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**Title**

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**Application of Biodiesel-Diesel Blend as the  
Continuous Phase in Drilling Fluid**

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**On: 17/06/2025**

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**Abstract:**

This dissertation explores the use of biodiesel from waste cooking oil as an alternative base fluid in oil-based drilling muds. Various biodiesel-diesel blends were tested for rheology, emulsion stability, and thermal performance. Biodiesel offers environmental benefits such as biodegradability and non-toxicity. The study concludes that biodiesel-rich blends are viable for drilling use and recommends further testing on other biodiesel sources, biodegradability, and glycerol reuse.

**Keywords:** Biodiesel, Drilling Fluids, Waste Cooking Oil, Emulsion Stability, Rheology, Thermal Stability, Biodegradability.

**Résumé :**

Ce mémoire explore l'utilisation du biodiesel issu d'huile de cuisson usagée comme fluide de base alternatif dans les boues de forage à base d'huile. Divers mélanges biodiesel-diesel ont été testés pour leurs propriétés rhéologiques, la stabilité de l'émulsion et les performances thermiques. Le biodiesel présente également des avantages environnementaux, notamment sa biodégradabilité et sa non-toxicité. L'étude conclut que les mélanges riches en biodiesel sont viables pour une utilisation en forage et recommande des tests supplémentaires sur d'autres sources de biodiesel, la biodégradabilité et la valorisation du glycérol.

**Mots-clés :** Biodiesel, Boues de forage, Huile de cuisson usagée, Stabilité d'émulsion, Rhéologie, Stabilité thermique, Biodégradabilité.

**ملخص:**

تتناول هذه الدراسة استخدام الديزل الحيوي المستخرج من زيت الطعام المستعمل كبديل مستدام للمذيبات المستعملة في سوائل الحفر. تم إجراء عدة اختبارات للخصائص الفيزيائية والكيميائية لسائل الحفر بتركيز مختلفة للديزل الحيوي مع الديزل البترولي. يتميز الديزل الحيوي بفوائده البيئية مثل القابلية للتحلل الحيوي وعدم السمية. توصلت الدراسة إلى أن سوائل الحفر ذات أساس البيوديزل قابلة للتطبيق في مجال الحفر، مع التوصية بإجراء اختبارات إضافية على مصادر أخرى للديزل الحيوي، وقابليته للتحلل، وسبل إعادة استخدام الجليسرول.

**الكلمات المفتاحية:** ديزل حيوي، سوائل الحفر، زيت طهي المستعمل، ثبات المستحلب، الخصائص الفيزيائية، الثبات الحراري، التحلل الحيوي.

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## **Dedication**

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I would like to express my deepest gratitude and dedicate this thesis to the following individuals who have been instrumental in my academic journey:

To my beloved mother and father, your unwavering love, support and encouragement have been my guiding light throughout this entire endeavour. Your sacrifices and belief in me have inspired me to pursue my dreams relentlessly. This accomplishment is as much yours as it is mine.

---

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**I would also like** to address the members of the jury for their interest in my research by agreeing to examine my work and enrich it with their proposals.

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### List of abbreviations

<b>WCO</b>	Waste Cooking Oil
<b>OBM</b>	Oil-Based Mud
<b>SBM</b>	Synthetic-Based Mud
<b>WBM</b>	Water-Based Mud
<b>BHR</b>	Before Hot Rolling
<b>AHR</b>	After Hot Rolling
<b>HHP</b>	High-Temperature High-Pressure
<b>FAME</b>	Fatty Acid Methyl Esters
<b>ASTM</b>	American Society for Testing and Materials
<b>DA</b>	Algerian Dinar
<b>rpm</b>	Revolutions Per Minute
<b>L</b>	Liter
<b>°C</b>	Degrees Celsius
<b>ppm</b>	Parts Per Million
<b>ES</b>	Electrical Stability
<b>API</b>	American Petroleum Institute
<b>PV</b>	Plastic Viscosity
<b>YP</b>	Yield Point

### List of symbols

<b><math>\tau</math></b>	Shear stress (Pa or lb/ft <sup>2</sup> )
<b><math>\gamma</math></b>	Shear rate (s <sup>-1</sup> )
<b><math>\mu</math></b>	Viscosity (Pa·s or cP)
<b><math>\mu_p</math></b>	Plastic viscosity (cP)
<b><math>\tau_0</math></b>	Yield point (lb/100 ft <sup>2</sup> )
<b>K</b>	Consistency index in Power Law Model
<b>n</b>	Flow behavior index in Power Law Model
<b><math>\rho</math></b>	Density (g/cm <sup>3</sup> or kg/m <sup>3</sup> )
<b>ES</b>	Electrical Stability (volts)
<b>G<sub>0</sub></b>	10-second Gel Strength (lb/100 ft <sup>2</sup> )
<b>G<sub>10</sub></b>	10-minute Gel Strength (lb/100 ft <sup>2</sup> )
<b>PV</b>	Plastic Viscosity (cP)
<b>T</b>	Temperature (°C)
<b>YP</b>	Yield Point (lb/100 ft <sup>2</sup> )

## CHAPTER I: INTRODUCTION

### I.1 Background

Drilling fluids, commonly referred to as drilling muds, are vital in drilling operations to create boreholes in the earth. These fluids are used extensively in the drilling of oil and natural gas wells, exploration drilling rigs, and simpler boreholes such as water wells (Ahmed et al., 2021). The primary functions of drilling fluids include lubricating the drill bit, transporting cuttings to the surface, maintaining wellbore stability, and controlling formation pressures (Zoveidavianpoor et al., 2019).

Drilling fluids are generally categorized into three main types: water-based muds (WBMs), non-aqueous muds (NAMs), and gaseous drilling fluids. WBMs, which can be dispersed or non-dispersed, utilize water as the continuous phase and are the most commonly used due to their cost-effectiveness and ease of disposal (Patel, Shah, & Patel, 2020). NAMs, often called oil-based muds (OBMs), use petroleum products like diesel fuel as the base fluid. OBMs are preferred for certain drilling conditions due to their superior lubricity, shale inhibition, and thermal stability (Xu et al., 2022). Gaseous drilling fluids, which can utilize air, nitrogen, or natural gas, are used in specific situations requiring underbalanced drilling (Yan et al., 2021).

OBMs, where diesel fuel is commonly used as the base fluid, offer several advantages over WBMs. These include increased lubricity, enhanced shale inhibition, and better cleaning capabilities with lower viscosity. OBMs can also withstand higher temperatures without degrading, making them suitable for deep and high-temperature wells (Smith, 2023). However, using diesel-based OBMs raises significant environmental and safety concerns due to the toxicity and non-biodegradability of diesel fuel, leading to stringent regulations and higher disposal costs (Li et al., 2022).

Synthetic-based muds (SBMs) were developed in response to these environmental concerns. SBMs, also known as Low Toxicity Oil-Based Muds (LTOBM), use synthetic oils as the base fluid. These fluids retain the beneficial properties of OBMs but exhibit significantly lower toxicity levels, making them more suitable for offshore drilling operations where environmental regulations are stricter (Tang et al., 2023).

Despite advancements in synthetic fluids, the search for more sustainable and environmentally friendly alternatives continues. Biodiesel, derived from renewable biological sources, has emerged as a promising candidate. Biodiesel is produced through the transesterification of vegetable oils or animal fats, resulting in a biodegradable and non-toxic fuel (Nazzal et al., 2023). The potential of biodiesel as a drilling fluid base has been recognized due to its environmental benefits, such as lower emissions and better biodegradability compared to traditional petroleum-based fluids (Al-Ansari et al., 2023).

The performance of non-aqueous fluid drilling mud, such as those based on biodiesel, significantly depends on the emulsion stability. Emulsions are mixtures of two immiscible liquids where one liquid is dispersed as small droplets within the other. Emulsifiers are added to stabilize these emulsions and ensure the drilling fluid performs effectively under downhole conditions (Wang et al., 2023). Additionally, lime (calcium hydroxide) is often incorporated into the drilling fluid to increase pH, provide alkalinity, and activate fatty acids in the emulsifier, further stabilizing the emulsion (Liu et al., 2023).

## **I.2 Problem Statement and Significance of Project**

This project addresses the challenge of using biodiesel as a base fluid for drilling muds, particularly related to thermal stability and emulsion performance. Previous research has highlighted biodiesel's potential as a renewable and biodegradable alternative to diesel, but significant limitations have been identified under demanding drilling conditions, including issues with thermal stability and emulsion effectiveness. This project aims to overcome these challenges by blending biodiesel with diesel, leveraging the thermal stability and emulsion performance of diesel while maintaining the environmental advantages of biodiesel. The research will assess the performance of these biodiesel-diesel blends against conventional diesel-based and synthetic-based muds, considering key indicators such as lubricity, shale inhibition, thermal stability, and environmental impact.

