EXPERIMENTAL STUDY OF POTASSIUM IN WATER-BASED MUD (WBM) FOR SHALE STABILITY

by

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13580

Dissertation submitted in partial fulfilment of

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Petroleum Engineering Programme
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Approved by,

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(Dr. Sonny Irawan)

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TRONOH, PERAK
September 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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ABDUL HAKIM BIN BASRI

ABSTRACT

Interest in designing Water-based Muds (WBM) have increased due to wellbore instability issues that arise from the abundance of problematic shale encountered while drilling. Conventional WBMs that are used to drill through sensitive shale formations cause a high degree of wellbore instability. Thus, Oil-based Mud (OBM) were adopted to solve the wellbore instability problems due to its superior shale stabilization properties. However, high costs, environmental restrictions, cuttings and used mud disposal difficulties and safety have largely limited the use of OBM. As a result of these challenges with OBMs, WBMs that have the ability to effectively reduce shale instability problems have once again come under the lime light to replace the OBMs. Potassium-based (KCl) muds are used in areas where inhibition is required to limit chemical alteration of shale. This research study therefore was undertaken to evaluate the inhibition effects of different concentrations of KCl on the rheological properties of WBM contaminated with shale. The rheological values using Fann viscometer with different concentrations of KCl (0.2%, 0.4%, 0.6%, 0.8% and 1.0%) respectively by weight of contaminated 8.7 ppg WBM with typical shale sample from the shale outcrop at Batu Gajah, Perak (N04°28’25.8’’, E 101°4’26.9”) were evaluated. Test results indicated that the KCl inhibited the swelling tendencies of the shale and the rheological values reduced drastically. The reduction in rheological values considering the 600rpm reading were 9.5%, 14.2%, 23.8%, 47.6% and 52.4% respectively compared to results without KCl in the mud as indicated above. Therefore, to avoid non-productive time resulting from hole instability problems caused by shale, when drilling is expected to encounter shale zones, proper design of the drilling fluids using WBMs with KCl that will inhibit shale swelling is imperative.

ACKNOWLEDGEMENTS

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I also take this chance to express a deep sense of gratitude to Mr. Jukhairi (Lab Technician) for his support and guidance during completing the project. I am very grateful for his cooperation during the period of my project.

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ABBREVIATIONS AND NOMENCLATURES

KCl	: Potassium Chloride
OBM	: Oil-based Mud
SBM	: Synthetic-based Mud
WBM	: Water-based Mud
XRD	: X-Ray Diffraction
τ	: Shear stress
τ_0	: Yield point
μ	: Viscosity
μ_∞	: Plastic viscosity
γ	: Shear rate

CHAPTER 1: INTRODUCTION

1.1 Background

Wellbore instability is one of the most serious problems in the oil and gas industry. It can lead to interruption in the drilling process, rise in cost, and in some cases even abandonment of the well[2]. This problem was estimated costs the oil and gas industry more than one billion U.S dollars every year. Moreover, in other engineering activities such as roadway tunnels and coal mining, weak shale formations always being the source of severe instability problems[7].

Shale is the most abundant rock type in the earth which act together inconsistently with the fluids in contact[9]. Whenever shale is met in engineering activities, it is treated as the most suspicious rock that could cause unpredicted instabilities and other problems[16]. It was estimated that shale formations make up more than 75 percent of all drilled formations and was a source to more than 90 percent of all costs associated with wellbore instability complications[9].

Shale stability is strongly affected by its complicated physical and chemical interaction with drilling fluids[7]. Drilling fluids were required during drilling of wells to transport bit cuttings to the surface, cleans the bottom of the hole and maintain the wellbore stability[10]. The behavior and properties of the formation to be drilled affect the selection of the drilling fluid. Often, Water-based Muds (WBM) was used whenever possible for many reasons including economics, convenience, and logistics. However, to drill using WBM in certain conditions mainly shale formations was often been difficult and very costly[6]. This is because shale failure and high degree of wellbore instability occurs when drilling using WBM which can cause various borehole problems and add substantial costs to the operation[5].

Historically, the only alternative to drill such sensitive formation was Oil-based Mud (OBM) due to its superior shale stabilization properties as it does not interacted with the formation clay which can cause the shale instability[9]. Although OBM was much more expensive than WBM, it was very effective in controlling the shale formations and always allow trouble-free drilling, thereby worth the higher cost. It was also very effective when used in troublesome shale formation that would otherwise swell and disperse in WBM[6].

However, environmental concerns and regulations have increasingly restricted the use of OBMs for the past several years. The major concern of using the OBM is that they contaminate areas of freshwater aquifers which cause severe environmental damage. Rig modifications may be necessary to contain possible spills, to clean up oil mud cuttings, and to handle whole mud without dumping which increase the capital and operating cost. As the result of these challenges, the industry has attempted to develop an enhanced WBM with the ultimate goal of replacing the OBMs to answer this increasing environmental demands.

1.2 Problem Statement

Shale is exposed to drilling fluid interactions while drilling that can affect the stability of the wellbore[3]. WBM was often used due to its environmental friendly nature. Though, use of WBM often related with shale problems that can lead to swelling, dispersion, shale hydration and abnormal pressure which cause severe shale instability[1]. The degrees of wellbore instability was measured by the severity of problems encountered by the formation. The use of WBMs in drilling shale formations results in the absorption of water onto the surface of the shale. Water absorption may cause various reactions such as increase in pore pressure which lead to wellbore instability to varying degrees depending on the shale type. Since pore pressure is appears as a minus strength in total strength which is($\sigma eff = \sigma t - Pp$), shear strength is reduced accordingly and a serious failure can occur, especially in the weaker compacted shale.

Problems encountered by this failure include:

- Excessive hole enlargement leading to inadequate mud return velocities which results in poor hole cleaning
- Sloughed chip accumulation in enlarged sections leading to mud rings and stuck pipe
- Massive intervals of sloughed material which must be laboriously cleaned before drilling can resume
- Lost circulation because of the increase in pressures and mud density adopted in an attempt to solve problems
- Total wellbore collapse requiring partial abandonment and re-initiation of drilling at a shallower depth

Associated loss of time with such problems is thought to account for 12 to 15% of drilling costs world-wide, which is actually a huge sum[8]. For many years, the industry has tried to develop WBM which perform like OBMs with respect to shale stability[15]. Wellbore stability analysis of shale formation involves studying the swelling phenomenon as the result of interaction between shale and drilling fluids. Many different theories were presented to explain the swelling phenomenon of shale. However, until now, the experimental data were not fully and effectively explained or even understood.

Therefore, proper selection of drilling fluids to be used on a particular well site is an essential phase of any carefully planned drilling operation. When this drilling is expected to encounter shale zones, the selection of the fluid becomes even more important. To maintain a stable borehole through such zones, a carefully designed mud will be required. The design of successful fluids for this type of application depends largely on a knowledge of the physical and mineralogical characteristics of the shale and its behavior when in contact with drilling mud.

