Coefficient of Friction (COF) and Wear Ranking of Water-based Muds (WBM) and Oil-based Muds (OBM)

by

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Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
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CERTIFICATION OF APPROVAL

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Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS

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May 2013

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 the original work contained herein have not been undertaken or done by unspecified sources or persons.

(MUHAMMAD IZHAM KAMIL BIN ISHAK)

ABSTRACT

Drilling mud is used to lubricate the drill bit as well as bore hole and tool joints. Lubrication job is a must in order to minimize the friction and wear to the drill string. No reference table of selecting the best composition of drilling mud has been made in past years to study this friction and wear activities on the bore hole and tool joints. By manipulating different kinds of compositions in water-based muds (WBM) and oil-based muds (OBM), the responding variables which are the coefficient of friction (COF) and wear can be tabulated and ranked from the highest to lowest value. In terms of drilling cost, it can reduce the cost of number of drill strings used due to abrasion wear. This study is conducted by using Multispecimen Wear Tester (MWT) which the equipment simulates the rotations of drill string to the wellbore formation. From the findings, calcium chloride is the best additive to reduce the friction and wear activities for WBM and VG Plus is the best additive for OBM. Synthetic and polymer-based muds should be included in future in order to complete the COF and wear ranking of drilling fluids.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Drilling longer, deeper and in high temperature and pressure has been made possible by advancement in drilling technologies, including more efficient and effective drilling muds. Drilling muds are essential to drilling success by maximizing the hydrocarbon recovery and minimizing the time it takes to achieve first oil. The drilling mud in the well drilling process can be defined same as the blood in the human body where the mud pump is the heart and the cuttings are the slag products. During drilling, cuttings are obviously created and carried along with mud. The cuttings will go directly to the mud circulation system for further processes such as filtration and separation where the mud will be “reused” again for next circulation. Different types of muds are used for different types of formation. Wrong type of drilling mud will affect the process of delivering the cuttings to the surface and impeding the drilling process as well.

A drill string on a drilling rig is a column of drill pipes that transmits drilling fluid and torque to the drill bit. The drill string is hollow so that the drilling fluid can be pumped down through it and circulated back up to the annulus. Both drilling muds and rock fragments (cuttings) are moving in the annulus during rotary drilling operations. The rotation of the drill string during this operation produces centrifugal force (torque and drag) on the rock fragments in drilling mud, which affects the surface of the wellbore formation. The drill string might be replaced over time because of the wear and this will increase the time and cost of drilling. Drilling personnel have relied primarily on observation and experience for determining the lifting ability of the drilling fluids [1]. The drill string rotation may have a significant impact on pressure drops in the annulus during fluid transport. During laminar flow, pipe rotation will induce and additional shear velocity component. The drill string rotation will increase total shear, reduce viscosity and thereby, reduce the pressure drop. Pressure drop will lead to the low productivity index (PI) as well as the production rate.

Inadequate reference table to determine the least minimum friction factor and wear to be used as the drilling mud in the well is the main reason for conducting this research. There have attempts to quantify the calculations by way of providing a range of coefficient of frictions for different operation conditions, but no laboratory experiment attempts have been made by using the actual bottom hole condition.

1.2 Problem Statement

No early prediction on the wearing behavior on the drill string during the activity of drilling and it will lead to excessive friction to the wellbore formation. Wearing will reduce the thickness of the drill string and changing of drill strings will increase the drilling cost. Drilling mud engineer has to choose the minimum friction and wear values but sadly, there is no reference table or figure has been made related to different compositions of drilling muds. Proper assessment needs to be done to study the effects of water-based muds (WBM) and oil-based muds (OBM) to the drill string and wellbore formation.

1.3 Objectives

The main objective of this project is:

- To prepare a tabulation reference of coefficient of friction (COF) and wear ranking of WBM and OBM in order to predict the frictional and wear effect between the drill string and wellbore formation.

The objectives of this project are:

- To prepare common WBM and OBM samples in the industry.
- To analyze on the density and mud rheology of formulated WBM and OBM used in the project
- To observe the topography of frictional and wear effects of WBM and OBM to the drill string and wellbore formation.

