91.54%

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. Njẹshu 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 (Njẹshu 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

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

S/N	DESCRIPTION	DIMENSION	QUANTITY	UNIT PRICE (₦)	TOTAL COST (₦)
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				972,000

Table 4.2 Material cost

The cost of fabrication 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.

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

Table 4.3 Fabrication Cost

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	CPO	50,000
	Total	105,000

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

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

= N1,137,000

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 Njẹshu 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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