

**EFFECT OF BLENDING RATIO OF JATROPHA BIODIESEL WITH  
FOSSIL DIESEL ON COMPRESSION IGNITION ENGINE**

**BY**

**NSUDE MICHAEL OBINNA**

**ENG1804650**

**DEPARTMENT OF CHEMICAL ENGINEERING**

**FACULTY OF ENGINEERING**

**UNIVERSITY OF BENIN**

**EDO STATE, NIGERIA**

**APRIL, 2024**

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**A PROJECT SUBMITTED TO THE DEPARTMENT OF CHEMICAL  
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## CERTIFICATION

This is to certify that this research project was carried out by **NSUDE MICHAEL OBINNA** with matriculation number **ENG1804650** in the Department of Chemical Engineering, University of Benin, Benin City, Edo State Nigeria.

-----  
Engr. Dr. (Mrs.) E.T. Akhiero  
**Project Supervisor**

-----  
Date

-----  
Engr. Prof. S.E. Uwadiae  
**Project Coordinator**

-----  
Date

-----  
Engr. Dr. (Mrs) E.T. Akhiero  
**Head of Department**

-----  
Date

-----  
**External Examiner**

-----  
**Date**

## **DEDICATION**

This project is dedicated to God Almighty who has made it possible for me to be alive today and also helped me throughout this project, to my dearest supervisor Engr. Dr. (Mrs) E.T. Akhiero for her continuous guidance and support and to my family who have been there for me from the beginning of my education till today.

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I am also grateful to my friends and colleagues who supported and encouraged me throughout this endeavour. Their words of encouragement have been a source of motivation during challenging times.

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This research would not have been possible without the collective efforts of all those mentioned above. While their names may not all be listed here, their contributions are deeply appreciated and will be remembered with gratitude.

## **ABSTRACT**

The aim of this study is to evaluate the effect of blending ratios of Jatropha biodiesel with fossil diesel on compression ignition engines. The main goal is to compare the physical and chemical properties of Jatropha biodiesel and fossil diesel and evaluate engine performance, such as power output, torque, and fuel consumption, for different blend ratios and also examine the emissions characteristics (TVOC, CO, PM) that arise from various blend compositions. Physiochemical analysis confirms the suitability of esterified Jatropha oil for industrial applications. Engine performance tests reveal favourable metrics for biodiesel blends, with varying emissions characteristics across blends. Operational assessment indicates blend-dependent differences in construction time, emissions, and particulate matter. Cost-benefit analysis shows economic feasibility and environmental benefits of Jatropha biodiesel. The optimal blending ratio considering performance, emissions, and economic factors suggested B30 and B40 blends for specialized applications and B10 for general use.

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## CHAPTER ONE

### INTRODUCTION

#### 1.1 Background to the Study

As the world seeks sustainable energy sources to reduce environmental impact and dependence on fossil fuels, the exploration of biodiesel derived from *Jatropha Curcas* Oil as an alternative for compression ignition engines gains significance. Blending *Jatropha* biodiesel with fossil diesel presents a potential solution towards cleaner energy utilization and reduced greenhouse gas emissions in energy utilization (Akhiero, 2022).

The investigation into the effect of blending *Jatropha* biodiesel with fossil diesel on compression ignition engines is a significant endeavor amid the global pursuit for sustainable energy solutions. Access to energy stands as a linchpin for societal development and well-being, intertwining with aspects like education, healthcare, and poverty alleviation, while also ensuring essential services such as clean water, lighting, and communication. However, the overwhelming reliance on fossil fuels as the primary energy source has raised substantial environmental concerns due to the emission of greenhouse gases, contributing significantly to climate change and environmental degradation (Akhabue & Ewah, 2021; Chmielewski, 2014; Chuah *et al.*, 2017; Mansir *et al.*, 2018; Wuebbles & Jain, 2001).

The urgent need to mitigate these environmental impacts and transit towards cleaner, renewable energy sources has spurred interest in biofuels as a viable alternative. Among these alternatives, biofuels derived from biomass, such as *Jatropha* biodiesel, present a promising avenue toward reducing reliance on fossil fuels (Nguyen *et al.*, 2021; Sorda *et al.*, 2010). *Jatropha* biodiesel, obtained from *Jatropha Curcas* Oil, serves as a renewable and potentially abundant source of

bioenergy, offering a feasible solution to the challenges posed by conventional fossil fuels (Osman *et al.*, 2021; Williams *et al.*, 2016).

The significance of biofuels, especially Jatropha biodiesel, lies in their potential to mitigate the environmental impact associated with fossil fuels. When used, biofuels emit carbon dioxide into the atmosphere; however, the subsequent growth of biomass recaptures this CO<sub>2</sub> during its life cycle, effectively balancing overall emissions, thereby presenting a more sustainable alternative to fossil fuels that release underground carbon (Akhabue *et al.*, 2014). These ecological advantages position biofuels as a critical component in the global transition towards renewable energy sources.

Amidst this backdrop, the investigation into the effect of blending ratios of Jatropha biodiesel with fossil diesel on compression ignition engines holds immense importance. The combustion characteristics, emissions profile, and operational suitability of engines are significantly influenced by the blending ratios of biodiesel and fossil diesel (Pritam *et al.*, 2019). Understanding how different blend ratios impact engine performance metrics such as power output, torque, and fuel efficiency is crucial for optimizing the use of biodiesel in compression ignition engines.

Moreover, the study delves into assessing the emissions profile concerning nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO), particulate matter (PM), and unburned hydrocarbons (HC) resulting from varying blend compositions. This comprehensive analysis aids in determining the environmental impact of different blending ratios, shedding light on their potential contribution towards reducing harmful emissions and fostering a more sustainable energy landscape.

Furthermore, the economic feasibility and practicality of utilizing Jatropha biodiesel blends in compression ignition engines need thorough exploration. Evaluating the cost-benefit ratio and market acceptance of different blend compositions is pivotal for gauging the viability and widespread adoption of biodiesel-fossil diesel blends as a feasible alternative in the transportation sector.

In essence, the investigation into the effect of blending ratios of Jatropha biodiesel with fossil diesel on compression ignition engines encompasses multifaceted considerations, spanning environmental impact, engine performance, emissions profile, economic feasibility, and market viability. Such an in-depth analysis is essential in informing stakeholders, policymakers, and researchers about the potential of biodiesel blends and their role in shaping a more sustainable and environmentally conscious future.

## **1.2 Problem Statement**

The optimization of blending ratios between Jatropha biodiesel and fossil diesel for use in compression ignition engines represents a critical research challenge in the quest for sustainable energy solutions. Determining the most effective blend ratio that ensures optimal engine performance, reduced emissions, and economic feasibility while addressing compatibility issues and operational concerns remains a pivotal area of investigation. The need to strike a balance between environmental benefits, engine efficiency, and practical usability necessitates a comprehensive exploration into the impact of varying blend compositions on engine characteristics, emissions profile, and long-term engine durability."

## **1.3 Research Justifications**

1. Investigating the effect of blending Jatropha biodiesel with fossil diesel on compression ignition engines aligns with environmental sustainability goals. Understanding the optimal blend ratios can contribute to reduced greenhouse gas emissions and air

pollutants, aiding in mitigating environmental degradation linked to conventional fossil fuel usage.

2. The exploration of Jatropha biodiesel as a renewable energy source, when blended with fossil diesel, presents an opportunity to optimize available resources. Assessing the feasibility and benefits of utilizing Jatropha biodiesel blends can diversify the energy matrix and reduce dependence on finite fossil fuel reserves.
3. Researching the impact of various blend ratios on compression ignition engines helps in optimizing engine performance. Understanding the most suitable blend ratio for enhanced efficiency, reduced engine wear, and improved combustion characteristics contributes to the advancement of engine technology.

#### **1.4 Aim and Objectives**

##### **Aim**

This research aim to evaluate the effect of blending ratios of Jatropha biodiesel with fossil diesel on the performance of compression ignition engines.

##### **Objectives**

**The specific objective of this research are to;**

1. Characterize Jatropha biodiesel and fossil diesel concerning their physical and chemical properties.
2. Assess engine performance metrics (power output, torque, fuel consumption) across various blend ratios.
3. Analyze the emissions profile (NO<sub>x</sub>, CO, PM, HC) resulting from different blend compositions.

4. Evaluate engine operational suitability and durability under varying blend ratios to ascertain long-term effects.
5. Determine the optimal blend ratio considering performance, emissions, and economic factors.

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

- The focus will be on blending Jatropha biodiesel with fossil diesel in varying ratios.
- Limited to compression ignition engines for performance analysis.
- Evaluation of power output, torque, fuel efficiency, and emissions characteristics.
- Investigating a range of blend ratios to determine optimal performance without compromising engine integrity.

### **1.6 Significance of the Study**

The significance of investigating the impact of blending Jatropha biodiesel with fossil diesel on compression ignition engines lies in its potential to revolutionize the energy landscape. Understanding the optimal blend ratios holds substantial environmental implications, offering a pathway towards reducing harmful emissions and mitigating the adverse effects of conventional fossil fuel combustion. By shedding light on how different blend compositions affect engine performance metrics and emissions profiles, this study aims to pave the way for more sustainable transportation solutions.

Moreover, the research holds economic significance by assessing the viability and market potential of Jatropha biodiesel blends. Insights gleaned from the study can inform policymakers, industry stakeholders, and investors about the economic feasibility of transitioning towards cleaner, renewable energy sources. This knowledge contributes to informed decision-making in resource allocation, fostering market acceptance and driving advancements in sustainable energy practices.

Furthermore, this study's findings carry substantial implications for optimizing engine performance and durability. Identifying the most suitable blend ratios not only aids in enhancing engine efficiency but also contributes to extending the lifespan of compression ignition engines. This aspect is crucial for industries reliant on such engines, ensuring operational reliability while simultaneously aligning with eco-friendly practices.

Ultimately, the study's significance extends beyond the laboratory, offering practical insights into real-world applications and shaping a more sustainable energy future. It aligns with global initiatives aimed at reducing carbon footprints, diversifying energy sources, and fostering a greener, more environmentally conscious society.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 BIODIESEL

The transesterification of vegetable oils or animal fats into biodiesel, also known as fatty acid methyl ester (FAME), demonstrates the production of this fuel with the addition of methanol (Athar & Zaidi, 2020). The liquid's composition and properties are generally similar to those of petroleum-derived diesel when compared to factors like cetane number, energy content, viscosity, and phase transitions. Therefore, when coupled with diesel obtained from petroleum, it can be used without modification in any combustion ignition diesel engine. Due to a variety of unique advantages over petroleum-derived diesel, including as lower greenhouse gas emissions, greater lubricity, and higher cetane ignition ratings, biodiesel is one of the most popular biofuels in the world. Vegetable oils have been used in diesel engines since 1900, when the man who created the engine that bears his name, Rudolf Diesel, displayed peanut oil as fuel at the Paris World Fair. Due to lower prices, greater quality, and government subsidies, diesel made from petroleum remained in use well into the 1920s, nearly eradicating vegetable oils from the market. Due to this, manufacturers changed the diesel engine to use lower viscosity petroleum-derived diesel, making it unable to use vegetable oils (Athar & Zaidi, 2020).

#### 2.2 BIO-OIL

Liquid fuels are primarily referred to as bio-oils. Developed and industrialized nations view bio-oils as crucial technology for a variety of reasons. They cover difficulties with energy security, the environment, preserving foreign currencies, and socioeconomic problems in rural areas. Bio-oils are liquid or gaseous fuels created through biochemical or thermochemical processes from biomass materials such as crops, municipal garbage,

and agricultural and forestry wastes. They can either entirely or partially replace conventional fuels in automobile engines (EC, 2004).