## **I.3 Objectives & Scope of Study**

The primary objective of this thesis is to develop and evaluate a biodiesel-diesel blended drilling fluid as a sustainable and effective alternative to conventional diesel and synthetic-based drilling fluids. This objective can be broken down into the following specific goals:

**Table 1: Objectives and scope of study**

<b>Objective</b>	<b>Scope of study</b>
<b>Evaluate the Performance of Biodiesel-Diesel Blends</b>	<ul style="list-style-type: none"><li>○ Assess the performance of biodiesel-diesel blended fluids compared to conventional diesel and synthetic-based muds.</li></ul>
<b>Develop an Optimized Biodiesel-Diesel Blended Drilling Fluid</b>	<ul style="list-style-type: none"><li>○ Identify suitable additives compatible with biodiesel-diesel blends and determine the optimal concentrations for superior mud properties. Conduct tests to refine the formulation for various drilling conditions.</li></ul>
<b>Assess Rheological and Thermal Properties</b>	<ul style="list-style-type: none"><li>○ Study the rheological properties and thermal stability of biodiesel-diesel blended fluids under different temperatures.</li></ul>
<b>Environmental Impact Analysis</b>	<ul style="list-style-type: none"><li>○ Analyze the biodegradability and toxicity of biodiesel-based drilling fluids.</li><li>○ Compare biodiesel-based fluids' environmental impact with conventional diesel and synthetic-based fluids.</li></ul>
<b>Economic Feasibility Study</b>	<ul style="list-style-type: none"><li>○ Evaluate the cost implications and compare the overall cost-effectiveness of biodiesel-diesel blends with conventional diesel and synthetic-based fluids.</li></ul>

#### **I.4 Hypotheses**

- Biodiesel-diesel blends will demonstrate comparable or superior performance in lubrication, shale inhibition, and rheological properties across various temperatures.
- Biodiesel-diesel blends will exhibit higher biodegradability than conventional diesel.
- Specific additives compatible with biodiesel-diesel blends will be identified, and their optimal concentrations will enhance rheological and thermal properties.
- The use of biodiesel-diesel blends will result in cost savings due to simplified waste management and disposal processes.

## **I.5 Relevancy of the Study**

This study on blending biodiesel with diesel in oil-based drilling mud is highly relevant for addressing environmental, economic, and performance challenges in the drilling industry. While biodiesel is a renewable and biodegradable alternative to diesel, its use in drilling fluids faces thermal stability and emulsion performance limitations. Blending it with diesel aims to overcome these issues while maintaining environmental benefits and operational efficiency. This approach could enhance drilling fluid performance, reduce environmental impact, and align with regulatory standards. Additionally, it supports sustainability efforts in the oil and gas sector and aligns with my petroleum engineering studies, helping me develop key industry skills.

## CHAPTER II: LITERATURE REVIEW

This chapter presents a comprehensive review of the literature on drilling fluids, examining their types, properties, applications, and environmental impacts. It covers water-based muds (WBM), oil-based muds (OBM), and biodiesel-diesel blended drilling fluids, outlining their advantages, limitations, and recent advancements. Additionally, it explores biodiesel as a potential drilling fluid component, considering its benefits and challenges. By analyzing previous studies and identifying research gaps, this chapter lays the foundation for the experimental work aimed at optimizing biodiesel-diesel blended drilling mud formulations.

### II.1. Drilling Fluid History Development

Drilling fluids, also known as drilling muds, have undergone significant evolution since their inception, playing a crucial role in the efficiency and success of drilling operations. The development of drilling fluids can be traced back to the early 1900s when water was the primary medium used in drilling operations. However, as drilling activities expanded and encountered more complex geological formations, the limitations of water as a drilling fluid became apparent, leading to the development of more sophisticated formulations.

In the 1920s, the introduction of bentonite clay marked a significant advancement in drilling fluid technology. Bentonite, when mixed with water, created a viscous, gel-like substance that improved the carrying capacity of the fluid, enabling it to transport drill cuttings to the surface more effectively (Baker, 2018). This innovation significantly enhanced drilling efficiency and wellbore stability.

The 1940s and 1950s witnessed further advancements with the development of oil-based muds (OBM). These fluids used petroleum products, such as diesel, as the base fluid, providing superior lubricity, shale inhibition, and thermal stability compared to water-based muds (WBM) (Smith, 2023). OBM became particularly valuable in drilling high-temperature and high-pressure wells, where WBM often failed. However, the environmental impact of using diesel-based fluids led to increasing scrutiny and regulatory constraints.

To address environmental concerns, the 1980s and 1990s saw the emergence of synthetic-based muds (SBM). These fluids used synthetic oils as the base fluid, offering similar performance benefits to OBM but with significantly lower toxicity levels (Tang et al., 2023). SBM became the preferred choice for offshore drilling operations due to their reduced environmental impact and compliance with stringent regulations.

Despite the advancements in synthetic fluids, the quest for more sustainable and environmentally friendly alternatives continued. In recent years, biodiesel has emerged as a promising candidate for drilling fluids. Derived from renewable biological sources, biodiesel is produced through the transesterification of vegetable oils or animal fats. This process results in a biodegradable and non-toxic fuel, which offers environmental benefits such as lower emissions and better biodegradability compared to traditional petroleum-based fluids (Nazzal et al., 2023).

The potential of biodiesel as a drilling fluid base has been recognized due to its favorable properties. Biodiesel-based drilling fluids exhibit excellent lubricity, comparable to OBMs, and enhanced environmental compatibility. These fluids also demonstrate good thermal stability and can be formulated to meet the stringent requirements of modern drilling operations (Al-Ansari et al., 2023). However, challenges such as emulsion stability and the interaction of biodiesel with other drilling fluid additives remain areas of active research.

## **II.2. Drilling Fluid Classification**

Drilling fluids are separated into three major classifications:

- Pneumatic
- Oil-Based
- Water-Based

### **II.2.1 Pneumatic**

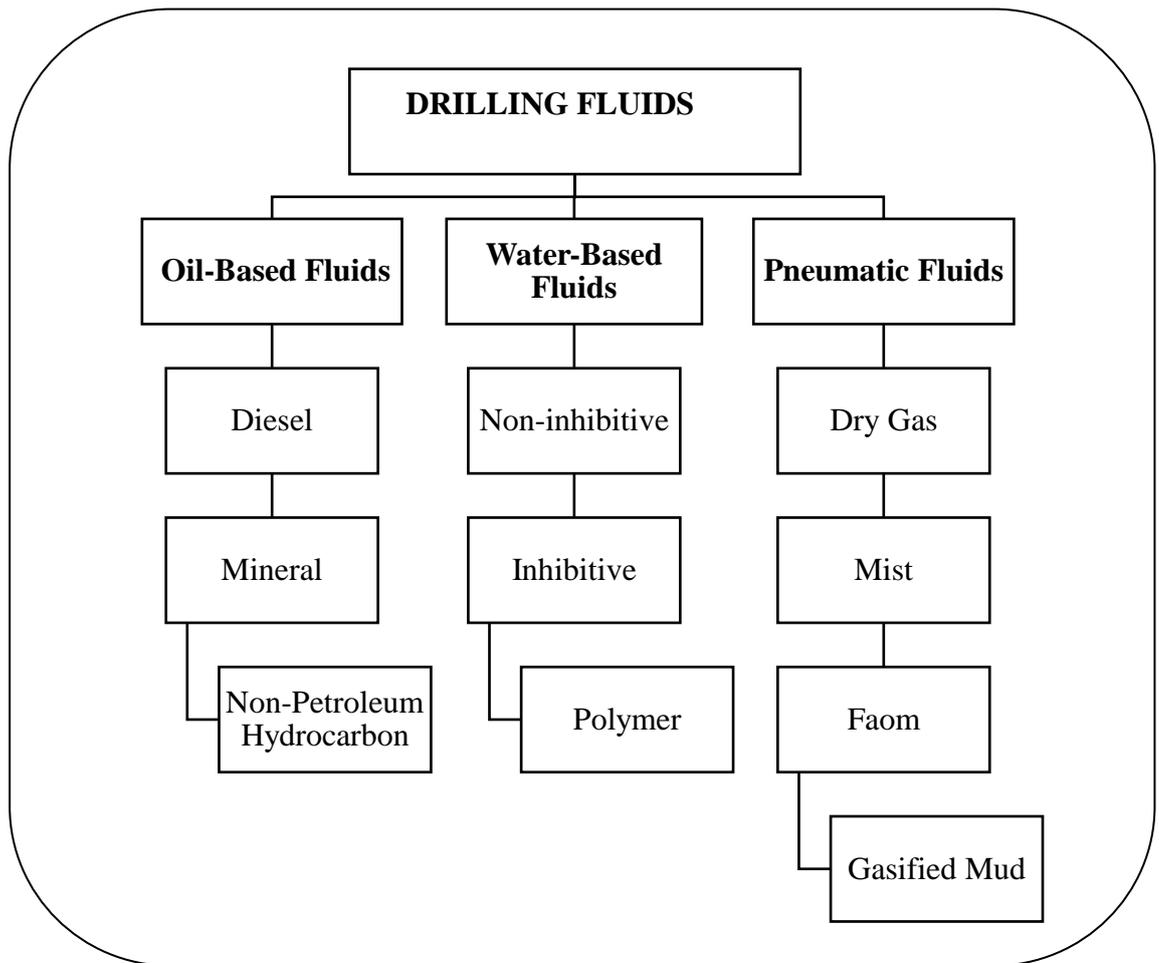
Pneumatic fluids, which use air or gas, are ideal for drilling in depleted zones or formations with abnormally low pressures, offering higher penetration rates than liquid-based muds. Their high-pressure differential efficiently removes cuttings from the bit and allows formation fluids to flow into the wellbore. However, they become ineffective in formations with high fluid influx, often requiring a switch to liquid-based systems, which increases the risk of lost circulation and formation damage. Additionally, pneumatic fluids are generally unsuitable for wells deeper than 10,000 feet, as the required air volume may exceed surface equipment capacity (Amoco Corporation, 1994).