1.4 Scope of Study

Compositions of drilling muds play an important role in minimizing the effect of frictional activities in the borehole. To minimize the effect of friction, the coefficient of friction for each drilling muds must be known. This study emphasizes more on different compositions of WBM and OBM to be used in mud circulating system and the effect of these drilling muds to the friction and wear activities imposed to drill string and wellbore formation. Topography and tribology of drill string and wellbore formation will be examined thoroughly and loss of materials will be identified as well.

CHAPTER 2

LITERATURE REVIEW

The literature review will be focusing on all of the elements that are going to be considered in order to understand this research.

2.1 Drilling mud

Drilling mud is one of the prominent aspects in drilling operations of a well as it must be carefully designed to ensure a successful drilling project. Drilling mud serves many purposes to the well; the mud has to transport the drilling cuttings from the bottom of the hole to the surface, to cool and lubricate the drilling bit as well as the drill string to minimize its wear [2]. Functions of a lubricant in drilling mud are to lubricate the drill string and prevent differential sticking. A range of lubricity values for various drilling mud compositions which demonstrate the ability of the fluid to wet or lubricate the drill pipe are known and used to lubricate the drill bit [3]. Commonly, the mud has to create an overbalanced drilling condition to control the formation pressure as well as the mud is capable to hold drilling cuttings in suspension when circulation is interrupted. Failure of the capability would allow the cuttings to move down the hole, settle at favorable places and block the drill string. Once the cuttings are at the surface, efficient mud cleaning (separation of cuttings, formation gas, from the mud) has to be possible applying a reasonable amount cleaning equipment.

2.2 Types of Drilling Mud

Drilling mud is a mixture of water, oil, clay and various chemicals contain in it. The composition of each ingredient does depend on the actual requirements of the individual well or well section. In other words, no universal drilling mud can be made for the entire wells in the reservoir. Two major types of drilling mud are water-base mud (WBM) and oil-base mud (OBM).

2.2.1 Drilling Mud Selection

The main criteria when choosing the best drilling mud is generally minimum overall well cost, production concerns, environmental impact, safety, application performance, and logistics. The considerations that must be taken into account when selecting drilling muds to drill a well are well type, problem formations, drilling rig, producing formations and kind of production, casing program, makeup water, potential corrosion, environmental impact, and availability of products in international operations.

i) Well type – Choosing between development or wildcat well drilling. Different types use different types of drilling muds.

ii) Problem formations – Shale formations, anhydrite formations, salt formation, high-temperature formation, abnormal pressure formation and inherently fractured formation use different types of muds as well.

iii) Shale intervals – OBM is widely used in shale formation. But, due to the mechanical pipe sticking, high torque/drag, annular hole-cleaning difficulties, logging difficulties and mud contamination, drilling in the shale gives these probable problems. Different types of OBM deal with these kinds of problems.

iv) Anhydrite intervals – Mainly involves use of WBM. Different concentrations of WBM affect the mud viscosity and fluid loss to different types of anhydrite formations. Proper assessment needs to be done to select the best WBM used.

v) Salt intervals – Contamination of bentonite-treated freshwater fluids from the drilling of salt sections has effects similar to those of the anhydrite formations. Contaminating ions can be magnesium, calcium, or chloride ions. To mitigate this problem, the treatment of ions by using different concentrations of WBM is implemented.

vi) High-temperature formation – Wellbore temperatures in excess of 250°F generally reduce the effectiveness of drilling-fluid chemical additives and thus can result in changes to such fluid properties as viscosity and fluid loss. Tolerant-to-high-temperature mud is selected to solve this problem.

vii) Abnormal pressure formation – Abnormal pressures result in intrusion of formation fluids into drilling muds, resulting in mud contamination and undesirable kicks. Proper selection of mud weight and suitable formation pressures can alleviate this problem.

viii) Loss circulation zones – Loss circulation zone is a formation interval that allows whole drilling fluid to be lost into the zone. If only part of the whole mud is lost, then the interval is called partial-loss circulation zone while total loss of circulation happens when no mud return to the surface.

ix) Producing formation – Minimum fluid filtrate in formations that are intended to be zones for oil/gas production will has no adverse effects on the producing formations.

x) Drilling rig – Success of a mud program in achieving optimum drilling is predicated on the proper selection of the rig and its layout.

xi) Casing program – Well-designed drilling mud will minimize casing-setting requirements and thus reduce well costs. For instance, changes in lithology and isolation of troublesome formations are typical requirements for setting casing at designated depths.

