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Substituting Oil-Based Mud with High-Performance Water-Based Mud: Technical, Economic and Environmental Study

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DEDICATION

With the name of Allah

This work is dedicated to:

To my beloved mother and father, my lovely sisters and brothers whose support, encouragement and constant love have sustained me throughout life.

To all my relatives
To my loyal friends

And finally, to you, dearest reader

ACKNOWLEDGMENTS

Firstly, I would like to express my great pride to my beloved mother & father, sisters and brothers for their endless love, sacrifice and support to finish this study.

This thesis marks the end of an arduous but insightful journey in scientific research. It would have never been completed without constant support and encouragement from my supervisor, Professor DOBBI Abdelmadjid. His wisdom, patience and encouragement gave me the energy to complete what at times seemed to be an unattainable goal. I would like to thank him for his invaluable advice and guidance throughout the course of this study.

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ملخص

تعتمد عمليات الحفرالناجحة بشكل كبير على الاستخدام الفعال لموائع الحفر لضمان استخراج الموارد من الخزانات الجوفية. ومع ذلك، فإن الاستخدام الواسع النطاق للمائع زيتي القاعدة (OBM) يمثل تحديات مثل ارتفاع التكاليف، والآثار البيئية، والتعقيدات اللوجستية، وانبعاثات ثاني أكسيد الكربون (CO_2). تبحث هذه الدراسة في إمكانات المائع مائي القاعدة المحسنة (HPWBM) كبديل من حيث التكلفة لا يعالج هذه التحديات فحسب، بل يعزز أيضًا معايير الحفر.

من خلال تحليل مقارن شامل يشمل التأثير البيئي واللوجستيات والنقل وانبعاثات ثاني أكسيد الكربون و إعتبارات التكلفة ومعايير الحفر مثل معدل الاختراق ROP ،و قيود استبدال من OBM إلى HPWBM. تساهم النتائج في تطوير ممارسات حفر مستدامة ومجدية اقتصاديًا، مما يوفر رؤى قيمة لأصحاب المصلحة في الصناعة. من خلال الانتقال إلى HPWBM، يمكن لعمليات الحفر تحقيق تحسين التكلفة وتحسين معايير الحفر ودعم المسؤولية البيئية وتعزيز الكفاءة التشغيلية الإجمالية.

الكلمات المفتاحية: موائع الحفر، الطين المرتكز على النفط، الطين عالي الأداء القائم على الماء، تحسين التكلفة، التأثير البيئي، معدل الإختراق.

Abstract

Drilling operations heavily rely on the effective utilisation of drilling fluids to ensure efficient extraction of resources from underground reservoirs. However, the widespread use of oil-based mud (OBM) presents challenges such as high costs, environmental implications, logistical complexities, and carbon dioxide (CO_2) emissions. This study investigates the potential of a High-Performance Water-Based Mud (HPWBM) as a cost-effective alternative that not only addresses these challenges but also enhances drilling parameters.

Through a comprehensive comparative analysis encompassing environmental impact, logistics, transport, CO_2 emissions, cost considerations, and drilling parameters such as rate of penetration (ROP) and operational time, the research evaluates the transitioning from OBM to HPWBM. The findings contribute to the development of sustainable and economically viable drilling practices, providing valuable insights for industry stakeholders. By transitioning to HPWBM, drilling operations can achieve cost optimization, improve drilling parameters, uphold environmental responsibility, and enhance overall operational efficiency.

Keywords: drilling fluids, high-performance water-based mud, cost optimization, environmental impact, rate of penetration.

Résumé

Les opérations de forage dépendent fortement de l'utilisation efficace des fluides de forage pour assurer une extraction fluide et efficace des ressources des réservoirs souterrains. Cependant, l'utilisation généralisée de la boue à base d'huile (OBM) présente des défis tels que des coûts élevés, des implications environnementales, des complexités logistiques et des émissions de dioxyde de carbone (CO_2). Cette étude étudie le potentiel d'une boue à base d'eau à haute performance (HPWBM) en tant qu'alternative rentable qui non seulement répond à ces défis, mais améliore également les paramètres de forage.

Grâce à une analyse comparative complète englobant l'impact environnemental, la logistique, le transport, les émissions de CO_2, les considérations de coût et les paramètres de forage tels que le taux de pénétration (ROP) et le temps opérationnel, la recherche évalue les avantages et les limites de la transition de l'OBM au HPWBM. Les résultats contribuent au développement de pratiques de forage durables et économiquement viables, fournissant des informations précieuses aux parties prenantes de l'industrie. En passant à HPWBM, les opérations de forage peuvent optimiser les coûts, améliorer les paramètres de forage, respecter la responsabilité environnementale et améliorer l'efficacité opérationnelle globale.

Mots-clés : fluides de forage, boue à base d'eau haute performance, optimisation des coûts, impact environnemental, taux de pénétration.

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LIST OF ABBREVIATIONS

AHR	After Hot Rolling
API	American Petroleum Institute
BHA	Bottom Hole Assembly
BHR	Before Hot Rolling
CMC	Sodium Carboxymethyl Cellulose
FL	Fluid Loss
HPWBM	High-Performance Water-Based Mud
KCL	Potassium Chloride
LCM	Lost Circulation Materials
LSND	Low-Solids Non-Dispersed
LSRV	Low Shear-Rate Viscosity
MBT	Methylene Blue Test
Mf	Methyl Orange Alkalinity End Point of Mud Filtrate
MSL	Metres above mean Sea Level
NA	Not Applicable
OBM	Oil-Based Mud
PAC	Polyanionic Cellulose
Pf	Phenolphthalein Alkalinity of the Mud Filtrate
Pm	Phenolphthalein End Point of the Mud
PPM	Parts Per Million
ROP	Rotation Per Minute
RPM	Rotation Per Minute.
μ	Viscosity (cP)
τ	Shear stress (in lbs/100 ft^2)
γ	Shear rate (per sec^{-1})
Cp	Centipoise

LISTE OF ABREVIATIONS

s.g	Specific Gravity
θ_{600}, θ_{300}	Viscometer Speeds
P	Pressure (bar)
D	Mud density (s.g)

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INTRODUCTION

The selection of an appropriate drilling fluid, or mud system, is a critical factor in achieving successful and cost-effective drilling operations in the exploration and extraction of hydrocarbon reservoirs. Drilling engineers must carefully consider the characteristics and properties of the drilling mud to ensure optimal performance and mitigate potential challenges throughout the drilling process.

Drilling engineering involves the use of specialized rigs and equipment to penetrate deep into the earth's strata. Cutting-edge drilling bits, attached to steel drill pipes, are essential for the drilling operation. They transmit torque and deliver drilling mud, a crucial fluid medium, to the bit. The drilling mud serves multifaceted functions, including cooling and lubricating the bit, providing borehole stability, mitigating fluid influx from surrounding formations, facilitating the removal of drilled cuttings, and conveying them to the surface.

The drilling process is divided into distinct sections based on the interplay between formation pressures and fracture pressures. This division helps assess the integrity of the rock in relation to the pressure regime of the reservoir. Upon completing each section, a casing made of sturdy steel is inserted into the wellbore and cemented in place. This casing provides mechanical strength, safeguards freshwater aquifers against contamination, and reinforces the well structure as drilling progresses to greater depths.

At the uppermost part of the well, a wellhead assembly is installed, allowing for the connection of pressure control equipment. This equipment typically includes a stack of blowout preventers that can be hydraulically operated to enclose the drill pipe and effectively manage downhole pressure conditions.

Once the well reaches its intended target depth, it undergoes evaluation using specialized well logging tools or comprehensive well testing. These evaluations assess reservoir productivity and characteristics. Positive results from the evaluations lead to the completion phase, during which the well is equipped with production equipment to enable safe and efficient hydrocarbon recovery.

Non-productive wells that do not yield commercially viable hydrocarbon reserves are permanently abandoned. Tested or completed wells may be temporarily suspended for future reactivation or intervention activities.

By carefully selecting the appropriate drilling fluid and implementing effective drilling practices, engineers can optimize drilling operations, minimize risks, protect human life, preserve the environment, and ensure the efficient extraction of hydrocarbon resources.

Chapter I:

The first chapter of this thesis introduces the field of drilling engineering within petroleum engineering, highlighting its significance in extracting oil and gas resources. It defines rotary drilling as a technique that employs a rotating drill bit to create boreholes efficiently, emphasizing its advantages over cable tool drilling.

The chapter explores the role of drilling fluid in the rotary drilling process, emphasizing its functions in cuttings removal and preventing fluid migration. It also acknowledges the challenges associated with drilling fluid properties and performance. The chapter concludes by emphasizing the importance of carefully selecting and designing drilling fluids to ensure their effectiveness in the drilling process. Overall, this chapter provides a foundation for understanding rotary drilling and the crucial role of drilling fluids in achieving successful drilling operations.

Chapter II:

The second chapter focuses on shale dispersion in drilling operations and its implications. It highlights the challenges posed by shale disintegration upon contact with water-based drilling fluids, leading to the release of fine particles that can disrupt the drilling process and impact wellbore stability.

The chapter presents the objectives of an experimental study on shale inhibition, aiming to evaluate the effectiveness of additives in reducing shale disintegration, compare the performance of different drilling fluids, investigate the influence of various factors on shale recovery and particle size distribution, and contribute to the development of effective and environmentally friendly drilling fluid systems. The findings and recommendations from this study will aid in the design and optimization of drilling fluid systems for shale exploration.

Chapter III:

The third chapter focuses on the selection of drilling fluid and compares oil-based mud (OBM) and high-performance water-based mud (HPWBM) in drilling operations in the South West of Algeria.

It highlights the economic and environmental implications of drilling fluid selection, with a particular emphasis on the advantages of HPWBM in reducing CO_2 emissions and environmental impact. The chapter addresses the challenges associated with OBM, such as environmental risks, logistics, transportation complexities, and high CO_2 emissions. It proposes a solution by transitioning from OBM to HPWBM, highlighting the benefits of HPWBM in mitigating the drawbacks of OBM and promoting sustainable practices in the industry. The findings of this study aim to inform decision-making, promote sustainable practices, and provide insights for industry stakeholders seeking cost-effective and environmentally friendly drilling solutions.

CHAPTER I

Introduction to Drilling and Drilling Fluids

Chapter I: Introduction to Drilling and Drilling Fluid

I.1. Introduction:

Drilling engineering is a vital discipline within petroleum engineering that involves planning, executing, and optimizing drilling operations to extract oil and gas resources from underground reservoirs. It combines technical expertise, advanced technologies, and interdisciplinary collaboration to achieve efficient and safe drilling practices in the oil and gas industry. [21]

I.2. Definition of Rotary Drilling:

Rotary drilling is a technique employed to create a borehole in the earth by utilising a rotating drill bit to fracture the rock at the hole's bottom. This method gained prominence following the discovery of the East Texas Field by "Dad" Joiner in 1930 and offers superior efficiency compared to cable tool drilling. A notable advantage of rotary drilling is its continuous nature, facilitated by the removal of cuttings through the circulation of drilling fluids up the wellbore to the surface, depicted in **Figure I.1**. In contrast, cable tool operations are characterised by intermittent drilling and less efficient cuttings removal. This efficiency contrast becomes particularly significant with increasing borehole depth. [7]

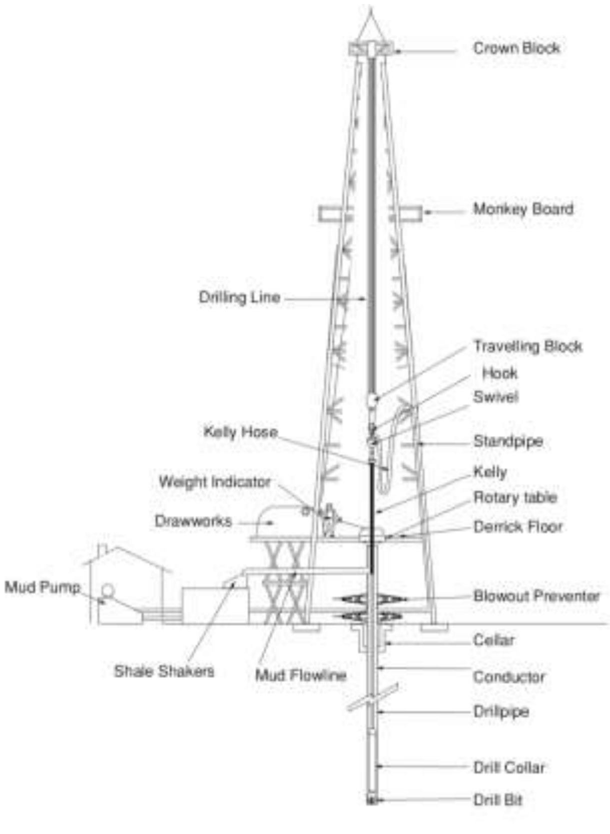

Figure I. 1: Diagram of Rotary Drilling Rig.

I.3. Drilling Systems:

The five drilling systems are a critical component of the drilling process, and they work together to make it possible to extract oil and gas from deep beneath the earth's surface. The drilling process involves the use of several interconnected systems, including the following:

1. Power system
2. Hoisting system
3. Circulating system
4. Rotating system
5. Well control system

I.3.1. Power System:

The power system in a drilling rig refers to the set of equipment and machinery responsible for generating, transmitting, and distributing power throughout the rig. It includes engines, generators, transformers, and switchgear, among others, and is crucial for operating other drilling systems, such as the hoisting, circulating, rotating, and well control systems. The generators in the power system convert the mechanical energy provided by the diesel engines into electricity.

I.3.2. Hoisting System:

It enables the drilling rig to raise and lower working strings into and out of the wellbore. The main components of the drilling rig hoisting system are:

- Draw works
- Drilling line
- Crown block
- Travelling block
- Mast
- Deadline
- Anchors
- Storage spool

I.3.3. Circulating System:

During drilling operations, in order to circulate the drilling fluids, the circulating system, mud pumps and prime movers are used. The drilling fluids are circulated from the mud tanks, through the drill string, down to the bit and up to the surface through the annulus as shown in **Figure I.2**. The cuttings are displaced from the bottom, up to the surface and separated from the drilling fluids using the shale shakers and mud cleaner. The recovered cuttings can be used by geologists to identify which formation is being drilled. [4]

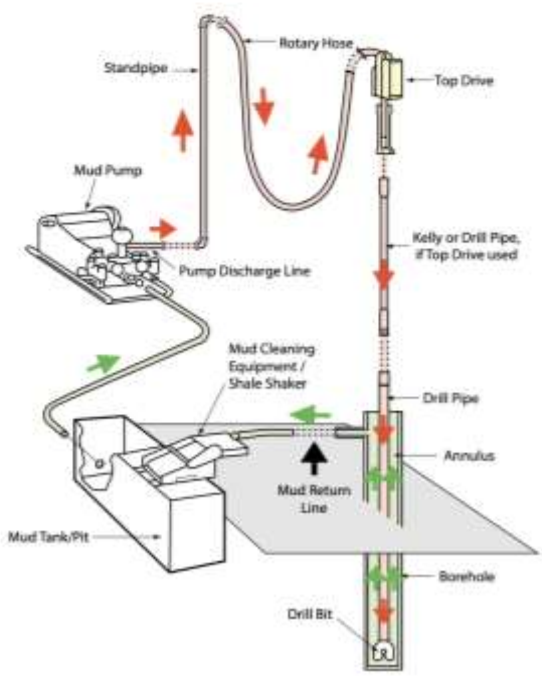

Figure I. 2: Mud circulation Diagram.

I.3.4. Rotating System:

The rotary system, as an important part of the drilling system, is responsible for rotating the drill pipe and drill bit. The rotary system includes: [11]

- Drilling mud pumps
- Rotating hose pipe
- Rotary hose
- Drill pipe string
- Drilling mud return path
- Drilling mud tanks.