The properties of WBM can be altered by adding additive as inhibitor to overcome these problems. KCl is known as the best inhibitor in the oil and gas industry. Successful application of KCl as inhibitor were observed in the late 1960s. This additive could reduce the severity of shale instability problems to the extent that deviated wells in shale formations could be drilled[7].

So, in order to solve the problems encountered by the interaction of WBM and shale, problem statements taken are:

1. What is the degree of inhibition of different concentration of KCl in WBM to mitigate in stability of shale formation
2. What is the effect of KCl concentration in WBM to the shale stability

1.3 Objectives

Aims of this paper therefore, is:

1. To evaluate the degree of inhibition of different concentrations of KCl on shale contaminated WBM
2. To determine rheological properties of water-based mud varies with KCl concentration

1.4 Scope of Study

In this research work, the interaction between shale and drilling fluids of different concentration of KCl will be investigated to determine shale strength variations for wellbore stability. Particularly, X-Ray diffraction analysis will be carried out to identify the mineralogical composition of shale sample that will be used throughout the study

Shale sample will be aged at 80 C for 16 hours in drilling fluids of different concentration of KCl using the roller oven. After aging, rheological test will be carried out to analyze the changes in the rheological values, plastic viscosity and the yield point of the WBM. Particularly, Fann viscometer will be used in order to obtain the results.

CHAPTER 2: LITERATURE REVIEW

2.1 Shale

Shale are sedimentary rocks molded under ancient oceans. Its behavior is both complicated and delicate. It is more complicated compared to other sedimentary rocks such as sandstone and limestone. Shale are low permeability, medium to high clay content, and medium porosity in addition to other minerals, such as quartz, feldspar, and calcite. Shale types range from soft shale to hard brittle shale with each type presenting its own set of problems. The distinguishing features of shale are its clay content and low permeability, which results in poor connectivity through narrow pore throats. Shale are also fairly porous and are normally saturated with formation water, with several factors affecting their properties, such as burial depth, water activity, and the amount and type of mineral present[9]. A good knowledge of the shale mechanical properties is often not enough. Concurrently, the chemical properties of the shale also play an important role in its engineering behavior. Hence, the chemical properties of any fluid in contact with the shale can affect its strength and physical properties[7]. As an example, interface between shale and drilling fluids or movement of drilling fluid into the shale matrix could happen just within a few hours which can lead to massive practical problem. When exposed by a borehole, shale formations can be unstable and create problems such as swelling[10].

Shale is still potentially a serious problem in oil and gas industry although the engineering sides of the formation have been studied for several decades. It was estimated that these problems costs the oil and gas industry billions of dollars every years[7].

2.1.1 Shale and WBM interaction

Shale is fairly porous and normally saturated with formation water, with several factors affecting it properties such as water activity, burial depth and the amount and also the type of minerals present[13]. Shale hydration can occur when WBM are used during the drilling process. The interaction between WBM and shale causes the movement of water and ions into and out of shale therefore it includes swelling stress and increases pore pressure that will lead to wellbore failure[17].

2.2 Drilling Fluids

The term drilling fluid or drilling mud in petroleum engineering represents a heavy, viscous fluid mixture that is used in drilling operations to aid the production and removal of cuttings from a borehole in the earth and also to lubricate and cool the drill bit. It is usually a mixture of water, clay, weighing material and a few chemicals. Choosing and maintaining the proper fluid for a particular job can be challenging. The significance of drilling fluid as a major component of drilling activities cannot be ignored and the success of drilling operations would strongly lie on the appropriate design of drilling fluids.

2.2.1 Functions

Historically, the primary function of the drilling fluid was to serve as a vehicle for the removal of cuttings from the borehole, but now there are diverse applications of drilling fluid.

It acts as a carrier for the materials being drilled, with material becoming suspended in the mud and then being carried up to the surface. Drilling fluid reduce the friction generated when drilling and lower the heat of drilling which reduce the risk of friction-related problems. Drilling fluid also helps to prevent the collapse of unstable formation into the borehole and the intrusion of water that may be encountered. The main functions of a drilling fluid can be summarized as follows:

- Removal cuttings from well
- Reduce friction during drilling
- Suspend and release cuttings
- Control formation pressures
- Seal permeable formations
- Maintain wellbore stability
- Minimizing formation damage
- Cool, lubricate and support the bit and drilling assembly

2.2.2 Types

Many types of drilling fluids are used in industry. The various types of fluid generally fall into three major categories including Oil-based mud (OBM), Water-based mud (WBM) and Synthetic-based mud (SBM). The key factors usually determine the type of fluid selected for a specific well consist of cost, technical performance and environmental effect.

- Oil-based mud (OBM)

  OBM is a mud where the base fluid is a petroleum product such as diesel fuel. It was used for many reasons including to increased lubricity, enhanced shale inhibition and greater cleaning of well.

  OBMs were very effective in maintaining shale stability in many oil and gas reservoir. They could offer proper lubricity and excellent wellbore stability, low formation damage potential, and reduced risk of differential sticking[7]. With addition of appropriate surfactants and salinity in aqueous phase, OBMs were easier to be used in reactive shale. Subsequently, OBMs were regarded as the most economic option for all wells and broadly used in shale formations[7]. Adversely, OBMs generally does not meet environmental regulations. This results in high costs of disposing the drilling wastes associated with the drilling operation.

- Water-based mud (WBM)

  As a consequence of non-environmental friendly of OBM, WBM were developed and used to comply with this this. The base fluid may be fresh water, seawater, brine, saturated brine, or a formate brine. WBM can cause shale formations to swell and slough into the hole. Swelling shale and clays can impede drilling, widen the hole, increase viscosity and harm the producing zones[10]. However, the properties of WBM can be altered by adding additive as inhibitor to overcome these problems.

  The Glossary of Drilling Fluid Terms defines Inhibited Muds as:

  "A drilling fluid having an aqueous base with a chemical composition that tends to retard and even prevent (inhibit) appreciable hydration (swelling) or dispersion of formation clays and shale through chemical and/or physical means.[16]"

2.2.3 Composition

Drilling mud compositions vary based on wellbore demands, rig capabilities and environmental concerns. The compositions of a drilling fluid generally divided into two categories which is base fluid and additives.

- Base fluid

  The base fluid of a drilling mud forms the continuous phase in which all other components are carried. As such, the base fluid has a major influence over the properties and technical performance of a mud. On the basis of material cost, water is always the first base fluid to be considered. It may be fresh water, seawater, brine, saturated brine, or a formate brine making this an exceptionally cheap option.

- Additives

  Although the base fluid is important in determining the properties of a drilling mud, its primary role is acting as a carrier for additives that determine the mud's final properties. This allow the mud to be tuned to the formation being drilled, and the downhole conditions. Additives may be broadly grouped according to function which are as below:

  - Weighting agent

  Added to provide sufficient hydrostatic head to match the formation pressure.

  - Viscosifier

  Plays a key role in determining viscosity, gel strength and filtration rate.