## **2.3 BIODIESEL - A RENEWABLE ENERGY**

Techniques for reducing the viscosity of vegetable oils, such as micro-emulsification, pyrolysis, and mixing, have all been investigated. However, they still contribute to problems like pollution and carbon dioxide ozone deposition (Akhavue & Ogogo, 2018b; Chang *et al.*, 2021). As a result, the transesterification procedure has become the most efficient way to transform vegetable oils for use as fuel in combustion engines (Aghbashlo *et al.*, 2021; Lim & Teong, 2010).

### **2.3.1 HISTORY OF BIODIESEL**

Since the 1800s, the method of transforming biomass feedstock into fuel has not altered. The history of biodiesel is less scientific and more commercial and political. Around the turn of the 20th century, the first gasoline-powered cars debuted. Since they had to refine so much crude oil to make gasoline, oil companies now have a distillate surplus that is far more economical than vegetable oils and great fuel for diesel engines. On the other hand, producers have long looked for new markets for their goods as resource depletion has been a concern. As a result, research into using vegetable oils as fuel has continued. Making biodiesel from vegetable oils is not a novel method.

Transesterification is the process by which vegetable oils and animal fats are converted into mono-alkyl esters or biodiesel. Oil triglyceride transesterification is not a new technological advancement (Athar and Zaidi, 2020). The concept and design of a rational heat engine was the subject of a paper written by eminent German inventor Dr. Rudolph Diesel in 1893. The thesis described a ground-breaking device that would heat up air by

forcing it through a piston at a very high pressure. Dr. Diesel invented the first vegetable oil diesel (Owolabi *et al.*, 2012).

### **2.3.2 SOURCES OF BIODIESEL**

Biodiesel mostly comes from three sources, which are as follows:

- Vegetable Oil
- Animal Fat
- Waste/ Recycle oil

#### **1. VEGETABLE OIL**

Using vegetable oil as feedstock, biodiesel can be produced from either of two sources, which are:

- I. Edible Oil
- II. Non Edible Oil

#### **i. EDIBLE OIL**

Vegetable seeds that people can eat are used to make edible oils. They consist of:

- Almond seed oil
- Babassu oil (*Orbignia* sp.)
- Bay Laurel Oil
- Coconut oil
- *Cynara cardunculus*
- Groundnut oil
- Oat oil
- Pequi oil (*Caryocar* sp.)

- Rice Bran oil
- Poppy seed oil
- Sesame oil
- Sorghum oil
- Wheat, etc.

## ii. NON-EDIBLE OIL

These are derived from plants that aren't suitable for human consumption but have a range of purposes, such as skin moisturizers, medicines, and skin-tone enhancers.

- Andiroba seed oil (*Carapa guianensis*)
- Camelina (*Camelina sativa*)
- Cumaru (*Dipteryx odorata*)
- *Jatropha curcas*
- Karanja (*Pongamia glabra*)
- *Lesquerella fendleri*
- Microalgae (*Chlorella vulgaris*)
- Neem seed Oil
- Rubber seed oil
- Tobacco seed oil, etc.

## 2. ANIMAL FATS

Animal fats include:

- Fish oil
- Pork Lard
- Tallow

## 3. WASTE/ RECYCLE OIL

This source of biodiesel includes waste oil from cooking and also recycled diesel oil. Waste cooking oil (JCO) originates from frying food repeatedly, rendering edible vegetable oil unsuitable for ingestion due to the presence of great amounts of free fatty acids (FFAs). JCO also contributes to a variety of disposal problems worldwide by polluting rivers and obstructing drainage systems, for example. As a result, using JCO as a fuel source might provide a variety of benefits. Making biodiesel from spent cooking oil is therefore one of the more effective and economical techniques to employ while avoiding disposal difficulties. (Nantha Gopal *et al.*, 2014)

### **2.3.3 PROPERTIES OF BIODIESEL**

Vegetable oil and animal fat production cannot currently replace the usage of liquid fossil fuels on a global scale (Silva *et al.*, 2020). Methyl esters of vegetable oils (biodiesels), when compared to other emerging renewable and clean engine fuel sources, have several distinct benefits. When starting with clean vegetable oil, biodiesel is easier to create and cleaner with comparable levels of processing. Due to their high levels of free fatty acids, tallow, lard, and yellow grease biodiesels need further processing after transesterification (Aghbashlo *et al.*, 2021)

#### **2.3.3.1 PHYSICAL PROPERTIES OF BIODIESEL**

- Biodiesel has a viscosity that is comparable to petroleum diesel and is a transparent, amber-yellow liquid.
- Biodiesel is neither flammable nor explosive like Petro diesel since it has a flash point of 423K as compared to 337K for Petro diesel.

- When used as a fuel, biodiesel dramatically decreases harmful and other pollutants while being biodegradable and non-toxic.
- The cost of producing biodiesel is higher than that of petroleum diesel, which appears to be the main barrier to its wider adoption.

### 2.3.3.2 CHEMICAL PROPERTIES OF BIODIESEL

Chemically speaking, biodiesel is defined as the monoalkyl esters of long-chain fatty acids produced by transesterification of renewable lipid sources, particularly the methylester. Longchain methyl esters like lauric, palmitic, stearic, and oleic acids are a component of biodiesel. Rapeseed oil, canola oil, soybean oil, sunflower oil, palm oil, and their derivatives are a few examples of popular plant-based oils. Additional sources of raw materials include cooking oil, animal-sourced beef, lamb, and poultry oils. In essence, the chemical involved in the conversion to biodiesel is the same. In the presence of a sodium hydroxide or potassium hydroxide catalyst, oil or fat interacts with methanol or ethanol to produce biodiesel, methyl esters, and glycerine.

Table 2.1 shows some technical properties of biodiesel according to Demirbas (2008).

*Table 2.1: Technical Properties of Biodiesel (Demirbas, 2008).*

<b>COMMON NAME</b>	<b>BIODIESEL</b>
Common chemical name	Fatty acid methyl ester

Chemical formula range	C14–C24 methyl esters or C <sub>15–25</sub> H <sub>28–48</sub> O <sub>2</sub>
Kinematic viscosity range (mm <sup>2</sup> /s, at 313 K)	3.3–5.2
Density range (kg/m <sup>3</sup> , at 288 K)	860–894
Boiling point range (K)	>475
Flashpoint range (°C)	157 – 182
Distillation range (°C)	197 – 327
Vapour pressure (mm Hg, at 295 K)	<5
Solubility in water	Insoluble in water
Physical appearance	Light to a dark yellow, clear liquid
Odour	Light musty/soapy odour

Biodegradability	More biodegradable than petroleum diesel
Reactivity	Stable, but avoid strong oxidizing agents

### 2.3.3.3 FUEL PROPERTIES OF BIODIESEL

Different characteristics are used to describe biodiesel as a fuel. They offer helpful insights regarding the effectiveness and purity of the biodiesel that is being evaluated.

These attributes comprise:

- Density
- Viscosity
- Cetane Number
- Flash Point
- Pour Point

1. **VISCOSITY:** The measurement of the resistance of a fluid to deformation at a given rate under particular circumstances is known as viscosity. Compared to petroleum diesel, biodiesel has a substantially lower viscosity (Lim & Teong, 2010). The transesterification procedure reduces the triglyceride's molecular weight and viscosity. The viscosity of biodiesel, which has an effect on the fuel injection system, is among its most important characteristics. This results from poor atomization of the fuel spray at higher viscosities (Demirbas, 2008).

2. **DENSITY:** The mass-to-volume ratio of a substance is known as its density. Biodiesel has a little higher density than petroleum-based diesel. Given that biodiesel has a density of about  $0.88\text{g/cm}^3$ , whereas petroleum diesel has a density of about  $0.85\text{g/cm}^3$ . (Lim & Teong, 2010).
3. **CETANE NUMBER:** Fuel's cetane number is a characteristic that is used to gauge the quality of its ignition. Merriam-Webster defines it as a measurement of a fuel's ignition value that is presented as a function of the volume percentage of liquid methylnaphthalene that produces the same ignition value as the oil being tested. Vegetable oil-based biodiesel has a cetane number in the range of 46 to 52, but biodiesel obtained from JCO has a cetane value of roughly 51 (Takase *et al.*, 2015).
4. **FLASHPOINT:** Another test for determining the quality of a fuel's igniting is the flashpoint. The Pensky-Martens Closed flash tester is used to carry it out. The biodiesel obtained from JCO has a flash point between 34 and  $285^{\circ}\text{C}$ . (Takase *et al.*, 2015).
5. **POUR POINT:** To ascertain a fuel's flow and transportation properties, pour point testing is done. The lowest temperature at which a sample will flow normally is measured by this metric. The range of biodiesel's pour point is 3 to  $-8^{\circ}\text{C}$ .

#### **2.3.4 ADVANTAGES OF BIODIESEL AS A RENEWABLE ENERGY SOURCE**

Some advantages of using biodiesel instead of regular fuel include the following:

- Both plant and animal waste can be used to make biodiesel.
- Biodiesel is a more biodegradable energy source than diesel made from petroleum.
- It has fewer sulfur and aromatics than Petrodiesel and burns more effectively.

- The cetane number value is greater.
- It has the advantage of being the only alternative fuel that can be used in a low concentration blend with diesel in an engine that has not been upgraded.
- Burning biodiesel reduces the total amount of unburned hydrocarbon by 90%.

(Demirbas, 2008).

### **2.3.5 DISADVANTAGES OF BIODIESEL AS A RENEWABLE ENERGY SOURCE**

Biodiesel also has a couple of disadvantages which include:

- It has a higher viscosity than Petrodiesel
- It has lower energy content.
- It also has a higher cloud point and pour-point
- It also has a higher nitrogen oxide emission which is a function of the engines that are being used.
- It has a lower engine speed and power.
- It has a lower injector coking, engine compatibility and a higher price (which is dependent on its manufacturing process)

The ASTM standard for biodiesel is shown below in Table 2.2

Table 2.2: ASTM Standards of Biodiesel and Petrodiesel fuels (Demirbas, 2008).

<b>PROPERTY</b>	<b>TEST METHOD</b>	<b>ASTM D975 (PETRODIESEL)</b>	<b>ASTM D6751 (BIODIESEL, B100)</b>
Flash point	D 93	325K min	403K
Water and sediment	D 2709	0.05 max %vol	0.05 max %vol
Kinematic viscosity (at 313K)	D 445	1.3 – 4.1 mm <sup>2</sup> /s	1.9-6.0 mm <sup>2</sup> /s
Sulfonated ash	D 874	-	0.02 max %wt
Ash	D 482	0.01 max %wt	-
Sulfur	D 5453	0.05 max %wt	-
Sulfur	D 2622/129	-	0.05 max %wt
Copper corrosion strip	D 130	No 3 max	No 3 max
Cetane number	D 613	40 min	47 min
Aromaticity	D 1319	35 max %vol	-

Carbon residue	D 4530	-	0.05 max %mass
Carbon residue	D 524	0.35 max % mass	-
Distillation temperature (90% volume recycle)	D 1160	555K min – 611K max	-

### 2.3.6 METHODS OF PRODUCING BIODIESEL

Vegetable oil has been utilized as fuel since the development of the diesel engine, with Rudolf Diesel being the first to do so. It is rarely used because it reduces the engine's power output despite having a high viscosity (Owolabi *et al.* 2012).

