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

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CERTIFICATION

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DEDICATION

This project is dedicated to the Almighty God, the giver of life and wisdom, for His grace, strength, and guidance throughout this journey. I also dedicate it to my beloved parents, Rev. Dr. and Mrs. Steve Leon, whose unwavering love, care, and support have been my greatest source of encouragement throughout my undergraduate years.

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All thanks and praise be to God for His divine guidance, provision, and wisdom throughout this project. His grace has been my constant source of strength and inspiration, making this work a reality. My heartfelt gratitude goes to my supervisor, Prof. Oduwa Onaiwu, for his time, guidance, patience, and valuable corrections throughout the course of this research. His unwavering support and encouragement greatly contributed to the success of this work.

I would also like to sincerely appreciate my Head of Department, Engr. Dr. I. Ohenhen, for his consistent support, leadership, and dedication to the growth of students in the Department of Petroleum Engineering.

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ABSTRACT

This project examines how sodium chloride (NaCl) affects the rheological properties of beneficiated gum Arabic-based drilling fluids and their blends with cocoyam starch, ginger extract, and xanthan gum. The aim was to develop an environmentally friendly drilling fluid that remains stable in saline environments. Laboratory tests were conducted using a Fann viscometer to measure key properties such as plastic viscosity, yield point, and gel strength at NaCl concentrations of 7.5 g and 15 g. The results showed that moderate salt levels improved gel strength and yield point, while higher salt concentrations slightly reduced viscosity due to polymer chain tightening. Among all the tested samples, the gum Arabic–ginger and xanthan gum blends performed best, showing strong salt tolerance and stable shear-thinning behavior described by the Herschel–Bulkley model. Overall, the study highlights gum Arabic's potential as a natural, cost-effective, and sustainable alternative to synthetic polymers for drilling operations.

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CHAPTER ONE

INTRODUCTION

1.1 Background Of Study

In oil and gas drilling operations, the stability of drilling fluids especially their ability to carry cuttings and maintain wellbore integrity largely depends on how well they maintain their rheological properties under various environmental conditions. One major challenge is salinity. Monovalent salts such as sodium chloride (NaCl) which are commonly present in formation fluids, can significantly influence the behavior of polymers used in drilling fluids. These salts affect the electrostatic interactions within polymer chains, often changing the way the fluid flows (Okaome & Akintola, 2022).

Gum Arabic and Xanthan Gum

Gum Arabic is a natural polymer that is water soluble and environmentally friendly, however, has low to moderate water solubility capacity. Its performance improves when it is mixed with more powerful rheology-modifying agents, especially xanthan gum. Xanthan gum has a particular value in its pseudoplastic (shear-thinning) nature and its comparative stability to salinity. Nevertheless, salt can lose a portion of its thickening capability when allowed to form in suspensions especially, when the salt concentration is high the zero-shear viscosity of salt reduces as its electrically-charged molecular structure is screened (Moon et al., 2024). An experiment by Bak and Yoo (2025) revealed that addition of NACl to blends of xanthan and gum Arabic can lead to the decrease in intrinsic and apparent viscosities and to viscoelastic behaviour deviation on the solution being either a pure aqueous or emulsion.

Guar Gum

Guar gum constitutes another familiar- natural polymer System that has robust thickening and shear-thinning properties when utilized at low shear rates. It also fares pretty well in salty substance such as seawater. NaCl lowers its intrinsic viscosity to certain extent but it is still more stable than the rest of synthetic polymers at identical conditions (Wang et al., 2015).

Natural Polymer Blends

The study of the rheological behaviour of the blending of gum Arabic with the conventional polymers like xanthan and guar gum shows that such blends usually perform better than gum Arabic alone particularly in the areas of enhanced viscosity and decreased fluid loss. However, the latest attempts of using mixtures such as gum Arabic and cocoyam starch as well as ginger extract are yet to be explored more especially the way they behave in the salts presence. Evidence, that can be summarised in Gil and Yoo (2015), demonstrates that in starch-xanthan mixtures, salt addition may produce a decrease in consistency and yield stress and, at the same time, an increase in elasticity or storage modulus.

However, there remain scanty empirical information on the rheological properties of gum Arabic in combination with cocoyam starch, ginger extract, HPAM (hydrolyzed polyacrylamide) and other biopolymers under salty chemistry like the one present in NaCl solutions. There is thus a need to carry out a systematic study on these mixtures which may result to producing environmentally friendly, salt-tolerant drilling fluids that are effective and economical to apply even in the complicated petroleum conditions.

1.2 Statement Of The Problem

The drilling of a well can be affected by saline formations, especially those which are rich with monovalent salts like NaCl, because these can affect the performance of liquids that are being used to catalyze the drilling of a hole on the ground. Gum Arabic is a natural and environmentally friendly polymer and possess significant fluid loss control properties but is not particularly effective in high salt sub-environments. As might be expected certain additions are also made with synthetic polymers, in particular xanthan gum and HPAM, to maximise performance. However, newer recipes involving newer combinations such as gum Arabic paired with cocoyam starch or ginger extract have largely been disregarded by the related literature. The study of the behaviour of such mutts, and their mutual responses to the influence of saline medium will still be the practically important task in need of a more detailed investigation, in order to approach the systematic development in the occurrence of fluid systems which are able to tolerate the challenges of field practice.

1.3 Aim And Objective

To investigate The influence of monovalent salts (NaCl) on the rheological properties of polymer compositions dealing with Arabic -based Beneficiated gum, designed to be used in drilling fluids.

Objectives:

1. In order to make various samples of drilling fluid by mixing gum Arabic with cocoyam starch, ginger extract, xanthan gum, guar gum, and HPAM.

2. To find out the effect of the addition of varying measures of NaCl on the thickness and flow rate of each fluid.

3. To determine the volume of liquid wasted by every sample as a result of filtration.

4. To determine which one of the galleries family each of the samples belongs to (e.g. Bingham Plastic, Power Law, or Herschel-Bulkley).

5. So as to find out which mixture is more effective in salty environments and safe to the environment.

1.4 Scope Of The Study

The proposed project will test the influence of monovalent salts NaCl on the flow and filtration characteristics in the form of gum Arabic combined with other natural and synthetic polymers as drilling fluids.

The work Involved is:

1. The various polymer blends prepared on gum Arabic, cocoyam starch, ginger extract, xanthan gum, guar gum and HPAM.

2.The experiments on rheological behavior (such as viscosity and gel strength) to varying salt concentrations.

3. Determining the flow model that every single fluid adheres to (Bingham Plastic, Power Law, Herschel-Bulkley, etc.).

CHAPTER TWO

LITERATURE REVIEW

2.1 Drilling Fluid Rheology

Drilling fluid rheology, the behavior of drilling fluids under varied states of flow and deformation, specifically exposed to applied shear stress, can be studied as a field of drilling fluid rheology. Rheology is a critical figure of merit of any drilling fluid system since it has a direct impact on how it transports, cleans the hole, suspends the cuttings, pumps, and manages the pressure during the drilling process.

The nature of drilling fluids is that they are non-Newtonian, i.e. their viscosity does not remain constant but is proportional to that of a shear rate. Contrary to Newtonian fluids (i.e. water or oil), drilling fluids display shear-thinning characteristic, meaning that viscosity reduces with increase in shear rate. This feature is very useful: a fluid can be thin when it passes through the narrow drill pipe sections and thickening so that it suspends solids when the pumps turn off (Caenn et al., 2017).

2.1.1 Drilling Fluids Rheological Models

The drilling fluids are normally non-Newtonian i.e. their viscosity varies with their shear rate as opposed to Newtonian fluids (e.g. water) which do not vary in viscosity with shear rate. A number of rheological models have been generated in order to predict and manage the manner in which drilling fluids act in various flow circumstances. Such models enable the engineers to design fluid to suit the particular conditions of different drilling.

1. Bingham Plastic model

One of the most basic and the most used models in drilling engineering is the Bingham Plastic model. It presupposes the fluid to be nearly similar to solid until the particular yield point (initial shear stress) is reached. At this state, the fluid contains a sustained plastic viscosity (PV).

Bingham model:

$\tau=\tau y+\mu p\gamma$

Where:

- τ = Shear stress (Pa)
- τy = Yield point (Pa)
- μp = Plastic viscosity (Pa·s)
- γ = Shear rate (s^{-1})

This model is common, as it gives an acceptable approximation of the behaviour of numerous water-based drilling fluids at medium shear rates. It is especially useful in measuring hole cleaning capability, dragging of cuttings under laminar conditions.

2. Power Law Model (Ostwald-de Waele Model)

A second model, which is more general and adheres to the shear-thinning behavior which is a major property of most drilling fluids, is the so-called Power Law model. This model is characterized by the fluid having no yield stress and viscosity, which reduces as the shear rate rises.

The equation constitutes:

τ=Kγn

Where:

- K = Consistency index ($Pa \cdot s^n$)
- n = Flow behavior index
- τ = Shear stress
- γ = Shear rate

If n<1 n is less than 1, then fluid is shear-thinning (pseudo-plastic);

the liquid is shear thickening (dilatant). The advantage of this model is that it is especially applicable in high shear cases such as those experienced at the bit or within the drill pipe (Al-Shajalee et al., 2020).

3. Herschel–Bulkley Model

The Bingham, Power Law, and the HerschelBulkley models are just extensions of each other. It also includes a yield point as in the case of the Bingham model, and also a flow behavior-like that of the Power Law model. This is more precise when modeling complex fluids particularly in high-performance drilling fluids or in a polymer-enriched drilling mud.

τ=τy+Kγn

This model is more difficult to apply manually due to the need for non-linear regression, but it is preferred in laboratory and simulation studies where precision is essential (Alkinani & Ahmed, 2019).

2.1.2 Key Rheological Parameters of Drilling Fluids

Rheological control of drilling fluids is essential in optimization of wellbore hydraulics, cuttings removal and management of pressure in the formation. The rheological parameters are the following:

1.Plastic Viscosity (Pv)

The viscosity of the drilling mud is normally expressed in terms of plastic viscosity and refers to the opposition to flow as a result of inside friction between the solid material (e.g., barite, cuttings), as well as the liquid component of the drilling mud. It is determined as the difference between 600 and 300 RPM value given by the viscometer:

$PV = \theta600 - \theta300$

Where $\theta600$ and $\theta300$ are dial readings at respective RPMs

A low PV indicates a low solid content and good pumpability, while a high PV may suggest **solids accumulation**, poor hydraulics, or excessive clay swelling (Caenn et al., 2017).