  - Fluid loss control

  Effectively plug the points in the formation where fluid losses are occurring.

  - Calcium precipitant and pH reducer

  To hold the drilling muds in an alkaline condition to stabilize clay suspensions, improve the solubility of various additive, and reduce corrosion of the drill pipe and casing.

- Clay inhibitor

To control and prevent interactions between shale and drilling mud.

Potassium Chloride (KCl) is known as the best inhibitor in the oil and gas industry. It is used in areas where inhibition is required to limit chemical alteration of shale. Potassium performance is based on cationic exchange of potassium for sodium or calcium ions on smectites and interlayered clays. Successful application of KCl as inhibitor were observed in the late 1960s. This additive could reduce the severity of shale instability problems to the extent that deviated wells in shale formations could be drilled[7]. Potassium based mud perform best on shale containing large quantities of smectites or interlayered clays in the total clay friction. In recent years, muds containing potassium chloride and a suitable polymer have been the subject of publications from several areas.

Laboratory studies of the effects of numerous salt solutions on the hardness of cores from water-sensitive sands found that 2% KCl was a much effective stabilizing agent than 2% calcium chloride or 10% sodium chloride[8]. Also based on the findings of thorough laboratory tests on some representative shale by O'Brien and Chenevert, it was concluded that KCl was the favored inhibitor for shale inhibition than any other additives[14]. Compared to other inhibitive ions, potassium ion fits more closely into the clay lattice structure, hence greatly reduce the hydration on clays. Studies on the effect of different concentration of KCL on rheological properties of shale contaminated WBM was carried out by Joel, O.F, Durueke, U.J and Nwokoye C.U in 2012. They found that there was progressive reduction in the rheological values with increase in KCL concentration[9].

In this research project, the effects of different concentration of KCl on the physical and mechanical properties of the shale and rheology of KCl on shale contaminated WBM will be carry out. Different concentration of KCl will be ranked by the following properties. This approach will provide a clear indication of the prominent impact of drilling fluid additives on shale structure and behavior.

Retaining hole stability while drilling shale formations can be difficult. No simple way out exists, but good drilling practices combined with good mud practices are useful[7]. While drilling, mud is always in contact with the shale formation. The existence of an aqueous drilling fluids may prompt swelling and alter the characteristics of the shale[7]. Hence, we cannot ignore the significance of drilling fluid as it may lead to wellbore instabilities. Appropriate design of drilling fluid was needed for the success of drilling operations in this formation. Large amount of money and manpower has been spent for many years in studying the mechanism of mud interactions with shale and developing solutions to shale instability problems[7].

2.3 Rheological Properties

Rheological properties is the properties of change in form and flow of matter, particularly viscosity and plasticity. It is the most sensitive properties of material characterization because flow behavior is responsive to this properties such as molecular weight and molecular weight distribution. In this research, we are focusing on the plastic viscosity and the yield point of our subject. We are measuring this properties by using the viscometer. As rheological properties decreasing, the shale will have lower tendencies to swelling and was more stable.

2.3.1 Shear Stress

An applied force (F), acting over an area (A), causes the layers to slide past one another. However, there is a resistance, or frictional drag, force that oppose the movement of these plates. Their resistance or drag force is called shear stress (τ). In equation form:

$$\tau = \frac{F}{A} \quad \text{..2.1}$$

2.3.2 Shear Rate

The difference in the velocities between two layers of fluid divided by the distance between the two layers is called the shear rate (γ). In equation form:

$$\gamma = \frac{Velocity\ Different}{Distance} \quad \text{.......................................2.2}$$

2.3.3 Newtownian Fluid Model

The Newtownian Fluid Model is the basis from which other fluid models are developed. The flow behavior of Newtownians fluids can be seen from this equation that the stress-shear relationship is given by:

$$\tau = (\pi)(\gamma) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.3$$

At a constant temperature, the shear stress and shear rate are directly proportional. The proportionality constant is the viscosity (μ).

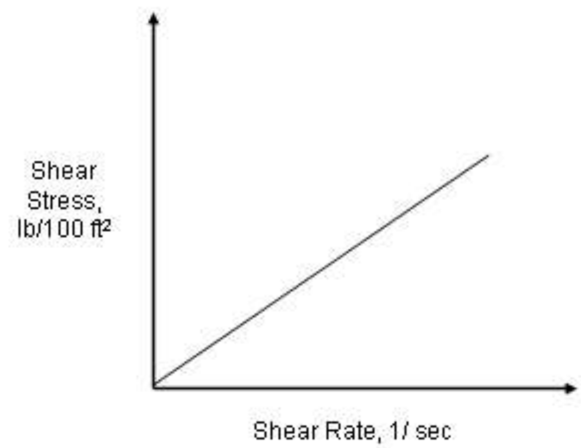

Figure 2.1: Flow curve for a Newtownian Fluid[8]

2.3.4 Bingham Plastic Model

The shear stress/shear rate relationship for the Bingham Plastic Model is given by:

$$\tau = \tau_o + (\pi_\infty)(\gamma) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.4$$

The flow curve for a Bingham Plastic fluid is illustrated in Figure 2.2. The effective viscosity, defined as the shear stress divided by the shear rate, varies with shear rate in the Bingham Plastic Model. The effective viscosity is visually represented by the slope of a line from the origin to the shear stress at some particular shear rate. The slopes of the dashed lines represent effective viscosity at various shear rates. As can be seen, the effective viscosity decreases with increased shear rate. This is referred to as shear thinning.

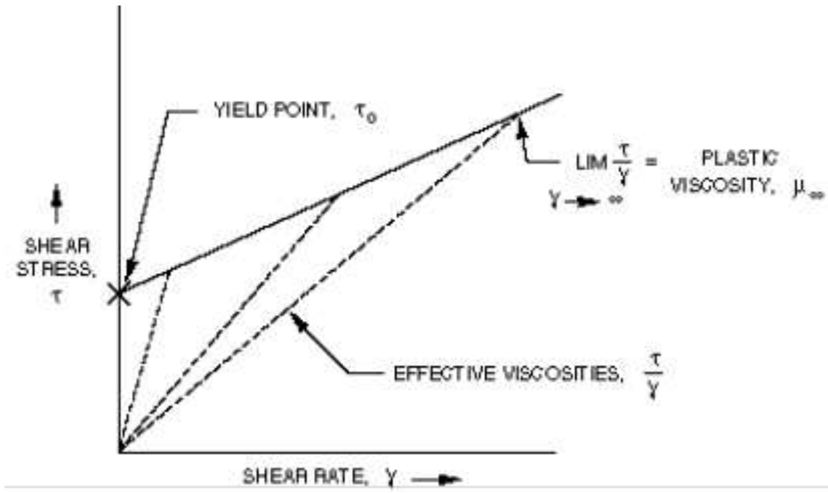

Figure 2.2: Flow curve for a Bingham Plastic Fluid[8]

As shear rates approach infinity, the effective viscosity reaches a limit called the Plastic Viscosity. The plastic viscosity of a Bingham Plastic Fluid represents the lowest possible value that the effective viscosity can have at an infinitely high shear rate, or simply the slope of the Bingham Plastic line.