There are numerous ways to lessen the viscosity of vegetable oil. They include:

- Direct use or Dilution/ Blending
- Micro-emulsions
- Pyrolysis
- Transesterification

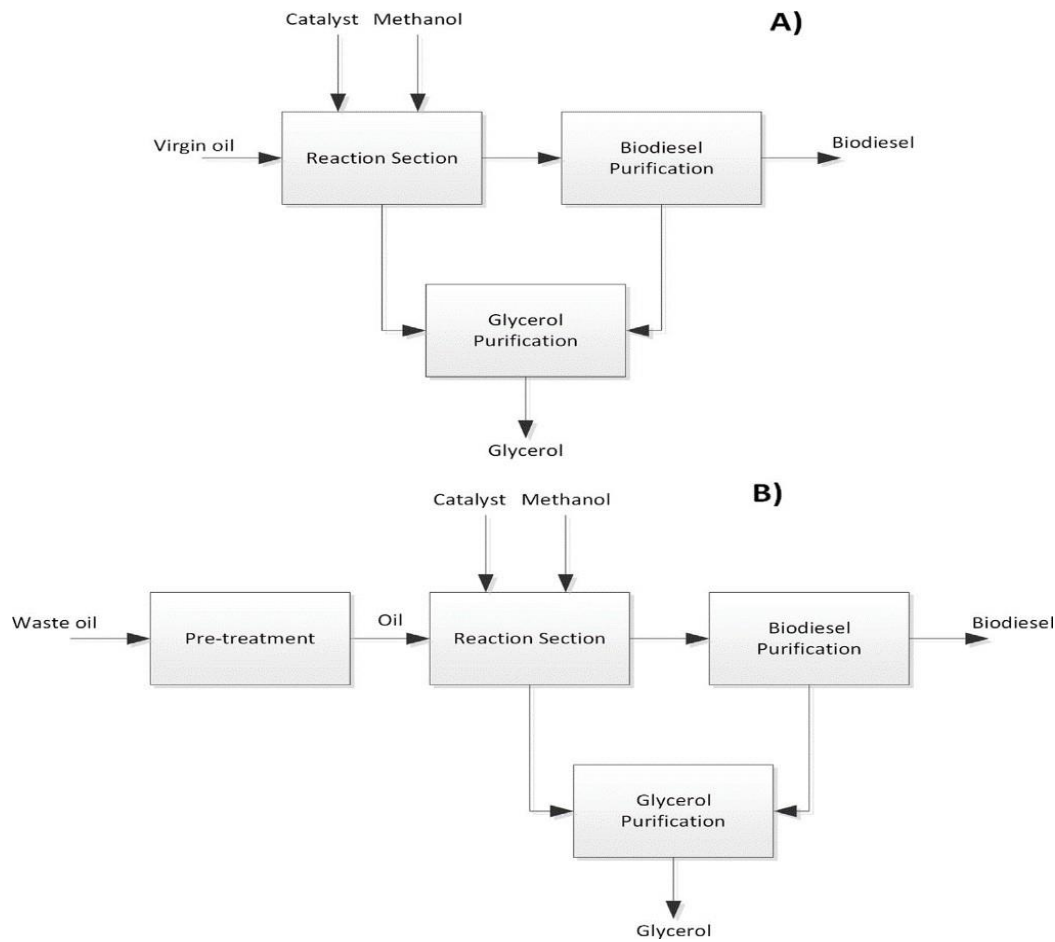


Figure 2.1: Block scheme of traditional biodiesel production process; A) case-study A1: feedstock = virgin oil; B) case-study B1: feedstock = waste cooking oil (Innocenzi and Prisciandaro, 2021).

### 2.3.6.1 DIRECT USE/BLENDING

Vegetable oils need to have their comparatively high kinematic viscosity reduced in order for them to work with modern compression-ignition engines and fuel systems. A straightforward, less expensive technique for raising viscosity is co-solvent blending, which involves mixing vegetable oil with a solvent having a high molecular weight.

The diesel fleet was propelled by the modified frying oil. 5 percent diesel fuel and 95% cooking oil were used. To compensate for the lower ambient temperatures, the proper

quantity of blending or preheating was used. There were no problems brought on by the build-up of carbon and coking. The deterioration of lubricating oil due to increased viscosity brought on by the polymerization of unsaturated vegetable oils was the only problem identified as a need for improvement (Ma & Hanna, n.d.).

The advantages of Dilution include:

- Its liquid nature and portability.
- It has a high heat content.
- It is less expensive.
- It is renewable.

The limitations of direct usage or blending of vegetable oil with diesel include:

1. Increased viscosity.
2. Increased volatility.
3. The hydrocarbon chain reactivity (Boro *et al.*, 2012).

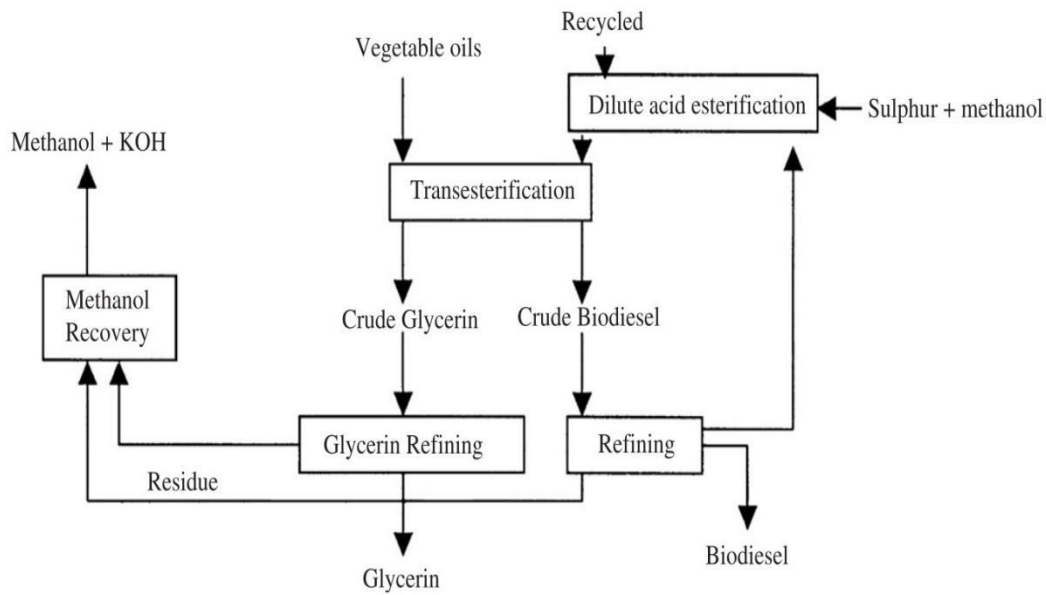


Figure 2.2: Basic scheme for Biodiesel production. (Marchetti et al., 2007)

### 2.3.6.2 MICRO-EMULSION

An ionic or non-ionic amphiphile and one or more ordinarily invisible liquids mix to generate a microemulsion, which typically has dimensions between 1 and 150 nm. The colloidal balance dispersion of optically isotropic microstructures is the name of this microemulsion. Ziejwski et al. (1984) created this emulsion using 53% (volumes) of alkaline and winterized sunflower oil, 13.3% (volumes) of 190-proof ethanol, and 33.4% (volumes) of 1-butanol. The non-ionic emulsion had a viscosity of 6.31cSt at 40°C, a low ash content of less than 0.01%, and a 25 Cetane number.

The major advantages of using micro-emulsion for the synthesis of biodiesel include:

1. It helps to lower the fuel viscosity
2. Through explosive vaporization of boiling components of the micelles, they may boost the sprays.

Although, Biodiesel synthesized from this method has a low viscosity, there is the problem of a very low cetane number and energy content (Boro *et al.*, 2012).

### **2.3.6.3 PYROLYSIS**

The chemical breakdown of materials at high temperatures in a sterile environment is known as pyrolysis. The substance's structure is altered in a lasting way. The word is derived from the Greek words "lysis" and "pyro," which both imply "flame."

Organic materials are the ones that undergo pyrolysis most frequently. The main byproduct of extreme pyrolysis, often referred to as excessive carbonization, is carbon residue. Industrial pyrolysis systems transform crude fuel into fuels and syngas from feedstock.

Pyrolysis in Biodiesel synthesis is important because:

1. Reduces the cost of treatment.
2. Compatibility with oil, engine and infrastructure requirements.
3. Flexibility of the feedstock.
4. The final products are similar in composition to diesel fuel.

The main disadvantage of pyrolysis is that it requires a lot of energy. (Maher & Bressler, 2007).

### 2.3.6.4 TRANSESTERIFICATION

These are the main techniques employed to address the issue of excessive fuel viscosity (Demirbas, 2008). Transesterification, one of the four techniques discovered, is the most popular since it yields biodiesel with a higher cetane value (Boro *et al.*, 2012). Triglyceride transesterification is not a novel process as it was originally applied in the middle of the 1800s, much before the creation of the first diesel engine. It was also used to assist in separating soap from glycerine during the production of soap. (Ali *et al.*, 2013).

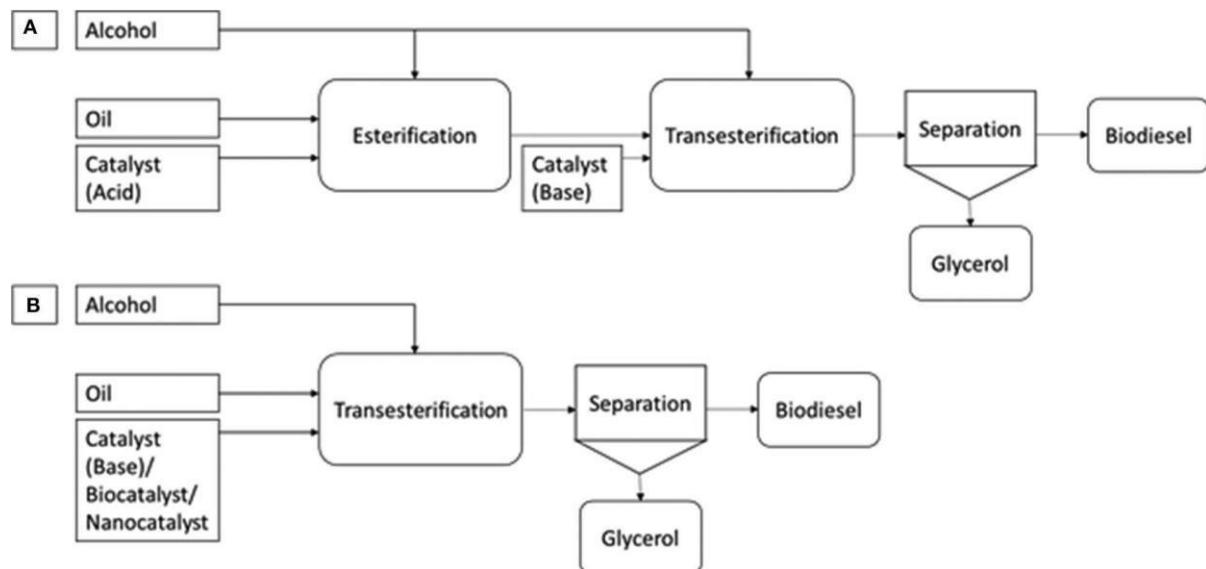


Figure 2.3: Biodiesel production from feedstock: (A) two-step process; (B) one-step process (Fattah *et al.*, 2020)

On a molecular level, the transesterification of oils produces methyl esters and glycerol. One mole of glyceride is required for the reaction, which produces methyl ester when combined with three mols of alcohol in the presence of a strong base catalyst, such as sodium hydroxide or potassium hydroxide. Because the temperature must not increase over 65°C, the boiling point of methanol, the reaction occurs between 60 and 65°C. To

separate the glycerine from the methyl ester, the reaction must also be heated and agitated constantly with a magnetic stirrer before being allowed to settle and transferred to a funnel for separation. After being left for at least 24 hours, two layers are created by gravity, the upper layer being the ester (biodiesel), and the lower layer being the glycerol. A little amount of soap is produced, and the ester (biodiesel) typically still retains some of the alcohol that was used in the process (Akhabue & Okwundu, 2019) Due to its volatility, you can let this dry out. The soap that forms beside the ester is removed by continuously washing it in water. Warm water which is about 10% of the volume of the biodiesel is used to wash it, which helps to get rid of any catalyst or alcohol or dissolved soap that may have been present. Repeating the procedure up until. This is carried out repeatedly until no foams are found in the water (Boro *et al.* 2012).