2. Yield Point (YP)

Yield point is the **initial stress required to initiate flow**. It reflects the electrical or attractive forces between particles in suspension The yield point that is lower than necessary may cause cuttings of barite settling, and an excessive yield point enhances the pump pressure as well as energy expenses.

$YP = \theta 300 - PV$

3. Gel Strength

Gel strength Gel strength is the capacity of the fluid to suspend particles when there is no circulation happening. It is a consequence of thixotropic nature of the mud. Through a viscometer, the strength of gels is determined at 10 seconds and 10 minutes following the static status.

The cuttings settlement might occur during connection times due to low gel strength. Unreasonably tight gel strength results in surge and swab pressures which can cause formation damages or instabilities in the wellbore.

Typical values:

Gel gels 10-sec: Original suspension

10-min gel: Suspension capacity in the long-term

Importance of Rheological Control

Once these parameters are well managed, they will ensure the performance of the drilling fluid under the dynamic (circulating) and the static (non-circulating) conditions. Alternations in rheology e.g. excessive viscosity or weak gel strength may result in extensive operations problems such as:

1. Poor cleaning of hole, which caused the problem of stuck pipe.

2. Fracturing of formation under high values of equivalent circulating density (ECD).
3. Lost circulation particularly in depleted or fractured areas.
4. The condition of the bore didn t provide good results in the logging.

It is even more important to design and follow rheological behavior carefully in case of using natural polymers like gum Arabic and its combinations, possibly sluggish to pH, temperature and ionic strength. Adjusting these fluids to ensure PV, YP and gel strength are correct is the key to their success during drilling activities (Orodu et al., 2020; Ayeni et al., 2019).

2.2 ROLE OF NATURAL POLYMERS IN DRILLING FLUIDS

The idea of using natural polymers (biopolymers) as drilling fluid has gained popularity in recent years, because of environmental laws, sustainability objectives, and the expense of synthetic adjuvants. Natural polymers are biodegradable, non-toxic, locally accessible and can be altered to enhance particular liquid qualities e.g. viscosity, filtration management and temperature resistance.

Gum Arabic is a natural polymer exudate obtained in the trees, Acacia Senegal and is one of the most promising natural polymers in drilling fluid technology. It is a heteropoly saccharide water-soluble and has been used due to its great emulsifying, thickening, and stabilizing properties. Purified gum Arabic is used, or better known as beneficiated gum Arabic, which has rheological and filtration control properties that are better than regular gum Arabic, and thus it can be used as a base or an additive in water-based mud systems (Orodu et al., 2020).

Other natural polymers which can be used along with gum Arabic are:

- **Xanthan Gum**: A microbial polysaccharide with high viscosity and thermal stability.

- **Guar Gum**: A galactomannan extracted from guar beans, effective as a viscosifier.
- **Cocoyam Starch**: A carbohydrate-based thickener with film-forming properties.
- **Ginger Extract**: Contains bioactive compounds with anti-microbial and stabilizing effects.
- **HPAM (Hydrolyzed Polyacrylamide)**: A partially synthetic polymer that, when combined with natural polymers, improves shear resistance and fluid loss control.

Natural polymers are very sensitive to solutions of ionic strength (e.g. NaCl, KCl) and pH. As another example, addition of monovalent salts may change the electrostatic interactions within the polymer network thus influencing the viscosity, yield point and gel strength of the fluid. This has the potential to be beneficial when optimized successfully but needs an optimized approach in the case of salt rich target environments such as a shale reservoir or an offshore well.

Abdulkadir et al. (2021) observed that a combination of gum Arabic and HPAM or xanthan gum have stable rheological behavior when the salt concentration varies. On the same note, Ayeni et al. (2019) emphasized that the natural polymer-based fluids are pH adjusted. significantly influenced their rheological behavior, making them more adaptable for field applications.

2.2.1 Monovalent salt Effects on Rheology

Addition of salts (monovalent e.g. NaCl) may improve and worsen the rheological behavior of polymer-based drilling fluids. Al-Shajalee et al. (2020) say NaCl changes the electrostatic conditions of the fluid system: it compresses the electrical double layer of clay particles or polymer particles, which weakens their repelling property and changes the dispersion of particles.

NaCl can minimize viscosity in a system with natural polymers, perhaps through contraction of the polymer chains (the salt screening effect), however, it can also enhance thermal stability and facilitation of cutting transport under certain conditions. KCl and NaCl have also been found to reduce clay degrading, swelling and dispersion processes which is also important in reactive shale rich formations.

Research on the topic conducted by Orodu et al. (2020) and Ayeni et al. (2019) has revealed that an increase in salt concentration influences the intermolecular forces between biopolymer chains and a water-based solution, resulting in the changes in rheological parameters that can be measured. At concentrations below saturation salts can act to stabilise the polymer network whereas at higher concentrations they can cause flocculation or reduction of viscosity

2.3. Polymer Formulations Investigated in Literature

Several combinations of gum Arabic with other additives have been studied for rheological performance under saline condition.

Formulation	Description	Effect of Salt
Gum Arabic–Cocoyam	Starch-rich blend	May experience retrogradation or decreased viscosity in NaCl
Gum Arabic–Ginger	Antioxidant-rich	May improve microbial stability, rheological effect under salt not fully studied
Gum Arabic–Xanthan Gum	Synergistic viscosity modifier	Enhanced rheology even in saline environments
Gum Arabic–Guar Gum	High-viscosity thickener	Salt-sensitive but synergistic effect possible
Gum Arabic–HPAM	Synthetic-natural hybrid	High salt resistance and shear thinning behavior

Abdulkadir et al. (2021) found that gum Arabic–HPAM blends maintained better rheological integrity under varying NaCl concentrations compared to gum Arabic alone. Similarly, **Orodu et al. (2020)** reported that the gum Arabic–xanthan gum combination offered enhanced shear-thinning behavior and improved salt tolerance.

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CHAPTER THREE

RESEARCH METHODOLOGY

3.0 Monovalent Salts Effect

This chapter outlines the procedures adopted in determining the effect of monovalent salts (NaCl) on the rheological properties of beneficiated gum Arabic polymer formulations. The formulations investigated include gum Arabic cocoyam, gum Arabic ginger, and gum Arabic xanthan gum blends. The chapter describes the equipment and materials used, experimental procedures for sample preparation, testing methods for rheological properties, and the calculations employed in analyzing the results.

3.1 Equipment And Raw Material

3.1.1 Equipment Used

The following equipment were used during the experiment:

- Electronic weighing balance (Scout-Pro)
- Measuring cylinder
- Mud mixing cup
- Spatula
- Viscometer (Fann type)
- Mud balance
- Hamilton Beach mud mixer

3.1.2 Scout Pro Weighing Balance

The weighing balance is a compact, reliable, and versatile instrument commonly used for quick and accurate measurements in laboratories, classrooms, fieldwork, and industries. It is designed to ensure precision, durability, and portability. The balance can measure in various units such as grams (g), milligrams (mg), ounces (oz), carats (ct), and pounds (lb). Balances may be digital; however, the model used in this experiment was digital model balance.

3.1.2 Measuring Cylinder

A measuring cylinder is a laboratory equipment that is used to precisely measure the volume of the liquids. It gives accurate values needed in the preparation of fluids used in the experiment.

3.1.3 Mud Mixing Cup

Mixing of mud samples is carried out in the mud mixing cup whereby the liquid and solid components are kept. It guarantees the homogeneous mixing of substances to create a homogeneous mud system.

3.1.4 Spatula

Transferring and mixing solid sample composite formulation was done using a spatula when preparing the formulations that included bentonite, gum Arabic, cocoyam, and ginger powders.

3.1.5 Viscometer

A Fann viscometer was used to determine the rheological properties (viscosity and gel strength) of the mud samples at rotational speeds of 600, 300, 200, and 100 rpm.

3.1.6 Hamilton Beach Mud Mixer

3.1.7 Major Materials Used

- Cocoyam
- Ginger
- Bentonite
- Gum Arabic
- Xanthan Gum
- Sodium chloride (NaCl)
- Distilled water

The Arabic cocoyam and Ginger were dried using sunlight as a source of energy and weighted regularly using the electronic weighing balance until a constant weight was attained, indicating that both had dried properly.

Ginger Drying Result

Days	Weight
1	189g
2	164g
3	168g
4	157g
5	157g
5	157g
7	157g

The dried cocoyam and ginger were grinded to powder and then sieved.

3.2 Experimental Procedure

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 monovalent salts (NaCl) on the best-performing mud systems from the first stage.

3.2.1 Experimental Procedure for The Preparation of The Mud System

1. Measure 500 ml of water using a measuring cylinder.
2. Pour the water into a mixing cup.
3. Weigh 30 g of bentonite using the electronic balance.
4. Gradually add the bentonite to the water while stirring for 3 minutes at medium speed.
5. Divide the mixture into two portions:

   - Portion A for viscosity and gel strength measurements using the viscometer at 600, 300, 200, and 100 rpm.
   - Portion B for density measurement using the mud balance.

Table 3.2.1: Rheological Properties of Bentonite–Water Base Mud

3.2.2 Procedure for The Determination of The Effect of Xanthan Gum on The Mud System

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 3.2.2: Rheological Properties of Gum Arabic–Xanthan Gum Mud System

3.2.3 Procedure for the Determination of The Effect Of 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 3.2.3

3.2.4 Procedure for The Determination of The Effect of Gum Arabic And Cocoyam (50/50)

1. Measure 500 ml of water and pour into the mixing cup.
2. Add 30 g of bentonite and stir for 3 minutes at medium speed.
3. Weigh 37.5 g of gum Arabic and 12.5 g of cocoyam.
4. Add both materials into the mixture and stir for another 3 minutes.
5. Measure viscosity, gel strength, and density using the viscometer and mud balance.

Table 3.2.4: Rheological Properties of Gum Arabic–Cocoyam Mud System

3.2.5 Procedure for The Determination of The Effect Of 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 3.2.5: Rheological Properties of Gum Arabic–Ginger Mud System

3.3 Effect of Sodium Chloride (NACL) On Mud System

The best-performing mud systems from the first stage were used to study the effect of sodium chloride (NaCl) on their rheological properties

3.3.1: Procedure for Determination of The Effect Of Monovalent Salt (NACL) On Xanthan Gum Mud System

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. Add 1 g of xanthan gum and stir for another 3 minutes.