## **II.2.2 Oil-Based Fluids**

Oil-based mud (OBM) is a drilling fluid where oil is the continuous phase, with water content between 2% and 5%. It is commonly used in high-temperature, deep, and challenging formations, such as salt and soft shale, where stability and lubrication are crucial. OBMs, made from fluids like diesel and mineral oils, offer superior thermal stability and lubricity, making them ideal for directional and horizontal drilling. However, they are expensive and require strict pollution controls. Invert emulsion OBM uses mineral oil as the external phase and CaCl<sub>2</sub> brine as the internal phase, while pseudo-oil-based muds (SOBMs) are biodegradable alternatives with lower toxicity but higher costs. Full-oil muds, with less than 5% water, offer excellent thermal stability and fluid loss control but need specialized additives to maintain their properties (Hossain, M.E., Al-Majed, A., & Apaleke, A.S., 2012).

## **II.2.3 Water-Based Fluids**

Water-based fluids (WBFs) are the most commonly used drilling fluids due to their cost-effectiveness, ease of formulation, and adaptability to different drilling conditions. They are classified into non-inhibitive, inhibitive, and polymer fluids based on their ability to control clay swelling. Non-inhibitive fluids, often used as spud muds, contain native clays or bentonite with additives like caustic soda and dispersants but offer minimal clay inhibition. Inhibitive fluids use cations such as sodium, calcium, or potassium to reduce clay swelling, with potassium and calcium providing the highest inhibition, though disposal costs can be significant. Polymer fluids modify mud properties through macromolecules and can be either inhibitive or non-inhibitive, serving functions like viscosity control, filtration reduction, and solids encapsulation. Some polymer systems withstand temperatures up to 400°F, but their efficiency can decline due to solids accumulation, increasing maintenance costs (Amoco Corporation, 1994).



**Figure 1: Drilling Fluids Classification (Amoco Corporation, 1994).**

### **II.3. Composition of Drilling Fluids**

Drilling muds are classified into water-based muds (WBMs), oil-based muds (OBMs), and synthetic-based muds (SBMs) based on their primary fluid phase. The composition of these muds varies depending on well conditions, drilling objectives, and environmental considerations. Table 2 provides a detailed comparison of the compositions of different drilling mud types.

**Table 2: Composition of Mud (Hossain, M.E., Al-Majed, A., & Apaleke, A.S., 2012).**

<b>Water-Based Mud</b>	<b>Oil-Based Mud</b>	<b>Synthetic-Based Mud</b>
<ul style="list-style-type: none"> <li>– Bentonite (0 to 50)</li> <li>– Barite (0 to 500)</li> <li>– Caustic Soda (0 to 5)</li> <li>– Soda Ash (0 to 3)</li> <li>– Sodium bicarbonate (0 to 3)</li> <li>– Seawater (any portion)</li> <li>– Freshwater (any portion)</li> <li>– Drill solids (0 to 100)</li> </ul>	<ul style="list-style-type: none"> <li>– Barite (60.8%)</li> <li>– Base oil (31.3 %)</li> <li>– CaCl<sub>2</sub> (3.3%)</li> <li>– Emulsifier (2.2 %)</li> <li>– Filtrate control/ wetting agent (1.8%)</li> <li>– Lime (0.2%)</li> <li>– Viscosifier (0.2%)</li> </ul>	<ul style="list-style-type: none"> <li>– A drilling fluid whose continuous phase is composed of one or more fluids produced by the reaction of specific purified chemical feedstock, rather than through physical separations such as cracking and hydro processing</li> </ul>

## **II.4. Functions of Drilling Fluids**

### **II.4.1 Major Functions**

Drilling fluids are designed and formulated to perform three major functions:

- Control Subsurface Pressure
- Transport Cuttings
- Support and Stabilize the Wellbore

#### **a) Control Subsurface Pressure**

Drilling fluids control subsurface pressure by maintaining hydrostatic pressure, which depends on fluid density and true vertical depth (TVD). This pressure counteracts formation pressures, preventing wellbore instability and uncontrolled fluid influx. Borehole instability results from mechanical stresses and physicochemical interactions between the fluid and formation. The natural pressure gradient is about 0.465 psi/ft (8.94 ppg), similar to seawater. In normal conditions, freshwater-based fluids with incorporated solids can balance pressures, but abnormally pressured formations require higher-density fluids. Improper pressure management can lead to kicks or blowouts, posing significant safety risks. (Amoco Corporation, 1994).

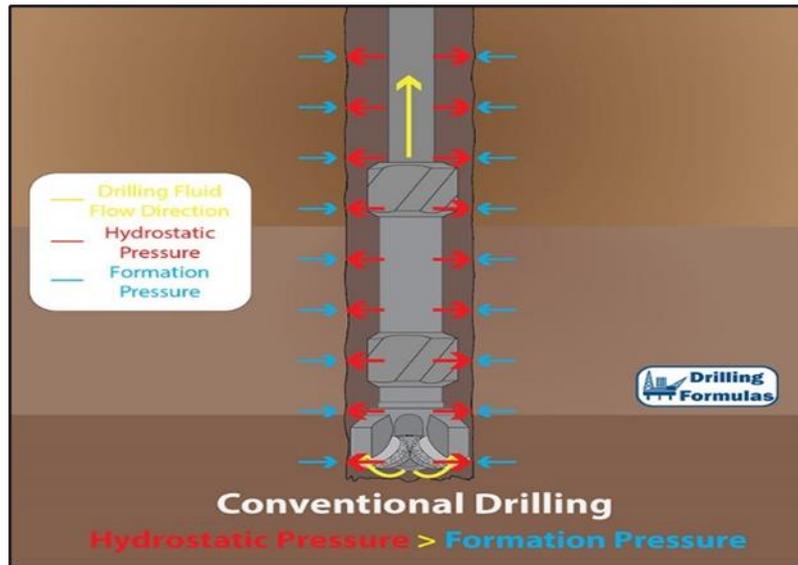


Figure 2: conventional drilling (DrillingFormulas.com).

### b) Transport Cuttings

Drilling fluid is essential for removing rock cuttings generated by the drill bit, preventing accumulation that could reduce drilling efficiency and cause pipe sticking. It must transport cuttings to the surface during circulation, suspend them when circulation stops, and allow their removal at the surface. Effective cuttings transport depends on annular velocity, density, and viscosity, while suspension relies on thixotropic properties that form a gel when circulation ceases. Surface equipment like shale shakers, desanders, and desilters aid in solids removal to maintain proper rheology (Heriot-Watt University 2024).