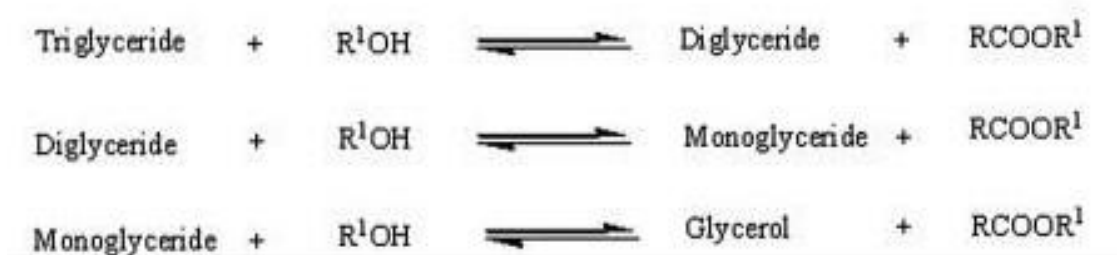


Figure 2.4: Three-step process of transesterification of fats and oils

The process of transesterification involves exchanging the functional group of an ester (Alkoxyl alkane R-COO-R) with alcohol (Alkanol R-OH). It's an equilibrium reaction that's also known as alcoholysis. When the ester and the alcohol come from the same source, alcoholysis is equivalent to transesterification. The presence of the catalyst aids in accelerating the pace of the reaction, which is catalysed by either an acid or a base. The reaction rate is accelerated when a basic or acid is applied, although this is done in a variety of ways. In the case of a base, it gives a proton to the alcohol, increasing its

reactivity, but in the case of an acid, it does the same for the carbonyl group of the ester, increasing reactivity. Alcohol must be used in excess since it is the reaction's limiting reagent in order to improve the yield of the ester. (Demirbas, 2008).

Transesterification is frequently characterized using four basic routes. They can be characterized either by using:

- Acids-Catalysed
- Base-Catalysed
- Enzyme-Catalysed
- Non-catalysed (Boro *et al.* 2012).

An easier means to classify transesterification reactions will be into two main types which could be:

- Homogeneous Catalysed Transesterification
- Heterogeneous Catalysed Transesterification

## **2.4 JATROPHA CURCAS OIL**

The multifunctional bush/small tree *Jatropha curcas* (Linnaeus) is a member of the Euphorbiaceae family. It's a plant with a wide range of traits, applications, and potential. The plant can be grown as a live fence to contain or exclude farm animals, be used to control erosion, restore land, and be planted as a true crop. Although it originated in tropical America, it now flourishes in many tropical and subtropical regions of Africa and Asia. It can survive in a wide range of rainfall circumstances, from 200 to over 1,500 mm per year, and is resistant to pests and diseases. The plant sheds its leaves as a result of little rainfall and prolonged dry spells (Ma & Hanna, n.d.).

Jatropha is a tough, drought-tolerant plant that is also simple to grow and grows swiftly. The leaves and stems are toxic to animals; thus, it is not browsed. However, after treatment, the seeds or seed cake can be used as animal feed. The fruit and wood of the plant can be used for a variety of things, including fuel, and the bark of the plant contains tannin. Bees are attracted to the blossoms, which allows the plant to generate honey. The jatropha plant's fruit produces viscous oil that can be used as a paraffin/diesel substitute or extender as well as in the cosmetics and soap industries. When seeking for practical fossil fuel equivalents to counter the build-up of greenhouse gases in the environment, this latter use could be essential. However, the full potential of jatropha has not yet been realized due to a number of technological and financial factors. There is little experience in the marketing of jatropha goods, and jatropha management and cultivation are poorly documented. Because of this, producers frequently fall short of achieving the maximum yield of the goods (like fruit) that would provide the greatest profit. Furthermore, they are largely ignorant about the markets for the many products that are currently or potentially the most lucrative. The costs and rewards of serving these markets haven't always been taken into account, nor have the markets for various products always been thoroughly studied (Fahad, *et al.*, 2016).



*Figure 2. 5 (a-h): Morphology of Jatropha curcas L., (a) Plant having leaves and fruits, (b) Stem (c) Leaves (d) Flower, (e) Immature fruits, (f) Mature fruits, (g) Seeds and (h) Crude seed oil*

### **2.4.1 JATROPHA AN ENERGY SOURCE**

Jatropha oil is one prospective substitute for diesel fuel. Diesel molecules contain 8 to 10 carbon atoms, whereas jatropha oil molecules include 16 to 18 carbon atoms. Due to its viscosity, JCO has a poorer ignition quality than diesel (cetane number). Therefore, it has not yet been fully tested over an extended period to use the oil directly in diesel engines. To reduce viscosity and increase cetane number, plant oils are commonly trans-esterified (processed with methanol/ethanol and sodium/potassium hydroxide) in Europe. This

produces "bio-diesel" oils that are similar to "mineral diesel" oils in terms of their properties. However, this is now an expenditure that is not cost-effective and requires a significant amount of money.

One of the primary causes of this is the relative, if not absolute, decline in the price of crude oil over the past ten years. Jatropha oil is currently not cost-competitive with diesel, save in certain cases.

As a result, it's important to review how the many products made from the jatropha plant are used to determine which ones are still useful as sources of energy.

Directly picked from the jatropha plant, wood, the entire fruit, and parts of the fruit, in particular the fruit flesh, nutshell, and kernel can all be burned separately or together (or seed).

After processing, it is possible to produce additional fuel products from the plant, including plant oil, seed cake, and charcoal, although this requires energy inputs (from the wood or nutshell). Each of these products' energy values and production costs varies.

#### **2.4.2 USES OF VARIOUS SPECIES OF JATROPHA**

The following are some of the uses of Jatropha

1. The Seri people of Sonora, Mexico, make baskets out of haat (*Jatropha cuneata*) stems. A complex procedure is used to roast, split, and soak the stems.
2. *Krameria grayi*, a different plant species, produces the root that is used to make the crimson dye that is frequently employed. Tropical regions plant spicy jatropha (*J. integerrima*) as an ornamental because of its perpetually flowering scarlet blossoms.

3. In Mexico and the Southwest of the United States, the Buddha belly plant (*J. podagrica*) was used to tan leather and create a red dye. It can also be kept inside as a plant.
4. The oil from the *Jatropha curcas* plant is typically converted into biodiesel for use in diesel engines. The protein-rich cake leftover from oil extraction can be used to produce fish or animal feed (if detoxified). It serves as both a premium organic fertilizer and a biomass feedstock for the production of biogas or electricity.

*Table 2.3: Physiochemical properties of Jatropha Oil (Mazumdar, et al., 2013)*

<b>PROPERTY</b>	<b>VALUE</b>
Acid Value (mg KOH/g)	25-28
Specific Gravity	0.912-0.922
Pour Point (°C)	1
Kinematic Viscosity (mm <sup>2</sup> /s)	20.5-22
Cetane Number	34.11-35.37
Aniline Point (°C)	64-65
Iodine Value (g I <sub>2</sub> /100g oil)	100-101

## 2.5 BLENDING JATROPHA BIODIESEL WITH FOSSIL DIESEL

Blending Jatropha biodiesel with fossil diesel represents a pivotal avenue in the pursuit of sustainable energy solutions, particularly in the transportation sector. The exploration of different blend ratios of Jatropha biodiesel and fossil diesel holds significant promise in mitigating the environmental impact associated with conventional fossil fuels while addressing the growing concerns regarding greenhouse gas emissions and climate change (Pritam *et al.*, 2019).

Understanding the impact of blending ratios involves a comprehensive analysis of how these blends affect various aspects of engine performance, combustion characteristics, and emissions profiles in compression ignition engines. This investigation is crucial in determining the optimal blend ratio that maximizes engine efficiency, minimizes emissions, and ensures long-term engine operability without compromising performance metrics (Akhabue & Ewah, 2021).

Blending biodiesel with fossil diesel alters the fuel composition and combustion behaviour in engines. The varying physical and chemical properties of biodiesel compared to traditional diesel impact combustion characteristics, including ignition delay, combustion duration, and heat release rates (Pritam *et al.*, 2019). The oxygen content in biodiesel enhances combustion, potentially influencing engine power output, torque, and fuel consumption (Chuah *et al.*, 2017).

Furthermore, the combustion of biodiesel blends affects emissions profiles. While biodiesel generally produces lower particulate matter (PM) emissions compared to fossil diesel due to its oxygen content and higher cetane number, the blend ratios significantly influence emissions of nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO), unburned hydrocarbons (HC), and particulates (Akhabue & Ewah, 2021; Pritam *et al.*, 2019). Different blend compositions

exhibit varying emissions characteristics, requiring thorough examination to ascertain their environmental implications.

The investigation extends beyond performance metrics and emissions profiles. It encompasses assessing the compatibility of different blend ratios with compression ignition engines. Operational suitability, engine durability, and long-term effects on engine components need scrutiny under varying blend compositions to ensure that the use of biodiesel blends does not compromise engine integrity or lifespan (Pritam *et al.*, 2019).

Moreover, the economic feasibility and market potential of Jatropha biodiesel blends are critical aspects that necessitate exploration. A comprehensive cost-benefit analysis considering factors like production costs, market acceptance, and potential incentives is essential in determining the commercial viability of biodiesel-fossil diesel blends (Akhavue & Ewah, 2021).

Investigating the effect of blending ratios of Jatropha biodiesel with fossil diesel on compression ignition engines involves multifaceted considerations. It encompasses evaluating engine performance, emissions profiles, engine durability, and economic feasibility. This comprehensive analysis aims to provide insights into optimizing blend ratios for sustainable energy solutions in the transportation sector while ensuring environmental benefits, engine efficiency, and economic viability.

### **2.5.1 ENGINE PERFORMANCE AND COMBUSTION CHARACTERISTICS**

The blending of Jatropha biodiesel with fossil diesel significantly impacts engine performance and combustion characteristics in compression ignition engines, serving as a critical area of investigation (Pritam *et al.*, 2019). Engine performance metrics such as power output, torque

generation, and fuel consumption are influenced by the varying blend ratios of biodiesel and fossil diesel (Akhavue & Ewah, 2021).

One of the notable aspects affecting engine performance is the altered combustion behavior resulting from biodiesel blends. Biodiesel possesses different physical and chemical properties compared to conventional diesel fuel, impacting the combustion process in compression ignition engines. The higher cetane number of biodiesel generally promotes smoother combustion, leading to reduced ignition delay and improved engine start-up (Chuah *et al.*, 2017).

Furthermore, the oxygen content in biodiesel influences its combustion characteristics. This oxygenation affects the combustion process, potentially enhancing the energy release during combustion and influencing the power output of the engine. The incorporation of biodiesel in different blend ratios alters the fuel's energy content, thus affecting the engine's power and torque output (Akhavue & Ewah, 2021).

However, the alteration in fuel composition due to biodiesel blending may have varying effects on engine performance. Higher blend ratios of biodiesel could lead to decreased energy content in the fuel, potentially affecting the engine's power output and torque generation. Conversely, lower blend ratios may have a less pronounced impact on engine performance, maintaining the energy content within an acceptable range (Pritam *et al.*, 2019).

Fuel consumption, another critical performance metric, is influenced by the altered combustion characteristics resulting from biodiesel blends. Biodiesel's oxygen content and different chemical properties may lead to variations in fuel consumption rates. Higher oxygen content might enhance combustion efficiency, leading to potentially lower fuel consumption, while

altered energy content due to blending could conversely affect fuel efficiency (Akhabue & Ewah, 2021).