4. Introduce 7.5 g of NaCl and mix for 3 minutes at high speed.
5. Take viscometer readings at 600, 300, 200, and 100 rpm.
6. Repeat the test using 15 g of NaCl.
7. Measure and record viscosity, gel strength, and density.

Table 3.3.1: Effect of NaCl on Gum Arabic–Xanthan Gum Mud System

3.3.2: Procedure for The Determination Of The Effect Of Monovalent Salt (NACL) On 50 Grams Gum Arabic Mud System

1. Measure 30g of bentonite and 500ml of water and mix for 3 minutes at medium speed.

2. Add 50 gram of Gum Arabic to the mixture and mix for 3 minutes

3. Then add 7.5g of NACL to the mixture and mix for another 3 minutes at high speed and 2 minutes on low speed and transfer the viscometer to record the RPM and Gel strength

5. Repeat the procedure for 15g of NACL

After adding the 15.0 gram of NACL we increased the speed of the mixer to high speed.

Table 3.3.2: Effect of NaCl on Gum Arabic

3.3.3: Procedure for The Determination of The Effect Of Monovalent Salt (NACL) On 50 Grams Gum Arabic Mud System

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. Add 25 g of gum Arabic and 25 g of cocoyam to the mixture.
4. Introduce 7.5 g of NaCl and stir at high speed for 3 minutes.

5. Take viscometer readings at 600, 300, 200, and 100 rpm.

6. Repeat the procedure using 15 g of NaCl.

7. Record viscosity, gel strength, and density.

Table 3.3.3: Effect of NaCl on Gum Arabic–Cocoyam Mud System

3.3.4: Procedure for The Determination of The Effect of Monovalent Salt (Nacl) On 25 Grams of Gum Arabic and 25 Grams of Ginger Mud System

1. Measure 500 ml of water and pour into the mixing cup.

2. Add 30 g of bentonite and stir for 3 minutes.

3. Add 25 g each of gum Arabic and ginger to the mixture.

4. Introduce 7.5 g of NaCl and stir for 3 minutes at high speed.

5. Measure viscosity, gel strength, and density.

6. Repeat the test using 15 g of NaCl.

Table 3.3.4: Effect of NaCl on Gum Arabic–Ginger Mud System

3.4 DETERMINATION OF RHEOLOGICAL PROPERTIES

3.4.1 Viscosity Measurement

The Fann viscometer is a laboratory instrument used for determining the viscosity of drilling muds and other fluid systems, a sample of mud was poured in to the rheometer beaker and the beaker was then raised up with the aid of a plate-like base on the viscometer until the rotor sleeve is immersed in the mud at the scribed line and held in position by tightening the lock screw on the right leg of the instrument. The gear was switched on to a speed of 600rpm, 300rpm, 200rpm and 100rpm respectively, the calibrated viscometer reading was allowed to stabilize and the reading was taken and recorded.

3.4.2 Density Measurement

The following steps were taken to determine the mud weight:

1. The lid was removed from the cup, and the cup was completely filled with the mud to be tested.
2. The lid was replaced and rotated until firmly seated, making sure some mud is expelled through the hole in the cup.
3. The outside of the cup was cleaned with tissue paper to remove the mud on the outside of the cup.
4. The balance arm was placed on the base, with the knife-edge resting on the fulcrum.
5. The rider was moved until the graduated arm level, as indicated by the level vial on the beam.
6. The mud weight was read at the left-hand edge of the rider and its value was recorded.
7. The above procedure was repeated for each addition of the processed peels to the mud and the corresponding values of the mud weight were recorded down.

3.5 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,** $\tau = 1.067 *$ dial reading ($lbf/100ft^2$)

7. **Shear rate, γ** $= 1.703 *$ rpm (sec^{-1})

8. **Bingham Plastic Model**

   $\tau = PV * \gamma + YP$

9. **Power Law Model**

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

10. **Hershely Buckley Model**

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

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

3.6 Precautions

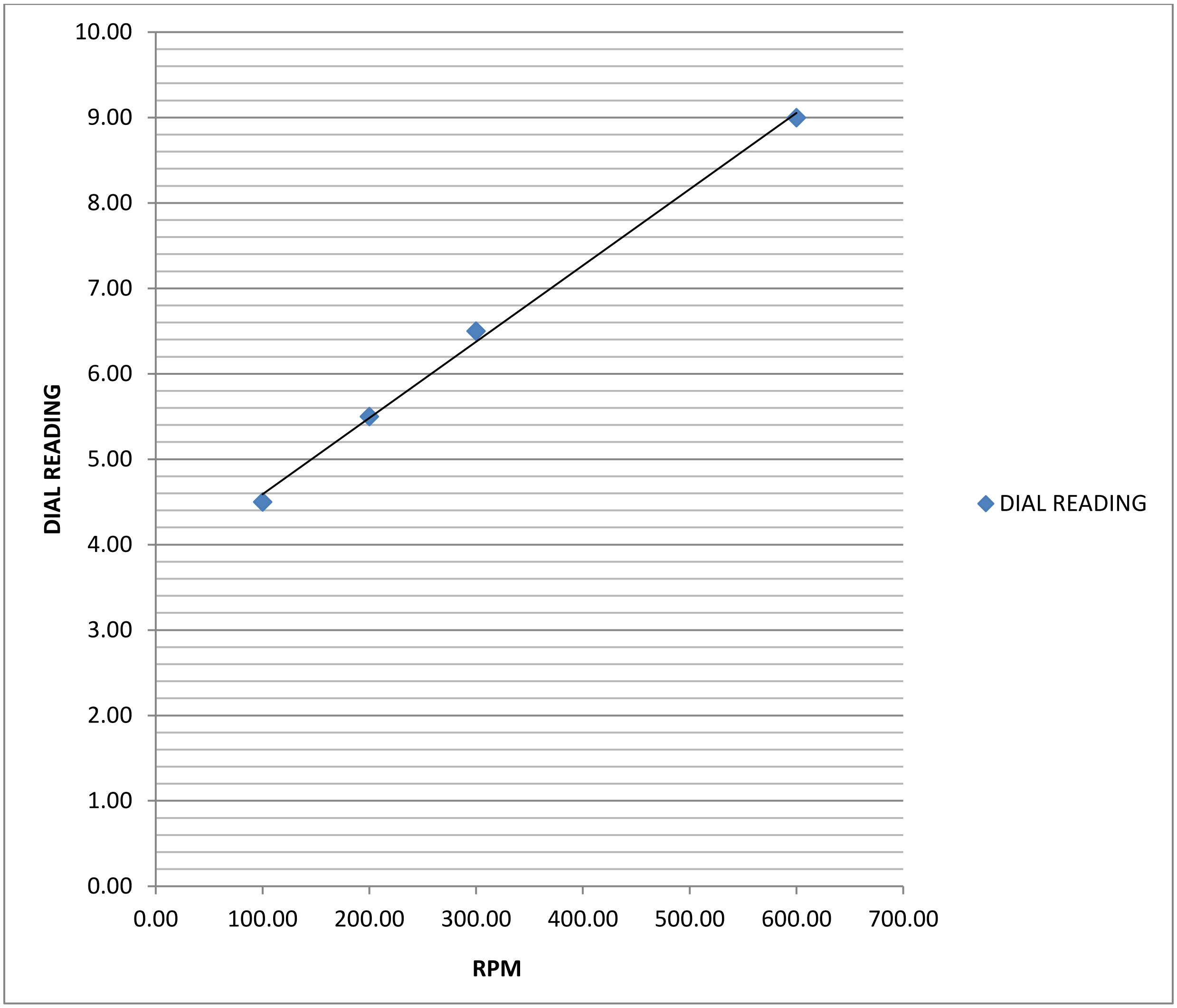
1. During the test for viscosity, it was ensured that the pointer settled on the scale before the reading was taken.
2. During the test for mud weight, it was ensured that the mud balance came to rest and built-in spirit level was at the middle of the scribed mark
3. It was ensured that the weight balance 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:

1: Table 3.2.1: Result of Bentonite and Water (Spud Mud)

