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**POLYPROPYLENE GLYCOLS SURFACTANT
AS ADDITIVES DRILLING FLUID FOR INJECTION WELL
IN LPLT AND HPHT ENVIRONMENTS**

by

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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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 not been undertaken or done by unspecified sources or person.

(Ezza Shazana Binti Mohd Shabarudin)

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ABSTRACT

This research is carried out to form a new formulation of drilling fluid for injection well that can be use for both high temperature high pressure (HPHT) and low temperature low pressure (LPLT) environments using non-ionic polypropylene glycol (PPG) based surfactant as an additive.

Usually for drilling wells, oil based mud are more favorable to be use because it can increase lubricity, enhance shale inhibition, and has great cleaning abilities with less viscosity. Oil based mud also withstands greater heat without breaking down. But due to its composition, oil based mud cannot decompose easily and often cause environmental issues. Therefore, having water based mud with surfactant additives is a good option to explore the potential of other drilling fluid that can be as efficient as oil based mud.

The laboratory work will be carried out to find the application of PPG in drilling fluid in which the focus will be on the improvement of LPLT and HPHT stability of conventional polymer, suspending agent (Xanthan Gum) and filtration reduction agent (PAC-LV) along with the existence of PPG based surfactant. This research will be divided into two stages and two phases in which the two stages are testing the concentration of PPG with and without presence of PAC-LV while the two phases are to determine the best concentration of PPG in mud samples and compare it with PETRONAS fluid bench mark.

Rheological and filtration properties of the drilling fluids will be conducted using standard testing apparatus, viscometer and API filter press respectively. It was observed after hot rolling at elevated temperature, mud with 0.57% PPG surfactant still maintaining high viscosity and proved to have lower fluid loss compared to the base mud. Besides, the improvement on the rheology properties was observed due to stabilization of the suspending polymers by the polyglycol system. These results showed that PPG has the potential to be use in LPLT and HPHT drilling environments.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Production of oil and gas over the years have decreasing due to depleted wells in which the wells unable to produce naturally. Consequently, this will result in economically unfeasible to the industry.

Primary recovery of oil utilizes the natural energy in the reservoir but production is often limited. Secondary recovery mechanism, like water flooding and surfactant flooding, increases oil recovery of original oil in place (C.E., Chineye 2009). In order to do water flooding and surfactant flooding, injection wells will be drilled. The water from injection wells physically sweeps the displaced oil to adjacent production wells.

When drilling injection wells, project design is one of the important design parameters. Well fluids have a natural tendency to lose the water phase (fluid loss) through the permeable rock formations commonly encountered during drilling. The problems are worsened by the high pressures inside the well which often exceed the pore pressure in the rock formation. For years various fluid loss control additives have been studied and successfully used. Under both static and dynamic conditions they can build up a filter cake on the well walls, thick enough not to limit fluid circulation in the well and impermeable enough to reduce the fluid lost by filtration into the formation (L. F. Nicora, W. M. McGregor, 1998).

The additives commonly used in oil or synthetic based drilling fluids were designed in past years with predominant focus on providing an efficient and economical function.

For nearly 50 years, the industry has relied on organically modified clays to provide viscosity and suspension to non aqueous fluids. However, the conventional quaternary ammonium salts to produce these additives have shown poor biodegradability, drawing scrutiny from some regulators (J. Miller, 2007).

The environment and technical performance of drilling fluid additives is a key characteristic of such products. One of the common additives drilling fluid which is still under study and has the most potential to perform as a biodegradable additive for drilling fluid is surfactants. Surfactants are compounds that lower the surface tension of a liquid, the interfacial tension between two liquids, or that between a liquid and a solid. Surfactant drilling fluid is a drilling mud prepared by adding surfactant to a water-based mud in order to change the colloidal state of the clay from that of complete dispersion to one of controlled flocculation. This research aimed to create stability of the rheological properties and fluid loss characteristics of optimized drilling fluid in order to drill an injection well. New formulation will be designed and analyzed in many ways to obtain the best outcome.

1.2 Problem Statement

Oil based mud can be a mud where the base fluid is a petroleum product such as diesel fuel. Oil based mud are used for many reasons, some being increased lubricity, enhanced shale inhibition, and greater cleaning abilities with less viscosity. Oil based mud also withstands greater heat without breaking down. The use of oil-based mud has special considerations. These include cost and environmental considerations. Oil based mud is considered as toxic waste therefore it cannot be disposed directly into land, river, or ocean. Many governments do not allow oil companies which don't have good waste management while drilling with oil base mud. In addition, mud cost of this system is higher than water base mud in terms of cost per barrel.

Due to that, water based mud count as an option even though it works not as excellent as oil based mud. In order to have performance at the same pace of oil based mud,

surfactant will be added to water based mud. This will not only help to cut the cost but also help to save the environment from oil contamination since surfactant additives drilling fluid can be made biodegradable.

There are many aspects of water based mud which must be improved before they can truly approach the performance of an oil based mud. Oil based mud provide increased drilling performance by combining shale hydration inhibition, drill string lubrication, reduced stuck pipe risk, low formation damage, corrosion avoidance and high temperature stability (C. A. Sawdon, M. E. Brady, S. Cliffe, S. G. James, 1995).

As surfactant based fluid systems is gaining acceptance as reservoir drilling fluids as it leave little residue compared to the conventional one and the non-ionic surfactant gaining more attention in improving drilling fluid technology, thus the capability of the non-ionic surfactant used in enhanced oil recovery to be used in the drilling fluid is now questionable (C. O. Chinenye, 2010).

Surfactant is a contraction of the words surface-active and agent. Surfactants function by changing the surface tension at the interface of mixtures, allowing non-miscible materials to either be dispersed into water or separated from water. In this research, polypropylene glycol (PPG) based surfactant will be use as an additive to water based mud. Water-based glycol mud is becoming increasingly popular due to its exceptional shale inhibition properties, environmental effectiveness and ease of handling and high lubricity (S. M. Samaei).

Therefore, in this research PPG can be used as an additive to water based mud drilling fluid to help achieve the same objective as oil based mud. Water based mud additive with surfactants aid to decrease shale sloughing and borehole instability while drilling. This is accomplishing by reducing the water-wettability of the rock and preventing water from interacting with the formation and causing the damage (Christensen et al, 1990).

1.3 Objectives

This research aimed to study the properties of the new formulation of drilling fluid by using surfactants as an additive to water based mud. These are the outlined objectives:

- 1) To design an optimized polypropylene glycol (PPG) based surfactants additive drilling fluid.
- 2) To analyze and compare rheological and filtration loss characteristics of polypropylene glycol (PPG) based surfactants additive drilling fluid with PETRONAS drilling fluid benchmark.

1.4 Scope of Study

The scope of study mainly revolves the important elements to achieve objectives stated. There are as listed:

- Conducting research on the mechanism of surfactants as an additive in drilling fluid.
- Conducting research on theory and definition of terms related to propylene glycol surfactant.
- Collecting data and sample for laboratory works.
- Preparing a new formulation for propylene glycol surfactant additive drilling fluid in LPLT and HPHT environment.
- Conducting performance test to see the effectiveness of a propylene glycol surfactant in exhibiting good rheology, fluid loss control and thermal stability when added to drilling fluid.
- Comparing drilling fluid performances between with and without surfactants and PAC-LV
- Optimizing propylene glycol surfactants additive drilling fluid to get the best result.
- Evaluating and analyzing results from laboratory works.

1.5 Relevance of Project

The findings from this research will enhance the applicability of propylene glycol surfactant as additive in drilling fluid for injection wells. Through lab experiments, it is hope that the prospect of propylene glycol surfactant will not just be limited to surfactant flooding and EOR but also applicable in drilling fluid. The research is relevant in providing explanation on rheology performance, fluid loss control and thermal stability.

1.6 Limitation of Study

This research is going to be prepared until all the objectives are achieved. But along the way, there are still limitations and shortcomings to make this research a success. The limitation of study for this research is it only covers experimental works and also analysis of the results. Beyond than that, such as field experimental are unable to conduct since this research is still understudy and need more exploration before it can be tested securely in the real industry.

The experimental works that will be done in this research are:

- Preparation of Mud Samples – new formulation of surfactants additive drilling fluid.
- Mud Rheology Test – determine viscosity, yield point and gel strength.
- Fluid Loss Test – measure volume of filtrate collected and observed mud cake formed.
- Data Gathering and Analysis – collect all the related data and analyze the results

CHAPTER 2

THEORY AND LITERATURE REVIEW

2.1 Theory

There are several parameters that need to be considering in this research. This section will explore the properties of drilling fluids which is important to design an optimized propylene glycol surfactant additives drilling fluid.

2.1.1 Rheology

Rheology refers to the deformation and flow behavior of all forms of matter. Certain rheologic measurements made on fluids, such as viscosity, yield point and gel strength help to determine how this fluid will flow under a variety of different conditions. This information is important in the design of circulating systems required to accomplish certain desired objectives in drilling operations. (Gray, 1988)

- **Plastic viscosity (PV)**

Plastic Viscosity (PV) is the resistance of fluid to flow. According to the Bingham plastic model, the PV is the slope of shear stress and shear rate. In the field, we can get the PV from a viscometer. Typically, the viscometer is utilized to measure shear rates at 600, 300, 200, 100, 6, and 3 revolutions per minute (rpm). Two types of fluid characterizations are:

- Newtonian (true fluids) where the ratio of shear stress to shear rate or viscosity is constant, e.g. water, light oils, etc. And
- Non-Newtonian (plastic fluids) where the viscosity is not constant, e.g. drilling mud, colloids, etc.

$$\text{Plastic Viscosity (PV)} = \text{Reading at 600 rpm} - \text{Reading at 300}$$

Figure 1: Formula to determine plastic viscosity (in centipoises)

- Yield Point (YP)

Yield Point (YP) is resistance of initial flow of fluid or the stress required in order to move the fluid. You can simply say that the Yield Point (YP) is the attractive force among colloidal particles in drilling mud. The YP indicates the ability of the drilling mud to carry cuttings to surface. Moreover, frictional pressure loss is directly related to the YP. If you have higher YP, you will have high pressure loss while the drilling mud is being circulated (R. Jetjongjit, 2010).

$$\text{Yield Point (YP)} = \text{Reading from a viscometer at 300 rpm} - \text{Plastic Viscosity (PV)}$$

Figure 2: Formula to determine yield point (in lb/100ft²)

- 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. Gel strength measurement give an indication of the amount of gellation that will occur after circulation ceased and the mud remains static. The more the mud gels during shutdown periods, the more pump pressure will be required to initiate circulation again. Most drilling mud are either colloids or emulsions which behave as plastic or non-Newtonian fluids. The flow characteristics of these differ from those of Newtonian fluids (i.e. water, light oils, etc.) in that their viscosity is not constant but varied with the rate of shear. Therefore, the viscosity of plastic fluid will depend on the rate of shear at which the measurements were taken.

Gel strength can be determining using viscometer, in lb/100sq.ft of a mud. To convert gel strength to dynes/cm², this formula can be use:

$$\text{Lb/100 ft}^2 \times 5.077 = \text{Gel strength in dynes/cm}^2$$

Figure 3: Formula to convert gel strength to dynes/cm²

2.1.2 Filtration Loss

The loss of liquid from a mud due to filtration is controlled by the filter cake formed of the solid constituents in the drilling fluid. The test in the laboratory consists of measuring the volume of liquid forced through the mud cake into the formation drilled in a 30 minute period under given pressure and temperature using a standard size cell. It has been found in early work that the volume of fluid lost is roughly proportional to the square root of the time for filtration, i.e.

$$V \propto \sqrt{t}$$

The two commonly determined filtration rates are the low-pressure, low temperature and the high-pressure high-temperature.

2.2 Literature Review

This research will focus on creating a drilling fluid in which the main components are water based mud and additive of surfactants to have an optimized design which is compatible with the common reservoir conditions. Therefore, the related literature is thoroughly reviewed in this section.

2.2.1 Principal Components of Drilling Fluids

“Drilling fluids can be classified on the basis of a principal component. These components are (1) water, (2) oil and (3) gas” (G. R. Gray, H. C. H. Darley, 1981)

- Water as a drilling fluid

Water was the first drilling fluid to be used and still is the principal component of most drilling fluids. Consequently, water mud will receive the most attention in subsequent discussions.

Water may contain several dissolved substances. These include alkalis, salts and surfactants: organic polymers in colloidal solution; droplets of emulsified oil; various insoluble substances (such as barite, clay and cuttings) in suspension. The mud composition selected for use often depends on the dissolved substances in the most economically available makeup water, or on the soluble or dispersive materials in the formations to be drilled (G. R. gray, H. C. H. Darley, 1981).

- Oil as a drilling fluid

Oil based mud have oil as the continuous liquid. The oil most often selected is diesel oil, although some crude oils are acceptable. Because some water will always be present, the oil must contain water-emulsifying agents (G. R. gray, H. C. H. Darley, 1981).

Oil base mud is drilling mud that has oil as the external phase. Oil base mud is invert emulsion because the external phase is oil and the internal phase is water. Oil water ratio has range from oil 50%: water 50% to oil 95 % to water 5 %. Currently, many operators prefer to use the oil base mud instead of water based mud even though oil based mud is expensive and has poor biodegradable.

- Gas as a drilling fluid

Gas drilling fluids can be classified as: (1) dry gas, (2) mist (in which droplets of water or mud are carried in the air stream), (3) foam (in which air bubbles are surrounded by a film of water containing foam stabilizing substance and (4) gel foam (in which the foam contains film-strengthening materials, such as polymers or bentonite). Air is the most common gas drilling fluid, although natural gas (methane), exhaust or combustion gases are sometimes used (G. R. gray, H. C. H. Darley, 1981).

This research will explore the potential of using water based mud and surfactant as additive to design a new formulation of drilling fluid in which can perform as effective as oil based mud. This is a review on surfactants:

2.2.2 Surfactants

A surfactant is a compound which lowers the surface tension of a liquid, increasing the contact between the liquid and another substance. There are a wide variety of surfactants, which work with oil, water, and an assortment of other liquids. Many companies manufacture a range of surfactants for various purposes, ranging from soaps to inks. You may also hear a surfactant referred to as a “wetting agent.”

