THE EXPERIMENTAL EFFECT OF CONTAMINANT IN WATER BASED DRILLING FLUID

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CERTIFICATION

This is to certify that this project was carried out by **ANUMENE NDUKAEGO** of the Department of Petroleum Engineering with matriculation number **ENG2106271** in partial fulfillment of the requirements for the Award of the Degree, Bachelor of Engineering (B.ENG)

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DEDICATION

This project is dedicated to God Almighty, whose grace, wisdom, and strength have guided me throughout this journey. Without His divine help, this achievement would not have been possible. I also dedicate this work to my beloved parents for their prayers, encouragement, and sacrifices, and to my siblings for their constant love and support. To my professors and lecturers, who have inspired me to value knowledge for its own sake and motivated me to keep striving for excellence, I remain deeply grateful.

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To God be the Glory.

ABSTRACT

The oil and gas industry is extremely risky and difficult, necessitating the safe and cost-effective execution of all operations. A drilling operation's success depends on the careful selection and application of drilling fluid. Investigating how contaminants affect the properties of water-based drilling fluids is the main goal of this study. This experiment revealed that the fluid loss into the formation was enhanced when sodium salt was present in the mud system. Additionally, as the mass of the mud sample increased from 1g to 5g, the apparent viscosity and gel strength increased, but the plastic viscosity and pH stayed constant. On the other hand, the yield point showed minimal growth. Since the amount of cement sample used was increased from 1g to 5g while the pH remained constant, all rheological properties of the mud increased significantly when cement was used as a contaminant. The carbonate effect is largely on the Gel strength which decreased as the amount of added carbonate increased. The pH had no charges, which also meant carbonate kept the mud in its alkaline state, as it was the case with cement. In conclusion, the presence of a contaminant on the drilling mud either reduces or increases the rheological properties of the mud sample. This in turn affects the rate of penetration, its performance and also could pose serious drilling problems.

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CHAPTER ONE

INTRODUCTION

1.1 Background of The Study

Just as blood is essential to the development of petroleum resources, so too is drilling mud, the fluid mixture used in rotary drilling. According to George and Darryl (1983), water was the first drilling fluid and was used for basic rotary tool drilling in ancient Egypt and China. A few patents from the 1800s also discuss how early rotary drilling designs used a drilling fluid. Early rotary water well drilling would have produced mud when the water combined with naturally occurring clay deposits, and it was likely observed that it was better at cleaning the hole than water alone. The use of mined bentonite clays and the addition of weighting materials (barite, iron oxides) marked the first significant changes to drilling mud in the 1920s. As a result, the first commercial drilling mud companies were established, including NL Baroid. Engineered drilling mud first appeared in the 1930s in response to more challenging and deep drilling conditions.

When drilling a well to the target zone, a number of related issues could arise, including lost circulation, formation damage, kick, and, if left unchecked, blowout, pipe sticking, hole instability, etc. which can be avoided by using sufficient drilling mud. Additionally, inadequate hole cleaning can result in decreased penetration rate, fluid circulation loss, increased rotary torque, formation breakdown, and stuck pipe (Hussain et al, 2010). In order to effectively drill a well to the reservoir's pay zone, it is necessary to formulate the proper drilling fluid, which is a key well control method to overcome the formation pressure as the well deepings. Since drilling mud is regarded as the lifeblood of any drilling operation, it must have certain physical and chemical qualities in order to withstand the wide range of well conditions that are encountered.

Care must be taken when choosing and applying the drilling fluid; these are important aspects that must be taken into account for any drilling operation to be considered successful. The properties of drilling fluids must be monitored, tested, and investigated from the beginning of the drilling operation and at regular intervals to ensure they have the desired qualities throughout. In most cases, drilling mud agents are added to the muds if necessary to ensure a successful drill operation. Any actions that go against the careful selection and application of drilling fluids could have very dire consequences, such as destruction of the drilling rig equipment, non-productive time leading to financial losses, damage to the environment, and loss of crew members. The performance of the drilling fluid is connected to almost every drilling issue, either directly or indirectly. This is not to say that every issue that arises can be traced back to or resolved by the drilling fluid.

As a result, a drilling fluid should generally be viewed as an extremely important and complex component of the entire drilling process that should be utilized to enhance other elements of the operation.

1.2 Statement of The Problem

The use of drilling muds is essential to the science and expertise of well drilling for a number of reasons, including the removal of cuttings to the surface and the preservation of wellbore stability. This suggests that the behavior of the formation to be drilled affects the choice of drilling mud. Kick/blowout, pipe sticking, lost circulation, borehole instability, formation damage, and other issues that arise from drilling operations are all part of the ongoing process of contaminating the drilling fluid. is frequently caused by the contamination. The drilling mud's properties are changed by contaminants, which leads to the mud's poor performance. The addition of solids to drilling fluid, which can raise viscosity, fluid loss, filter cake, and gel strength, which ultimately lead to loss circulation and mud cake, are some issues with these contaminants. Also, High Concentration of sodium chloride in bentonite-based mud generates an energy barrier and result to several flocculation. Thus, in small amounts, sodium chloride thickens fresh water mud and also increases the filtration rate. Hence, proper study of the effects of contaminants and selection of drilling fluids is necessary in order to ensure a successful drilling operation.

1.3 Aim and Objectives of The Study

The aim of this work is Laboratory Investigation of Effects of Contaminants on Water-Based Drilling Fluid Properties.

The specific objectives are to:

- ✓ Comprehensive understanding of the different drilling fluid properties and contaminants.
- ✓ Laboratory determination of the effect of contaminants on the drilling fluid properties and performance.

- ✓ Determine which of the contaminants will have significant effect on the drilling fluid properties.

1.4 Scope of The Study

This present study is basically on the determination of the effect of drilling fluid contaminants on its rheological properties and also, how it will indirectly affect it's performance during drilling operations. Generally, Water-Based mud is mostly prone to contamination. Thus, in this study, Water-Based Mud was used and a blank mud (control sample) was prepared, and other samples with the following contaminants: Salt (NaCl), Cement, Silica Sand, Carbonate (Na_2CO_3) were analyzed in the laboratory.

1.5 Research Questions

i. What was the purpose of introduction to investigate the effect of contaminants on Drilling Muds

ii. What are the effects of different contaminants on Drilling Mud

1.6 Significance of The Study

The aspect of research on the effect of contaminants on the drilling mud performance cannot be overemphasized. Thus, this study is important to:

i. Reduce drilling cost

ii. Increase personnel safety

iii. Minimize downtime of the rig

iv. Increase productivity in the well

CHAPTER TWO

LITERATURE REVIEW

Drilling operations use a variety of drilling mud types on a daily basis. Because of the nature of the formation found at different points in the wellbore or in combination with other mud systems, certain wells require the use of different types of mud. The different drilling fluids were divided into a few general categories by the Oilfield Glossary, including "air, air/water, air/polymer, water-based mud (WBM), oil-based mud (WBM), and synthetic-based fluid (SBM).".

Olufemi *et al* (2011) did a work to experimentally investigate the alteration of flow properties of oil based mud after the intrusion of contaminants and based on their results, they deduced that maintaining a low mud density minimizes its viscosity, and when the pressure within the wellbore annulus is reduced which is caused by the fluid circulation, it minimizes the filter cake thickness. In a scenario where there is a thick filter cake sealing or restricting flow, the pressure beneath the bit increases and can result to loss circulation of mud. They also concluded that as the drill cuttings are removed, the plastic viscosity decreases and a decrease in the plastic viscosity will increase the low shear rate viscosity which will bring larger, more easily removable cuttings to the surface.

Ali et al. (2013) investigated the effect of NaCl salt contamination on rheological properties of bentonite drilling mud and from the result they obtained, they inferred that both plastic viscosity and the electrical resistivity were reduced with an increase in salt content. Basirat et al (2013) also conducted similar research and stated that for a mud system that is contaminated, there is about 30% increase in the filter loss and 86% decrease in resistivity as compared to the same sample without contamination. Furthermore, the result obtained by Hassiba and Amani (2013) showed that NaCl contamination increases the shear stress/shear rate while KCl contamination decreases the shear stress/shear rate curves of water based mud.

Hussain *et al* (2010) stated that in the process of drilling, one of the major problems affecting its operation is poor or inadequate hole cleaning which can result to loss circulation, it reduces the rate of penetration, break down of the formation, pipe sticking and high rotary torque amongst others. Therefore, they defined hole cleaning as the ability of a drilling mud to transport drilled cuttings from the hole to the surface and also suspend the cuttings in case of circulation stoppage.

According to Chinwuba and Igwilo (2000), the geographic location influences the rock type, well depth, and drilling mud composition. Additionally, when the depth of the rock formations and other factors change, the composition of the mud also changes. Neff (2005) states that the grain size of the crushed rock from the strata being drilled determines the amount of solids, such as drill cuttings and formation solids, in the drilling mud that cling to or remain attached to the cuttings.

Kumapayi et al (2014) investigated the effect of clay and sea water containing magnesium and calcium ions contaminations on the rheology of the oil based invert emulsion fluid. Barite was addition in the mud formulation as the weighting agent; the based fluid for the invert emulsion system was EDC-99. The results obtained indicated that as temperature increases, the rheological properties of the mud decreases, The initial low viscosity of the invert emulsion fluid reflects its ability to reduce frictional pressure loss. They concluded that clay contamination increases the gel strength and low shear yield point of fluid as compared to only sea water as contaminants decreasing the tendency for sagging of weighting material to occur. This suggests the usage of clay as rheology modifiers for an invert emulsion based fluid system. Mud electrical stability decreases in the presence of contaminations which indicate the partial emulsification of water in the oil phase. Therefore, as stated by Kumapayi et al (2014) that the plastic viscosity of the invert emulsion fluid was slightly out of API recommended range for each set of contaminations before heat aging; however the invert emulsion fluid can still tolerate and withstand such level of contamination. Nevertheless if threatening to the fluid, pretreatment is advised. Fluid rheology stabilization after heat aging reveals the suitability of the oil based invert emulsion fluids for downhole HTHP drilling that may take longer time.

In an effort to better understand the fluid loss and rheological behavior of water-based mud made with sepiolite clay, Gursat and Umran (2005) conducted a study. They noted that the flocculation phenomenon of bentonite plates can easily cause damage to fresh water-bentonite mud used in geothermal wells in high temperature environments (above 1750C). This phenomenon raises the cost of drilling and has an adverse effect on the drilling process. They came to the conclusion that high temperatures negatively impact sepiolite muds' ability to filter. Without additives, the filtration properties of sepiolite muds are unsuitable for any kind of drilling.

Furthermore, Gursat and Umran (2005) also stated that there is no logging and temperature measurements that could be run as a result of mechanical difficulties in lowering logging tools into a hole due to gelled mud. Another worse case situation for the same phenomenon occurs when brine intrusion is encountered as the drilling operation in progress. High temperature environment along with salt contamination result in unacceptable rheological and filtration properties for the use of fresh-water bentonite mud. Consequently, it would necessitate a complete renewal of mud system.

Nnamdi (2012) performed an experimental for a period of 30days to investigate how the interface of the formation and cement integrity can be affected by the intrusion of drilling mud contamination. This was done using composite core sandstone in addition with approximate 20000 ppm salinity of brine at a confining pressure of 2100 psi, a temperature of 72°F (22.22°C) and flow rate of 1 ml/min. Three composite core samples where used, one was used as a base case with contaminated layer and the other two were contaminated with 5% or 10% mud contamination by volume.

According to Nnamdi's (2012) flow-through experimental result, the presence of mud contamination causes the cement to develop large pores, which become more numerous throughout the core as contamination rises. If the cement surrounding the large pores leaches over time, the large pores may become interconnected. Therefore, he came to the conclusion that, within the range of contaminated used in the experiment, 1% mud contamination of cement seems to be a critical contamination level that will have a long-term detrimental effect on zonal isolation and mechanical failure of wellbore cement to a much greater degree than uncontaminated cement.

Tellisi et al (2005) stated that zonal isolation is one of the most critical functions of wellbore cement; this implies that a failure of any selected cement slurry to provide this necessary function can lead to the contamination of fresh water aquifer, the produced from the wellbore hydrocarbon is lost to a nearby formation, fluid injected into the wellbore is lost as well, it lead to sustained pressure in the casing and may eventually collapse the case or blowout may occur. According to Dusseault et al, (2000) and Cavanagh et al, (2007), they stated that the result from previous studies show that failure of cement can occur in both active and abandoned wells. In the same vein, Nelson (2006) said that cement failure could be created at the cement-casing interface, cement-formation interface or even within the bulk cement.

Fosso et al (2000) stated that drilling fluid contamination is a major cause of cement plug failure because during oil well cementation, leading to alteration in the cement mechanical and chemical properties by the contamination of undisplaced mud.

