DETERMINATION OF THE EFFECT OF NaOH ON THE RHEOLOGICAL PROPERTIES BENEFICIATED GUM ARABIC

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BENIN CITY

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CERTIFICATION

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DEDICATION

This project work is dedicated to the Almighty God, the giver of life for seeing me through this phase and journey. To my beloved parents, Mr. & Mrs. Osariemen for their unwavering love, care and support throughout my undergraduate years.

ACKNOWLEDGEMENT

All thanks return to God for His guidance, provision, help, and tutelage; for making this project work a reality and for seeing me through. A heartfelt gratitude goes to my supervisor, Prof. Oduwa Onaiwu for his sacrifice, time, guidance, corrections, total support and supervision throughout the course of my project work.

ABSTRACT

This research examines how sodium hydroxide (NaOH) influences the flow characteristics of purified gum Arabic-based drilling mud formulations, positioning them as eco-friendly substitutes for conventional synthetic additives. The experiment involved developing seven initial formulations combining bentonite with different polymer systems: xanthan gum, gum Arabic, and mixtures of gum Arabic with either cocoyam starch or ginger extract in proportions of 50/50 and 75/25. Subsequently, selected formulations underwent alkaline modification using NaOH at measurements of 3.0g, 7.5g, and 15.0g to replicate varying pH environments.

Flow behavior parameters encompassing plastic viscosity (PV), yield point (YP), gel strength, and mud weight were determined through Fann viscometer measurements and evaluated against three mathematical model frameworks: Bingham Plastic, Power Law, and Herschel-Bulkley models. Experimental findings demonstrated that 50g of gum Arabic delivered comparable rheological characteristics to 1g of xanthan gum under neutral conditions. The introduction of alkaline treatment produced substantial modifications in fluid behavior, with response patterns dependent on both the specific polymer-starch pairing and alkalinity level.

The most remarkable transformation occurred in the gum Arabic-cocoyam (50/50) formulation treated with 7.5g NaOH, which demonstrated PV of 65 cp and YP of 180 lb/100ft^2 corresponding to increases of 261% and 1025% respectively relative to the 3.0g NaOH variant. The gum Arabic-ginger combination displayed considerable viscosity enhancement (PV = 108 cp with 7.5g NaOH) yet revealed temporal degradation of gel structure at elevated alkalinity levels. Every alkaline-treated system manifested pseudoplastic (shear-thinning) characteristics with flow behavior indices (n) spanning 0.3 to 0.948, validating their appropriateness for drilling fluid applications.

Comparative model analysis indicated that the Herschel-Bulkley model most accurately characterized the behavior of alkaline-modified natural polymer systems, whereas both Bingham Plastic and Power Law models exhibited substantial prediction errors, especially under high-alkalinity conditions. These results established that purified gum Arabic, when strategically combined with indigenous starches, (cocoyam & ginger) and subjected to pH optimization, represents a viable, environmentally degradable, and economically advantageous alternative to synthetic drilling fluid components, delivering ecological advantages while preserving operational performance standards required for petroleum drilling activities.

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CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Drilling fluids serve many functions: controlling formation pressures, removing cuttings from the wellbore, sealing permeable formations encountered while drilling, cooling and lubricating the bit, transmitting hydraulic energy to downhole tools and the bit and, perhaps most important, maintaining wellbore stability and well control. Often referred to as mud, drilling fluid was first introduced around 1913 for subsurface pressure control. The 1920s and '30s saw the birth of the first US companies specializing in the distribution, development and engineering of drilling fluids and components. In the decades that followed, drilling fluid companies introduced developments in chemistry, measurement and process engineering that led to significant improvements in drilling efficiency and well productivity.

Drilling fluid compositions vary based on wellbore demands, rig capabilities and environmental concerns. Engineers design drilling fluids to control subsurface pressures, minimize formation damage, minimize the potential for lost circulation, control erosion of the borehole and optimize drilling parameters such as penetration rate and hole cleaning. In addition, because a large percentage of modern wellbores are highly deviated,

drilling fluid systems should allow one to deal with the hole-cleaning and hole-stability issues unique to these wells. Drilling muds Drilling fluids the name drilling muds is commonly used to indicate drilling fluids, which are essential to the functioning of a petroleum engineering operation. They serve to cool and lubricate the drill bit, promote rock cuttings to the surface, preserve pressure in the well and stabilize the wellbore (Caenn, Darley, & Gray, 2011). These significant functions are highly reliant on rheological characteristics of fluid like plastic viscosity and shear point and shear strength.

These properties have traditionally been regulated with synthetic polymers and chemical additives. However, environmental issues, increased expenses, and the necessity of sustainable solutions have caused a variety of researchers to investigate the possibility of utilizing biopolymers, particularly in water-based drilling fluids, in the past few years (Amanullah & Al-Arfaj, 2010). A potential natural additive causing a stir is Gum Arabic, a biodegradable non-toxic compound harvested by the Acacia trees of Senegal and Acacia seyal species among others.

Gum Arabic is distinguished through its very good thickening, emulsifying, and film forming characteristics (Ali, 2014). Such characteristics present it as a prospect as an environment-friendly alternative to improving drilling mud. Nevertheless, it is not in a form that can be put into immediate use because in its raw state, Gum Arabic usually requires being beneficiated, i.e., cleaned and processed to eliminate impurities and make it more effective (Gideon & Abdulkadir, 2019).

An important factor that affects how well biopolymers like Gum Arabic work in drilling fluids is pH. The structure and behavior of these natural polymers change with pH levels, influencing how they dissolve, interact with other mud components, and perform overall (Thomas, 2001). In drilling operations, Sodium Hydroxide (NaOH) is often added to raise the pH, which helps improve clay swelling and solid dispersion (Bourgoyne et al., 1986).

That's why this study focuses on understanding how changing the pH with NaOH affects the rheological properties of drilling fluids made with beneficiated Gum Arabic. The goal is to help optimize the use of natural polymers in drilling, supporting the industry's move toward more environmentally friendly solutions.

1.2 Statement of The Problem

The rheology of any fluid system, or the way in which fluids move and act under different conditions, is largely what determines its ability to perform on a drill or other petroleum project. These properties directly affect the effectiveness of removing cuttings out of the well, the stability of the wellbore, and pressure control.

Recently, there has been an increase in the use of natural, biodegradable products like gum Arabic as alternative synthetic drilling fluid additives. They are attractive due to their low prices, availability, and eco-conscientiousness. The full promise of the gum Arabic remains unexploited, however, particularly due to the inconstancy of pH environments that often occur on site. This is particularly so when combined with other natural products such as cocoyam starch, ginger extract, xanthan gum, or guar gum. pH may change significantly during actual drilling, especially where alkaline reagents like sodium hydroxide (NaOH) are used to improve performance.

These pH variations can result in different flow behavior of the fluid, sometimes positively. The effect of pH levels on the behaviour of these blends of natural polymers remains unclear, although increasing attention is given to so-called green drilling fluids. In the absence of this information, the formulations may be difficult to optimize in terms of field uses, thus leading to lower efficiency and higher costs of operation. It is in that view that, by observing carefully how different pH can modify the rheological properties of gum Arabic-based mixes, this work attempts to bridge that gap. The study is focused on helping to create more sustainable, multifunctional drilling fluids to modern petroleum activities, testing that would allow determining the formulations that are most effective and stable in alkaline environments.

1.3 Aim and Objectives Of The Study

1.3.1 AIM

To investigate the effect of pH (through NaOH variation) on the rheological and filtration properties of beneficiated gum Arabic-based polymer formulations and classify them under appropriate drilling models.

1.3.2 Objectives

- To determine the rheological properties (e.g viscosity, yield stress) of each gum Arabic formulation (with cocoyam, ginger, xanthan gum, guar gum) under varying NaOH concentrations.
- To access the filtration characteristics of each formulated systems.
- To evaluate and classify the flow behavior of each formulation samples using standard rheological models.

1.4 Scope of The Study

This study focuses on evaluating how varying NaOH concentrations (pH levels) affect the rheological and filtration properties of drilling fluid formulations made from beneficiated gum Arabic blended with cocoyam starch, ginger extract, xanthan gum, and guar gum. The research involves: Preparing and treating polymer formulations with different NaOH concentrations. Measuring rheological properties such as plastic viscosity, yield point, and gel strength.

CHAPTER TWO

LITERATURE REVIEW

2.1 Drilling Fluids

Drilling Fluids Introduction Drilling fluids that are also known as drilling mud are vital in rotary drilling in exploring oil and gas. They perform several roles such as drill bit cooling and lubrication, cuttings to the surface transportation, borehole stability, and formation pressures regulation (Zhang et al., 2020). Efficient well construction would hardly be possible without a well-engineered drilling fluid.

Uses of Drilling fluids have the following prominent roles: Cutting out of the wellbore (Abdulkadir et al., 2019). Managing subsurface formations pressures. The drill bit and the drill string cooling and lubrication (Adewole et al., 2019). Strengthening the walls of wellbore. Passing hydraulic energy to down hole equipment. Maximizing the prevention of formation damage (Ewulonu et al., 2022).

Introduction of rotary drilling made the use of drilling fluids as early as the start of the 20th century. Drilling mud was first witnessed in Spindle top, Texas in 1901. To start with, the water was utilized in getting cuttings out of the borehole. Bentonite clay became gradually introduced as a way of enhancing fluid characteristics such as viscosity and the filtration process (Darley & Gray, 1988). As the drilling problem became more difficult, such as deeper wells, higher pressure, deviated wells, formulations increased to include not only polymers but also oil based muds and synthetic fluids

2.1.1 Function of Drilling Fluid

1.Drill Cuttings Removal:

Transporting of drill cuttings to the surface is one of the fundamental functions of the drilling fluid. This is done by the viscosity and the flow rate of the fluid that guarantees the constant extraction of rock pieces produced by the bit. With effective transport of cuttings, the solids will not pile up at the bit, there is less chance of the stuck pipe, and optimal drilling rates are achieved (Caenn, Darley, & Gray, 2017; Zhang et al., 2018).

2. Formation Pressure Control:

The drilling fluids assist in regulating the wellbore pressure exerting a hydrostatic head against the formation fluid pressure. Mud weight determines the density of the fluid, and should be well monitored so as not to experience any kicks or blowouts or loss of circulation. In case the mud weight is excessively low, some formation fluids might flow up to the wellbore where high mud weight might cause the formation to fracture causing loss of fluids (Al-Yaseri et al., 2020).