I.3.5. Well Control System:

The well control system is implemented to mitigate the occurrence of well eruptions, which entail the uncontrolled influx of gas, oil, or other fluids from the wellbore into the external environment or subsurface formations. This critical scenario arises when the pressure within the reservoir surpasses the counteracting pressure exerted by the drilling mud. A well eruption poses severe risks including the destruction of the drilling rig, loss of valuable hydrocarbons, and potential environmental harm. It is characterised by the high-pressure discharge of fluids (such as oil, gas, or saline water) from the wellhead, often leading to ignition and the development of an intense conflagration, particularly when combustible gases are present.

Essential constituents of the well control equipment encompass Blowout Preventers as shown in **Figure I.3**, Accumulators, Chokes, and Choke Manifolds. These sophisticated apparatuses are pivotal in ensuring operational control, safeguarding personnel, and averting catastrophic events associated with well eruptions. [11]

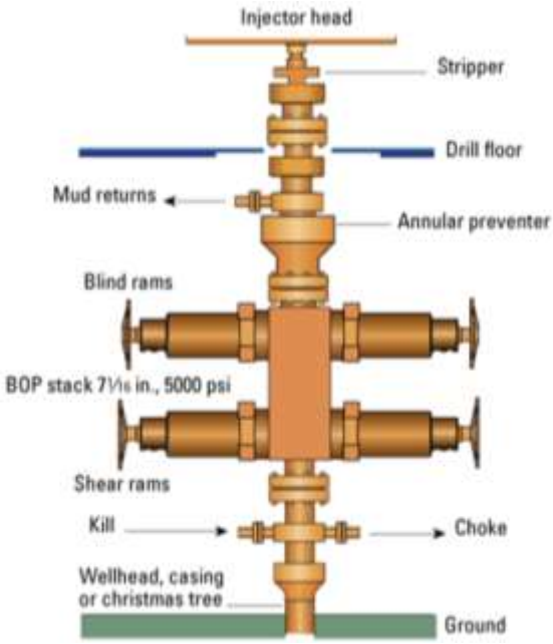

Figure I. 3: Schematic Diagram of a Blowout Preventer

I.4. Drilling Problems and Challenges:

I.4.1. Wellbore Instability:

Wellbore or Borehole instability refers to the risk of structural instability and failures in the wellbore during drilling. It occurs as a result of increasing pressure with depth, mechanical properties of rocks, and interactions between drilling mud and formation. This instability can lead to rock fractures, formation fluid influx, hole sloughing, or washout, impacting the stability and dimensions of the wellbore. [9]

I.4.2. Formation Damage:

Formation damage is a condition most commonly caused by wellbore fluids used during drilling, completion and workover operations. It impairs the permeability of reservoir rocks, thereby reducing the natural productivity of reservoirs. Formation damage can adversely affect both drilling operations and production, which directly impacts economic viability. Although the severity of formation damage may vary from one well to another, any reduction in recovery potential is unwanted.

From the initial drilling operation and completion of a well to reservoir depletion by production, the effects of formation damage can negatively impact oil and gas recovery. [10]

I.4.3. Lost circulation:

It is the uncontrolled influx of drilling mud into the formation, resulting in partial or total mud loss. This occurrence arises when the downhole fluid pressure surpasses the formation's threshold, potentially leading to fracture. Highly permeable formations characterised by low pressure exhibit a heightened susceptibility to lost circulation. [9]

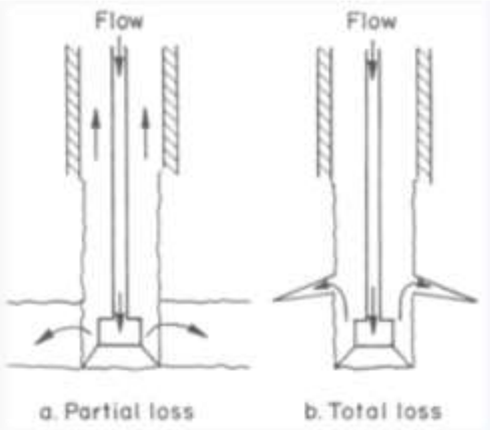

Figure I. 4: Lost Circulation Zones.

I.4.4. Stuck Pipe:

Drilling a well necessitates the presence of a drill string, which consists of pipe and collars. This drill string serves the purpose of transmitting torque from the surface to rotate the drill bit and transmitting the required weight to facilitate the drilling process. The driller and directional driller play a vital role in steering the well by adjusting the torque, revolutions per minute (RPM), and the weight applied to the bit.

In situations where the drill string encounters limitations that impede its desired movement, such as upward, downward, or rotational restrictions as intended by the driller, it becomes stuck. Sticking can occur during various operations, including drilling, making connections, logging, testing, or when equipment is left in the wellbore. A drill string is deemed stuck if the sum of BF (background friction) and FBHA (force exerted by the sticking mechanism on the bottom hole assembly) exceeds the maximum overpull (MO). The maximum overpull represents the maximum force that the derrick, hoisting system, or drill pipe can endure, with the smallest value being selected for MO. [8]

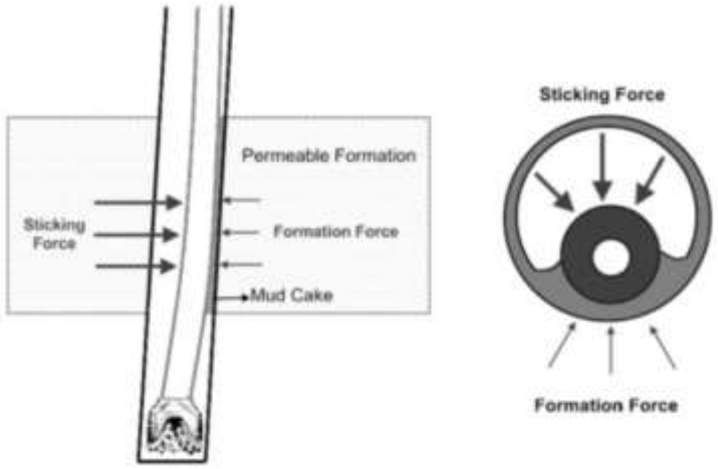

Figure I. 5: Differential Sticking due to Differential Pressure between Mud Cake and Permeable Zones

I.4.5. Blowouts and Well Control:

The problem of well control arises when the pressure within the wellbore needs to be managed and regulated to prevent undesirable outcomes. It involves ensuring that the borehole pressure remains higher than the formation pressure (primary control) or using surface valves to close off the well (secondary control). Failure to maintain control can result in severe consequences such as loss of life, equipment damage, fluid depletion, environmental harm, and the substantial costs associated with regaining control. Prompt and decisive actions are crucial to address this problem and prevent blow-outs. [20]

I.6. Introduction:

Drilling fluid, also known as drilling mud, plays a vital role in the rotary drilling process, serving multiple functions. Its primary objectives include the removal of drilled cuttings from the borehole and the prevention of fluid migration from the formations into the wellbore. Additionally, drilling mud possesses various other essential functions, which will be explored in the subsequent sections. As drilling fluid significantly impacts the drilling operations, many challenges encountered during well drilling can be attributed to its properties and performance. Consequently, the careful selection and design of drilling fluids are crucial to ensure their effective contribution to the drilling process.

I.7. Drilling Fluids Definition:

A drilling fluid, commonly referred to as mud, is a fluid employed in drilling operations. This fluid is circulated or pumped from the surface, down the drill string, passed through the drill bit, and returned to the surface through the annulus. [1]

I.8. Drilling Fluids Selection:

Drilling fluids are a vital component in the drilling process, with various compositions and properties available for selection based on the specific requirements of well design. Factors such as:

1. Formation pressures
2. Rock mechanics
3. Formation chemistry
4. Temperature
5. Environmental regulations
6. Economics

These are critical considerations in selecting a drilling fluid. To meet these design factors, drilling fluids offer a complex array of interrelated properties, including rheology, density, fluid loss, solids content, and chemical properties. The chemical properties of a fluid are largely determined by the type of mud selected, which is based on the type of well, formation to be drilled, and environmental conditions. Additives can be used to manipulate all five properties of a drilling fluid. [6]

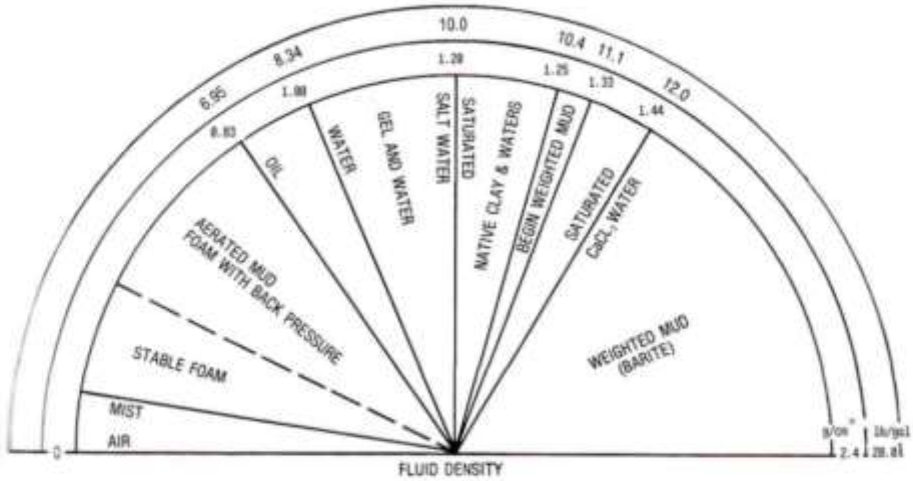

Figure I. 6: The Range of Drilling Fluids Density.

I.9. Drilling Fluids Functions:

Drilling fluids play a crucial role in facilitating the drilling process by providing hydraulic support, lubrication, and cooling to the drilling assembly. In addition to these primary functions, they also serve several other critical purposes that are essential for ensuring the safety and efficiency of the drilling operation such as the following functions:

1. Remove Cuttings from the Well

Well and fluid factors which affect cuttings removal include:

- Cuttings (size, shape, and density)
- Rate of penetration
- Drill string rotation
- Annular velocity
- Drilling fluid rheology (viscosity)

2. **Control Formation Pressures**

The use of drilling fluid is essential to maintain control of a well. The fluid is pumped down the drill string, passed through the bit, and directed back up the annulus. In the open hole, the hydrostatic pressure exerted by the mud column serves to balance any increases in formation pressure, which could otherwise push formation fluids into the borehole, resulting in a loss of well control. However, the pressure exerted by the drilling fluid should not surpass the fracture pressure of the rock, as this may result in mud leakage into the formation, which is commonly referred to as lost circulation.

3. **Suspend and Release Cuttings**

Drilling fluids are required to effectively suspend drill cuttings, weighting materials, and additives under a variety of conditions while also enabling the removal of cuttings via solids control equipment. The use of drilling fluids also prevents fill after trips and connections, avoids packing-off when circulation is halted, and enhances solids control efficiency.

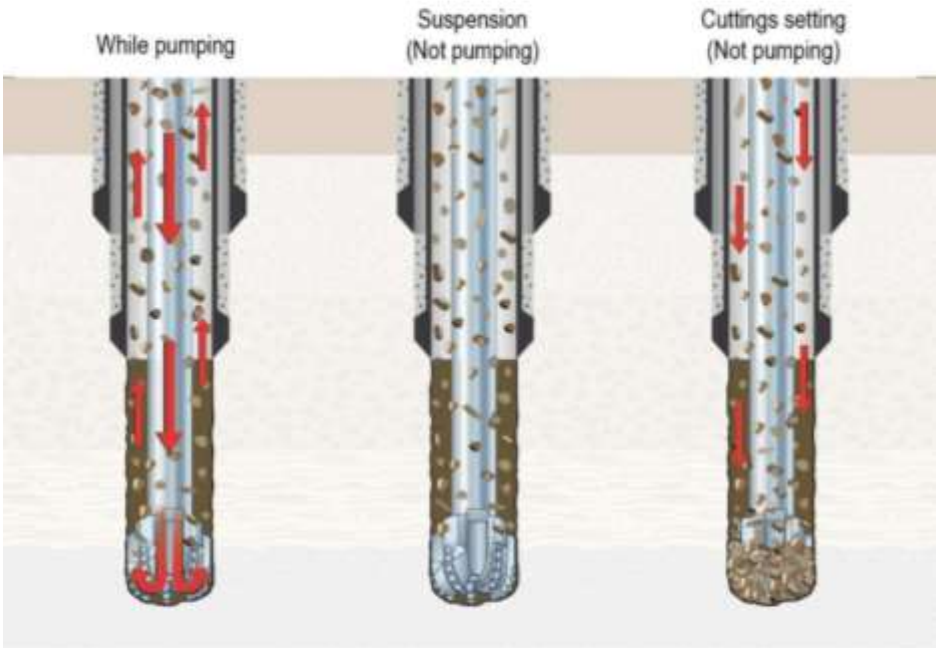

Figure I. 7: Cuttings in Suspension and Release States.

4. **Seal Permeable Formations**

The ability of fluids to flow through porous formations, or permeability, is essential for hydrocarbon production. Various types of permeable formations, including sands, fractures, vugular formations, porous formations, and caverns, allow for fluid flow. To ensure wellbore stability and prevent loss of fluids, it is necessary to seal permeable formations during drilling operations.

5. Maintain Wellbore Stability

To maintain wellbore stability, drilling engineers must regulate density, minimise hydraulic erosion, and control clays. Density is balanced by slightly overbalancing the weight of the mud column against formation pore pressure. Hydraulic erosion is minimised by balancing hole geometry against cleaning requirements, fluid carrying capacity, and annular flow velocity. Controlling clays is complex, but can be managed by modifying the drilling fluid's properties. Ensuring the fluid's effect on the formation is controlled promotes a cleaner, more easily maintained drilling fluid, and enhances the borehole's integrity and cuttings.

6. Minimise Formation Damage

The process of drilling a well can lead to a reduction in a producing formation's natural porosity or permeability, which is referred to as formation damage. This damage can occur through various mechanisms, also known as skin damage. To prevent this damage, specially designed drilling fluids can be used in several ways.

7. Cool, Lubricate and Support the Bit and the Drilling Assembly

As the drilling fluid passes through and around the rotating drilling assembly, it helps cool and lubricate the bit. Thermal energy is transferred to the drilling fluid, which carries the heat to the surface. In extremely hot drilling environments, heat exchangers may be used at the surface to cool the mud.

8. Transmit Hydraulic Energy to Downhole Tools and Bit

Drilling fluid is pumped through nozzles at the bit to release hydraulic energy that loosens and lifts cuttings away from the formation. This energy also powers downhole motors that steer the bit and obtain real-time data. Mud pulse telemetry is used to transmit downhole data to the surface using pressure pulses through the mud column.

9. Ensure Adequate Formation Evaluation

It is critical to accurately evaluate the formation, particularly with exploratory drilling.

10. Control Corrosion

Drillstring and casing components that are in constant contact with drilling fluid are susceptible to various forms of corrosion. Common corrosive agents include:

- Oxygen;
- Carbon dioxide;
- Hydrogen Sulphide.

Figure I. 8: Corroded DrillPipes

11. Facilitate Cementing and Completion

Drilling fluid plays a critical role in creating a wellbore that enables successful casing runs and cementing while not hindering completion operations. Proper cementing is essential for achieving zonal isolation and requires the complete displacement of mud.

General cementing rules of thumb include conducting pre-flushes with the turbulent flow around the pipe, maintaining a contact time of 10 minutes across all zones, and using a chemical wash with a viscosity of 5 centipoises.

Displacement fluid, typically drilling mud, is used to force a cement slurry out of the casing string and into the annulus as it is in **Figure I.9**.

Mud removal for cementing is a three-step process that involves:

- Hole cleaning;
- Conditioning;

- Displacement of mud from the annulus.