The effect of blending Jatropha biodiesel with fossil diesel significantly influences engine performance and combustion characteristics. The varying blend ratios alter combustion behavior, affecting power output, torque generation, and fuel consumption in compression ignition engines. Understanding these impacts is crucial for optimizing blend ratios to strike a balance between improved engine performance and fuel efficiency while ensuring environmental benefits.

### **2.5.2 IMPACT ON EMISSIONS PROFILE (NO<sub>x</sub>, CO, PM, HC)**

Blending Jatropha biodiesel with fossil diesel in compression ignition engines introduces substantial changes to the emissions profile, including nitrate oxides (NO<sub>x</sub>), carbon monoxide (CO), particulate matter (PM), and unburned hydrocarbons (HC) (Pritam *et al.*, 2019). Understanding the impact of these varying blend ratios on emissions is crucial for assessing the environmental implications and regulatory compliance associated with using biodiesel blends.

NO<sub>x</sub> emissions, a key contributor to air pollution, are influenced by combustion temperature and oxygen availability. Biodiesel blends often exhibit lower NO<sub>x</sub> emissions due to their oxygen-rich composition, which alters combustion characteristics, reducing peak temperatures and mitigating NO<sub>x</sub> formation (Akhabue & Ewah, 2021). This reduction in NO<sub>x</sub> emissions is particularly significant, considering the environmental concerns surrounding nitrogen oxides and their detrimental effects on air quality.

Carbon monoxide emissions are another critical aspect affected by biodiesel blending. CO emissions tend to decrease with higher biodiesel content in the blend due to the fuel's improved

oxygenation and enhanced combustion characteristics (Chuah *et al.*, 2017). The increased oxygen content in biodiesel facilitates more complete combustion, resulting in lower CO emissions during engine operation.

Particulate matter emissions are significantly impacted by the combustion behaviour of biodiesel blends. PM emissions, including soot and other fine particles, can vary based on the blend ratio and fuel properties. Biodiesel's oxygen content and altered chemical composition affect combustion efficiency, potentially leading to reduced particulate matter emissions compared to conventional diesel (Pritam *et al.*, 2019). The improved combustion process minimizes the formation of unburned particulates, contributing to a reduction in PM emissions.

Additionally, unburned hydrocarbon emissions can be influenced by the blending of Jatropha biodiesel with fossil diesel. The combustion characteristics of biodiesel blends affect the completeness of combustion and the amount of unburned fuel components in the exhaust. Higher oxygen content in biodiesel tends to enhance combustion efficiency, potentially leading to reduced unburned hydrocarbons in the emissions (Akhavue & Ewah, 2021).

The impact on emissions profile resulting from blending Jatropha biodiesel with fossil diesel underscores the potential for reducing harmful pollutants. Lower NO<sub>x</sub>, CO, PM, and HC emissions associated with biodiesel blends signify their environmental advantages over conventional diesel. Understanding the emissions characteristics of different blend ratios is crucial for regulatory compliance, environmental impact assessment, and achieving cleaner air quality standards.

### **2.5.3 OPERATIONAL SUITABILITY AND DURABILITY OF COMPRESSION**

#### **IGNITION ENGINES**

The introduction of Jatropha biodiesel-fossil diesel blends into compression ignition engines prompts a critical inquiry into their operational suitability and long-term durability. Such blends can influence engine performance, reliability, and durability due to variations in fuel properties and combustion behavior (Pritam *et al.*, 2019).

One aspect under scrutiny is the fuel's lubricating properties. Jatropha biodiesel has inherent lubricity characteristics owing to its higher oxygen content compared to traditional fossil diesel (Chuah *et al.*, 2017). This increased lubricity might positively impact engine components like fuel injectors and pumps by potentially reducing wear. However, it also raises concerns about potential seal deterioration and fuel system compatibility issues over prolonged usage (Pritam *et al.*, 2019).

The altered chemical composition of biodiesel blends can also influence engine performance metrics such as power output and torque. While biodiesel possesses a higher cetane number than traditional diesel, which can improve combustion efficiency and hence engine power, it may also have lower energy content per unit volume, potentially leading to a slight reduction in engine power output (Chuah *et al.*, 2017).

Moreover, the different combustion characteristics of biodiesel can affect engine combustion efficiency and thermal stability. The presence of oxygen in biodiesel may alter the combustion process, impacting the engine's thermal efficiency and potentially causing a rise in engine temperature due to changes in fuel injection timing and combustion duration (Akhabue & Ewah, 2021). This necessitates a comprehensive assessment of engine components' heat resistance and overall durability under altered combustion conditions.

Blending *Jatropha* biodiesel with fossil diesel also raises concerns regarding fuel compatibility, particularly in terms of material compatibility with engine components and fuel storage systems (Akhabue & Ewah, 2021). Biodiesel's solvent properties could affect elastomer seals and gaskets in engines designed for traditional diesel, potentially leading to degradation over time. Addressing material compatibility issues and ensuring compatibility with existing engine designs are crucial considerations for the successful integration of biodiesel blends into compression ignition engines.

Furthermore, the durability of engine components, such as fuel injection systems, pistons, and valves, is paramount. The varying blend ratios and altered combustion characteristics may affect the wear rates and longevity of these components (Pritam *et al.*, 2019). A comprehensive study of the impact of biodiesel blends on engine durability involves extensive testing, simulation, and long-term monitoring to assess component wear, fatigue, and overall engine reliability.

In essence, evaluating the operational suitability and durability of compression ignition engines when using *Jatropha* biodiesel-fossil diesel blends requires a holistic approach. It involves investigating lubricity, combustion characteristics, material compatibility, and long-term effects on engine components. This comprehensive assessment is crucial for ensuring the seamless integration of biodiesel blends into existing engine technologies while maintaining performance, reliability, and durability standards.

## CHAPTER THREE

### MATERIALS AND METHODS

#### 3.1 RAW MATERIALS

##### 3.1.1 REAGENTS AND RAW MATERIALS USED

The reagents and raw materials used in this study are presented in table 3.1

*Table 3.1 Raw Materials and Reagents for Blending Study*

<b>Material</b>	<b>Source</b>	<b>Uses</b>
Jatropha Biodiesel	Locally prepared from Jatropha Curcas Oil	Feedstock for blending with fossil diesel.
Fossil Diesel	Purchased from a local fuel station	Base fuel for blending with jatropha biodiesel
Engine Oil	Supplied by a local automotive store	Lubrication of the compression ignition engine.
Fuel Additives	Purchased from a chemical supplier	To enhance combustion efficiency and stability in blended fuels
Distilled Water	Chemical Engineering Lab, University of Benin	Used for preparing solutions and cleaning engine components

### 3.1.2 APPARATUS USED FOR THIS STUDY AND THEIR FUNCTION

The apparatus used in this study are presented in Table 3.2.

Table 3.2 Apparatus and Their Functions for Blending Study

Equipment	Source	Uses
Compression Ignition Engine	Automotive store	Conducting performance and emission tests with various biodiesel-diesel blends.
Engine Dynamometer	Automotive research lab	Measuring engine power output and torque.
Exhaust Gas Analyzer	Environmental Engineering Lab, UNIBEN	Analyzing exhaust gas emissions, including NOx, CO, PM, and HC.
Fuel Flow Meter	Automotive research lab	Measuring fuel consumption rates during engine operation.
Data Acquisition System	Automotive research lab	Collecting and recording engine performance and emission data.

## 3.2 METHODOLOGY

### 3.2.1 Pretreatment of the oil

Pretreatment of *Jatropha curcas* oil is a key step in biodiesel production to ensure the quality of the raw material and improve the transesterification process. Pretreatment involves steps to remove impurities such as moisture, free fatty acids (FFA) and other impurities.

### 3.2.2 Acid Value Test

The acid value is expressed as milligrams of potassium hydroxide per gram of sample required to titrate a sample of a specified endpoint. The acid value of the oil is the measure of the acid content of the oil. The free fatty acids can lead to corrosion and maybe a sign of high moisture before titration. The titration was carried out to determine the acid value of the oil and hence it's free fatty acid content. The titration analysis was carried out using a standard solution of KOH. The burette was filled with 0.05M of KOH, equal volume of ethanol and benzene. 10ml of each were measured using the measuring cylinder and hence poured into the conical flasks. Two drops of phenolphthalein indicator were added to the mixture. The mixture was titrated with KOH in the burette, the change in volume of carriage was recorded, and this volume was recorded as the volume of the blank test (EN 14104 standard method). The 0.05M KOH solution in the burette was added dropwise to the oil-alcohol-phenolphthalein solution until the solution stayed pink (magenta) for 20 seconds. The millimeters obtained from the blank and main experiments were inputted into a formula to obtain the acid value as shown below;

$$AV = \frac{0.05 \times 56.1 \times V_c}{\text{weight of oil sample (g)}}$$

Where

AV = Acid value

$V_c$  = Change in volume to KOH

0.05M = Concentration of KOH

Molecular Mass of KOH = 56.1g/mol

$$\text{FFA content} = \frac{AV}{2}$$

It was observed that the oil had an acid value of 26.928 and FFA value of 13.464 which could cause soap formation during the transesterification reaction when the alkaline catalyst is used and this will affect the esters yield.

### 3.2.3 Saponification value test

The saponification value is determined by measuring the amount of KOH needed to neutralize the fatty acids in a known quantity of oil. Similar to the procedure above, 1g of jatropha oil sample was introduced into the conical flask and a 50ml of alcoholic KOH was added and the resulting mixture was refluxed for 1 hour. This solution was titrated against 0.5M HCl, and phenolphthalein indicator was used to define its end point of pink colourless to colourless. This procedure was used to obtain the blank. Saponification value is expressed as;

$$S.V = \frac{56.1 \times (B - Vc) \times 0.5}{\text{weight of oil sample}(g)}$$

where, B = Blank

Vc = Titre value

0.5 = Molarity of HCl

The value of the saponification test was gotten as 378. Higher saponification values indicate higher molecular weight fatty acids in the oil.

### 3.2.4 Peroxide value test

Using 0.1M in of sodium thiosulphate, 12 ml of acetic acid-chloroform was measured in ratio of 3:2 into a conical flask. To the acetic acid, 0.5ml potassium iodide was added and swirled for one minute after which 12 ml of distilled water was added to liberate the iodine from the chloroform layer then 1ml of starch solution was added and was titrated against sodium

thiosulphate until the blue grey colour disappears in the aqueous upper layer. The change in volume of sodium thiosulphate was taken to be blank.

$$\text{Peroxide Value} = \frac{10x(N1-N2)}{\text{weight of oil (g)}}$$

Where,  $N_1$  = volume of thiosulphate used for blank

$N_2$  = volume of sodium thiosulphate used for 1g of oil test

### 3.2.5 Iodide value test

1.0g of *Jatropha curcas* oil was weighed and transferred into a 250ml conical flask after which another 10ml of chloroform was added and warmed gently and allowed to cool for 10 minutes. 20ml of wj's solution was added in the same flask and was placed in a cupboard to prevent reaction sunlight for about 30 minutes. 20ml of potassium iodide solution was added to the mixture brought out of the dark place and was titrated against thiosulphate until the appearance of a yellow colour, then 10ml of starch was introduced as indicator, the color change to a dark indigo/ blue, it was swirled for proper mixing and titrated against the sodium thiosulphate in the burette. The disappearance of the blue color indicates that the endpoint has been reached, the same procedures are repeated without using the oil which is the blank.

$$\text{Iodine Value} = \frac{((B-Vc) \times 0.1 \times 12.69)}{\text{weight of oil (g)}}$$

Where, B = Blank

$V_c$  = Volume of thiosulphate required by blank

### 3.2.6 Viscosity

The NDJ-5S viscometer was used to test the kinematic viscosity of the oil. The viscosity is the ratio of the applied shear stress and the rate of shear of a liquid.