El Sayed (1995) performed an experiment on three types of drilling fluid such as oil based mud, water based mud and polymer based mud to investigate the effect of mud contamination of cement on cement properties such as consistency, compressive strength, thickening time and rheological properties. The base slurry used for this study comprises a 15.9 ppg density of class G cement slurry, 144 cp plastic viscosity and 7 lb/100 ft^2 yield stress. The range of cement contamination used were 10, 20, 30, 40, 50% mud by volume for the mud types used. For the compressive strength tests, the cement slurry was poured in 2 in steel cubes and cured at 80°C for 12 and 24 hrs.

Based on the observations by El Sayed (1995), the consistency development, compressive strength, thickening time and rheological properties were all changed by the intrusion mud contamination. The compressive strength indicated reasonable reduction due to the increase in mud contamination. The result of neat cement after 12 hrs, gave a compressive strength of about 330 psi while some of the cements that are highly contaminated had almost unmeasurable compressive strength. As the slurry was aged for 24 hrs, the compressive strength in neat cement increased to 1170 psi while the cements that are highly contaminated gave about 200 psi. The 24-hr compressive strength of cement dropped by about 300 psi for every 10% increase in water based mud contamination. Oil based mud contamination reduced the 24-hr compressive strength of cement by about 200 psi for every 10% increase in mud contamination. 10% mud contamination of the cement by polymer based mud reduced the compressive strength from 1170 psi to 300 psi and the compressive strength stayed almost constant at 300 psi as the mud contamination level was increased.

Bradford (1982) conducted an experiment to determine how mud contamination affected the compressive strength of cement samples. Cement slurries of three kinds were utilized. dispersant-containing reduced water slurry, normal slurry, and class H cement. The range of mud contamination used for the experimental study are from 5% to 50%, these cement contaminated mud were formulated and cured at 170-230°F before being subjected to compressive strength tests. The result obtained from the formulated slurries showed a reasonable change in compressive strength as the level of mud contamination increased. The Class H cement slurry was tested after 8hrs and after 16 hrs. For the 8-hr test, 10% mud contamination caused the compressive strength to decrease by about 44% while during the 16-hr test the reduction was by 23%.

Charlez and Heugas (1991) stated that during drilling operation, wellbore instability is the monumental source of concern, causing waste of drilling time and unnecessary costs. This serious problem mainly occurs in shales (principally clays), which represent 75% of all formations drilled by the oil and gas industry. The remaining 25% are composed of other minerals such as sand, salt, etc. The wellbore instability is due to the dispersion of the clay into ultra fine colloidal particles and this has a direct impact on the drilling fluid properties. Chen (2002) pointed out that "wellbore instability problems is estimated to cost the oil industry about 1 billion US dollars each year. Thus, oil-based drilling fluids which contain elevated levels of salt can address this problem; however, excessive costs and environmental requirements limit their use".

Remillard (2010) investigated the effect of nanoparticles on drilling fluid performance and the result obtained from his laboratory study showed that within 15 minutes, about a 100% of hydrogen sulphide contaminant can be removed from water-based drilling muds on addition of nano-scale Zinc oxide to drilling muds, whereas bulk Zinc oxide removes only 2.5% after 90 minutes of treatment.

Similar research using nanoparticles on drilling mud was also done by Jamal et al. (2013), who reported that adding nanoparticles to the drilling mud system improves the mud's rheological characteristics at higher temperatures and pressures. Consequently, the properties of drilling fluids can be improved by using nanotechnology.

As stipulated by Bourgogne A.T. Jr. (1986); Stated that drilling fluid is directly or indirectly related to most drilling problems and an overview of this effect cannot be overemphasized. Also, the presence of hydrated clays in the water has undesirable as well as desirable effects on the rotary drilling process. A reduction in penetration rate and an increase in the frictional pressure losses are observed when the clay content of the drilling fluid increases.

Besides, a high mud pH is desirable to suppress the corrosion rate, hydrogen embrittlement and the solubility of Ca^{2+} and mg^{2+}. Also, the high pH is a favorable environment for many of the organic viscosity control additives, the pH of the most mud is maintained between 9.5 and 10.5 and even higher pH may be used if H_2S is anticipated.

According to Medermonth John's 1973 book, "Drilling mud and fluid additives," contaminants are found during every stage of the drilling process. They are also present in water supplies, drilled formations, and materials used to create and preserve the characteristics of drilling fluids. The drilling mud's chemical and physical properties can be quickly changed by them. It is important to remember that the type of contaminant, the degree of contamination, and the type of drilling mud used all affect how serious the issues are.

Bariod N. L (1985) divided the drilling fluid contaminants into six groups to be able to look at their adverse effects. These include:

1. Contaminants due to solids
2. Contaminants due to sodium chloride
3. Contaminants due to calcium
4. Contaminants due to soluble carbonate
5. Contaminants due to bacterial
6. Contaminants due to hydrogen sulphide.

Some of these contaminants above can be treated chemically while others can be treated physically. It is worth knowing that all contaminants perform the same function which is to distort the properties of the drilling mud and thus reduces its efficiency. Some not only alter the properties but also its pH content thereby causing it to change its function such as corroding subsurface equipment. Based on this, if they are not removed and are continually re-circulated, they can develop series of problems. There will be a marked increase in viscosity, filter cake, fluid loss and gel strength.

Luminous J.L in his book; “Drilling fluids optimization and practical Approach” states that though the primary indication of contamination is the general instability of the drilling fluid properties which manifest itself in a difficulty in controlling the fluid loss, alkalinity or rheology of the mud often in circulation, certain contamination may be tolerated for an extended periods with no adverse effects. He also stated that the severity of the problems experienced depends on the type of contaminants, the degree of the contamination and the type of drilling mud in use.

High temperatures disrupt the cohesiveness and intermolecular forces between the clay particles, according to Ogiri et al. (1991) in their book "The effect of temperature and salt on drilling mud.". This typically leads to a decrease in the mud's viscosity, gel strength, dispersion, and water evaporation in the clay particles, which ultimately causes the filtrate loss and mud cake size to increase. In addition to the aforementioned issue, drilling mud reagents and additives are less effective and cause stuck pipes.

Ezzat et al. (1997) stated that microbial growth in the mud can result in contamination of the well and near-wellbore zone leading to fouling, corrosion and reservoir souring that may occur during subsequent operations. Also, if bacterial growth is extensive, significant consumption of the organic polymers can occur and may result in a loss in the rheological properties of the mud. They further identified bacterial contamination as causing the following problems: Micro-biological corrosion of well tubulars and screens, biomass plugging in injection wells and in the formation and hydrogen sulphide production deep in the formation, leading to reservoir souring.

From the above literature, it is clear that at every point of the drilling process, the drilling mud ought to be monitored continuously. This is because of the adverse effects the contaminants will pose to the driller if not detected early and properly handled for a long run, they will cause an increase in the cost of drilling thus reduce the expected profitability.

2.1 Types of Drilling Fluid

Many types of drilling fluids are used on a day-to-day basis. Some wells require that different types be used at different parts in the hole, or that some types be used in combination of others. The various types of fluid generally fall into a few broad categories;

- **Air:** Compressed air is pumped either down the borehole's annular space or down the drill string itself.
- **Air/Water:** The same as above, with water added to increase the viscosity, flush the hole, provide more cooling, and/or control dust.
- **Air/Polymer**: A specially formulated chemical, most often referred to as a type of polymer, is added to the water and air mixtureto create specific conditions. A foaming agent is a good example of a polymer.
- **Water:** Water by itself is sometimes used. In offshore drilling sea water is typically used while drilling the top section of the hole.
- **Water-Based Mud (WBM):** Most basic water based mud systems begins with water, then clays and other chemicals are incorporated into the water to create a homogenous blend resembling something between chocolate milk and a malt (depending on viscosity).
- **Oil-Based Mud (OBM):** This is a mud where the base fluid is a petroleum product such as diesel fuel. Oil-based muds are used for many reasons, including increased lubricity, enhanced shale inhibition, and greater cleaning abilities with less viscosity. Oil-based muds also withstand greater heat without breaking down.
- **Synthetic-Based Fluid (SBM):** Synthetic-based fluid is a mud where the base fluid is synthetic oil. This is most often used on offshore rigs because it has the properties of

an oil-based mud, but the toxicity of the fluid fumes are much less than the oil-based fluid.

2.2 Requirements of A Good Drilling Mud

In addition to being non-corrosive to the tubular used in the drilling and completion operations, a drilling fluid should be suitable for the local environment. Above all, the drilling fluid must not slow down the rate of penetration and must not harm the productive formation. Lastly, at the intended circulation rate, the drilling fluid shouldn't need a high pump pressure.

2.3 Components of Drilling Fluid

Drilling mud often contains a variety of chemicals which are formulated as required from a generally limited list of additives (Gray *et al.,* 1980) .The type and amount of chemical additives included in the mud formulation varies according to the required characteristics of the mud depending on the well to be drilled. Around 2,014 products are sold to offshore drillers (Vorabutr, 1983) .In general; the quantities of additives for OBM/SBM are less than that added to WBM.

Tables 2.4a and 2.4b show an example of a typical water and oil-based drilling mud. The composition of drilling mud is continually being altered throughout the drilling process to solve particular down-hole problems that may be encountered. Although the type of drilling mud used has changed over the years due to the perceived toxicities and the damage they may cause towards the marine environment, the toxicities for each type of mud cannot be stated.

Table 2.1a: Example of Typical Water Based Drilling Mud Composition (Adapted from UKOOA drill cutting programme, 1999a)

S/N	Material	Composition (% of Weight)
1	Barite	58

2	Salt	33
3	Bentonite	4
4	Caustic Soda	1
5	Polyanionic Cellulose	1
6	Soda Ash	1
7	Starch	1
8	Xanthan	1
9	Other	0.2

Table 2.1b: Example of Typical Oil Based Drilling Mud Composition (Adapted from UKOOA drill cutting programme, 1999a)

S/N	Material	Composition (% of Weight)
1	Barite	69
2	Base oil	26
3	Calcium Chloride	2
4	Emulsifiers	2
5	Other	1
6	Bentonite	0.3
7	Oil Wetting Agent	0.1

2.4 Properties of Drilling Fluids

The large number of functions performed by drilling fluid requires that some minimum properties of the fluids be maintained. The measurement of these properties gives the mud engineer a "status report" of the fluid and how it is reacting with the formation and subsurface environment. The properties include:

i. **Density (Specific Gravity):** Density is defined as the weight per unit volume. It is expressed either in ppg (lbs gallons) or pound per cubic feet (lb/ft^3) or kg/m^3 or compared to the weight of an equal volume of water as specific gravity. Density is measured with a mud balance.

ii. **Viscosity and Gel strength:** Viscosity is defined as the resistance to flow while the gel strength is the thixotropic property of the mud i.e. mud tends to thicken up if left unagitated for some time. Viscosity is usually measured by marsh funnel. More meaningful information regarding viscosity and its control can be obtained by rotational viscometer.

iii. **Plastic Viscosity (PV):** Plastic viscosity is that part of flow resistance, which is caused by mechanical friction. For practical purposes, however, the pv depends upon the concentration of mud solids.

iv. **Yield Point:** Yield point is the second component of resistance to flow in a drilling fluid on account of the electro-chemical or attractive forces present in the mud. These forces are as a result of the negative and positive charges located on or near the particle surfaces.

v. **Filtration Loss:** The filtration property of a drilling fluid is indicative of the ability of the solid components to the mud to form a filter cake and the magnitude of cake permeability. The lower the permeability, the thinner is the filter cake and lowers the volume of filtrate from the mud.

vi. **pH:** pH is the measurement of the relative acidity or alkalinity of a liquid. Mud pH affects the dispersability of clay, solubility of various products, and chemical corrosion of steel materials, and mud rheological properties. Typical pH range is 9.0 to 10.5; however, high pH muds can range up to 12.5 to 13.0.

2.5 Materials for The Production Of Drilling Fluid

1. **Bentonite Clay:** Bentonite is a material composed of clay minerals, predominantly montmorillonite with major amounts of other smectite group minerals, commonly used in drilling muds.
2. **Weighting Agents:** They are used to increase the fluid density to get the fluid to control formation pressures. E.g. Barite, Iron Oxides, Calcium Carbonates, etc.
3. **Thickeners:** These are added to influence the viscosity of the drilling mud. Examples include xanthan gum, guar gum, glycol, starch, etc.
4. **Deflocculants:** Deflocculants are used to reduce the viscosity of clay based muds; anionic polyelectrolytes. Tannic acids derivatives such as Quebracho are frequently used.
5. **Fluid Loss Additives:** These are used to control loss of drilling fluids into permeable formations.
6. **Lubricants:** Lubricants are used to alter the coefficient of friction of the drill bit. Poor lubrication causes high torque and drag.
7. **Stabilizers:** They help to increase the rheological and shale stability by helping drilling fluids to perform the intended tasks under unconventional (HPHT) conditions or by preventing water contacting a shale zone.
8. **Alkalinity Agents:** They are used to control the alkalinity of the fluids as any pH level above 9.5 will increase the viscosity, however, any pH below 7 is considered acidic.