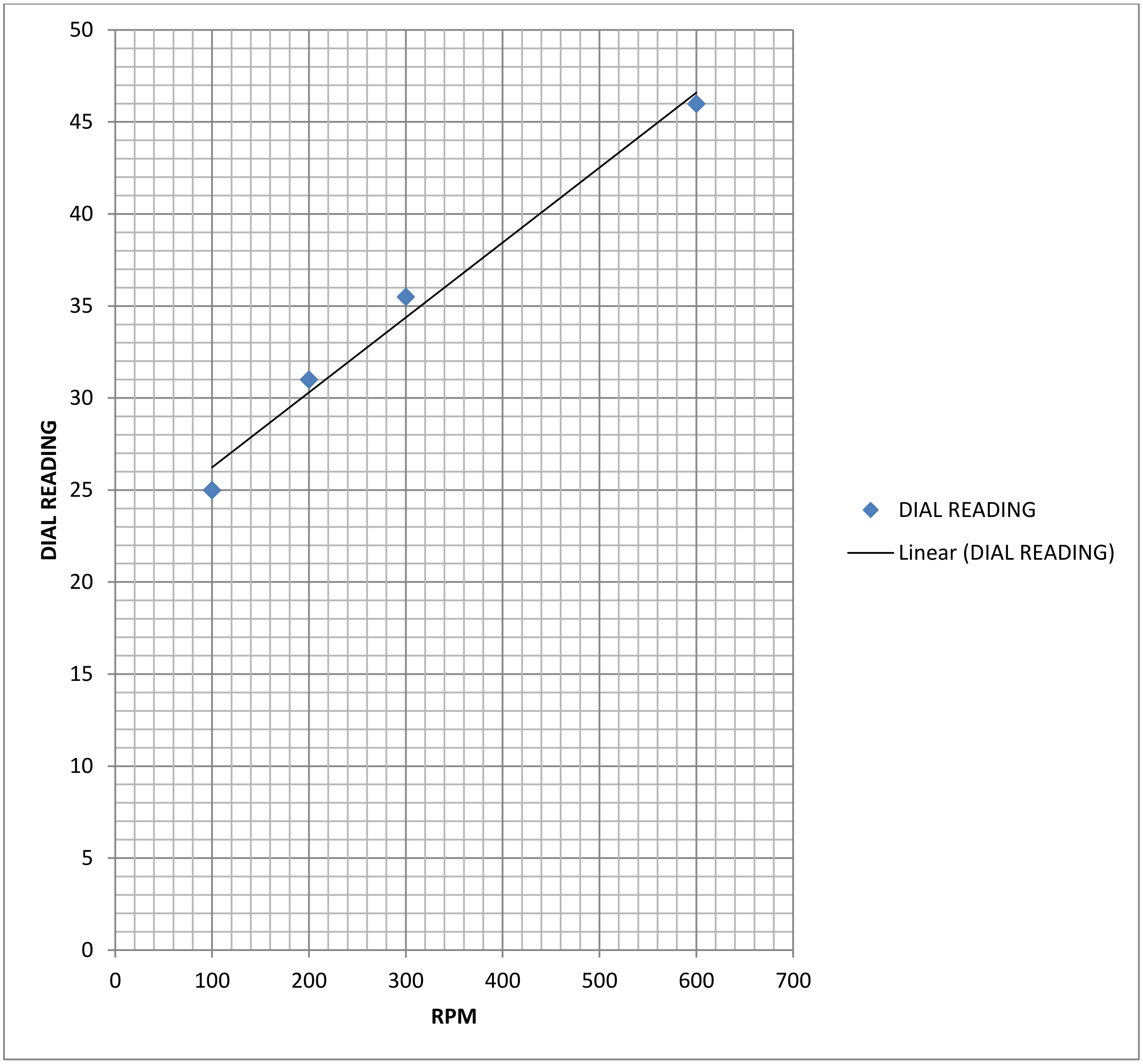
RPM	**DIAL READING**
600	9.0
300	6.5
200	5.5
100	4.5
Gel strength	
10 SECONDS	5.5
10 MINUTES	7
PV	2.5
YP	4.0
DENSITY	8.6g/cc



1: Fig 3.1.1 Plot of Dial reading versus RPM on bentonite and water (spud mud)

2:Table 3.2.2: Result of Mud With 1g Of Xanthan Gum

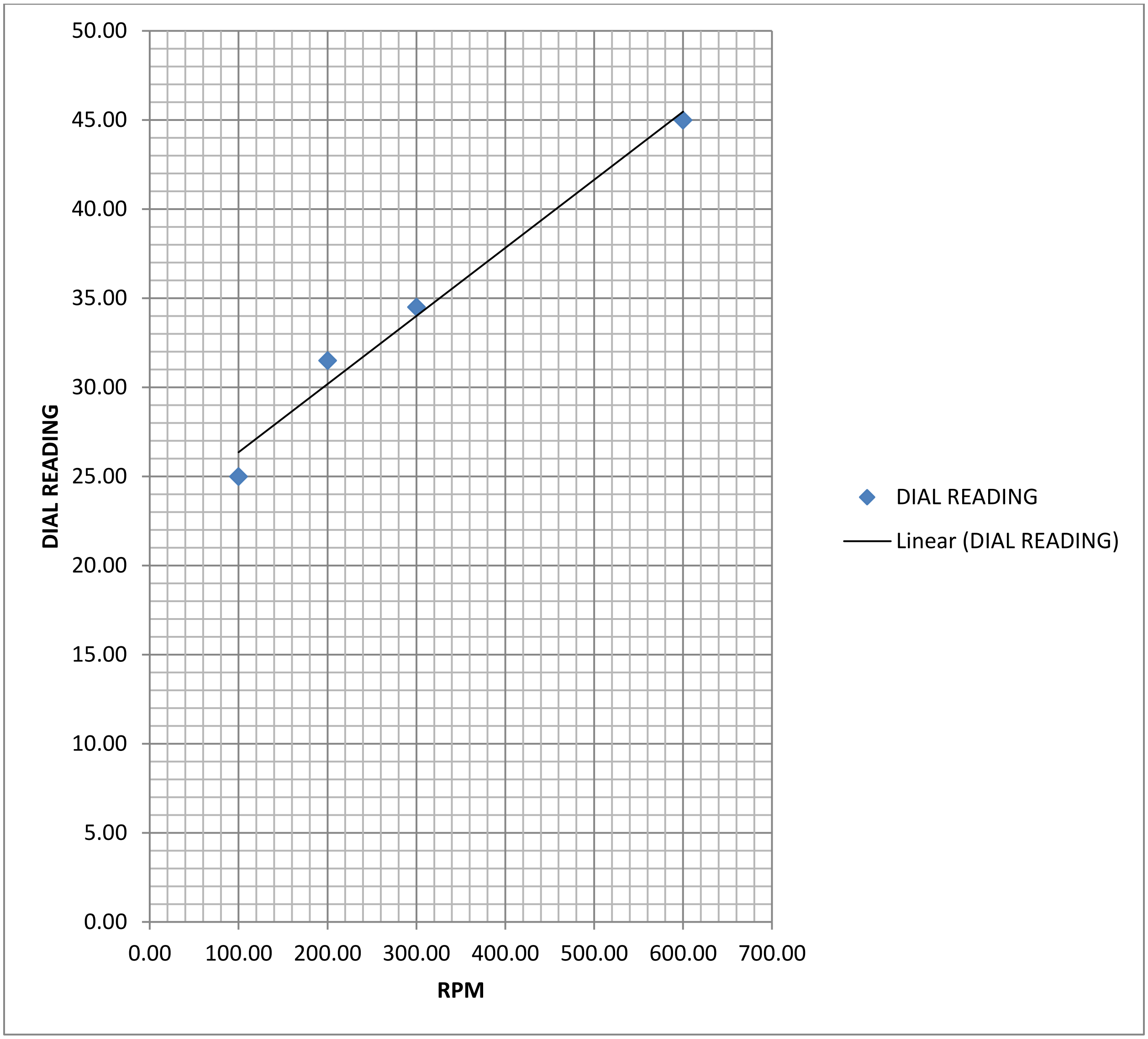
RPM	DIAL READING
600	46.0
300	35.5
200	31.0
100	25.0
Gel strength	
10 SECONDS	25.0
10 MINUTES	29.0
PV	10.5
YP	25.0
DENSITY	8.7g/cc



2: Fig 3.2.2 Plot of Dial reading versus RPM on 1g of Xanthan Gum mud system

3: Table 3.2.3: Result of Mud With 50g Of Gum Arabic

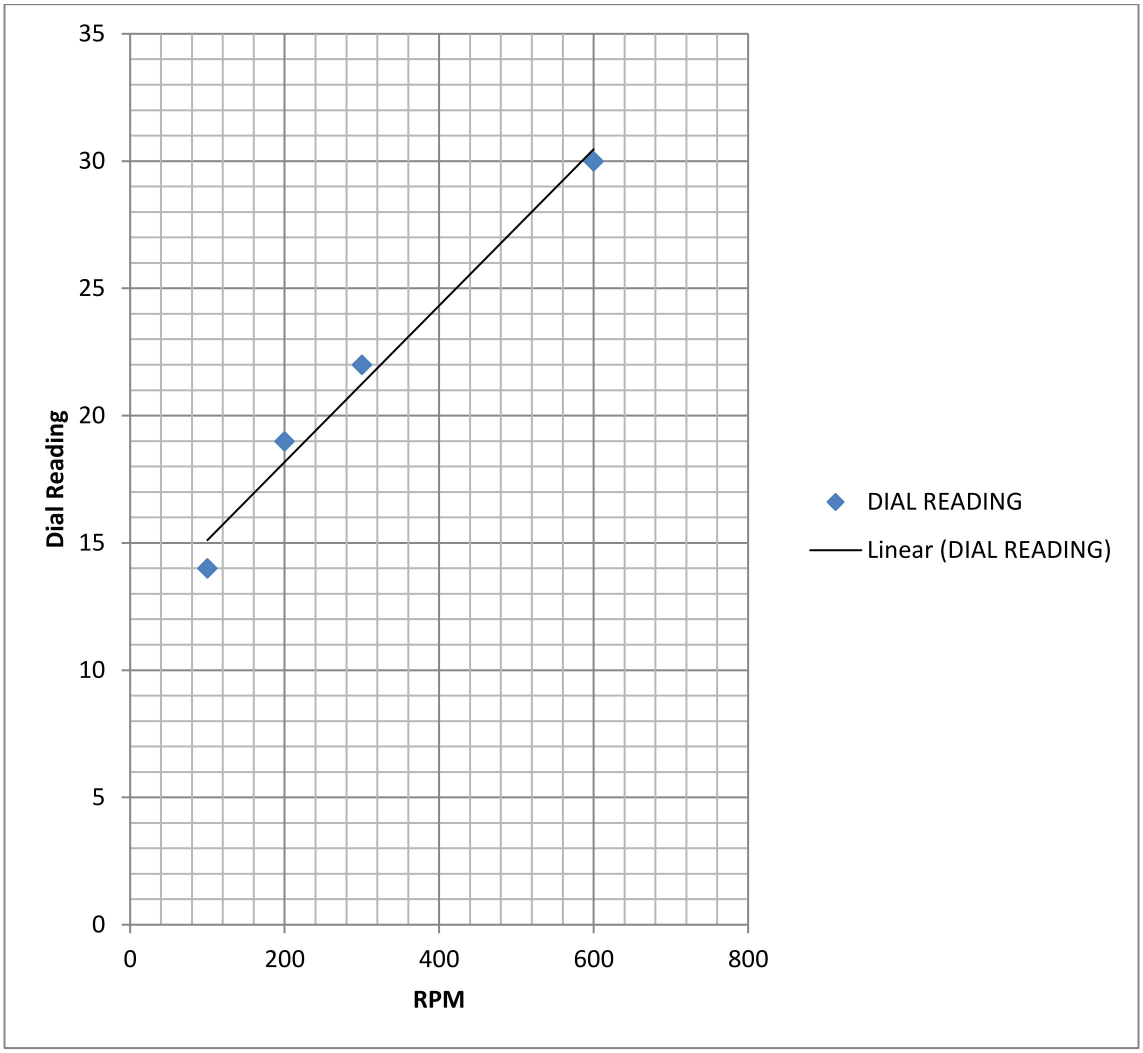
RPM	DIAL READING
600	45.0
300	34.5
200	31.5
100	25.0
Gel strength	
10 SECONDS	28.0
10 MINUTES	30.0
PV	10.5
YP	24.0
DENSITY	8.6g/cc