xii) Makeup water and availability – Primary considerations in the selection of the mud programs are source and the chemical composition of the makeup water. Availability and source of the makeup water must be considered so that mud treatment cost can be minimized. For example, freshwater is abundant on location, then mud dilution may be the most economical treatment.

xiii) Corrosion – Presence of dissolved gases in drilling muds decreases the life expectancy of drill pipe significantly. Drill pipe failure occurs at any applied cyclic stress if the number of fatigue cycles becomes sufficiently large.

xiv) Environmental impact – Mineral-oil-based or synthetic-oil-based mud systems are universally selected over the conventional diesel oil-based system when environmental impact involves.

2.2.2 Water-based Mud (WBM)

WBM (aqueous drilling fluid) refers to any drilling fluid where the continuous phase, in which some materials are in suspension and others are dissolved, is water [4]. It is generally easy to build, inexpensive to maintain, and can be formulated to overcome most drilling problems. WBM consists of four major ingredients which are water, inert solids (low & high gravity solids), reactive solids (low gravity solids) and chemical additives. WBM is divided into three major sub classifications; Non-inhibitive (do not significantly suppress clay swelling), inhibitive fluids (retard clay swelling) and polymer (rely on macromolecules, either with or without clay interactions). Non-inhibitive WBM are the least expensive and are easy to make and maintain. The application ceases when it is expected that high-temperature formations, dispersive formations, or formations that may contain certain contaminants such as H_2S will be encountered. Inhibitive drilling fluids include calcium-based muds, salt-based muds, potassium-based muds, and polymer drilling muds. Polymer drilling muds are those that have been treated with a certain type of polymer. Polymers are added to viscosify, to control fluid loss, to flocculate or deflocculate certain solids, to encapsulate wellbore walls, to provide high-temperature mud stabilization, and to extend the yield of bentonite.

2.2.3 Oil-based Mud (OBM)

OBM (non-aqueous drilling fluid) systems crude or diesel oil forms the continuous phase in the water-in-oil emulsion. Solid particles are suspended in oil. Water or brine is emulsified in oil. OBM are inert to contamination, as by H_2S, CO_2, salt, anhydrite, and active shales. There are two types of OBM; invert emulsion and oil muds. Invert emulsions mud contains dispersed water greater than 5% while oil muds contain less than 5% of dispersed water. A primary use of oil-based fluids is to drill troublesome shale and to improve hole stability. They are also applicable in drilling highly deviated holes because of their degree of lubricity and ability to prevent hydration of clays [5]. Cost is a major concern when selecting oil-based muds. Initially, the cost per barrel of an oil based mud is very high compared to a conventional water-based mud system. The use of OBM requires safeguards for environmental protection and safety. Main applications of OBM are in high-temperature formations, water-sensitive shales, thick salt sections, areas where lubricity is critical, low-pore-pressure formations and formations that contain corrosive elements (H_2S, $CO_{2,}$ etc.) [6].

The selection of WBM and OBM are based on several factors. One of the factors is temperature and pressure in the formation. WBM shows a temperature/viscosity relationship different from that of OBM; i.e., the viscosity of WBM decreased linearly with temperature [7]. Besides that, the type of formation is also one of the selection factors. OBM favors in shale formation because OBM does not react with clay formation leading to unstable shale. By using base oil as the external phase, it is good substance to reduce drilling torque. The advantages and disadvantages of using WBM and OBM are concluded in Table 2.1 [8].

2.2.4 Advantages and Disadvantages of WBM and OBM

TABLE 2.1: Advantages and disadvantages of WBM and OBM [8]

Drilling Mud	Advantages	Disadvantages
WBM	• No use of hydrocarbons which reduces impact on environment • Easy to control viscosity • Easy to control density for low pressure formation well drilling • Drill chips easier removed from fluid at shakers	• Not as efficient lubricant as OBM • Can promote corrosion to drill bit • Not efficient at high temperatures • Does not carry cuttings to the surface as efficient as OBM.
OBM	• Improved lubrication and anticorrosive properties • Maintains formation at high temperatures	• Can cause toxic fumes that affect the drilling team • Can be very high density/pressure and cause damage to well bore/surrounding formation

Based on Table 2.1, it is clearly shows that both WBM and OBM have their own advantages and disadvantages. WBM is mainly used at low pressure well drilling while OBM is used at high temperature and high pressure well formation.