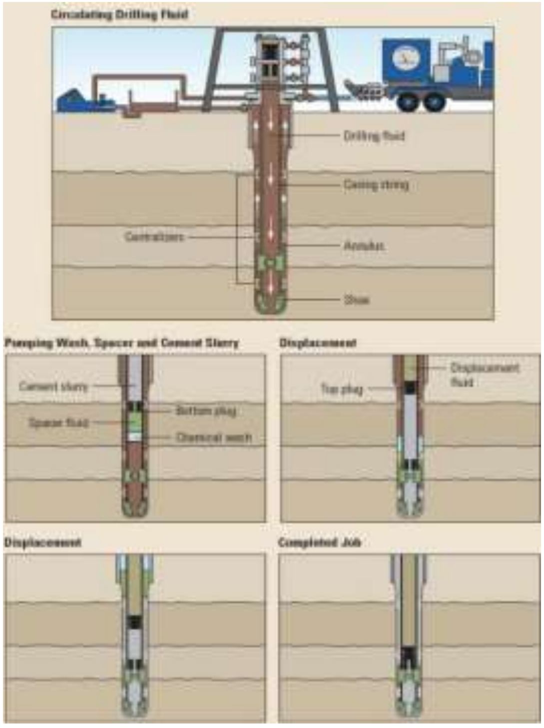

Figure I. 9: Drilling Fluid Facilitating Cementing Job

12. Prevent Gas Hydrate Formation

Gas hydrates **Figure I.10** are solids made of gas molecules trapped inside water molecules.

Figure I. 10: Gas Hydrate Formation

13. Minimise Impact on the Environment

Drilling fluid, such as water-base mud, oil-base mud, and synthetic-base mud, eventually becomes a waste product and must be disposed of according to local environmental regulations.

I.10. Drilling Mud Properties:

The essential characteristics used to delineate the properties of a drilling mud encompass the following:

1. Density or mud weight;
2. Rheology:
    a. Viscosity in its plastic state;
    b. Yield point;
    c. Gel strength.
3. Filtrate and the formation of filter cake;
4. pH-value.

I.10.1. Mud Weight:

Drilling fluid density, measured using a mud balance, determines the hydrostatic pressure and is reported in units like lb/gal or ppg, SG, kg/cu m, or lb/cu ft. It allows easy calculation of pressure at any depth by using the following formula:

$$d = P \times 10.2/h \qquad \textbf{I.1}$$

Where:

d: Mud density;

P: Pressure (bar);

h: Depth (m).

Apparatus:

A mud balance as shown in the **Figure I.11** is an instrument employed to determine the density of mud or cement slurry. It comprises a cup and a graduated arm with a sliding weight that is counterbalanced, allowing it to achieve equilibrium on a pivot point. [20]

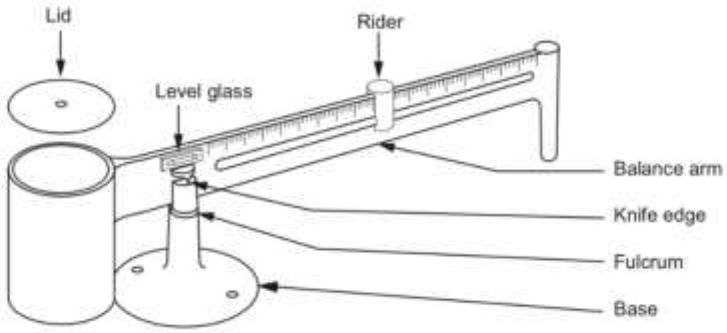

Figure I. 11: Mud Balance

I.10.2. Rheology:

Rheology is a scientific field that investigates the deformation and flow properties of matter. It specifically focuses on analysing the correlation between shear stress, shear rate, and flow behaviour within tubular and annular spaces.

a. Viscosity:

A property of fluids and slurries that indicates their resistance to flow, defined as the ratio of shear stress to shear rate. [7]

Viscosity (μ) can be explained in terms of the ratio of the shear stress (τ) to the shear rate (γ).

$$\mu = \tau/\gamma \qquad \textbf{I.2}$$

Where:

μ: viscosity (cP);

τ : shear stress (in lbs/100 ft^2);

γ : shear rate (per sec^{-1}).

- **Funnel Viscosity:**

Funnel viscosity is an indication of the overall viscosity of drilling mud. It is affected by the concentration, type, size, and size distribution of the solids present, and the electrochemical nature of the drilling mud's solid and liquid phase tested by the Marsh funnel which is a simple device used primarily as an indicator of change in the drilling fluid viscosity. [5]

Apparatus:

The Marsh Funnel, depicted in **Figure I.12**, is utilized for a rapid assessment of drilling mud viscosity. It provides a general indication of viscosity variations but is not suitable for precise quantification of rheological properties like Yield Point or Plastic Viscosity.

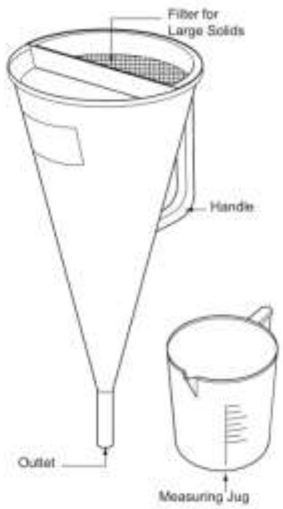

Figure I. 12: Marsh Funnel and Graduated Cup.

- **Plastic Viscosity:**

Plastic viscosity is the resistance of a fluid to flow caused by mechanical friction. It is quantified using the formula:

$$PV = \theta_{600} - \theta_{300} \quad \textbf{I.3}$$

Where:

PV: Plastic Viscosity (cP)

θ_{600} and θ_{300}: the measurements at 600 and 300 RPM, respectively.

Apparatus:

The multi-rate rotational viscometer, illustrated in **Figure I.11**, is employed to measure and analyse the rheological characteristics of the drilling mud. This instrument applies shear forces to a mud sample at various predetermined rates, allowing for the measurement of shear stress on the fluid at these different rates.

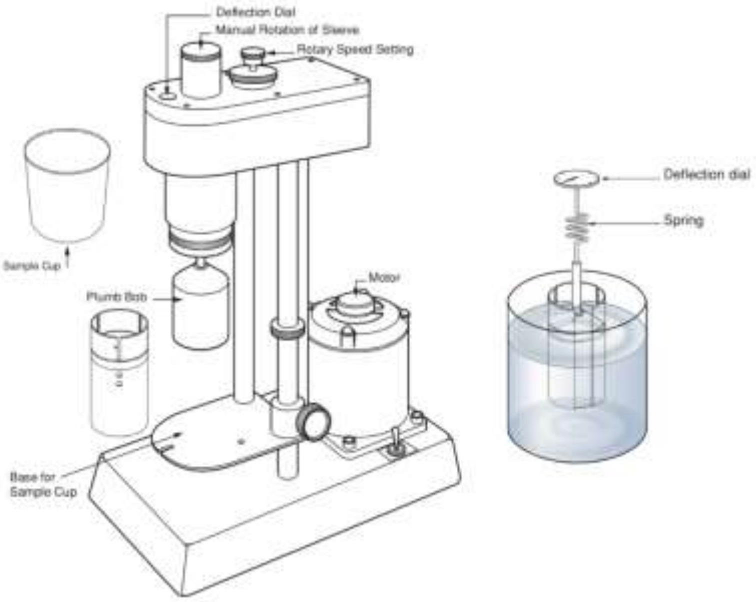

Figure I. 13: Multi-rate Viscometer.

a. Yield Point:

The yield point is a critical stress level at which a material experiences notable deformation in response to a slight increase in the applied force (Woven Textile Structure, 2010). It signifies the point at which plastic deformation initiates, following a phase of reversible elastic deformation. Once the yield point is exceeded, a portion of the deformation becomes permanent and irreversible, indicating the material's transition to a plastic state. [14]

It is calculated using the following formula:

$$YP = \theta_{300} - PV \qquad \textbf{I.4}$$

Where:

YP: Yield Point (lb/100 sq ft);

θ_{300}: Viscometer Speed;

PV: Plastic Viscosity.

b. Gel Strengths:

Gel strength is a characteristic that quantifies the capacity of a colloidal dispersion to form and maintain a gel structure by withstanding shear forces.

Gel strengths are determined by slowly turning the viscometer wheel to observe the maximum deflection before gel breakage. Measurements are taken after allowing the mud to stand for specific time intervals, typically 10 seconds and 10 minutes. [16]

I.10.3. Fluid Loss and Filter Cake:

Fluid loss, in the context of drilling operations, refers to the extent of interaction between the drilling fluid and the wellbore under simulated pressure and temperature conditions. It represents the ability of the fluid to form a thin, flexible, and impermeable layer, known as a filter cake, along the borehole wall.

The primary objective of a drilling mud system is to prevent the filtration of fluid, or filtrate, into the surrounding rock formations. A mud system with low fluid loss exhibits minimal swelling of clays and reduces the risk of damaging the formation.

Apparatus:

A device used in the measurements of the mud filtration properties as shown in **Figure I.12.**

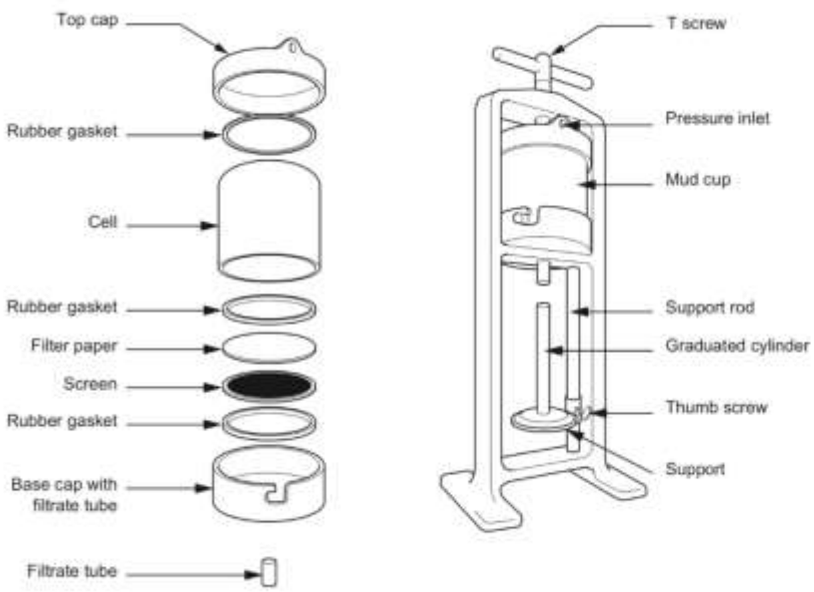

Figure I. 14: Filter Press Apparatus.

I.10.4. pH-Value:

pH measures water acidity or alkalinity on a scale from 0 to 14. A pH of 7 is neutral, values below 7 are acidic, and values above 7 are alkaline. pH represents the balance of hydrogen and hydroxyl ions in water. Changes in pH indicate chemical variations. The scale is logarithmic, with each unit representing a tenfold difference. [18]

$$pH = -\log[H_3O+] \quad \textbf{I.5}$$

The **Table II.5** presents the pH values and fluid description as follows: [12]

Table I. 1: pH Values and Fluid Description.

H^-	OH^-	$pH = -\log H^-$	Description
10^0	10^{-14}	0	**Acidic**
10^{-7}	10^{-7}	7	**Neutral**
10^{-10}	10^{-4}	10	**Basic**
10^{-17}	10^0	14	**Basic**

I.11. Drilling Fluid Types:

Drilling fluid systems consist of liquid and solid components, and sometimes a gas phase. Based on their continuous phase, they can be categorised as gas, aqueous or nonaqueous systems. Each component is added to modify a specific property of the drilling fluid, such as viscosity and density. The following sections will discuss the two main types of drilling fluid systems.

I.11.1. Water-Based Mud:

The term "water-based mud" pertains to a drilling fluid in which water serves as the continuous phase, accommodating both suspended and dissolved materials. Consequently, any water-based mud system encompasses distinct components, namely the water phase, inert solids, reactive solids, and chemical additives, all of which contribute to the overall properties of the mud. These individual constituents play specific roles, including the following: [17]

- **Water:**

As an integral part of the system, water acts as a medium for suspending inert solids, reactive solids, and chemical additives. It influences the initial viscosity of the mud.

- **Inert solids:**

The inclusion of low-gravity solids such as sand and chert, as well as high-gravity solids like barite and lead sulfides, is crucial for achieving the desired mud weight required for drilling operations.

- **Reactive solids:**

Incorporating low-gravity solids such as bentonite and attapulgite clays further enhances the viscosity and yield point of the mud, contributing to its overall rheological behaviour.

- **Chemical additives:**

Mud thinners, such as phosphate, chrome, lignosulphonate, lignites, and surfactants, along with mud thickeners like lime, cement, and polymers, play a significant role in controlling various mud properties. These additives aid in regulating viscosity, yield point, gel strength, fluid loss, pH value, filtration characteristics, corrosion, hydrogen embrittlement, and the solubility of Ca^{2+} and Mg^{2+}.

Together, the water phase, inert solids, reactive solids, and chemical additives collaborate to establish and maintain the desired properties of water-based mud, enabling effective control over its rheological behaviour and overall performance in drilling operations.

A. Water-Based Mud Types:

There are four types of water-based mud as the following: [19]

a. Non-dispersed system:

Non-dispersed systems utilize gel-and-water or advanced polymer systems with minimal bentonite content. They manage natural clays through dilution, encapsulation, and flocculation. Solids-control systems remove fine solids for efficient drilling. Low-solids, non-dispersed polymer systems use long-chain polymers for viscosity and fluid-loss control. Encapsulation and flocculation aid in the removal of low-colloidal solids, reducing dilution needs. Specially formulated high-temperature polymers address gelation challenges in HP/HT wells. Some LSND systems can withstand high temperatures and be weighted up to 17.0 to 18.0 ppg. [19]

b. Dispersed system:

Dispersed systems employ chemical dispersants to control clay particles and improve rheology in high-density muds. Common dispersants include lignosulfonates, lignitic additives, and tannins. Caustic soda is used to maintain a pH of 10.0 to 11.0. Dispersed systems tolerate solids well, allowing densities up to 20.0 ppg. Lignosulfonates are widely used and cost-effective, while lime and cationic systems are also common. However, high solids content can slow penetration and cause hole erosion.

c. Salt water:

Saltwater-based drilling fluids are commonly used for shale inhibition and drilling in salt formations. They also prevent the formation of hydrates, which can obstruct subsea equipment. High-density brines like Calcium Chloride, Calcium Bromide, Zinc Bromide, Potassium Formate, and Cesium Formate are employed in solids-free and low-solids systems for optimal performance.

d. Polymer drilling fluid:

Polymer drilling fluids inhibit reactive formations effectively by using shale inhibitors like salts, glycols, and amines. They rely on polymers such as xanthan gum for viscosity and starch or cellulose derivatives for fluid loss control. Potassium chloride serves as a widely used and economical shale inhibitor in polymer-based fluids, which can be further enhanced with glycol and amine-based additives.

I.11.2. Oil-Based Mud:

In contrast to water-based muds, where water serves as the continuous phase, oil-based mud systems utilize crude or diesel oil as the continuous phase, forming a water-in-oil emulsion. The water content in oil-based muds can range from as little as 3% to 5% to as high as 20% to 40% in inverted emulsions. Oil-based mud systems are employed under the following circumstances: [17]

- Drilling in sensitive production zones or problematic shales;

- Drilling in salt sections and formations containing hydrogen sulphide;
- Mitigating the risk of stuck pipe issues;
- Drilling in bottom hole temperatures within the permissible range for water-based muds.

Close monitoring of the low-gravity solids content is crucial when using oil-based muds, as these solids do not readily hydrate in this environment. Failure to control low-gravity solids can lead to excessive levels, resulting in reduced penetration rate, formation damage, and an increased risk of differential sticking. Oil-based muds, characterized by lower concentrations of colloidal particles, exhibit spurt fluid loss. Therefore, careful monitoring of high-pressure, high-temperature filtration and drilling conditions is essential to prevent excessive filtration or the build-up of filter cake, which can give rise to operational issues.

A. Oil-Based Mud Types:

There are two types of oil-based mud as the following:

a. Invert Emulsion mud:

An Invert Emulsion Mud refers to an oil-based drilling fluid where the majority of the liquid phase consists of diesel oil (60-90%) with a portion of water (10-40%) emulsified within the oil.