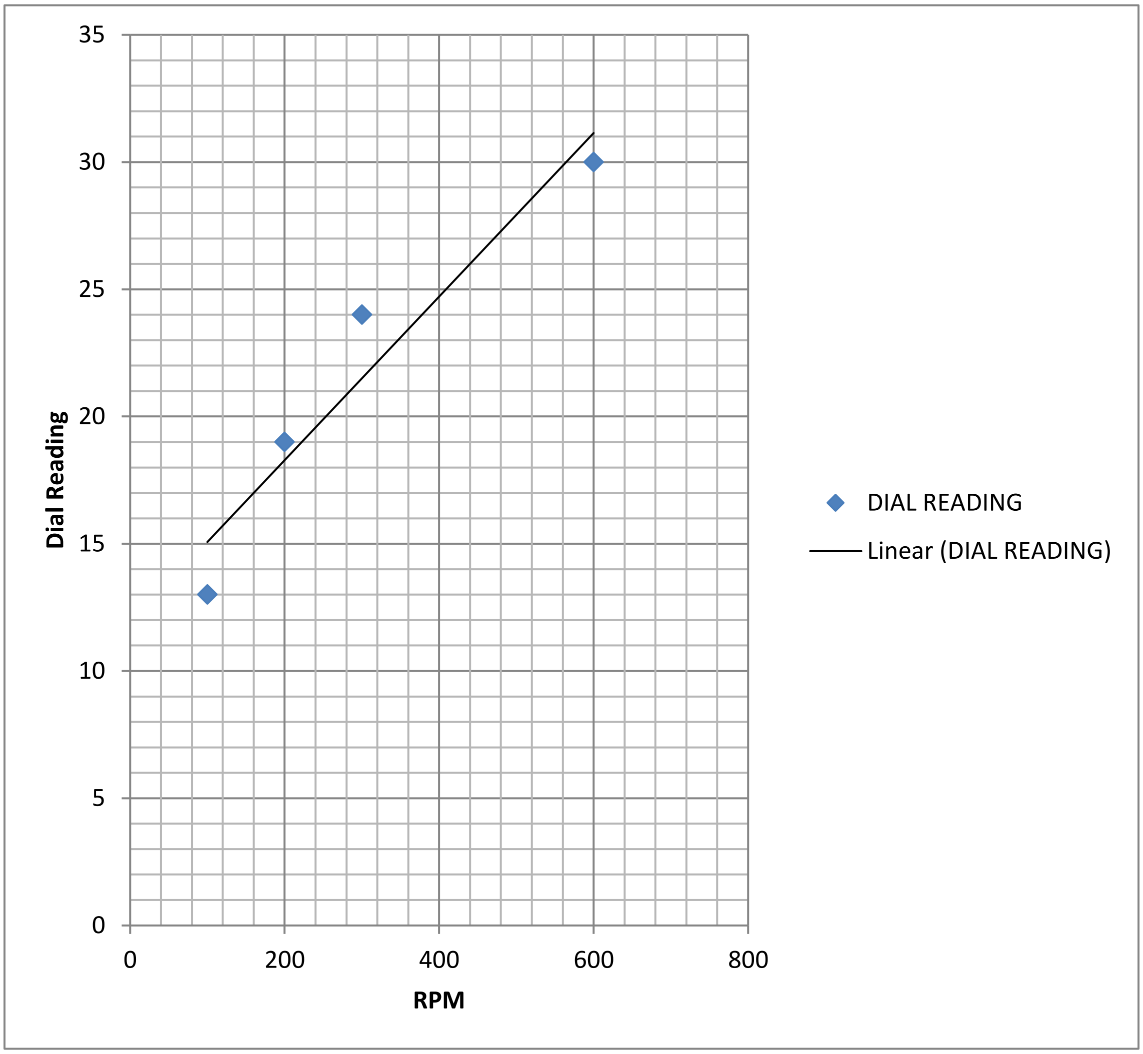
3.Fig 3.2.3 Plot of Dial reading versus RPM on 50g of Gum Arabic mud system

4: Table 3.2.4: 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 Strength		
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



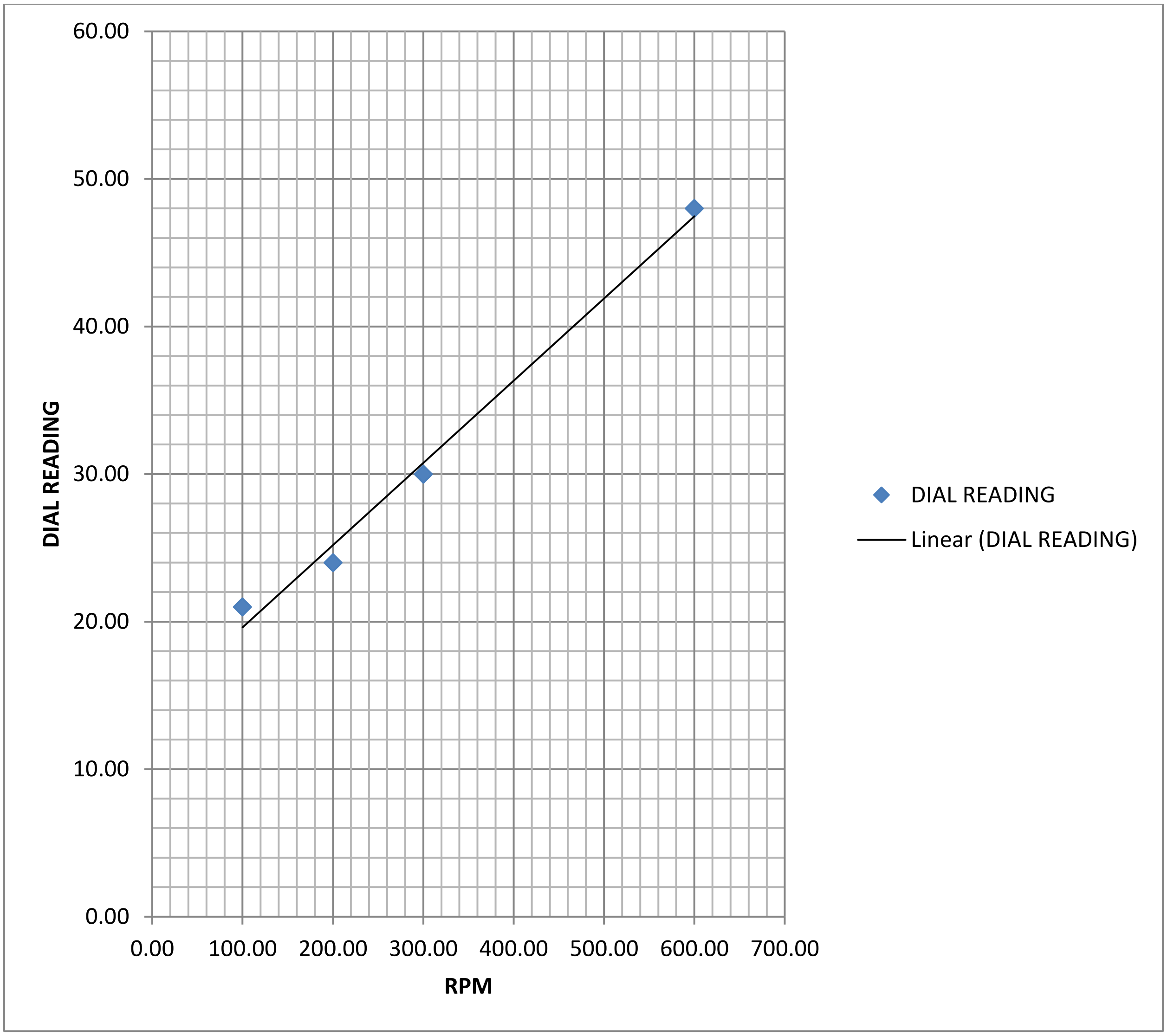
5. *Fig 3.4.1 Plot of Dial reading versus RPM on 25g of gum Arabic + 25g of cocoyam*



6. Fig 3.4.1.b Plot of Dial reading versus RPM on 37.5g of gum Arabic + 12.5g of cocoyam

7:Table 3.2.5: 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 Strength		
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



4:Fig 3.5.1 Plot of Dial reading versus RPM on 25g of Gum Arabic + 25g of Ginger and 37.5g of Gum Arabic + 12.5g of Ginger and

Taking out the experimental samples which gave the best reading in experiment one, will lead to experiment two of which the effect of salt on each of the best samples will be tested.