*Plate 3.1 Viscometer*

### **3.2.7 Density**

The Jatropha oil was introduced into a density bottle of known volume. The density of the bottle was weighed initially when it was empty and then the value was recorded after which the weight of the jatropha oil was measured alongside the the density bottle and then recorded. The change in weight was noted by taking the difference between both values recorded to determine weight/mass of the oil, from which the density of the oil was determined by dividing the mass with known volume of the density bottle, the value was recorded in gm<sup>3</sup> as its density.

$$\text{Density} = \frac{\text{Mass of oil}}{\text{Volume of oil (m3)}}$$

### **3.3 Esterification (Reduction of the free fatty acid)**

With the aim of increasing the methyl ester yield a two-step acid catalyst esterification and alkali catalyst transesterification, proposed by Hanny and Shizuko (2008), were employed. During the first acid pretreatment process of esterification, the FFA content of *Jatropha curcas*

oil was reduced to around 1.7% using methanol and sulphuric acid as a catalyst. Then the alkali-based transesterification process was employed to produce biodiesel.

As obtained in the acid value test carried out, the Free fatty acid value contents are high (13.464). This allows for a first step esterification reaction to reduce the acid value content. 570g of *Jatropha curcas* oil was measured and heated to 60°C in a round bottom flask on a magnetic stirrer. A mixture of concentrated H<sub>2</sub>SO<sub>4</sub> 1.0wt% with 22wt% methanol were added to the jatropha oil and stirred for 60 minutes. The mixture was then transferred into a separating funnel and left to settle for 24 hours. This procedure was repeated 3 times using the same number of reagents.



*Plate 3.2 Esterification process*

### **3.4 Biodiesel preparation**

Before carrying out the transesterification reaction, it's important to know the molecular weight of the oil after esterification. This is essential for figuring out the reaction's stoichiometry and making sure the right amounts of reactants are employed.

To ascertain the esterified oil's composition and quality, acid value test and saponification value test were carried out. The oil's acidity can have an impact on the kinetics of the reaction and the final product's quality; hence the acid test aids in determining this. The average molecular

weight of the fatty acids in the oil may be determined by the saponification value test, which is useful in determining how much methanol is required for transesterification. The molecular weight of the oil was expressed as

$$M_{wt} = \frac{3 \times 1000 \times 56.1}{SV - AV}$$

Based on the desired methanol to oil ratio, (6:1) you can calculate the mass of methanol needed for the reaction. This ratio ensures that there is excess methanol present to drive the equilibrium towards the formation of biodiesel.

The mass of methanol is calculated using the given expression below;

$$\frac{\text{Molecular weight of methanol} \times \text{Ratio of methanol}}{\text{Mass of methanol}} = \frac{\text{Molecular weight of oil} \times \text{Ratio of oil}}{\text{Mass of oil}}$$

The transesterification process was carried out after the oil was esterified. A magnetic stirrer equipped with inbuilt heating mantle and automatic temperature probe was used for this experiment. The experimental steps are described below.

- 100g of the esterified *Jatropha curcas* oil was poured into a 250ml conical flask and heated to a high temperature on the magnetic stirrer to remove any moisture.
- Then the oil was cooled to the required temperature.
- The mass of methanol required was weighed into a beaker and the crushed pellets of NaOH was mixed with methanol and stirred.
- The mixture was poured into the conical flask and was stirred for the required amount of time.

- After reaction was concluded, the mixture was poured into a separating funnel and was allowed to separate by gravity into layers for 24 hours. The glycerol was then drained into a tiny container by opening the separating funnel's tap.
- The biodiesel was taken off, washed with warm water and dried to remove the remaining water content.
- Biodiesel percentage yield was fully evaluated.



*Plate 3.3 Transesterification process*



*Plate 3.4 Separating process*

### 3.4.1 Transesterification Reaction Conditions

To achieve the desired biodiesel yield, specific reaction conditions were established:

- Reaction Temperature: 55°C
- Reaction Time: 55 minutes
- Molar Ratio of Methanol to Oil: 6:1
- Catalyst Concentration: 0.4wt%,

### 3.5 Characterization of Biodiesel produced.

#### 3.5.1 Acid value test

It is commonly used to describe the FFA content of the finished biodiesel and is the amount of KOH needed to react with a given amount of oil in grams. The acid value is one of the ASTM tests for finished biodiesel.

1.0g of the biodiesel was weighed and transferred into a flask in which 10ml of ethanol was added. 10 ml of Benzene was also added in the same flask and then the solution was shaken. Two drops of phenolphthalein were added and then titrated with 0.05KOH. The results were calculated using the following formula:

$$\text{Acid value} = \frac{\text{Titration value} \times 56.1 \times 0.1}{\text{Oil weight.}}$$

$$\text{FFA (Free Fatty Acid)} = \frac{\text{Acid Value}}{2}$$

#### 3.5.2 Flash Point

The flash point temperature of a diesel fuel is the minimum temperature at which the fuel will ignite (flash) on application of an ignition source According to ASTM D 93, the flash point of

biodiesel was determined using the SYD-261 Pensky Martens Closed Cup Flash Point Tester. The cup was filled with biodiesel up to the mark (about 75 ml) and placed in the tester. The machine was then set to heat at about 5°C/min until a rise in temperature with simultaneous stirring was observed. A small open flame was maintained from an external supply of petroleum gas. Periodically, the flame was passed over the surface of the oil. When the flash temperature was reached and the surface of the oil caught flame, the temperature at that moment was noted and reported as the flash point temperature.

### **3.5.3 Cloud Point**

The cloud point is the temperature at which wax first appears when the fuel is cooled. Make sure there are no observable pollutants or impurities in the biodiesel sample. The sample should be gradually warmed until it is fully homogenous and liquid, if it is not already. Make a chilled cooling bath or utilize a freezer with regulated temperature that may be kept at different temperatures. Ascertain the initial temperature that you want for the cooling bath. Usually, the cloud point test starts at a temperature that is just a little bit over ambient temperature. Select a test tube or clean, dry glass test jar. Enough of the biodiesel sample should be placed inside the jar or tube. A sufficient sample volume is required to detect any cloudiness or solid development. Put the test tube or jar that has been filled in the freezer or cooling bath. To guarantee equal cooling, use a stirring rod to swirl the biodiesel sample gently and constantly. Use the thermometer to keep an eye on the cooling bath's temperature. Note the starting temperature. Watch the biodiesel sample closely as it cools. Check the sample for any signs of haze or cloudiness. The wax crystallization process is started as a result of this cloudiness. Keep track of the temperature of the sample at which cloudiness first manifests itself. The cloud point is at this temperature. Note the temperature at which the cloud point occurs as well as any other experimental parameters, such as the date, the sample source, and the surrounding environment. To guarantee accuracy, repeat the experiment if needed with more samples or

under other circumstances. The recorded cloud point temperature provides important information about the low-temperature performance and stability of the biodiesel fuel. Lower cloud point temperatures indicate better cold flow properties and less susceptibility to wax crystallization, which is crucial for the operability of the fuel in cold climates.

### 3.6 BLENDING OF ESTERIFIED JATROPHA OIL AND FOSSIL DIESEL



*Plate 3.5: Jatropha biodiesel blended with fossil diesel*

Total volume for each blend = 200ml

**For B10 (10% Jatropha Biodiesel and 90% fossil diesel):**

- 20ml of Jatropha Biodiesel was measured using the measuring cylinder and afterward, poured into a bottle
- 180ml of pure fossil diesel was also measured using a measuring cylinder and afterwards poured into the same water bottle, making 200ml.

- The mixture was shaken vigorously until the fluids were well mixed and didn't separate on standing

**For B20 (20% Jatropha Biodiesel and 80% fossil diesel) :**

- 40ml of Jatropha Biodiesel was measured using the measuring cylinder and afterward, poured into a bottle.
- 160ml of pure fossil diesel was also measured using a measuring cylinder and afterwards poured into the same water bottle, making 200ml.
- The mixture was shaken vigorously until the fluids were well mixed and didn't separate on standing.

**For B30 (30% Jatropha Biodiesel and 70% fossil diesel):**

- 60ml of Jatropha Biodiesel was measured using the measuring cylinder and afterward, poured into a bottle.
- 140ml of pure fossil diesel was also measured using a measuring cylinder and afterwards poured into the same water bottle, making 200ml.
- The mixture was shaken vigorously until the fluids were well mixed and didn't separate on standing.

**For B40 (40% Jatropha Biodiesel and 60% fossil diesel):**

- 80ml of Jatropha Biodiesel was measured using the measuring cylinder and afterward, poured into a bottle
- 120ml of pure fossil diesel was also measured using a measuring cylinder and afterwards poured into the same water bottle, making 200ml.
- The mixture was shaken vigorously until the fluids were well mixed and didn't separate on standing.

### **3.6.1 CHARACTERIZATION OF THE BLENDS OF JATROPHA BIODIESEL AND FOSSIL DIESEL**

#### **3.6.1.1 PHYSICAL AND CHEMICAL PROPERTIES**

- The physical and chemical properties of Jatropha biodiesel and fossil diesel will be characterized according to established standards such as ASTM D6751 and ASTM D975. This includes properties like density, kinematic viscosity, flash point, cetane number, and moisture content.

#### **3.6.2 ENGINE PERFORMANCE AND EMISSION TESTING**

##### **3.6.2.1 COMPREHENSIVE ENGINE SETUP**

- The compression ignition engine will undergo a meticulous setup process on a state-of-the-art dynamometer. This setup will involve the integration of a comprehensive array of sensors and equipment to ensure precise data collection and analysis throughout the testing procedures. The advanced instrumentation will be strategically connected to various engine components, allowing for real-time monitoring of critical parameters.



*Plate3.6: IC engine and the experimental set-up for combustion of fuels.*

### **3.6.2.2 RIGOROUS BLENDING PROCEDURE**

- A systematic and rigorous blending procedure will be employed to create different ratios of Jatropha biodiesel blended with fossil diesel. The blending ratios will span from B10 (10% biodiesel, 90% diesel) to B40 (40% biodiesel, 60% diesel). This process will be conducted in a controlled environment with strict adherence to standardized protocols, ensuring the production of uniformly mixed blends. Careful attention will be given to guarantee the homogeneity of each blend, promoting consistent and reliable results.

### **3.6.2.3 THOROUGH ENGINE TESTING**

- The engine will undergo a series of comprehensive tests at various load conditions and speeds for each blending ratio. The testing protocol will encompass a wide range of operating conditions, simulating diverse scenarios to capture the engine's behavior under different stress levels. Performance metrics, including power output, torque, and fuel consumption, will be meticulously recorded and analyzed. This thorough testing approach aims to provide a detailed understanding of how each blend ratio influences the engine's performance characteristics.
- The combined use of advanced equipment, precise sensor integration, and a systematic blending and testing approach will contribute to a comprehensive evaluation of the engine's response to Jatropha biodiesel blends. The resulting data will be instrumental in drawing meaningful conclusions regarding the impact of varying blend ratios on engine performance and emissions.

### **3.6.2.4 EMISSION ANALYSIS**

- Exhaust gases will be meticulously collected from the engine operating under various blend ratios of Jatropha biodiesel with fossil diesel. The collected gases will undergo thorough

analysis using an advanced exhaust gas analyzer. This analyzer will provide precise measurements of key emissions, including nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO), particulate matter (PM), and hydrocarbons (HC). The objective is to gain insights into the environmental impact of different blend compositions and assess the potential benefits in terms of reduced emissions.



*Plate 3.8: BTMETER BT-5800M and JD – 302. (Used for testing for TVOC and CO<sub>2</sub> emission)*

### **3.6.3 ENGINE OPERATIONAL SUITABILITY AND DURABILITY**

To ensure a comprehensive evaluation, the engine will be subjected to continuous and prolonged operation using different blend ratios of Jatropha biodiesel and fossil diesel. This extended operational phase aims to assess the long-term performance, durability, and any potential adverse effects on critical engine components. Monitoring parameters such as power output, torque, fuel consumption, and emissions throughout the extended operation will contribute valuable data for understanding the engine's operational characteristics under varying blend conditions.