3. Chill and Grease of the Drill Bit:

The drilling works produce a significant amount of heat since there is the friction between the rock and the drill bit. This heat is removed by drilling fluid that functions as coolers, thus making the bit last long. Also, the fluid covers the drill string and the bit with the lubricating effect, reducing the torque and drag of drilling (Caenn et al., 2017).

4. Borehole Stability and Support:

The drilling fluids will assist in stabilizing the walls of the borehole, by exerting some pressure and creating a thin and airtight filter cake on the wellbore. This will avoid collapse of unstable formations and reduce fluid intrusion into the rock. Borehole stability is essential, including swelling or sloughing prone shale (Ahmed et al., 2020; Chenevert & Sharma, 2020).

5. Settling of Solids in Stagnant State:

In the event of circulation being stopped, the drilling fluid should possess adequate gel strength to retain the solids including cuttings of the drill and weighting materials. In the absence of this property, solids can precipitate on the bottom of well, possibly causing stuck pipe or inability to restart circulation. This is an important role of the rheological behavior of the fluid, especially its thixotropic property (Zhang et al., 2018)

6. MWD/LWD Systems Data Transmission:

In modern drilling activities, particularly, Measurement While Drilling (MWD) and, Logging While Drilling (LWD), data transmission occurs through the drilling fluids. The wellbore acts like a speaker when pulses or pressure waves are generated within the fluid and transferred to the surface where they are decoded in real-time, offering the possibility to make decisions (Caenn et al., 2017).

7. Borehole Support and Stability:

Drilling fluids balance the pressure of the walls of the boring hole, pressing on the walls of the hole, forming a thin and an impermeable filter cake on the wellbore. This stops the slumping of unstable installations and reduces the amount of invasion into the rock. Adequate stability of boreholes is also important, particularly in shale beds that are likely to slough off or swell (Ahmed et al., 2020; Chenevert & Sharma, 2020).

2.2 Classification of Drilling Fluids

Drilling fluids are categorized based on their continuous phase**:**

Type	Description	Example
Water-Based Mud (WBM)	Water is the base fluid. It can contain bentonite, polymers, and salts.	Bentonite + water + PAC
Oil-Based Mud (OBM)	Oil is the continuous phase. Offers thermal stability and lubricity.	Diesel + emulsifiers
Synthetic-Based Mud (SBM)	Uses synthetic oils to reduce environmental impact.	Esters, polyalphaolefins
Air/Gas-Based Mud	Used in underbalanced drilling. Contains no liquid phase.	Air, mist, foam

2.3 Basic Components of Drilling Fluids

Each drilling fluid is a complex blend of:

- Base Fluid (water, oil, synthetic fluids)
- Viscosifiers like bentonite, xanthan gum, and gum Arabic (Oboh et al., 2021)
- Weighting agents like barite
- pH control additives like NaOH or lime (Musa et al., 2019)
- Filtration control agents like starch or PAC

2.3.1 Physical and Chemical Properties of Drilling Fluids

According to API Specification 13A and 13B, drilling fluids must meet certain physical and chemical requirements to perform efficiently and safely in the wellbore. These include:

- **Plastic Viscosity (PV)** - Physical property that denotes the mechanical friction that happens between solid particles and in turn that provides internal resistance of flow. It gives an idea as to how well the fluid circulates through the drill pipe and the annulus
- **Yield Point (YP)** - Physical property of determining the stress required to begin initiating move of fluids. An increase in YP enhances the ability of the fluid to carry and suspend cuttings of the drilling (Mohammed et al., 2020)
- **Gel Strength**- It is a physical property that deals with coagulant properties of a fluid to hold debris once the circulation ceases. It is expressed in lb/100 ft 2 and it avoids formation of cuttings which can lead to stuck pipe.
- **Filtration Rate and Mud Cake Thickness**- These are physical as well as chemical properties where they influence fluid loss in course of the permeable formations and the mud cake quality developed. These parameters are tested through the use of API tests including low-pressure, low-temperature (LPLT) and high-pressure, high-temperature (HPHT) filtration tests.
- **pH** - is a chemical characteristic of the fluid that indicates the acid, or alkaline, level. It influences the clay swelling, corrosion inhibition, additive solubility and fluid stability. To work effectively, most water-based muds run between 9.5 pH and 12.0 pH (Oladipo et al., 2021).
- **Density**- A physical attribute, which determines hydrostatic pressure. To manage the formation pressures in order to manage the blowouts, it is modified with weighting agents such as barite.
- **Rheology**- Flow behaviour with varying shear rates. It embraces PV and YP and its value shows the fluid response to the downhole conditions.

- **Chemical Stability** – A chemical property reflecting the resistance of fluid additives to degradation under thermal or chemical interactions. This affects the lifespan and reusability of the drilling mud.
- **Contamination Tolerance** – A chemical property indicating how well the mud maintains its properties when exposed to contaminants like salt, cement, or drill solids.

2.4 Biopolymer-Based Drilling Fluids

Other natural polymers such as gum Arabic, guar gum, xanthan gum, cocoyam starch, and ginger extract are some of the most investigated sources because of their bio degradability and affordability (Abdulkadir et al., 2019; Nwachukwu et al., 2022). These materials also offer superior environmental conditions in addition to exhibiting requisite rheology and filtration conditions needed by efficient drilling mud systems.

Gum Arabic

Gum Arabic is a natural polymer, which is obtained as a product of Acacia species, and it features high water-solubility, emulsifying power, and film-making ability. It has also been explored as a rheology modifier of water-based drilling fluid; this is because it is biodegradable and non-toxic (Abdulkadir et al., 2020). Raw gum Arabic can however be necessitated to undergo beneficiation or treatment to improve its viscosity and suspension qualities. Al-Khafaji and Al-Bazali (2019) found that base fluids with gum Arabic added to them have a value of yield point and gel strength that is much higher, showing better suspension properties. It has pH-dependent rheological behavior; especially at alkaline conditions

Xanthan Gum Gum Arabic

The mixture of gum Arabic with xanthan gum has been reported to improve the shear -thinning of the drilling muds. The synergy leads to a better flow behavior, especially in dynamic conditions hence its application in the horizontal and extended-reach wells. The blend can also enhance the fluid in transporting the cuttings and ensuring low viscosity as the shear-rate increases hence decreasing the amount of energy pumped in pumps (Ibrahim & Ismail, 2022).

2.5 Rheology of Drilling Fluid

Rheology refers to the science of deformation and flow of materials with respect to the stress imposed on the material. As applied to drilling operations, it is the response of drilling fluids to various shear rates and flow situations created during circulation in the wellbore. These drilling fluids are usually non-Newtonian, which implies that their viscosity does not remain unchanged with the shear rate. Rheological behavior of a drilling fluid plays a critical role in the transportation of cuttings, pressure maintenance, stability of the borehole, and solid suspensions when flush circulation is lost.

Alkinani and Ahmed (2019) state that the rheological behaviour of drilling fluids can be understood and optimised to enhance rate of penetration, eliminate the threat of stuck pipe, and generally boost drilling efficiency, especially in the case of high-angle and horizontal wells. The rheology will determine the flow rates of the fluid through the drill pipe and annulus, the ability of the fluid to carry and suspend the drill cuttings and the amount of pressure drop across the flow system.

There are various rheology mathematical tools employed to define the rheology of drilling fluids. The most frequently used of them are Bingham Plastic Model, Power Law Model, and Herschel-

Bulkley Model. These models include correlation of shear stress (t) to shear rate (g) and determine how the fluid behaves on various working conditions:

2.5.1 Bingham Plastic Model

The Bingham Plastic Model assumes that a fluid behaves as a rigid body at low stresses but flows as a viscous fluid once the applied stress exceeds a certain yield value.

The relationship between shear stress (τ) and shear rate (γ) is expressed as:

$$\boldsymbol{\tau = \tau_{\gamma} + \mu_{p}\gamma}$$

Where:

- τ = Shear stress (lb/100 ft^2 or Pa)
- τ_{γ} = Yield stress (lb/100 ft^2 or Pa)
- μ_p = Plastic viscosity (cP)
- γ = Shear rate (s^{-1})

This model is widely used because it provides a simple and fairly accurate representation of drilling mud flow characteristics, particularly for water-based muds.

2.5.2 Power Law Model

The Power Law Model (also called the Ostwald-de Waele Model) describes the behavior of non-Newtonian fluids that do not exhibit a yield stress.

The relationship between shear stress and shear rate is given as:

$$\boldsymbol{\tau = K\gamma^n}$$

Where:

- τ = Shear stress (lb/100 ft^2 or Pa)
- K = Consistency index (lb·s^n/100 ft^2 or Pa·s^n)
- n = Flow behavior index (dimensionless)
- γ = Shear rate (s^{-1})

If $n = 1$, the fluid behaves as a Newtonian fluid.

If $n < 1$, the fluid is pseudoplastic (shear-thinning).

If $n > 1$, the fluid is dilatant (shear-thickening).

This model is useful for describing shear-thinning fluids such as polymer muds.

2.5.3 Herschel–Bulkley Model

The Herschel–Bulkley Model is a more general form that combines the features of both the Bingham Plastic and Power Law models. It is expressed as:

$$\boldsymbol{\tau = \tau_\gamma + K\gamma^n}$$

Where:

- τ = Shear stress (lb/100 ft^2 or Pa)
- τ_γ = Yield stress (lb/100 ft^2 or Pa)
- K = Consistency index (lb·s^n/100 ft^2 or Pa·s^n)

- n = Flow behavior index (dimensionless)
- γ = Shear rate (s^{-1})

This model provides a more accurate representation of drilling fluids that exhibit both yield stress and shear-thinning behavior. It is particularly suitable for polymer-enhanced drilling muds and complex fluid systems.

2.6 Effect of Ph On Rheology

PH is an important criterion, which plays a major role in the rheology of water-based drilling fluids and especially natural or natural-based polymer. pH change has an influence on the ionization state, molecular structure and interaction of polymer chains in the fluid system. These variations, in turn, affect some of the crucial rheological attributes, including viscosity, yield point, and gel strength those are of the essence to the effective drilling process.

Increasing the pH of a drilling fluid using alkaline reagents like sodium hydroxide (NaOH) causes anionic groups of such biopolymers as gum Arabic to be more ionized. This causes more electrostatic repulsion between the polymer chains which expands them and makes them absorb more water. Consequently, the fluid would become more viscous and have greater solids suspension capabilities and cuttings transport. The phenomenon proves especially useful, in the case of non-Newtonian, shear-thinning fluids, when a balance between high shear viscosity and low shear viscosity is needed (Ayeni et al., 2019).