5:3.3: Effect of Salt On 1 Gram Xanthan Gum and Mud System

RPM	7.5g of NACL	15g of NACL
600	36.9	40.5
300	24.9	28
200	20	24
100	15.5	19
Gel Strength		
10 SECONDS	45	39
10 MINUTES	60	50
PV	12	12.5
YP	12.9	15.5
N	0.56	0.51
K	0.76	0.99

MODEL DATA TO DETERMINE THE EFFECT OF 7.5G OF NACL ON THE RHEOLOGICAL PROPERTIES OF 1G OF XANTHAN GUM

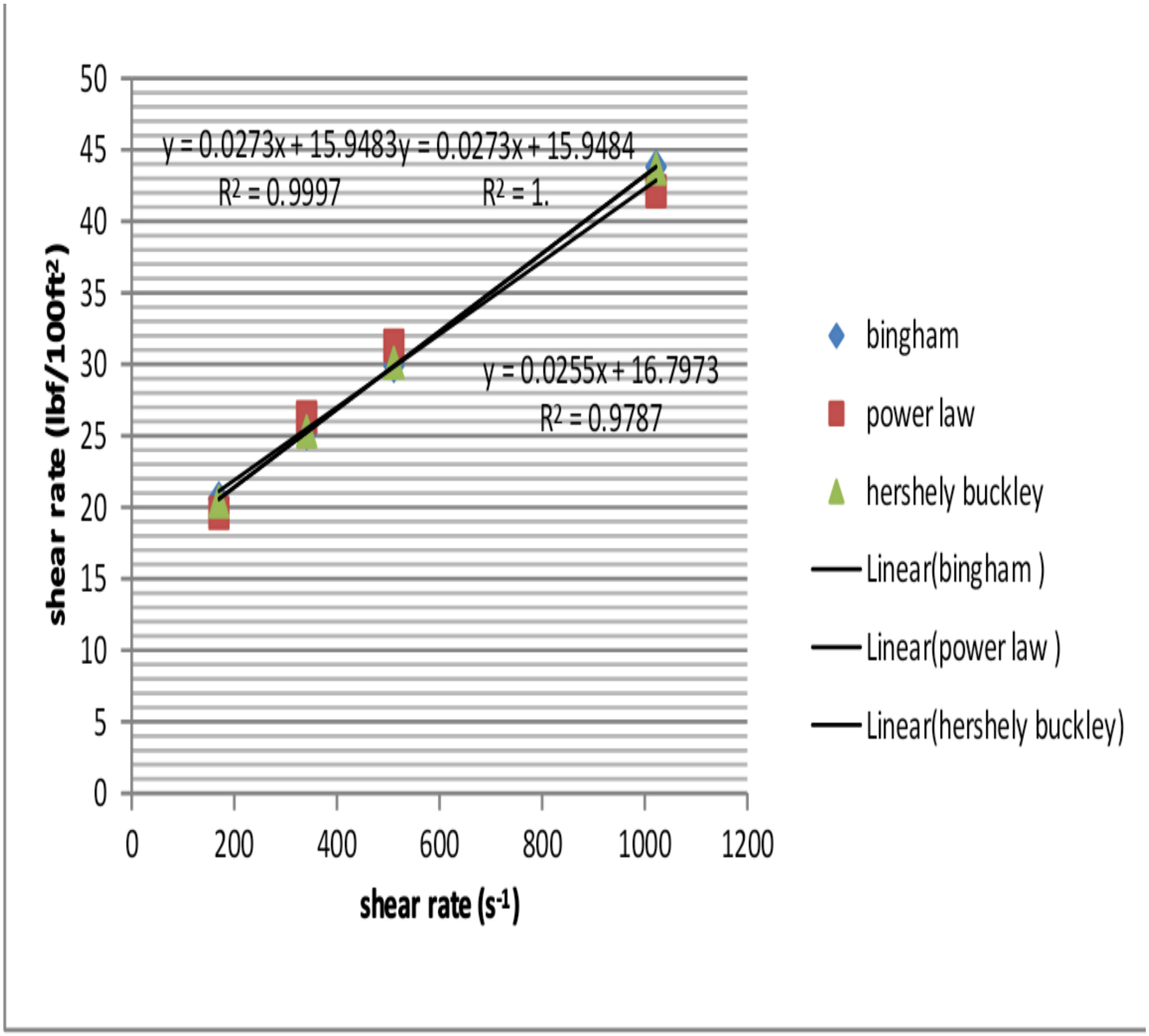
8:TABLE 3.2.2b

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	39.5	39.7	38.3	39.5
511	26.7	26.0	27.3	26.4
341	21.3	21.4	22.4	21.6
170	16.5	16.9	15.9	16.4

MODEL DATA TO DETERMINE THE EFFECT OF 15G OF NACL ON THE RHEOLOGICAL PROPERTIES OF 1G OF XANTHAN GUM

9:TABLE 3.1.2c

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	43.7	43.8	42.1	43.7
511	29.9	29.9	31.3	30.1
341	25.6	25.2	26.3	25.3
170	20.3	20.6	19.6	20.4



10:*Fig 3.1.2b Plot of Shear stress versus shear rate of the effect of 7.5g of NACl on 1g of xanthan gum mud system*

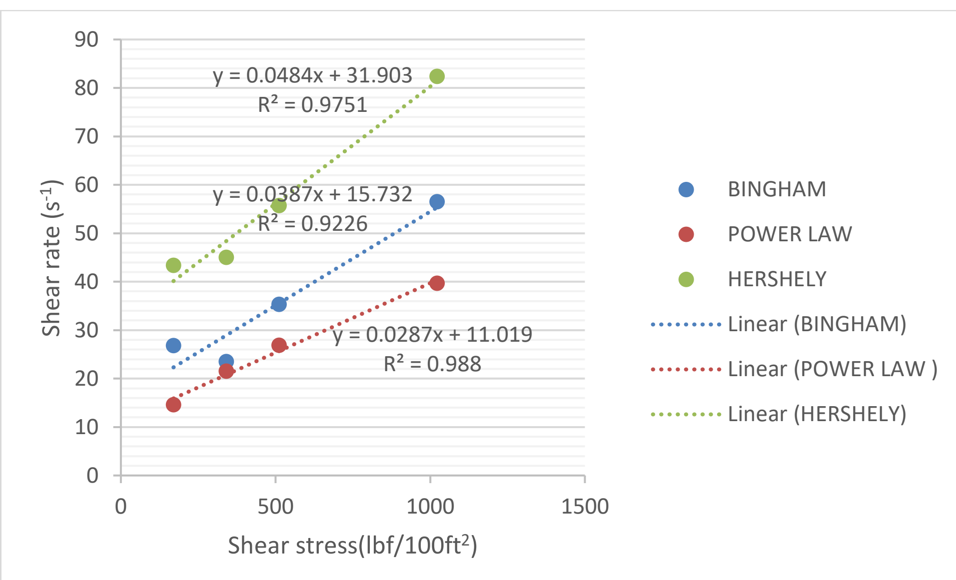
11:3.3.1: Effect of Salt On 50 Grams Gum Arabic Mud System

RPM	7.5g of NaCL	15g of NaCL
600	35	33.5
300	22.5	23
200	19	18.5
100	13	13
Gel Strength		
10 SECONDS	21	18
10 MINUTES	25.0	25.0
PV	12.5	10.5
YP	10.3	12.5
N	0.64	0.54
K	0.41	0.79
DENSITY	8.3g/cc	8.0g/cc

MODEL DATA TO DETERMINE THE EFFECT OF 7.5G OF NACL ON THE RHEOLOGICAL PROPERTIES OF 50G OF GUM ARABIC

12:TABLE 3.2.2b

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	37.3	54	34.5	71.8
511	24	34	22.2	46.2
341	20.3	28	17.1	37.4
170	13.9	15	10.9	24.8

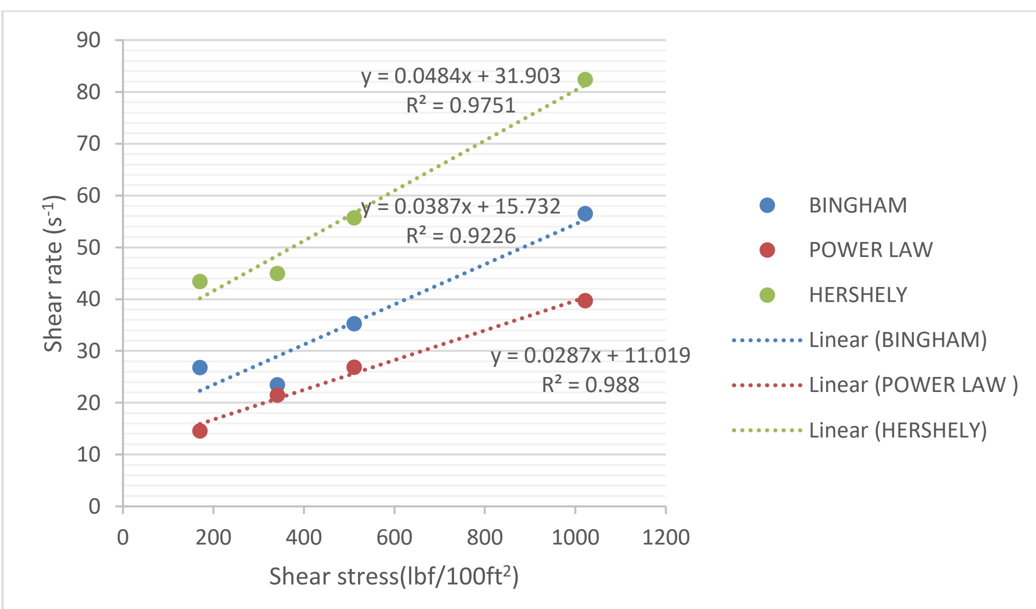


6:Fig 3.2.2b Plot of Shear stress versus shear rate of the effect of 7.5g of NaCl on 50g of Gum Arabic mud system

MODEL DATA TO DETERMINE THE EFFECT OF 15G OF NACL ON THE RHEOLOGICAL PROPERTIES OF 50 G OF GUM ARABIC

13:TABLE 3.2.2c

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	35.7	45	33.3	69
511	24.5	38.5	22.9	47.4
341	19.7	26	18.4	38.1
170	13.9	23.5	12.6	26.5



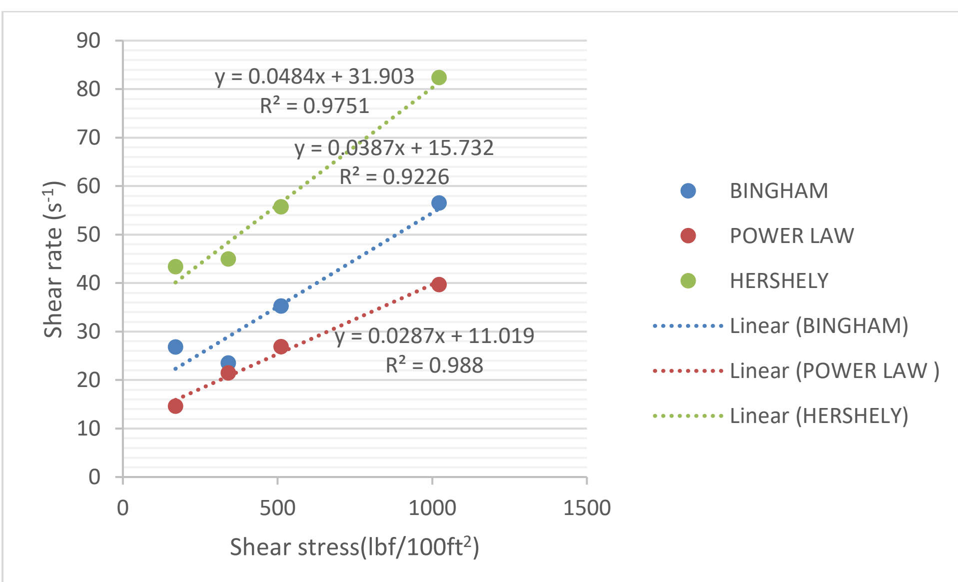
14:3.3.2: Effect of Salt On 25 Grams of Gum Arabic and 25 Grams Of Cocoyam Mud System