The Bingham Plastic Model and the terms plastic viscosity (PV) and yield point (YP) are used extensively in the drilling fluids industry. Plastic viscosity is used as an indicator of the size, shape, distribution and quantity of solids, and the viscosity of the liquid phase. The yield point is a measure of electrical attractive forces in the drilling fluid under flowing conditions.

- PV should be as low as possible for fast drilling and is best achieved by minimizing colloidal solids.
- YP must be high enough to carry cuttings out of the hole, but not so large as to create excessive pump pressure when starting mud flow.

2.3.5 Power Law Model

Another model that can describe non-Newtonian fluid is Power Law Model. The shear rate and shear stress curve has the exponential equation. A fluid described by the two parameter rheological model of a pseudo plastic fluid, or a fluid whose viscosity decreases as shear rate increases.

$$\tau = K \times (\gamma)^n \quad \text{...2.5}$$

In this equation, K is the consistency index and n is the flow behavior index. The value of n is less than unity for Power Law.

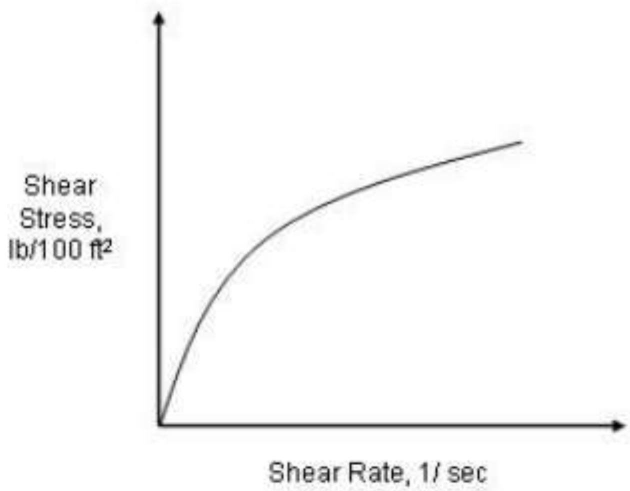

Figure 2.3: Flow curve for a Power Law Fluid[8]

2.3.6 Plastic Viscosity (PV)

PV is a parameter of the Bingham plastic rheological model. It is the slope of shear stress-shear rate plot above the yield point.

The formula to calculate PV is as follow:

Plastic Viscosity (PV) = Reading at 600 rpm – Reading at 300 rpm………..……..2.6

A low PV indicates that the mud is capable of drilling rapidly because of the low viscosity of mud exiting at the bit. As shale hydrates, it will further increased the PV as their volume is increased. This makes the hydration and dispersion of shale particles particularly detrimental. This means that if the PV was high, mud was unable to drill rapidly. To lower the PV, KCl will be introduced as the additive in WBM.

2.3.7 Yield Point (YP)

YP is the resistance to initial flow or the stress required to start the fluid movement. This is an indication of dispersion and settling tendency of the solid particles in the mixture.

The formula to calculate YP is as follow:

Yield Point (YP) = Reading from a viscometer at 300 rpm – Plastic Viscosity (PV)……………………………………………………………………………………….2.7

A high YP indicates that the mud has high dispersion and settling tendency of the solid particles in the mixture. Depending on the shale type, water adsorption may lead to various reactions such as swelling, cutting dispersion, and increase in pore pressure creating wellbore instability to varying degrees. We are using KCl to reduce the yield point in order to solve this problem.

2.3.8 Gel Strength

Gel strength is the shear stress of drilling mud that is measured at low shear rate after the drilling mud is static for a certain period of time. The gel strength is one of the important drilling fluid properties because it demonstrates the ability of the drilling mud to suspend drill solid and weighting material when circulation is ceased. Evaluation of gel strength consists of two types according to API standard which are 10 second and 10 minute reading.

Gel strength occur in drilling fluids due to the presence of electrically charged molecules and clay particles which aggregate into a firm matrix when circulation is stopped. Two types of gel strength occur in drilling fluids, progressive and fragile. A progressive gel strength increases substantially with time. This type of gel strength requires increased pressure to break circulation after shutdown. A fragile gel strength increases only slightly with time, but may be higher initially than a progressive gel.

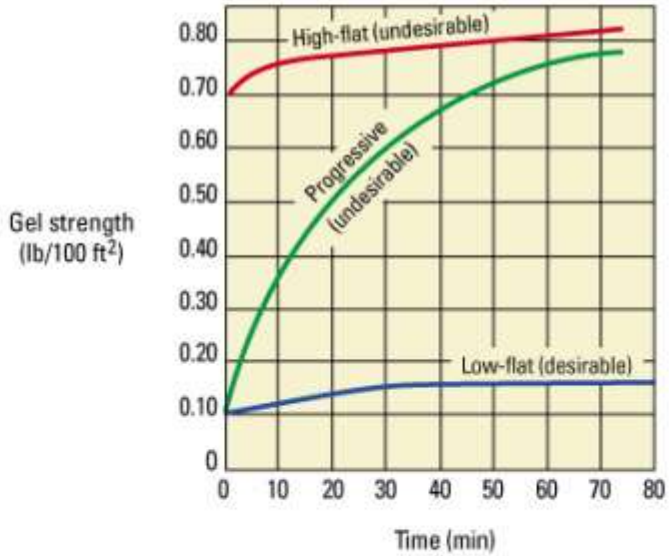

Figure 2.4: Gel strength characteristics vs Time

- Gel 10 minutes – the reading of maximum deflection at 3 rpm speed using Fann Viscometer after the mud is let in static condition for 10 minutes.
- Gel 10 seconds – the reading of maximum deflection at 3 rpm speed using Fann Viscometer after the mud is let in static condition for 10 seconds.

CHAPTER 3: METHODOLOGY

In this research work, particularly shale sample will be collected from shale outcrop at Batu Gajah and X-Ray diffraction analysis will be carried out to identify the mineralogical composition of shale sample that will be used throughout the study

Shale sample will be aged at 80^0C for 16 hours in drilling fluids of different concentration of KCl using the roller oven. After aging, rheological test will be carried out to analyze the changes in the rheological values, plastic viscosity and the yield point of the WBM. Detail of the methodology of the project are as below:

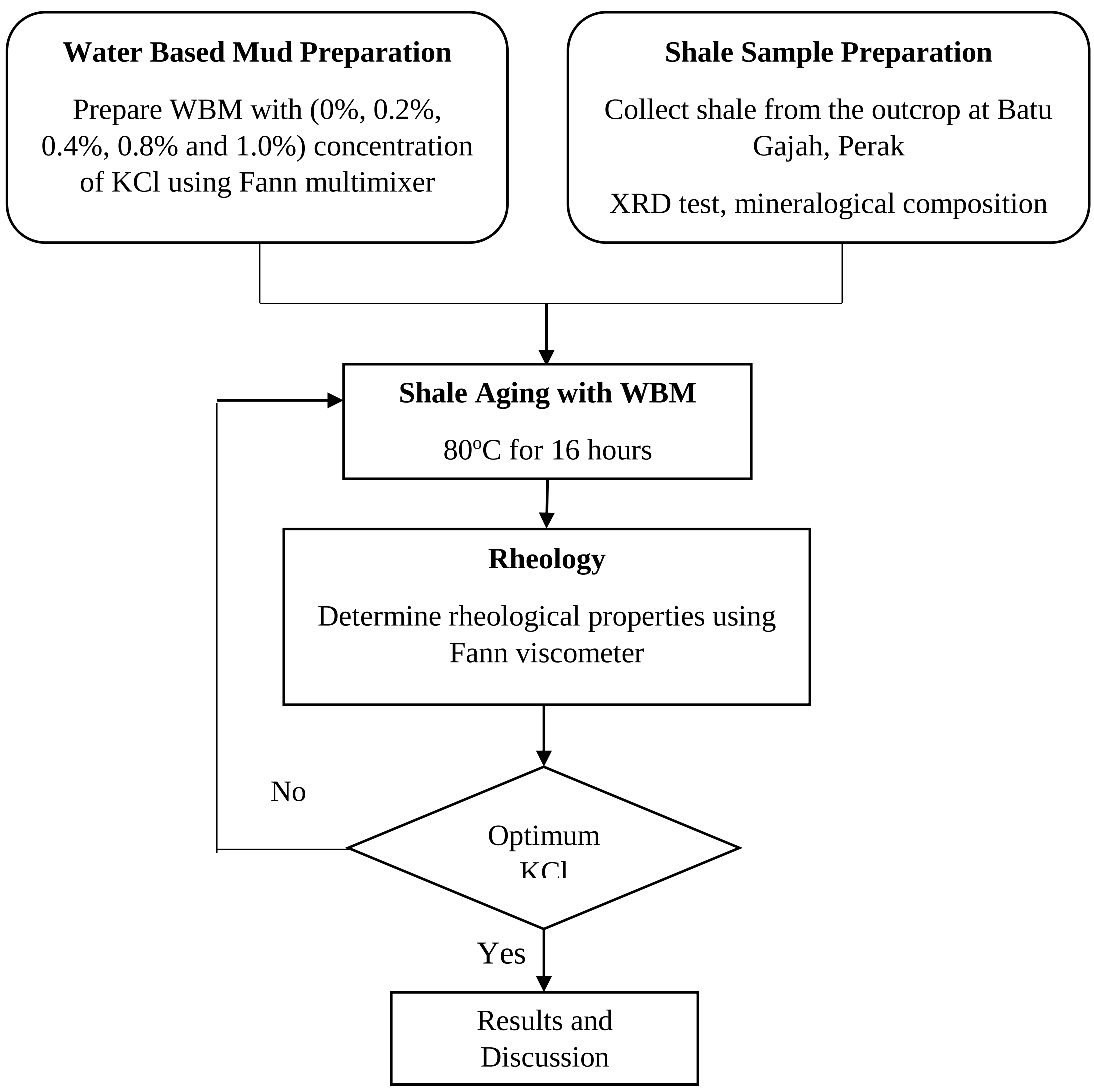

Figure 3.1: Methodology of the project

3.1 Shale sample preparation

Technically, shale sourced from the oil will give better results rather than the outcrop. But due to the time constraint and complex procedures of getting the shale, the only alternative is to source shale from the outcrop.

3.1.1 Sample location

The shale outcrop is located at Batu Gajah. The coordinate of the outcrop is N04°28’25.8’’, E 101°4’26.9” and the evaluation is 30m above sea level.

Figure 3.2: Location of the shale outcrop (Batu Gajah)

3.1.2 Sample collection

Figure 3.3: Shale outcrop

Figure 3.4: Shale collected

Figure 3.2 shows the location of shale outcrop by Google Earth. The shale outcrop located at Batu Gajah as shown in the figure. Figure 3.3 and Figure 3.4 shows the shale outcrop and the shale sample collected from the site respectively.

3.1.3 X-Ray Diffraction (XRD)

XRD was used to determine the structural properties of the shale sample. Mineralogical composition, clay fraction and physical properties will be obtained by using this method. This method was important to be done to identify the structural properties of shale sample that will be used throughout the study. During this experiment, shale sample will be analyzed using XRD machine in laboratory. All the information obtained regarding the shale sample will be noted.

Procedures:

Sample Setup

1. Mount sample that can fit into the holder on 2x2 inch glass slide. Adhere it to slide with tape. The sample must be secure on X-ray platform and ensure that the platform is at the centre. Close the door of the machine securely.

Machine & Computer Setup

1. Check knobs. Check if kV and mA knobs are at zero position. (Knobs are at bottom left front of the machine). Then, turn generator on.
2. Turn on computer monitor. The computer should already be on.
3. On the desktop start the XRD software. Initialize the diffractometer.
4. Adjust the kV (voltage) and mA (current) knobs. Adjust one knob at a time. Slowly increase voltage dial in 5kV steps up to amount indicated on label (usually around 40 kV). Sometimes you may need to wait as long as 1 minute in between dial turns. Increase current dial slowly to amount indicated on label (usually around 30 mA). Do not exceed 40kV and 30mA.
5. Set parameters of X-Ray. The software will calculate the estimated time. Then, set speed for x-ray either 0.02 for longer, slower speed, or 0.2 for shorter, faster speed.
6. Run the sample for 10 minutes.
7. When finished, copy the file from the "X-Rray Data" folder on the desktop to a zip drive.
8. Close the software.
9. Leave the computer on.
10. Slowly turn down the High Voltage and Current over the 5 minutes.

11. Turn off the high voltage.
12. Open the enclosure. Remove sample.
13. Always return the goniometer (centre platform) to a typical starting position.

Figure 3.5: XRD equipment used in the analysis. Model: Bruker D8 Advance

3.2 Water-based Mud (WBM) preparation

Apparatus:

1. Multimixer
2. 341 grams of water
3. 4.0 grams of bentonite
4. 0.2 grams of Xanthan gum
5. 0.4 grams of Pac-R
6. 0.6 grams of Pac-L
7. 0.25 grams of Soda ahs
8. 13.0 grams of barite
9. KCl with (0.2%, 0.4%, 0.6%, 0.8% and 1.0%) concentration

Procedure:

1. Measure 341 grams of water and pour into the Multimixer.
2. Add 4.0 grams of bentonite and prehydrate for 30 minutes under stirring condition
3. After 30 minutes, add 0.2 grams of Xanthan gum, 0.4 grams of Pac-R, and 0.6 grams of Pac-L respectively to the Multimixer.