2.2.5 Drilling Mud Properties

i) Viscosity – Internal resistance of a fluid to flow. This is attributed to the attraction between molecules of a liquid and is a measure of the combined effects of adhesion and cohesion on suspended particles and the liquid environment.

ii) Density (mud weight) – Ideally, a mud weight as low as the weight of water is desired, for optimum drilling rates and for minimizing the chances of fracturing the formation. However, in practice, mud weights in excess of two times the weight of water may be necessary, to contain abnormal pressures or to mechanically stabilize unstable formations.

iii) pH – hydrogen ion concentration, is a measure of the relative acidity or alkalinity. pH of mud plays a major role in controlling the solubility of calcium. High pH values of drilling mud are suitable to use at carbonate formations, which normally are susceptible to erosion and dissolution by freshwater mud. pH also important indicator for the control of corrosion.

iv) Rheology – Study of deformation fluids. It is the basis for all analyses of wellbore hydraulics.

v) Plastic viscosity – Part of the flow resistance of the fluid caused by mechanical friction within the fluid. This mechanical friction is due to the interaction of individual solid particles, the interaction between solid and liquid particles, and the deformation of the liquid particles under shear stress.

vi) Yield stress – Part of the flow resistance of the fluid caused by electrochemical forces within the fluid. These electrochemical forces are due to the electrical charges on the surface of reactive particles, the electrical charges on the submicron particles, and in WBM, the presence of the electrolytes.

vii) Gel strength – Measurement of the electrochemical forces within the fluid under static conditions.

2.3 Directional Drilling

In the early days, the main concern was to maintain a vertical course down to a target area located directly underneath the rig floor. However, in recent years, the concern has been extended to include the ability to drill a hole down to a pay zone target that may be located thousands of feet of horizontal departure away from the surface location under the rig floor. Figure 2.1 and 2.2 refer to directional well drilling, which consists of drilling a vertical hole section beneath the rig floor to a certain preselected kick-off depth and then intentionally deviating the wellbore along a preselected trajectory to reach the geological target zone.

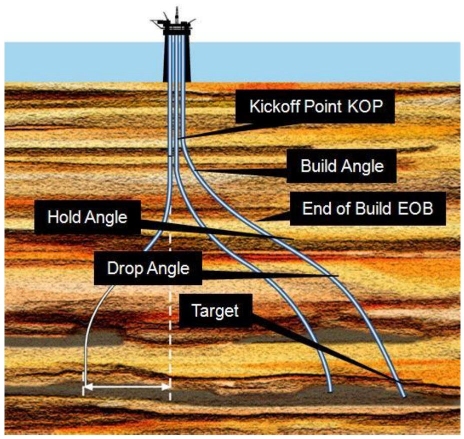

FIGURE 2.1: Directional drilling and its measurement components [9]

FIGURE 2.2: Drag and torque happens when drill string "slides" with wellbore formation [10]

When drilling directional wells to exploit underground hydrocarbons, the same elements are needed to drill the well successfully and economically; they differ only in terms of requirements. These elements are [11];

i) Force

There is inherent contact between the drill string and the walls of the wellbore; consequently considerable friction forces (drag) can be encountered, reducing the amount of weight needed to be transferred to the bit. This means that tubular placed above the bit should be of a weight variation such that their contribution to drag forces will be minimized and their contribution to weight-on-bit will be maximized.

Drilling muds also play major role in reducing this force by using different mud compositions.

ii) Rotation

Drill bit rotation may be induced at the surface, through the conventional rotary table or top-drive motor, or at bottom, through the use of down hole mud motors. In directional well drilling, rotation is induced at surface, and the portion of the drill string that is in contact with the walls of the wellbore will cause friction torque, in addition to bit torque, that can be five to ten times the friction torque encountered when drilling vertical wells. As hole angle increases from vertical to horizontal, the drag and torque due to friction forces will likewise increase. Excessive torque may limit a rig's available to rotary power; by contrast, when there is excessive drag, advancement of the bit may become the limiting factor in reaching the desired target.

iii) Circulation

High annular fluid velocities for the effective removal of drilled cuttings from annulus to the surface are needed in directional well drilling. Higher flow rates cause high friction pressure losses and, therefore, higher rig hydraulic horsepower requirements.