A typical low toxicity invert emulsion fluid includes base oil, water, emulsifiers, wetting agent, organophillic clay, and lime. These components work together to control viscosity, stability, and water migration in the mud system. [15]

b. Pseudo Oil-Based Mud:

Pseudo Oil Base Mud (POBM) is a specialized drilling fluid employed predominantly in oil and gas drilling activities. It is a non-aqueous system consisting of petroleum distillate and synthetic oil, serving the purpose of lubricating the drill bit and minimizing friction during drilling operations. By effectively reducing friction, it enables drilling through challenging formations. Furthermore, this fluid aids in regulating downhole pressure, stabilizing the borehole, and facilitating the removal of cuttings from the well. [15]

I.12. Drilling Fluids Additives:

Drilling fluid additives are integral to achieving desired mud properties, reflecting the growing complexity of mud systems in response to challenging drilling conditions. This section provides a comprehensive explanation of the additives used in water- and oil-based muds.

I.12.1. Rheology Control Materials:

Thinners, dispersants, and deflocculants are added to drilling fluids to control viscosity and gel development when adjusting viscosifier concentration alone is insufficient. These substances modify the physical and chemical interactions between solids and dissolved salts, reducing viscosity and structure-forming properties. Common thinners include plant tannins, lignitic materials, lignosulfonates, and low molecular weight polymers.

I.12.2. Weighting Agent:

Weighting agents increase mud weight when suspended or dissolved in water. They require viscosifiers for suspension, with clay being a common option. Higher mud weights are necessary to control formation pressures and address sloughing or heaving shales in stressed areas.

I.12.3. Filtration Control:

Filtration control materials prevent fluid loss from drilling fluid into formations. Bentonite forms a compressible filter cake, polymers such as Polyanionic cellulose (PAC) and Sodium Carboxymethylcellulose (CMC) and starches absorb water to plug pore spaces, and thinners/deflocculants separate clay particles for a thin filter cake.

I.12.4. Alkalinity and pH Control:

pH affects mud properties, contaminant treatment, and solubility of thinners and divalent metal ions. Alkalinity and pH control additives, like NaOH, KOH, $Ca(OH)_2$, $NaHCO_3$, and $Mg(OH)_2$, maintain desired pH and alkalinity in water-based fluids. [15]

I.12.5. Lost Circulation Materials:

Lost-circulation materials (LCMs) are substances used in drilling operations to address fluid loss into porous formations. Examples include calcium carbonate, mica, fibrous materials, cellophane, and crushed walnut shells. Advancements include deformable graphitic materials for sealing fractures, while hydratable and rapid-set pills are effective for severe losses. Specialized equipment may be needed for their application.

I.13. Drilling Fluid Problems:

- **Contaminations:**

Most challenges related to drilling fluids can be attributed to the negative impact of various types of contaminants that enter the mud system. These contaminants can exist in the form of solids or liquidsand each one has a specific treatment. Here are the following contaminations:

- Ca^{2+} / Mg^{2+};
- Cement / Lime;
- Sodium Chloride;
- Carbonate / Bicarbonate;
- Hydrogen Sulphide (H_2S), Water Flows.

I.14. Conclusion:

Chapter I provides an objective and professional introduction to drilling and drilling fluids, focusing on rotary drilling and its advantages over cable tool drilling. It covers the five drilling systems (power, hoisting, circulating, rotating, and well control) and their components and functions. Common drilling challenges, such as wellbore instability and formation damage, are outlined. The importance of drilling fluids is emphasized, including their roles in cuttings removal, pressure control, wellbore stability, and environmental impact minimization. The properties of drilling mud, such as density and viscosity, are discussed. This chapter lays the foundation for further exploration of drilling and drilling fluids.

CHAPTER II

Experimental Study of Shale Inhibition in High-Performance Water-Based Mud -HydraGlyde-

II.1. Introduction:

In the realm of drilling operations, shale dispersion is a significant phenomenon that occurs when shale rocks interact with drilling fluid. Shale, a widely prevalent sedimentary rock in hydrocarbon exploration sites, can pose several challenges during drilling due to its potential to break down upon contact with water-based drilling fluids. The disintegration of shale can result in the release of fine particles that could interfere with the drilling process.

Furthermore, the released particles can also lead to complications with wellbore stability, which could cause significant drilling issues that result in unnecessary expenses and time constraints. Therefore, mitigating shale dispersion is a critical concern in the drilling industry, and addressing this problem requires innovative solutions and careful consideration of various factors, including the selection of drilling fluid and its constituents.

II.2. Objectives:

The objectives of this experimental study of shale inhibition in high-performance water-based mud and fresh water are:

1. To evaluate the effectiveness of shale inhibition additives in reducing the tendency of shale formations to disintegrate and release fine particles that can impair the properties and performance of drilling fluids.

2. To compare the performance of high-performance water-based mud and fresh water in mitigating the detrimental effects of shale dispersion.

3. To investigate the impact of temperature, pressure, salinity, and fluid composition on the recovery percentage of dispersed solids and the particle size distribution of shale samples.

4. To contribute to developing effective and environmentally friendly drilling fluid systems that can maintain wellbore stability and prevent drilling problems associated with shale dispersion.

5. To provide insights and recommendations for the design and optimization of drilling fluid systems for hydrocarbon exploration in shale formations.

II.3. Formulation of High-Performance Water-Based Mud:

The formulation of the drilling fluid will be mentioned in the next table.

II.3.1. Formulation Procedure:

The HydraGlyde Drilling Fluid -HPWBM- was formulated as the following:

Tableau II. 1: Formulation of HydraGlyde Drilling Fluid.

MUD TYPE	HPWBM	
DENSITY	1.10 – 1.20 sg	
PRODUCT NAME	Concentration Kg/m³	Primary Function
FRESH WATER	0.837 (m³/m³)	
SODA ASH	0.7	Hardness Treatment
POTASSIUM CHLORIDE	50	Shale Inhibitor – K+ source
HYDRACAP	2.5	Encapsulating additive
HYDRAHIB	18	Shale inhibitor
MI PAC UL	5.7	FL Control
MI PAC R	2.85	FL/Viscosity
DUOVIS	1	Viscosity
POLYSAL HT	8.55	FL Control
UltraFree	2	Lubricant
CALCIUM CARBONATE	50	Weighting & Bridging Agent

II.3.2. Mixing Procedure:

A mixing procedure of mud refers to the step-by-step instructions for combining various components **Table II. 2**, such as solids and liquids, in the proper order and proportions to form a drilling fluid. The procedure typically includes specific instructions for mixing equipment, mixing time, and operating parameters to ensure consistent and effective blending of the components. The type of mixer used can also have an impact on the quality and performance of the drilling fluid and will be further defined in the following section.

Table II. 3: Mixing Procedure of HydraGlyde Drilling Fluid.

ORDRE	PRODUCT NAME	MIXING TIME (Min)	MIXER SPEED
1	**FRESH WATER**		
2	**SODA ASH**	2	Low
3	**KCL**	2	Low
4	**HYDRAHIB**	2	Low
5	**HYDRACAP**	2	Low
6	**POLYSAL HT**	10	Low
7	**MI PAC R**	10	Low
8	**MI PAC UL**	10	Low
9	**DUOVIS**	10	Low
10	**CALCIUM CARBONATE**	25	Medium
11	**ULTRAFREE**	5	Low

The goal of a mixing procedure in this study is to produce HPWBM HydraGlyde with the desired properties and characteristics for the dispersion test simulating the drilling operation.

Figure II. 1: Mixing the HydraGlyde Mud.

II.3.2.1. Mixing Apparatus:

A laboratory mixer is commonly used for mixing various substances and solutions in a laboratory setting. It is designed to be durable, easy to clean, and capable of producing consistent mixing results. The mixer typically has variable speed settings and interchangeable mixing attachments to accommodate a variety of mixing tasks.

Figure II. 2: SILVERSON® L5M-A LAB MIXER.

II.4. Testing of HydraGlyde:

The physical and chemical properties of a high-performance water-based mud (HPWBM) were evaluated through a series of tests. Initially, a fresh sample of HPWBM was examined to establish baseline characteristics. Subsequently, a sample of HPWBM was subjected to dynamic ageing at a temperature of 160 °F for a period of 16 hours. This ageing process aimed to simulate the conditions experienced during drilling operations. The aged sample was then assessed to determine any changes in its physical and chemical properties. The results obtained from these tests provide valuable insights into the behaviour and stability of HPWBM under challenging drilling conditions. This section presents the findings of the physical and chemical analysis, shedding light on the effects of dynamic ageing on the HPWBM formulation.

II.4.1. Before & After Hot-Rolling Tests:

II.4.1.1. Physical Properties:

The dynamically aged sample of HPWBM exhibited no phase separation **Table II. 4**, indicating the stability of the formulation. Both before and after hot rolling, the sample demonstrated good physical properties, indicating the maintenance of desired characteristics. The rheological properties of the fluid were also observed to be good in both cases. Additionally, the filtrate volume was small, indicating effective fluid retention, and the filter cake thickness was very thin, indicating minimal formation damage.

Table II. 5: Physical Properties of the Drilling Fluid HydraGlyde.

PHYSICAL PROPERTIES			EQUIPMENT USED
			Designation
	Units	Sample 1	
PERIOD AGED	Hours	16	Roller Oven
PRESSURE		0	

TEMPERATURE		F°	160		
DYNAMIC/STATIC		D/S	D		
RHEOLOGY	RHEOLOGY		BHR	AHR	
	FUNNEL VISCOSITY	Sec	NA	NA	
	Operating Temperature	F°	120	120	Dial Thermometer
	600 RPM		49	33	
	300 RPM		32	23	Heating Cap
	200 RPM		24	18	
	100 RMP		16	10	Rheometer 8 Speeds
	6 RPM		4	3	
	3 RPM		3	2	
	GELS 10 s	lbs/100ft²	3	2	
	GELS 10 min	lbs/100ft²	5	3	
	APPARENT VISC.	cP	24.5	16.5	
	PLASTIC VISC.	cP	17	10	
	YIELD POINT	lbs/100ft²	15	13	
	LSRV	lbs/100ft²	2	1	
Density		s.g	1.20	1.20	Mud Balance
API FLUID LOSS @100 Psi		ml	4	6	API Filter Press

II.4.1.2. Chemical Properties:

The chemical properties **Table II. 6** of the dynamically aged HPWBM were evaluated both before and after hot rolling, and the test results indicate that the fluid exhibited good chemical properties in both cases. This suggests that the formulation of the HPWBM remained stable and did not undergo any significant chemical changes during the dynamic ageing process.

Table II. 7: Chemical Properties of the Drilling Fluid HydraGlyde.

CHEMICAL PROPERTIES				EQUIPMENT USED Designation
	Units	**Sample 1**		
		BHR	**AHR**	
Pf	cc of H_2SO_4	**0**	**0**	Agitator
Mf	cc of H_2SO_4	**2.1**	**2.2**	
Pm	cc of H_2SO_4	**0**	**0**	
CL^-	mg/l	**33000**	**32000**	
Total Hardness	mg/l	**1200**	**2000**	
Ca^{2+}	mg/l	**525**	**1200**	
Mg^{2+}	mg/l	**292**	**729**	
MBT	Meq ppb	**3.75**	**3.75**	Hot Plate

II.5. Shale Dispersion Test:

The shale dispersion test, also known as cutting dispersion, involves grinding and sieving clay cuttings. The aged and weighted clay cuttings are combined with the drilling fluid. Shale cuttings are washed, recovered, and heated to determine the shale recovery percentage. Higher recovery indicates better shale fluid inhibition.

The immersion test evaluates inhibition performance visually by immersing mud balls in water and water with shale inhibitors. Swelling, dispersion, and inhibition are observed and photographed.

The swelling test assesses shale swelling tendency by measuring the volume of swollen bentonite in different solutions.

These tests provide valuable insights into shale behaviour and the effectiveness of shale inhibitors. [22]

II.5.1. Principle of Procedure:

The Shale Dispersion test is to assess the tendency of shale formations to disintegrate and release fine particles that can impair the properties and performance of drilling fluids. This Shale Dispersion provides a standardised procedure to measure the recovery percentage of dispersion of shale samples under controlled conditions of temperature, pressure, salinity, and fluid composition. By measuring the number of dispersed solids and the particle size distribution, the Shale Dispersion test enables the comparison of different shale types in high-performance drilling fluid and fresh water to mitigate the detrimental effects of shale dispersion. Ultimately, the research aims to contribute to developing effective and environmentally friendly drilling fluid systems that can maintain wellbore stability and prevent drilling problems associated with shale dispersion.

II.5.2. Physical Characteristics of Shale Samples:

The table presented below comprehensively summarises the physical shale characteristics of the four different types of shale tested in the experiment.

Tableau II. 8: Physical Characteristics of the Shale Samples.

Shales	Sample 1	Sample 2	Sample 3	Sample 4

Picture				
Colour	White	Green	Red	Light Green
Hardness	Soft	Abrasive	Hard	Less abrasive

II.5.3. Shale Dispersion Test Materials and Methods:

II.5.3.1. Equipment:

- Laboratory balance ± 0,01g;
- Drying oven;
- Hot-Rolling oven running at approximately 40 RPM;
- 500 ml Ageing Cells, stainless steel 316 or plastic bottles;
- Weighing boats;
- Spatula;
- 10 cm sieves of 10 mesh and 20 mesh aperture size (or 1 and 2 mm) Inhibitive;
- Wash water (10% KCl).

- **Laboratory Balance:**

It is a measuring instrument used in scientific and industrial settings to accurately measure the mass of an object or substance. It typically consists of a weighing pan, a digital display, and a set of weights or an electronic sensor.

Figure II. 3: Laboratory Balance

- **Drying Oven:**

A drying oven is a laboratory instrument designed to remove moisture or other solvents from samples through the application of heat. It typically consists of an enclosed chamber with adjustable temperature controls and often includes a fan to circulate air and improve heat distribution.

Figure II. 4: Drying Oven for Laboratory.

- **Hot-Rolling Oven:**

The Roller Oven is an effective aid in determining the effects of temperature on drilling fluid as it circulates through the wellbore. The Roller Oven is designed to provide heating and rolling functionality simultaneously or independently. It is available with either 4 or 5 rollers and includes a circulation fan for uniform heating. [2]

Figure II. 5: Hot-Rolling Oven- OFITE #173-00-C - 5-Roller Oven.

- **Ageing Cells:**

The High-Temperature Aging Cell is a pressure vessel that enables samples to be subjected to temperatures higher than the boiling point of water (up to 600°F / 315.6°C) and still be maintained in a liquid state. The cells may be used for static temperature exposure or in a dynamic mode in a roller oven (sold separately) [2].

Figure II. 6: High-Temperature Ageing Cell- #175-80 -

II.5.3.2. Procedures:

1. Size separately each of the four shale types to between 2 and 4 mm (cutting samples should be kept at all times in a sealed plastic container when not in use);
2. Determine the initial moisture content of the shale samples;
3. Prepare drilling fluids to be tested following standard procedures for the respective fluid, and test the properties required;
4. Place 350 ml drilling fluid HydraGlyde in four hot-rolling cells.

Figure II. 7: Filling the Ageing Cells with Drilling Fluid.

5. Preheat the oven to the desired temperature.

6. Accurately weigh approximately 30 grams of sized cuttings and add to the 350 ml of the drilling fluid to be tested.

Figure II. 8: HydraGlyde Mud with Shales in the Aging Cells.

7. Use a spatula and stir gently to wet and separate the shale cuttings prior to sealing the cells.
8. Place the cells in the hot-rolling oven and age the sample at a time of 16 hours and a temperature of 71.11ºC/160°F.

Figure II. 9: HydraGlyde Mud with Shales in the Hot-Rolling Oven.