RPM	7.5g of NACL	15g of NACL
600	37	41
300	25	28
200	20	24
100	15.5	19
Gel Strength		
10 SECONDS	25	25
10 MINUTES	25	32
PV	12	13
YP	13	15
N	0.57	0.55
K	0.71	0.90
DENSITY	8.3	8.4

MODEL DATA TO DETERMINE THE EFFECT OF 7.5G OF NACL ON THE RHEOLOGICAL PROPERTIES OF 25G OF GUM ARABIC + 25G OF COCOYAM

TABLE 3.3.2b

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	39.5	48.5	36.9	76.4
511	26.7	26	24.8	51.5
341	21.3	34	19.7	41
170	16.5	26	13.2	29.7

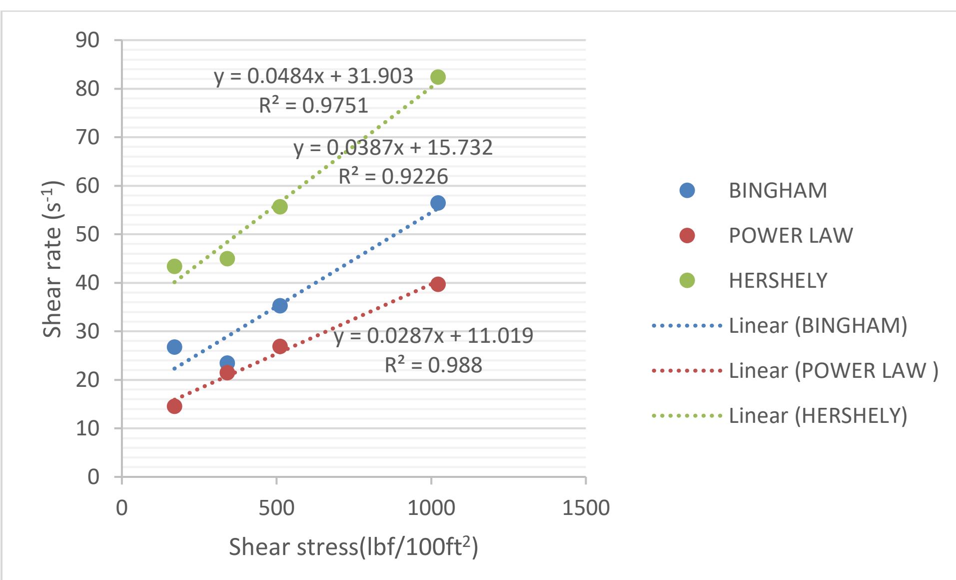


7:Fig 3.3.2b Plot of Shear stress versus shear rate of the effect of 7.5g of NaCl on 25g Gum Arabic + 25g of cocoyam mud system

MODEL DATA TO DETERMINE THE EFFECT OF 15G OF NACL ON THE RHEOLOGICAL PROPERTIES OF 25G OF GUM ARABIC + 25G OF COCOYAM

15:TABLE 3.3.2c

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	43.7	64.4	40.7	84.4
511	29.9	32.5	27.8	57.7
341	25.6	33	22.2	47.8
170	20.3	28	15.2	35.5



8;Fig 3.3.2c Plot of Shear stress versus shear rate of the effect of 15g of NaCl on 25g Gum Arabic + 25g of cocoyam mud system

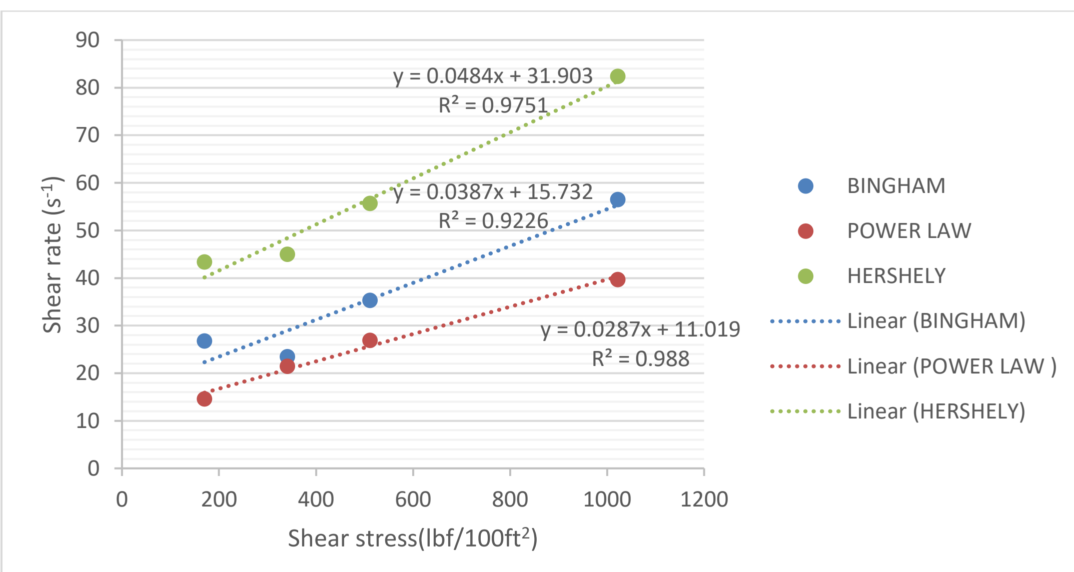
16:3.3.3: Effect of Salt On 25 Grams of Gum Arabic and 25 Grams of Ginger Mud System

RPM	7.5g of NACL	15g of NACL
600	40	40
300	25.5	27
200	20	22
100	15	17
Gel Strength		
10 SECONDS	20	25
10 MINUTES	22	26
PV	14.5	13
YP	11	14
N	0.65	0.56
K	0.44	0.82
DENSITY	7.8g/cc	8.1g/cc

MODEL DATA TO DETERMINE THE EFFECT OF 7.5G OF NACL ON THE RHEOLOGICAL PROPERTIES OF 25G OF GUM ARABIC + 25G GINGER

17;TABLE 3.4.2b

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	42.7	45.5	39.8	82.5
511	27.2	28.5	25.3	52.5
341	21.3	29	19.5	40.8
170	16	15	12.4	28.4

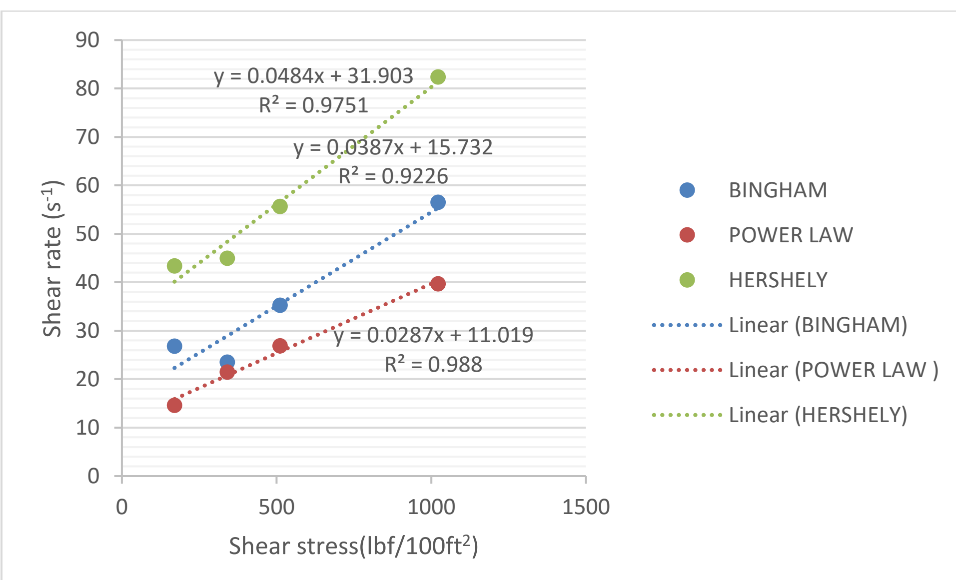


9:Fig 3.4.2b Plot of Shear stress versus shear rate of the effect of 7.5g of NaCl on 25g of Gum Arabic + 25g of ginger mud system

MODEL DATA TO DETERMINE THE EFFECT OF 15G OF CACL2 ON THE RHEOLOGICAL PROPERTIES OF 25G OF GUM ARABIC + 25G GINGER

18:TABLE 3.4.2c

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	42.7	56.5	39.7	82.4
511	28.8	35.5	26.9	55.7
341	23.5	23.5	21.5	45
170	28.8	26.8	14.6	43.4



10;Fig 3.4.2c Plot of Shear stress versus shear rate of the effect of 15g of CaCl2 on 25g of Gum Arabic + 25g of ginger mud system

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Sodium Chloride (NaCl) Effects On The Rheological Properties Of Gum Arabic–Based Polymer Mud Systems

This chapter presents and discusses the results of the laboratory experiments carried out to evaluate how sodium chloride (NaCl) affects the rheological properties of gum Arabic–based polymer mud systems. The findings are interpreted based on measurements of plastic viscosity (PV), yield point (YP), gel strength, and density obtained from the Fann viscometer readings. Results from each table in Chapter Three are referenced and compared to determine the performance of each formulation and its behavior under saline conditions.

4.1 Results Of Base Mud And Polymer Blends

4.1.1 Bentonite–Water Mud (Base Mud)

From Table 3.2.1, the bentonite–water system gave a low PV of 2.5 cP and YP of 4.0 lb/100ft^2, indicating weak particle interaction and poor suspension ability. The low gel strengths (5.5 lb/100ft^2 at 10 seconds and 7 lb/100ft^2 at 10 minutes) show that the mud could not effectively hold cuttings when circulation stops. The almost linear increase of shear stress with shear rate suggests a Bingham Plastic behavior, typical of spud muds used as baseline fluids.