2.6 Factors Affecting Drilling Fluid Performance

The factors affecting drilling fluid performance are:

- The change of drilling fluid viscosity
- The change of drilling fluid density
- The change of mud pH
- Corrosion or fatigue of the drill string
- Thermal stability of the drilling fluid
- Differential sticking

2.7 Functions of Drilling Fluids

The main functions of drilling muds can be summarized as follows:

- **Remove cuttings from the well:** Drilling fluid carries the rock excavated by the drill bit up to the surface. Its ability to do so depends on the cutting size, shape, and density, and speed of fluid travelling up the well (annular velocity)
- **Suspend and release cuttings:** Drilling fluids must suspend drill cuttings, weight materials and additives under a wide range of conditions.
- **Control formation pressures:** If formation pressure increases, mud density should also be increased to balance the pressure and keep the wellbore stable. Unbalanced formation pressures will cause an unexpected influx (also known as a kick) of formation fluids in the wellbore possibly leading to a blowout from the pressured formation fluid.
- **Seal permeable formations:** Drilling fluids ensure the mud column pressure must exceed the formation pressure, in this condition, mud filtrate invades the formation, and a filter cake of mud is deposited on the wellbore wall.
- **Maintain wellbore stability:** Chemical composition and mud properties must combine to provide a stable wellbore.
- **Minimizing formation damage:** Drilling muds control skin damage of any reduction in natural formation and porosity and permeability (washouts) which constitutes formation damage.
- **Cool, lubricate, and support the bit and drilling assembly:** The drilling fluid cools and transfers heat away from the source and lower to temperature than borehole. The drilling fluid cools the drill bit as heat is generated at the bit when the drill string rotates and rubs against the casing and wellbore.
- **Facilitate cementing and completion:** To ensure cement and completion operation properly, drilling mud displace by flushes and cement.

2.8 Drilling Fluids Selection Criteria

There are so many factors considered when selecting a particular fluid type employed for during drilling operations. One of the major criteria is the COST of the drilling fluid, other factors are the design of the well, mud performance, the mechanics of the rock, pressures of the formation anticipated to be encountered, formation chemistry, safety and environmental implications, the need to reduce damage to the formation, formation temperature, the regulations of the environment, logistics and economics (Dosunmu and Ogunrinde, 2010; Xiaoqing and Lihui, 2009).

Additionally, the drilling fluid that is chosen must not: have a propensity to erode or deteriorate the bit, the drill string and casing, surface facilities, impair the productive zones, or pollute the environment. Drilling fluids offer a variety of intricate, interconnected properties that are constantly checked and monitored during drilling operations in order to meet the design requirements. By adding additives to the mud system, these characteristics of any selected type of drilling mud can be enhanced or somewhat controlled to decrease fluid loss into the formation, minimize pipe sticking, minimize pressure losses, increase penetration rate, lessen environmental impact, and increase safety. The major five properties are: rheology, density, fluid loss, solids content and chemical properties.

When selecting between oil base mud (OBM) and water-based mud (WBM), there are key advantages OBM has over water base mud due as a result of the attractive or desirable rheological properties that is exhibited by oil. The composition of a typical OBM is: Clays and sand about 3%, Salt about 4%, Barite 9%, Water 30%, Oil 50-80% with oil as the dominant or continuous phase. Hence, oil is hereditary or a native to the hydrocarbon formation, it will not cause a damage to formation or the pay zone by filtration as compared to a water which is not a native of such formation (Sachez et al., 1999). Moreso, OBM is required where WBM cannot be effectively used especially in hot environment and salt beds where formation compositions can be dissolved in WBM.

On the other hand, water-based muds (WBMs) are seen as a preferred or predominant mud in most drilling operation; however some operations require the use of other drilling mud system to provide the acceptable basic functions. Some of these operations are: the drilling of deeper wells, high temperature/pressure formation, alternative shale-sand reservoir, deep-water reservoir, and shale resource reservoir (Dosunmu and Ogunrinde, 2010; Xiaoqing and Lihui, 2009; Fadairo et al, 2012)

2.9 Drilling Mud Additive

To achieve the desirable performance of the mud system at any reasonable set of conditions, the properties of mud must be adjusted, thereby overcoming most drilling problems such as abnormal pressure, lost circulation and sloughing shale. The additives are selected based on their application or specific performance requirements. The control of drilling fluid always presents two problems:

- The determination of what is needed in the way of properties (weight, viscosity, gel strength, filtration e.t.c) for the drilling mud to satisfactorily handle the drilling operations.
- The selection of the type of mud, the materials and the chemicals that produce the desired mud properties.

2.9.1 Sub Classification of Drilling Mud Additives

Weighting materials

- Barite, barium sulfate ($BaSo_4$)
- Galena lead sulfide (PbS)
- Iron oxide
- Calcium carbonate
- Dissolved salts

Viscosifiers

- Bentonite
- Premium clays (Clays)
- Polymers.

Thinners or deflocculating agents

- Lignosulfonate (Q-Broxin)
- Lignites
- Quebracho
- Phosphates
- Mix

Filter loss

- Starch
- Bentonite
- Polymers

Loss circulation materials

- Feberous
- Flake
- Granular

Emulsifiers

- Oil water
- Water in oil

2.10 What is Drilling Mud Contaminant?

It is important to note that some contaminants, like cement and salt, can be prevented from contaminating the mud system by adding additives to the mud as long as they are not added in excess. Excessive additives negatively impact the mud's properties, and some of these additives are unexpected and unpredictable when the concentration of contaminants gradually increases. Therefore, drilling mud contaminant can be defined as any material that causes undesirable alteration of the mud properties when it is incorporated into the mud system. Solids are the most dominate contaminant. Furthermore, when there is too much solids emanating from the formation, it results to high values of its rheological properties and also a reduction in rate of drilling. The nature of some contaminants is chemical and thus, requires a specific chemical treatment to restore the mud properties to its original properties with some engineering degree of tolerance; but it is not always 100% possible to completely remove the contaminant(s) from the mud system but can be reduced to a minimum tolerance of error. A drilling fluid is said to be contaminated when there is intrusion of foreign materials into the drilling fluid system or emanated from excessive treatment drilling fluid system with additives (i.e incorrect mud additives) thereby causing undesirable changes in the properties (eg viscosity, density, yield point, gel strength, filtration etc) of the drilling mud (Mahmood and Khaled, 2012).

2.10.1 How to Recognize Contaminants

- The primary indication of contamination is a change in the drilling fluid properties. This change may result in difficulty controlling:
  – Fluid loss
  – Alkalinity
  – Rheology
  – Density
- Some form of contamination should be suspected when there is an unexpected change in drilling fluid properties.
- Contamination can have multiple causes
- Contaminants will sometimes "mask" each other’s effects on the drilling fluid
- The most reliable method for determining the presence of contaminants is regular and accurate analyses of the physical and chemical properties of the drilling fluid through mud check/monitoring.

2.10.2 Natural Occurring Contaminants

2.10.2.1 Salt contamination

Drilling of salt formations, the encroachment of formation water, or the use of salty makeup water are some of the ways that salt contamination can occur. An increase in the filtrate's chloride content makes it simple to identify salt contamination (SIEP, 2003). An increase in the yield point, an increase in fluid loss, and a potential drop in pH and alkalinities are additional indicators. The density of the mud may also drop if a saltwater flow is the source of the salt. Therefore, it should be noted that while freshwater mud turns into a contaminant, saltwater mud is not considered a contaminant when it is used to drill large quantities of salt formation. Examples of evaporite salts are:

- Sodium chloride, $NaCl$
- Potassium chloride, KCl
- Calcium chloride, $CaCl_2$
- Magnesium chloride, $MgCl_2$

Far back in 1942, Chaney stated that aside the well-known contaminations by rock salt and salt water, sea water which contains magnesium and calcium ion and in combination with clay particles is a major source of contamination. Calcium and magnesium ions in seawater are detrimental to water base muds. Thus, at higher pH values, magnesium and calcium hydroxide are relatively insoluble, and the application of caustic employed to expunge magnesium and suppress the solubility of calcium and precipitate lime. Kumapayi et al (2014) stated that "the Gulf of Mexico seawater requires 1.5 to 2 lb/bbl caustic soda (4.3 to 5.7 kg/m^3) to precipitate all magnesium. In seawater, the preferred treatment for magnesium removal is caustic, while the preferred treatment for calcium removal is soda ash".

2.10.2.2 Contamination by Acid Gases

Carbon dioxide (CO_2) and hydrogen sulfide (H_2S) are often components produced from natural gas stream. These gases often form weak acid solutions when added to water, thus causing the clays to flocculate and probably increase the polymer viscosifying effect. Formations that have component of H_2S or/and CO_2 can be drilled safely with the aid of water-based mud provided the formation pressures are contained by a hydrostatic pressure greater than the pore pressure. However, proper control of the mud properties is paramount to the safety of the personnel and the avoidance of embrittlement and parting of the drill pipe when significant H_2S contamination occurs.

2.10.2.3 Contaminants Introduced at the Surface (accidental and/or intentional):

- Cement, $Ca(OH)_2$
- Seawater
- Completion or workover fluids
- Spotting fluid (generally a type of oil)
- Bicarbonate, $NaHCO_3$
- Bacteria from water source or LCM

2.10.2.3.1 Cement contamination

Every time a portion of a well is drilled, it is cased before being cemented. As the well is drilled deeper, the cement in the wellbore must be removed, which results in the formation of calcium hydroxide and severe flocculation of the clays in the drilling fluid. When calcium levels rise or when hardness, viscosity, and pH all rise, it is easy to identify cement contamination. Applying sodium bicarbonate or soda ash can help reduce cement contamination. If a low pH is needed, sodium bicarbonate is better than soda ash. Therefore, at a point in the drilling operation where cement contamination reaches a certain level where removal of the contaminant is no longer practical, it may be attractive to switch the mud system to a calcium-based mud or possibly isolate the mud contaminated and discarded at surface.

2.10.2.3.2 Carbonate/Bicarbonate Contamination

In course of drilling a well with alkaline drilling fluids, the encroachment of CO_2 can form bicarbonate or carbonate ions. Immediately CO_2 enters an alkaline mud system, it reacts with OH- ions and soluble carbonates accumulate. Overtreatment of mud system contaminated by other sources with soda ash or sodium bicarbonate can also contribute to the problem known as "carbonate alkalinity". Practically, this results to an inability of the lignosulphonate to treat high gel strengths and yield point.

2.10.2.4 Drilled Solids Contaminants

These are contaminants encountered while drilling. They are classified as:

- Reactive solids - clays and shales
- Non-reactive solids - sands, limestone, etc.

During drilling operation, solids are an unavoidable component of all drilling fluids which may be added as commercially processed materials, or incorporated as a result of the drilling operation. They can also be generated as the formation is drilled and they are classified as either cuttings or cavings.

On the other hand, clays are usually present in drilling fluids which are added intentionally to condition the mud in the form of bentonite or they may be incorporated into the mud as drilled solids such as smectite, illite, chlorite, kaolinite etc. We should note that the water that is bounded to the clay is essentially unavailable to the mud. This reduction in the fluid phase component of the mud causes the effective viscosity to increase.

2.10.2.4 Warning of excess solids in mud system

- High plastic viscosity
- High gel strengths
- Poor response to deflocculants
- High retort solids volumes
- High MBT values and high D/B ratio (Drill Solids/Bentonite)
- Thick filter cake and high fluid loss
- Slow rate of penetration

- Difficulty during trips with tight hole, swab and surge

2.10.2.5 Chemically Treatable Contaminants

- Calcium, Ca^{2+}
- Magnesium, Mg^{2+}
- Soluble carbonates, CO_3^{2-}
- Hydrogen sulfide, H_2S
- Bacteria

2.11 Rheological properties

Rheology can be defined as the science of deformation and flow behavior of all types of matter (i.e from gases to solids). This term is coin from two Greek words; “rheo” meaning to flow and “logos” meaning science or logic. The rheology of drilling fluid actually deals with the relationship between flow rate and flow pressure/temperature and the influence fluid flow characteristics.