Abdulkadir et al. (2021) carried out an experiment to examine the influence of different pH on drilling muds produced using gum Arabic sourced in Nigeria and NaOH. The findings revealed that viscosity and yield point rose as pH rose, which demonstrated enhanced dispersion of the polymer and enhanced particle hydration. On the same note, Orodu et al. (2020) validated that alkaline conditions improved rheological of gum-based muds and similar to traditional bentonite systems with regard to flow behavior and ability of holding solids.

Moreover, pH affects the gelation of the fluid. Higher pH levels result in more intense hydrogen bonding and ionic interactions, which enhance the fluid potential of forming gels to aid the upholding of hole cleaning effectiveness and barite sag or cuttings to rest throughout periods of idling.

CHAPTER THREE

RESEARCH METHODOLOGY

3.0 Overview

This chapter presents the methods that were used in the establishment of the influence of Alkali (NaOH) on the rheological characteristics of beneficiated gum Arabic polymer formulations. The formulations explored are gum Arabic cocoa ginger, gum Arabic cocoa xanthan and blends of gum Arabic. The equipment and materials that were utilized, the procedures of the experiment in terms of sample preparation, testing procedures of rheological properties, and calculations that were made to analyze the results are described in the chapter.

3.1 Major Materials Used

1. Cocoyam
2. Ginger
3. Bentonite
4. Gum Arabic
5. Xanthan Gum
6. Sodium Hydroxide (NaOH)

3.2 Instrumentation

1. Scout Pro Weighing Balance
2. Hamilton Beach Mud Mixer

3. Fann Viscometer

4. Measuring Cylinder

5. Spatula

3.2.1 Scout Pro Weighing Balance

The Scout Pro weighing balance is a compact, reliable, and versatile digital instrument widely used for quick and accurate measurements in laboratories, classrooms, fieldwork, and industries. It is designed for precision, durability, and portability. The balance supports multiple measurement units such as grams (g), milligrams (mg), ounces (oz), carats (ct), and pounds (lb). The digital model was used in this experiment to ensure accuracy and consistency of weight measurements.

3.1 Weight Balance

3.2 Hamilton Beach Mud Mixer

3.3 Fann Viscometer

3.4 Measuring Cylinder

3.5 Spatula

3.3 Samples and Sampling Techniques

3.3.1 Preparation of The Cocoyam Powder

The cocoyam roots were bought in bulk; it was peeled and placed in thin slices to make the drying process quicker, it was measured with a weight of approximately 1500g prior to drying. This cut cocoyam then dried in the sun during a period of one week and the air dried during one week as it was under constant rain. When the 2 weeks were expired, the cocoyam was then weighed at a weight of 430g; due to loss of fluids and moisture. This was then grinded and it was ready to be utilized for the experiment.

3.3.2 Preparation of The Ginger Powder

Fresh ginger was bought and peeled and sliced; in its wet condition, prior to drying its weight was approximately 450g. It was also dried under the sun over a period of a week and air-dried over a period of a week. Once the 2-week time had passed, the mass of the ginger sample had decreased to approximately 40g. It was then ground and preparation to use in the experiment.

3.4 Experimental Procedures

The experiment was carried out in two main stages:

- Preparation and testing of various gum Arabic-based mud systems without salt.
- Evaluation of the effect of Sodium Hydroxide (NaoH) on the best-performing mud systems from the first stage.

3.4.1 Experimental Procedure for Bentonite Mixture Only

1. measured 500ml of water using the measuring cylinder and placed in the mixing cup.
2. measured 30g of bentonite using the weighing balance and add the powder into the mixing cup containing the water and stir using the mud mixer for 3mins on medium speed.
3. After mud mixing, part of the mixture was placed into the viscometer and its viscosity and gel strength was measured at 600rpm, 300rpm, 200rpm, and 100rpm. Measure the maximum deflection at 15secs and 10mins.
4. The second part of the mixture that was reserved was placed in the mud cup and its density was measured.

Table 3.4.1: Rheological Properties of Bentonite–Water Base Mud

3.4.2 Experimental Procedure for Bentonite and Xanthan Gum

1. Measure 500 ml of water and pour it into the mixing cup.
2. Add 30 g of bentonite and mix for 3 minutes at medium speed.
3. Weigh 1 g of xanthan gum and add it to the bentonite mixture.
4. Stir the mixture for 3 minutes at high speed.
5. Measure the viscosity and gel strength at 600, 300, 200, and 100 rpm.
6. Record gel strength after 10 seconds and 10 minutes.

Table 3.4.2: Rheological Properties of Gum Arabic–Xanthan Gum Mud System

3.4.3 Experimental Procedure for Bentonite Gum Arabic

1. 30g of bentonite and 500ml of water were measured and then stirred using the mud mixer at medium speed for 3mins.

2. 50g of gum arabic was then measured and added to the mixture and stirred for another 3mins.

3. The resulting mixture was then measured for viscosity, gel strength and density. (Observation: 1g of xanthan gum is equivalent to 50g of gum Arabic as a result of the nature of their resulting mixture).

Rheological properties were then measured and the result is tabulated in Table 3.4.3

3.4.4 Experimental Procedure for Bentonite, Gum Arabic And Cocoyam

1. Measure 500 mL of water and 30 g of bentonite, then mix thoroughly for 3 minutes to form a uniform slurry.
2. Add varying quantities of gum Arabic and cocoyam for different samples as follows:

Sample A: 25 g of cocoyam and 25 g of gum Arabic

Sample B: 12.5 g of cocoyam and 37.5 g of gum Arabic
Mix each sample for an additional 3 minutes to ensure uniform blending.

3. Pour the prepared mixture into the viscometer cup and record the readings at 600rpm, 300rpm, 200rpm, and 100rpm.

Table 3.4.4: Rheological Properties of Gum Arabic–Cocoyam Mud System

3.4.5 Experimental Procedure for Bentonite, Gum Arabic And Ginger

1. Measure 500 ml of water and pour into the mixing cup.
2. Add 30 g of bentonite and mix for 3 minutes at medium speed.
3. Prepare two separate samples:
    - Sample A: 25 g of gum Arabic + 25 g of ginger
    - Sample B: 37.5 g of gum Arabic + 12.5 g of ginger
4. Add the materials into the mixture and stir for 3 minutes.
5. Determine viscosity, gel strength, and density of each sample.

Table 3.4.5: Rheological Properties of Gum Arabic–Ginger Mud System

3.5 Experimental Procedures (With NAOH)

3.5.1 Experimental Procedure with Bentonite, Xanthan Gum (1g), NaOH (7.5 g).

This experiment was considered immiscible due to the formation of a lot of “fish eye”.

3.5.2 Experimental Procedure with Bentonite, Gum Arabic (50g), NaOH (7.5g & 15g)

1. 30g of bentonite and 500ml of water were measured and then stirred using the mud mixer at medium speed for 3mins at low speed.

2. 50g of gum arabic was then measured and added to the mixture and stirred for another 3mins.

3. 7.5g of NaOH was then measured and added into the mixture and stirred for another 3mins at medium speed.

4. The resulting mixture was then measured for viscosity, gel strength and density and its pH was also tested using the litmus paper.

5. The same procedure was then repeated, but using 15g of NaOH.

Table 3.5.2: Effect of NaOH on Gum Arabic

3.5.3 Experimental Procedure Using Bentonite, Gum Arabic (25g), Cocoyam (25g), NaOH (3.0g & 7.5g)

1. 30g of bentonite and 500ml of water were measured and then stirred using the mud mixer at medium speed for 3mins at low speed.
2. 50g of gum arabic was then measured and added to the mixture and stirred for another 3mins.
3. 50g of cocoyam was also added to the mixture and stirred for 3mins on medium speed.
4. 3.0g of NaOH was then measured and added into the mixture and stirred for another 3mins at medium speed.
5. The resulting mixture was then measured for viscosity, gel strength, density and pH.
6. The procedure is then repeated, but using 7.5g of NaOH.

Table 3.5.3: Effect of NaOH on Gum Arabic–Cocoyam Mud System

Experimental Procedure Using Bentonite, Gum Arabic (25g), Gingr (25g), NAOH (3.0g & 7.5g)

1. 30g of bentonite and 500ml of water were measured and then stirred using the mud mixer at medium speed for 3mins at low speed.
2. 50g of gum arabic was then measured and added to the mixture and stirred for another 3mins.
3. 50g of cocoyam was also added to the mixture and stirred for 3mins on medium speed.
4. 3.0g of NaOH was then measured and added into the mixture and stirred for another 3mins at medium speed.
5. The resulting mixture was then measured for viscosity, gel strength, density and pH.
6. The procedure is then repeated, but using 7.5g of NaOH.

Table 3.5.4: Effect of NaCl on Gum Arabic–Ginger Mud System

3.6 Determination of Rheological Properties

3.6.1 Viscosity Measurement

The Fann viscometer is a laboratory instrument used to determine the viscosity of drilling muds and other fluid systems. A sample of mud was poured into the viscometer beaker, which was then raised using the plate-like base until the rotor sleeve was immersed in the mud up to the scribed line. The beaker was held in position by tightening the lock screw on the right leg of the instrument. The gear was then switched on sequentially to speeds of 600 rpm, 300 rpm, 200 rpm, and 100 rpm. The calibrated viscometer reading was allowed to stabilize at each speed, and the corresponding readings were taken and

3.6.2 Density Measurement

1 The lid was removed from the cup, and the cup was completely filled with the mud sample to be tested.

3 The lid was replaced and rotated until it was firmly seated, ensuring that some mud was expelled through the hole in the lid.

4 The outside of the cup was cleaned with tissue paper to remove any mud residue.

5 The balance arm was placed on the base, with the knife-edge resting on the fulcrum.

6 The rider was moved along the graduated arm until the beam was level, as indicated by the spirit level vial.

7 The mud weight was then read at the left-hand edge of the rider and recorded.

8 The procedure was repeated for each sample, and the corresponding mud weight values were recorded accordingly.

3.7 Calculation

The following formulas were used to calculate the rheological parameters:

1. **Plastic Viscosity (PV)** = $\theta_{600} - \theta_{300}$
2. **Yield Point (YP)** = $\theta_{300} - PV$
3. **Apparent Viscosity (AV)** = $\theta_{600} / 2$
4. **Power Law Index (n)** = $3.32 \log (\theta_{600} / \theta_{300})$
5. **Consistency Index (K)** = $\theta_{300} / (511^n)$
6. **Shear stress,** $\tau = 1.067 * \text{dial reading}$ (lbf/100ft^2)
7. **Shear rate,** $\gamma = 1.703 * \text{rpm}$ (sec^{-1})

8. **Bingham Plastic Model ,**

   $\boldsymbol{\tau = \tau_\gamma + \mu_p\gamma}$

9. **Power Law Model**

   $\tau = K (\gamma)^n$

10. **Hershely Buckley Model**

    $\tau = \tau_\gamma + K\gamma^n$

where **θ** represents the viscometer dial readings at the specified rotational speeds.