4.1.2 Xanthan Gum–Bentonite Mud System

According to Table 3.2.2, adding 1 g of xanthan gum greatly improved the rheological properties, increasing PV to 10.5 cP and YP to 25 lb/100ft^2. Gel strength also rose significantly

(25 lb/100ft² at 10 seconds and 29 lb/100ft² at 10 minutes), indicating a stable gel network capable of suspending cuttings. The fluid showed clear shear-thinning behavior, fitting well into the Power Law model, which describes non-Newtonian pseudoplastic flow. This result aligns with Orodu et al. (2020), who reported xanthan gum's strong thickening and shear stability.

4.1.3 Gum Arabic–Bentonite Mud System

From Table 3.2.3, the gum Arabic sample produced PV and YP values similar to xanthan gum (10.5 cP and 24 lb/100ft² respectively), showing that gum Arabic also increases viscosity but with slightly weaker gel strength. The fluid exhibited non-linear shear-thinning behavior and corresponded more closely with the Power Law model. However, compared to xanthan gum, gum Arabic displayed less stability at higher shear rates, suggesting that its polymer chains are more easily disrupted by flow.

4.1.4 Gum Arabic–Cocoyam Blends

The results in Table 3.2.4 show that the (25 g + 25 g) and (37.5 g + 12.5 g) gum Arabic–cocoyam blends yielded PVs of 8 cP and 6 cP respectively, with corresponding YPs of 14 and 18 lb/100ft². The data indicate that higher gum Arabic content led to slightly better rheology. The 37.5 g gum Arabic blend also had a smoother flow curve, indicating stronger pseudoplasticity. This suggests that gum Arabic contributes more to the viscosity structure, while cocoyam adds moderate elasticity and filtration control. The fluids followed the Power Law model, showing shear-thinning characteristics.

4.1.5 Gum Arabic–Ginger Blends

As presented in Table 3.2.5, the (25 g + 25 g) gum Arabic–ginger mixture exhibited better rheology (PV = 18 cP; YP = 12 lb/100ft²) than the (37.5 g + 12.5 g) blend. Equal proportions of gum Arabic and ginger produced stronger gel structure (20 lb/100ft^2 at 10 seconds; 24 lb/100ft^2 at 10 minutes), indicating a stable suspension system. The fluid demonstrated shear-thinning behavior similar to the Herschel–Bulkley model, suggesting a combination of yield stress and pseudoplastic flow. The ginger extract likely enhanced stability by reducing flocculation.

4.2 Effect Of NaCl On Rheological Properties

4.2.1 Xanthan Gum System

According to Table 3.3.1, adding 7.5 g of NaCl slightly reduced PV but maintained good YP (12.9 lb/100ft^2), while 15 g NaCl increased YP to 15.5 lb/100ft^2. The flow behavior index (n) decreased from 0.56 to 0.51, showing stronger shear-thinning at higher salt concentration. This means NaCl enhanced molecular interaction at moderate levels but compressed polymer chains at higher concentrations. The Power Law and Herschel–Bulkley models both fitted the data well, confirming xanthan gum's salt tolerance and consistent pseudoplastic flow.

4.2.2 Gum Arabic System

From Table 3.3.2, the gum Arabic mud experienced a slight decrease in PV (12.5 → 10.5 cP) with increasing NaCl, but YP increased from 10.3 to 12.5 lb/100ft^2. This suggests that Na^+ ions created weak cross-links between charged polymer sites, improving gel structure but reducing free fluidity. The n-value dropped from 0.64 to 0.54, indicating increased shear-thinning behavior. The Herschel–Bulkley model best represented this system, as both yield stress and pseudoplastic behavior were evident.

4.2.3 Gum Arabic–Cocoyam Blend

The gum Arabic–cocoyam blend (Table 3.3.2b and 3.3.2c) maintained stable PV (12–13 cP) and YP (13–15 lb/100ft²) values under NaCl exposure. Unlike gum Arabic alone, this blend showed improved salt resistance. The polymer–starch matrix likely prevented excessive flocculation. The n-values (0.55–0.57) confirmed shear-thinning flow, while the Power Law and Herschel–Bulkley models provided excellent fits. This stability suggests that the cocoyam starch acted as a reinforcement agent under saline conditions.

4.2.4 Gum Arabic–Ginger Blend

From Tables 3.4.2b and 3.4.2c, the gum Arabic–ginger mixture showed remarkable stability under salt influence. PV reduced slightly from 14.5 to 13 cP, while YP increased from 11 to 14 lb/100ft² as NaCl concentration rose from 7.5 g to 15 g. The n-value dropped from 0.65 to 0.56, showing better shear-thinning performance. The increase in consistency index ($K = 0.44 \rightarrow 0.82$) suggests enhanced viscosity stability. The Herschel–Bulkley model best described its flow behavior, confirming that this blend retained both viscosity and gel strength even under salinity.

4.3 Model Comparison And Flow Behavior

Overall comparison of the models shows the following (referencing all model data tables such as 3.2.2b, 3.2.2c, 3.3.2b, and 3.4.2b–c):

- The Bingham Plastic model suited only the base bentonite mud.

- The Power Law model fitted polymer systems like xanthan gum and gum Arabic–cocoyam.

- The Herschel–Bulkley model best represented gum Arabic and gum Arabic–ginger systems, as both exhibited yield stress and shear-thinning behavior.

The flow behavior index ($n < 1$) in all polymer-based fluids confirmed their non-Newtonian pseudoplastic nature, which is ideal for drilling operations since viscosity decreases at high shear (during pumping) and increases at low shear (to suspend cuttings).

4.4 Comparative Discussion

Comparing all the mud systems:

- Xanthan gum maintained the most consistent rheology under both 7.5 g and 15 g NaCl, indicating excellent salt tolerance.

- Gum Arabic alone showed moderate sensitivity to salt, losing some viscosity but improving in yield strength.

- Gum Arabic–cocoyam blends resisted salinity well due to starch–polymer interactions that enhanced structure.

- Gum Arabic–ginger performed almost as well as xanthan gum, showing steady viscosity and strong gel formation even at 15 g NaCl.

The results correspond with findings by Orodu et al. (2020) and Abdulkadir et al. (2021), who observed similar improvements in rheological stability for gum-based polymer combinations.

4.5 Summary Of Findings

1. Adding gum Arabic and its blends to bentonite mud greatly improved viscosity, yield point, and gel strength compared to the base mud (Tables 3.2.1–3.2.5).

2. Sodium chloride affected all samples differently—moderate salt improved gel structure, but higher concentration compressed polymer chains, slightly reducing viscosity (Tables 3.3.1–3.4.2c).

3. Xanthan gum and gum Arabic–ginger blends showed the best resistance to salinity and maintained pseudoplastic behavior.

4. The Herschel–Bulkley model accurately described most polymer-based fluids, reflecting both yield stress and shear-thinning characteristics.

5. Among all formulations, gum Arabic–ginger and xanthan gum systems demonstrated the most stable and environmentally friendly rheological performance.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study investigated the effect of sodium chloride (NaCl) on the rheological properties of gum Arabic–based polymer drilling muds and their blends with cocoyam starch, ginger extract, and xanthan gum. Experimental results revealed that gum Arabic and its natural blends significantly improved the viscosity, yield point, and gel strength of bentonite mud, thereby enhancing its capacity for effective hole cleaning and cuttings suspension.

The presence of NaCl influenced the flow behavior of the mud systems differently. At moderate concentrations (7.5 g), NaCl enhanced polymer–particle interaction and slightly improved the yield point, while at higher concentrations (15 g), it compressed polymer chains, leading to reduced plastic viscosity. Among all systems, xanthan gum and gum Arabic–ginger blends displayed superior salt tolerance and stable pseudoplastic behavior.

The rheological models applied showed that the Herschel–Bulkley model best described the flow characteristics of the polymer-based mud systems, as it accounted for both yield stress and shear-thinning behavior. These findings confirm that gum Arabic and its blends, especially with ginger and xanthan gum, can serve as cost-effective, biodegradable, and environmentally friendly alternatives to synthetic polymers for drilling in saline formations.

5.2 Recommendation

1. Industrial Application:

Gum Arabic–based mud systems, particularly the gum Arabic–ginger and gum Arabic–xanthan gum blends, should be adopted for drilling operations in saline and offshore environments where salt contamination is common.

2. Optimization of Polymer Ratios:

Further work should be done to determine the most efficient proportions of gum Arabic and its additives to maximize salt tolerance, viscosity, and gel stability.

3. Evaluation of Divalent Salts:

Future research should include the effects of $CaCl_2$ and $MgCl_2$ on the rheology of these polymer blends to simulate more complex saline conditions.

4. Thermal and pH Behavior:

Additional tests should investigate how temperature and pH variations influence the rheological stability of gum Arabic–based systems under downhole conditions.

5. Filtration and Lubricity Studies:

Beyond rheology, future experiments should assess how these natural polymers affect fluid loss, lubrication, and shale stabilization in drilling fluids.

6. Local Production and Scale-Up:

The government and private oil service companies should support the local production and beneficiation of gum Arabic, cocoyam, and ginger polymers for industrial-scale use. This would reduce import dependence and promote sustainable drilling practices.

5.3 Contribution to Knowledge

This study makes significant contributions to drilling fluid engineering, particularly in the development of sustainable polymer-based mud systems for saline environments.

1. **Novel Evaluation of Natural Polymer Blends**: The study advances knowledge by systematically evaluating blends of gum Arabic with cocoyam starch, ginger extract, and xanthan gum under sodium chloride contamination. The findings establish that gum Arabic–ginger and gum Arabic–xanthan gum blends exhibit improved salt tolerance and stable pseudoplastic behavior, contributing new insights into synergistic polymer interactions in saline mud systems.

2. **Salt Concentration–Rheology Relationship**: This research provides a clearer understanding of how varying NaCl concentrations influence polymer chain behavior and mud rheology. It demonstrates that moderate salt concentration (7.5 g) enhances polymer–particle interaction and yield point, whereas higher concentration (15 g) compresses polymer chains and reduces plastic viscosity. This contributes to the theoretical understanding of electrolyte–polymer interactions in drilling fluids.

Overall, this study bridges the gap between laboratory-scale rheological evaluation and practical application of natural polymer blends in saline drilling environments, providing both theoretical insight and industrial relevance.

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