The term surfactant is the standard contraction for surface active agent, so called because these agents are adsorbed on surfaces and at interfaces, and lower the surface free energy thereof. They are used in drilling fluids as emulsifiers, wetting agents, foamers, defoamers, and to decrease the hydration of clay surfaces (G. R. Gray, H. C. H. Darley, 1981)

Surfactants are some compounds, like short-chain fatty acids, are amphiphilic or amphipathic, they have one part that has an affinity for nonpolar media and one part that has an affinity for polar media. These molecules form oriented monolayer at interfaces and show surface activity (they lower surface or interfacial tension of the medium in which they are dissolved). The polar-attractive portion is often recognized as hydrophilic part or hydrophile while the apolar part is recognized as hydrophobe or lipophilic.

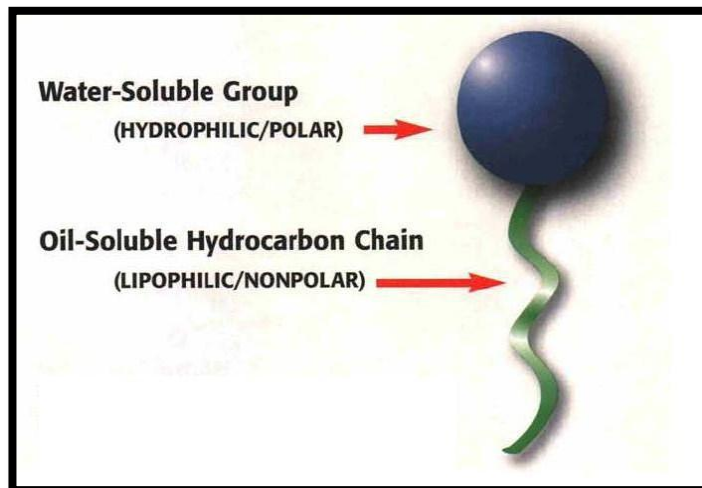


Figure 4: A typical surfactant molecule showing a hydrophilic water-attracting group and a long, oil soluble (lipophilic) hydrocarbon chain (Karnok et al., 2004)

Due to their dual-affinity behaviour, amphiphilic molecules align themselves with each region of their structure is in its preferred environment. Surfactants will end up settle in interfaces between different chemical environments or phases. In this process, molecules actually cause a physical change at the surface of liquids in medium which they are dissolved by lower the interface between two liquids (interfacial tension) or between a liquid and a gas or a liquid and a solid (surface tension). Thus, oriented monolayers are formed at the interfaces which signify the surface activity.

The primary classification of surfactant is made on the basis of the charge of the polar head group. Surfactant can be classified into (Darley and Gray, 1988):

- Anionics (Negatively charged group) dissociate into large organic anion and simple inorganic cation. The classic example is soap.
- Cationics (Positively charged group) dissociate into large organic cation and a simple inorganic anion. They are usually the salt of a fatty amine or polyamine.
- Nonionic (No charge group) surfactants are long chain polymers which do not dissociate.

“Recently surfactants are commonly used in well completion or workover operations to reduce formation damage and preventing water blocks and emulsions” (Hower, F. Wyne, J. Stegelman, 1956; S. K. Baijal, L. R. Houchin, K. L. Bridges, 1991)

According to (C. O. Chinenye, 2010), surfactant based fluid typically have little residue or formation damage compared to biopolymer systems, thereby gaining acceptance as reservoir drilling fluids. Low interfacial tension existing between surfactant based fluid and the produced or injected fluid is one of major criteria for this reduction in formation damage. In addition, a controlled flocculated mud system incorporating non-ionic surfactant plus water soluble electrolytes proved thermally stable which would give good hole condition and logging characteristics as reported by Burdyn (1956).

Table 1: Types of Surfactant (James R. Kanicky, 2001)

Anionic	Dissociated in water in an amphiphilic anion, and cation which is in general an alkaline metal (Na ⁺ , K ⁺) or a quaternary ammonium
Non-ionic	Do not ionize in aqueous solution, because their hydrophilic group is of a non dissociable type, such as alcohol, phenol, ether, ester or amide. A large proportion of these non-ionic surfactants are made hydrophilic by the presence of a polyethylene glycol chain, obtained by the polycondensation of ethylene oxide. They are called polyethoxylated non-ionic.
Cationic	Dissociated in water into an amphiphilic cation and an anion, most often of the halogen type.
Zwitterionic	A single surfactant molecule exhibit both anionic and cationic dissociation.
Polymeric surfactants/ surface active polymers	Result from association of one or several macromolecular structures exhibiting hydrophilic and lipophilic characters, either as separated blocks or as grafts

2.2.3 Polypropylene Glycol (PPG) Non-Ionic Surfactant

This research is focusing on using PPG non-ionic surfactant as an additive to water based mud. Polypropylene glycol or polypropylene oxide is the polymer of propylene glycol. They are clear, viscous liquids with low pour points. Viscosity increases and water solubility decreases with increasing molecular weight. Chemically it is a polyether. The term polypropylene glycol or PPG is reserved for low to medium range molar mass polymer when the nature of the end-group, which is usually a hydroxyl group, still matters. The term "oxide" is used for high molar mass polymer when end-groups no longer affect polymer properties. In 2003, 60% of the annual production of propylene oxide of 6.6×10^6 tonnes was converted into the polymer. Polypropylene glycol is produced by ring-opening polymerization of propylene oxide. The initiator is an alcohol and the catalyst a base, usually potassium hydroxide. When the initiator is ethylene glycol or water the polymer is linear. With a multifunctional

initiator like glycerine, pentaerythritol or sorbitol the polymer branches out. The chemical composition of polypropylene glycol can be summarized as $H(C_3H_6O)_nOH$, where C_3H_6O is propylene oxide and n is the number of occurrences of this molecular unit commonly between 300 and 4,000. It thus consists of repeating units of propylene oxide with a hydrogen atom at one end and a hydroxyl (OH) group at the other.

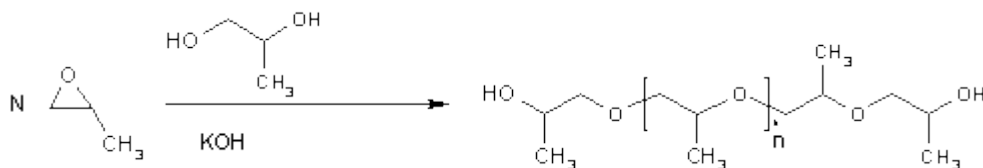


Figure 5: Polymerization of Polypropylene glycol (Wikipedia)

Properties and Uses of PPG

PPG has many properties in common with polyethylene glycol (PEG). The polymer is a liquid at room temperature. Solubility in water decreases rapidly with increasing molar mass. One reason why water based mud with additives of surfactant is more successful maybe that the molecules are small enough to penetrate the shale matrix, whereas large molecules will be screened out on the surface of the shale. Also, the lower molecular weight materials are liquids, and so are easily mixed into drilling fluid (Samaei S. M.). In addition, PPG is less toxic than PEG, so biotechnological are now produced in PPG. It is also widely use in the industries:

- PPG is used in many formulations for polyurethanes. It is used as a rheology modifier.
- PPG is used as a surfactant, wetting agent, dispersant in leather finishing.
- PPG is also employed as a tuning reference in mass spectrometry.
- PPG is used as a primary ingredient in the manufacture of paintballs.
- PPG is used to administer the drug Melarsoprol in patients suffering from second stage trypanosomiasis since the drug is insoluble in water. This mixture must be injected intravenously.

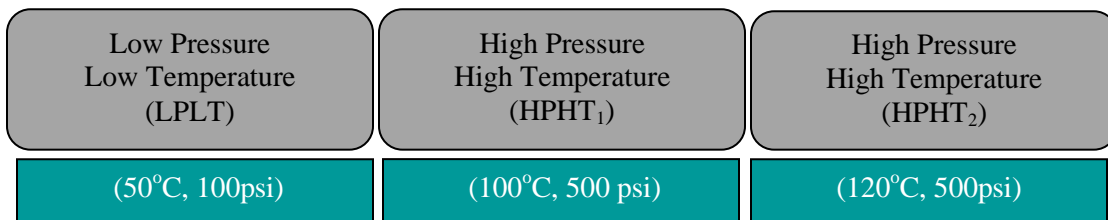
CHAPTER 3

RESEARCH METHODOLOGY

3.1 Experiment Work Flow

Laboratory work is carried out to investigate the interactions water based mud drilling fluid with and without presence of surfactant and PAC-LV for LPLT and HPHT environment. The polymers focused in this study are rheology modifier, Xanthan Gum and filtration control polymer, Poly Anionic Cellulose – Low Viscosity (PAC-LV). On the other hand, the surfactant used is a non ionic PPG surfactant.

In order to better understand the nature of fluid loss of water based mud drilling fluid at high pressure and high temperature, experimental analysis was performed on base fluid (with and without PAC-LV). The analysis carried out includes rheology test (LPLT and HPHT) as well as fluid loss test (LPLT and HPHT). The same procedures are repeated for fluid with surfactant (with and without PAC-LV), PPG added in order to understand its interactions with polymers and thus, finding its application in HPHT drilling fluid.



From the project flow chart, this research will be break into two phases. The first phase will be focusing on the mud samples preparation and the second phase will be on the rheological and filtration loss test. In addition, for the first phase, it will be divided into two stages in which the mud preparation is differentiate with presence and absence of PAC-LV. Combining the two stages, all mud will be then differentiate based on concentration of surfactants (+0% v/v PPG, +0.29% v/v PPG, +0.57% v/v PPG and 1% v/v PPG).