9. After ageing, take the cells out of the oven and cool them in a water bath. When the cells have reached room temperature the cells are opened.
10. Prepare an inhibitive wash solution (10% w/v KCl and 90% freshwater for water-based drilling fluids and base oil).
11. Pour the content of each cell into two sieves (stacked with 10 mesh above 20 mesh or 2mm above the 1 mm sieve) taking care of the drilling fluid in a mixing cup.
12. Carefully pour the wash water over the cuttings on the sieve to remove any adhering mud and solids using the wash solution already prepared.
13. Weigh cuttings after removal from sieves.
14. Record wet cuttings weight from each sieve size plus combined recovered cutting weight.
15. Dry the cuttings to constant weight in an oven set to 96.11°C/ 205°F.
16. Re-weigh the dish with "dry" cutting.

II.5.3.3. Calculations:

- **Percent Recovery Formulation:**

The percent recovery is determined as the following:

$$\%Recovery = (W_3 / W_1) \times 100$$

- **Moisture of Recovered Samples Formulation:**

The moisture contents determined as the following:

$$\%Moisture\ of\ Recovered\ Sample = [(W_2 - W_3) / W_2)] \times 100$$

Where:

W_1: Initial weight of cuttings used (g)

W_2: Wet sample weight after hot-rolling (g)

W_3: Dry sample weight (after drying to constant weight) (g)

II.6. Results:

II.6.1. Shale Dispersion Test in HydraGlyde:

This section presents the physical properties of High-Performance Water-Based Mud samples after undergoing hot rolling. The HPWBM samples were dynamically aged at a temperature of 160 °F for 16 hours to simulate challenging drilling conditions. The resulting physical properties were then compared among four samples (Sample 1, Sample 2, Sample 3, and Sample 4) to evaluate their performance.

The table below showcases various physical properties, including rheology, viscosity, gel strength, apparent viscosity, plastic viscosity, yield point, density, and fluid loss. These properties provide valuable insights into the behaviour and stability of HPWBM under high-temperature conditions.

II.6.1.1. Physical Properties After Hot-Rolling:

The physical properties **Table II. 9** of the mud can be observed to have undergone degradation, as indicated in the table above. Sample 1 experienced a decrease in Yield Point from 13 lbs/100 ft² to 10 lbs/100 ft², while sample 2 showed a decrease to 8 lbs/100 ft², sample 3 to 7 lbs/100 ft², and sample 4 to 6 lbs/100 ft². Furthermore, changes in API fluid loss were observed, with samples 1 and 4 showing a small change in the filtrate, while samples 2 and 3 exhibited a significant increase in the filtrate. These variations can be attributed to the presence of shale cuttings in the HPWBM samples. To restore the desired specifications, appropriate treatment measures are necessary.

Table II. 10: The Physical Properties After Hot-Rolling.

PHYSICAL PROPERTIES	EQUIPMENT USED
	Designation

		Units	Sample 1	Sample 2	Sample 3	Sample 4	
HydraGlyde Sample		ml	350	350	350	350	
Shale Sample		g	30	30	30	30	
PERIOD AGED		Hours	16	16	16	16	Roller Oven
PRESSURE			0	0	0	0	
TEMPERATURE		F°	160	160	160	160	
DYNAMIC/STATIC		D/S	D	D	D	D	
RHEOLOGY	**CUTTINGS**		**AHR**	**AHR**	**AHR**	**AHR**	
	FUNNEL VISCOSITY	Sec	**NA**	**NA**	**NA**	**NA**	
	Operating Temperature	F°	120	120	120	120	Dial Thermometer
	600 RPM		34	30	29	28	
	300 RPM		22	19	18	17	Heating Cap
	200 RPM		17	15	14	18	
	100 RMP		11	10	9	10	Rheometer 8 Speeds
	6 RPM		3	3	3	3	
	3 RPM		2	2	2	2	
	GELS 10 s	lbs/100ft²	2	2	2	2	
	GELS 10 min	lbs/100ft²	3	3	3	3	
	APPARENT VISC.	cP	17	15	14.5	14	
	PLASTIC VISC.	cP	**12**	**11**	**11**	**11**	

	YIELD POINT	$lbs/100ft^2$	**10**	**8**	**7**	**6**	
	LSRV	$lbs/100ft^2$	1	1	1	1	
Density		s.g	1.20	1.20	1.20	1.20	Mud Balance
API FLUID LOSS @100 Psi		ml	**6.2**	**9.4**	**7.8**	**6.8**	API Filter Press

II.6.1.2. Chemical Properties After Hot-Rolling:

Tabl II. 11: The Chemical Properties After Hot-Rolling.

CHEMICAL PROPERTIES						**EQUIPMENT USED**
						Designation
	Units	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	
Pf	cc of H_2SO_4	**0**	**0**	**0**	**0**	Agitator
Mf	cc of H_2SO_4	**2.2**	**2.5**	**2.6**	**2.3**	
Pm	cc of H_2SO_4	**0**	**0**	**0**	**0**	
CL^-	mg/l	**30000**	**34000**	**34000**	**33000**	
Total Hardness	mg/l	**2400**	**2000**	**2200**	**2000**	
Ca^{2+}	mg/l	**1200**	**1000**	**1200**	**1400**	
Mg^{2+}	mg/l	**729**	**608**	**608**	**365**	
MBT	Meq ppb	**10**	**6.25**	**8.75**	**7.5**	Hot Plate

The presented table reveals a notable overall increase in various chemical properties of the mud. Specifically, the MBT test exhibited a consistent rise from 3.75 Meq ppb to over 6 Meq ppb across all samples. Moreover, both Mf and Total hardness demonstrated an increase in all samples. While the chlorides experienced an increase in samples 2, 3, and 4, a slight decrease in the chloride value was observed in sample 1.

The inclusion of shale cuttings in the HPWBM samples has had a discernible impact on the physical and chemical characteristics of the mud. Consequently, a suitable treatment is required to restore the desired water specifications.

II.6.1.3. Shale Recovery Results:

Upon analyzing the provided table **Table II. 8**, a significant recovery percentage is evident in all samples. Samples 1, 2, and 3 exhibited a recovery rate exceeding 92% of shale cuttings, while the last sample demonstrated a recovery of 86%. It is worth noting that the type of shale cuttings influenced the dispersion percentage within the mud. Despite the soft nature of samples 1, 3, and 4, a minimal dispersion percentage was observed in the HPWBM.

These findings highlight the effective inhibition of the HPWBM and validate the superior performance of the inhibitive products utilized in the mud formulation.

Table II. 8: Shale Recovery in the HydraGlyde Mud Results

	Units	Sample 1	Sample 2	Sample 3	Sample 4
Cuttings		**AHR**	**AHR**	**AHR**	**AHR**
Initial Cuttings	ppb	30	30	30	30
Wet Weight	pbb	42	38.91	41.05	42.58
Dry Weight	ppb	27.57	28.34	27.34	25.67
Moisture of Recovered Sample	%	**35.36**	**27.17**	**33.40**	**39.71**
Recovery	%	**91.90**	**94.47**	**91.13**	**85.57**

II.6.2. Shale Dispersion Test in Freshwater:

To evaluate the shale dispersion characteristics in freshwater, a series of experiments were conducted using four water samples, each with a volume of 350 ml. The objective of the test was to assess the behaviour of shale cuttings when subjected to dynamic ageing at a temperature of 160 °F for 16 hours.

During the ageing process, the cuttings were introduced into the samples. Subsequently, the recovery percentage of the shale cuttings was determined, providing insights into their dispersion potential in freshwater conditions.

II.6.2.1. Physical and Chemical Properties in Freshwater After Hot-Rolling:

Based on the results obtained from the hot-rolling procedure, it can be inferred that the freshwater did not yield any physical or chemical properties for the shale samples. The absence of physical and chemical properties is likely attributed to the complete absorption of water by some shale samples.

II.6.2.2. Shale Recovery in Freshwater After Hot-Rolling:

Table II. 9 : Shale Recovery in Freshwater Results

	Units	Sample 1	Sample 2	Sample 3	Sample 4
Cuttings		**AHR**	**AHR**	**AHR**	**AHR**
Initial Cuttings	ppb	30	30	30	30
Wet Weight	pbb	0	28.15	0	0
Dry Weight	ppb	0	15.74	0	0
Moisture of Recovered Sample	%	**0**	**44.09**	**0**	**0**
Recovery	%	**0**	**52.47**	**0**	**0**

Based on the data presented in the table above, it is evident that the recovery percentage of shale cuttings was significantly low in all samples, indicating poor performance. Samples 1, 3, and 4 exhibited a complete absence of recovery, with a recorded recovery rate of 0%. In contrast, sample 2 showed a relatively higher recovery rate of 52%. It is noteworthy that the nature of the shale cuttings influenced their dispersion characteristics in water. Despite being sharp and highly solid in sample 2, these cuttings still demonstrated a considerable level of dispersion, challenging the assumption that their solid nature would prevent dispersion.

II.7. Discussion

The results of the shale dispersion test conducted on the four shale types using HPWBM and freshwater revealed significant differences in the recovery percentages. In the HPWBM dispersion tests, the recovery percentages ranged from 85.56% to 94.46%, with an average recovery of 90.76%. However, in the freshwater tests, the recovery percentages were considerably lower, ranging from 0% to 52.46% where samples 1, 3 and 4 were 0% and only sample 2 was 52.46%, with an average recovery of 13.11%as shown in **Figure II.10**.

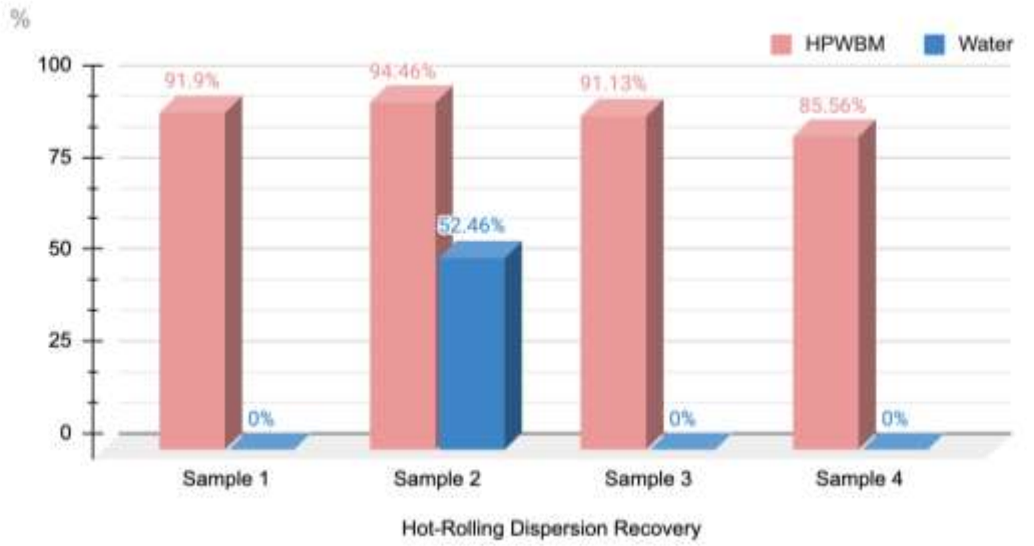

Figure II.10: Hot-Rolling Dispersion Recovery.

The data obtained from the HPWBM tests demonstrate the beneficial effect of HPWBM on shale recovery. The higher recovery percentages obtained in the dispersion test in HPWBM tests can be attributed to the ability of HPWBM to maintain the integrity of the shale sample during the hot rolling process. Mud behaves as a protective barrier that prevents the shale from breaking down and losing its structural integrity. This is particularly important because the shale sample's structural integrity can significantly impact the test results accuracy.

Moreover, the dispersion tests in HPWBM also showed lower moisture content in the recovered shale samples, indicating that the mud is effective in preventing the absorption of water by the shale. This is important because the presence of water in the recovered shale samples can significantly alter the physical and chemical properties of the shale, potentially leading to erroneous test results.

The significantly lower recovery percentages obtained in the freshwater tests highlight the critical role that mud plays in shale recovery. The absence of inhibition additives in the freshwater tests resulted in poor recovery percentages, suggesting that HPWBM is essential in maintaining the structural integrity of the shale sample and preventing water absorption. The results of this study underscore the importance of using HPWBM while drilling to avoid any shale dispersion and its great impact on the accuracy of the test results.

II.8. Conclusion

Based on the results obtained from the shale dispersion tests conducted in both freshwater and HPWBM, it can be concluded that the use of high-performance water-based mud is highly effective in shale recovery. The results from the mud tests showed a significantly higher recovery percentage compared to the freshwater tests, indicating the superior performance of the mud in maintaining the integrity of the shale formation.

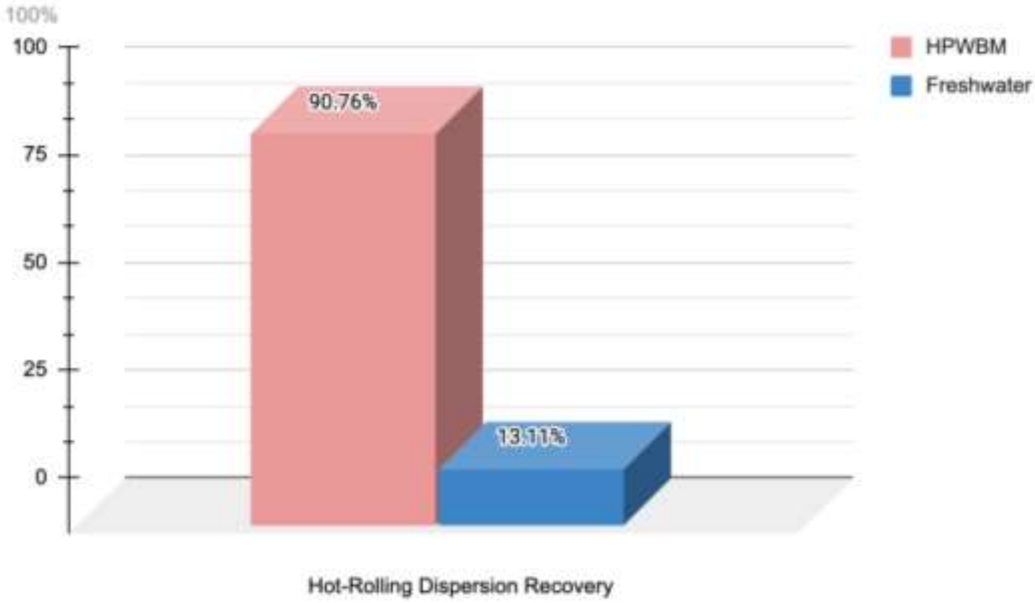

Figure II.11: Comparison between the Results of HPWBM and Freshwater tests.

The high-performance water-based mud used in the tests was specifically designed to address the challenges of drilling in shale formations, and its success in recovering shale samples further validates its suitability for this purpose. The mud is formulated with specific additives that help in maintaining the stability of the formation, reducing the risk of formation damage and loss of circulation **Figure II.11**.

Furthermore, the recovery percentage observed in the mud tests is consistent with the expected performance of the mud, based on its properties and the conditions of the test. The high recovery percentage is indicative of the mud's ability to effectively control the dispersion of shale and prevent it from disintegrating into small particles during the drilling process. This property is crucial for minimising the impact of shale on the drilling operations and the environment.

In conclusion, the use of high-performance water-based mud is highly recommended for shale drilling operations due to its superior performance in maintaining the integrity of the formation and recovering shale samples. This is particularly important in shale formations, where the risk of formation damage and circulation loss is high. The findings of this study add to the growing body of evidence on the effectiveness of high-performance water-based muds in shale drilling and underscore the importance of proper mud engineering in drilling operations.

CHAPTER III

Economic Study and Deployment

III.1. Introduction:

The selection of drilling fluid is pivotal in oil and gas drilling, impacting efficiency, cost, sustainability, and overall performance. This study compares oil-based and high-performance water-based fluids in two wells drilled in the South West of Algeria. The research aims to provide insights into the economic and environmental implications, informing industry decision-making, promoting sustainable practices, and understanding the benefits of high-performance water-based fluids in reducing CO_2 emissions and environmental impact. This chapter sets the stage for the subsequent analysis, emphasizing the significance of drilling fluid selection for the Algerian economy and the environment.