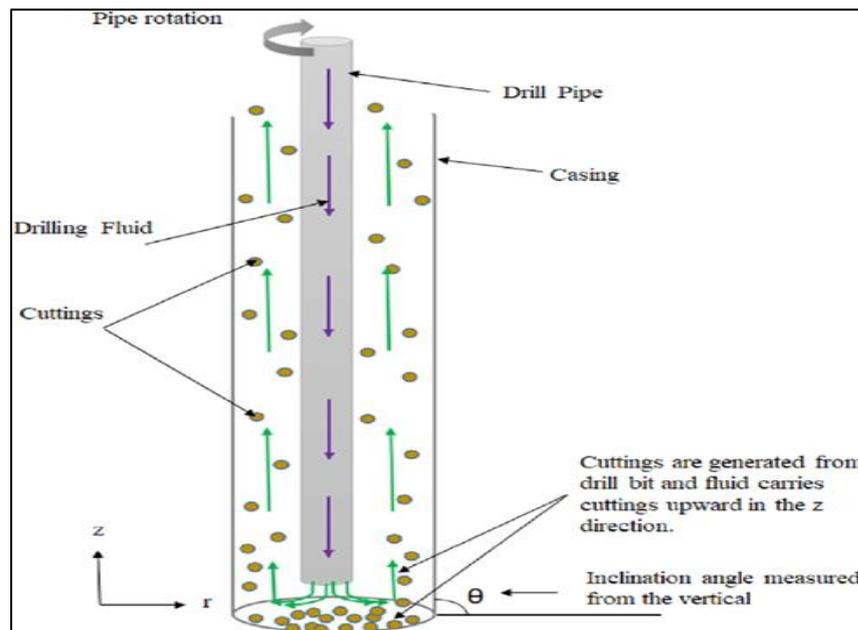


Figure 3: Schematic diagram of cuttings transport in the annulus (Awad et al., 2021)

### c) Support and Stabilize Wellbore

The hydrostatic pressure of drilling fluids helps maintain wellbore stability by reinforcing the formation through a properly formed filter cake, which minimizes collapse risks. Stability also depends on controlling fluid loss to permeable formations and managing the fluid's chemical composition to prevent adverse reactions. While whole mud cannot invade most formations, filtrate can enter pore spaces depending on the pressure differential and filter cake quality. Excessive filtrate loss or chemical incompatibility can weaken the formation, causing hole enlargement, sloughing, and instability. Poor filter cakes may lead to tight hole conditions, stuck pipe, and cementing issues, making proper mud design and filtrate control essential for wellbore integrity. (Amoco Corporation, 1994).

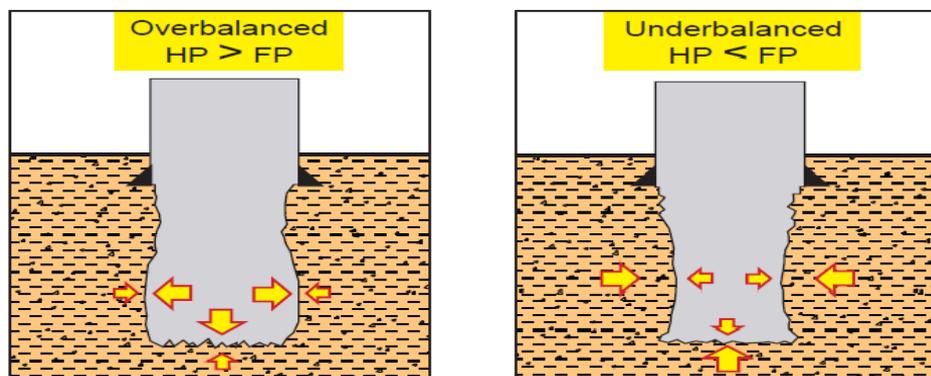


Figure 4: Bottom Hole Pressure Concept (DrillingCourse.com, 2017).

#### II.4.2 Minor Functions

Minor functions of a drilling fluid include:

- Support Weight of Tubulars
- Cool and Lubricate the Bit and Drill String
- Transmit Hydraulic Horsepower to Bit
- Provide Medium for Wireline Logging
- Assist in the Gathering of Subsurface Geological Data and Formation Evaluation
- Cool and Lubricate the Bit

## II.5. Additives for Oil-Based Mud

**Table 3: Additives for Oil-Based Mud (Hossain & Apaleke, A.S., 2012)**

<b>Additive Type</b>	<b>Function</b>
<b>Emulsifiers</b>	Stabilize the water-in-oil emulsion, preventing phase separation. Classified into primary (fatty acid soaps) and secondary emulsifiers for enhanced stability.
<b>Wetting Agents</b>	Convert water-wet solids into oil-wet solids to prevent settling and maintain emulsion stability. Used in high-density fluids to ensure uniform dispersion.
<b>Organophilic Clays</b>	Provide viscosity control by suspending solids, preventing settling, and maintaining gel strength for effective hole cleaning.
<b>Lime (Ca(OH)<sub>2</sub>)</b>	Maintains alkaline pH (8.5–10.0) for corrosion prevention, enhances emulsifier performance, neutralizes acidic gases (CO <sub>2</sub> , H <sub>2</sub> S), and controls calcium levels.
<b>Density Control (Weighting Agents)</b>	Barite (BaSO <sub>4</sub> ) for high-density muds; Calcium Carbonate (CaCO <sub>3</sub> ) for lower-density applications and reservoir drilling fluids.
<b>Filtration Control</b>	Asphalt, gilsonite, and polymeric agents reduce filtrate invasion and enhance fluid loss control in high-temperature conditions.
<b>Alkalinity Control</b>	Ensures proper emulsifier function and corrosion control, particularly in CO <sub>2</sub> or H <sub>2</sub> S-exposed environments. Maintains OBM pH between 8.5–10.0.
<b>Water Content Control</b>	Prevents emulsion instability and excessive viscosity caused by water evaporation. Uses emulsifiers to stabilize water-in-oil emulsions.
<b>Lubricants &amp; Surfactants</b>	Reduce torque, friction, and differential sticking in extended-reach and horizontal wells. Includes diesel, fatty soaps, and gilsonite.

## II.6. Mathematica Fluid Models

A mathematical fluid model defines the relationship between shear rate and shear stress to describe fluid flow behavior. Newtonian fluids follow a linear relationship where shear stress is directly proportional to shear rate. In contrast, non-Newtonian fluids exhibit a more complex correlation, requiring specialized models to approximate their flow characteristics. Although no single equation fully captures non-Newtonian behavior, models such as the Bingham Plastic Model and Power Law Model provide useful approximations for engineering applications (Darley & Gray, 2011).

### II.6.1 Newtonian Fluid Model

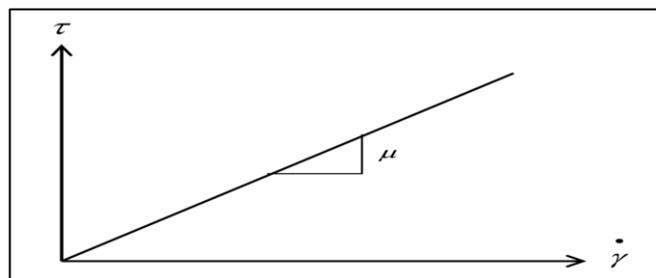
The Newtonian Fluid Model serves as the foundation for developing other fluid models. As previously discussed, the flow behavior of Newtonian fluids follows a simple relationship between shear stress and shear rate, expressed by the equation:

$$\tau = (\mu)(\dot{\gamma}) \dots\dots\dots (1)$$

where:

- $\tau$ = shear stress
- $\mu$ = viscosity
- $\dot{\gamma}$ = shear rate

At a constant temperature, shear stress is directly proportional to shear rate, with viscosity ( $\mu$ ) acting as the proportionality constant. This means Newtonian fluids maintain a constant viscosity regardless of the applied shear rate (Baker Hughes INTEQ, 2006). The flow curve is a straight line passing through the origin (0,0). The slope of this line represents the viscosity ( $\mu$ ), demonstrating the linear relationship between shear stress and shear rate.



**Figure 5: Flow Curve for a Newtonian Fluid (Hasanzadeh, B. 2017).**

## II.6.2 Non-Newtonian Fluids

### a) Bingham Plastic Model

The Bingham Plastic Model describes a non-Newtonian fluid that requires a minimum shear stress, known as yield stress, before it starts to flow. Unlike Newtonian fluids, which flow immediately upon force application, Bingham plastics remain rigid under low stress and only begin moving once the applied force exceeds the yield point. After this threshold, the fluid flows with a constant viscosity, termed plastic viscosity (Hossain & Al-Majed, 2015).

The relationship between shear stress and shear rate for a Bingham Plastic fluid is expressed as:

$$\tau = \tau_0 + \mu_{\infty} \dot{\gamma} \dots\dots\dots (2)$$

where:

- $\tau$  = shear stress
- $\tau_0$  = yield point
- $\mu_{\infty}$  = plastic viscosity
- $\dot{\gamma}$  = shear rate

The flow curve for a Bingham Plastic fluid illustrates how its effective viscosity defined as shear stress divided by shear rate varies with shear rate. The effective viscosity decreases as shear rate increases, meaning that at higher shear rates, the fluid flows more easily.