3.8 Precautions

1. During the test for viscosity, it was ensured that the pointer settled on the scale before the reading was taken.
2. During the test for mud weight, it was ensured that the mud balance came to rest and built-in spirit level was at the middle of the scribed mark
3. It was ensured that the weight balance was placed on a flat working surface.
4. It was ensured that no external force acted on the weigh balance before taking reading.
5. It was ensured that errors due to parallax were avoided while taking the reading from the instrument.

RESULT TABLE:

EXPERIMENT ONE

Table 3.4.1: Result of Bentonite and Water (Spud Mud)

RPM	DIAL READING
600	9.0

300	6.5
200	5.5
100	4.5
Gel	
10 SECONDS	5.5
10 MINUTES	7
PV	2.5
YP	4.0
DENSITY	8.6g/cc

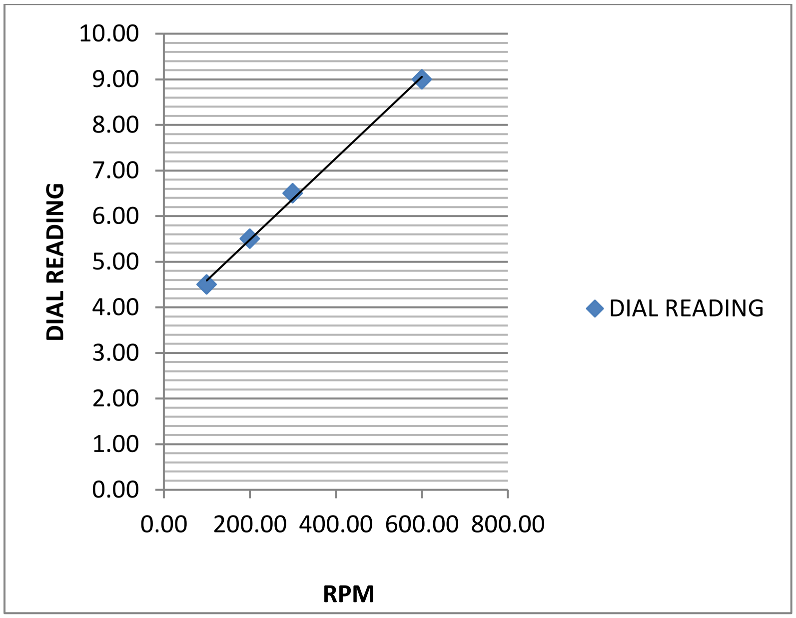


Fig 3.6 Plot of Dial reading versus RPM on bentonite and water (spud mud)

Table 3.4.2: Result of Mud With 1g Of Xanthan Gum

RPM	**DIAL READING**
600	46.0
300	35.5
200	31.0

100	25.0
GEL	
10 SECONDS	25.0
10 MINUTES	29.0
PV	10.5
YP	25.0
DENSITY	8.7g/cc

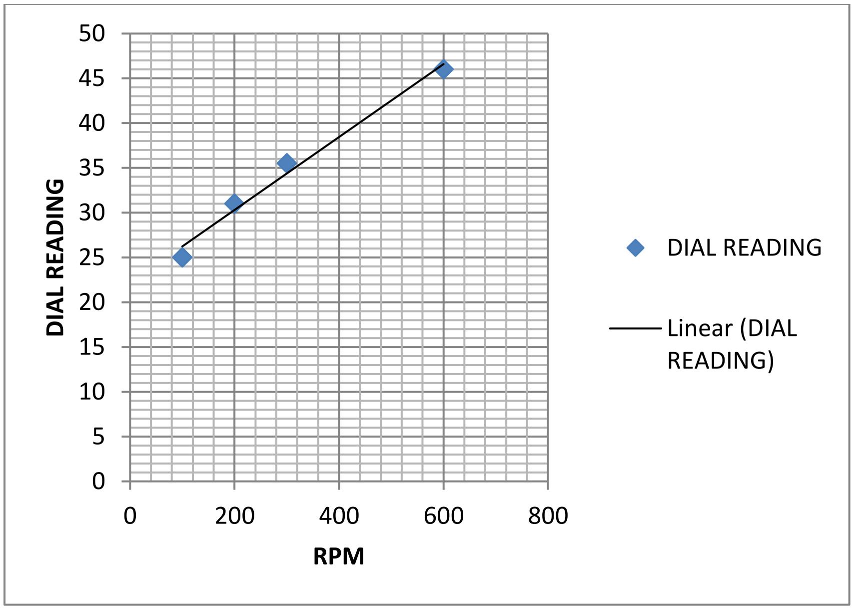


Fig 3.7 Plot of Dial reading versus RPM on 1g of Xanthan gum mud system

Table 3.4.3: Result of Mud With 50g Of Gum Arabic

RPM	**DIAL READING**

600	45.0
300	34.5
200	31.5
100	25.0
GEL	
10 SECONDS	28.0
10 MINUTES	30.0
PV	10.5
YP	24.0
DENSITY	8.6g/cc

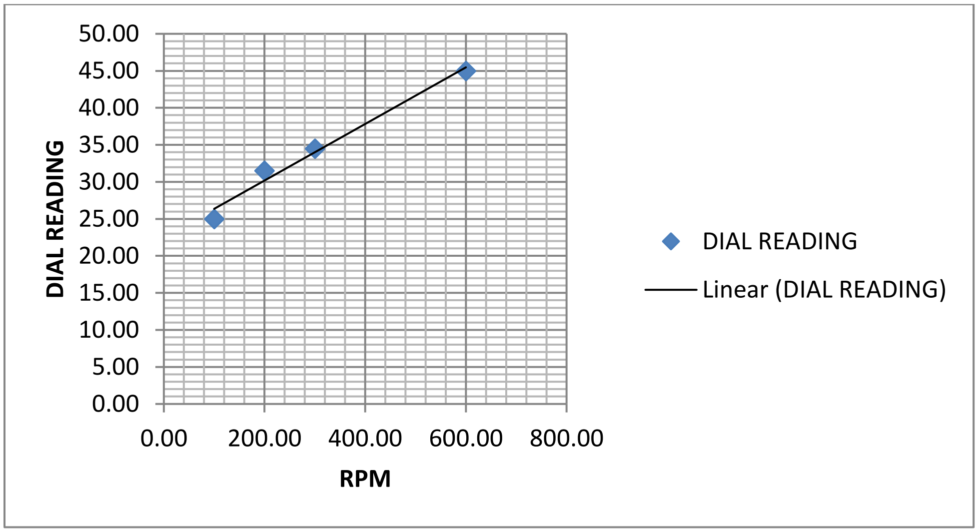


Fig 3.8 Plot of Dial reading versus RPM on 50g of Gum Arabic mud system

Table 3.4.4: Result of Mud with Gum Arabic And Cocoyam

RPM	**25g of Gum Arabic +25g of cocoyam**	**37.5g of Gum Arabic + 12.5g of cocoyam**
600	30.0	30.0

300	22.0	24.0
200	19.0	19.0
100	14.0	13.0
GEL		
10 SECONDS	15.0	16.0
10 MINUTES	20	19.0
PV	8.0	6.0
YP	14.0	18
DENSITY	8.3g/cc	8.2g/cc

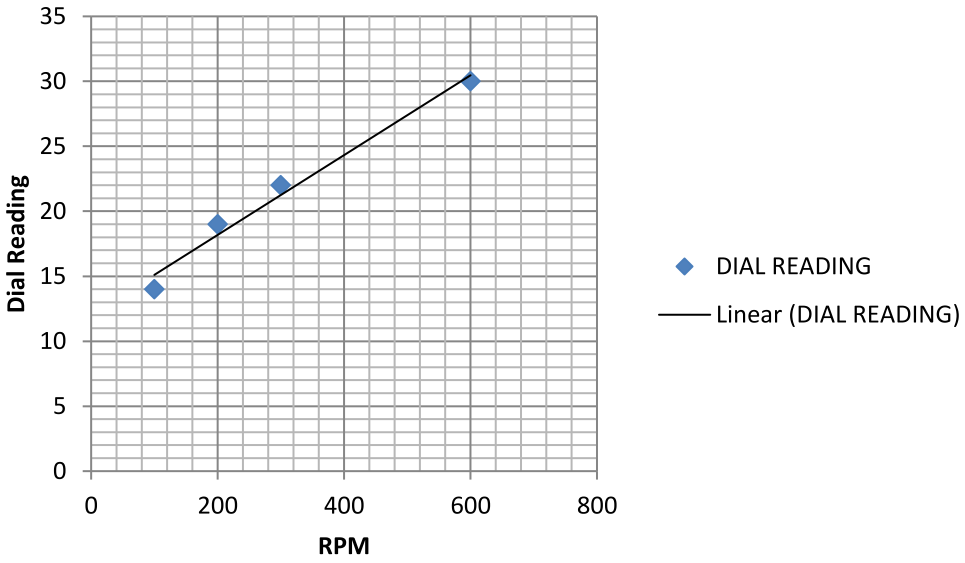


Fig 3.8a Plot of Dial reading versus RPM on 25g of gum arabic + 25g of cocoyam

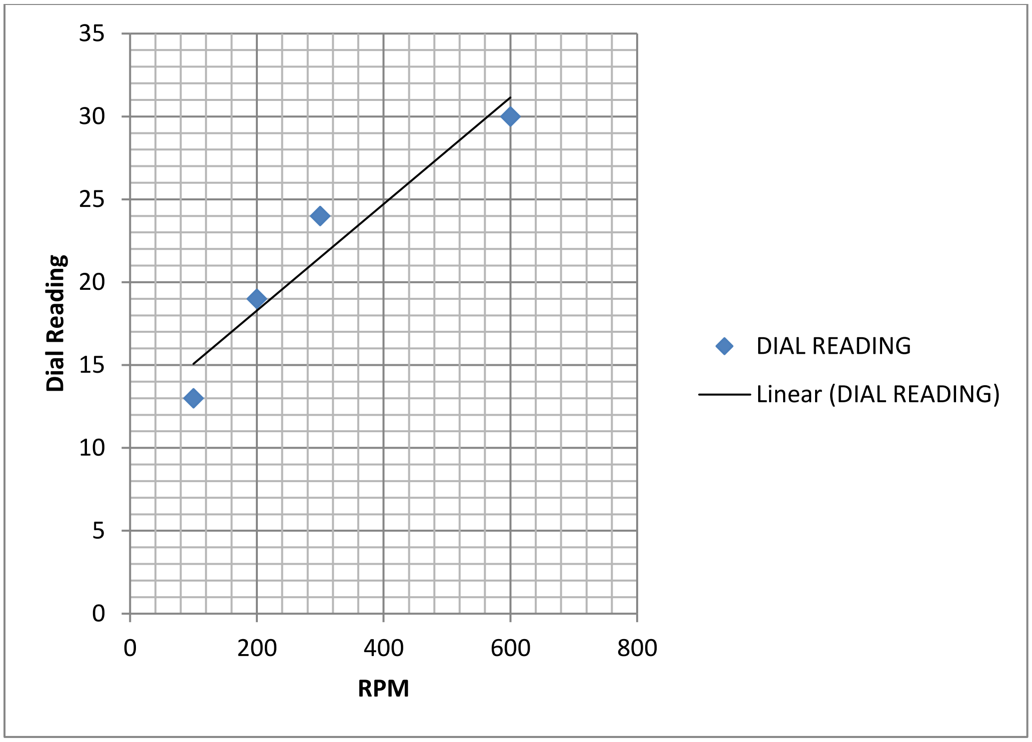


Fig 3.8b Plot of Dial reading versus RPM on 37.5g of gum arabic + 12.5g of cocoyam