These properties, otherwise known as flow properties, describe the flow characteristics of a mud under different flow conditions. In order to predict or know the effects of this flow, it is important that the flow behavior of the mud at various points of interest in the mud circulating system are known. The categories of drilling fluid are determined by the fluid behavior when it is subjected to an applied force (shear stress). Based on fluid behavior, then it would be important to know the following;

a) At what point of applied shear stress is movement initiated in the fluid?

b) Once movement has been initiated, what is the nature of the fluid movement (shear rate)?

The shear stress is the frictional drag exerted by a flowing fluid on the surface of a conduit, its magnitude dependent on the frictional drag between adjacent layers of fluid moving at different speeds, and the difference in velocities of adjacent layers next to the wall of the pipe. This difference in the velocities between adjacent layers across a flow path is termed the shear rate and for a driller, the effect of the flow at the wall where both shear stress and shear rate are at a maximum is his area of concern. Based on rheological properties, fluids can be categorized into two types depending on the viscosity of the fluid.

- Newtonian fluids
- Non-Newtonian fluids.

Very simple fluids such as oil or water that have the ratio of the shear stress to shear rate giving a constant are called **Newtonian fluids**. For such, measurement of shear stress at one shear rate is good enough to predict flow behavior at all shear rates. The ratio of shear stress to shear rate is termed the viscosity.

Viscosity, which is a measure of a fluids resistance to flow, is used to characterize flow behavior of Newtonian fluids. It has units of centipoises. Between layers of a liquid, it can be said to be a measure of the internal friction developed as one layer slides over another and shows how thick a fluid is.

Mathematically, viscosity μ = shear stress, τ /shear rate, γ.

Deformation of a Newtonian fluid occurs instantly once a force or shear stress (regardless of magnitude) is applied and thereafter, the degree of movement or flow is proportional to the applied stress. A phenomenon known as "**shear thinning**" occurs when the effective viscosity or the ratio of shear stress to shear rate is high at low shear rates and low at high or increased shear rate. Put differently, with increasing shear rate, the increase in effective viscosity over that of water decreases. Drilling fluids where the flow relationship between shear stress and shear rate is non-linear are referred to as "**Non-Newtonian fluids**". They require a certain amount of shear stress to initiate flow, and thereafter, additional stress must be added as there is an increase in shear rate. For these kinds of fluids e.g. drilling fluids and cement slurries, they contain solids that connect together to form a structure causing flow to stop when the pressure or shear stress is reduced to a point which is less than the shear strength of the structure. This point at which the shear stress is required to initiate flow is called the fluid's yield stress or point. Allowing these non-Newtonian fluids to stand static for some time would continue to build a semi rigid structure causing the shear stress required to initiate flow to increase. The shear stress at this point is called the gel strength and the structure gains more rigidity with time resulting to increased gel strength. To the driller, 4 important areas where shear rate values are of paramount interest include;

- The annulus: where shear rates are low.
- The bits, having super high shear rates.
- The pits, with almost no shear rate values.
- The drill string and collars, through which hydraulic power is supplied to the bit from a pump.

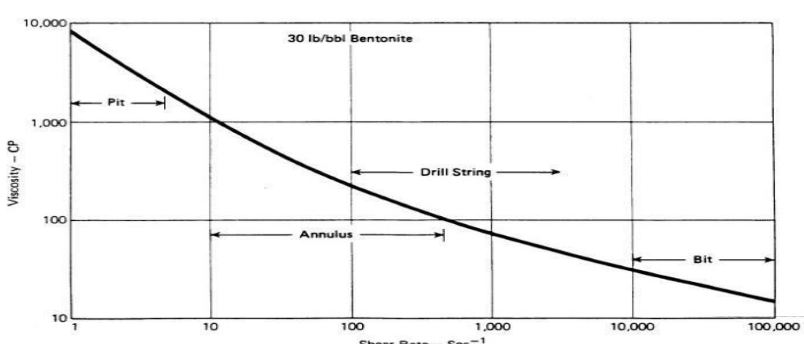


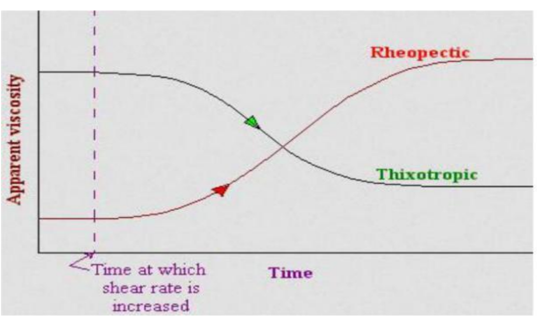
Figure2 2 Viscosity curve for Bentonite suspension (Max R. Annis 1996)

Figure 1.2 shows a graph illustrating the different shear rate ranges in a mud circulating system and the effective viscosity of a bentonite suspension at these shear rates.

Non-Newtonian fluids can be categorized into 2 based on their shear stress/shear rate behaviors;

- Time-dependent fluids: Here, shear stress is dependent on duration of shear as represented in flow curves in figure 8. Examples are thixotropic fluids, rheopectic fluids.
- Time-independent fluids: For these, shear stress is independent of duration or time of shear. Examples include Bingham plastic fluids, pseudo-plastic fluids, and dilatant fluids.

A third types of fluid are the viscoelastic fluids which exhibit elastic recovery from the deformation that occur during flow. They portray dual characteristics of being viscous and elastic. Some level of recovery is made after deformation upon removal of the stress. Examples of viscoelastic fluids include flour dough, bitumen, polymer melts. The flow curves for the different fluid types are shown in figure 1.4.



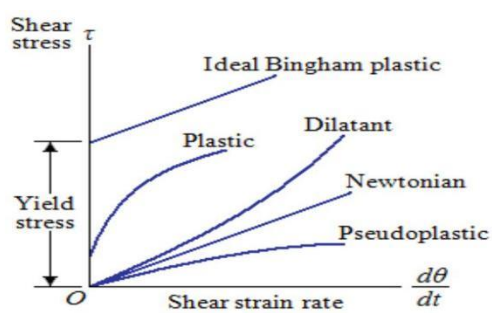


Figure 2.2 Time dependent fluid flow curves Figure 2.3 Flow curves for different fluid

2.11.1 Plastic viscosity

It is an important mud property that gives a measure of the internal resistance to flow due to amount, type and size of solids in the mud. Due to collision of solids with one another and with the liquid phase of the mud, mechanical friction is produced deterring movement. The plastic viscosity is essentially a function of the viscosity of the liquid phase and the volume of solids contained in a mud. It describes the expected behavior of mud at the bit. In order to minimize high shear rate viscosity, the plastic viscosity has to be minimized. By decreasing the plastic viscosity, a driller correspondingly reduces the viscosity at the bit giving rise to higher ROP.

Generally, a high plastic viscosity is never desirable as one might think that having a high plastic viscosity would improve the hole cleaning ability of a mud, but this would only cause more harm than good. Actually, an increase in plastic viscosity, which causes a pressure drop increase down the drill string would retard the rate of flow and tend to offset any increase in lifting ability. It is therefore safe practice to keep the plastic viscosity as practically low as possible. The viscosity of the liquid phase is increased by addition of any soluble material.

In a mud, the volume of solid is made up of the sum of the dry volume of solids and the increase in volume caused by hydration which means that the water of hydration actually becomes a part of the solid so far as its effect on viscosity is concerned. As mentioned earlier, plastic viscosity can be increased by adding any type of solid to the mud, but with solids like clays which absorb water and swell, the plastic viscosity in increased further due to hydration. Factors such as time, temperature and agitation tend to disperse and allow hydration of individual clay platelets, which cause increased viscosities. To minimize plastic viscosity, then the amount of drilled solids in the mud must be kept at a very minimal level. However, to increase plastic viscosity, then increasing the percentage by volume of solids in the mud would make this happen, and if the volume percent solids remain constant, reducing the size of the solid would be the next option (Max R. Annis 1996). This can be done by either reducing the concentration of the solid or by adding a flocculant to increase the size of the particles thereby reducing the available surface area.

2.11.2 Yield point

This is a measure of the attractive forces between the particles in a mud as a result of opposite charges existing on the particle surfaces causing initial resistance to flow. This mud property is dependent on the type of solids present and their respective surface charges, the concentrations of these solids, and the type and concentration of other ions or salts that may be present.

Ways by which yield point is increased include;

- Increased solids concentration e.g. addition of bentonite, -as a result of increased surface charges if the solids are in an active mode. This reduces the space between the particles if they are inactive.
- Bit action by grinding of the particles thereby exposing more active surface charges.
- Less chemical treatment as dispersants making some active charges available for interaction.
- Introduction of contaminants such as salt, cement, e.t.c. that cause the mud particles to flocculate.

A fluid with large molecules or colloidal solids tend to have them bumping into one another producing large resistance to flow. With particles that are quite long compared to their thickness, then at low shear rates, the inter-particle interference will be quite large when they are randomly oriented in the flow stream causing them to link together. However, at increased shear rates, the effect of particle interaction is reduced as the particles will be arranged in line in the flow stream. This would lead to the linked bonds being broken and fluidity is increased. The combination of these two effects determines the yield point of a mud. Chemical treatment is used to control the electrical interaction of the solids while the mechanical interaction is controlled by regulating the quantity and type of solids in a mud.

In summary, a high yield point is caused by flocculation of clay solids or high concentrations of colloidal solids. Flocculation may be caused by high temperature, lack of sufficient deflocculent, or contaminants introduction. Flocculating agents or clay extenders are sometimes added to promote linking and cause higher yield points to be achieved. Examples include soda ash, polyacrylates and several calcium compounds. Two important mud functions which are associated with yield point include;

a) Hole cleaning capability and

b) Pressure control capability of the mud.

In terms of hole cleaning, the carrying capacity of a mud and the circulating annular pressure drop is increased by a higher yield point. Due to the fact that an increased yield point is detrimental to the problems of lost circulation and swabbing but good for hole cleaning, then a compromise has to be reached. Since hole cleaning capabilities are improved by increasing mud weights, then, higher yield points are usually not necessary in high weight muds to insure good cuttings carrying capacity. Furthermore, in terms of pressure control, this is often critical where high weight muds are required. As a consequence, the need to get yield point to a minimum usually outweighs any advantages of maintaining a high yield point in high density muds (Max R. Annis 1996).

2.11.3 Gel strength

This is a very vital mud property that measures the shear stress necessary to initiate flow of a fluid that has been quiescent for a length of time i.e. a measure of its thixotropic character. In very plain language, it is the ability of the mud to suspend cuttings when circulation stops. It is as a result of the association between electrically charged particles within the structure causing it to be rigid which means that anything that prevents or promotes the bonding of particles in the mud will decrease or increase respectively, the tendency to gelate. The rigidity of the structure so formed is dependent on factors as the quantity and type of solids in suspension, the chemical environment, time and temperature.

To measure the gel strength of a mud, a V-G meter is used by taking the peak dial deflection when the gel structure breaks, and this is done at selected times of 10 seconds and 10 minutes. These set times are necessary to provide a comparison of gelation qualities of muds and the difference between the two measured values simply represents the rate of gelation. Gel strength is measured in lb/100 sq. ft and for a mud to be able to suspend barite, it is necessary for it to have gel strength between 2 to 4 lb/100 sq. ft(Max R. Annis 1996). At values lower than this, barite will not suspend but settle down in the mud, regardless of its viscosity. A high viscosity would only have the effect of slowing down the settling rate and time. It is easier to have barite suspended in water based muds than oil based mud because the clay particles are very active in water, whereas in oil, they are essentially inert. A mud with a high viscosity will not necessarily have high gel strength as they are two different phenomena and should not be mixed up. As drilling operation takes place, the viscosity and gel strengths will both tend to increase as solids are being introduced e.g. drilled cuttings, barite, e.t.c. into the mud system. This can be reduced by addition of more fluids or surface removal of mud solids.

An increase in gel strength shows that flocculation has just begun as is the case in water base muds, while deflocculating reduces gel strength. Excessive gel strengths are not desirable in a mud as they cause the following problems:

- During tripping, large surge pressures could be encountered while running the pipe in causing possible breakdown of formation.

- During solids separation, it hinders them from settling down.
- Increased problems due to swabbing. This can cause the hole to cave in below the bit.

Solids Analysis

In order to control the filtration properties and flow behavior of a mud, the amount and types of solids in it are the main areas to concentrate on. This means that the amount of each of the different types of solids present would be determined and this is done by running some tests on the mud. The volume percent water and its specific gravity, the volume percent oil and its specific gravity, the volume percent solids, and the mud density are to be known. The major solids making up drill mud are barite (nonreactive solid) which is a weighting agent, drilled solids (non-reactive solid) enjoined in the mud and bentonite (reactive solid or colloidal phase). The mud retort is the equipment used for measuring the volume percent oil and that of distilled water in the mud. With huge amounts of dissolved salt in the mud, the volume percent distilled water from the retort is smaller than the actual volume percent distilled water as these salts increase the volume capacity of water and its specific gravity. Once the actual water volume and oil volume have been established, the number of suspended solids can be calculated by subtraction. If the mud density has been measured and the volume percent of suspended solids found, then the relative amounts of barite and low gravity solids can be calculated. As different types of solids have different cation exchange capacities, a distinction can be made between bentonite being the major faction of the mud and the low-quality drilled solids, which have much lower exchange capacities. Carrying out a methyl blue test would help determine the cation exchange capacity of the clay solids and with knowledge of the volume percent low gravity solids, the percent bentonite and percent drilled solids can be estimated.