4. Stir with prehydrated bentonite for 15 minutes before adding 0.25 grams of Soda ash and stir for another 10 minutes.
5. Then, add 13.0 grams of barite and stir the mixture further for another 20 minutes for homogeneity
6. Thereafter, add the KCl respectively with 0.2% concentration by weight of the formulated mud
7. Repeat the mixing procedure using KCl with (0.4%, 0.6%, 0.8% and 1.0%) concentration to obtain 5 sets of drilling muds.

Table 3.1 listed the additives used in preparing the water-based mud and the respective functions.

Table 3.1: Additives and Functions

Number	Additive	Function (s)
1	Water	Base fluid
2	Soda Ash	Calcium precipitant and pH reducer in cement contaminated mud
3	Bentonite	Viscosity and Filtration control
4	XCD	Viscosity and Filtration control
5	Par R	Fluid loss control and Viscosifier
6	Par L	Fluid loss control and Viscosifier
7	Barite	Weighting agent
8	KCl	Clay inhibitor

Figure 3.6: Additives weighed using weighing scale

Figure 3.7: WBM prepared using multimixer

Figure 3.6 and Figure 3.7 shows the additives being weighed using the weighing scale and the multimixer that was used to prepare the WBM respectively.

3.3 Shale Aging

To get accurate and useful results from mud tests, mud samples should be put to conditions similar to those in the well[9]. The mud should be allowed to age for days so that the dry materials will react and mix properly before being tested.

Shale aging will be made in stainless steel high pressure cells as shown in Figure 2. To simulate aging of the mud while it is circulating in the well, the cells are rolled in an oven, which is shown in Figure 3, for at least 16 hours at the average well circulating temperature. The cells are then cooled to room temperature, and the hardness are measured. In this case, the average well circulating temperature in shale formations was 80 C. Hence the cell will be aged at 80 C for 16 days to get quick and good precision of results.

Figure 3.8: Pressure cells used

Figure 3.9: Fann Roller oven used

Figure 3.8 and Figure 3.9 shows the pressure cells that was used and shale being aged with WBM in the roller oven respectively.

3.4 Rheology

We are using Fann viscometer to study the rheology of the WBM contaminated with shale. The procedures to determine the apparent viscosity are:

Procedure:

1. A recently agitated sample in the cup is placed, tilted back the upper housing of the viscometer, located the cup under the sleeve and lowers the upper housing to its normal position.
2. The knurled knob is turned between the rear support posts to raise or lower the rotor sleeve until it is immersed in the sample to the scribed line.
3. Stir the sample for about 5 seconds at 600 rpm, and then select the RPM desired for the best.
4. Wait for the dial reading to stabilize.
5. Record the dial reading and RPM.

Figure 3.10: Fann Viscometer used

Figure 3.10 shows the viscometer being used to measure the rheological properties of the WBM

CHAPTER 4: RESULTS AND DISCUSSION

The results of the various tests done are recorded and discussed. From XRD analysis, we could identify the mineral composition of the shale sample taken. This was to conform that the sample taken was shale before further experiment was done. The rheology test was done to measure the rheology of the WBM that was prepared with different concentration of KCl. This result was compared to find the relationship between different concentrations of KCl in WBM with the shale stability. The results was as followed.

4.1 Mineral composition of shale sample

XRD was carried out to determine the mineral constituent of the shale sample taken. The result was as shown in Figure 4.1.

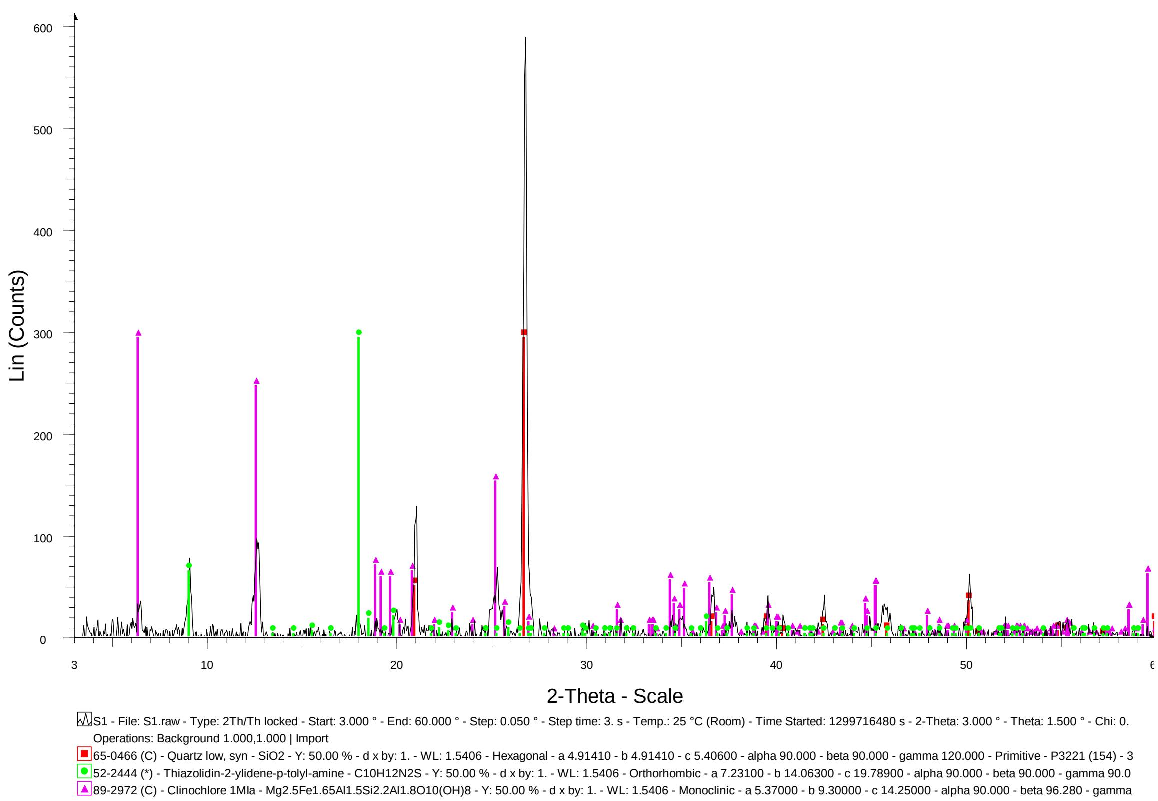

Figure 4.1: Mineral composition of shale sample

From the result, we found that the sample are dominant by quartz. It is because quartz is a very stable mineral and also the main element of the shale. Other major minerals found in the sample are Chlinochore and Thiazolidin-2-ylidene-p-tolyl-amine. Some other clay minerals also found in the sample such as kaolite and momtmorillonite which was the element of the shale. However, there are some other minerals such as potassium manganese and lavendulan exist which might result from weathering or contamination during preparation of the sample powder. As a conclusion, XRD result shows that the sample taken was shale.

4.2 Rheological properties

From the rheology test, the rheological properties of the mud was measured and the yield point and plastic viscosity was calculated. Referring to the formula 2.6 and 2.7, we calculate the plastic viscosity and the yield point of the formulated mud which was set to have weight of 8.7 PPG.