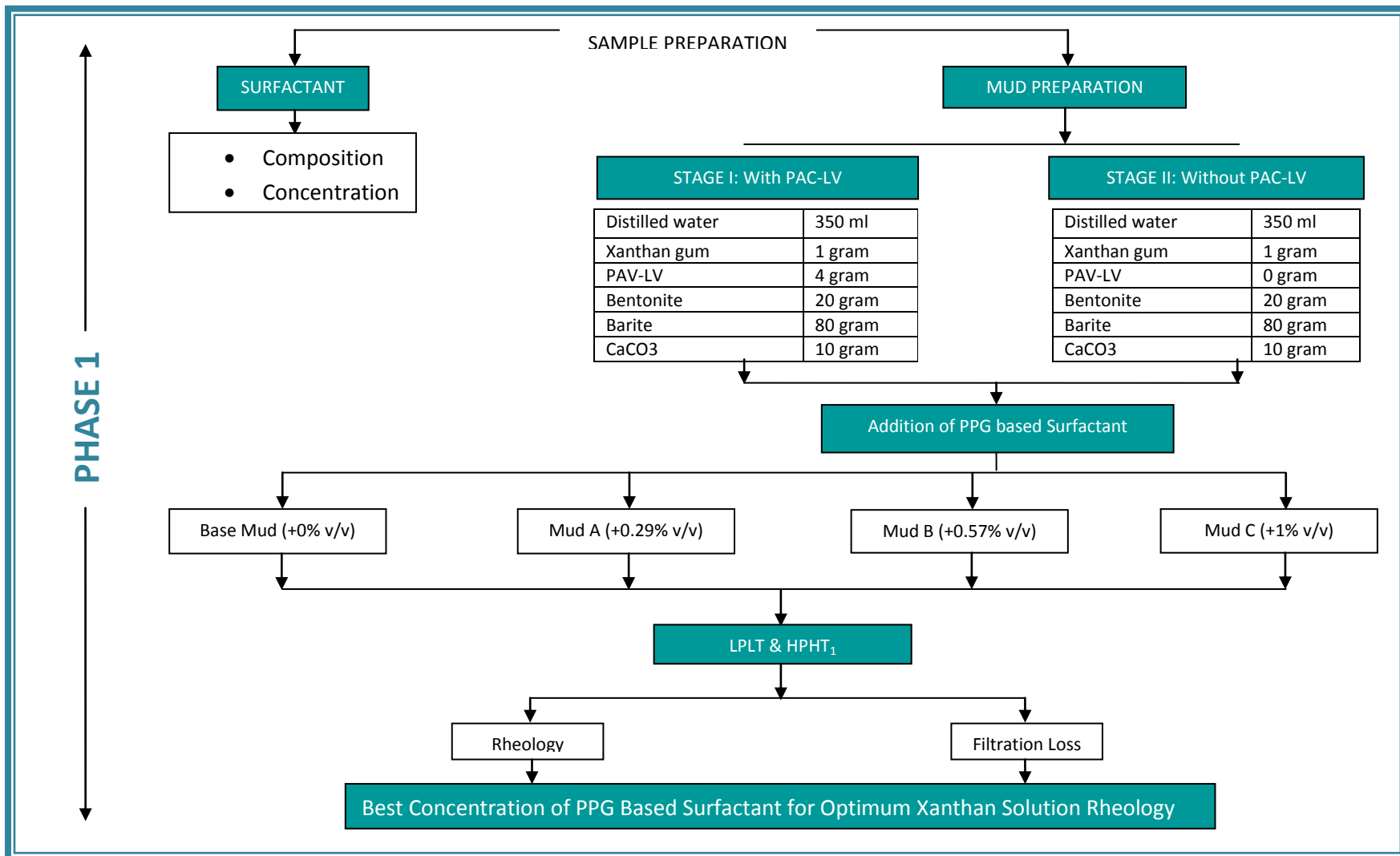


Figure 6.1: Project Flow Chart Phase I

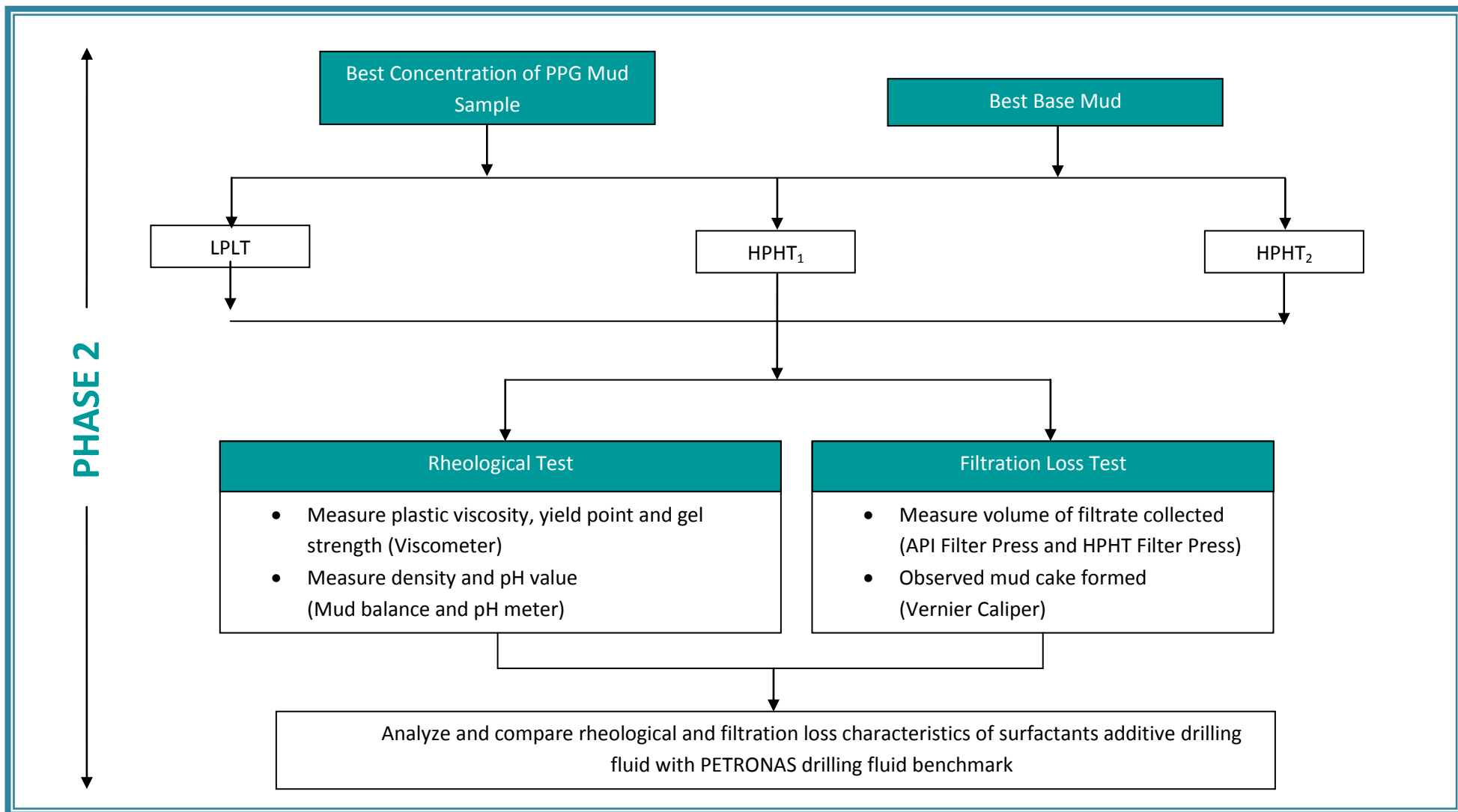


Figure 6.2: Project Flow Chart Phase II

3.2 Tools and Equipments

For better understanding on how to work in the laboratory, all tools and equipments must be familiarize first. In this table below is the list of tools or equipments with their respective primary functions.

Table 2: Tools and equipment

Equipments / Tools	Primary Function
Electronic Balance	Weighting raw materials
Graduated Cylinder	Volume measurements
Multi-Mixer (Model 9B)	Mixing of drilling fluid
Baroid Mud Balance	Determines density of drilling fluid
Digital pH Meter	Determines pH of drilling fluid
FANN Viscometer	Measures viscosity of drilling fluid
Roller Ovens	Aging fluid samples
Aging Cells	Contains drilling fluid for aging
Filter Press API	Determines the filtration properties of drilling fluid
Filter Paper 3.5" (9cm)	To be used together with filter press API
Vernier Caliper	Measures mud cake thickness
Stopwatch	Accurately measures elapsed time

3.2.1 Baroid Mud Balance

The Baroid Mud Balance as shown below is used to determine density of the drilling fluid. the instrument consists of a constant volume cup with lever arm and rider calibrated to read directly the density of the fluid in ppg (water 8.33), pcf (water 62.4), specific gravity (water = 1.0) and pressure gradient in psi/1000ft (water 433psi/ft.).

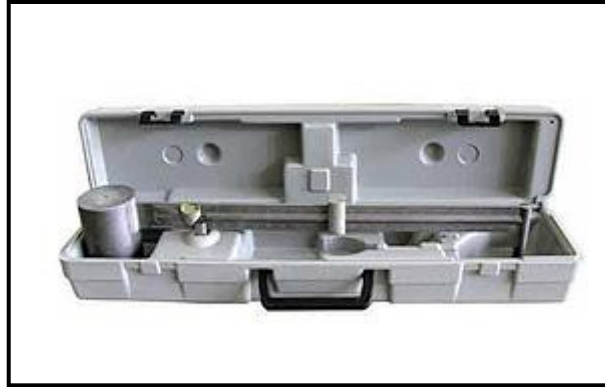


Figure 7: Baroid Mud Balance

3.2.2 Digital pH meter

A pH meter is an electric device utilizing glass electrodes to measure a potential difference and indicate directly by dial reading the pH of the sample. The pH meter is the most accurate method in measuring pH.



Figure 8: pH meter

3.2.3 FANN Viscometer

The FANN (Model 35A) Viscometer is a coaxial cylindrical rotational viscometer, used to determine single or multi-point viscosities. It has fixed speeds of 3 (GEL), 6, 100, 200, 300 and 600 RPM that are switch selectable with the RPM knob.

The FANN Viscometer is also used to determine the Gel strength, in lb/100 sq. ft., of a mud. The Gel strength is a function of the inter-particle forces. An initial 10-second gel and a 10-minutes gel strength measurement give an indication of the amount of gellation that will occur after circulation ceased and the mud remains static. The more the mud

gels during shutdown periods, the more pump pressure will be required to initiate circulation again.



Figure 9: FANN Model 35A Viscometer

3.2.4 Filter Press

The low pressure test is made using standard cell under the API condition of 100 ± 5 psi for 30 minutes at room temperature. Another special cell will be used to measure filtration rate at elevated temperatures and pressure. Filter press used for filtration tests consists of four independent filter cells mounted on a common frame. Each cell has its own valve such that any or all the cells could be operational at the same time. Toggle valve on the top of each cell could be operated independently for the supply of air for each individual cell.



Figure 10: Filter Press

3.2.5 Aging of Mud Samples at High Temperatures

Roller oven is used for this stage. 175ml of mud sample is contained in a stainless steel cell of 260ml. Then, the cell is pressurized with nitrogen to prevent boiling of the liquid phase during aging at high temperatures later. The applied pressure should be at least equal to the vapour pressure of liquid at the test temperature. Roller oven is set to be at desired test temperature and the cell is placed in it and rolled. The purpose of roller oven is to stimulate aging of mud while it is circulating in the well. The minimum time for aging is 16 hours.

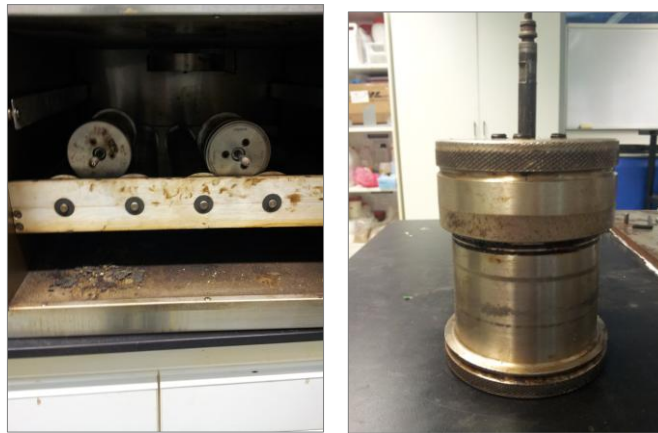


Figure 11: Aging Cells inside Hot Rolling Oven

3.3 Mud Composition

In drilling fluids, polymer is applied to several varied and versatile substances which are composed of a number of repeating or similar units, or groups of atoms (known as *monomers*) consisting primarily of compounds of carbon (Darley and Gray, 1988; Devereux, 1999). Polymers are intentionally added to perform very specific functions, such as rheology modification, fluid loss control, shale inhibition etc. (Van Oort, 1997; Jayanth, 2010). Examples of polymer frequently used in drilling fluids are starch, carboxymethyl cellulose (CMC) and their derivatives, xanthan gum (XC), partially hydrolyzed polyacrylamide (PHPA). Their general properties are well known because they have been used for many years (Thomas, 1982). It is the colloidal properties that decide its role in drilling fluids. A few has strong affinity for water which developing highly swollen gels in low concentration. Also, others offer protection from flocculation

by salts after strongly absorbed by clay particles. Polymers also reduce the flow of water through a filter cake using its slimy particles even though it does not swell as much as they do in fresh water. Unfortunately, these polymers pose limitations at elevated temperature mainly due to two factors: degradation of additives and chemical reaction between additives and silicate minerals in drilling fluids (Burdyn et al, 1956; Rogers, 1953).

Table 3: Thermal Stability of Common Organic Polymer (Gulf Professional Publishing-Composition and Properties of Drilling and Completion Fluids,1988)

Polymer	Classification	Temperature Stability
Starch	Filtration control	Up to 200°F (93°C)
Guar gum	Filtration control, hole stability	Up to 150°F (66°C)
Xanthan gum	Suspending agent	Up to 250°F (120°C)
CMC	Filtration control	Up to 300°F (150°C)
HEC (mostly in completion fluid)	Filtration control, viscosifier	Up to 275°F (135°C)
PAC	Filtration control	Up to 300°F (150°C)

3.3.1 Xanthan Gum

Xanthan gum is properly classed with the natural polymer, although it is actually obtained in its produced rather than in its natural form. Xanthan is a water-soluble polysaccharide produced by bacterial action (genus *Xanthomonas*) on carbohydrates. Deily et al reported several interesting properties of xanthan gum solutions. The polymer builds viscosity in water or salt solutions, although somewhat more gum is required for the same viscosity increase in saturated salt solution. Xanthan gum's major application in drilling fluid is as a thickener or more precisely, as a suspending agent. Carico concluded that the suspending ability of a polymer solution is directly related to the low shear rate viscosity of the solution, i.e., K taken at 200 and 100 rpm, or the 3 rpm dial reading, on the Fann viscometer. Results of a simple settling test show that the suspending ability of xanthan gum surpasses any other polymer currently used in

drilling fluids. The exceptional suspending ability of xanthan gum at low concentrations favors its use wherever transportations costs are high. Although xanthan gum is not a filtration control agent, it is compatible with filtration reducing substances, such as bentonite and CMC. (Gray, 1988)

3.3.2 PAC-LV (Polyanionic Cellulose Low Viscosity Grad)

PAC-LV effectively reduces the API filtration rate of many water based drilling fluids, especially solids-laden fluids, without causing significant increases in viscosity or gel strengths. In addition small amount of PAC-LV polymer can reduce and stabilize the rheology of flocculated or solids laden fluids. (Gray, 1988)

3.3.3 Calcium Carbonate

Calcium carbonate is A compound with formula CaCO_3 that occurs naturally as limestone. Ground and sized calcium carbonate is used to increase mud density to about 12ppg and is preferable to barite because it is acid soluble and can be dissolved with hydrochloric acid to clean up production zones. Its primary use is as a bridging material in drill in, completion and workover fluids. Sized calcium carbonate particles, along with polymers, control fluid loss in brines or drill-in., completion and workover fluids. Insoluble calcium carbonate is the precipitated by product of mud treatments used for removal of either Ca^{2+} or CO_3^{2-} by addition of the other ion. (Gray, 1988)

3.3.4 OCMA Clay

The organophilic clay is prepared from bentonite or attapulgite. The organic cation is added to a suspension of the clay in the water. The amino groups replace the sodium and calcium cations originally present on the clay surfaces. At the same time, the hydrocarbon chains displace the previously adsorbs water molecules. The clay precipitates because it is no longer wetted by water. The organophilic clay is separated, washed and dried. (Gray, 1988)

3.3.5 Barite

Barite is virtually soluble in water, and does not react with other components of the mud. Commonly used as a weighting agent for all types of drilling fluids. (Gray, 1988)

3.4 Composition of PPG Based Surfactant

To identify the composition of the sample known as S13A, GC-MS (Gas chromatography - mass spectrometry) is being use. GC-MS is a method that combines the features of gas-liquid chromatography and mass spectrometry to identify different substances within a test sample.

The GC-MS is composed of two major building blocks: the gas chromatograph and the mass spectrometer. The gas chromatograph utilizes a capillary column which depends on the column's dimensions (length, diameter, film thickness) as well as the phase properties (e.g. 5% phenyl polysiloxane). The difference in the chemical properties between different molecules in a mixture will separate the molecules as the sample travels the length of the column. The molecules are retained by the column and then elute (come off) from the column at different times (called the retention time), and this allows the mass spectrometer downstream to capture, ionize, accelerate, deflect, and detect the ionized molecules separately. The mass spectrometer does this by breaking each molecule into ionized fragments and detecting these fragments using their mass to charge ratio.

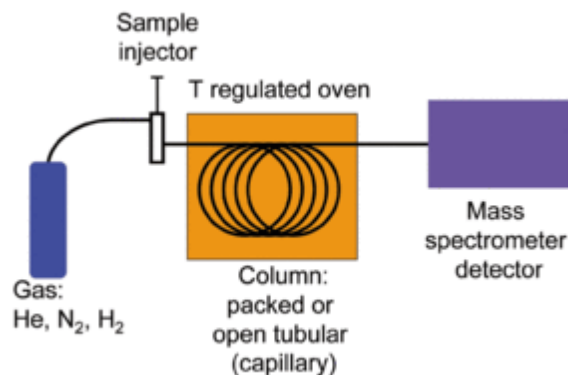


Figure 12: GC-MS schematic (Wikipedia)

These two components, used together, allow a much finer degree of substance identification than either unit used separately. It is not possible to make an accurate

identification of a particular molecule by gas chromatography or mass spectrometry alone. The mass spectrometry process normally requires a very pure sample while gas chromatography using a traditional detector (e.g. Flame ionization detector) cannot differentiate between multiple molecules that happen to take the same amount of time to travel through the column (*i.e.* have the same retention time), which results in two or more molecules that co-elute. Sometimes two different molecules can also have a similar pattern of ionized fragments in a mass spectrometer (mass spectrum). Combining the two processes reduces the possibility of error, as it is extremely unlikely that two different molecules will behave in the same way in both a gas chromatograph and a mass spectrometer. Therefore, when an identifying mass spectrum appears at a characteristic retention time in a GC-MS analysis, it typically increases certainty that the analyte of interest is in the sample.