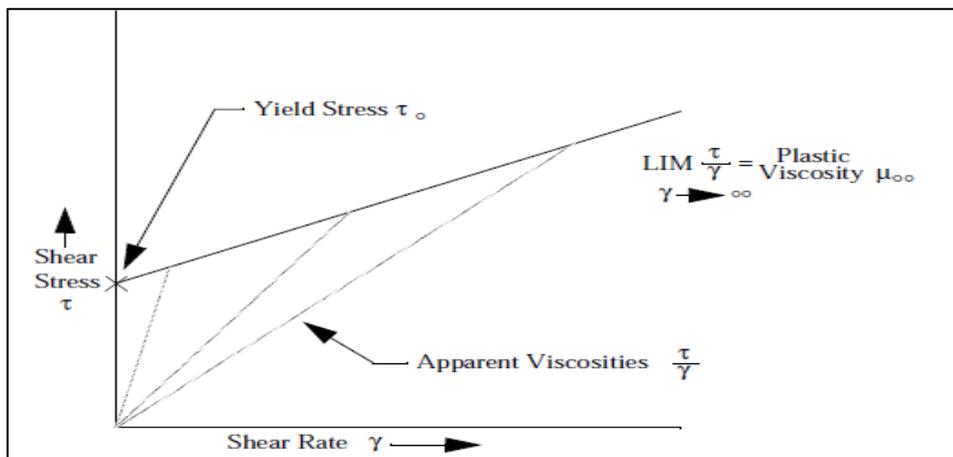


Figure 6: Flow Curve for a Bingham Plastic Fluid (Petroleum and Gas Engineering, 2016)

## b) Power Law Model

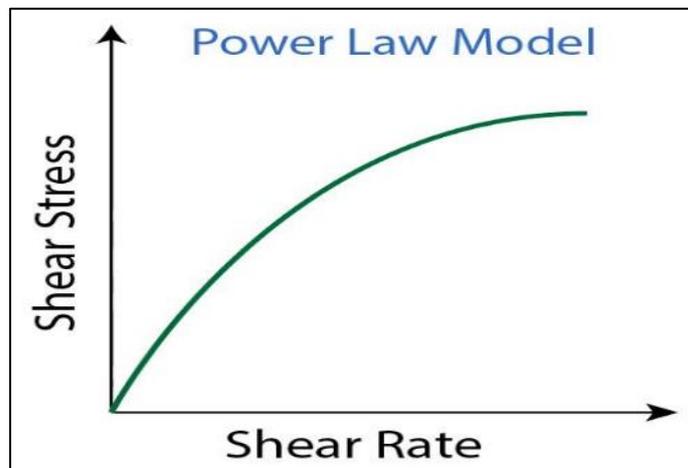
The Power Law Model describes the flow behavior of pseudo-plastic (shear-thinning) fluids, where viscosity is not constant but decreases as shear rate increases. Unlike Newtonian fluids with a linear shear stress-shear rate relationship and Bingham plastics that require a yield stress, pseudo-plastic fluids flow immediately when shear is applied, with resistance reducing at higher shear rates (Hossain & Al-Majed, 2015). The relationship between shear stress and shear rate for pseudo-plastic fluids is described by the Power Law model:

$$\tau = k\gamma^n \dots\dots\dots (3)$$

where:

- $\tau$  = shear stress
- $K$  = consistency factor
- $\gamma$  = shear rate
- $n$  = flow behavior index

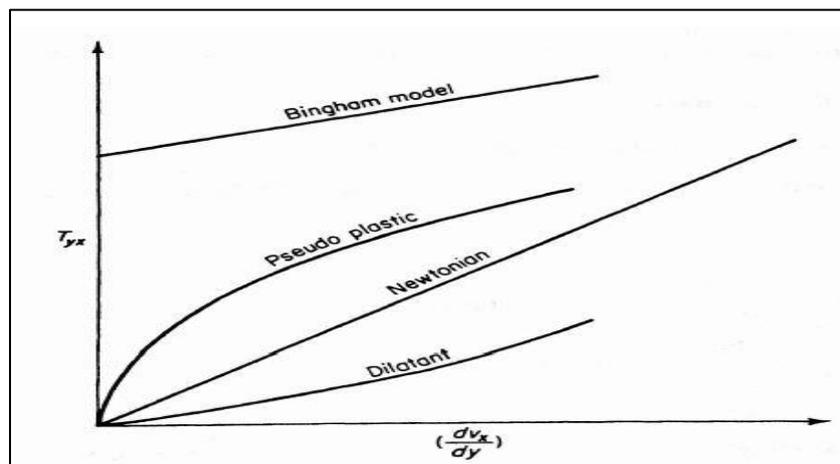
The flow curve of a pseudo-plastic fluid is illustrated in Figure 7.



**Figure 7: Flow Curve for a Power Law Fluid (Drilling Formulas).**

In the Power Law Model, the two constants  $K$  and  $n$  define the fluid's flow behavior. The parameter  $K$ , known as the consistency factor, represents the thickness of the fluid and is somewhat analogous to effective viscosity. An increase in  $K$  corresponds to a more viscous drilling fluid, effectively describing its shear stress-shear rate relationship.

The parameter  $n$ , called the flow behavior index, indicates the degree of non-Newtonian behavior. When  $n=1$ , the Power Law Model simplifies to the Newtonian Model, meaning the fluid exhibits constant viscosity. If  $n$  is greater than 1, the fluid is classified as dilatant, meaning its viscosity increases as shear rate increases. However, most drilling fluids exhibit pseudo-plastic behavior, characterized by  $n$  values between zero and one. Pseudo-plastic fluids display shear-thinning properties, where viscosity decreases as shear rate increases, similar to the Bingham Plastic Model. Figure 8 illustrates the flow curves for different values of  $n$  (Baker Hughes INTEQ, 2006).



**Figure 8: Flow Behavior for Power Law Fluids (Chegg, Bingham fluid)**

## II.7. Biodiesel Definition

Biodiesel is a renewable diesel fuel made from vegetable oils or animal fats through transesterification, where triglycerides react with alcohol to produce mono-alkyl esters (biodiesel) and glycerol as a byproduct. Unlike petroleum diesel, it lacks sulfur and aromatic compounds, resulting in lower emissions of soot, carbon dioxide, and particulate matter. Biodiesel is environmentally friendly, derived from renewable sources, and can be used in diesel engines with minimal modifications, supporting sustainable energy solutions (Khoudrane, 2020).

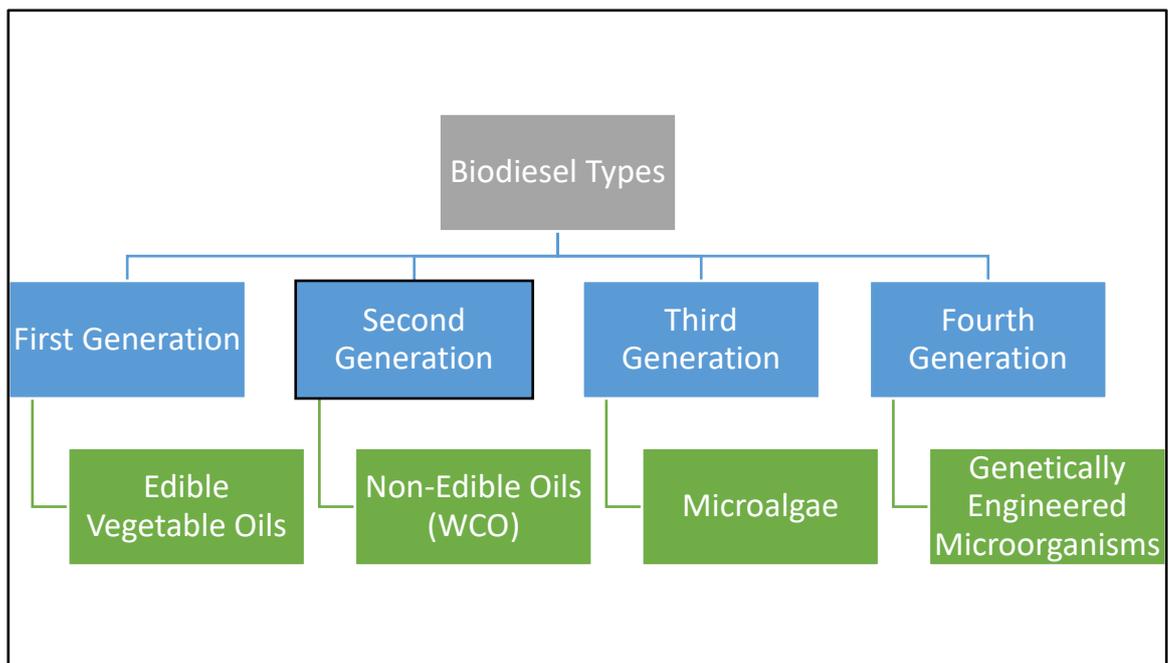
## II.8. Biodiesel Types

Biodiesel can be classified based on its feedstock and generation. First-generation biodiesel is primarily derived from edible vegetable oils, such as soybean, sunflower, and palm oil, which are widely available but raise concerns about food security (Demirbas, 2009). In response, second-generation biodiesel is produced from non-edible oils (e.g., Jatropha and neem), waste

cooking oil (WCO), and animal fats, offering a more sustainable and cost-effective alternative (Atabani et al., 2012).

Researchers have explored third-generation biodiesel, which utilizes microalgae as a feedstock to further improve biodiesel sustainability. Microalgae have a higher lipid content than conventional crops and do not compete with food production, making them an efficient biodiesel source (Chisti, 2007). More recently, fourth-generation biodiesel has emerged, leveraging genetically engineered microorganisms to directly produce biodiesel-like compounds, reducing land use and enhancing biofuel production efficiency (Lee & Lavoie, 2013).