Table 4.1: Rheological properties of formulated mud (8.7PPG)

No.	RPM	Dial reading			
		1st trial	2nd trial	3rd trial	Average
1	Ø600	20	21	21	21
2	Ø300	14	14	14	14
3	Ø6	2	2	2	2
4	Ø3	1	1	1	1
5	Plastic viscosity (Cp)	6	7	7	7
6	Yield Point ($lb/100ft^2$)	8	7	7	7
7	10sec Gel Strength ($lb/100ft^2$)	2	2	2	2
8	10mins Gel Strength ($lb/100ft^2$)	3	3	3	3

Table 4.1 shows the results of the rheological properties of formulated mud recipe. The plastic viscosity measured is 7cp while the yield point measured is 7 $lb/100ft^2$. This result will be the benchmark to determine how rheological properties of water-based mud varies with KCl concentration.

The rheological properties of the WBM with different concentration of KCl was and then measured and the plastic viscosity and the yield point was calculated. Table below shows the rheological properties, the PV and YP of the WBM with different concentration of KCl.

Table 4.2: Rheology results for the mixture of WBM with different concentrations of KCl

Mixture	600 RPM (Cp)	300 RPM (Cp)	6 RPM (Cp)	3 RPM (Cp	10sec gel (Cp)	10mins gel (Cp)	PV (Cp)	YP (lb/100ft^2)	Mud weight (PPG)
Mud + 0.2% KCl	19	12	2	1	2	3	7	5	8.7
Mud + 0.4% KCl	18	12	2	1	3	4	6	6	8.6
Mud + 0.6% KCl	16	10	1	1	2	3	6	4	8.7
Mud + 0.8% KCl	11	7	1	1	2	2	4	3	8.6
Mud + 1.0% KCl	10	6	1	1	1	2	4	2	8.5

This results was then compared with the formulated mud to find the relationship between the concentrations of KCl in WBM with the shale stability.

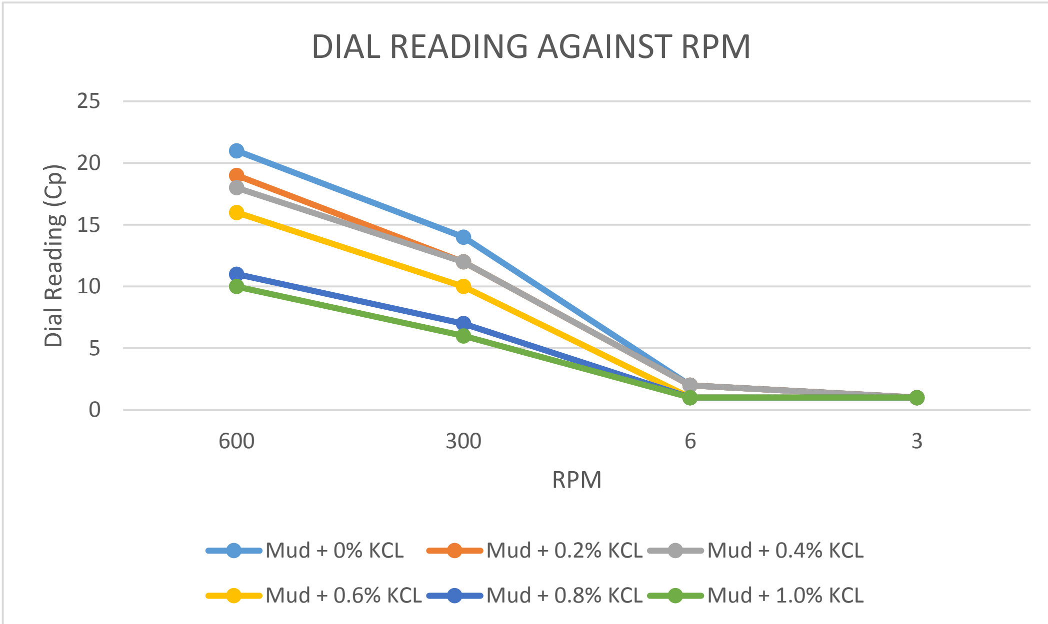

Figure 4.1: Dial Reading against RPM

Looking at Table 4.2 and Figure 4.1 with 0.2%, 0.4%, 0.6%, 0.8% and 1.0% of KCl introduced in the mud and considering the 600rpm reading, test results showed that the rheological values decreased progressively as KCl concentration increased. The decrease in rheological values were (21 to 19 for 0.2%KCl), (21 to 18 for 0.4%KCl), (21 to 16 for 0.6%KCl), (21 to 11 for 0.8%KCl) and (21 to 10 for 1.0%KCl) as indicated in the table and graph. From the literature review, the use of conventional WBM in drilling shale formation results in the adsorption of water associated with the drilling mud onto the surface of shale. However, when KCl was introduced, there were progressive reduction in the rheological values with increase in KCl concentration. This results indicated that KCl inhibited the swelling tendencies of shale as rheological values reduced drastically and considering the 600rpm reading, the percentage reduction were 9.5%, 14.2%, 23.8%, 47.6% and 52.4% respectively compared to results without KCl in the water based mud. This agrees with previous study that KCl is very effective stabilizing agent in shale sensitive formation.

The Plastic Viscosity of the WBM with different concentration of KCl was then compared as in the bar chart below.

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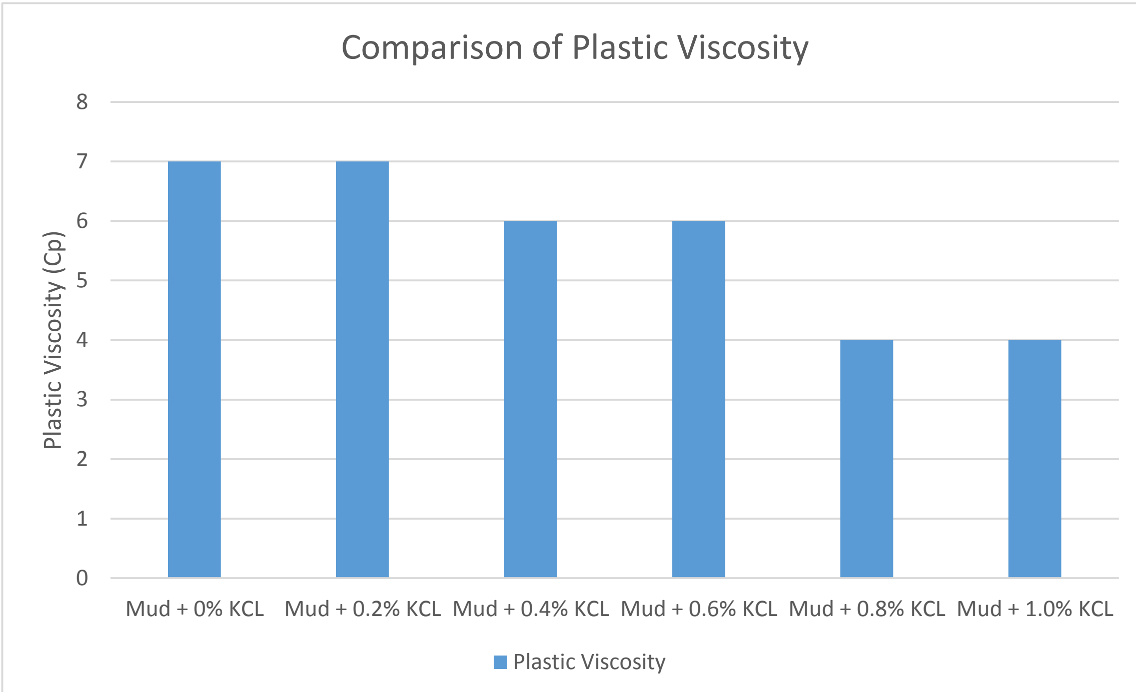