Table 3.4.5: Result of Mud with Gum Arabic And Ginger

RPM	**25g of Gum Arabic +25g of Ginger**	**37.5g of Gum Arabic + 12.5g of Ginger**
600	48.0	44.5
300	30.0	28.0
200	24.0	21.5
100	21.0	15.5
GEL		
10 SECONDS	20.0	19.0
10 MINUTES	24.0	18.0
PV	18.0	16.5
YP	12.0	11.5

DENSITY	8.0g/cc	8.1g/cc

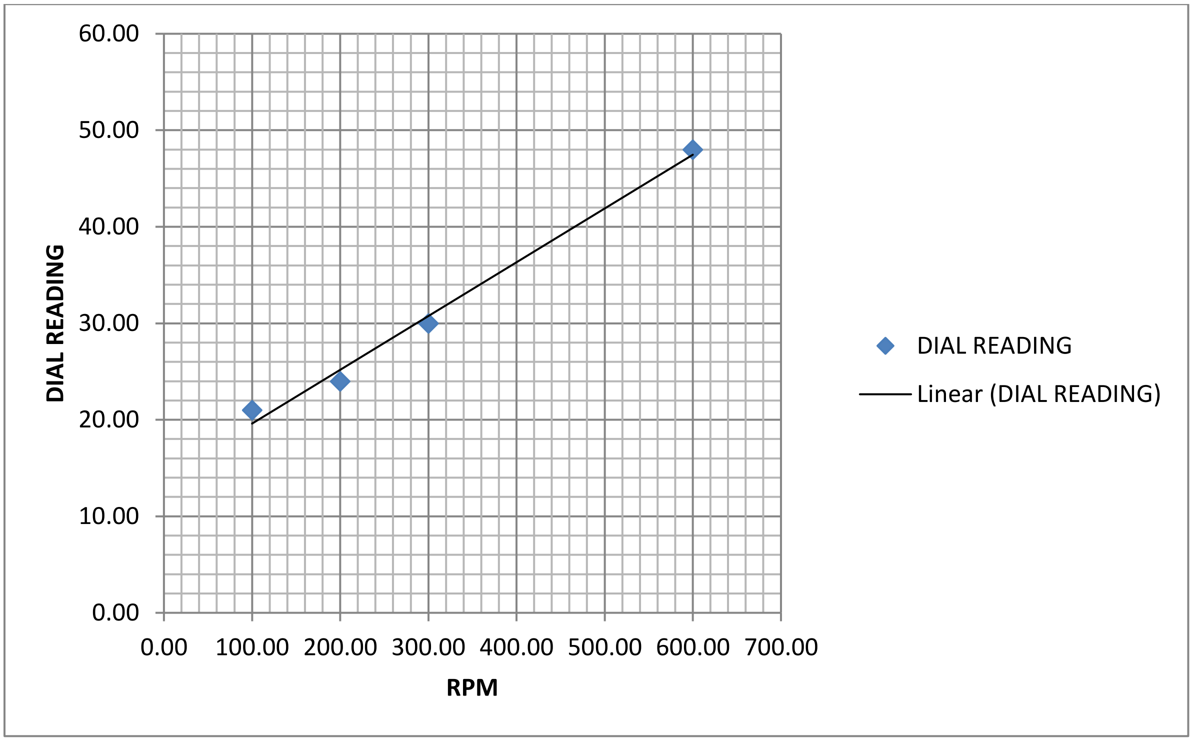


Fig 3.9a: Plot of Dial reading versus RPM on 25g of Gum Arabic + 25g of Ginger and 37.5g

Experiment Two (Using Alkaline)

3.5.1 Experimental Procedure with Bentonite, Xanthan Gum (1g), NAOH (7.5 g).

The experiment on the mixture using NaOH and 1g of Xanthan gum was concluded to be Immiscible as its mixture resulted in a lot of “fish eye”.

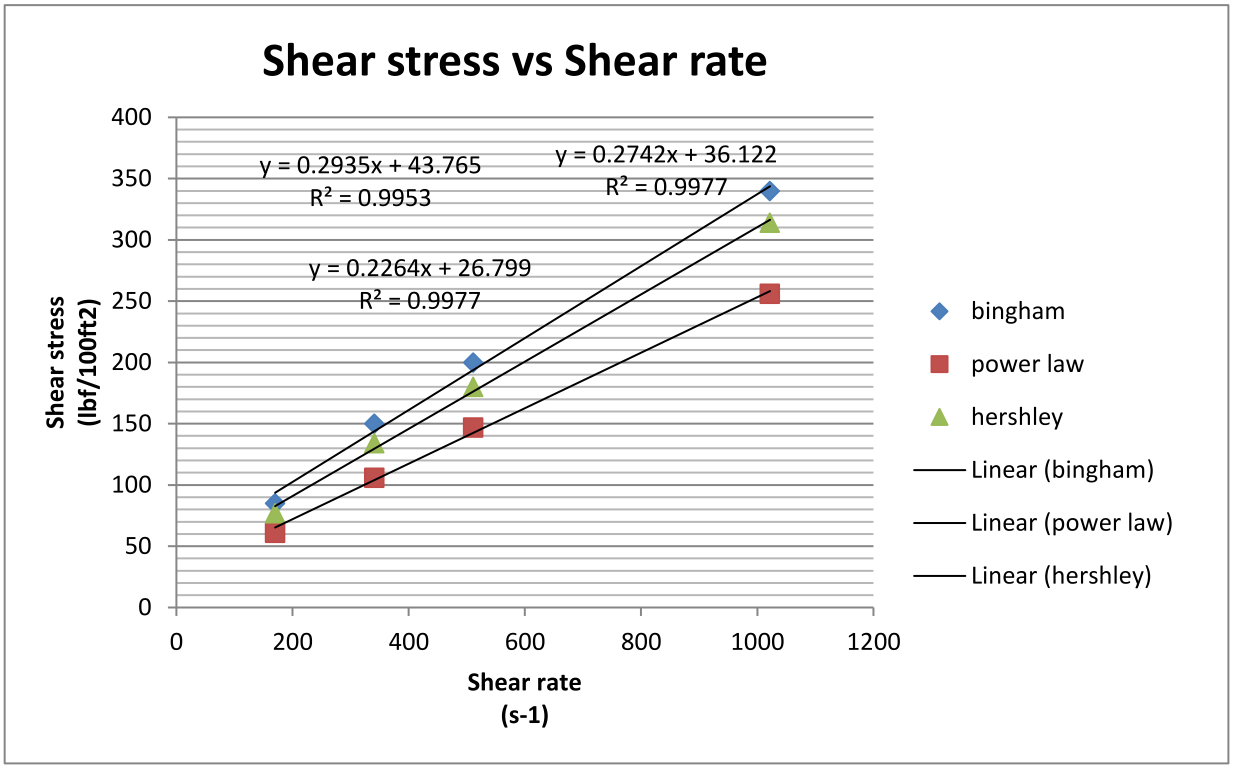
Table 3.5.2 Effect Of 7.5g Of NAOH on the Rheological Properties of 50g Of Gum Arabic

RPM	**7.5g of NaOH**	**15.0g OF NaOH**
600	54	56.5
300	31	33
200	25.5	21
100	15	11
Gel strength		
10 secs	20	20
10 mins	24	16
Density (g/cc)	7.85	7.7
pH	10	11
N	0.8	0.78
K	1.0	1.0
PV	23	23.5
YP	8	9.5

Model Data to Determine the Effect Of 7.5g Of Naoh On The Rheological Properties Of 50g Of Gum Arabic

Table 3.5.2b: Model data of 7.5g of alkaline on 50g of Gum Arabic

Shear rate (s^{-1})	**Shear stress($lbf/100ft^2$)**	**Bingham plastic model ($lbf/100ft^2$)**	**Power law model ($lbf/100ft^2$)**	**Hershely Buckley model ($lbf/100ft^2$)**
1022	58	340	256	314
511	33	200	147	180



341	28	150	106	134
170	16	85	61	77

Fig 3.9b: Plot of Shear stress versus shear rate of the effect of 7.5g of NaOH on 50g of gum arabic mud system

Model Data to Determine the Effect Of 15g Of NAOH on The Rheological Properties Of 50g Of Gum Arabic

Table 3.5.2c: Model data of 15.0g of alkaline on 50g of Gum Arabic

Shear rate (s^{-1})	**Shear stress(lbf/100ft^2)**	**Bingham plastic model (lbf/100ft^2)**	**Power law model (lbf/100ft^2)**	**Hershely Buckley model (lbf/100ft^2)**
1022	61	312	223	284
511	33	180	130	163