III.2. Problem Presentation:

Oil-based mud (OBM) has emerged as a significant drilling fluid in the oil and gas industry, providing notable advantages. Nonetheless, it is imperative to acknowledge and address the challenges and predicaments that accompany its utilization. This section delves into the salient issues associated with OBM, encompassing its environmental impact, logistics, transport, and CO_2 emissions.

A primary concern regarding oil-based mud is its environmental impact. OBM comprises hydrocarbon-based constituents, which, if mismanaged, may pose risks to ecosystems. Discharging OBM into water bodies can result in contamination and adversely affect aquatic life. Moreover, the disposal of OBM waste necessitates meticulous handling to avert soil and groundwater pollution. Complying with environmental regulations and implementing rigorous waste management practices are indispensable for mitigating these risks and ensuring responsible OBM deployment.

The logistical aspects of employing oil-based mud can present formidable challenges. OBM typically demands specialised equipment and facilities for handling, storage, and transportation. The availability of these resources can vary based on the drilling operation's location and infrastructure. Additionally, the costs associated with OBM handling and transportation tend to be higher compared to alternative drilling fluids, which can impact overall project costs and efficiency. Methodical logistical planning and coordination are vital to minimising delays and optimising OBM utilisation.

The transportation of oil-based mud from its source to the drilling site can entail logistical and safety complexities. OBM is often transported in substantial quantities using tankers or containers. Ensuring secure transportation of OBM necessitates adhering to a pertinent road or marine transport regulations, implementing spill prevention measures, and maintaining readiness for emergency response. Implementing appropriate handling procedures and safety protocols during transportation is indispensable to prevent accidents or incidents that could jeopardize human safety and the environment. The use of oil-based mud contributes to the emission of carbon dioxide (CO_2) during drilling operations. The extraction, production, and transportation of oil-based additives and fluids result in the release of greenhouse gases. These emissions contribute to climate change and global warming. Curtailing CO_2 emissions associated with OBM necessitates adopting more sustainable practices, exploring alternative drilling fluid options, and optimizing drilling processes to diminish the overall environmental footprint.

This chapter aims to address the challenges and drawbacks of oil-based mud (OBM) in drilling operations through a comprehensive comparative study. By carefully examining the environmental impact, logistics, transport considerations, and CO_2 emissions associated with OBM, this study endeavours to identify effective solutions to mitigate the costly problems that arise. A key focus of this analysis will involve investigating the potential substitution of High-Performance Water-Based Mud (HPWBM) as an alternative drilling fluid. Through a rigorous comparative study and troubleshooting exercise, this research endeavour seeks to provide valuable insights into the advantages and limitations of transitioning from OBM to WBM. The findings of this study are expected to contribute to the development of cost-effective and environmentally sustainable drilling practices, offering practical recommendations for industry stakeholders.

III.3. Proposed Solution:

This section presents a proposed solution: transitioning from oil-based mud (OBM) to high-performance water-based mud (HPWBM) in drilling operations. The aim is to address the environmental impact, logistical challenges, transportation complexities, high CO_2 emissions, and expensive costs associated with OBM.

By conducting a comprehensive comparative study, this research endeavour explores the advantages of HPWBM as an alternative drilling fluid. It evaluates its potential to mitigate the drawbacks of OBM in terms of environmental impact, logistics, transport, emissions, and cost.

The transition to HPWBM offers opportunities to overcome challenges posed by OBM. It acts as a protective barrier, preserves shale integrity in clay formations, reduces CO_2 emissions, improves drilling efficiency, and lowers operational costs. This shift promotes sustainable practices in the oil and gas industry, contributing to environmental consciousness and financial prudence.

III.4. High-Performance Water-Based Mud Well:

This section focuses on the use of high-performance water-based mud in a specific well, highlighting the well location, summary and the results obtained.

The well drilled using high-performance water-based mud and it has its coordinates and lithology.

III.4.1. Well Presentation:

The BOUTRAA SUD-1 (BTAS-1) well is situated in the AHNET/GOURARA basin **Figure III.1**, located in the TAMANRASSET province. The precise geographical coordinates of the well are as follows:

- Latitude: 27° 51' 50.17416" N
- Longitude: 01° 51' 02.99143" E
- Elevation: 600.256 meters above mean sea level (MSL)

Figure III. 1: Location of the In Salah Field

This particular well is part of Block 343 and is included in the ongoing study 91GOU-EGS40&97GOU-2D-BPVII. The drilling contractor and installation are both provided by Entreprise Nationale des Travaux Pétroliers.

Access to the drilling site can be achieved by following a specific route originating from HASSI MESSAOUD. Commencing from Hassi Messaoud, a journey of approximately 480 kilometres towards EL GOLEA is required. Continuing on the road to In SALAH, passing the ISG TEG plant for a distance of 280 kilometres, is necessary. Subsequently, a right turn leads to the ISG REG plant, covering a distance of 40 kilometres. From the ISG REG plant, a left turn onto the designated track, spanning 6 kilometres, guides to the REG-15 well. Finally, a right turn towards the north/west and adherence to the marked route for 38 kilometres will lead to the drilling location of BTAS-1.

III.4.2. Mileage Count from Hassi Messaoud:

Table III.1 presents the mileage count from Hassi Messaoud to the BTAS-1 drilling site, including various waypoints along the access route. The cumulative distance travelled is recorded as 844 kilometres, providing information for logistical planning as the following:

Table III.1*: Mileage Count of BTAS-1 from Hassi Messaoud*

Access Route	Tar	Track A	Track B	Track C	Total
HMD → ELGOLEA	480				480
ELGOLEA → Embr Usine REG	280				280
Embr Usine REG → Embr REG-15	40				40
Embr REG-15 → Embr BTAS-1		6			6
Embr BTAS-1 → Drilling BTAS-1				38	38
Total (km)	800	6		38	844

III.4.3.Well location:

Synoptic schematicin map **Figure III.2** of drilling of the well BTAS-1 from Hassi Messaoud

Figure III. 2: Synoptic Schema of BTAS-1 Well

III.4.4. Well Summary:

The well summary provides an overview of the lithology and stratigraphy encountered during drilling as in

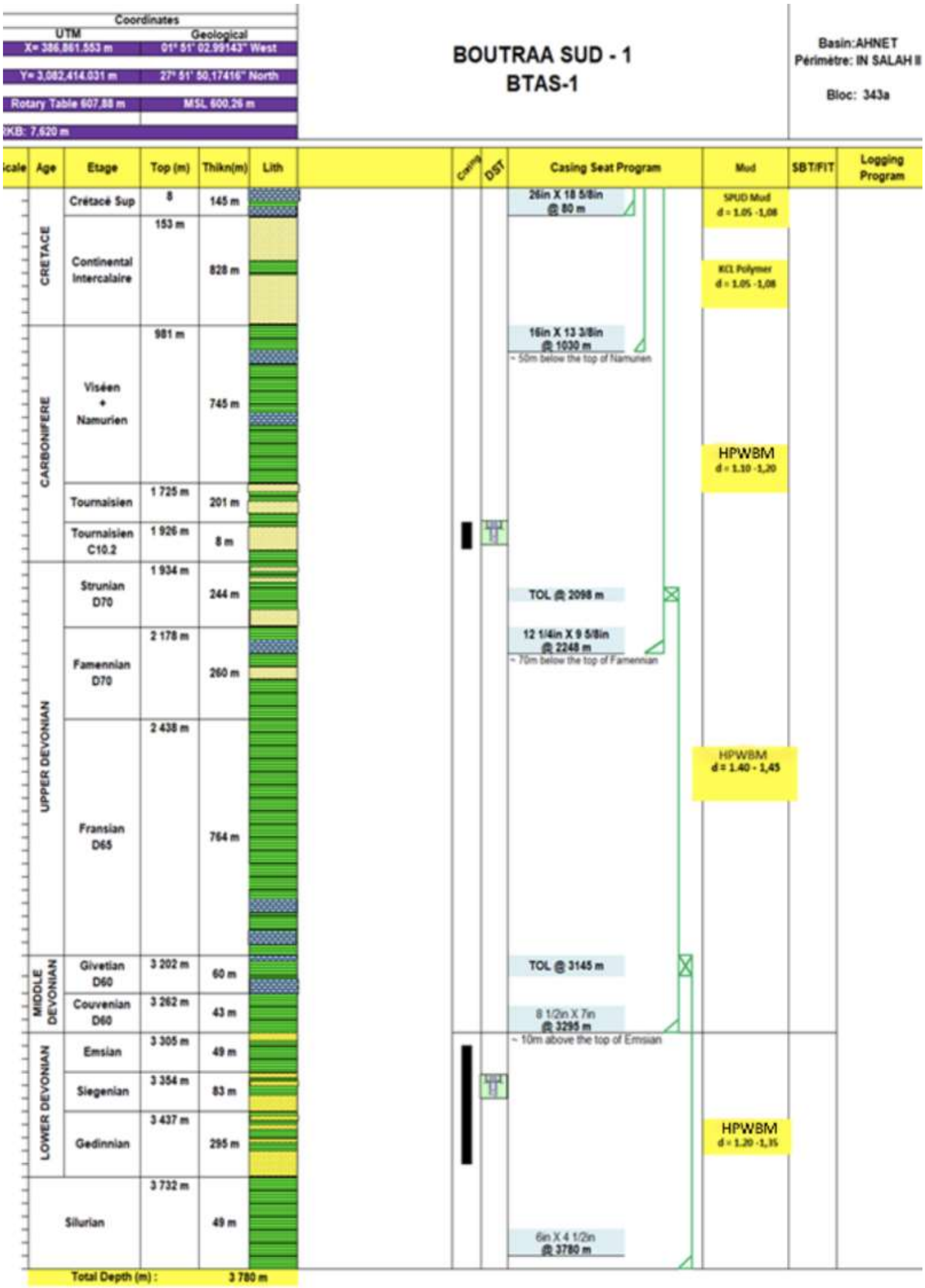

Figure III. 3: Lithology of the well BTAS-1 in In Salah Field.

III.5. Oil-Based Mud Well:

This section focuses on the use of oil-based mud in a specific well, highlighting the well location, summary and the results obtained.

The well drilled using oil-based mud and it has its coordinates and lithology

III.5.1. Well Presentation:

The AZRAFIL EST-1 (BTAS-1) well is situated in the REGGANE basin depicted in **Figure III.4**, located in the ADRAR province. The precise geographical coordinates of the well are as follows:

- Latitude: 26° 39' 25.55352" N
- Longitude: 0° 19' 29.76698" E
- Elevation: 237.59 metres above mean sea level (MSL)

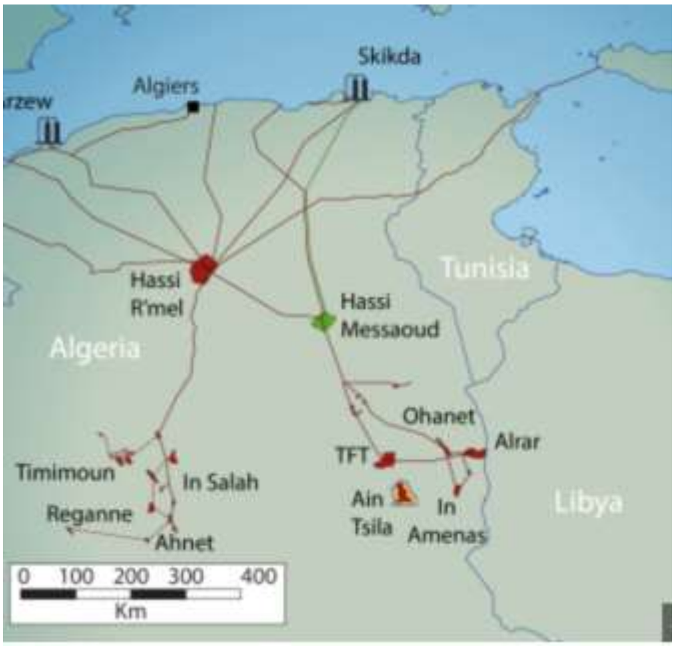

Figure III. 4: Location of the Reggane Field

III.5.2. Mileage Count from Hassi Messaoud:

The mileage count from Hassi Messaoud to the AZRE-1 drilling site is shown in **Table III.2**. It describes the distances travelled between various waypoints along the access route, providing useful logistical information for the project. The total distance travelled is 1236.3 kilometres, which provides useful navigational information.

Table III.2: Mileage Count of AZRE-1 from Hassi Messaoud.

Access Route	Tar	Track A	Track B	Track C	Total
HMD → Adrar	**1060**				**1060**
Adrar → Reggane	**150**				**150**
Reggane → Azrafil	**10**				**10**
Azrafil → Embr. AZRS-1	**5.4**				**5.4**
Embr AZRS-1 → AZRS-1				**5.6**	**5.6**
Embr AZRS-1 → AZRE-1	**5.3**			**5.3**	**5.3**
Total (km)	**1213.5**			**11.4**	**1236.3**

III.5.3. Well location:

Synoptic schematic map **Figure III.5** of drilling of the well AZRE-1 from Hassi Messaoud.

Figure III. 5: Synoptic Schema of AZRE-1 Well.

III.5.4. Well Summary:

The well summary provides an overview of the lithology and stratigraphy encountered during drilling as in **Figure III.6.**

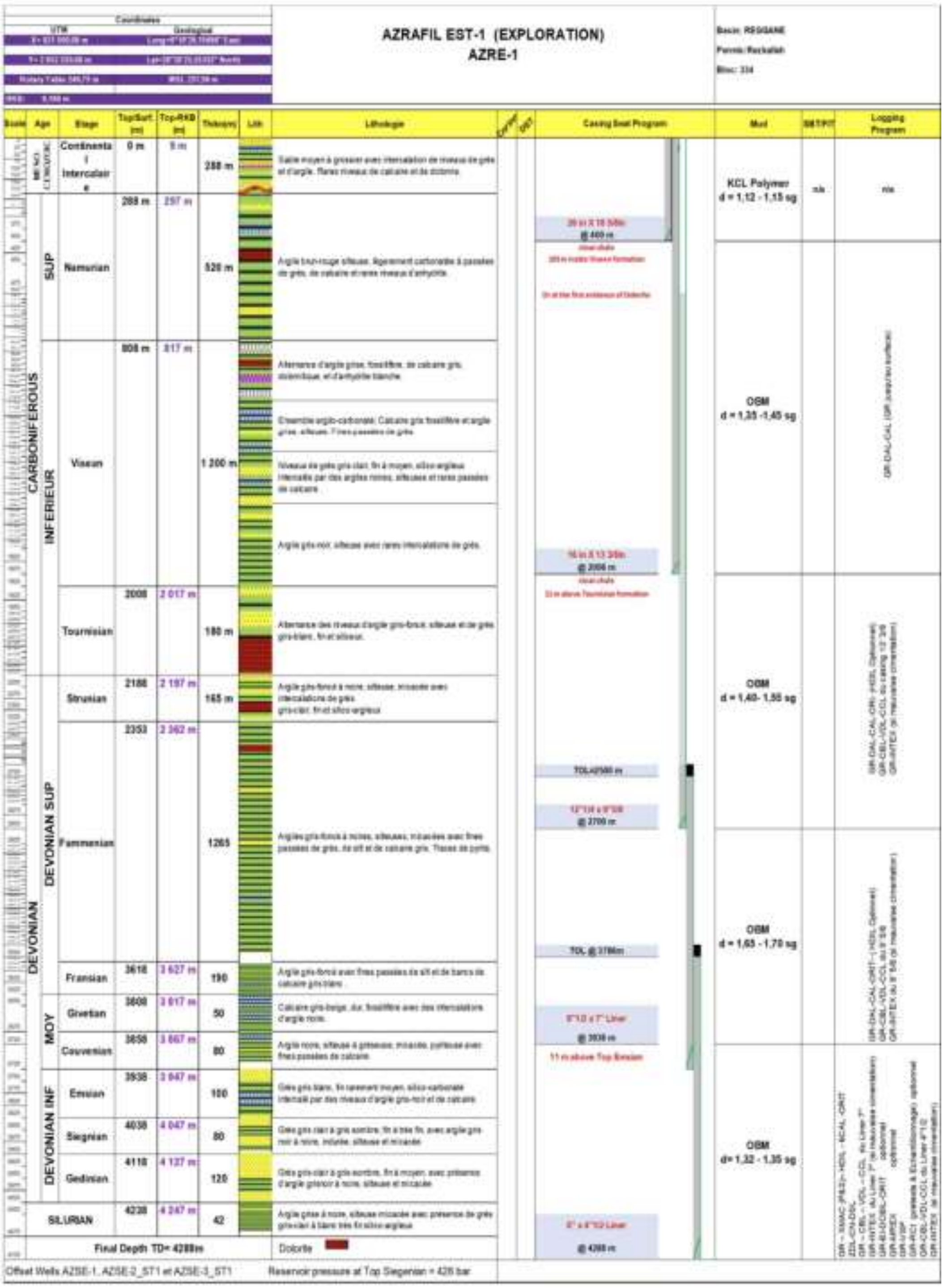

Figure III. 6: Lithology of the well AZRE-1 in Reggane Field.