Figure 4.2: Comparison of Plastic Viscosity

A low PV indicates that the mud is capable of drilling rapidly because of the low viscosity of mud exiting at the bit. As shale hydrates, it will further increased the PV as their volume is increased. This makes the hydration and dispersion of shale particles particularly detrimental. This means that if the PV was high, mud was unable to drill rapidly. Figure 4.2 shows the Plastic Viscosity result of the mud with different concentration of KCl. There was noticeable reduction in Plastic Viscosity as the concentration of KCl increases. This result indicated that the introduction of KCl reduces the tendency of hydration and dispersion of shale particles.

Then, Yield point of the WBM with different concentration of KCl was compared as in bar chart below.

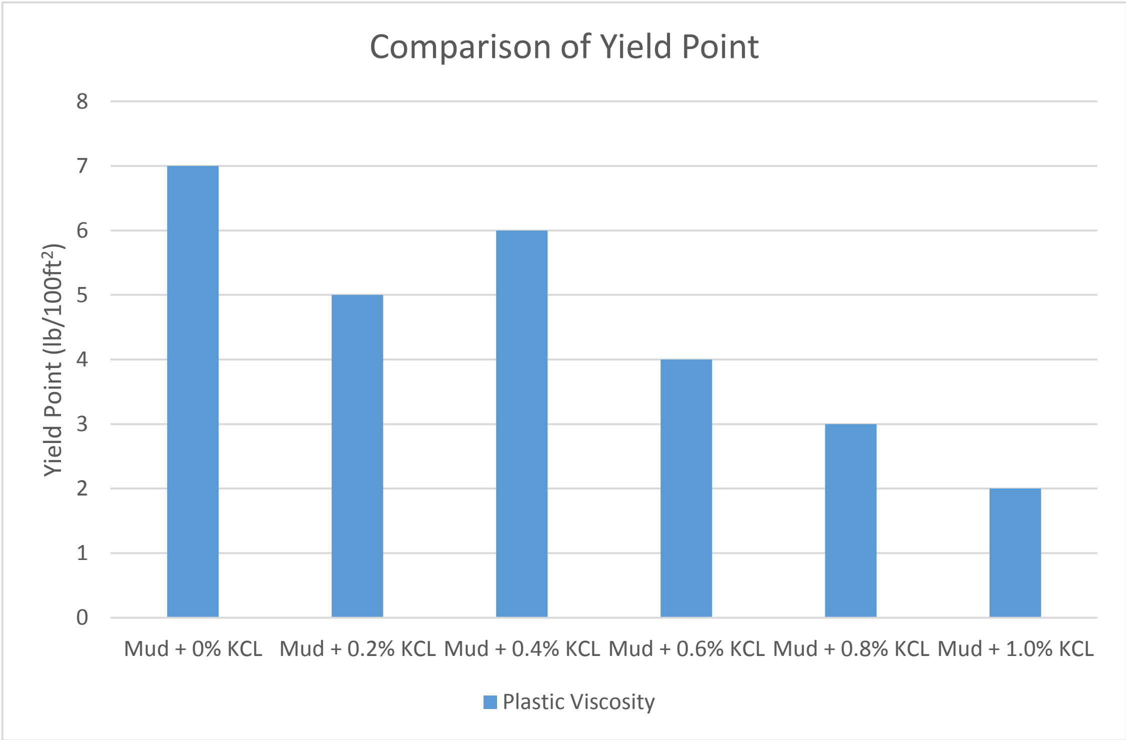

Figure 4.3: Comparison of Yield Point

Yield Point (YP) is resistance of initial flow of fluid or the stress required in order to move the fluid. YP is used to evaluate the ability of a mud to lift cutting out of the annulus measured in unit of lb/100 ft^2. It is also indicate how much pressure needed for the pump to start circulate cutting from wellbore to the surface. Very high YP can cause high pressure loss and high dispersion and settling tendency of the solid particles in the mixture. Depending on the shale type, water adsorption may lead to various reactions such as swelling, cutting dispersion, and increase in pore pressure creating wellbore instability to varying degrees. Figure 4.3 shows the yield point results with the different concentrations of KCl. It shows that the highest concentration of KCl gave the least yield point value. This is an indication that the dispersion and settling tendency reduces as KCl concentration increases which can avoid swelling, cutting dispersion and increase in pore pressure which creates wellbore instability to varying degrees.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

Test results indicated that the KCl inhibited the swelling tendencies of the shale and the rheological values reduced drastically. The reduction in rheological values considering the 600rpm reading were 9.5%, 14.2%, 23.8%, 47.6% and 52.4% respectively compared to results without KCl in the mud. This indicated that the degree of inhibition of KCl on shale contaminated increases as the concentration of KCl increased.

The variation of rheological properties of WBM varies with KCl concentration was measured by comparing the Yield Point and the Plastic Viscosity. There was noticeable reduction in Plastic Viscosity as the concentration of KCl increases. This result indicated that the introduction of KCl reduces the tendency of hydration and dispersion of shale particles. It was also observed that the highest KCl concentration gave the least yield point value. This indicates that there is a low dispersion and settling tendency of the solid particles in the mixture. Depending on the shale type, this high dispersion and settling tendency may lead to various reactions such as swelling, cutting dispersion and increase in pore pressure creating wellbore instability to varying degrees.

To improve the results of the experiment, more variation of KCl concentration need to be evaluated. This will get better view on the effect of different concentration of KCl in WBM to shale stability. Moreover, the shale sample that have been aged with WBM also can be tested by the X-Ray Diffraction analysis to find the changes in the clay interlayer spacing of the shale. This analysis will further find the effect of KCl in WBM to the shale stability.

Therefore, proper selection of drilling fluids to be used on a particular well site is an essential phase of any carefully planned drilling operation. To maintain a stable borehole through such zones, a carefully designed mud will be required. The design of successful fluids for this type of application depends largely on a knowledge of the physical and mineralogical characteristics of the shale and its behavior when in contact with drilling mud.

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