341	22	135	95	117
170	12	75	55	67

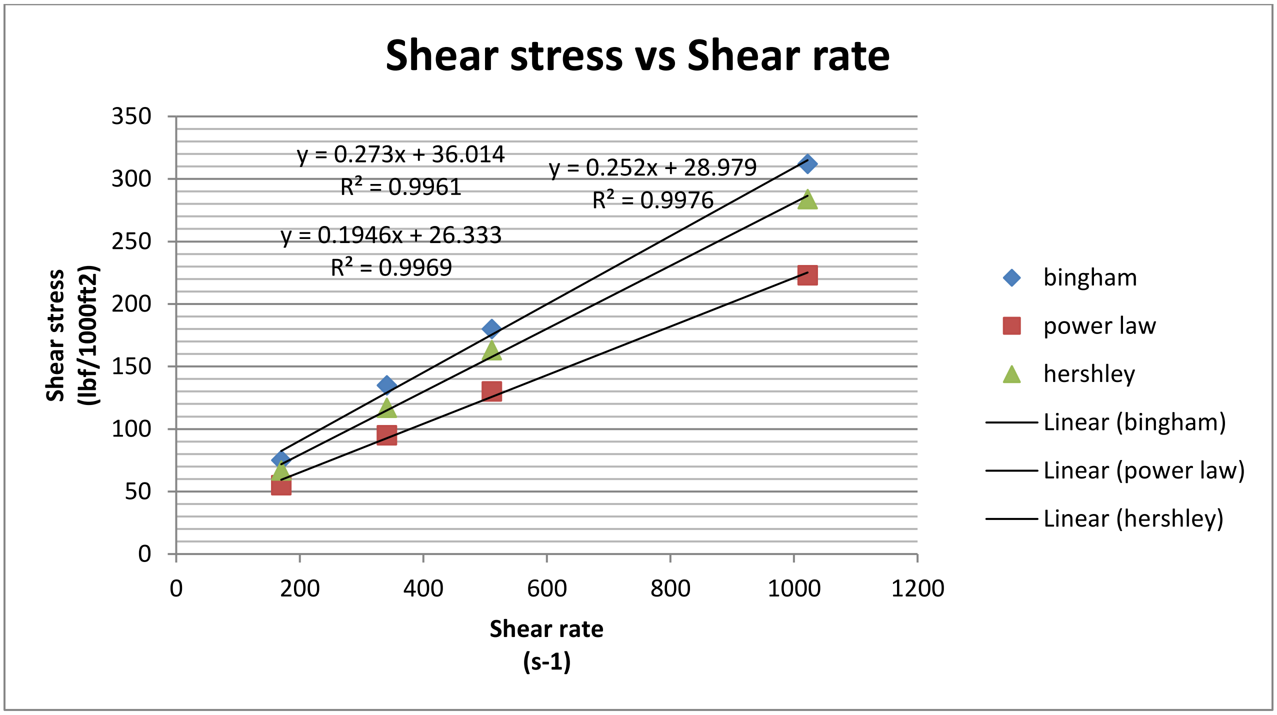


Fig. 3.9c: Plot of Shear stress versus shear rate of the effect of 15.0g of NaOH on 50g of gum arabic mud system

Table 3.5.3 Effects of NAOH (3.0g & 7.5g) on Gum Arabic (25g) and Cocoyam (25g)

RPM	**NaOH of 3.0g**	**NaOH of 7.5g**
600	52	310
300	34	245
200	26	50
100	19	45
Gel Strength		
10 secs	18	90
10 mins	32	112
Density (g/cc)	8.2	8.5
pH	10	11
n	0.948	0.3
K	0.4	0.8
PV	18	65

YP	16	180

Table 3.5.3: Effect of Alkaline on 25g of Gum Arabic & 25g of Cocoyam

Model Data to Determine the Effect Of 3.0g Of NAOH On The Rheological Properties Of 25g Of Gum Arabic & 25g Of Cocoyam

Shear rate (s^{-1})	**Shear stress(lbf/100ft^2)**	**Bingham plastic model (lbf/100ft^2)**	**Power law model (lbf/100ft^2)**	**Hershely Buckley model (lbf/100ft^2)**
1022	55	302	285	340
511	36	155	148	186
341	28	122	101	129
170	20	66	52	72

Table 3.5.3b: Model data of 3.0g of alkaline on 25g of Gum Arabic & 25g of Cocoyam

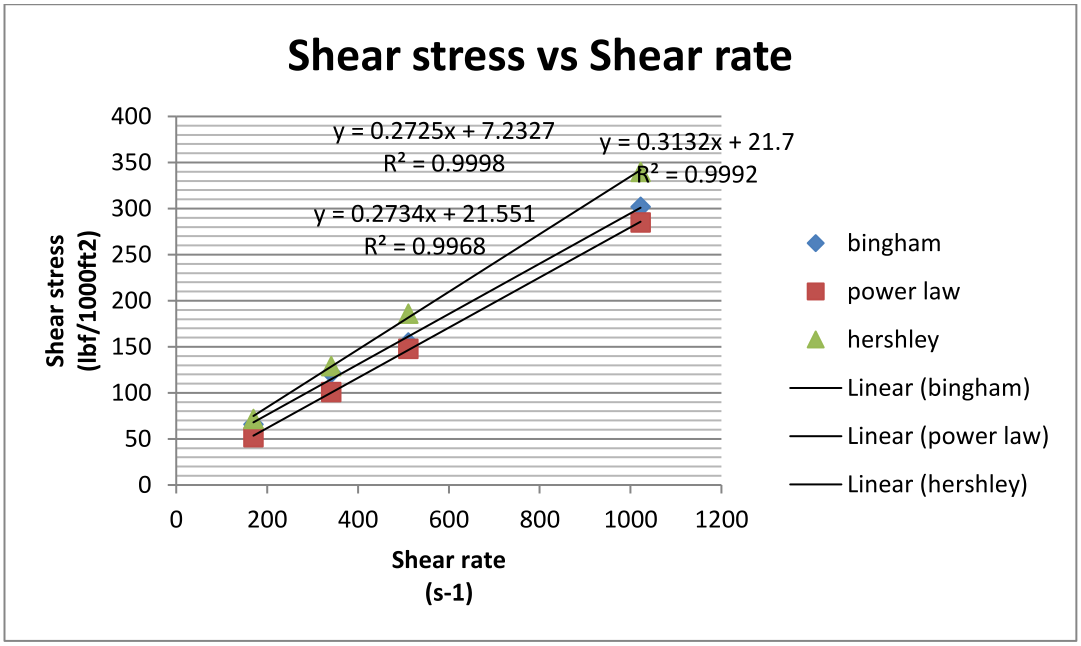


Fig. 3.10: Plot of Shear stress versus shear rate of the effect of 3.0g of NaOH on 25g of gum arabic & 25g of cocoyam mud system

Model Data to Determine The Effect Of 7.5g Of Naoh On The Rheological Properties Of 25g Of Gum Arabic & 25g Of Cocoyam

Shear rate (s^{-1})	Shear stress($lbf/100ft^2$)	Bingham plastic model ($lbf/100ft^2$)	Power law model ($lbf/100ft^2$)	Hershely Buckley model ($lbf/100ft^2$)
1022	331	66610	6	337
511	261	33395	5	266
341	53	22345	4	57
170	48	11230	3	51

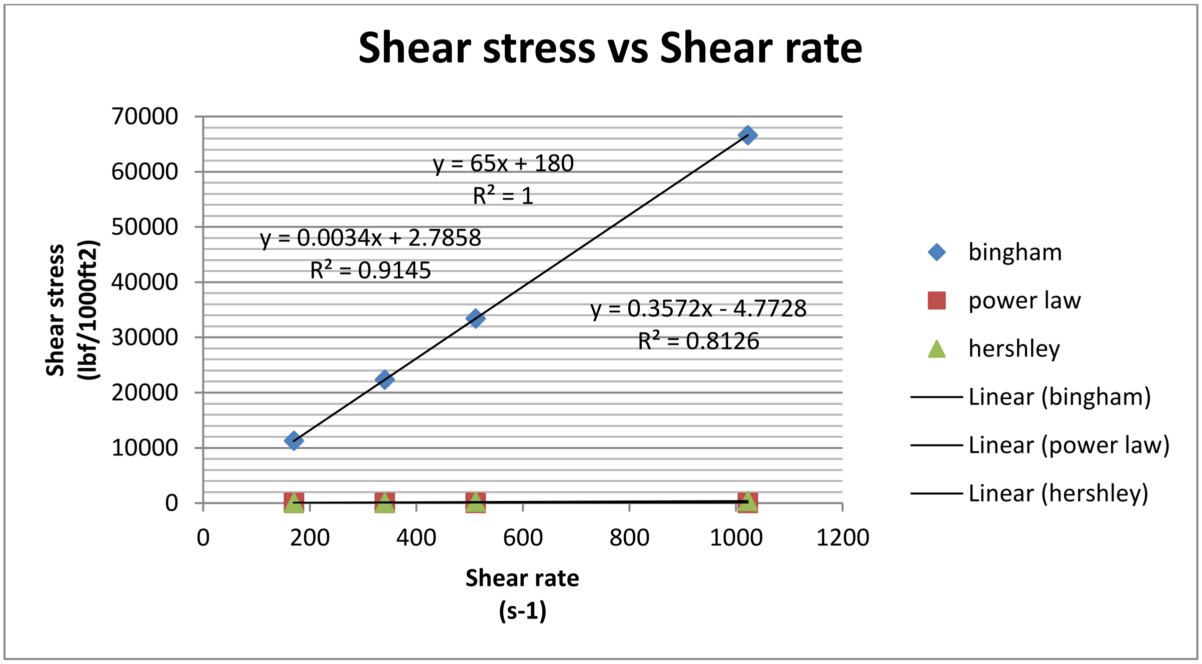


Fig. 3.11a: Plot of Shear stress versus shear rate of the effect of 7.5g of NaOH on 25g of gum arabic & 25g of cocoyam mud system

Table: 3.5.4 Effects of NAOH on Ginger (25g) & Gum Arabic (25g)

RPM	**NaOH of 3.0g**	**NaOH of 7.5g**
600	85	225
300	54	117
200	43	120
100	30	85
Gel Strength		
10secs	45	90
10mins	50	10
Density (g/cc)	6.7	8.2
pH	11	11
n	0.948	0.943
K	0.74	0.91
PV	31	108
YP	23	9

Model Data to Determine the Effect Of 3.0g Of NAOH On The Rheological Properties Of 25g Of Gum Arabic & 25g Of Ginger

Table 3.5.4b: Model data of 3.0g of alkaline on 25g of Gum Arabic & 25g of Ginger

Shear rate (s^{-1})	**Shear stress(lbf/100ft^2)**	**Bingham plastic model (lbf/100ft^2)**	**Power law model (lbf/100ft^2)**	**Hershely Buckley model (lbf/100ft^2)**
1022	91	412	527	618
511	58	172	273	331
341	46	96	186	232
170	32	74	96	128