Given the environmental benefits and diverse feedstock options, biodiesel continues to gain global attention as a viable alternative to fossil fuels, particularly in industries seeking lower carbon emissions and enhanced fuel sustainability (Khoudrane, 2020).



**Figure 9: Biodiesel types according to source and generation**

## **II.9. Transesterification Process:**

The transesterification process is the most commonly used method for biodiesel production, involving the reaction of triglycerides (oils or fats) with an alcohol (typically methanol or ethanol) in the presence of a catalyst to produce fatty acid methyl esters (FAME) and glycerol as a byproduct. This reaction reduces the viscosity of the feedstock, making biodiesel suitable for use in diesel engines (Demirbas, 2009).

The general reaction follows this equation:

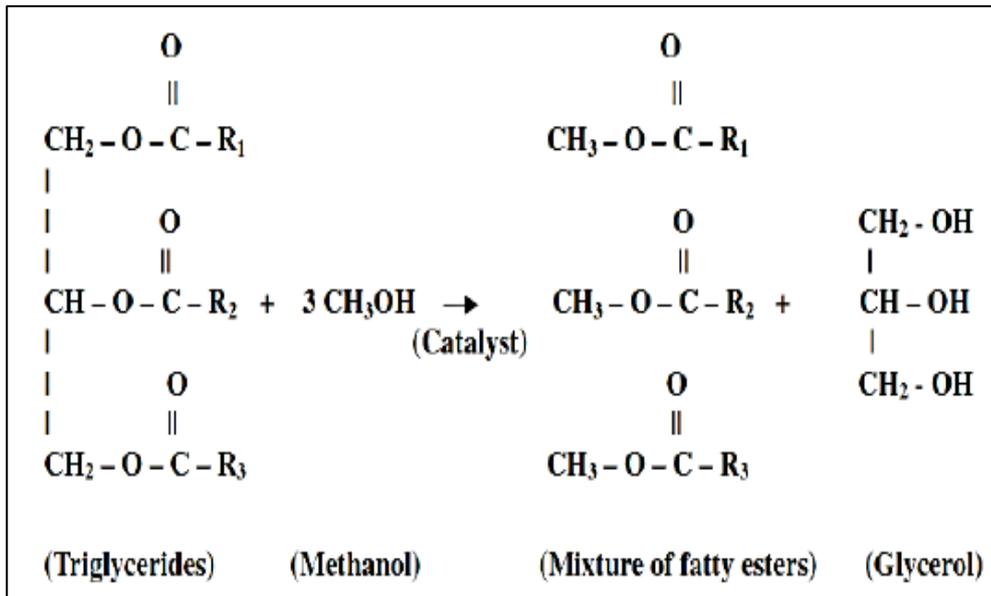


Figure 10: The transesterification Reaction (Knothe, G. 2015).

## CHAPTER III: METHODOLOGY

This research is an experimental study aimed at evaluating the use of biodiesel derived from waste cooking oil (WCO) in drilling fluid formulations. Before initiating laboratory work, preliminary research was conducted through a literature review to understand the theoretical background and identify knowledge gaps related to biodiesel applications in drilling operations. However, the information available on using biodiesel-diesel blends as a continuous phase in drilling fluids is limited, which justifies the need for experimental validation.

The experimental work is divided into three main phases. The first phase involves the characterization of biodiesel produced from WCO. Several physicochemical properties are measured, including viscosity, density, flash point, cloud point, pour point, and water content. These tests are carried out using various instruments to ensure accuracy and repeatability, and to determine whether the biodiesel meets the standards required for drilling fluid applications.

In the second phase, the produced biodiesel is used as the base fluid in the preparation of drilling fluids. The rheological behavior of these biodiesel-based muds is evaluated by performing tests such as plastic viscosity, yield point, gel strength, emulsion stability, and high-temperature high-pressure (HTHP) fluid loss. These tests are essential for assessing the fluid's performance under simulated downhole conditions.

Finally, the results obtained from the experimental phases were analyzed and discussed in comparison with conventional diesel- and synthetic-based drilling fluids. The findings are evaluated in relation to industry standards, highlighting key challenges, potential optimizations, and the broader implications for sustainable drilling fluid development. This experiment has been conducted completely in Kasdi Merbah & Sonatrach Laboratories.

### III.1 Project Work

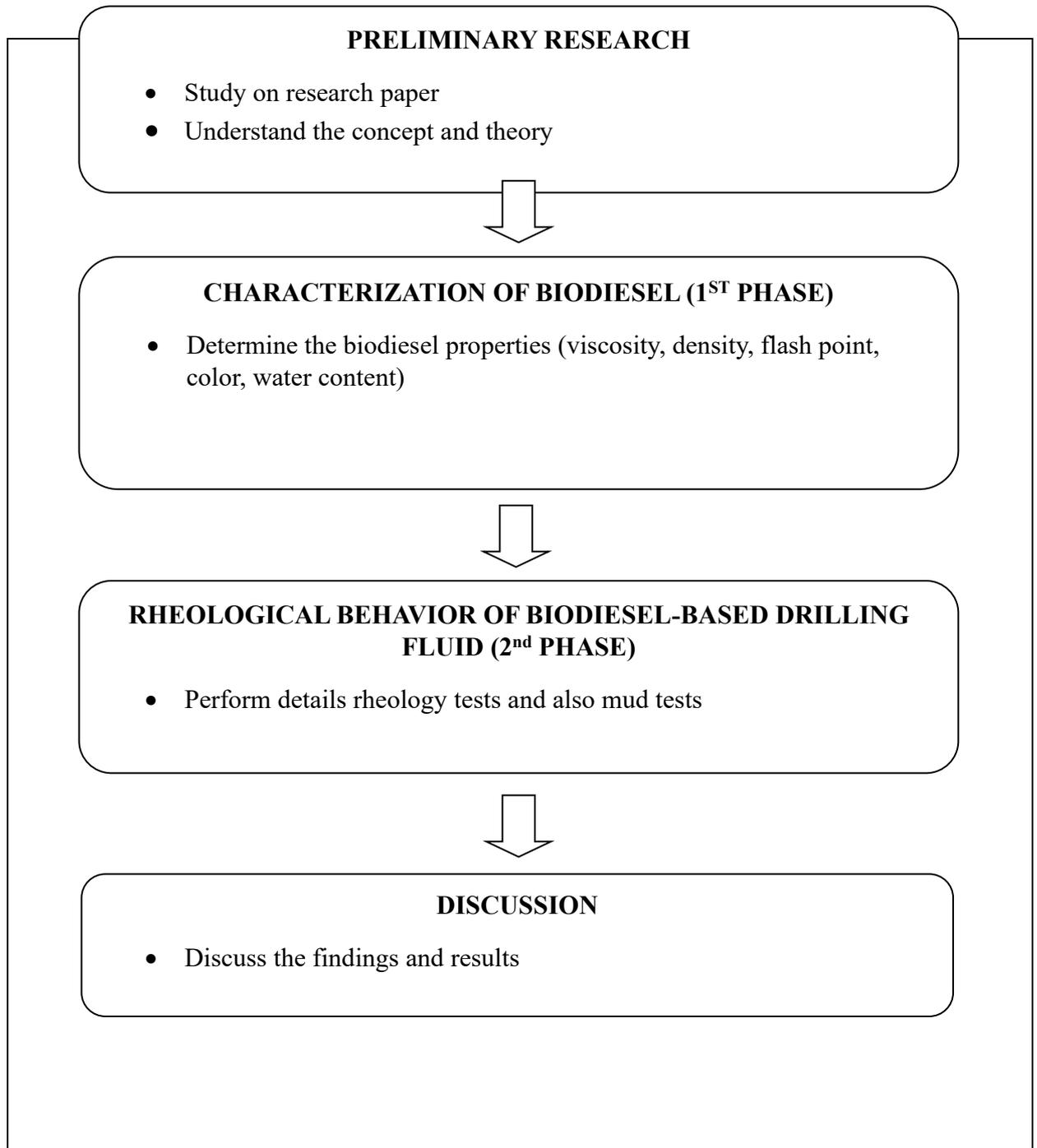


Figure 11: Project Workflow

## III.2 Biodiesel Production from Waste Cooking Oil:

### III.2.1 Materials and equipment:

Table 4: Materials and products used in biodiesel production.

Products	Materials
- Methanol. - Waste cooking oil. - NAOH. - Distill.	- Thermometer. - Balance. - Beaker. - Magnetic stirrer with hot plate. - Separatory funnel. - Magnet.