Method used:

- Agilent 9780A
- Column: DB-5 MS, 30m x 0.25mm x 1.00 μ m (USC120525H)

Sample was injected in split less mode and helium was used as a carrier gas with a flow of 2, 8 mL/minute at the temperature of 290°. Initial column temperature was 70° and was maintained for 3 minutes. It was increased at 160° with a rate of 20°/minute and finally reached 280° with a rate of 10°/min where it was kept for 10 minutes. Injector temperature was 270°. The chromatographic method was adopted from Diaz A and Ventura F. The result obtained is then analyzed and found that polypropylene glycol (PPG) is the main composition in S13A surfactant.



Figure 13: The insides of the GC-MS, with the column of the gas chromatograph in the oven on the right (Wikipedia)

3.5 Mud Sample Preparation

Table 4: Sample Nomenclature (Drilling Fluid Samples)

Samples		Types of Drilling Mud		Elements					
Stage I									
LPLT (50°C, 100psi) HPHT (100°C, 500psi) HPHT (120°C, 500psi)	Base Mud	Blank	0 ml PPG Surfactant	350 ml Distilled water	1 gram Xanthan gum	0 gram PAV- LV	20 gram Bentonite	80 gram Barite	10 gram CaCO ₃
	A	+ 0.29% v/v Surfactant	1 ml PPG Surfactant						
	B	+ 0.57% v/v Surfactant	2 ml PPG Surfactant						
	C	+ 1% v/v Surfactant	3.5 ml PPG Surfactant						
Stage II									
LPLT (50°C, 100psi) HPHT (100°C, 500psi) HPHT (120°C, 500psi)	Base Mud	Blank	0 ml PPG Surfactant	350 ml Distilled water	1 gram Xanthan gum	4 gram PAV- LV	20 gram Bentonite	80 gram Barite	10 gram CaCO ₃
	A	+ 0.29% v/v Surfactant	1 ml PPG Surfactant						
	B	+ 0.57% v/v Surfactant	2 ml PPG Surfactant						
	C	+ 1% v/v Surfactant	3.5 ml PPG Surfactant						

The compositions for each mud are the same but with different additions of surfactant and PAC-LV as shown in Table 4.

In stage I, the objective is to determine the optimum concentration of PPG surfactant and the optimal rheological and filtration properties of mud with and without surfactant at elevated temperatures. Thus, samples in different concentration (0% v/V, 0.29% v/V, 0.57% v/V, 1% v/V) without presence of PAC-LV were tested.

In stage II, the objective is the same as in the stage I but with the presence of PAC-LV. The reason that PAC-LV is a manipulative composition because this research is focusing on getting the better result using surfactant as an additives instead of using other substance overtake it roles in this research. With the results obtained from with and without surfactants and PAC-LV, they can be comparing through its performance.

3.6 Laboratory Work Procedures

In this research, the laboratory works are crucial as all the results and discussion will be focusing on the data that obtained from the laboratory works.

3.6.1 Preparation of Mud Samples

Multi-mixer is used in this stage. To prepare the base mud, 350ml distilled water is poured into the multi-mixer cup and stirred well. Xanthan gum is firstly added into the cup slowly bit by bit. After all Xanthan gum has been added, mixture is stirred for another 5 minutes before adding the next compounds. If Polyacrylamide (PAC-LV) is added, slowly stir the mixture for another 2 minutes. The same steps are repeated for OCMA clay / Bentonite and Barite. Calcium Carbonate (CaCO_3) is added and continues to stir for another 20 minutes. For mud samples with surfactant, surfactant is added into the base mud and stirred for another 5 minutes.



Figure 14: Drilling fluid after mixing

The sequences to mix all the mud composition are shown in Table 5:

Table 5: Mixing sequences

Sequence	Compositions	Duration
1	Distilled water	-
2	Xanthan gum	5 minutes
3	PAC-LV	2 minutes
4	OCMA-Clay/Bentonite	2 minutes
5	Barite	2 minutes
6	CaCO ₃	20 minutes
7	Surfactant	5 minutes

3.6.2 Mud Rheology Test

175ml of the prepared mud is taken and poured into a viscometer cup. The upper housing of viscometer is tilted back to locate the cup under the sleeve. Then, the upper housing is lowered to its normal position. Mud in the cup is stirred for about 5 seconds at 600rpm before the desired RPM is selected. Readings at 600, 300, 200, 100, 6 and 3 rpm are taken and recorded.

Another rheological parameter, gel strength measured in lb/100sqft is also obtained by noting the maximum dial deflection of viscometer turned to low rotor speed (6 rpm) after the mud is remained static for some period of time. The mud remained static for 10 seconds is recorded as 10s gel strength while 10 minutes as 10min gel strength.

3.6.3 Filtration Loss Test

The prepared mud is poured to a filter press cup and which is assembled as shown in figure below. 100psi of pressure is applied through an air supply line and the valve is opened. At the same time, timing clock is started. The volume of fluid collected in graduated cylinder is recorded every minute for duration of 30 minutes.

The thickness of filter cake developed on the filter paper is also measured using a scale nearest 1/32" and observed physically.

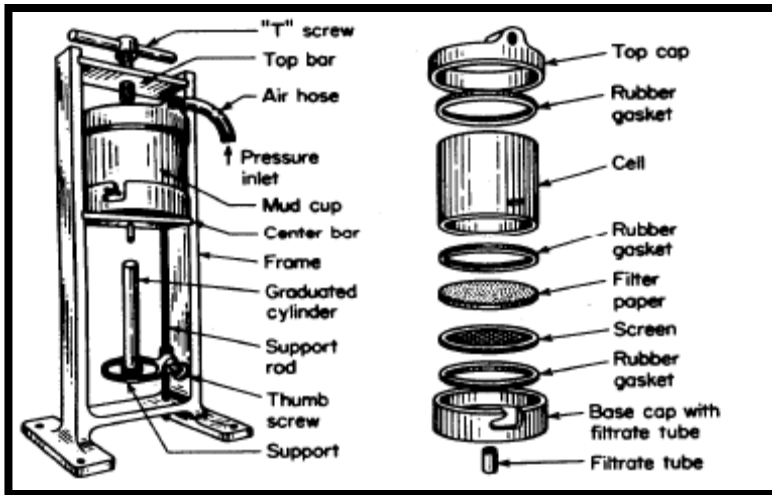


Figure 15: Standard API Filter Press



Figure 16: High Temperature High Pressure Filter Press

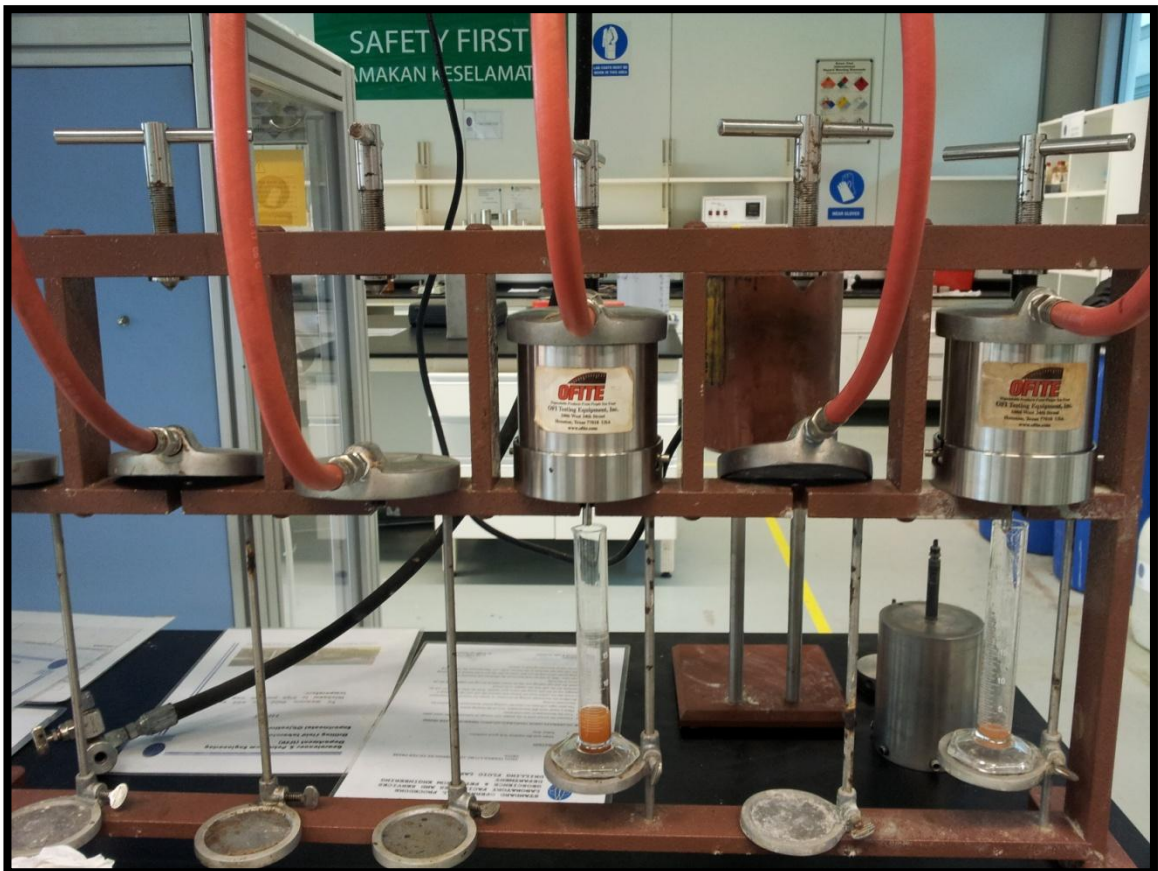


Figure 17: Fluid loss test in progress

3.7 Project Schedule

Table 6: Gantt chart and key milestones

Activities	FYP I				FYP II			
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
FYP Research: Literature review and understanding theory related								
Mud sample preparation: Materials and apparatus								
Surfactant selection: Composition and concentration								
Rheology test LPLT and HPHT								
Filtration loss test LPLT and HPHT								
Compare effect of drilling fluid between with and without presence of PPG surfactants and PAC-LV								
Surfactant optimization								
Evaluate and analyze laboratory result								
Milestones	FYP I				FYP II			
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Completion of theory understanding and research methodology								
Documentation of PPG surfactant								
Formulation of drilling mud ready for experiments								
Documentation of rheological and filtration properties of PPG based surfactant drilling mud for LPLT and HPHT								
Documentation of improvement done by PPG								
PPG based surfactant optimization								
Evaluation and analysis of laboratory result.								
Project completion								

CHAPTER 4

RESULT AND DISCUSSION

4.1 Data Gathering and Analysis

Generally, the laboratory work is divided into two phases:

Table 7: Phase, stages and objectives

Phase	Objectives
Phase I	To design an optimized propylene glycol surfactants additive drilling fluid. (Presence and absence of PAC-LV and surfactant: Stage I and stage II)
Phase II	To analyze and compare rheological and filtration loss characteristics of propylene glycol surfactants additive drilling fluid with PETRONAS drilling fluid benchmark.

For phase I of this research, all mud at different concentration of surfactant is tested at low pressure and low temperature (LPLT) and high pressure and high temperature (HPHT₁) to determine the density, pH value, plastic viscosity, yield point, gel strength, fluid loss and also thickness of the mud cake formed. Phase I is divided into two (2) stages in which stage I has presence of PAC-LV while in stage II is without PAC-LV. (Note: LPLT: 50°C, 100psi, HPHT₁: 100°C, 500psi). The reason of comparing the presence and absence of PAC-LV is to see the effects of using polymer additives and concentration of surfactant that can affects the drilling fluid properties. The purpose is also to determine the sufficient concentration of surfactant in polymer based drilling fluid in order to yield optimal rheological and filtration performances when exposed to high temperatures (after hot-rolling). These performances will reflect mud thermal stability and therefore, optimum concentration is then selected.

Next, experimental analysis is proceeded to phase II whereby hot rolling temperature is increased to 120°C (HPHT₂) and the effect of various temperatures on surfactant mud are observed. Rheological and filtration performances reflect its thermal stability. The results will then be compared to PETRONAS drilling fluid benchmark. (*Note: HPHT₂: 120°C, 500 psi*)

4.2 Rheology Measurements and Filtration Loss

4.2.1 Phase I: Best Concentration of the PPG Surfactant to Yield Optimum Drilling Fluid Properties

There are two stages under phase I in which experiments are conducted with both, with and without presence of PAC-LV. All the rheology was tested at various additions of surfactant and at two different pressure and temperature (LPLT and HPHT₁).

(*Note: LPLT: 50°C, 100psi, HPHT₁: 100°C, 500psi*)

Stage I: With presence of PAC-LV & Stage II: Without presence of PAC-LV

Table 8: Viscometer readings and rheology for mud samples (Stage I)

Mud Samples	Base Mud		0.29% PPG		0.57% PPG		1% PPG	
Speed (RPM)	LPLT	HPHT ₁	LPLT	HPHT ₁	LPLT	HPHT ₁	LPLT	HPHT ₁
600	143	74	360	270	235	207	209	180
300	96	52	248	183	175	155	152	130
200	76	41	203	120	146	130	125	115
100	52	31	147	99	105	95	103	82
6	22	12	50	42	33	28	34	28
3	17	10	41	35	25	23	24	22
Mud Samples	Base Mud		0.29% PPG		0.57% PPG		1% PPG	
(Parameters)	LPLT	HPHT ₁	LPLT	HPHT ₁	LPLT	HPHT ₁	LPLT	HPHT ₁
PV	47	22	112	87	60	63	57	50
YP	49	30	136	96	115	103	95	80
AV	71.5	37	180	135	117.5	103.5	104.5	90
YP/PV	1.04	1.36	1.21	1.10	1.92	1.98	1.67	1.60

Table 9: Viscometer readings and rheology for mud samples (Stage II)

Mud Samples	Base Mud		0.29% PPG		0.57% PPG		1% PPG	
Speed (RPM)	LPLT	HPHT ₁	LPLT	HPHT ₁	LPLT	HPHT ₁	LPLT	HPHT ₁
600	90	80	120	78	101	88	92	83
300	63	64	100	64	85	70	75	68
200	52	47	82	59	72	55	67	45
100	38	32	74	53	67	42	58	21
6	20	18	60	44	51	30	41	12
3	15	12	54	32	49	24	39	5
mud samples	Base Mud		0.29% PPG		0.57% PPG		1% PPG	
(Parameters)	LPLT	HPHT ₁	LPLT	HPHT ₁	LPLT	HPHT ₁	LPLT	HPHT ₁
PV	27	16	20	14	16	18	17	15
YP	36	48	80	50	69	52	58	53
AV	45	40	60	39	50.5	44	46	41.5
YP/PV	1.33	3.00	4.00	3.57	4.31	2.89	3.41	3.53

Table 8 and Table 9 show the viscometer readings and rheological properties of Xanthan solution with and without the addition of PPG surfactant and also with and without presence of PAC-LV. The PPG surfactant will be added gradually from 1mL to 3.5 mL. To have clearer picture of the results, each properties of the drilling fluid will be presented in a bar chart.