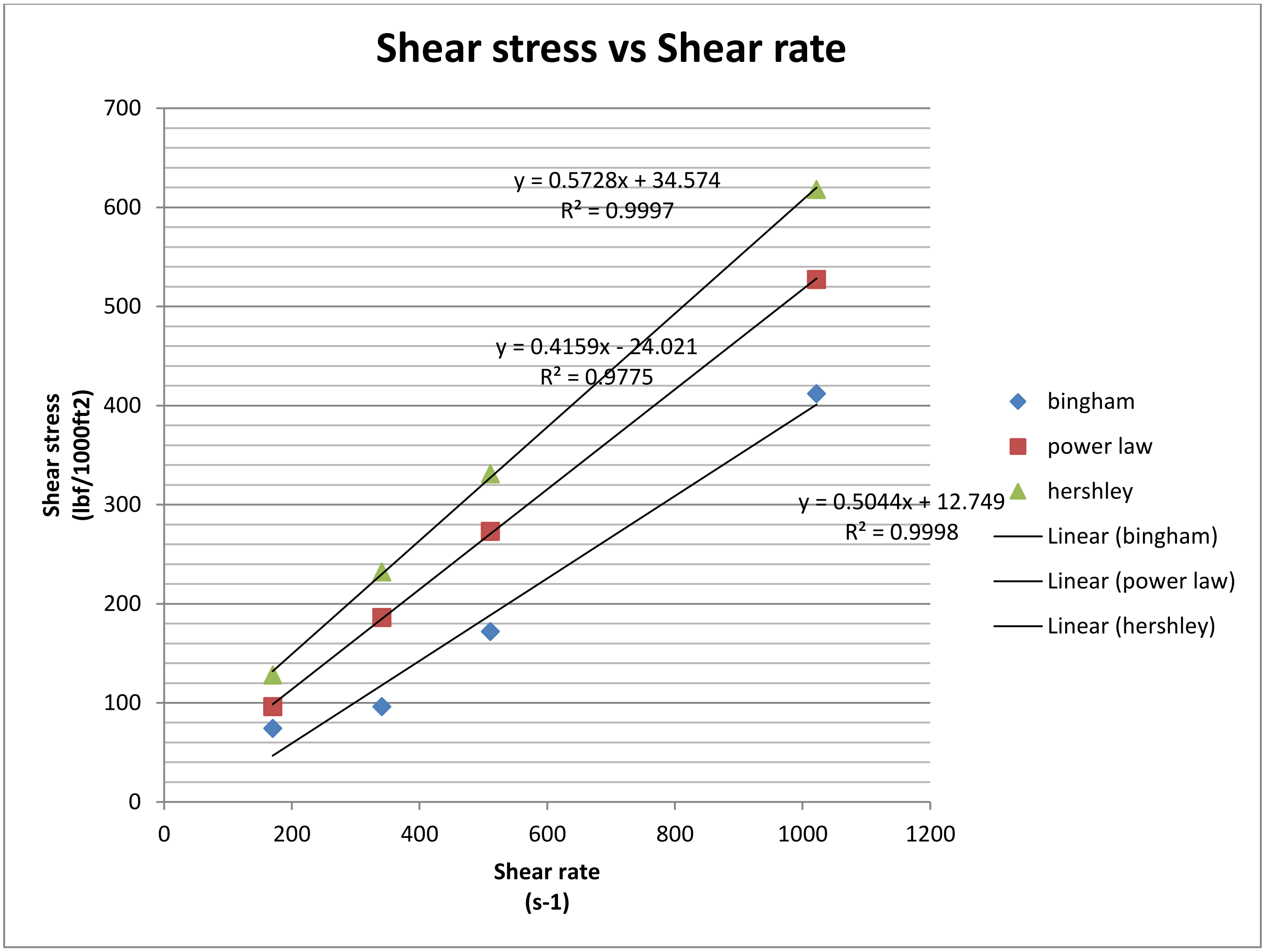
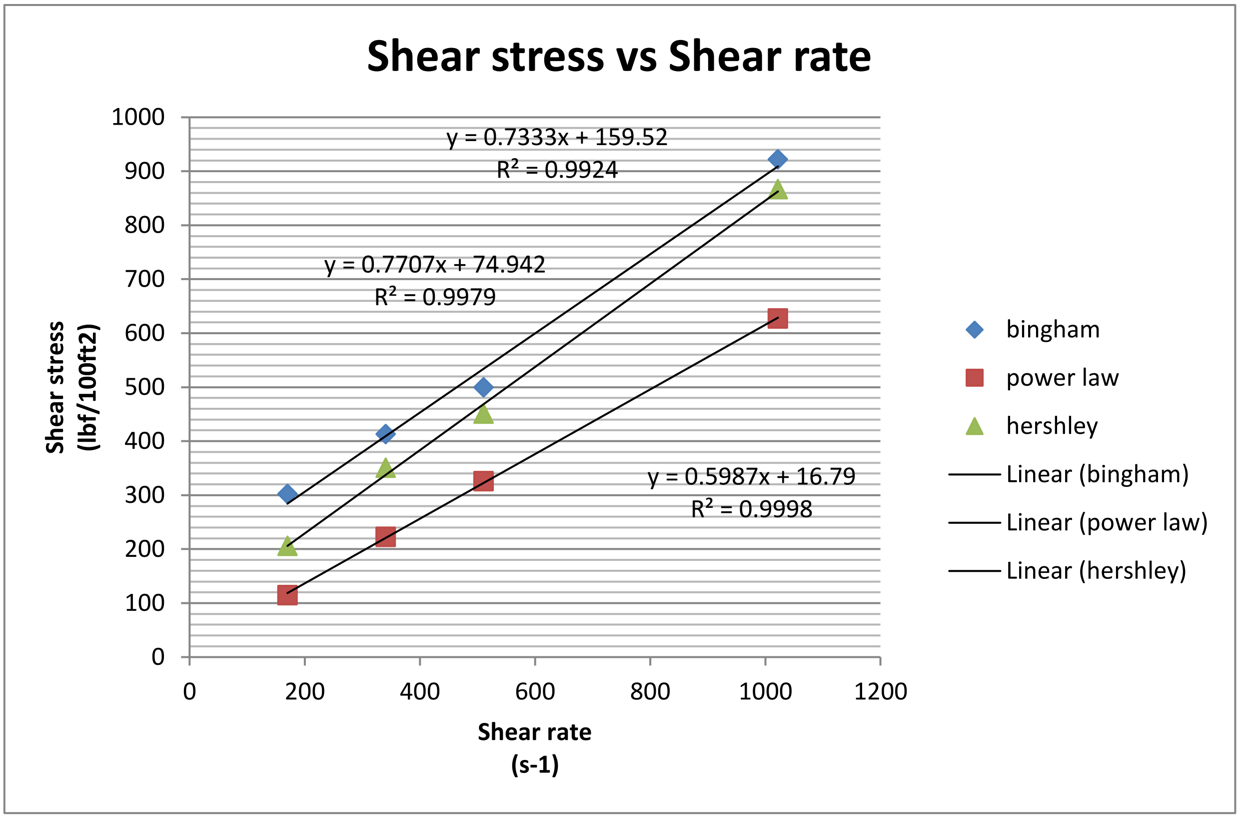


Fig. 3.11b: Plot of Shear stress versus shear rate of the effect of 3.0g of NaOH on 25g of gum arabic & 25g of ginger mud system



Model Data to Determine The Effect Of 7.5g Of Naoh On The Rheological Properties Of 25g Of Gum Arabic & 25g Of Ginger

Table 3.5.4c: Model data of 7.5g of alkaline on 25g of Gum Arabic & 25g of Ginger

Shear rate (s^{-1})	**Shear stress(lbf/100ft^2)**	**Bingham plastic model (lbf/100ft^2)**	**Power law model (lbf/100ft^2)**	**Hershely Buckley model (lbf/100ft^2)**
1022	240	922	627	867
511	125	500	326	451
341	128	413	223	351
170	91	302	115	206

Fig. 3.11c: Plot of Shear stress versus shear rate of the effect of 7.5g of NaOH on 25g of gum arabic & 25g of ginger mud system

CHAPTER 4

ANALYSIS AND DISCUSSION OF RESULTS

4.1 Overview

This chapter presents and discusses the results obtained from the rheological investigation of beneficiated gum Arabic-based drilling fluids. The study was carried out in two main phases: the baseline experiment (without NaOH) and the alkaline-modified experiment (with NaOH at different concentrations). The parameters evaluated include plastic viscosity (PV), yield point (YP), gel strength, and density. These parameters were analyzed to determine the effects of polymer type, blending ratio, and alkalinity on the performance of the formulated drilling fluids. The rheological behavior of each mud sample was also modeled using the Bingham Plastic, Power Law, and Herschel–Bulkley models to determine which best describes the flow characteristics of the systems.

4.2 Baseline Experimental Results (Without NAOH)

4.2.1 Comparison of Polymer Systems

The baseline results presented in Tables 3.4.1 to 3.4.5 (Chapter 3) represent the rheological properties of seven drilling mud formulations: bentonite-only, bentonite with xanthan gum, bentonite with gum Arabic, and gum Arabic blended with cocoyam or ginger at ratios of 50/50 and 75/25.

Plastic Viscosity (Pv)

From the results, the bentonite-only mud (Table 3.4.1) had the lowest PV of 2.5 cP, showing that it had minimal resistance to flow and poor viscosity. The addition of polymers significantly increased PV. Xanthan gum (Table 3.4.2) recorded a PV of 11.5 cP, while gum Arabic (Table 3.4.3) gave 10.5 cP, indicating their effectiveness as viscosifiers. Among the blended systems, the gum Arabic–ginger (25 g + 25 g) blend (Table 3.4.5) recorded the highest PV (18.0 cP), while the gum Arabic–cocoyam (37.5 g + 12.5 g) blend (Table 3.4.4) had the lowest (6.0 cP). This suggests that ginger contributes more to the mud's internal structure, possibly due to the starch and fiber content of the ginger powder.

Yield Point (YP)

The YP values (Tables 3.4.1–3.4.5) ranged from 4.0 lb/100 ft² for the bentonite mud to 24.0 lb/100 ft² for both the xanthan and gum Arabic muds. The blended systems recorded YP values between 11.0 and 18.0 lb/100 ft², with gum Arabic–cocoyam (37.5 g + 12.5 g) having the highest among the blends. Higher YP indicates a stronger ability to suspend and transport drilled cuttings, suggesting that the blends possess good carrying capacity.