### III.2.2 Experimental Procedure:

#### a) Waste cooking oil preparation

The Waste Cooking Oil (WCO) has food particles, polymer and decomposition products, that are very unfavorable for the transesterification and would affect the Biodiesel production, Thus, the pretreatments of WCO including physical and chemical treatments are necessary before starting the reaction

- Firstly, the WCO was filtered to remove any food particles.
- Secondly, WCO was heated to 100°C remove any water drops that may be contained in the oil.



Figure 12: Pre-treatment of WCO

## b) Reaction

- Methanol was mixed with of hydroxide sodium NAOH in a beaker, placed on a magnetic stirrer until the NAOH is totally solved in the methanol, and acquire the methoxide solution.
- Prepared oil were cooled to the reaction temperature 55°C to 60°C, then the produced methoxide was added to the oil, placed on the magnetic stirrer with hot plate at 65°C, the stirrer is switched on during the reaction at a speed of 400 rpm. The reaction lasts up to 2 hours.

## c) Separation

After the transesterification, the mixture obtained was is poured into Separator funnel where the mixture rests for more than 8 hours, incrementally, two phases appear as shown in figure 13.

- The upper phase is the biodiesel obtained, and the lower phase is glycerol.
- Glycerol can be used in many other important productions, such as soap.
- By opening the separator funnel van cautiously, the glycerol is allowed to fall into a beaker, and the van is closed quickly when only biodiesel is left in the separation funnel.



**Figure 13: Biodiesel separation.**

## d) Washing biodiesel

- Washing biodiesel is a necessary step to remove the residues of methanol, NaOH, soap, and glycerol, by washing the biodiesel carefully several times with hot distilled water, with one minute of shaking.
- Washed biodiesel must rest for 2 hours to separate the water and biodiesel.



**Figure 14: washing biodiesel**

#### **e) Drying Biodiesel**

- The biodiesel obtained was dried on the hot plate at 100°C for 2 hours to remove any water content.



**Figure 15: Drying process of the produced biodiesel**

### III.3 Physico-Chemical Analyses of Biodiesel

#### III.3.1 Flash Point Tester

The flash point is the minimum temperature at which the vapors of a liquid form a flammable mixture with air under the action of an ignition source. This test method allows the flash point to be determined in a temperature range from 40 to 360°C (Anton Paar, n.d).



Figure 16: Flash point tester - Anton Paar

#### III.3.2 Densimeter

Density, defined as the mass per unit volume of a liquid, is a key indicator of biodiesel quality and energy content. The DMA 4500 M digital density meter by Anton Paar uses oscillating U-tube technology to determine biodiesel density with high precision, typically measured at a reference temperature of 15°C (Anton Paar, n.d).



Figure 17: Densimeter DMA-4500

### III.3.3 Viscometer

Viscosity is a measure of a fluid's resistance to flow, influencing fuel injection and atomization in diesel engines. The SVM 3001 Stabinger Viscometer measures both dynamic and kinematic viscosity at standard temperatures (typically 40°C and 100°C), in accordance with ASTM D445. This dual-parameter device enhances the efficiency of viscosity analysis in biodiesel testing (Anton Paar, n.d).



Figure 18: Viscometer SVM 3001

### III.3.4 Colorimeter

The color of biodiesel serves as a qualitative indicator of its purity and the effectiveness of the transesterification process. Devices like the LICO 620 Colorimeter by Lovibond evaluate the optical properties of biodiesel and compare them against standard color scales, supporting compliance with ASTM D6751 (Lovibond, n.d.).



Figure 19: Colorimeter-LICO 620

### III.3.5 Coulometer

Moisture content is a critical factor affecting the storage stability and combustion characteristics of biodiesel. The Karl Fischer coulometric titration method is widely used for its high sensitivity in detecting trace amounts of water. Instruments such as the Metrohm Coulometric KF Titrator ensure precise quantification of water content in biodiesel samples (Metrohm, n.d.).



Figure 21: Coulometer 917



Figure 20: Balance Mettler Toledo

## III.4 Properties of Drilling Fluids

### III.4.1 Density

Density, also known as mud weight, is one of the most crucial properties of drilling fluids. It is measured in pounds per gallon (ppg) or kilograms per cubic meter ( $\text{kg}/\text{m}^3$ ). The density of the mud must be carefully controlled to ensure that it provides sufficient hydrostatic pressure to prevent formation fluids from entering the wellbore, a condition known as a blowout. Conversely, excessive mud density can lead to fracturing the formation, resulting in lost circulation (Kelessidis et al., 2022).



Figure 22: Mud Balance

### III.4.2 Plastic viscosity and Yield point

Plastic viscosity (PV) depends on the concentration of solids and the viscosity of the liquid phase, while yield point (YP) represents the electrochemical attraction between particles. Together, they control the mud's flow behavior and its ability to carry cuttings to the surface (Patel et al., 2020).



**Figure 23: Rheometer to measure rheological properties**

### III.4.3 Gel strength

Gel strength is the measure of a fluid's ability to suspend solids when circulation stops. It is essential for maintaining wellbore stability and preventing cuttings from settling at the bottom of the hole. Gel strength is measured at different time intervals to assess the mud's thixotropic behavior, which helps in avoiding issues like stuck pipe and excessive pressure surges during restarting circulation (Ahmed et al., 2021).

### III.4.4 Filtration Control

Filtration control is the ability of the mud to form a thin, impermeable filter cake on the walls of the wellbore. This property minimizes the invasion of drilling fluids into the formation, reducing the risk of formation damage and wellbore instability. Low fluid loss is achieved through the use of additives that enhance the mud's sealing properties (Smith, 2023).



**Figure 24: HPHT Filtrate**

### **III.4.5 Electric stability**

Emulsion stability is particularly important for non-aqueous muds (NAMs) like oil-based and synthetic-based muds. It ensures that the emulsion remains stable under downhole conditions, preventing phase separation and maintaining the mud's performance. Emulsifiers are used to stabilize the emulsion and are crucial for the mud's overall stability and effectiveness (Wang et al., 2023).



**Figure 25: Electric stability tester**

### **III.5 Experimental Evaluation of Diesel/Biodiesel Blends:**

As part of the experimental phase of my research, I formulated and tested eleven diesel/biodiesel blends ranging from 100% diesel to 100% biodiesel, including intermediate ratios such as 90D/10B, 80D/20B, and so on. The mud formulation used was based on a field-proven oil-based mud system designed for the 12¼" phase in the Hassi Messaoud field, where the electrical stability (ES) of the mud must exceed 1000 volts, ensuring proper emulsion quality and thermal resilience.

Each blend was evaluated for key rheological parameters — plastic viscosity (PV) and electric stability, both before and after hot rolling to simulate thermal aging. Electrical stability tests were also conducted to verify that the mud maintained stable emulsion properties under high-temperature conditions.

**Table 5: Mud formulation for oil-based drilling fluid, Hassi Messoud field 12<sup>1/4</sup> phase**

<b>Mud Materials</b>	<b>Mixing Time (min)</b>	<b>Speed</b>
Diesel	/	/
Primary Emulsifier	5	Medium
Secondary Emulsifier	5	Medium
Lime	10	Medium
Water	15	High
NaCl		
Viscosifier	10	High
Fluid Loss Agent	10	High
Weighting Agent	5	High
Barit	30	High

## CHAPTER IV: RESULTS & DISCUSSION

### IV.1 Characterization of Biodiesel (1<sup>st</sup> phase)

The first step in this study was to examine the properties of the prepared biodiesel samples. This assessment aimed to determine whether the samples met the requirements of the ASTM D6751:06b standard for biodiesel fuel. The table below presents the physicochemical properties of the biodiesel produced during this project.

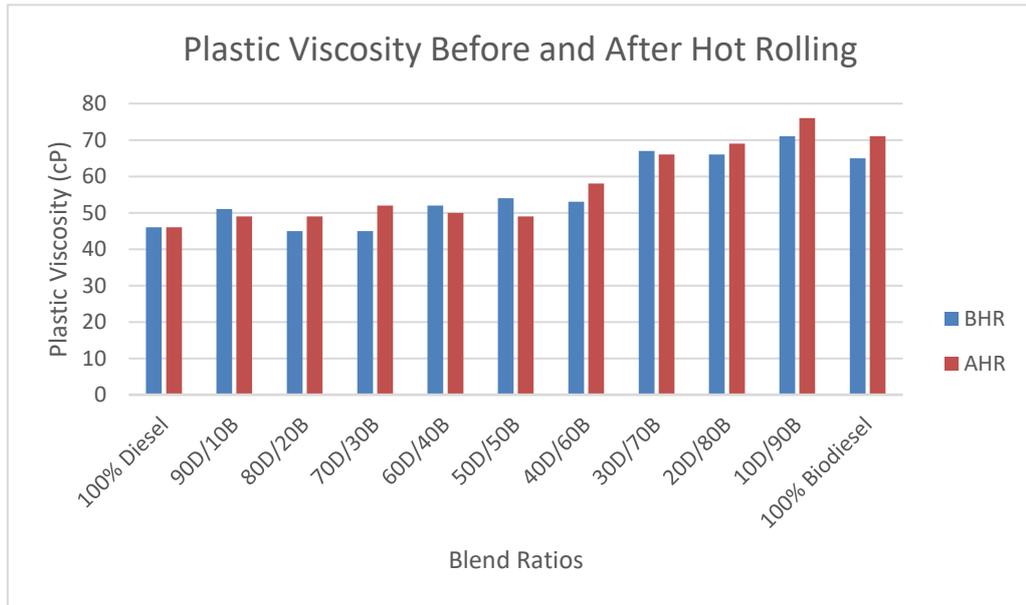
**Table 6: Physicochemical characteristics of biodiesel (Khoudrane, 2020).**