Plastic Viscosity (PV)

a) PV for Stage I

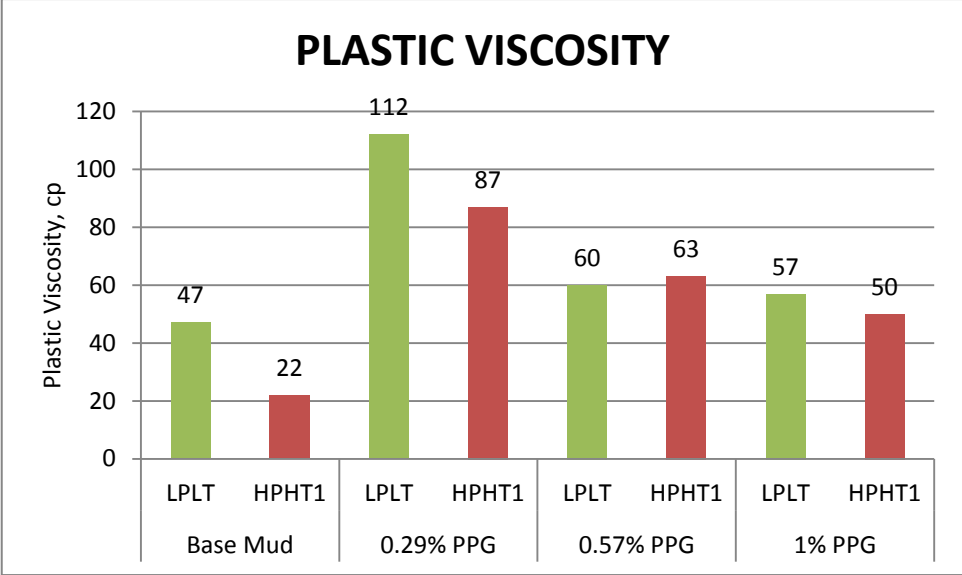


Figure 18: Result of plastic viscosity for mud samples with PAC-LV

b) PV for Stage II

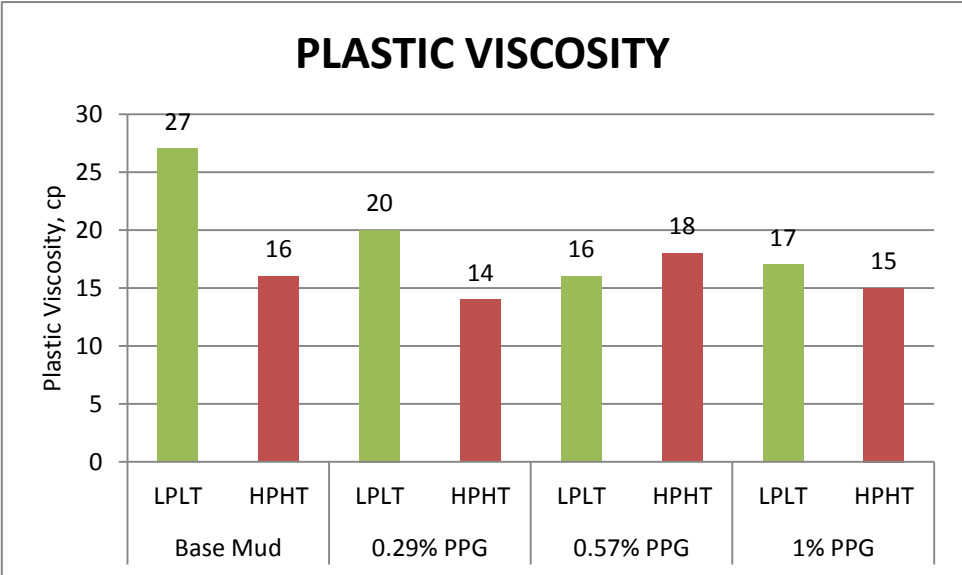


Figure 19: Result of plastic viscosity for mud samples without PAC-LV

Figure 18 shows the plastic viscosity result for LPLT (50°C, 100psi) and HPHT₁ (100°C, 500 psi) for stage I (presence of PAC-LV) xanthan polymer base solutions with 1 mL (0.29% PPG), 2 mL (0.57% PPG) and 3.5 mL (1% PPG) additions of polypropylene glycols (PPG) surfactant. As shown in the chart, for base mud and 0.29% PPG mud, the plastic viscosity decreases after 16 hours of hot rolling of the polymer in which for base mud from 47 cp dropped to 22 cp while for 0.29% PPG mud, the plastic viscosity dropped from 112 cp to 87 cp.

However, the plastic viscosity has improved after 16 hours of hot rolled which is from 60 cp to 63 cp at 0.57% PPG concentration.

Figure 19 shows the plastic viscosity result for LPLT (50°C, 100psi) and HPHT₁ (100°C, 500 psi) for stage II (without presence of PAC-LV). As shown in the chart, for base mud and 0.29% PPG mud, the plastic viscosity decreases after 16 hours of hot rolling of the polymer in which for base mud from 27 cp dropped to 16 cp while for 0.29% PPG mud, the plastic viscosity dropped from 20 cp to 14 cp.

During drilling, cuttings are obviously created, but they do not usually pose a problem until drilling stops because a drill bit requires replacement or another problem. When this happens, and drilling fluids are not used, the cuttings then fill the hole again. Drilling fluids are used as a suspension tool to keep this from happening. The viscosity of the drilling fluid increases when movement decreases; allowing the fluid to have a liquid consistency when drilling is occurring and then turn into a more solid substance when drilling has stopped. Cuttings are then suspended in the well until the drill is again inserted. This gel-like substance then transforms again into a liquid when drilling starts back up.

For that reason, this research will focus onto finding the best plastic viscosity that improved after hot rolled. It shows that at 0.57% PPG for both with and without presence of PAC-LV, the plastic viscosity has improved. But between both stages, stage I with PAC-LV shows a slightly higher increase in plastic viscosity and the value is more reliable compared to stage II result for 0.57% PPG.

Yield Point (YP)

a) YP for Stage I

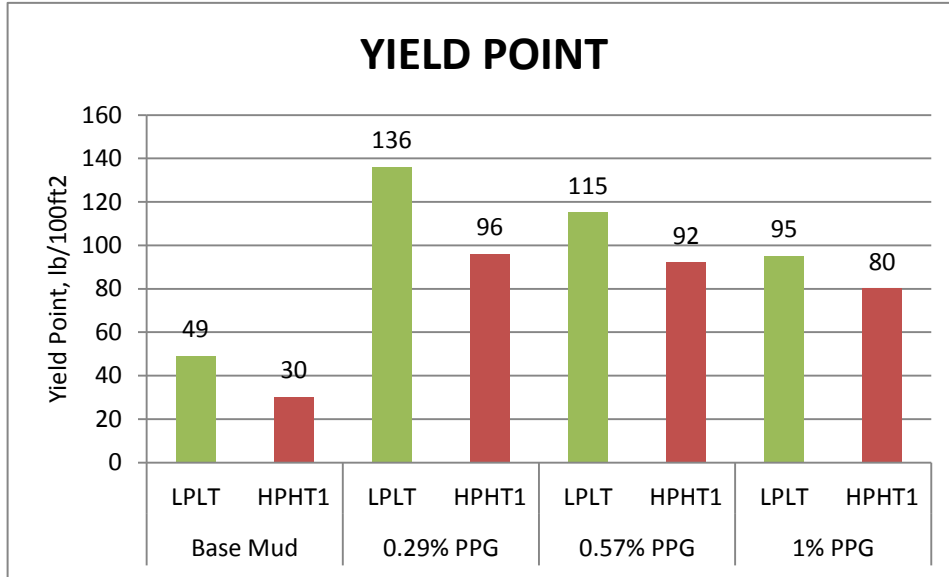


Figure 20: Result of yield point for mud samples with PAC-LV

b) YP for Stage II

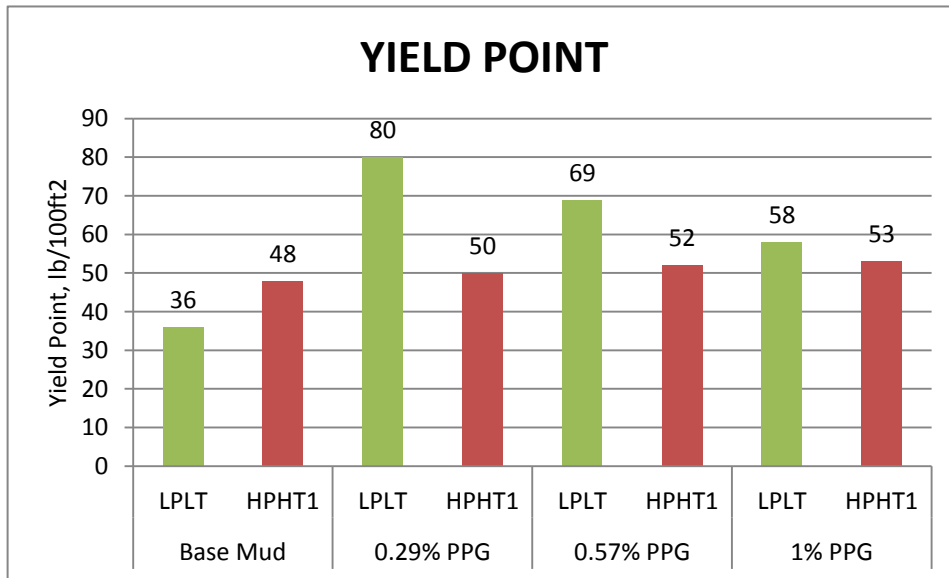


Figure 21: Result of yield point for mud samples without PAC-LV

Figure 20 shows the yield point result for LPLT (50°C, 100psi) and HPHT₁ (100°C, 500 psi) for stage I (with presence of PAC-LV) xanthan polymer base solutions with with 1 mL (0.29% PPG), 2 mL (0.57% PPG) and 3.5 mL (1% PPG) additions of polypropylene glycols (PPG) surfactant. As shown, yield point decreases after 16 hours of hot rolling of the xanthan base solution for base mud and also PPG based surfactant additions into mud. From the chart, for base mud, yield point has decreases from 49 lb/100ft² to 30 lb/100ft², at 0.29% PPG yield point decreases from 136 lb/100ft² to 96 lb/100ft², at 0.57% yield point decreases from 115 lb/100ft² to 92 lb/100ft² and lastly at 1% PPG, the yield point decreases from 95 lb/100ft² to 80 lb/100ft².

Figure 21 shows the yield point results for LPLT (50°C, 100psi) and HPHT₁ (100°C, 500 psi) for xanthan polymer base solution for stage II which is without the presence of PAC-LV. For the base mud, the yield point has increases from 36 lb/100ft² to 48 lb/100ft² but for the rest of the mud samples in stage II, the yield point decreases. From the chart, at 0.29% PPG yield point decreases from 80 lb/100ft² to 50 lb/100ft², at 0.57% yield point decreases from 69 lb/100ft² to 52 lb/100ft² and lastly at 1% PPG, the yield point decreases from 58 lb/100ft² to 53 lb/100ft². This is the results of thermal degradation of the polymer.

Yield point is used to evaluate the ability of a mud to lift cuttings out of the annulus. A high yield point implies a non-Newtonian fluid, one that carries cuttings better than a fluid of similar density but lower yield point.

However, with increasing in addition of PPG based surfactant, the yield point properties were retained and almost fully recovered at 0.57% PPG and also 1% PPG concentration for both stages.