For high salt content muds, the following steps 1-4 are relevant for solid analysis;

Step 1: Calculate the volume of salt water in percent.

Step 2: Calculate the volume of the suspended solids in %.

Step 3: Calculate the Average Specific Gravity (ASG) of the salt water.

Step 4: Calculate the Average Specific Gravity of the solids suspended in the mud.

2.11.5 Filtration

When mud pressure is higher than formation pressure, filtrate is forced to flow into the formation with deposition of mud solids on the walls of the borehole, thus with filtration, both the filtrate invasion and filter cake deposition could pose problems. The problems posed by filtrate invasion are more of formation evaluation and completion problems. For instance, flushing of the zone around a well bore may be caused by excessive fluid loss to the point that incorrect logging and testing information are gathered. Furthermore, another problem could be a huge reduction of formation permeability by fluid invasion. Consequently, the type of filtrate is of greater significance than the volume of filtrate lost and from the stand point of drilling operation, more focus should be given to the filter cake than the volume of filtrate. This is because it has a direct connection with problems such as lost circulation, differential pressure sticking, torque and drag and poor primary cement jobs. Therefore of primary concern should be ways to minimize the thickness and permeability of the deposited cake.

Two types of filtration could occur –"**dynamic and static filtration**". Dynamic filtration occurs when the fluid is being circulated and when it is at rest, it is static filtration.

At equilibrium thickness, the rate of filtration becomes constant. This is not the case with static filtration. In static filtration, the cake grows continually with time increasing in thickness and causing a continuous reduction in filtration rate. Static filtration should be controlled in order to control filter cake thickness and dynamic filtration should be controlled in order to check invasion of filtrate. The erosion rate is a function of annular velocity, mud viscosity and flow regime.

Increasing annular velocity or mud density would result in an increase in erosion rate, yielding an increased filtration rate.

❖ Changing the flow from laminar to turbulent will also increase the erosion rate, therefore, it is of great importance that the flow regime in the annulus is laminar and that the velocity is kept practically as low as possible to insure greatly reduced dynamic filtration rates.

❖ Increasing the viscosity will bring about a proportionate increase in erosion rate. Dynamic filtration rates may be increased also by fluid loss control additives that cause huge increases in mud viscosity.

The deposition rate is a function of the rate at which solids are being transferred to the cake by the filtrate flow. The amount of solids and the type as well play a role in how much filtrate is allowed to pass through the filter cake. Bentonite has been seen to be the most effective additive in reducing dynamic filtration rate. Some materials which are very good for reducing static filtration have been found to have very little effect on dynamic filtration as they cause a decrease in the permeability of the cake thereby causing a decrease in the equilibrium cake thickness rather than a reduction in the rate of filtration, hence, such materials will not function in reducing dynamic filtration rate, but can only reduce the API fluid loss. Examples of such materials include lignosulfonate, starch, oil, CMC, lignite (Kranenburg et al. 2011; Max R. Annis 1996).

Static filtration control on the other hand is important in controlling the properties of the filter cake deposited downhole as the cake is the primary cause of filtration related drilling problems. Of major interest are the cakes thickness, permeability, slickness and texture. The volume of filtrate is important but more important is the cakes characteristics, so both should be looked into critically.

Talking about the characteristics of the filter cake, it is desirable that the cake is thin and of low permeability. The permeability of the cake is proportional to the product of cake thickness and fluid loss. The slickness of a cake is related to the frictional drag that can develop during differential pressure sticking. Using a stickometer, the effect of a mud treatment on this property can be evaluated with the test. This sticking coefficient is increased with increasing mud density due to increased solids content of the cake and to minimize this effect, drilled solids have to be removed, with addition of bentonite or special lubricating additives. The texture of filter cake is a characteristic for which no direct test is run. It is so closely related to the other cake characteristics that it will probably never be a problem if the other cake properties are in good shape. Static filtration tests are normally of two types – a low temperature low pressure test run at surface temperature and 100 psi filtration pressure, and a high temperature high pressure test at 300^{o}F and 500 psi filtration.

A Very Brief Description of All Chemicals and Additives Used and Their Functions Is Outlined Below:

- Bentonite: Powdery clay mineral predominantly montmorillonite, which is used as a viscosifying additive and also good for reducing fluid loss.
- Barite: A dense sulfate mineral used to add weight to drilling mud.

- Potassium chloride (KCl): A white crystalline salt of the alkali metal potassium. It is a swell inhibitor at high concentrations, and helps to encapsulate mud particles. It is also a major source of K^+ ions in potassium polymer muds.
- MI PAC ELV: An ultra-low viscosity polyanionic cellulose polymer for fluid loss control in water based drilling mud.
- DUO TEC-NS: Duo-vis xanthan gum is a high molecular weight biopolymer used for increasing viscosity in water based system. Small quantities provide viscosity and suspension of weight materials, and it produces a highly shear-thinning and thioxotropic fluid.
- Soda ash (Na_2CO_3): It is a weak base in granular powder form soluble in water and dissociates into Na and CO_3 ions in solution. Its main function is to reduce calcium ion in water base drilling muds and make up waters. It also increases pH of makeup water and flocculates spud mud.
- Glycol: A liquid solution which is viscous and soluble in water at low temperatures belonging to the alcohol series. It is used as effective shale inhibitors and improves lubricity.
- Carboxyl Methyl Cellulose (CMC): Used primarily as a fluid loss additive. It also gives higher apparent viscosities at low shear rates.
- Starch: A drilling mud additive used to control fluid loss in water muds ranging from freshwater to saturated salt to high-pH lime.
- Sodium Hexametaphosphate (SHMP): Granular white substance used as effective deflocculants for clays in fresh water. Helps to reduce viscosity and overcome cement contamination of fresh water.
- Sodium Pyrophosphate Decahydrate: Crystalline white substance which deflocculates clays in fresh water and acts as a viscosity reducing agent.
- WBM Premix: Viscous water based prepared mud

CHAPTER THREE

3.0 Research Methodology

This chapter will focus on the method used in carrying out this experiment. Information will be provided on how the experimental data were obtained, the sources of data, and the experimental work was carried out. Specifically, the chapter contains the data collection method, the apparatus/materials, the experimental and measurement procedures.

3.1 Materials

The materials used in this work are shown in table 3.1 below:

Table 3.1 Materials Used For Experiment and Function

S/N	MATERIALS	FUNCTION (s)
1	Bentonite (Gel)	Control of viscosity and filtration
2	Barite	Weighting agent
3	Soda Ash (sodium carbonate)	Calcium precipitant and pH reducer in cement contaminated mud
4	Water	Base fluid
5	XCD	Control of viscosity and filtration
6	Par R	Viscosifier and fluid loss control
7	Par L	Viscosifier and fluid loss control
8	Caustic soda (sodium hydroxide)	pH control
9	KCl	Control borehole stability

Plate 3.1: Mud additives

3.2 Water Chemistry

The suitability of water for use during mud mixing is a vital aspect to be considered prior to preparing a mud sample. For the experiments to be carried out, fresh water from the university laboratory taps.

a) **pH Determination**: The pH of a solution is a measure of its hydrogen ion concentration. There is an equilibrium hydroxyl ion concentration for each hydrogen ion concentration, so by measuring the hydrogen ion concentration, the concentration of hydroxyl ion is also measured in effect. In measuring pH, a pH paper or pH meter could be used, but a pH meter preferably was used in the experiments as it gives more accurate values. The pH meter is calibrated using two buffer solutions that are of different pH values so the pH of the actual sample to be determined can fall within range. The electrode is rinsed with demineralized water each time after being used in a solution. Figure 3.3 gives a pictorial view of a standard pH meter.

The pH scale is logarithmic and it is on a scale of 0 to 14 with a neutral point of 7. It is acidic from 0 to 7 and alkaline from 7 to 14. The pH of the tap water was measured at a value of 7 indicating neutrality, while the sea water was measured at a pH of 7.47. Literature has it that for good mixing, pH values above 8.5 and below 10.5 are very suitable (Max R. Annis 1996).

Alkaline pH is necessary for a number of reasons;

- Corrosion rates are suppressed more at higher pH values.
- It helps for better mixing of bentonite.

a) **Hardness**: The amount of Ca^{2+} and Mg^{2+} present in water determines if water is hard or not and the atomic absorption spectometry is used to detect their levels. Theoretically, a desirable limit for both cation concentrations in water should be less than 100 mg/l (100 ppm) for it to be considered soft water and above 100 mg/l, water is considered hard. Tests conducted by the university laboratory staff showed that the amount of Ca^{2+} was given as 50 mg/l (conducted in past experiments) and 254.4 mg/l in fresh tap water and sea water respectively. The amount of Mg concentration in fresh water and sea water was found to be 4 mg/l (conducted also in past experiments) and 948.05 mg/l respectively. Caustic soda (NaOH) is used sometimes to suppress the amount of soluble calcium contained in the mud in a mud. Soda ash (Na_2CO_3) is mainly used to precipitate Ca^{2+} ions but care should be taken not to over treat water with soda ash as a carbonate problem would occur. Overtreatment would also pose problems of high yield point; high gel strength and fluid loss therefore the level of Ca^{2+} should be kept at acceptable levels of not more than 100 mg/l.

(b) Chloride Determination: The salinity of water is determined by the amount of chloride ions present in the water solution and Ion Chromatography is used to detect its level. It is important because increased salinity could have detrimental effects on properties as yield point, gel strength, degree of hydration e.t.c of the mud. Theoretical data shows that a desirable limit of chloride ions should be less than 10,000 mg/l, as fresh water has chloride content between 1 to 250 mg/l. The chloride content of the sea water was found at about 10,500 mg/l by the laboratory staff. The importance of determining the salt content of water cannot be overemphasized because most salts are contaminants in the mixture especially the chlorides of the alkali metals e.g NaCl and KCl.

3.4 Equipment Used for Experiment

1. Weighing balance
2. Retort Stand
3. Hamilton Beach Mixer
4. Mud balance
5. Round bottom flask
6. API filter press

7. Variable speed rheometer

8. pH kit

9. Measuring cylinder

10. Stop Watch

11. Marsh Funnel Viscometer

3.5 Instrumentation

The range of oil field equipment is so vast that we will limit ourselves to the equipments which are used in the course of the experiments. This equipment includes;

1) Weigh balance and measuring cylinder: This device finds it place when there is need to determine the weight or volume of samples been use for experiment. Whereas the weigh balance measure dry substance, the measuring cylinder measure wet samples i.e liquid.

Plate 3.2: Digital weigh balance

2) Mixer: The mixer is use to provide proper mixture. They come in handy when homogeneity in the drilling fluid system is needed. The instrument has low, medium and high speed. Any of this speed can be selected depending on the desired speed.

Plate 3.3: Mud mixer

3) Mud Balance: Mud balance was used to measure the density and effectively the weight of the drilling fluid. It measures in pounds per gallon (lb/gal). This is necessary because the weight of the drilling fluid is an important parameter which determines whether there will be need for weighting up or further analysis. The mud weight is taken at certain temperatures which are room temperature, at 20^{o}F and at higher temperature if necessary.

Plate 3.4: Mud balance

4) API Filter Press: Filter Press consists of a mud reservoir mounted in a frame, a pressure source, a filtering medium, and a graduated cylinder for receiving and measuring filtrate.

Plate 3.5: API Filter Press

5) pH kit: Used to measure the pH of any drilling fluid system. The principles are as simple and basic as always. The pH of the drilling fluid is important because different formation types have different pH requirements, thus the pH of the drilling fluid has to be carefully monitored to ensure that when the drilling fluid is used on the formulation there is a balance in properties to prevent the seeping in of formation fluids to the system.

Plate 3.6: pH content kit

6) Marsh Funnel Viscometer: Marsh funnel is a simple device for measuring viscosity by observing the time it takes a known volume of liquid to flow from a cone through a short

Plate 3.7: Marsh Funnel

7) **Baroid sand content tube:** This was used to measure the quantity of sand present in the mud. The quantity of sand in the mud is represented in percentage by volume.

Plate 3.8: Sand Content Tube

3.6 Determination of Drilling Mud Properties

API RP-13B Standard procedures were employed throughout the laboratory work to determine mud properties. All the mud samples are based on the formulation of 350 ml of fluid that contains only fresh water.