2.3.1 Drill String

The major portion of the drill string is composed of drill pipes. Figure 2.3 shows a common stack of drill pipes. Drill pipes are commonly made out of steel and butt-welded tool joints at each end. Tool joints provide a means for fastening the individual lengths of pipe together. The pipe is upset at both ends to reinforce the ends of the pipe. For design purposes, drill pipes are classified according to the outside diameter (OD), nominal unit weight, steel grades and class.

FIGURE 2.3: Drill pipes [12]

2.4 Friction

When surfaces touch and slide, there is friction; and where there is friction, there is also wear present. Theoretically, if the friction could be eliminated, the efficiency of solid materials would increase and if wear could be eradicated, they would also last longer. By implying this theory (reduces friction and wear), the longevity of borehole tools such as drill string can last much longer.

There are various types of friction but there are less research have been conducted to study the friction between solid rolling (drill string) on solid (wellbore formation) materials with lubricant (drilling mud). When two surfaces are placed in contact under a normal load *Fn*, and one is made to slide over the other, a force *Fs* opposes the motion. This force is proportional to *Fn*, but does not depend on the area of the surface.

The coefficient friction, μ is defined by

$$Coefficient\ friction, \mu = \frac{Static\ force, Fs}{Normal\ force, Fn}$$

There are two types of coefficient which are coefficient of static and kinetic friction, μs and μk. This project will concern on the coefficient of kinetic friction because there are sliding movements between drill string and wellbore formation and once sliding starts, the limiting frictional force decreases slightly.

$$Static\ force, Fs = \ Coefficient\ of\ kinetic, \mu k\ \times\ Normal\ force, Fn\ where\ \mu k < \mu s$$

Wellbore condition pictures a radial face where a wellbore formation can symbolize by a thin disk. Thin disk deflects when a pressure difference is applied across its surfaces [13]. The deflection causes stresses to appear in the disk. Spinning disks, rings, and cylinders store kinetic energy. Centrifugal forces generate stresses in the disk. The maximum rotation rate and energy are limited by the burst-strength of the disk. They are found by equating the maximum stress in the disk to the strength of the material. Figure 2.4 shows when a disk rotates with certain angular velocity and fixed density of material used, a number of energy is released as well. Maximum stress produced is perpendicular to the angular velocity of the disk. In this study, the disk will be the wellbore formation and drill string will rotate where friction and wear will be studied by using Multispecimen Wear Tester (MWT). Figure 2.4 explains the variables involve when a spinning disk rotates and the equations to find the energy, *U* and maximum stress, σ_{max}.

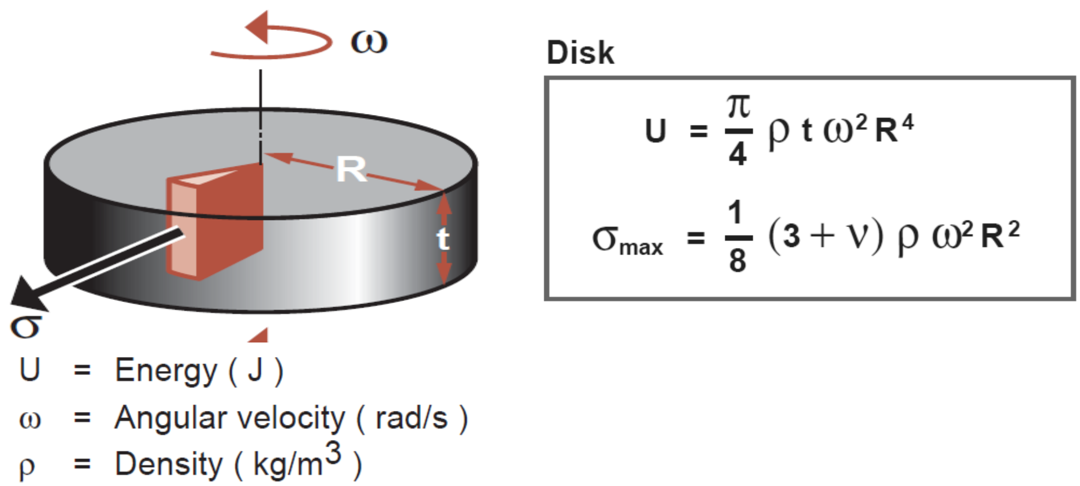

FIGURE 2.4: Variables involved when a spinning disk rotates [13]

This project also involves topography of materials used. High magnification of surface images will be produced and wearing phenomena can be observed on the surface. If two surfaces are placed in contact (drill string and wellbore formation) together, both will contact only at the occasional points where both surfaces meet the other.