YP/PV Ratio

a) YP/PV Ratio for Stage I

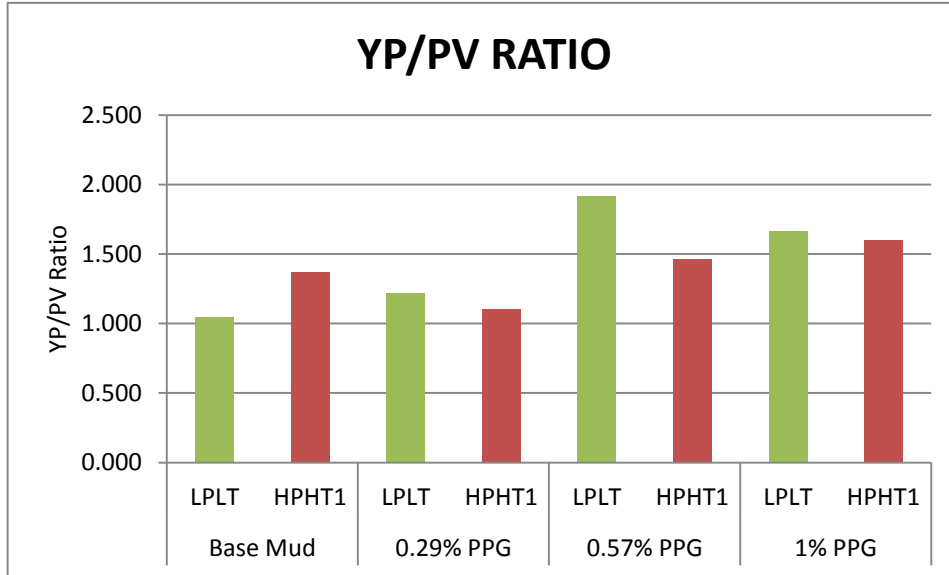


Figure 22: Result of YP/PV Ratio for mud samples with PAC-LV

b) YP/PV Ratio for Stage II

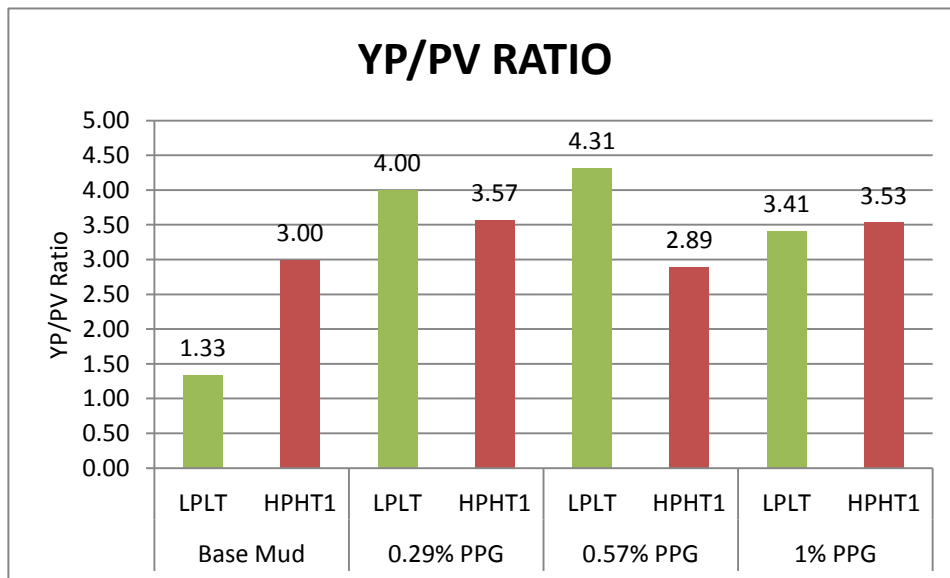


Figure 23: Result of YP/PV Ratio for mud samples without PAC-LV

Figure 22 shows the yield point and plastic viscosity ratio results for LPLT (50°C, 100psi) and HPHT₁ (100°C, 500 psi) for stage I (with presence of PAC-LV) xanthan polymer base solutions with 1 mL (0.29% PPG), 2 mL (0.57% PPG) and 3.5 mL (1% PPG) additions of polypropylene glycols (PPG) surfactant. The API standard for the yield point and plastic viscosity ratio maximum value is 3.0. As shown in the chart, all the yield point to plastic viscosity ratio is less than 3.0.

While in figure 23 shows the yield point and plastic viscosity ratio results for LPLT and HPHT₁ for stage II (without presence of PAC-LV) xanthan polymer base solutions with and without PPG based surfactant. From the chart, it shows that most of the mud results in the value of more than 3.0 for yield point to plastic viscosity ratio except before hot rolled for base mud and also after hot rolled at 0.57% PPG.

The ratio of yield point to plastic viscosity is a measure of thinning, the higher the ratio the greater the shear thinning. The decrease in effective viscosity with increase in shear rate is known as shear thinning, and normally is a desirable property, because the effective viscosity will be relatively low at high shear rates prevailing in the drill pipe, thereby reducing pumping pressures, and relatively high at low shear rate prevailing in annulus, thereby increasing cutting carrying capacity (Gray, 1988).

Based on the ratio observed, 0.57% PPG concentration mud yields better result for stage I and stage II. But for overall, stage I which with presence of PAC-LV yield better result compared to stage II which is without presence of PAC-LV since all the ratio is less than 3.0.

Gel strength for 10 seconds and 10 minutes

a) Gel strength for Stage I

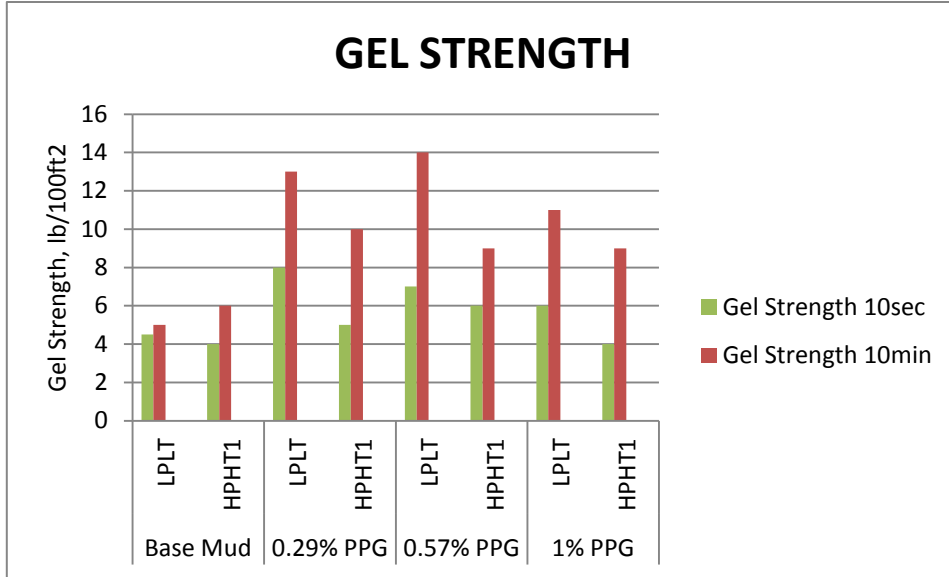


Figure 24: Result of gel strength for mud samples with PAC-LV

b) Gel strength for Stage II

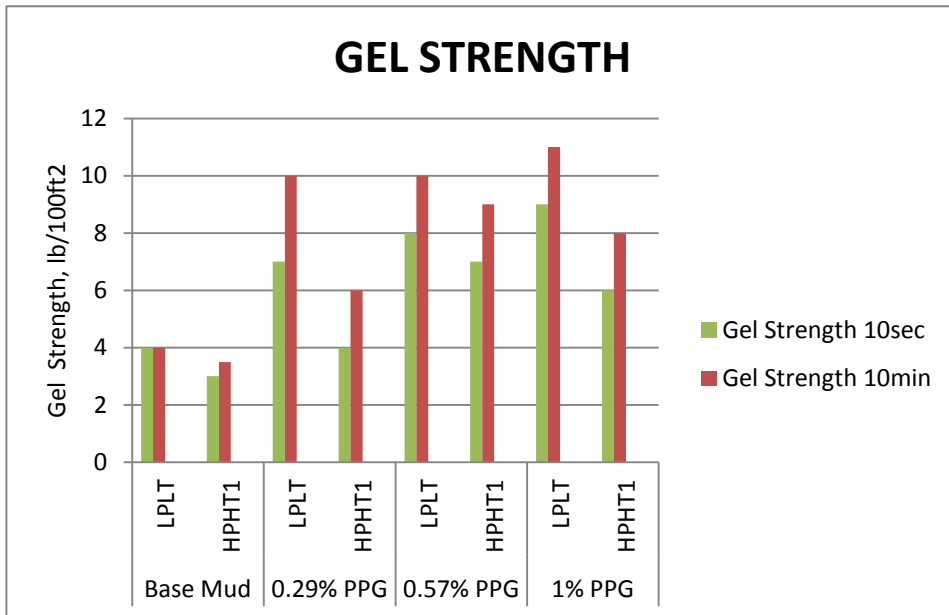


Figure 25: Result of gel strength for mud samples without PAC-LV

Table 10: Result of gel strength for mud samples with PAC-LV

Mud Samples (Parameters)	Base Mud		0.29% PPG		0.57% PPG		1% PPG	
	LPLT	HPHT ₁	LPLT	HPHT ₁	LPLT	HPHT ₁	LPLT	HPHT ₁
Gel Strength 10sec	4.5	4	8	5	7	6	6	4
Gel Strength 10min	5	6	13	10	14	9	11	9

Table 11: Result of gel strength for mud samples without PAC-LV

Mud Samples (Parameters)	Base Mud		0.29% PPG		0.57% PPG		1% PPG	
	LPLT	HPHT ₁	LPLT	HPHT ₁	LPLT	HPHT ₁	LPLT	HPHT ₁
Gel Strength 10sec	4	3	7	4	8	7	9	6
Gel Strength 10min	4	3.5	10	6	10	9	11	8

Figure 24 and Figure 25 show the gel strength results for LPLT (50°C, 100psi) and HPHT₁ (100°C, 500 psi) for stage I (with presence of PAC-LV) and stage II (without presence of PAC-LV) xanthan polymer base solutions with 1 mL (0.29% PPG), 2 mL (0.57% PPG) and 3.5 mL (1% PPG) additions of polypropylene glycols (PPG) surfactant. Generally, the 10 minutes gel strength of the mud is slightly higher than 10 seconds gel strength. As shown in the charts, the gel strength decreases after 16 hours of hot rolling of the xanthan base solution with and without addition of PPG based surfactant shows thermal degradation of the polymer. With addition of PPG based surfactant, the gel strength properties were able to retained and almost fully recovered at 0.57% PPG and 1% PPG concentration for both stage. But mud samples with PAC-LV presents better results. 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. Low get strength drilling mud will not be able to efficiently suspend cuttings; therefore, the cutting will quickly drop once pumps are shut down. This can lead to several problems such as stuck pipe, hole pack off, and accumulation of cutting beds.

Fluid Loss

a) Fluid loss for Stage I

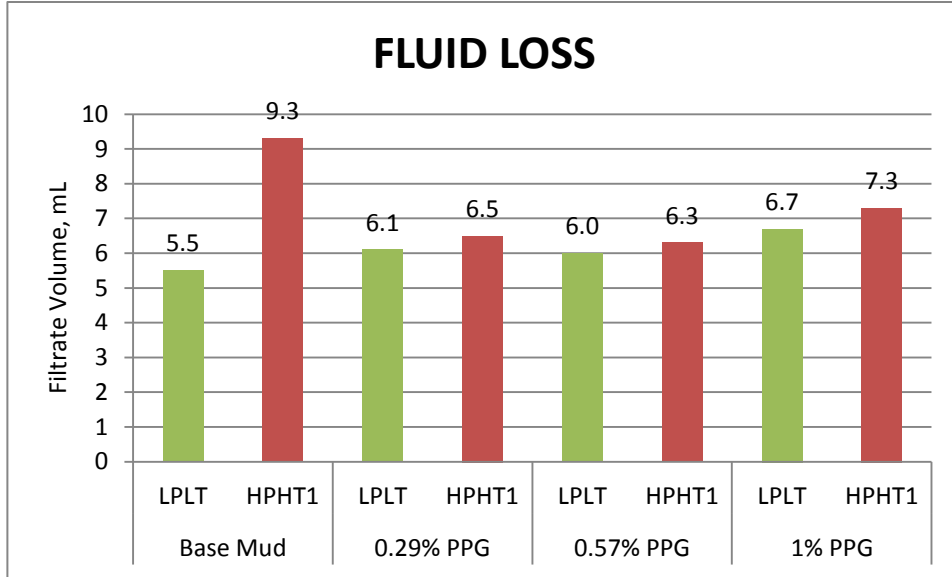


Figure 26: Result of fluid loss for mud samples with PAC-LV

b) Fluid loss for Stage II

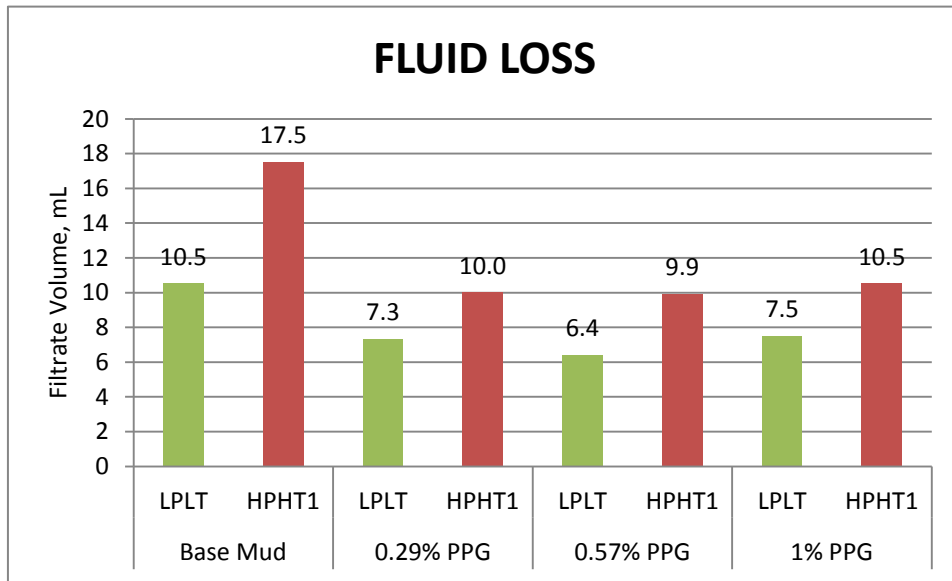


Figure 27: Result of fluid loss for mud samples without PAC-LV

Table 12: Result of fluid loss for mud samples with PAC-LV

Mud Samples	Base Mud		0.29% PPG		0.57% PPG		1% PPG	
	LPLT	HPHT ₁	LPLT	HPHT ₁	LPLT	HPHT ₁	LPLT	HPHT ₁
5	1.3	4.2	1.6	2.0	1.7	2.5	1.9	2.5
10	2.8	5.9	2.9	3.0	2.6	3.4	2.7	3.7
15	3.7	6.3	3.7	3.9	3.5	4.2	4.0	4.6
20	4.3	7.5	4.3	4.5	4.3	4.9	5.6	5.3
25	4.9	8.7	5.2	5.6	5.5	5.8	6.5	6.0
30	5.5	9.3	6.1	6.3	6.0	6.6	6.7	7.3

Table 13: Result of fluid loss for mud samples without PAC-LV

Mud Samples	Base Mud		0.29% PPG		0.57% PPG		1% PPG	
	LPLT	HPHT ₁	LPLT	HPHT ₁	LPLT	HPHT ₁	LPLT	HPHT ₁
5	3.9	4.5	2.9	2.8	2.8	3.0	3.0	3.2
10	6.5	7.3	3.6	4.4	3.3	4.8	4.5	4.9
15	8.7	9.8	4.7	5.8	4.7	5.9	5.3	6.3
20	10.2	13.2	5.3	7.0	5.1	7.5	6.1	7.7
25	13.4	15.7	6.5	8.5	5.9	9.2	6.9	9.6
30	15.5	17.5	7.3	10.0	6.4	9.9	7.5	10.5

Figure 26 and Figure 27 show the fluid loss results for LPLT (50°C, 100psi) and HPHT₁ (100°C, 500 psi) for stage I (with presence of PAC-LV) and stage II (without presence of PAC-LV) xanthan polymer base solutions with 1 mL (0.29% PPG), 2 mL (0.57% PPG) and 3.5 mL (1% PPG) additions of polypropylene glycols (PPG) surfactant. As shown in the charts, the fluid loss for all the mud in both stages result in increment after being hot rolled for 16 hours. But, base mud for both stages experienced the highest fluid loss. Mud with 0.57% PPG with PAC-LV was found to experience the lowest fluid loss among all mud samples. Thus, an addition of PPG based surfactant into base mud did decrease the degradation of fluid loss polymer and 0.57% PPG concentration is sufficient enough. The loss of both water and oil based drilling mud filtrate to the formation in the near wellbore region due to leak off during overbalanced drilling operations, or due to spontaneous imbibitions in some situations during underbalanced drilling operations, can result in permanent entrapment of a portion or all of the invading fluid resulting in adverse relative permeability effects which can reduce oil or gas

permeability in the near wellbore region (D. Bennion, F. Thomas, Jamaluddin, T. Ma, C. Agnew, 1997).