3.7 Formulation of Water-Based Mud

In the formulation of the drilling mud, sixteen (16) standard lab barrel samples were prepared. The experiment was done in two phases:

- **Phase One**: Formulation of fresh drilling mud with no contaminants (Control Specimen)

- **Phase Two**: Formulation of drilling mud with the following contaminants

1. Cement (of: 1g, 3g & 5g)
2. Silicon Sand (solid) (of: 1g, 3g & 5g)
3. Salt (NaOH) (of: 1g, 3g & 5g)
4. Anhydrite (of: 1g, 3g & 5g)
5. Carbonate (Na_2CO_3) (of: 1g, 3g & 5g)

The materials and composition by weight used in the formulation of the water-based mud to determine the rheological properties are given in the Table 3.2.

Table 3.2: Composition of materials used for the mud formulation

MATERIALS	WEIGHT (g)
Water (H_20)	350ml
Soda ash (sodium carbonate)	0.3
Bentonite	5
XCD	0.5
PAC-R	0.5
PAC-L	1.3
Caustic soda (sodium hydroxide)	0.5
KCl	20
Barite	24.5

3.7.1 Laboratory Procedure for Mud Formulation

- 350ml of water was measured and poured into the Hamilton mixing cup.
- The mixing cup was placed in the Hamilton beach mixer.
- 5grams of Bentonite was added and pre-hydrated for 30 minutes under stirring condition.
- Then 0.3grams of soda ash was added into the water.
- Also, 0.5grams caustic soda was added.
- 0.5grams of XCD, 0.5grams of Pac-R, 1.3grams Pac-L respectively were added to the mixing cup.
- Thereafter, 24.5grams of Barite was added to the mixture to form one-Standard Lab bbl.
- The sample was allowed to age for 24 hours.

- The mixture was stirred further with the Hamilton beach mixer for another 20 minutes for homogeneity before taking the rheological readings and (10 seconds/minutes) gel strength.

3.8 Determination of Drilling Mud Properties

API RP-13B Standard procedures were employed throughout the laboratory work to determine mud properties.

3.8.1 Determination of Rheological Properties

This test is done to obtain the Rheological properties of the mud such as viscosity at 600 rpm and 300 rpm, 10 minutes and 10 seconds Gel strength, plastic viscosity and yield stress. The equipment used was an OFITE 900 MODEL viscometer while the reagents/materials were freshly prepared mud sample, masking tape, recording book and biro.

- The cord of the viscometer was connected to the power source and the instrument power button switched on.
- The freshly prepared mud was poured into the sample cup of the viscometer, the ENTER button pressed and the rotor was allowed to rotate for few seconds for stabilization.
- The rotor sleeve was then immersed until the mud touched the scribed line of the rotor sleeve.
- The mud button was pressed and the viscometer automatically carried out the measurement of the θ600rpm and θ300rpm.
- The equipment calculated the 10seconds and 10minutes gel strength.

3.8.2 pH Determination

The degree of acidity or alkalinity of mud is indicated by the hydrogen ion concentration, which is commonly expressed in terms of pH. A neutral mud has a pH of 7.0. An alkaline mud has pH readings ranging from just above 7 for slight alkalinity, to 14 for the strongest alkalinity, Acid mud range from just below 7 for slight acidity, to less than 1 for the strongest acidity. pH measurements aid in determining the need for chemical control of the mud, and indicates the presence of contaminates such as cement and gypsum. The appropriate pH of drilling mud varies with the mud type. This study used the Multi-Hamilton beach mixer equipment with freshly prepared sample, ph-hydrion dispenser paper, masking tape, recording book and biro as reagents/materials.

As a procedure to determine the pH of the mud, the following were carried out

- The freshly prepared mud was re-stirred to obtain homogeneous mixture.

- About one inch strip of the ph-hydrion dispenser paper was removed and placed gently on the surface of the mud and sufficient time was allowed to elapsed (about few seconds) for the paper to soak up filtrate and change color.
- The soaked paper strip was matched with chart on the dispenser from which the strip was taken.
- The pH range of the mud was read and the value recorded in the table of result respectively.

3.8.3 Determination of The Mud Weight

The mud density test was conducted in order to determine the weight per unit volume of the mud. Mud density must be great enough to provide sufficient hydrostatic heat to prevent influx of formation fluids, but not so great to cause loss of circulation, damage to the drilled formation, or reduce the rate of penetration (ROP). This test was done to determine whether the prepared mud samples possess API minimum required weight for oil well drilling. The Multi-Hamilton beach mixer and Bariod mud balance were the equipment used in this study while freshly prepared sample, rag, water, masking tape, recording book and biro were reagents/materials used.

The procedures used to determine the weight of the prepared mud are;

- The instrument base was set up so that it was approximately leveled; the freshly prepared mud was poured into a clean, dried mud balance cup.
- The lid was placed on the cup and set it firmly but slowly with twisting motion. It was ensured some mud spilled on the outside of the cup through the vent.
- Then the reading of the mud balance scale was taken and recorded properly against the mud type.

The mud cup was then emptied, washed, dried and properly kept away for future use.

3.8.4 Determination of Sand Content

By definition, solid particles larger than 74 micros (200 meshes) are classified as API sand (A micron is one (million) inch of a meter there are about 25, 400 microns to an inch). Regular determination of the sand content of drilling mud is necessary because these particles can be highly abrasive, and can cause excessive wear of pump parts, drill bits, and pipe connections, excessive sand may also result in the deposition of a thick filter cake on the walls of the hole, or it may settle in the hole around the tools when circulation is temporarily halted, interfering with the operation of drilling tools of settling casing. The sand content test for set is used in the test for sand content determination. The equipment used was the Bariod sand content set while reagents/materials were freshly prepared sample, rag, water, spatula, masking tape, recording book and biro.

As a procedure to determine the sand content of the prepared mud;

- The Baroid sand content tube was filled to mark “MUD TO HERE” with the formulated mud sample.
- Water was then added to the mark “WATER TO HERE”, and then the tube was covered with thumb and shaken vigorously.
- The mixture of the mud and water was poured out through the screen, the held back sand were carefully washed to ensure that the mud sample was out in a gently running tap.
- The sand left in the screen was then washed back into the tube through a funnel that is fitted over and inverted slowly into the mouth of the tube.
- The quantity of the sand that settle in the calibrated tube was then read and recorded as the sand content of the mud in percentage by the volume of mud.

3.8.5 Determination of Funnel Viscosity

Apparent viscosity is one of the main rheological properties of drilling fluid. Monitoring apparent viscosity during drilling operations is very important to prevent various drilling problems and improve well cleaning efficiency.

The procedures used to determine the viscosity of the prepared mud are;

- The orifice was covered with a finger ensuring the funnel is in an upright position and the freshly collected mud sample was poured into a clean, dry funnel through the screen until the fluid level reached the bottom of the screen (1500ml).

- Immediately the finger was removed from the outlet and the time required for the mud to fill the receiving vessel to the 1-quart (946 ml) level was measured.
- The result was reported to the nearest second as Marsh Funnel Viscosity at the temperature of the measurement in degrees Fahrenheit or Centigrade.

Plate 3.9: Formulated water-based mud

3.8.6 Mixture of Drilling Mud with Contaminants

Twelve (12) blank samples were prepared, which were to be contaminated by 1g, 3g and 5g of each of Cement, Silica Sand, Sodium Chloride (salt) and Carbonate as contaminants.

For determination of mud properties after mixing the freshly prepared mud with contaminants, all experimental procedures in **3.7.1 and 3.8** were repeated to obtain the results.

3.9 Calculations

From tables of result, the results for mud properties such as rheology, mud weight, and sand content were gotten from direct reading on the instrument. However, other properties such as, plastic viscosity, yield point and apparent viscosity of the mud were calculated using Equations (3.1), (3.2) and (3.3) respectively.

Plastic viscosity (PV)/cP = 600 RPM reading – 300 RPM reading……....... (3.1)

Yield point (YP), Ib/100ft^2 = 300 RPM reading- plastic viscosity…………… (3.2)

Apparent viscosity (AV), cP = 600 RPM reading/2 …............................. (3.3)

CHAPTER FOUR

4.0 Results and Discussion

4.1 Presentation of Results

Table 4.1: Salt and Anhydrite contamination

	Salt		Anhydrite	
Case	**Without contaminant**	**With contaminant**	**Without contaminant**	**With contaminant**
Temperature (^{0}F)	120	125	120	125
Density (ppg)	14.7	14.8	15	15
Funnel Viscosity (cp)	45	68	41	61
Plastic Viscosity	33	55	32	39
Yield point (lb/200ft^2)	8	22	11	37
Gel 10 sec/10 min (lb/200ft^2)	4/9	19/18	4/9	12/25
Filtrate API/HPHT (ml)	9	16.7	9	16.7
Cake 32nd (in)	2	6	2	4
Solids (% vol)	20	23	25	25
Water (% vol)	80	77	75	75
sand (% vol)	Tr	Tr	Tr	Tr
MBT (lb/bbl) equiv	20	20	20	20
pH meter	10	9	10.8	8.5
Mud Alkalinity, Pm (cc H_2SO_4/cc)	1.8	1.1	1.6	0.7
Filtrate Alkalinity, Pf/Mf (cc H_2SO_4/cc)	1.0/3.1	0.7/1.8	1.2/3.1	0.2/1.1
Chloride (mg/l)	4000	28600	4000	4000
Calcium Hardness (mg/l)	200	420	80	800

Table 4.2: Solid contamination (Clay and Cement)

	Clay		**Cement**	
Case	**Without contaminant**	**With contaminant**	**Without contaminant**	**With contaminant**
Temperature (^{0}F)	120	125	120	125
Density (ppg)	14.1	14.4	15	15
Funnel Viscosity (cp)	47	58	41	69
Plastic Viscosity	33	56	32	39
Yield point (lb/200ft^2)	6	17	11	28
Gel 10 sec/10 min (lb/200ft^2)	3/5	4/17	4/9	12/25
Filtrate API/HPHT (ml)	8	13	8	16.8
Cake 32nd (in)	2	4	2	4
Solids (% vol)	16	20	17	17
Water (% vol)	84	80	83	83
sand (% vol)	Tr	Tr	0.5	0.5
MBT (lb/bbl) equiv	17.5	25	20	20
pH meter	10	9.5	9.5	11.5
Mud Alkalinity, Pm (cc H_2SO_4/cc)	1.6	1.1	1.6	6.7
Filtrate Alkalinity, Pf/Mf (cc H_2SO_4/cc)	1.0/2.4	0.8/1.9	1.2/3.1	5.1/5.8

Chloride (mg/l)	4000	4000	4000	4000
Calcium Hardness (mg/l)	200	200	80	480

Table 4.3: Carbonate and Bicarbonate contamination

	Carbonate		**Bicarbonate**	
Case	**Without contaminant**	**With contaminant**	**Without contaminant**	**With contaminant**
Temperature (^{0}F)	120	125	120	125
Density (ppg)	15	15	15	15
Funnel Viscosity (cp)	47	74	47	74
Plastic Viscosity	33	55	33	55
Yield point (lb/200ft^2)	11	32	11	34
Gel 10 sec/10 min (lb/200ft^2)	4/11	21/43	3/10	21/49
Filtrate API/HPHT (ml)	8	16.8	8	16.8
Cake 32nd (in)	2	4	2	4
Solids (% vol)	25	25	25	25
Water (% vol)	75	75	75	75
sand (% vol)	Tr	Tr	Tr	Tr
MBT (lb/bbl) equiv	20	20	20	20
pH meter	9.5	10.8	10.5	8.8
Mud Alkalinity, Pm (cc H_2SO_4/cc)	0.6	1.7	1.6	0.7
Filtrate Alkalinity, Pf/Mf (cc H_2SO_4/cc)	1.2/3.1	8/17.4	1.2/3.1	1.1/17.4
Chloride (mg/l)	4000	4000	4000	4000