III.6. Comparison between OBM Well and HPWBM Well:

This section presents a comprehensive comparison between an OBM well and a HPWBM well, specifically AZRE-1 and BTAS-1, respectively. The comparison of the two wells that are sharing the same lithology focuses on evaluating their performance, cost-effectiveness, and operational efficiency. By analysing real data and drilling parameters. The accompanying tables deliver practical insights into the attainments, challenges, and associated costs of each well, contributing to a better understanding of the considerations involved in selecting the most suitable drilling fluid for oil and gas exploration.

III.6.1. Section 26":

Table III.3: Comparison between the wells AZRE-1 and BTAS-1 in Section 26".

Section	26"	
	OBM Well	HPWBM Well
Well	AZRE-1	BTAS-1
Field	Reggane	AHNET
Drilling Fluid System	KCL/Polymer	Enhanced Spud Mud
Start Date	01/03/2021	02/08/2019
End Date	13/03/2021	15/08/2019
Section Days	13	14
Footage (m)	426	86
Mud Weight (sg)	1.12 - 1.17	1.05 - 1.08
Chemical Cost (kddz)	9,742.536	2826.63
Diesel Cost (kddz)	0.000	//
Diesel Transport Cost (kddz)	0.000	//
Total Services Cost (kddz)	5,198.716	2,577.15
Total Section Cost (kddz)	15,296.367	4,773.87
Drilling Problems	1. WBM came out from the cellar	1 - Got communication on the cellar. 2 - Got total losses at 24m depth. 3 - IBS set @ 11 m
Solution Adopted	1. Pumped cement plug	1. Pumped 07 cement plugs. 2. Pumped 4m³ cement plug, losses cured. 3. Worked intervals from 10 to 15 m.
Total Lost Volume (m³)	868.00	246
Formation Losses (m³)	0.00	0
LCM cost (kddz)	5.07	0
Re-usable Volume (m³)	0.00	69
Avr. ROP (m/hr)	2.80	1.31

Due to both wells being drilled using a water-based mud, it is important to note that the interpretation of the table should be approached with caution, as the comparison may lack accuracy. The similar drilling fluid composition introduces a potential confounding factor that could influence the observed results and limit the reliability of any direct comparisons made between the wells.

III.6.2. Section 16":

Table III.4: Comparison between the wells AZRE-1 and BTAS-1 in Section 16".

Section	16"	
	OBM Well	HPWBM Well
Well	AZRE-1	BTAS-1
Field	Reggane	AHNET
Drilling Fluid System	OBMB VERSADRILL 70-79	KCL/Polymer
Start Date	14/03/2021	16/08/2019
End Date	20/04/2021	02/09/2019
Section Days	38	18
Footage (m)	1593	939
Mud Weight (sg)	1.35 - 1.45	1.05 - 1.08
Chemical Cost (kddz)	30,555.587	13,703.43
Diesel Cost (kddz)	11,066.178	//
Diesel Transport Cost (kddz)	5.736	//
Total Services Cost (kddz)	3,631.856	1,044.48
Total Section Cost (kddz)	18,729.553	14,169.72
Drilling Problems	1. slow ROP &High torque and lost rotation many times @1318 m	1. Formation losses 209m3. 2. Tight hole at several points. 3. MW increase due to bad solids control equipment efficiency.
Solution Adopted	1-increase mud weight of active system from d=1.35sg to d=1.40sg	1. Pumped LCM pills. 2. Work intervals. 3. Dump and dilute.
Total Lost Volume (m^3)	384.00	576
Formation Losses (m^3)	0.00	209
LCM cost (kddz)	0.00	878.874
Re-usable Volume (m^3)	401.00	153
Avr. ROP (m/hr)	3.10	5.52

The cost analysis reveals significant differences between the OBM well (AZRE-1) and the HPWBM well (BTAS-1), with a particular emphasis on diesel costs. The OBM well incurred higher diesel costs of 11,066.178 kddz, while the HPWBM well did not report any diesel costs.

This disparity in diesel costs highlights one of the advantages of using HPWBM over OBM. By transitioning to HPWBM, drilling operations can potentially eliminate or notably reduce diesel costs, leading to cost savings and improved cost-effectiveness. The absence of diesel costs in the HPWBM well indicates its potential as an environmentally friendly and economically viable alternative.

Furthermore, the cost of the overall services, including chemical and other expenses, was lower for the HPWBM well (14,169.72 kddz) compared to the OBM well (18,729.553 kddz). This cost reduction further supports the economic advantages of utilizing HPWBM in drilling operations.

However, it is essential to consider other factors such as drilling performance, formation losses, and reusable volume when evaluating the overall cost-effectiveness of the drilling fluid systems. The HPWBM well demonstrated higher drilling efficiency with an average ROP of 5.52 m/hr compared to the OBM well's ROP of 3.10 m/hr which is a strong point for the HPWBM performance in this difficult section that is well-known by the several problems encountered usually. The OBM well had a larger re-usable volume of drilling fluid (401.00 m^3) compared to the HPWBM well (153 m^3).

In conclusion, while the HPWBM well showed cost advantages with lower services costs and no diesel expenses, a comprehensive analysis considering drilling performance, lost circulation, and re-usable volume is necessary to assess the overall cost-effectiveness of each drilling fluid system.

III.6.3. Section 12"¼

Table III.5: Comparison between the wells AZRE-1 and BTAS-1 in Section 12"¼.

Section	12"¼	
	OBM Well	HPWBM Well
Well	AZRE-1	BTAS-1
Field	Reggane	AHNET
Drilling Fluid System	OBMB VERSADRILL 80-89	HydraGlyde
Start Date	21/04/2021	03/09/2019
End Date	18/05/2021	10/10/2019
Section Days	28	38
Footage (m)	732	1166
Mud Weight (sg)	1.4 - 1.65	1.1 - 1.20
Chemical Cost (kddz)	11,714.938	9,327.080
Diesel Cost (kddz)	3,796.764	//
Diesel Transport Cost (kddz)	1.968	//
Total Services Cost (kddz)	2,588.284	2,177.590
Total Section Cost (kddz)	17,305.652	7,829.520
Drilling Problems	1. Tight hole and stuck pipe @ 2031m 2. Formation losses 96m³.	No problems were encountered.
Solution Adopted	1. POOH and change 12 1/4" BHA. 2. Pumped LCM pill	
Total Lost Volume (m³)	306.00	211.00
Formation Losses (m³)	96.00	0.00
LCM cost (kddz)	85.54	0.00
Re-usable Volume (m³)	319.00	238.00
Avr. ROP (m/hr)	2.04	5.39

The comparison of the OBM well (AZRE-1) and the HPWBM well (BTAS-1) in the 12"¼ section reveals notable differences in drilling parameters, costs, and drilling problems encountered.

In terms of drilling parameters, the HPWBM well demonstrated higher efficiency with a longer section duration of 38 days and larger footage of 1166m compared to the OBM well's 28 days and 732m, respectively. The HPWBM well also exhibited a significantly higher average ROP of 5.39 m/hr, indicating faster drilling progress.

The cost analysis shows that the HPWBM well had lower chemical costs (9,327.080 kddz) compared to the OBM well (11,714.938 kddz). Additionally, as always the HPWBM well did not report any diesel costs, whereas the OBM well incurred a diesel cost of 3,796.764 kddz excluding its transport. Consequently, the total services cost and the overall section cost were lower for the HPWBM well, reflecting its cost-effectiveness.

Regarding drilling problems, the OBM well encountered tight hole and stuck pipe issues at 2031m, requiring the adoption of solutions such as pulling out of the hole (POOH) and changing the 12¼" bottom hole assembly (BHA) along with the pumping of LCM pills. In contrast, no significant problems were encountered in the HPWBM well.

The lost circulation analysis reveals that the OBM well experienced a total lost volume of 306.00 m³, including 96.00 m³ of formation losses. LCM was employed to mitigate losses, resulting in a cost of 85.54 kddz. The re-usable volume in the OBM well was reported as 319.00 m³. On the other hand, the HPWBM well had a lower total lost volume of 211.00 m³, with no formation losses or LCM usage. The re-usable volume in the HPWBM well was reported as 238.00 m³.

Overall, the HPWBM well demonstrated better drilling performance, lower costs, and no major drilling problems compared to the OBM well.

III.6.4. Section 8"½:

Table III.6: Comparison between the wells AZRE-1 and BTAS-1 in Section 8"½.

Section	8"½	
	OBM Well	HPWBM Well
Well	AZRE-1	BTAS-1
Field	Reggane	AHNET
Drilling Fluid System	OBMB VERSADRILL 90-96	HydraGlyde
Start Date	19/05/2021	11/10/2019
End Date	05/06/2021	27/10/2019
Section Days	18	17
Footage (m)	1164	1053
Mud Weight (sg)	1.65 - 1.70	1.4 - 1.45
Chemical Cost (kddz)	5,774.645	6,756.900
Diesel Cost (kddz)	995.493	//

Diesel Transport Cost (kddz)	0.516	//
Total Services Cost (kddz)	1,649.076	972.990
Total Section Cost (kddz)	12,137.298	5,192.220
Drilling Problems	No problems encountered	No problems encountered
Solution Adopted		
Total Lost Volume (m³)	178.00	88.00
Formation Losses (m³)	0.00	0.00
LCM cost (kddz)	0.00	0.00
Re-usable Volume (m³)	210.00	247.00
Avr. ROP (m/hr)	7.65	7.77

In the 8"½ section, both the OBM well (AZRE-1) and the HPWBM well (BTAS-1) performed well without encountering any drilling problems.

The HPWBM well outperformed the OBM well in various drilling parameters, showcasing its higher efficiency. With a longer section duration of 38 days and larger footage of 1166m compared to the OBM well's 28 days and 732m, respectively, the HPWBM well demonstrated faster drilling progress with a significantly higher average ROP of 5.39 m/hr.

In terms of costs, the HPWBM well exhibited lower chemical costs of 9,327.080 kddz compared to the OBM well's 11,714.938 kddz. Moreover, the HPWBM well did not incur any diesel costs, further contributing to its cost-effectiveness. Consequently, both the total services cost and the overall section cost were lower for the HPWBM well.

Unlike the OBM well, the HPWBM well did not encounter any significant drilling problems, highlighting its smooth operational performance.

When it comes to lost circulation, the OBM well experienced a total lost volume of 306.00 m³, including 96.00 m³ of formation losses. LCM was utilised to mitigate losses, incurring a cost of 85.54 kddz. In contrast, the HPWBM well had a lower total lost volume of 211.00 m³, without any formation losses or the need for LCM. The re-usable volume in the HPWBM well was reported as 238.00 m³, indicating efficient fluid management.

Overall, the HPWBM well demonstrated superior performance in terms of drilling parameters, cost-effectiveness, and encountering fewer operational challenges, making it a favourable choice in the given context.

III.6.5. Section 6":

Table III.7: Comparison between the wells AZRE-1 and BTAS-1 in Section 6".

Section	6"	
	OBM Well	HPWBM Well
Well	AZRE-1	BTAS-1
Field	Reggane	AHNET
Drilling Fluid System	OBMC VERSADRILL 90-96	HydraGlyde
Start Date	06/06/2021	28/10/2019
End Date	23/6/2021	28/12/2019
Section Days	18	62
Footage (m)	356	496
Mud Weight (sg)	1.3 - 1.35	1.2 - 1.35
Chemical Cost (kddz)	7,194.088	11,708.345
Diesel Cost (kddz)	4,769.106	//
Diesel Transport Cost (kddz)	2.472	//
Total Services Cost (kddz)	12,317.116	9,450.050
Total Section Cost (kddz)		
Drilling Problems	1- Stuck pipe @4058m, mechanical pack-off, fishing	1. Tight holes at some points. 2. Volume increase due to influx. 3. Damaged bit. 4. Stuck with a 4 1/2" liner
Solution Adopted	1- Fishing with 4"3/4 overshot	1. Work intervals. 2. Increase MW. 3. Run with a Magnet and junk basket. 4. Mechanical Back-off, fishing.
Total Lost Volume (m³)	328.00	782.000
Formation Losses (m³)	0.00	0.000
LCM cost (kddz)	0.00	0.000
Re-usable Volume (m³)	0.00	0.000
Avr. ROP (m/hr)	1.14	1.10

In the 6" section, the OBM well (AZRE-1) and the HPWBM well (BTAS-1) faced different challenges and had varying performances.

The OBM well completed the section in 18 days, drilling 356m with an average ROP of 1.14 m/hr. Total services cost was 12,317.116 kddz, including chemical costs of 7,194.088 kddz and diesel costs of 4,769.106 kddz. It encountered a significant drilling problem, resulting in a lost volume of 328.00 m³.

In contrast, the HPWBM well took 62 days to drill 496m with an average ROP of 1.10 m/hr. Total services cost was 9,450.050 kddz, with chemical costs of 11,708.345 kddz. It faced multiple drilling problems and reported a higher lost volume of 782.000 m^3.

Although the OBM well had a shorter duration and lower cost, it encountered a major drilling problem. The HPWBM well had a longer duration but faced multiple challenges. The HPWBM well demonstrated slightly better performance in terms of section duration, average ROP, and cost efficiency.

III.7. Results Analysis and Discussion:

III.7.1. Environmental impacts:

The analysis highlights significant environmental concerns regarding CO_2 emissions within the oil and gas industry, particularly related to diesel transportation. Each metric ton of CO_2 emitted during the combustion and transportation of diesel exacerbates the industry's environmental impact. The transportation of diesel, including the use of lorries and other modes, amplifies CO_2 emissions, contributing to the equivalent of 880 Teq CO_2.

Addressing these concerns necessitates proactive measures, such as adopting non-oil-based fluids like high-performance water-based mud, to promote sustainable practices, reduce transportation requirements, mitigate CO_2 emissions, and foster a more sustainable and environmentally friendly future.

III.7.2. Diesel Consummation:

The analysis reveals that diesel consumption accounts for 22.05% of the total well cost, reflecting a significant financial burden. However, it is important to note that the actual cost of diesel may exceed this percentage due to additional procurement and handling expenses. Diesel consumption further represents 24.30% of the total chemical products cost, highlighting its substantial contribution to overall expenditure. Notably, the use of diesel in well operations raises environmental concerns, as its combustion emits harmful pollutants contributing to air pollution and climate change. Additionally, it poses a risk to natural aquifers, when facing severe or total lost circulation all the mud penetrates natural reservoirs of water causing environmental damage and contamination.