From all the rheology properties and fluid loss observed, it indicates that the addition of PPG (Polypropylene Glycols) helps to stabilize Xanthan. The stabilizing effect proved to be dependent on the type of polyglycol where not all polyglycol proved equally effective in stabilizing rheology (Eric van Oort, R.G. Bland, S. K. Howard, R. J. Wiersma, Loyd Roberson, 1997). In this research, it can be concluded that the polypropylene glycol (PPG) based surfactant verified to be one of the candidates that can help in improving the rheology by the stabilization of xanthan polymer.

Based on the results of the rheological properties examined, it can be concluded that the best concentration of the surfactant that can be used in the water based mud is 0.57% PPG concentration with presence of PAC-LV. When the concentration of these polyglycols in solution is increased the concentration of the single molecule will increase until some concentration which is known as critical micellar concentration (CMC) is reached. At the CMC, PPG aggregated to form small micelles as shown in figure 28. The micelles are believed to stabilize the xanthan polymer and slowing the rate of thermal degradation.

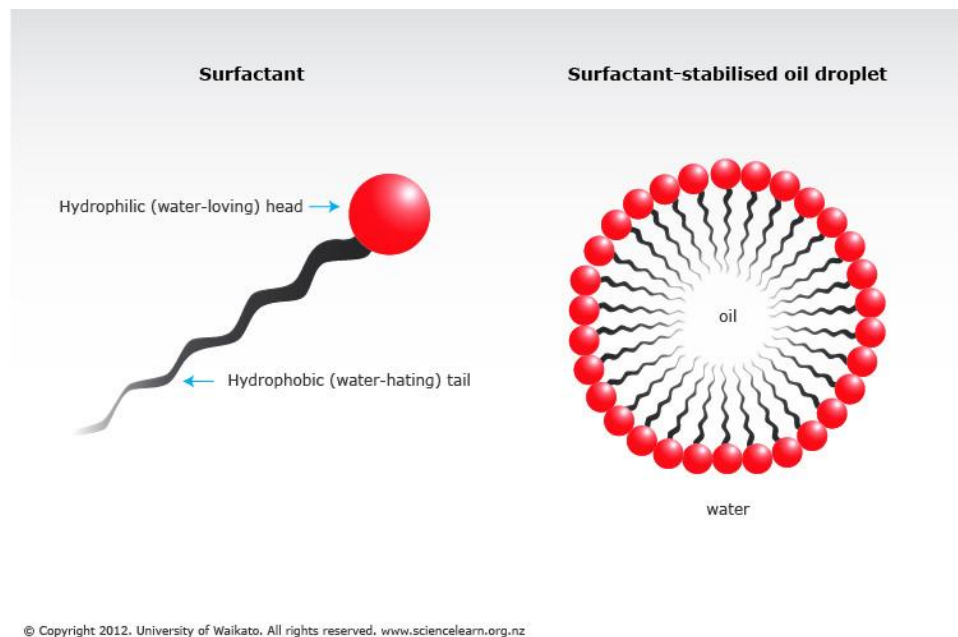


Figure 28: Micelle Structure (www.sciencelearn.org.nz)

4.2.2 Phase II: Drilling Fluid Performance at Different Temperature and Comparison with PETRONAS Drilling Fluid Bench Mark

Drilling Fluid Performance at Different Temperature

Table 14 shows the result of rheology and fluid loss test at different temperature for the PAC-LV mud with and without addition of 0.57% PPG concentration based surfactant.

(Note: LPLT: 50°C, 100psi, HPHT₁: 100°C, 500psi, HPHT₂: 120°C, 500 psi)

Table 14: Rheology and Fluid Loss Test for Phase II

Mud Samples	Base mud			0.57% PPG		
Speed (RPM)	LPLT	HPHT ₁	HPHT ₂	LPLT	HPHT ₁	HPHT ₂
600	143	74	65	235	218	172
300	96	52	43	175	155	123
200	76	41	35	146	130	102
100	52	31	22	105	95	71
6	22	12	10	33	25	15
3	17	10	8	25	13	6
Mud Samples	Base mud			0.57% PPG		
Parameters	LPLT	HPHT ₁	HPHT ₂	LPLT	HPHT ₁	HPHT ₂
PV	47	22	22	60	63	49
YP	49	30	21	115	92	74
AV	71.5	37	32.5	117.5	109	86
YP/PV	1.043	1.364	0.955	1.917	1.460	1.510
Mud Samples	Base mud			0.57% PPG		
Parameters	LPLT	HPHT ₁	HPHT ₂	LPLT	HPHT ₁	HPHT ₂
Gel Strength 10sec	4.5	4	1	6	5	3
Gel Strength 10min	11	6	1	11	7	4
Mud Samples	Base mud			0.57% PPG		
Time (mins)	LPLT	HPHT ₁	HPHT ₂	LPLT	HPHT ₁	HPHT ₂
5	1.3	4.2	19.3	1.7	2.5	18.2
10	2.8	5.9	23.5	2.6	3.4	22.4
15	3.7	6.3	25.7	3.5	4.2	25.8
20	4.3	7.5	27.9	4.3	4.9	27.7
25	4.9	8.7	29.1	5.5	5.8	28.3
30	5.5	9.3	40.5	6.0	6.6	30.0

To have a better understanding on the results, each properties of the drilling fluid will be presented in bar charts and be explaining in details.

a) Plastic Viscosity (PV)

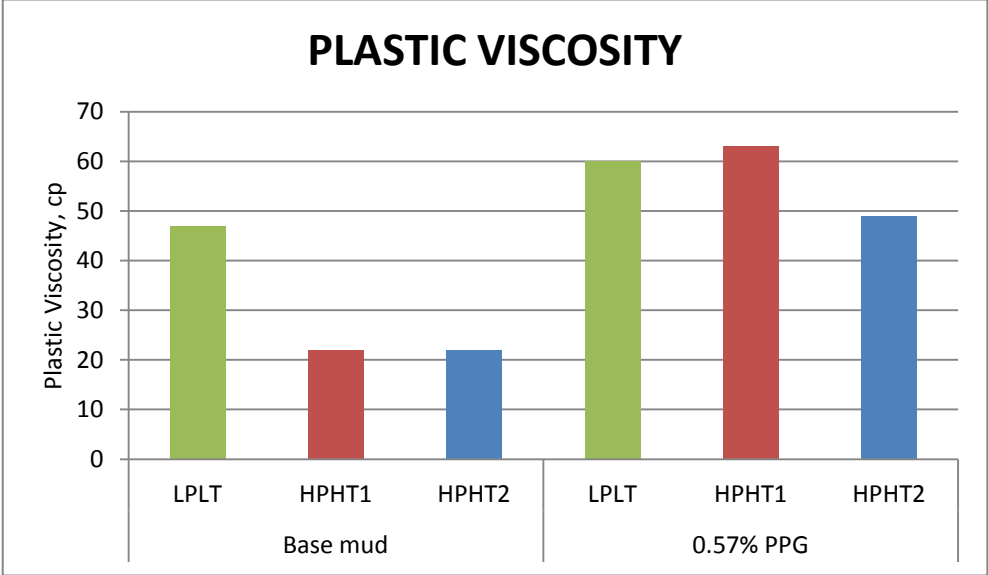


Figure 29: Result of plastic viscosity for PAC-LV base mud and 0.57% PPG based surfactant mud

Figure 29 shows plastic viscosity results for LPLT (50°C, 100psi), HPHT₁ (100°C, 500 psi) and HPHT₂ (120°C, 500 psi) for phase II comparisons between PAC-LV base mud and also PAC-LV 0.57% PPG xanthan polymer solutions. As shown in the chart, plastic viscosity of PAC-LV base mud decreases after 16 hours of hot rolling at increasing temperature. This indicate that the polymer gradually degrade as temperature increases. However, at 0.57% PPG concentration, the plastic viscosity of the mud increase and also consistently higher than the plastic viscosity of the PAC-LV base mud. This shows that at 0.57% PPG concentration, stabilization of suspending polymers is done by the polyglycols.

b) Yield Point (YP)

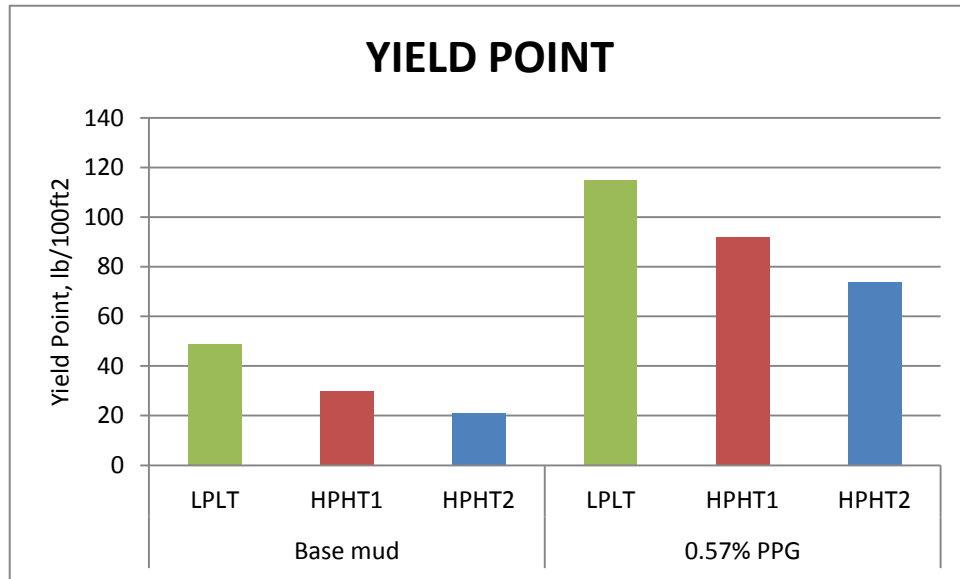


Figure 30: Result of yield point for PAC-LV base mud and 0.57% PPG based surfactant mud

Figure 30 shows yield point results for LPLT (50°C, 100psi), HPHT₁ (100°C, 500 psi) and HPHT₂ (120°C, 500 psi) for phase II comparisons between PAC-LV base mud and also PAC-LV 0.57% PPG xanthan polymer solutions. As shown in the chart, yield point for PAC-LV base mud after 16 hours of hot rolling is gradually decreases as the temperature increases showing polymer degradation.

On the other hand, yield point for 0.57% PPG concentration is also decreasing as the temperature increases but the values are consistently higher than yield point of the PAC-LV base mud. These differences prove the stabilization of suspending or encapsulating polymers done by polyglycols.

c) YP/PV Ratio

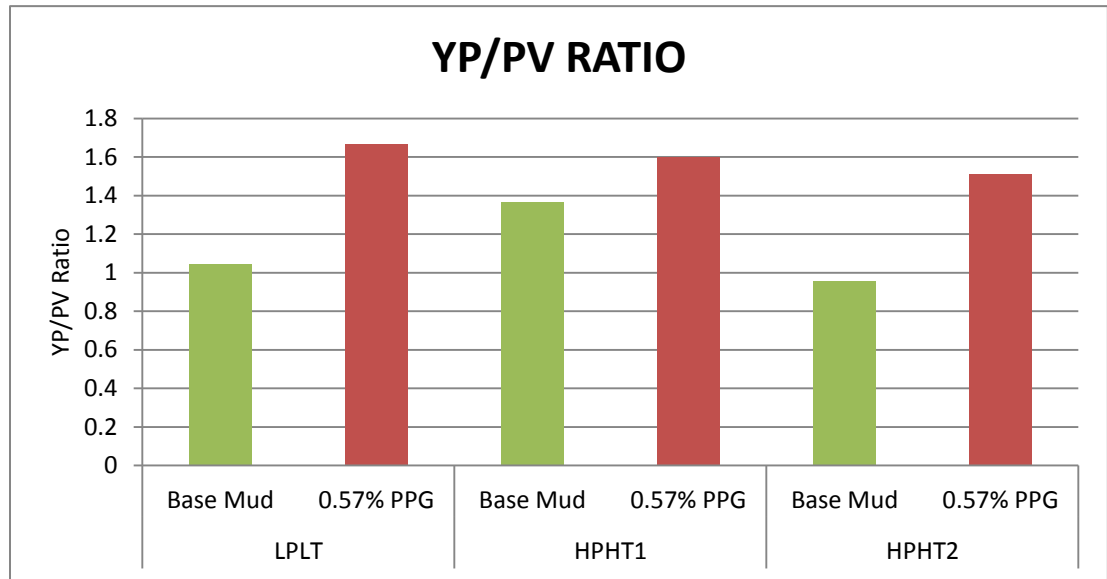


Figure 31: Result of YP/PV Ratio for PAC-LV base mud and 0.57% PPG based surfactant mud

Figure 31 shows the yield point and plastic viscosity ratio results for LPLT (50°C, 100psi), HPHT₁ (100°C, 500 psi) and HPHT₂ (120°C, 500 psi) for phase II comparisons between PAC-LV base mud and also PAC-LV 0.57% PPG xanthan polymer solutions. The API standard for the yield point and plastic viscosity ratio maximum value is 3.0. As shown in the chart, all the yield point to plastic viscosity ratio is less than 3.0.