Calcium Hardness (mg/l)	200	0	200	0

4.1.1 Comparison of Mud Properties With/Without Salt Contamination

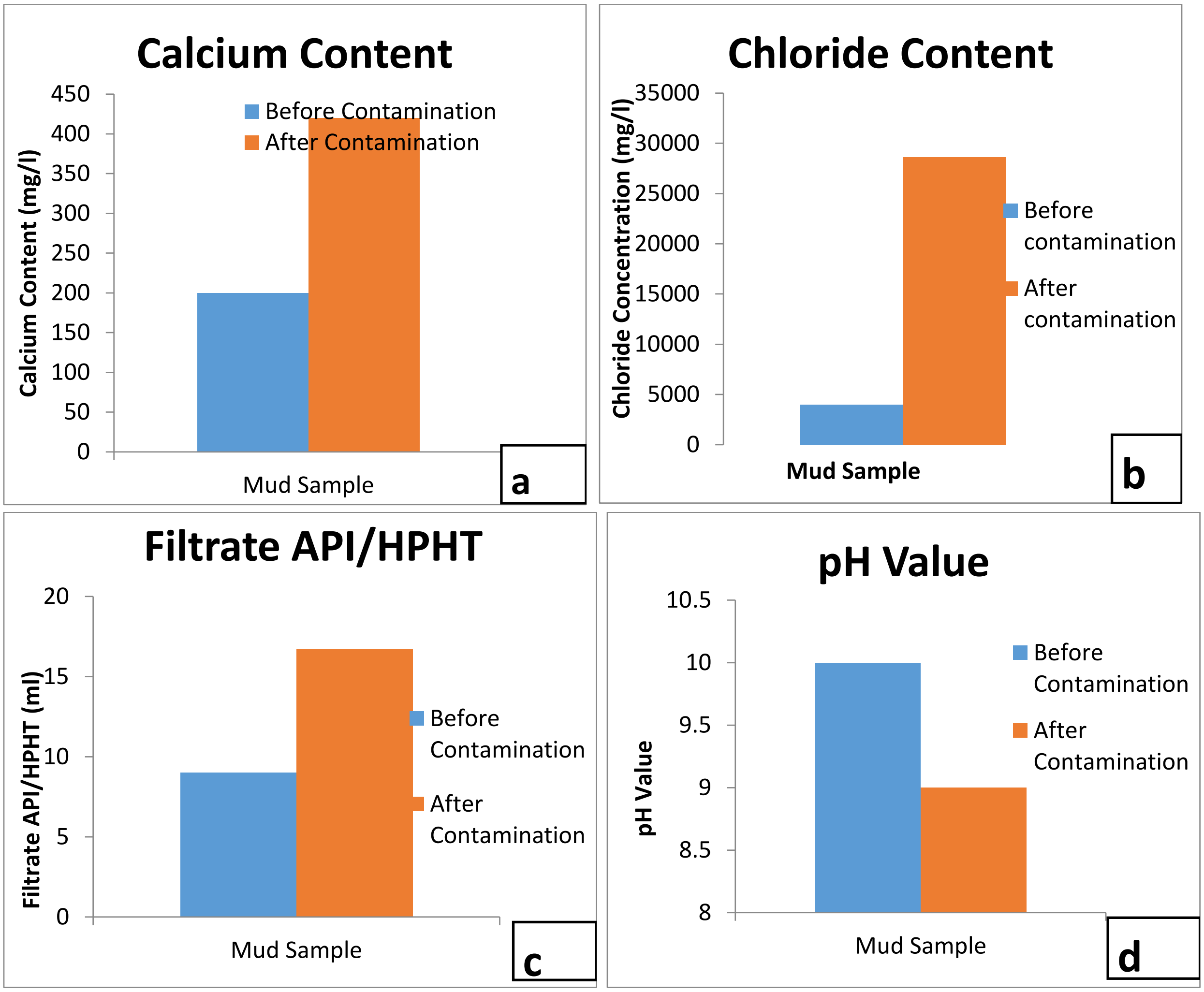


Figure 4.1: Salt contaminated mud: (a) Calcium content (b) Chloride content (c) API/HPHT filtrate (d) pH value

4.1.2 Comparison of Mud Properties With/Without Anhydrite Contamination

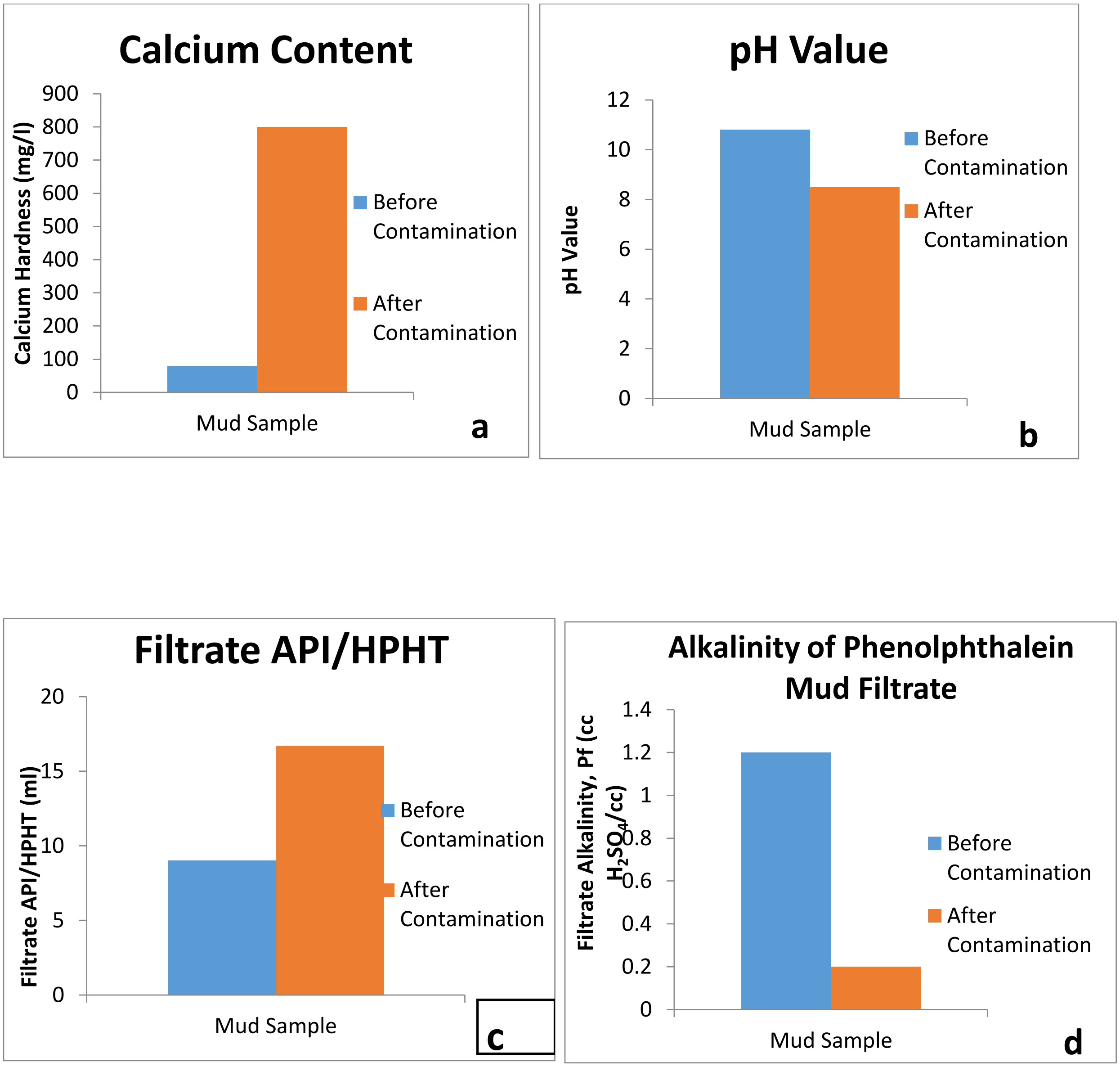


Figure 4.2: Anhydrite contaminated mud: (a) Calcium content (b) pH (c) API/HPHT filtrate (d) Filtrate Alkalinity, Pf

4.1.3 Comparison of Mud Properties With/Without Sand/Shale and Cement Contamination

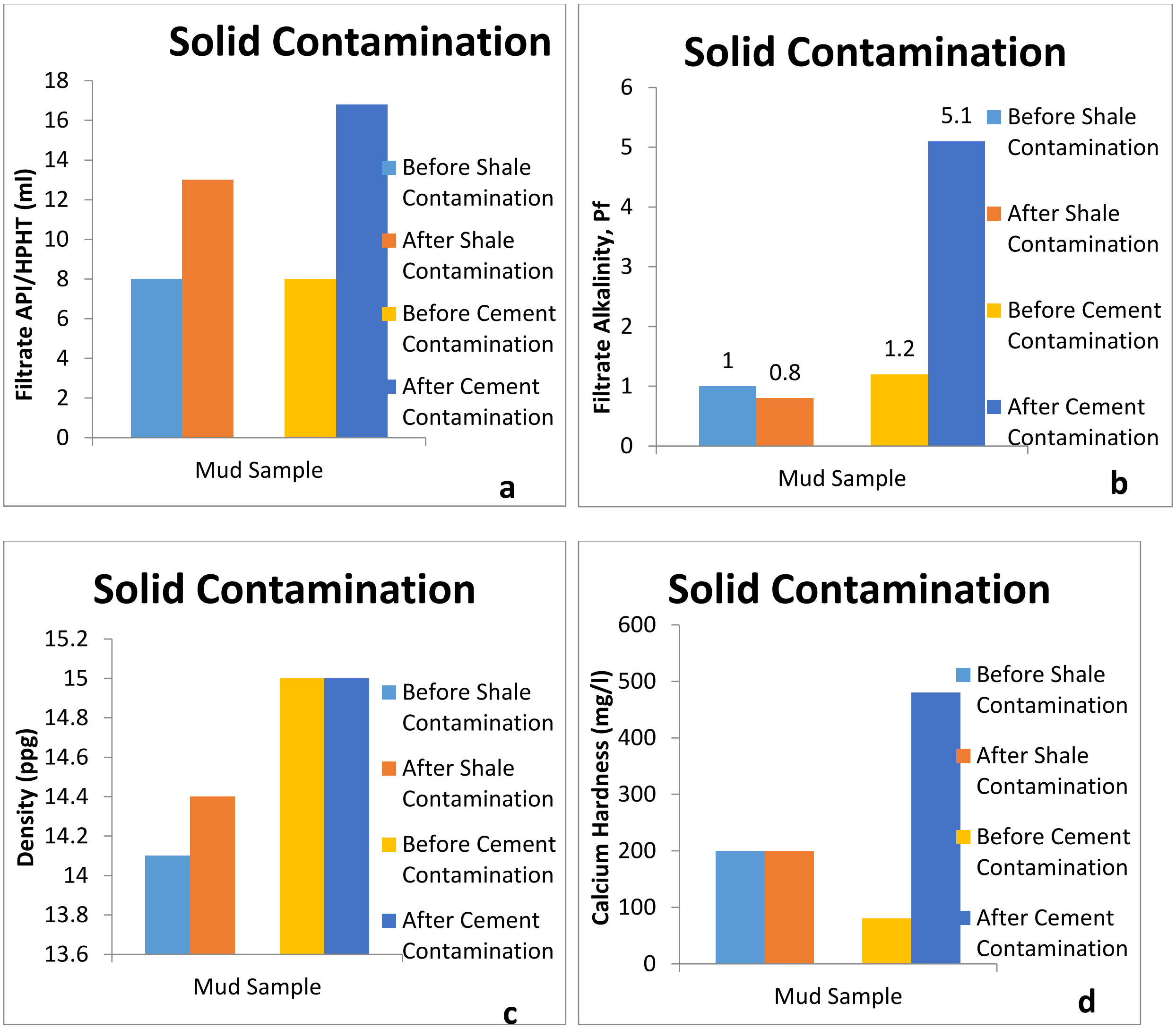


Figure 4.3: Solid (Shale & Cement) contaminated mud: (a) API/HPHT filtrate (b) Filtrate Alkalinity, Pf (c) Density (d) Calcium content