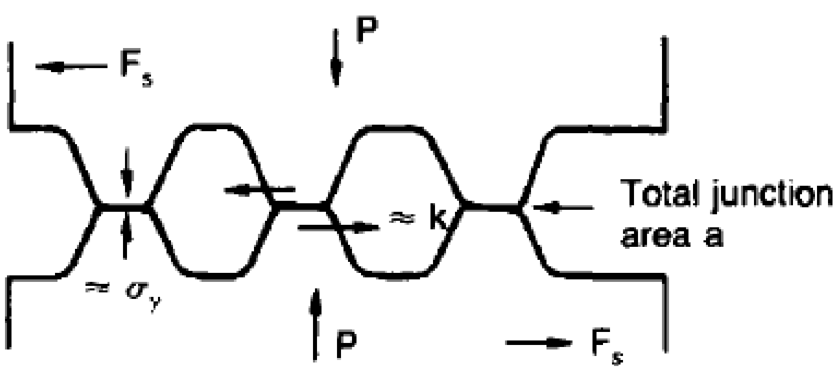

FIGURE 2.5: Variables involved between two contact surfaces [13]

Figure 2.5 shows that the load pressing the surfaces together is supported solely by the contacting surfaces. The real area of contact, a, is very small and because of this, the stress, P/a (load/area) on each points is very large. The real contact area between surfaces is less than it appears to be, because of the surfaces touch only where asperities meet. σy is the compressive yield stress. The area of contact is given by

$$Area\ of\ contact, a = \frac{Applied\ load, P}{Compressive\ yield\ stress,\ \sigma y}$$

2.4.1 Friction Factor

Friction factor can be given in terms of the coefficient of friction between the materials, lubricity coefficient of mud (L), pipe sticking coefficient (S), pipe rotational speed (N), temperature (t), well path profile which includes the curvature and borehole torsion (τ) [14].

$$Friction\ factor, \mu_v = f(\mu; L; S; N; t; E; \tau)$$

The composition of mud does affects wear and friction of casing and tool joints where when there is at least friction effect of a drilling fluid that creates a protective layer between the casing and the tool joint to minimize the wear [15]. The other major discovery is the beneficial effect of lubricants decreases with an increase of mud weight in barite-weighted muds. At mud weights in excess, reduction in friction was no longer observed. There are also interactions between friction coefficients with mud quality, mud cake, and lubricant addition in low-solids, water-based muds [16]. The research also included oil-based muds to compare with. From the research, it is concluded that the friction coefficients for the OBM were equal to those of the WBM. API (mud weight) factor also affects the friction factor of the drilling muds. A study which used Mud Lubricity Tester to test on small-scale measurements of mud friction coefficient concludes that certain types of mud additives tested lubricants effectively lubricants steel on steel and steel on rock, while some are not [17].

TABLE 2.2: Range of friction factors by using Mud Lubricity Tester [17]

Fluid type	Friction factors	
	Cased hole	Open hole
Oil-based	0.16-0.20	0.17-0.25
Water-based	0.25-0.35	0.25-0.40
Brine	0.30-0.40	0.30-0.40
Polymer-based	0.15-0.22	0.20-0.30
Synthetic-based	0.12-0.18	0.15-0.25
Foam	0.30-0.40	0.35-0.55
Air	0.35-0.55	0.40-0.60

There are two equipment to conduct and study friction factor of drilling muds to bore hole tools and joints which are Mud Lubricity Tester and Multispecimen Wear Tester. Table 2.2 shows ranges of values recorded by using Mud Lubricity Tester. Based on Figure 2.6, by using Multipecimen Wear Tester, the range of friction factor values for water-based muds is 0.80-090 which is quite relatively different from Mud Lubricity Tester [18]. No oil-based muds are being tested yet by using Multipecimen Wear Tester.