### **3.6.4 EXTENSIVE COST-BENEFIT ANALYSIS**

An extensive cost-benefit analysis will be conducted, considering a range of factors that contribute to the overall economic feasibility of using Jatropha biodiesel blends. This analysis will encompass detailed assessments of production costs, engine maintenance expenses, and potential economic benefits associated with the use of Jatropha biodiesel blends. By accounting for both initial investment and long-term operational costs, this analysis aims to provide a comprehensive understanding of the economic implications and potential advantages of adopting Jatropha biodiesel blends in compression ignition engines.

### **3.6.5 OPTIMAL BLEND RATIO DETERMINATION**

The determination of the optimal blend ratio will involve a thorough analysis of the collected data, taking into account engine performance metrics, emission profiles, and the results of the cost-benefit analysis. By employing a comprehensive approach, the research aims to identify the blend ratio that strikes the best balance between enhanced engine performance, reduced emissions, and economic viability.

## CHAPTER FOUR

### RESULT AND DISCUSSION

#### 4.1 PHYSIOCHEMICAL PROPERTIES OF ESTERIFIED JATROPHA OIL

The physical and chemical properties of the Jatropha Curcas Oil (JCO) were analyzed according to ASTM standards. Table 4.1 presents the results obtained from the characterization of the JCO.

*Table 4.1 Physiochemical Properties of Jatropha Oil*

PROPERTIES	VALUES
Specific gravity	0.91
Viscosity at 31.2 <sup>0</sup> C (mpa.s)	38.2
Acid Value (mgKOH/g)	26.928
FFA (%)	13.464
Density(g/ml)	0.815
Peroxide value (sMeq/Kg)	46
Saponification Value (mgKOH/g)	378
Iodine Value	68.9

Based on table 4.1, the specific gravity of Jatropha oil is 0.91, indicating its density relative to water. At a temperature of 31.2°C, its viscosity measures 38.2 mpa.s, reflecting its resistance to flow. The acid value, a measure of free fatty acids, is 26.928 mgKOH/g, with a corresponding free fatty acid (FFA) percentage of 13.464%. This suggests the presence of fatty acids in the oil.

The density of Jatropha oil is 0.815 g/ml, indicating its mass per unit volume. The peroxide value, a measure of oxidative rancidity, is recorded at 46 sMeq/Kg, suggesting its susceptibility to oxidation. The saponification value, an indicator of the average molecular weight of the fatty acids, is measured at 378 mgKOH/g, while the iodine value, reflecting the degree of unsaturation, stands at 68.9.

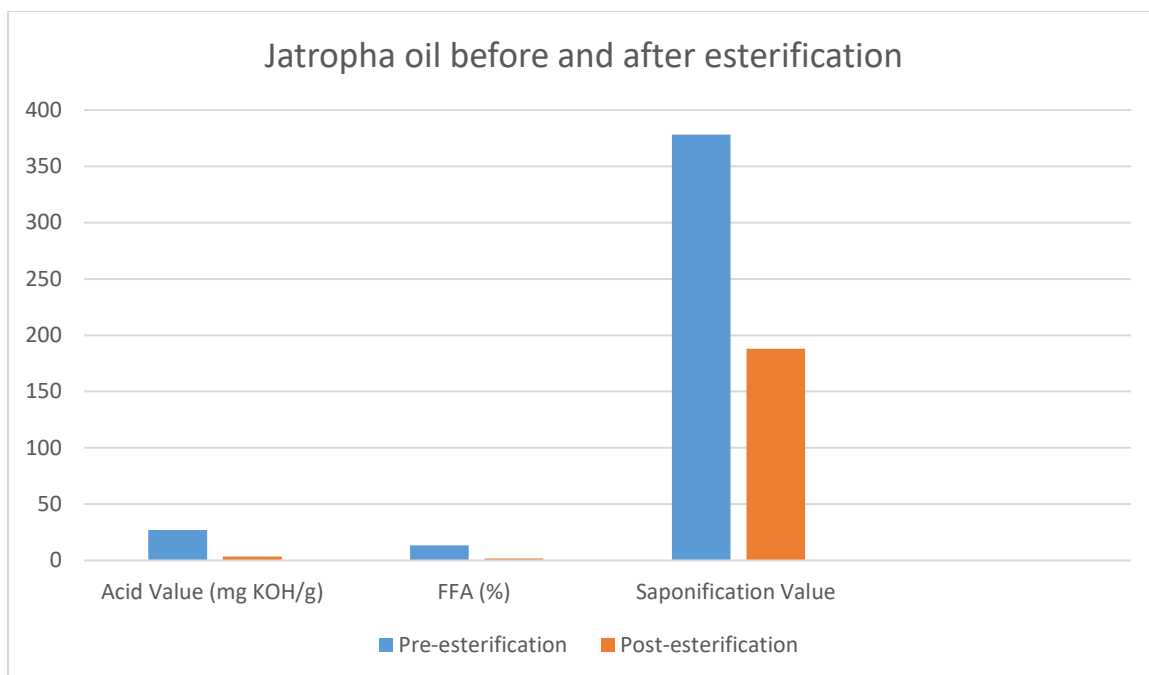
*Table 4.2 Physiochemical Properties of Esterified Jatropha Oil*

<b>PROPERTIES</b>	<b>VALUES</b>
Acid Value (mg KOH/g)	3.55
FFA (%)	1.7
Saponification Value	188

The saponification value of esterified Jatropha oil was found to be 188.0 mgkOH/g which is similar to saponification values for most vegetable oils ranging from 188-253 mgkOH/g (Olube et al., 2018).

*Table 4.3 Physiochemical Properties of Jatropha Oil before and after Esterification*

	<b>Pre-esterification</b>	<b>Post-esterification</b>
Acid Value (mg KOH/g)	26.928	3.55
FFA (%)	13.464	1.7
Saponification Value	378	188



*Figure 4.1: Physiochemical Properties of Jatropha Oil before and after Esterification*

Before esterification, the acid value of the oil is notably higher at 26.928 mg KOH/g, indicating a higher concentration of free fatty acids. Correspondingly, the free fatty acid (FFA) percentage is 13.464%, suggesting a significant portion of the oil consists of these unbound fatty acids.

The problem associated with the processing of high FFA oils using an alkaline catalyst is the formation of fatty acid salts (soap). The soap could prevent separation of the methyl ester layer from the glycerol layer. An alternative method is to use acid catalysis, which can esterify FFA. But in many cases the esterification reaction stops because of water formation when FFA react with methanol to form esters. Therefore, a dual step process, acid catalyzed esterification followed by base catalyzed transesterification process was selected for converting JCO into biodiesel. The saponification value of the esterified *Jatropha* oil was found to be 188.0 mgKOH/g which is similar to saponification values for most vegetable oils ranging from 188-253 mgKOH/g (Oluba *et al.*, 2018).

The molecular weight of the oil was expressed as

$$M_{wt} = \frac{3 \times 1000 \times 56.1}{SV - AV} = \frac{3 \times 1000 \times 56.1}{188 - 3.55} = 912 \text{g/mol}$$

The mass of methanol is calculated using the given expression below;

$$\frac{\text{Molecular weight of methanol} \times \text{Ratio of methanol}}{\text{Mass of methanol}} =$$

$$\frac{\text{Molecular weight of oil} \times \text{Ratio of oil}}{\text{Mass of oil}}$$

$$\frac{32.04 \times 6}{M} = \frac{912 \times 1}{100} = 21.08 \text{g}$$

However, after undergoing esterification, there is a marked reduction in both the acid value and FFA percentage. The acid value drops substantially to 3.55 mg KOH/g, indicating a significant decrease in free fatty acids. The FFA percentage also decreases significantly to 1.7%, signifying a successful conversion of free fatty acids into esters.

Furthermore, the saponification value of the oil decreases from 378 to 188 after esterification. This reduction suggests a change in the average molecular weight of the fatty acids present in the oil due to the esterification process.

These changes indicate that esterification effectively reduces the acidity and free fatty acid content of Jatropha oil, making it more suitable for various industrial applications such as biodiesel production.

*Table 4.4: Physiochemical Properties of Biodiesel with 0.4wt% NaOH catalyst*

PROPERTIES	VALUES
Specific gravity	0.85

Viscosity at 31.2 <sup>0</sup> C (mpa.s)	3.69
Acid Value (mgKOH/g)	0.84
FFA (%)	0.42
Density(g/ml)	0.86
Flash point ( <sup>0</sup> C)	158
Cloud point	2.4

The specific gravity of the biodiesel is 0.85, indicating its density relative to water. At a temperature of 31.2<sup>0</sup>C, its viscosity measures 3.69 mpa.s, indicating its resistance to flow, which is relatively lower compared to the original oil. The acid value of the biodiesel is notably low at 0.84 mgKOH/g, suggesting a minimal concentration of free fatty acids. Correspondingly, the free fatty acid (FFA) percentage is 0.42%, indicating a successful conversion of free fatty acids into esters during the biodiesel production process. The density of the biodiesel is 0.86 g/ml, indicating its mass per unit volume. The flash point, which is the temperature at which the vapor of the biodiesel can ignite in air, is noted as 158<sup>0</sup>C, indicating its safety in handling and storage. Additionally, the cloud point of the biodiesel is recorded as 2.4<sup>0</sup>C, indicating the temperature at which the liquid begins to form a cloudy appearance due to the presence of solid particles.

Therefore biodiesel produced with a 0.4wt% NaOH catalyst exhibits favorable characteristics such as low acidity, viscosity, and sufficient safety measures, making it suitable for various applications in the transportation and industrial sectors, this align with the study of Gonzalez (2005), who investigated the impact of biodiesel composition on low-temperature properties.

## 4.2 ENGINE PERFORMANCE

The performance evaluation of biodiesel blends was conducted on a one cylinder 10.0 hp diesel engine equipped with a single phase 220V 15kw alternator situated at Luco Chemical Laboratory Ltd Benin city. This engine is often used for medium-scale power generation. Before running the engine with the biodiesel-blended fuels, the engine was first run with diesel fuel for a few minutes to warm up the engine. It was also run by diesel fuel before the engine was shutdown. The same procedure was maintained for each fuel. In order to carry out engine performance tests, the engine was first run at 100% load, keeping the throttle 100% wide open.

The brake torque, brake power (BP), BSFC, and brake thermal efficiency (BTE) were calculated according to Sai et al. (2021) shown in Equations (4.1) to (4.2), respectively.

$$\text{Break Power (BP)} = \frac{2\pi N\{WR_e(9.81)\}}{60000} \quad 4.1$$

Where;

N is engine speed (rpm)

W is load applied on the engine

Re is the effective radius of brake drum

Break Mean Effective Pressure (BMEP)

$$\text{Break Mean Effective Pressure (BMEP)} = \frac{BP60}{SVN} \quad 4.2$$

Where;

SV is stroke volume

N is engine speed (rpm)

$$\text{Total Fuel Consumption (TFC)} = \frac{5.SG.3600}{1000t} (kg/h) \quad 4.3$$

Where;

SG is the specific gravity of fuel

T is time for 5cc fuel consumption in seconds

$$\text{Break Specific Fuel Consumption} = \frac{TFC}{BP} \text{ (kg/kWh)} \quad 4.4$$

$$\text{Break Thermal Efficiency (BTE)} = \left[ \frac{BP \cdot 3600}{TFC \cdot C_v} \right] \cdot 100 \quad 4.5$$

Where;

$C_v$  is calorific value of fuel. (Amount of energy that discharges when a unit quantity of fuel burns).

The test fuels would be petroleum diesel and diesel blends with castor and jatropha biodiesel.