SAMPLE INFORMATION			
<b>Sample identification:</b> Biodiesel-B100			
<b>Date of receipt:</b> April 9, 2025			
<b>Date of preparation:</b> February 2025			
<b>Type of sample:</b> Biofuel			
Physicochemical measurements	Standards	Units	Limit according to ASTM D6751
Kinematic viscosity at 40°C	ASTM D 7042	mm <sup>2</sup> /s	1.9-6
Dynamic viscosity at 40°C	ASTM D 7042	MPa.s	/
Density at 15°C	ASTM D 4052	g/cm <sup>3</sup>	0.80-0.90
Flash point	ASTM D 93	°C	Min 130
Contamination	Standards	Units	Limit according to ASTM D6751
Water content	ASTM D 6304	ppm	Max 500
ASTM color	ASTM D 6045	/	/

## IV.2 Rheological Behavior of Biodiesel-Based Drilling Fluid (2<sup>nd</sup> phase)

The table below presents the results of the rheological and electrical stability tests for different diesel/biodiesel blends before and after hot rolling.

### IV.2.1 Plastic Viscosity

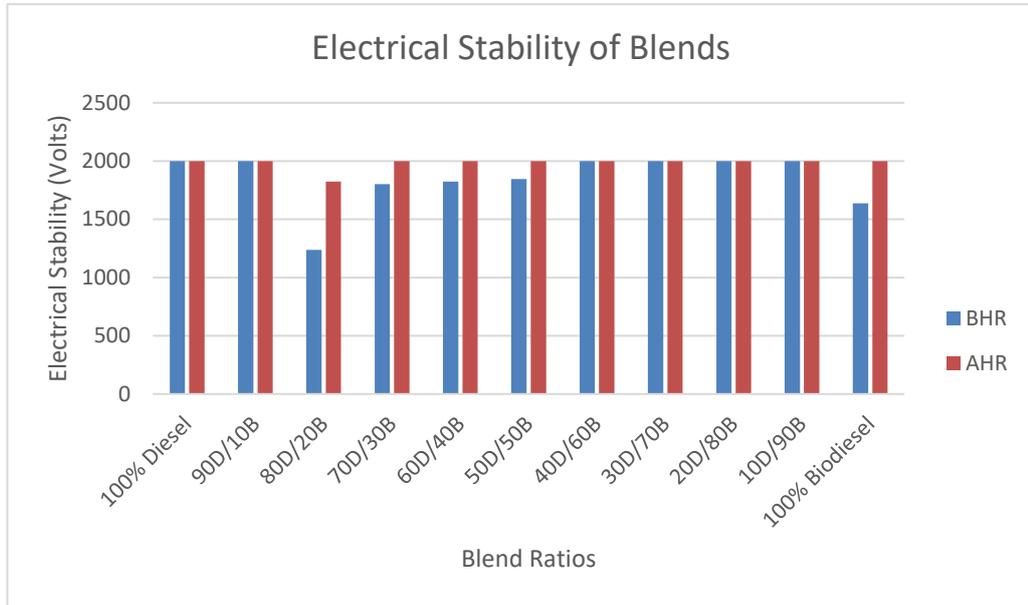


**Figure 26: Plastic Viscosity Comparison of Biodiesel-Diesel Blends**

The graph "Plastic Viscosity Before and After Hot Rolling" evaluates the flow resistance of biodiesel-diesel blends under thermal stress, with the y-axis showing plastic viscosity (PV) in centipoise (cp) (10–80 cp) and the x-axis representing blend ratios from 100% diesel (0% biodiesel) to 100% biodiesel (B100).

Mid-range blends (30-60% biodiesel) demonstrate excellent stability, with viscosity values remaining within the 40-60 cp range after hot rolling, indicating robust thermal resistance. These results suggest that such blends maintain optimal fluidity for efficient cuttings transport even in high-temperature downhole conditions. Pure biodiesel (B100) shows higher initial viscosity (70-80 cp) due to its molecular structure, but exhibits greater susceptibility to thermal degradation, likely attributable to oxidation and residual water content. The minimal viscosity variation in optimal blends confirms their potential as reliable alternatives to conventional diesel-based fluids, particularly for operations where temperature fluctuations are significant.

## IV.2.2 Electrical Stability



**Figure 27: Electrical Stability of Biodiesel-Diesel Emulsions**

The "Electrical Stability of Blends" graph measures emulsion integrity, with the y-axis showing voltage (0–2500 V) and the x-axis indicating blend compositions. The data clearly shows that mid-range biodiesel blends maintain electrical stability values well above the critical 1000V threshold, with many exceeding 1500V even after hot rolling. This demonstrates that properly formulated biodiesel-diesel emulsions can achieve and maintain the necessary stability for effective drilling operations. The results also reveal that emulsion stability is more dependent on proper additive formulation than on biodiesel content alone, as evidenced by the strong performance of optimized mid-range blends compared to some higher biodiesel formulations.

## CHAPTER V: CONCLUSION & RECOMMENDATION

### V.1 Conclusion

This dissertation investigated the feasibility of using biodiesel, derived from waste cooking oil, as a base fluid for oil-based drilling muds, with a particular focus on formulating and evaluating biodiesel-diesel blends. The study was driven by the need to find environmentally friendly, cost-effective, and high-performance alternatives to conventional diesel and synthetic-based fluids used in the oil and gas industry.

Through a comprehensive experimental program, biodiesel was successfully produced and characterized to assess its physicochemical properties, confirming its suitability for drilling applications. A series of biodiesel-diesel blends were then formulated and tested to evaluate their rheological performance, thermal stability, emulsion quality, and environmental characteristics. Among the formulations tested, the 10D/90B blend (10% diesel, 90% biodiesel) demonstrated promising results, achieving excellent electrical stability, acceptable rheological properties, and strong thermal resilience—particularly after hot rolling. Additionally, by optimizing additive concentrations, notably viscosifiers and emulsifiers, the performance of high-biodiesel blends was further enhanced without compromising functional integrity.

Economically, the use of biodiesel-diesel blends was shown to be highly competitive. The 10D/90B blend was over 70% cheaper than typical synthetic-based fluids, with a production cost of only 120 DA/L compared to 400–800 DA/L for synthetic alternatives. The economic study also highlighted strong profitability and scalability potential, making biodiesel-based fluids a financially viable solution.

Overall, the findings confirm that biodiesel-diesel blends especially those rich in biodiesel can serve as sustainable substitutes for conventional oil-based and synthetic drilling fluids. While further optimization and field validation are recommended, this research contributes valuable insights into advancing eco-friendly drilling technologies and aligns with broader industry efforts toward sustainability and reduced environmental impact.

## V.2 Recommendation

- Future studies should investigate the use of biodiesel as a biodegradable and non-toxic lubricant additive in water-based mud systems. This application could significantly improve lubricity while maintaining the environmental advantages of WBM.
- Although biodiesel is generally recognized as biodegradable, it is essential to perform standardized biodegradability tests (e.g., OECD 301 series) on the formulated drilling fluids to quantify degradation rates and confirm environmental compliance under actual disposal conditions.
- Testing biodiesel derived from different feedstocks—such as animal fats, jatropha oil, or microalgae—may reveal alternative formulations with improved thermal stability, lower water content, or enhanced lubricating properties.
- As a byproduct of biodiesel production, glycerol has potential value in various oilfield applications. Research should explore its use in areas such as cement retarders, shale stabilizers, or as a component in environmentally friendly completion fluids to enhance overall process sustainability.

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## APPENDIX

### Equipment used to prepare drilling mud

Pictures	Description
 A Hamilton Beach mixer with a stainless steel mixing bowl and a motor base, sitting on a light blue surface. A blue container and other items are visible in the background.	Mud formulation mixing using Hamilton Beach Mixer
 A stainless steel retort test equipment with a digital display showing '277' and '950F'. The door is open, revealing a vertical cylindrical chamber and a glass tube.	Retort test being run at 950F to determine the oil water ratio (OWR) using retort kit
 The interior of an oven showing several cylindrical rollers or tubes arranged horizontally. The oven is made of stainless steel.	Oven for placing formulation, 16 hours of hot rolling