Gel Strength

Gel strength results (Tables 3.4.1–3.4.5) showed that xanthan gum had the highest gel strength, increasing from 29 lb/100 ft² (10 seconds) to 35 lb/100 ft² (10 minutes), indicating strong structural build-up during rest periods. The gum Arabic–cocoyam (25 g + 25 g) blend increased slightly from 15 to 20 lb/100 ft², implying a more stable and less time-dependent structure.

Density

As shown in Chapter 3, the mud densities ranged between 8.0 and 8.7 g/cc. Xanthan gum (Table

3.4.2) had the highest density (8.7 g/cc), while gum Arabic–ginger (Table 3.4.5) had the lowest (8.0 g/cc). These small differences indicate that polymer addition did not significantly alter fluid density but mainly affected viscosity and gel structure.

4.2.2 Rheological Behavior Classification

The flow curves presented in Figures 3.4.1 to 3.4.5 (Chapter 3) illustrate how each mud behaved under different shear rates:

- Bentonite Mud (Fig. 3.4.1): Displayed near-linear behavior typical of a Newtonian or slightly pseudoplastic fluid with low internal structure.
- Xanthan Gum Mud (Fig. 3.4.2): Showed strong shear-thinning (pseudoplastic) behavior, with viscosity decreasing as shear rate increased.
- Gum Arabic Mud (Fig. 3.4.3): Exhibited a similar trend to xanthan gum, confirming its potential as a natural viscosifier.
- Blended Systems (Figs. 3.4.4–3.4.5): Demonstrated intermediate rheology, where the 50/50 ratios showed higher viscosity and yield points than the 75/25 ratios, suggesting optimal polymer–starch interactions occur at equal proportions.

These findings confirm that gum Arabic and its blends significantly enhance mud rheology, making them promising natural substitutes for synthetic polymers.

4.3 Effect of Sodium Hydroxide on Rheological Properties

4.3.1 Gum Arabic with NAOH (7.5 G And 15.0 G)

The data presented in Table 3.5.2 (Chapter 3) show that alkaline treatment slightly improved gum Arabic's rheology. At 7.5 g NaOH (pH 10), the PV was 23 cP and YP 8 lb/100 ft², while at 15.0 g NaOH (pH 11), the PV increased slightly to 23.5 cP and YP to 9.5 lb/100 ft². The Herschel–Bulkley model (Figures 3.5.2b–3.5.2c) best fitted the data ($R^2 \approx 0.96$–0.97), confirming pseudoplastic flow behavior.

4.3.2 Gum Arabic–Cocoyam Blend with Naoh (3.0 G And 7.5 G)

The results in Table 3.5.3 (Chapter 3) show a remarkable increase in viscosity and yield stress when NaOH was added. At 3.0 g NaOH, PV was 18 cP and YP 16 lb/100 ft², but at 7.5 g NaOH, PV rose sharply to 65 cP and YP to 180 lb/100 ft². The Herschel–Bulkley and Power Law models (Figures 3.5.3b–3.5.3c) confirmed highly pseudoplastic behavior with $n = 0.30$ and $R^2 = 0.98$. This demonstrates strong polymer–starch synergy and excellent cuttings suspension capability.

4.3.3 Gum Arabic–Ginger Blend with NAOH (3.0 g AND 7.5 g)

From Table 3.5.4 (Chapter 3), the gum Arabic–ginger blend at 3.0 g NaOH gave PV = 31 cP and YP = 23 lb/100 ft², while at 7.5 g NaOH, PV increased to 108 cP but YP dropped to 9 lb/100 ft². The decrease in yield point suggests partial degradation of ginger starch at high alkalinity. The gel strength also fell from 50 lb/100 ft² (10 min) to 10 lb/100 ft², indicating weak long-term structure. The Herschel–Bulkley model provided the best fit with $R^2 \approx 0.95$–0.96 (Figures 3.5.4b–3.5.4c).

4.4 Comparative Analysis of Alkaline Effects

Each system reacted differently to alkaline modification:

- Gum Arabic: Showed limited improvement after 7.5 g NaOH, indicating saturation of active sites.
- Gum Arabic–Cocoyam: Showed the most dramatic improvement, with high PV, YP, and gel strength, due to starch gelatinization and cross-linking.
- Gum Arabic–Ginger: Improved at moderate pH but degraded at higher alkalinity due to polysaccharide breakdown.

4.5 Rheological Model Evaluation

Table 4.5 presents the parameters derived from fitting the experimental data to the Bingham Plastic, Power Law, and Herschel–Bulkley models.

Mud System	Rheological Model	N	K	R²	Function / Interpretation
Bentonite–Water	Bingham Plastic	1.00	0.35	0.91	Near-Newtonian flow with weak carrying capacity.
Gum Arabic (50 g + 7.5 g NaOH)	Herschel–Bulkley	0.80	1.00	0.97	Moderate shear-thinning with good structural stability.
Gum Arabic (50 g + 15.0 g NaOH)	Herschel–Bulkley	0.78	1.00	0.96	Slightly higher pseudoplasticity; over-ionization limits gel stability.

Gum Arabic–Cocoyam (25 g + 25 g + 3.0 g NaOH)	Power Law	0.95	0.40	0.94	Mild shear-thinning; steady viscosity and flow.
Gum Arabic–Cocoyam (25 g + 25 g + 7.5 g NaOH)	Power Law	0.30	0.80	0.98	Strong pseudoplasticity; best for cuttings transport.
Gum Arabic–Ginger (25 g + 25 g + 3.0 g NaOH)	Herschel–Bulkley	0.95	0.74	0.95	Balanced shear-thinning; stable gel structure.
Gum Arabic–Ginger (25 g + 25 g + 7.5 g NaOH)	Herschel–Bulkley	0.94	0.91	0.96	High pseudoplasticity with moderate gel retention.

Source: Data from Tables 3.5.2–3.5.4 and Figures 3.5.2b–3.5.4c,

4.6 Experimental Observations

During the experiments, foam formation was noticed in 15 g NaOH samples, possibly from air entrainment and gum Arabic protein denaturation. The NaOH addition generated mild heat, and incomplete hydration (“fish eyes”) occurred with xanthan–NaOH mixtures. Some highly viscous systems approached the upper torque limit of the Fann viscometer, potentially affecting accuracy at high shear rates.

4.7 Summary of Key Findings

- Gum Arabic at 50 g concentration produced similar results to 1 g xanthan gum.
- NaOH modification improved viscosity and yield point, especially for blended systems.
- The gum Arabic–cocoyam (7.5 g NaOH) mud achieved the highest PV (65 cP) and YP (180 lb/100 ft^2).
- Gum Arabic–ginger showed stable behavior at moderate pH but degraded at higher alkalinity.

- All systems exhibited pseudoplastic flow ($n < 1$).
- The Herschel–Bulkley model best described the overall rheology.

4.8 General Discussion

The overall results demonstrate that beneficiated gum Arabic and its blends with cocoyam and ginger can effectively serve as biodegradable and sustainable drilling fluid additives. The baseline results confirmed gum Arabic's ability to enhance viscosity and gel strength, matching xanthan gum performance. The addition of NaOH further improved the rheological performance by activating the polymer chains, enhancing molecular interactions, and promoting hydrogen bonding. The gum Arabic–cocoyam (7.5 g NaOH) blend displayed the most desirable performance due to the synergistic effect of alkaline-activated gum Arabic and gelatinized cocoyam starch, resulting in high viscosity, yield strength, and suspension ability.

The gum Arabic–ginger blend showed initial improvement at moderate alkalinity but degraded at higher pH, likely due to partial breakdown of ginger polysaccharides. All muds displayed pseudoplastic behavior thick at low shear and thin at high shear ideal for drilling operations, as this ensures good cuttings transport and efficient pump performance. The rheological model evaluation showed that the Herschel–Bulkley model provided the best overall fit, indicating predictable and controllable flow behavior.

In general, the study confirms that beneficiated gum Arabic-based muds can replace synthetic polymers like xanthan gum in drilling applications, reducing environmental impact while maintaining high performance.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This research investigated the effect of sodium hydroxide (NaOH) on the rheological properties of beneficiated gum Arabic-based drilling fluids blended with natural additives such as cocoyam starch and ginger powder. The aim was to understand how alkaline variation influences the flow behavior, viscosity, yield strength, and gel properties of these environmentally friendly drilling mud formulations.

The results revealed that NaOH concentration plays a significant role in modifying the rheological behavior of the mud systems. Generally, increasing alkalinity improved viscosity and yield point, particularly for the gum Arabic–cocoyam blend. The synergy between gum Arabic and cocoyam under alkaline conditions enhanced molecular interactions and starch gelatinization, resulting in the highest plastic viscosity (65 cP) and yield point (180 lb/100 ft^2). This indicates strong structural stability and excellent cuttings suspension capability.

The gum Arabic–ginger blend also showed improved rheology at moderate pH (around pH 10–11), but at higher NaOH concentrations, degradation occurred, likely due to the breakdown of starch and polysaccharide chains in ginger. Conversely, gum Arabic alone exhibited limited improvement beyond a certain NaOH level, suggesting that its polymer network becomes saturated at high alkalinity.

All the mud formulations displayed pseudoplastic (shear-thinning) behavior, desirable for drilling operations, as it ensures efficient hole cleaning at low shear rates and reduced viscosity at high shear rates, thus minimizing pump pressure losses. Among the rheological models applied, the

Herschel–Bulkley model provided the best fit, indicating that the fluids possess both yield stress and shear-thinning characteristics.

In conclusion, this study confirmed that beneficiated gum Arabic, particularly when blended with cocoyam, can serve as a sustainable and biodegradable alternative to synthetic polymers such as xanthan gum in water-based drilling muds. These natural additives improve drilling fluid performance while promoting environmental sustainability and reducing dependency on non-renewable synthetic materials.

5.2 Recommendation

1. Adoption of Natural Polymer Blends: The gum Arabic–cocoyam blend treated with 7.5 g of NaOH is recommended as an eco-friendly replacement for synthetic viscosifiers in water-based muds due to its superior viscosity and yield strength.

2. Maintain Moderate Alkalinity: NaOH concentration should be controlled within a pH range of 9–11 to prevent polymer degradation while maintaining optimal fluid properties.

3. Field Validation: Further testing is recommended under high temperature and high pressure (HTHP) conditions to evaluate the real-field performance of these natural mud systems.

4. Extended Property Evaluation: Future studies should investigate fluid loss control, shale inhibition, and lubricity to better understand the full operational potential of gum Arabic-based drilling fluids.

5. Exploration of Other Local Biopolymers: Researchers are encouraged to explore other locally available biodegradable materials that could complement gum Arabic and enhance drilling fluid formulation efficiency.

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