The fuels were blended by using an overhead mixer/homogenizer device at a speed of 3000 rpm for 10 min.

Given:

Engine speed (N) = 1500 rpm

Load applied on the engine (W) = 50 kg

Effective radius of brake drum (Re) = 0.15 meters

Stroke volume (SV) = 0.1 liters (100 cc)

Specific gravity of fuel (SG) = 0.85

Time for 5cc fuel consumption (T) = 20 seconds

Calorific value of fuel ( $C_v$ ) = 42.8 MJ/kg (for diesel fuel)

$$\text{Break Power (BP)} = \frac{2\pi N W R_e \times 9.81}{60000}$$

$$BP = \frac{2\pi \times 1500 \times 50 \times 0.15 \times 9.81}{60000}$$

$$BP = 9.43 \text{ Kw}$$

Brake Mean Effective Pressure (BMEP) =

$$BMEP = \frac{BP \times 60}{SVN}$$

$$BMEP = \frac{9.43 \times 60}{0.1 \times 1500}$$

BMEP = 3.77 bar

Total Fuel Consumption (TFC) =

$$TFC = \frac{5 \times SG \times 3600}{1000T}$$

$$TFC = \frac{5 \times 0.85 \times 3600}{1000 \times 20}$$

$$TFC = 7.65 \text{ kg/h}$$

Brake Specific Fuel Consumption (BSFC) =

$$BSFC = \frac{TFC}{BP}$$

$$BSFC = \frac{7.65}{9.43}$$

BSFC = 0.81 kg/kWh

Brake Thermal Efficiency (BTE) =

$$BTE = \frac{(BP \times 3600)}{(TFC \times C_v)} \times 100$$

$$BTE = \frac{(9.43 \times 3600)}{(7.65 \times 42.8)} \times 100$$

BTE = 61.44%

Table 4.5 Engine Performance

Performance Metric	Value
Break Power (BP)	9.43 kW
Brake Mean Effective Pressure (BMEP)	3.77 bar
Total Fuel Consumption (TFC)	TFC≈7.65 kg/h
Brake Specific Fuel Consumption (BSFC)	0.81 kg/kWh
Brake Thermal Efficiency (BTE)	61.44%

The Break Power (BP) is recorded at 9.43 kilowatts, indicating the amount of power produced by the engine. The Brake Mean Effective Pressure (BMEP) stands at 3.77 bars, reflecting the average pressure exerted on the piston during the power stroke. Total Fuel Consumption (TFC) is estimated at approximately 7.65 kilograms per hour, denoting the total amount of fuel consumed by the engine within the given time frame. The Brake Specific Fuel Consumption (BSFC) is noted as 0.81 kilograms per kilowatt-hour, representing the amount of fuel consumed per unit of power produced. Finally, the Brake Thermal Efficiency (BTE) is calculated at 61.44%, indicating the percentage of input energy from fuel that is converted into useful work output by the engine. These metrics collectively provide insights into the operational efficiency and performance characteristics of the engine.

#### 4.3 ENGINE EMISSION

Different blends of synthesized biodiesel B10, B20, B30, B40 with petroleum diesel was conducted with a load of 1000 Watts were tested to analyze the performance and emission characteristics of fuel in compression ignition (IC) engine. The exhaust emissions from the engine was analyzed using an exhaust gas detector/analyzer. Rate of fuel consumption with load was conducted at various fuel blends.

Table 4.6: Engine Emission

Property	B0	B10	B20	B30	B40
Density (g/cm <sup>3</sup> )	0.853	0.848	0.843	0.841	0.838
Flash point (°C)	61	64	67	71	78
Viscosity (mPa.s)	3.82	4.58	4.71	5.14	5.36
Calorific value (MJ/kg)	43.814	43.013	42.050	41.543	40.418

Based on table 4.6, there is a discernible trend in the flash point, which denotes the temperature at which the substance releases vapor sufficient to ignite when exposed to an ignition source. Starting from 61°C for B0, the flash point gradually escalates, reaching its zenith at 78°C for B40. Additionally, the calorific value, representing the amount of heat liberated upon combustion of a specific quantity of the substance, follows a contrasting trajectory. Commencing at 43.814 MJ/kg for B0, the calorific value progressively diminishes, registering at 40.418 MJ/kg for B40.

#### 4.4 ENGINE OPERATIONAL SUITABILITY AND DURABILITY

Table 4.7 Engine Operational Performance

Time taken to consume 100ml of the blends	Blends	Gas Analysis		PM 2.5	PM 1	PM 10 IRg/m <sup>3</sup>
		TVOC	CO <sub>2</sub>			
5:31.16	B100	0.021	385	89	73	109
5:11.47	B40	0.011	393	55	44	67
5:27.51	B30	0.139	491	67	55	82
5:27.24	B20	0.021	405	63	51	78
5:25.89	B10	0.103	488	75	61	93
5:29.42	B0	0.081	466	107	87	132

Based on table 4.7 blend B100, the engine took 5 minutes and 31.16 seconds to consume 100ml of fuel. The gas analysis revealed a TVOC value of 0.021 and CO<sub>2</sub> emissions of 385 parts per million. Additionally, PM emissions for this blend were measured at 89 µg/m<sup>3</sup> (PM 2.5), 73 µg/m<sup>3</sup> (PM 1), and 109 µg/m<sup>3</sup> (PM 10), indicating the engine's performance and emissions characteristics under this specific blend composition.

For blend B40, the engine required 5 minutes and 1.47 seconds to consume 100ml of fuel. Gas analysis showed a TVOC value of 0.011 and CO<sub>2</sub> emissions of 393 parts per million. PM emissions for this blend were recorded at 55 µg/m<sup>3</sup> (PM 2.5), 44 µg/m<sup>3</sup> (PM 1), and 67 µg/m<sup>3</sup> (PM 10), providing insights into the engine's performance and emissions profile under this blend composition.

Under blend B30, the engine took 5 minutes and 27.51 seconds to consume 100ml of fuel. The gas analysis indicated a TVOC value of 0.139 and CO<sub>2</sub> emissions of 491 parts per million. PM

emissions for this blend were observed at 67  $\mu\text{g}/\text{m}^3$  (PM 2.5), 55  $\mu\text{g}/\text{m}^3$  (PM 1), and 82  $\mu\text{g}/\text{m}^3$  (PM 10), offering valuable information about the engine's performance and emissions characteristics under this specific blend composition.

For blend B20, the engine required 5 minutes and 27.24 seconds to consume 100ml of fuel. Gas analysis revealed a TVOC value of 0.021 and CO<sub>2</sub> emissions of 405 parts per million. PM emissions for this blend were measured at 63  $\mu\text{g}/\text{m}^3$  (PM 2.5), 51  $\mu\text{g}/\text{m}^3$  (PM 1), and 78  $\mu\text{g}/\text{m}^3$  (PM 10), providing insights into the engine's performance and emissions profile under this blend composition.

Under blend B10, the engine took 5 minutes and 25.89 seconds to consume 100ml of fuel. Gas analysis showed a TVOC value of 0.103 and CO<sub>2</sub> emissions of 488 parts per million. PM emissions for this blend were recorded at 75  $\mu\text{g}/\text{m}^3$  (PM 2.5), 61  $\mu\text{g}/\text{m}^3$  (PM 1), and 93  $\mu\text{g}/\text{m}^3$  (PM 10), offering insights into the engine's performance and emissions profile under this blend composition.

Lastly, under blend B0, the engine required 5 minutes and 29.42 seconds to consume 100ml of fuel. Gas analysis indicated a TVOC value of 0.081 and CO<sub>2</sub> emissions of 429 parts per million. PM emissions for this blend were observed at 107  $\mu\text{g}/\text{m}^3$  (PM 2.5), 87  $\mu\text{g}/\text{m}^3$  (PM 1), and 132  $\mu\text{g}/\text{m}^3$  (PM 10), providing valuable information about the engine's performance and emissions characteristics under this specific blend composition.

On average, biodiesel blends B30 and B40 exhibit lower CO<sub>2</sub> emissions compared to B0 (pure diesel). This could indicate that these blends improve engine efficiency. Conversely, B10 and B20 blends show higher CO<sub>2</sub> emissions, potentially suggesting a decrease in efficiency.

## 4.5 OPTIMAL BLEND RATIO CONSIDERING PERFORMANCE, EMISSIONS, AND ECONOMIC FACTORS

Table 4.8: Optimal Blend Ratio considering Performance, Emissions, and Economic Factors.

<b>Blend Ratio</b>	<b>Performance Factors</b>	<b>Emissions Factors</b>	<b>Economic Factors</b>	<b>Optimal Blend Ratio</b>
B0	High power output, efficient combustion	Higher CO2 emissions, air pollutants	Low production cost, availability	Not optimal
B10	Slight decrease in power, comparable efficiency	Moderate CO2 emissions, reduced pollutants	Moderate production cost, moderate availability	Potential for blend optimization
B20	Further decrease in power, slightly reduced efficiency	Moderate to high CO2 emissions, increased pollutants	Increased production cost, moderate availability	Consider for specific applications
B30	Significant decrease in power, decreased efficiency	Moderate to high CO2 emissions, increased pollutants	Higher production cost, limited availability	Potential for specific use cases
B40	Lowest power output, least efficient	Highest CO2 emissions	Highest production cost, least availability	Specialized applications only

## CHAPTER FIVE

### SUMMARY CONCLUSION, AND RECOMMENDATIONS

#### 5.1 Summary

This study aimed to investigate the physiochemical properties of esterified Jatropha oil, evaluate engine performance using biodiesel blends, analyze engine emissions, assess operational suitability and durability, conduct a cost-benefit analysis, and determine the optimal blend ratio considering performance, emissions, and economic factors.

#### 5.2 Findings

- Physiochemical analysis revealed that esterification of Jatropha oil resulted in a significant reduction in acid value, free fatty acid percentage, and saponification value, making it suitable for various industrial applications.
- Engine performance evaluation demonstrated that biodiesel blends exhibited favorable metrics such as brake power, brake specific fuel consumption, and thermal efficiency, indicating their potential as viable alternatives to petroleum diesel.
- Engine emission analysis showed varying emissions characteristics across different biodiesel blends, with lower CO<sub>2</sub> emissions observed in B30 and B40 blends compared to pure diesel (B0).
- Operational performance assessment indicated differences in construction time, gas analysis, and particulate matter emissions among different biodiesel blends, suggesting the influence of blend composition on engine operation.
- Cost-benefit analysis revealed the economic feasibility of Jatropha biodiesel production, with potential fuel cost savings, environmental benefits, and market expansion opportunities outweighing production and distribution costs.

- The optimal blend ratio considering performance, emissions, and economic factors indicated that B30 and B40 blends may be suitable for specialized applications, while B10 could be optimized for general use.

### **5.3 CONCLUSION**

- Esterification effectively improves the physiochemical properties of Jatropha oil, enhancing its suitability for industrial applications.
- Biodiesel blends demonstrate promising engine performance characteristics, with potential environmental benefits and cost savings compared to petroleum diesel.
- Different biodiesel blends exhibit varying emissions profiles and operational suitability, suggesting the importance of blend optimization for specific applications.
- Jatropha biodiesel production shows economic feasibility, with potential for market growth and environmental sustainability.

### **5.4 RECOMMENDATIONS**

- Further research is recommended to optimize biodiesel blend ratios for specific engine types and operating conditions to maximize performance and minimize emissions.
- Continued investment in Jatropha biodiesel production and market development is recommended to capitalize on its economic and environmental benefits.
- Collaboration with government agencies and stakeholders is advised to establish policies and incentives that promote the adoption of biodiesel as a sustainable alternative to petroleum diesel.
- Long-term monitoring and assessment of engine performance, emissions, and economic viability are recommended to ensure the sustainability and scalability of Jatropha biodiesel production and utilization.

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