d) Gel Strength for 10 Seconds and 10 Minutes

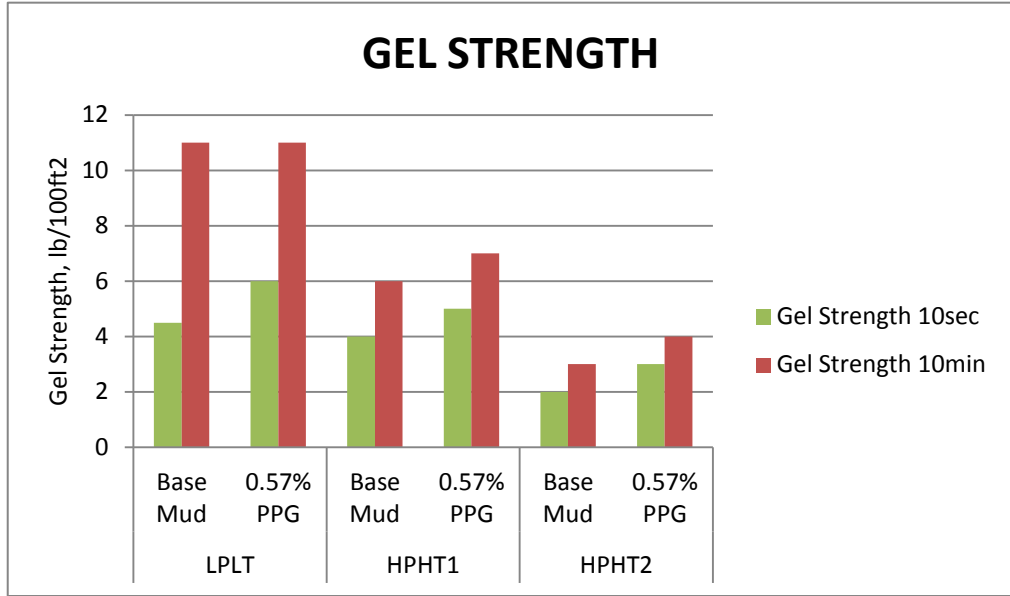


Figure 32: Result of Gel Strength for PAC-LV base mud and 0.57% PPG based surfactant mud

Figure 32 shows 10 seconds and 10 minutes gel strength results for LPLT (50°C, 100psi), HPHT₁ (100°C, 500 psi) and HPHT₂ (120°C, 500 psi) for phase II comparisons between PAC-LV base mud and also PAC-LV 0.57% PPG xanthan polymer solutions.

From the chart, it shows that generally 10 minutes gel strength of the mud is slightly higher than 10 seconds gel strength. As shown, the gel strengths are typically higher with the polyglycol system indicating better stabilization of the suspending polymers.

e) pH Value

Table 15: Result of pH value for PAC-LV base mud and 0.57% PPG based surfactant mud

Mud Samples	LPLT		HPHT ₁		HPHT ₂	
Parameters	Base Mud	0.57% PPG	HPHT ₂	0.57% PPG	Base Mud	0.57% PPG
pH	8.2	8.91	8	8.05	7.83	7.87

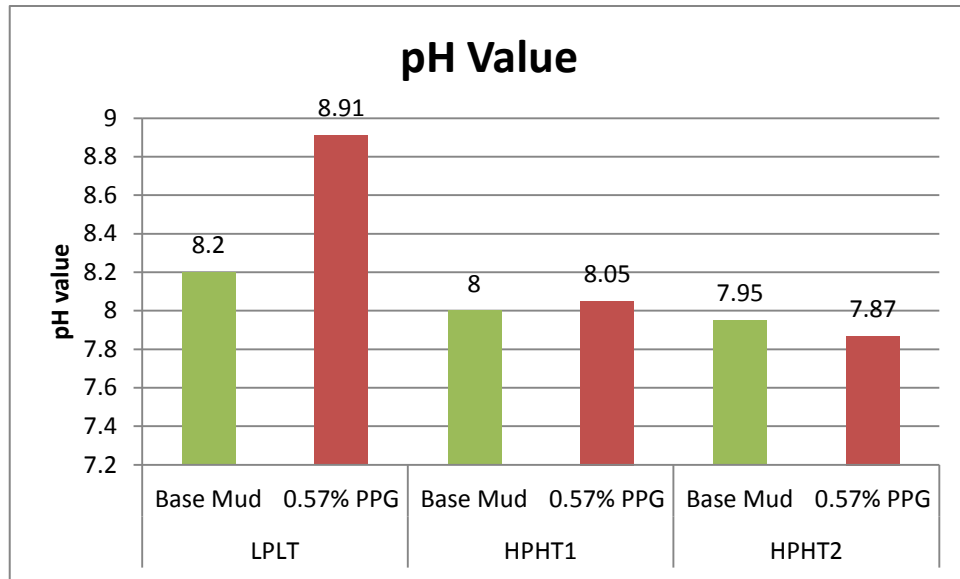


Figure 33: Result of pH value for PAC-LV base mud and 0.57% PPG based surfactant mud

Figure 33 shows pH results for LPLT (50°C, 100psi), HPHT₁ (100°C, 500 psi) and HPHT₂ (120°C, 500 psi) for phase II comparisons between PAC-LV base mud and also PAC-LV 0.57% PPG xanthan polymer solutions. As shown in the chart, the pH value of PAC-LV base mud decrease from 8.2 to 7.95 as the temperature increases.

The addition of PPG based surfactant keep the pH level decreases from 8.91 to 7.87 at 120°C. This clearly shows that the surfactant can helps to decrease the alkalinity of the mud.

f) Filtration Loss Test

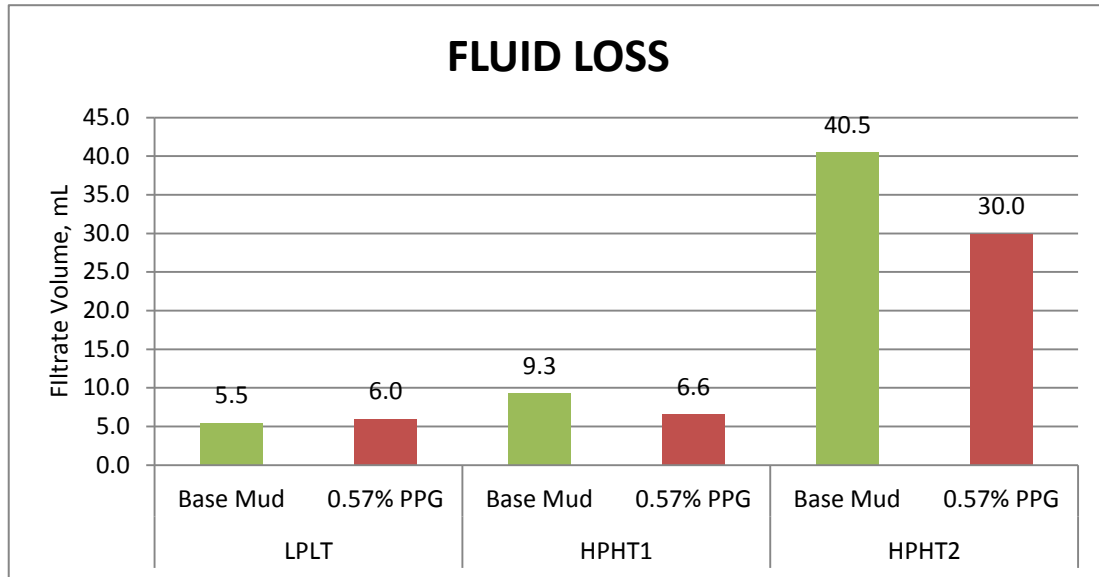


Figure 34: Result of filtration loss for PAC-LV base mud and 0.57% PPG based surfactant mud

Figure 34 shows fluid loss test results for LPLT (50°C, 100psi), HPHT₁ (100°C, 500 psi) and HPHT₂ (120°C, 500 psi) for phase II comparisons between PAC-LV base mud and also PAC-LV 0.57% PPG xanthan polymer solutions. As shown in the chart, the fluid loss for both mud increases as temperature increases. The increment in temperature reduces the viscosity of the filtrate and thus, filtrate volume also increases. The viscosity deterioration at increasing temperature was caused by thermal degradation of polymer and xanthan gum which is only thermally stabilized up to 120°C. So it is evident that changed in temperature may have substantial effect on filtrate volume due to changes in filtrate viscosity.

However, with addition of 0.57% PPG based surfactant, it was found that the fluid loss is consistently lower than the fluid loss of the PAC-LV base mud and the improvement of the fluid loss indicates that the surfactant helped in lowering the fluid loss by slowing the rate of degradation of the PAC-LV polymer.

Comparison of PPG Mud Properties with PETRONAS Standard Conventional Drilling Fluid Bench Mark

The 0.57% PPG PAC-LV mud will be compared to PETRONAS Standard Conventional Drilling Fluid to determine the opportunity for the 0.57% PPG mud to be alternative for conventional drilling fluid.

Table 16: PETRONAS Carigali Sdn. Bhd. Drilling fluid bench mark properties for 12 ¼ inch interval

Property	Programmed	Actual	0.57% PPG HPHT ₁	0.57% PPG HPHT ₂
Density, lb/gal	11.5 – 12.0	11.5 – 12.0	10.0	11.2
Plastic Viscosity, cP	ALAP	26 – 44	63	49
Yield Point, lb/100ft ²	20 - 26	15 – 20	92	74
Gel Strength 10 ³ & 10 ² , lb/100ft ²	10 – 25 / 20 - 40	12 – 18 / 31 – 40	5 / 7	3 / 4
6 RPM reading	12 - 14	9 – 12	25	15
3 RPM reading	10 - 13	8 – 11	13	6
HPHT Fluid Loss, ml/30 min @ 275°F	< 5.0	3.6 – 5.0	6.6	30
Cake Thickness, 32 nd inch	-	2	3	3

Table 16 provides data of 0.57% PPG PAC-LV mud as to compare to PETRONAS Carigali Sdn. Bhd. (PCSB) drilling fluid bench mark properties for 12 ¼ inch interval. In addition, the standard set for PETRONAS was for oil based mud. As a whole, 0.57% PPG PAC-LV mud properties have the opportunity to be considered as a replacement to composition of the original mud that has been used for this standard provided as there are still rooms for improvements. All the data above will be discussed accordingly in details.

Density

The density of the drilling fluid must be controlled to provide adequate hydrostatic head to prevent influx of formation fluids, but not so high as to cause loss of circulation or adversely affect the drilling rate and damaging the formation. The 0.57% PPG PAC-LV mud has the density of 10.0 ppg (HPHT₁) and 11.2 ppg (HPHT₂). In order to increase the mud weight, an amount of Barite is needed in order for the mud to be in the range of 11.5 to 12 ppg.

Plastic Viscosity

Viscosity is defined as the resistance of a fluid to flow and is measured as the ration of the shearing stress to the rate of shearing strain. A low plastic viscosity indicates that the mud is capable of drilling rapidly because of the low viscosity of mud exiting at the bit. High plastic viscosity is caused by a viscous base fluid and by excess colloidal solids. The range of the actual set by the PETRONAS standard is in between 26 cp to 44 cp. After hot rolled at 100°C and 120°C, the readings are between 49 cp to 63 cp which are quite higher than the actual range.

Yield Point

Yield point is the measure of the electro-chemical or attractive forces in the mud under flow dynamic conditions. A high yield point implies a non-Newtonian fluid, one that carries cuttings better than a fluid of similar density but lower yield point. The standard set range for yield point is 20 to 26 lb/100ft² while 0.57% PPG PAC-LV mud obtained very high reading especially after hot rolled at 100°C and 120°C. Yield point can be lowered by adding deflocculates to a clay-based mud and increased by adding freshly dispersed clay or a flocculent, such as lime.

Gel Strength

An initial 10-second gel and a 10-minutes gel strength measurement give an indication of the amount of the gellation that will occur after circulation ceased and the mud remain static. The standard set by PETRONAS shows that the gel strength should be in the range of 10 to 40. The 0.57% PPG PAC-LV mud after hot rolled at 100°C and 120°C have a range of gel strength of 3 to 7 which is less than the range of the standard. The gel strength needs to be improved.

6 RPM Reading

The standard set for 6 rpm is in the range of 9 to 14. The 0.57% PPG PAC-LV mud obtained reading in the range of 15 to 25. This is value of RPM reading is acceptable because it is still near the range provided by PETRONAS.

3 RPM Reading

The standard set for 3 rpm is in the range of 8 to 13 and 0.57% PPG PAC-LV mud obtained the value from 6 to 13 which is within the range.

Fluid Loss

The loss of liquid from a mud due to filtration is controlled by the filter cake formed of the solid constituent in the drilling fluid. The standard range set is 3.6 to 5ml. 0.57% PPG PAC-LV mud obtained is between 6.6 ml at 100°C to 30.0 ml at 120°C. The fluid loss can be improved by adding more fluid loss additive to prevent total loss control of the mud.

Cake Thickness

Cake thickness is assumed to be proportional to filter loss and therefore only filter loss needs to be specified. The filter loss decreases with increase in the concentration of solids, but the cake volume increases. The standard set as shown in table above is 2 and the 0.57% PPG PAC-LV mud obtain the value of 3 which is still acceptable for the provided range.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the research done, the following conclusion can be made:

- The addition of PPG based surfactant helps in improving the thermal stability of mud based on the evaluation of its rheological and filtration performances.
- 0.57% PPG concentration with presence of PAC-LV proven to be the best concentration to yield optimum fluid properties. The rheology of the mud proved to retain back their initial properties provided that the best concentration of the surfactant is being used. PPG also proven in stabilizing the rheology modifier for xanthan polymer solution.
- After hot rolling at elevated temperature, mud with 0.57% PPG surfactant still maintaining high viscosity and proved to have lower fluid loss compared to the base mud.
- 0.57% PPG with presence of PAC-LV rheology properties has the opportunity to be used in real well.

5.2 Recommendations

Based on the research done, these are the proposed recommendations:

- For evaluating such works, both temperature and time of exposure to that temperature are relevant factors and must be taken into account. As only temperature effect is able to be carried out this time due to time constraint, this research can be further extended for the effect of exposure time in the next stage.
- Deeper experiment should be done for this research such as measuring the surface tension of the mud and also use other additives to upgrade the mud.

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