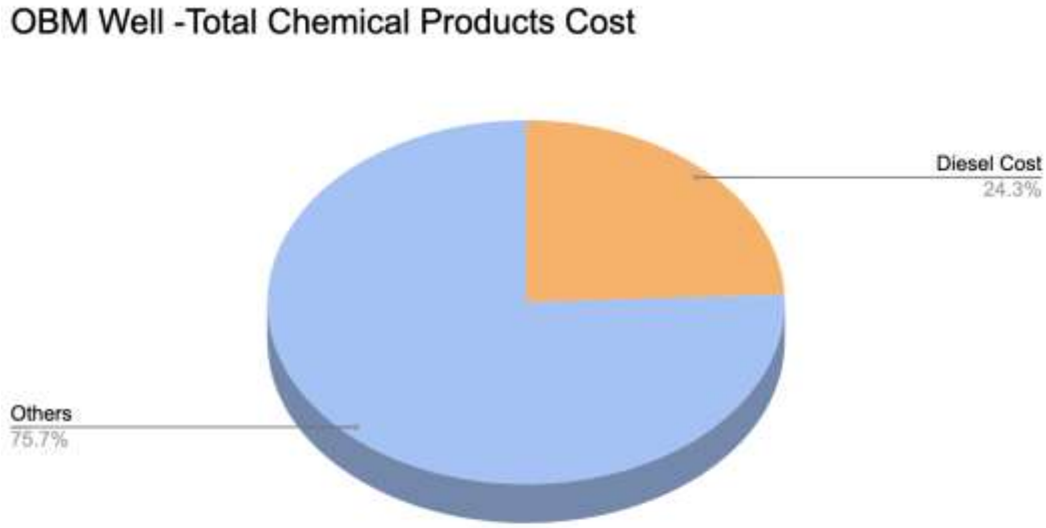

Figure III. 7: Diesel Cost Compared to Chemical Products Cost.

III.8. Conclusion:

The findings highlight that the transition to HPWBM not only provides environmental benefits but also offers significant cost-saving opportunities. By eliminating the need for costly OBM and reducing logistical complexities, HPWBM enhances cost efficiency in drilling operations despite the quantity of chemical products used to formulate it. Moreover, the use of HPWBM reduces transportation costs associated with OBM, further contributing to overall cost reduction.

In summary, the shift to HPWBM presents a sustainable solution to address the environmental challenges of OBM while delivering substantial cost benefits. This transition promotes environmental consciousness and financial prudence, making it an appealing choice for the oil and gas industry seeking to optimize costs and enhance operational efficiency.

Table III.8: Comparison between the Wells Costs.

Section	36"	26"	16"	12"¼	8"½	6"	Total	Footage	Days	Location
HPWBM										
KTDO-1		16,240.25	19,607.33	76,578.78	42,727.02	7,407.06	162,560.43	4071.87	235	Oued Namous
KL0-1	2,151.67	11,576.48	34,240.06	64,599.33	18,922.68	59,984.06	191,474.27	3938	297	Reggane
BTAS-1		4,773.87	14,169.72	7,829.520	5,192.220		74,556.49	3740	256	Ahnet
GF-26		11,063.19	7,540.70	40,214.56	8,295.61		88,903.13	2220	185	Garet ElGuefoul
BIRN-1		8,937.95	17,072.68	35,079.83	43,512.34		104,602.81	3260	141	Alrar
NKT-1		3,801.05	23,747.30	26,771.41	26,442.90		80,762.67	3063	168	Reggane
TNK-303		2,715.48	5,176.51	7,883.22	16,603.11		32,378.32	1726	73	Timimoune
TNK-3O6		3.299.760	2.995.083	8.185.365	16.609.061		31.089.268	1692	62	Timimoune
OBM										
AZRE-1	15,296.367	18,729.553	17,305.652	12,137.298	5,192.22		93,545.76	4271	235	Reggane
HMR-1	3,926.80	12,312.71	19,443.50	5,995.22			58,615.05	3150	129	Oued Namous
KTDO-1					42,727.02					

The table presents the footage and duration of drilling operations for different wells in various locations, comparing the use of high-performance water-based mud (HPWBM) and oil-based mud (OBM).

For the HPWBM category:

- KTDO-1 well: The drilling operation covered a total footage of 162,560.43 feet over 4,071.87 days in Oued Namous.

- KL0-1 well: The drilling operation covered a total footage of 191,474.27 feet over 3,938 days in Reggane.

- BTAS-1 well: The drilling operation covered a total footage of 74,556.49 feet over 3,740 days in Ahnet.

- GF-26 well: The drilling operation covered a total footage of 88,903.13 feet over 2,220 days in Garet ElGuefoul.

- BIRN-1 well: The drilling operation covered a total footage of 104,602.81 feet over 3,260 days in Alrar.

- NKT-1 well: The drilling operation covered a total footage of 80,762.67 feet over 3,063 days in Reggane.

- TNK-303 well: The drilling operation covered a total footage of 32,378.32 feet over 1,726 days in Timimoune.

- TNK-306 well: The drilling operation covered a total footage of 31,089.268 feet over 1,692 days in Timimoune.

For the OBM category:

- AZRE-1 well: The drilling operation covered a total footage of 93,545.76 feet over 4,271 days in Reggane.

- HMR-1 well: The drilling operation covered a total footage of 58,615.05 feet over 3,150 days in Oued Namous.

The data highlights the varied performance and efficiency of drilling operations when utilizing HPWBM compared to OBM. Further analysis and comparison of the data can provide insights into the effectiveness and potential benefits of using HPWBM over OBM in terms of operational duration, well footage, and specific locations.

GENERAL CONCLUSION

In conclusion, the analysis emphasizes the importance of selecting the right drilling fluid for achieving cost-effectiveness and exceptional performance. The Hydraglyde system, a high-performance water-based mud, offers distinct advantages over traditional oil-based mud systems.

One key advantage of the Hydraglyde system is its environmental friendliness, aligning with global sustainability efforts. Unlike diesel used in oil-based mud systems, the Hydraglyde system minimizes ecological impact and reduces costs. Diesel is expensive and environmentally harmful, contributing to climate change and air pollution.

The transition to the Hydraglyde system not only addresses environmental concerns but also delivers superior performance. Laboratory tests confirm its effectiveness in controlling shale swelling without reacting to water, preventing bit balling and wellbore instability. the results from the shale dispersion tests demonstrate the remarkable effectiveness of high-performance water-based mud in shale recovery, highlighting its superiority over freshwater.

Incorporating the Hydraglyde system enables operators to achieve cost-effectiveness while reducing environmental harm. By eliminating the need for diesel and embracing water compatibility, operational costs and ecological footprints are minimized.

To summarize, selecting the appropriate drilling fluid, such as the Hydraglyde system, ensures cost-effectiveness, and exceptional performance, and addresses the challenges associated with diesel usage. Embracing these advancements reflects a commitment to academic and professional excellence in sustainable drilling practices.

RECOMMENDATIONS

Based on the findings of this study, it is recommended that the oil and gas industry consider the following actions to optimize drilling operations and promote sustainability:

1. The transition from oil-based mud (OBM) to high-performance water-based mud (HPWBM): The use of HPWBM offers environmental benefits, reduces costs, and improves drilling efficiency. Implementing this transition can significantly mitigate the environmental impact and logistical challenges associated with OBM.
2. Analyze the economic implications: While this study touched upon the cost-saving potential of transitioning to high-performance water-based mud, further research is needed to conduct comprehensive economic analyses. Future studies should consider factors such as upfront investment costs, operational expenses, and the potential return on investment associated with adopting alternative drilling fluid technologies.
3. Enhance environmental stewardship: Recognizing the adverse effects of diesel on the environment and natural aquifers, it is crucial to adopt practices that minimize pollution and damage. This can include implementing stringent environmental regulations, investing in advanced filtration systems, and promoting responsible disposal of drilling waste.
4. Collaborate with stakeholders: Effective collaboration between industry stakeholders, government bodies, and environmental organizations is essential. By sharing knowledge, expertise, and resources, collective efforts can be made to develop sustainable drilling practices, address environmental concerns, and foster long-term industry growth.

By implementing these recommendations, the oil and gas industry can achieve a more sustainable and cost-effective approach to drilling operations, while minimizing environmental impact and promoting responsible resource management.

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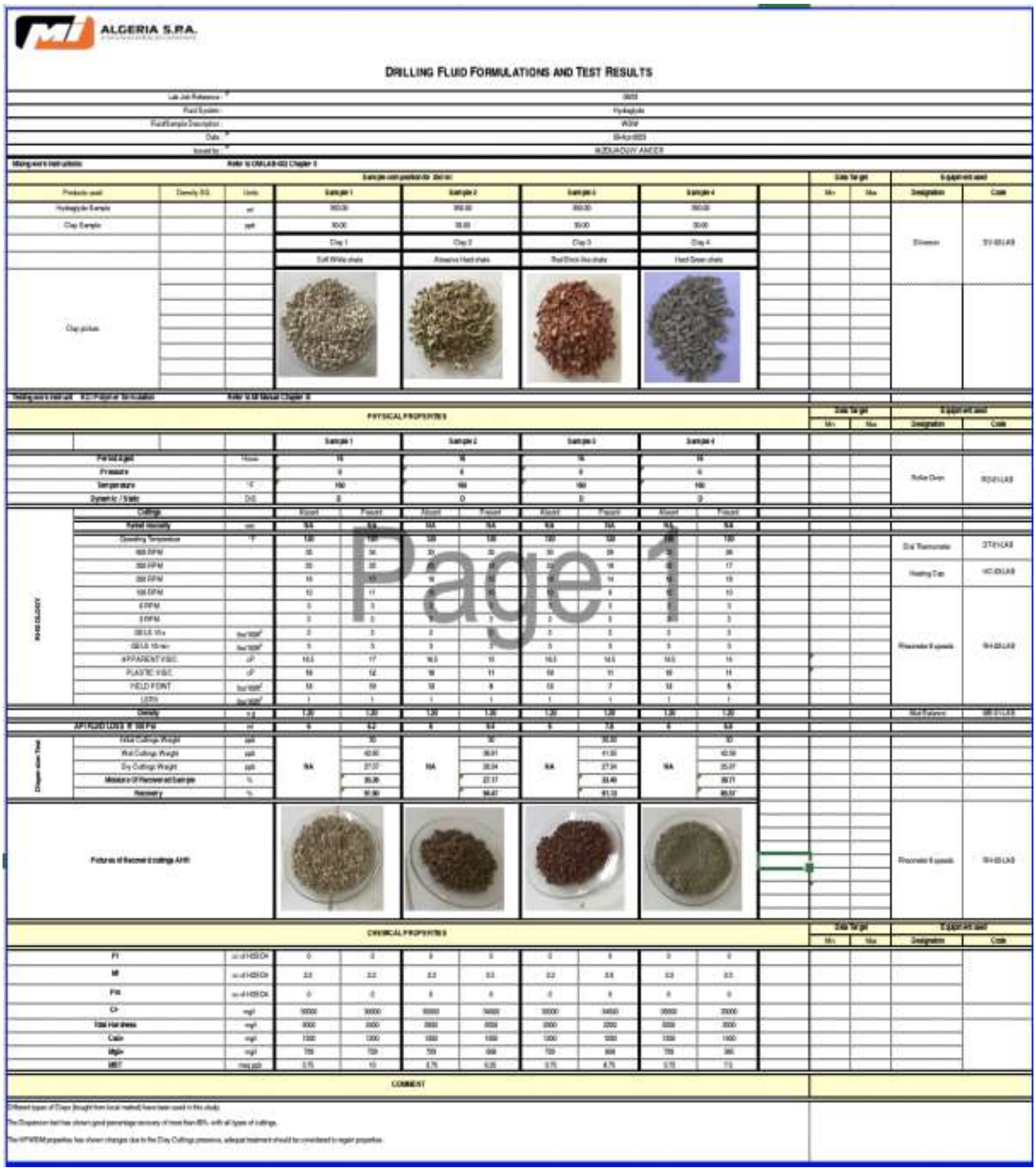
APPENDIX

Appendix 01: Dispersion Test with High-Performance Report



Appendix 02: Dispersion Test with Fresh-Water Report

APPENDIX

Table 01: Cost Comparison between each Section of two Wells with the same Lithology and Different Drilling Fluids

Section	26"		16"		12"¼		8"½		6"	
	OBM Well	HPWBM Well	OBM Well	HPWBM Well	OBM Well	HPWBM Well	OBM Well	HPWBM Well	OBM Well	HPWBM Well
Well	AZRE-1	BTAS-1	AZRE-1	BTAS-1	AZRE-1	BTAS-1	AZRE-1	BTAS-1	AZRE-1	BTAS-1
Field	Reggane	AHNET	Reggane	AHNET	Reggane	AHNET	Reggane	AHNET	Reggane	AHNET
Drilling Fluid System	KCL/Polymer	Enhanced Spud Mud	OBMB VERSAD RILL 70-79	KCL/Poly mer	OBMB VERSAD RILL 80-89	HydraGlyde	OBMB VERSADR ILL 90-96	HydraGlyde	OBMC VERSAD RILL 90-96	HydraGlyde
Start Date	March 1 2021	02/08/2019	14/03/2021	16/08/2019	21/04/2021	03/09/2019	19/05/2021	11/10/2019	06/06/2021	28/10/2019
End Date	March 13 2021	15/08/2019	20/04/2021	02/09/2019	18/05/2021	10/10/2019	05/06/2021	27/10/2019	23/6/2021	28/12/2019
Section Days	13	14	38	18	28	38	18	17	18	62
Footage (m)	426	86	1593	939	732	1166	1164	1053	356	496
Mud Weight (sg)	1.12 - 1.17	1.05 - 1.08	1.35 - 1.45	1.05 - 1.08	1.4 - 1.65	1.1 - 1.20	1.65 - 1.70	1.4 - 1.45	1.3 - 1.35	1.2 - 1.35
Chemical Cost (kddz)	9,742.536	2826.63	30,555.587	13,703.43	11,714.938	9,327.080	5,774.645	6,756.900	7,194.088	11,708.345
Diesel Cost (kddz)	0.000	//	11,066.178	//	3,796.764	//	995.493	//	4,769.106	//
Diesel Transport Cost (kddz)	0.000	//	5.736	//	1.968	//	0.516	//	2.472	//
Total Services Cost (kddz)	5,198.716	2,577.15	3,631.856	1,044.48	2,588.284	2,177.590	1,649.076	972.990	12,317.116	9,450.050
Total Section Cost (kddz)	15,296.367	4,773.87	18,729.553	14,169.72	17,305.652	7,829.520	12,137.298	5,192.220		
Drilling Problems	1. WBM came out from the cellar	1 - Got communication on the cellar. 2 - Got total losses at 24m depth. 3 - IBS set @ 11 m	slow ROP &High torque and lost rotation several time @1318 m	1. Formation losses 209m3. 2. Tight hole at several points. 3. MW increase due to bad solids control equipment efficiency.	1. Tight hole and stuck pipe @ 2031m 2. Formation losses 96m³.	No problems were encountered.	No problems encountered	No problems encountered	1- Stuck pipe @4058m, mechanical pack-off, fishing	1. Tight holes at some points. 2. Volume increase due to influx. 3. Damaged bit. 4. Stuck with a 4 1/2" liner
Solution Adopted	1. Pumped cement plug	1. Pumped 07 cement plugs. 2. Pumped 4m³ cement plug, losses cured. 3. Worked intervals from 10 to 15 m.	1-increase mud weight of active system from d=1.35sg to d=1.40sg	1. Pumped LCM pills. 2. Work intervals. 3. Dump and dilute.	1. POOH and change 12 1/4" BHA. 2. Pumped LCM pill				1- Fishing with 4"3/4 overshot	1. Work intervals. 2. Increase MW. 3. Run with a Magnet and junk basket. 4. Mechanical Back-off, fishing.

Total Lost Volume (m^3)	868.00	246	384.00	576	306.00	211.00	178.00	88.00	328.00	782.000
Formation Losses (m^3)	0.00	0	0.00	209	96.00	0.00	0.00	0.00	0.00	0.000
LCM cost (kddz)	5.07	0	0.00	878.874	85.54	0.00	0.00	0.00	0.00	0.000
Re-usable Volume (m^3)	0.00	69	401.00	153	319.00	238.00	210.00	247.00	0.00	0.000
Avr. ROP (m/hr)	2.80	1.31	3.10	5.52	2.04	5.39	7.65	7.77	1.14	1.10