4.1.4 Comparison of Mud Properties With/Without Carbonate and Bi-Carbonate Contamination

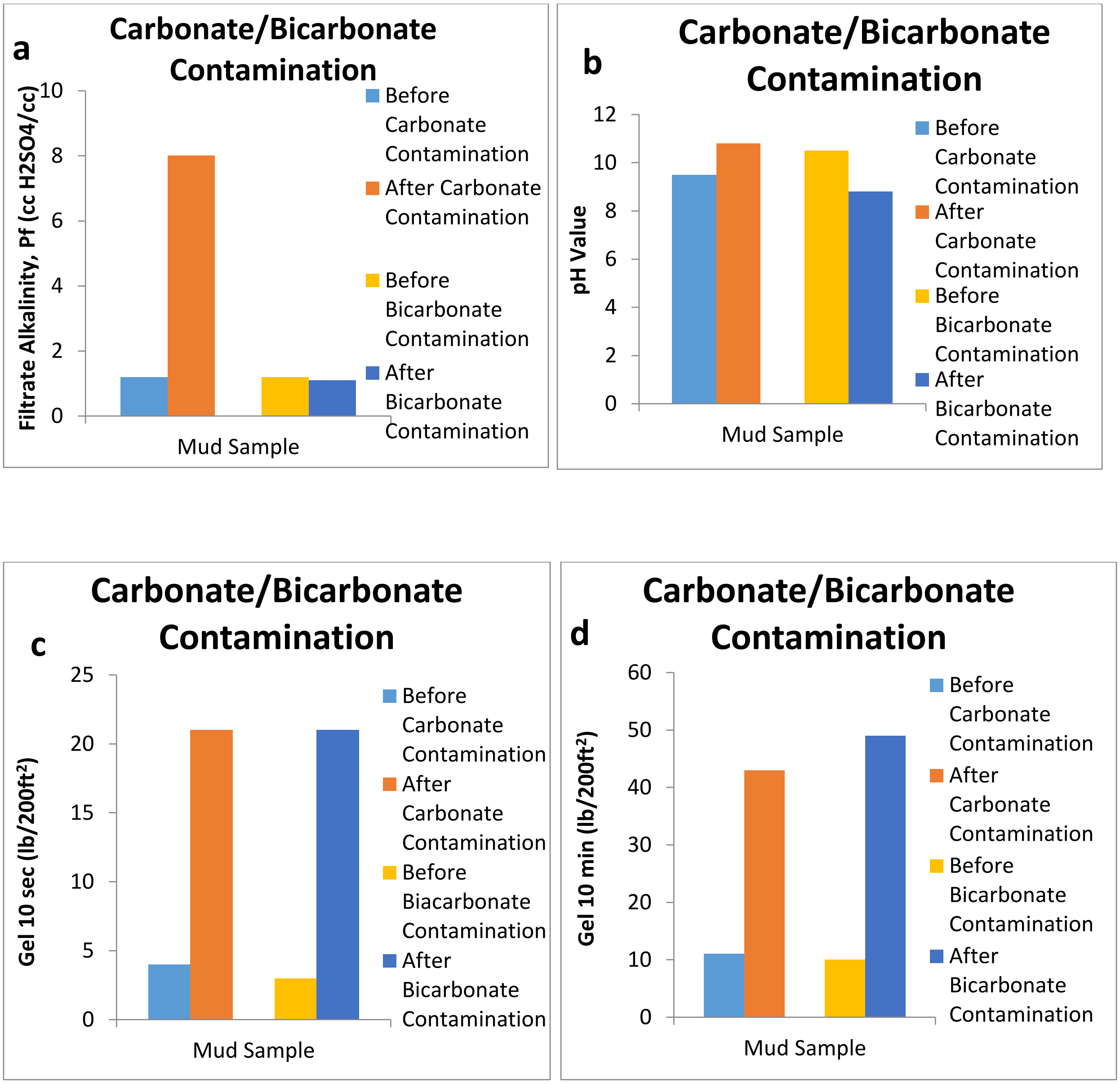


Figure 4.4: Carbonate and Bicarbonate contaminated mud: (a) Filtrate Alkalinity, Pf (b) pH (c) 10 sec gel strength (d) 10 min gel strength

4.2 Discussion of Results

4.2.1 Discussion of Results of Mud Properties on Salt Contaminated Mud

It is usually easy to detect salt when it enters the mud system while drilling. Once it contaminates the mud, there will be an increase in the chlorides content of the filtrate, an increase in rheology; specifically the yield point, an increase in fluid loss, and a possible decrease in pH and alkalinities and observed results show an increase in rheological properties (This could be seen from results in Table 4.1). It was also observed that the presence of calcium salt in the mud system increased the fluid loss into the formation. Thus, if the salt source is a saltwater flow, there may also be a decrease in mud density and the result obtained shows that the source of salt contamination is not a saltwater flow. From Figure 4.1.1b, there was a drastic increase in the chloride content which will require a high treatment cost and if the cost of treatment is excessively high, the mud can be converted to another mud system that tolerates the salt problem. Furthermore, if the mud system is not adequately treated and further increase in the salt concentration will distort the mud function.

4.2.1.1 Recommended Treatment for Salt Contamination

- May be controlled by adding soda ash (Na_2CO_3) if the pH is below 9.5. (Should the pH be above 9.5, use bicarbonate of soda)
- After adding soda ash, a chemical dispersant is usually added to help reduce viscosity and gel strength.
- Additional problems can be encountered if large amounts of soda ash are added. The soluble sodium sulfate tends to build-up and cause "ash gels".

4.2.2 Discussion of Results of Mud Properties on Anhydrite Contaminated Mud

The properties to identify when a mud system is contaminated with clay/shale are: increase in solids, increase in cation exchange capacity (CEC) or MBT, decreases in alkalinity, density increase. While the case of cement is identified by API/HTHP filtrate increase, increase in pH, Pm/Pf increase and high calcium. The result observed when the mud system was contaminated with shale and cement show different trend in some properties. In shale contamination, the filtrate alkalinity decreases but increases rapidly in cement contamination (Figure 4.3b). There was no change in calcium content for shale/clay contamination but a rapid increase of 500% for cement contamination (Figure 4.3d) and other results are shown in Figure 4.3a & c and Table 4.2 respectively.

4.2.2.1 Recommended Treatment for Anhydrite Contamination

- Raise pH
- Add water
- Disperse with thinners
- Maximize use of solids control equipment

- Add dissolved lignite/polymer for filtration control (HP-HT)

4.2.3 Discussion of Results of Mud Properties on Sand/Shale and Cement Contaminated Mud

The properties to identify when a mud system is contaminated with clay/shale are: increase in solids, increase in cation exchange capacity (CEC) or MBT, decreases in alkalinity, density increases. While the case of cement is identified by API/HTHP filtrate increase, increase in pH, Pm/Pf increase and high calcium. The result observed when the mud system was contaminated with shale and cement show different trend in some properties. In shale contamination, the filtrate alkalinity decreases but increases rapidly in cement contamination (Figure 4.3b). There was no change in calcium content for shale/clay contamination but a rapid increase of 500% for cement contamination (Figure 4.3d) and other results are shown in Figure 4.3a & c and Table A2 respectively.

4.2.3.1 Recommended treatment for Solids (Clay or Shale) Contamination

- Raise pH
- Add water
- Disperse with thinners
- Maximize use of solids control equipment
- Add dissolved lignite/polymer for filtration control (HP-HT)

4.2.3.2 Recommended treatment for Solids (Cement) Contamination

Pretreatment of the fluid for cement's adverse effects may cause problems because very little hard cement will react with the bicarbonate of soda. This preventative over-treatment can lead to gelling problems. Treatment of cement contamination can cost in excess of 100% of the average daily fluid cost. If contamination is severe, a lime system should be considered. Hence, the recommended treatments are:

- Add bicarbonate of soda ($NaHCO_3$) to precipitate calcium. Control total hardness of the filtrate between 150 - 200 mg/L to avoid over treatment.
- Bicarbonate of soda will reduce the pH.
- Most fluids require a pH above 9.5 to be effective.
- Add thinners for rheology control.
- Add water for dehydration and barite to maintain weight.

4.2.4 Discussion of Results of Mud Properties on Carbonate and Bicarbonate Contaminated Mud

To identify a carbonate and bicarbonate contaminant in the mud system, there will be an indication of high gel strengths, high filtrate, high Mf, no calcium present but in the case of carbonate contamination, the Pf high and low for bicarbonate contamination. The observed result in Figure 4.4 a-d and Table 4.3 show the same trend in properties variation for carbonate and bicarbonate contamination identification. The pH values show a reverse trend as shown in Figure 4.4b where the pH value increased for carbonate contamination and decreased for bicarbonate contamination. Thus, for the mud to still perform optimally, treatments additives need to be introduced into the mud system if the cost of treatment is still within some economic tolerance.

4.2.4.1 Recommended treatment for Carbonate Contamination

- Add Gypsum ($CaSO_4$) to remove carbonate by precipitating it as $CaCO_3$, and lower pH to 9.5 - 10.5 (OH- ions only)
- Monitor total lb/bbl (kg/m^3) of gypsum added to system. Too much Na_2SO_4 in the system will cause viscosity problems
- Add thinners as needed for chemical dispersion
- Add water for dehydration
- Lime and gypsum can be added together to achieve the proper pH and to precipitate $CaCO_3$ from the system.

4.4.2 Recommended treatment for Bicarbonate Contamination:

- Increase pH with lime [$Ca(OH)_2$] pH 9.5 to 10.0 It may be necessary to supplement lime with caustic soda (NaOH).
- Maintain 150 to 200 mg/L total hardness in the filtrate to buffer the problem so that it does not reoccur. This is usually easy to obtain with lime treatments.
- Add thinners for chemical dispersing of clays and rheology control.
- Add water for dehydration.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The oil and gas industry is extremely dangerous and difficult, necessitating the safe and cost-effective execution of all operations. Therefore, the characteristics of drilling mud must always be stable in order for it to function properly. According to the findings of the experiment conducted on a water-based mud system to determine the impact of contaminants (salt, anhydrite, shale, cement, carbonate, and bicarbonate) on the rheological characteristics and performance of the mud, the presence of a contaminant on the drilling mud either decreases or increases the properties and rheological characteristics of the mud system, which in turn affects the rate of penetration, performance, and may also pose serious drilling problems.. Therefore, for a driller and a mud engineer to obtain a well control and optimum safe drilling experience, a proper knowledge of the drilling mud chemistry, properties, their resultant contaminants and how to control them must be known. The importance if this study cannot be overemphasized as it was observed that most drilling problems arise from these contaminants.

5.2 Recommendations

This project recommends the following;

1. If further study should be carried out on this work, then the effect of acid gas such as H_2S contamination on the mud system should be evaluated.
2. Every Drilling Mud Engineer must have a basic knowledge of the drilling mud chemistry so as to effectively supervise the contaminants control.
3. Every drilling operation must be planned with solid removal equipment for proper operation prior to drilling wells.
4. Mud must be properly treated and on time to prevent the destruction of subsurface equipment.
5. The degree and the economic implication of these contaminants on the drilling mud system should be ascertained.

5.3 Contribution to Technology

This research contributes to the advancement of drilling fluid technology in several significant ways:

1. **Comprehensive Contaminant Database:** This study provides empirical data on the specific effects of six common contaminants (sodium salt, cement, silica, carbonate, anhydrite, and shale) on water-based drilling fluids. The quantitative relationships established between contaminant concentration (1g to 5g) and rheological properties (apparent viscosity, plastic viscosity, yield point, gel strength, pH, and fluid loss) serve as reference values for field engineers and researchers developing contamination control protocols.
2. **Predictive Framework for Mud Property Changes:** The experimental findings contribute to the development of predictive models for drilling fluid behavior under contaminated conditions. By demonstrating that different contaminants produce distinct rheological signatures (e.g., cement increasing all properties, silica having minimal effect, carbonate primarily affecting gel strength), this work enables the creation of diagnostic tools and decision-support systems for real-time mud management.
3. **Enhanced Understanding of Formation Damage Mechanisms:** The identification of increased fluid loss due to sodium salt contamination advances understanding of formation damage mechanisms during drilling operations. This contribution informs the design of fluid loss control additives and wellbore strengthening strategies, particularly in salt-bearing formations where contamination is inevitable.
4. **Optimization of Drilling Fluid Formulations:** The research findings facilitate the optimization of water-based drilling fluid formulations for specific geological conditions. Understanding how silica contamination has minimal impact on mud properties, for instance, allows engineers to adjust base fluid compositions when drilling through silica-rich formations, potentially reducing chemical treatment costs while maintaining operational efficiency.
5. **Foundation for Automated Contamination Detection Systems:** The distinct rheological signatures identified for each contaminant type provide a foundation for developing automated contamination detection systems. By integrating these findings with machine

learning algorithms and real-time rheological monitoring equipment, future technologies can automatically identify contaminant types and recommend appropriate remedial treatments, reducing non-productive time and improving well construction efficiency.

6. **Educational Resource for Industry Training:** This experimental work serves as a practical educational resource for training drilling engineers and mud engineers. The methodology and results can be incorporated into technical training programs, helping practitioners develop a deeper understanding of contaminant behavior and improve their ability to diagnose and resolve drilling fluid problems in the field.
7. **Cost Reduction through Proactive Contamination Management:** This research enables more economical drilling operations by clearly demonstrating how contaminants affect drilling fluid performance, which in turn affects rate of penetration and drilling issues. Predicting and preventing contamination-related problems minimizes non-productive time, lowers the cost per foot of well construction, and eliminates the need for expensive mud replacements.

In conclusion, by bridging the gap between theoretical knowledge and real-world application, this research advances drilling fluid technology. In addition to contributing to safer, more effective, and more cost-effective drilling operations, the experimental data, techniques, and insights produced by this work lay the groundwork for upcoming technological advancements in the field of drilling fluid engineering.

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