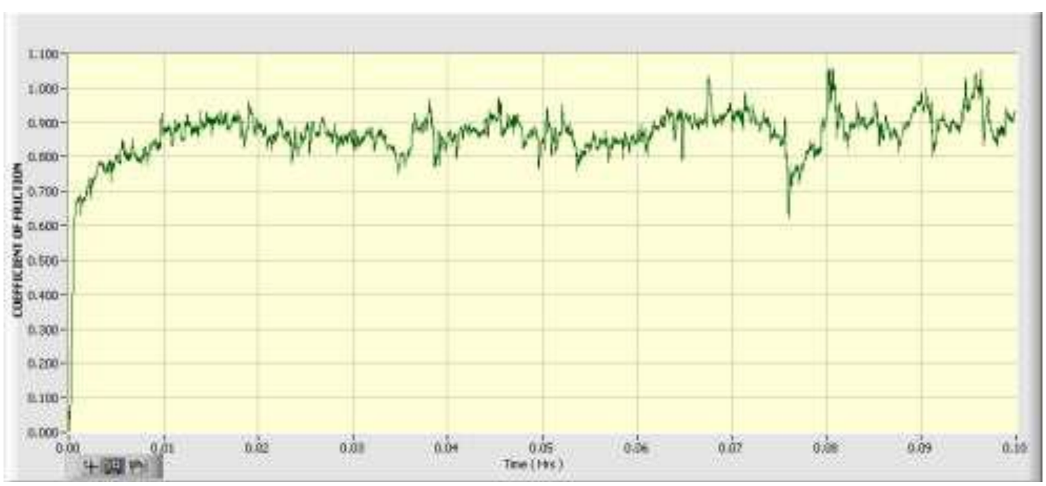

FIGURE 2.6: Friction factor of water-based mud by using Multispecimen Wear Tester (MWT) [18]

2.5 Wear

Wear presents when surfaces slide. Wear is damage to solid surface, generally involving progressive loss of material, due to relative motion between the surface and a contacting substance [19]. Material is lost from both surfaces, even when one is much harder than the other.

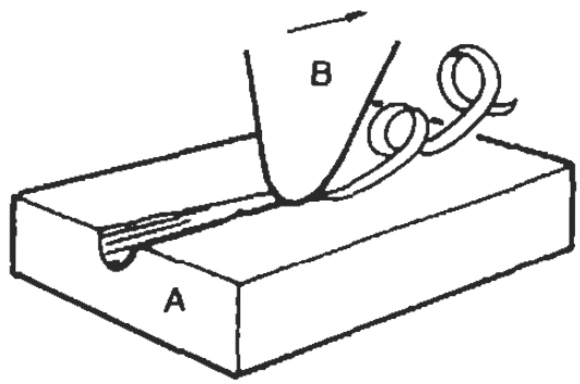

FIGURE 2.7: Wear activity between a pin and a flat contact surface [19]

Figure 2.7 shows how a hard material can 'plough' wear fragments from a softer material, producing severe abrasive wear. Abrasive wear is not confined to indigenous wear fragments, but can be caused by dirt particles making their way into the system.

The wear-rate, W, is conventionally defined as

$$Wear\ rate, W = \frac{Volume\ of\ material\ removed\ fom\ contact\ surface, V}{Distance\ slid, d}$$

Under normal mechanical and practical procedures, the wear-rate normally changes through three different stages; first, surfaces adapt to each other and the wear-rate might vary between high and low. Second, a steady rate of ageing is in motion and the final stage is the components are subjected to rapid failure due to a high rate of ageing.

2.6 Torque and Drag

As the work string is tripped in or out, or rotated on or off bottom, the friction force must be considered. It plays an important role in the solid mechanics calculations, such as torque and drag, as well as in the hydraulics calculations, such as surge, swab, and hook load estimation during cementing.

Accurate analysis for torque and drag is important for several reasons, including

i) Optimizing the well path to minimize torque and drag
ii) Fine-tuning the well path to minimize local effects, such as excessive normal loads
iii) Providing normal force loads for inputs into other programs, such as casing-wear models
iv) Identifying the depth or reach capabilities or limitations, both for drilling and for running casing/tubing
v) Matching the strength of drill string components to the loads (axial, torsional, or lateral) in the wellbore
vi) Identifying the hoisting and torque requirements of the drilling rig

A simplified drill string element is shown at Figure 2.8:

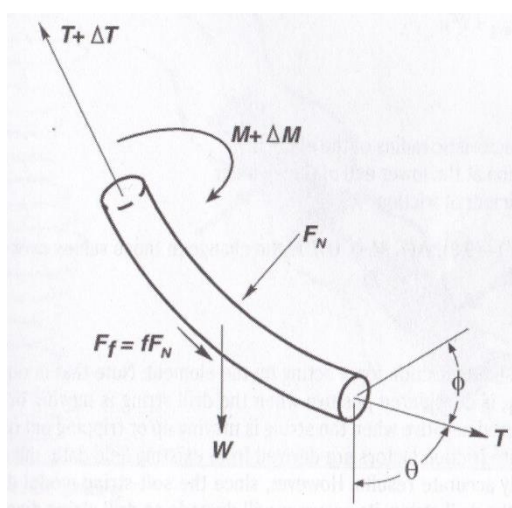

FIGURE 2.8: Drill string element for torque and drag model [20]

The normal force, $F_,$ is determined by:

$$F_N = \sqrt{\left(T_{axial}\,\Delta sin\theta_{avg}\right)^2 + \left(T\Delta\emptyset + \omega sin\theta_{avg}\right)^2}$$

Where F_N is the net normal force

T_{axial} is the axial tension at the lower end of the element

ω is the buoyed weight of the element

θ is the inclination angle at lower end of the element

$\emptyset$ is the azimuth angle at lower end of the element

The calculation of tension, T and torsion, M elements are then made by using equations:

$$\Delta T = \omega cos\theta_{avg} \pm fF_N$$

$$\Delta M = fF_N R$$

Where

R is the characteristics radius of the element

M is the torsion at the lower end of the element

f is the coefficient of friction

Drag is the excess load compared to rotating drill string or negative while sliding into the well [21]. This drag force is attributed to friction generated by drill string contact with the wellbore. This friction will reduce the surface torque transmitted to the bit when it rotates. The drill string can be simultaneously rotated and tripped in or out, and the drag force can be given as:

$$F_d = \mu_v\ X\ F_n X\ \frac{|V_{ts}|}{|V_{rs}|}$$

Drag is directly proportional to the normal force, coefficient of friction and tubular movement.

Increase in pipe stiffness and hole curvature result in high normal forces and therefore, an increase in torque and drag. Field experience shows that axial drill string drag is reduced when the drill string is rotated. Torque-and-drag models account for this mathematically by the use of velocity vectors [22].

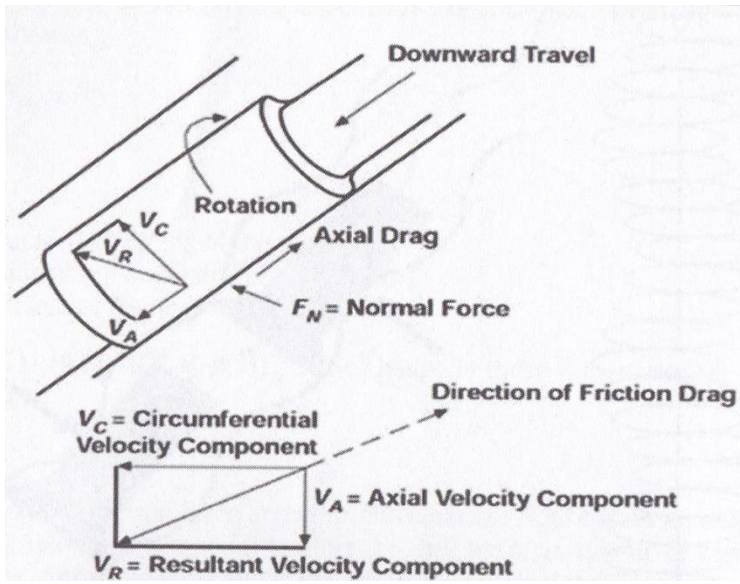

FIGURE 2.9: Effect of drill string rotation on axial friction [22]

From Figure 2.9, resultant velocity, V_R of a contact point on the drill string is the vector sum of two components: circumferential velocity, V_C (caused by rotation), and axial velocity, V_A (affected by drilling rate or tripping speed). The direction of the resultant frictional force is assumed to act in the direction opposite to that of the resultant velocity V_R therefore; its vector components will be in proportion to those of resultant velocity. The magnitude of the resultant frictional force is simply the product of the normal force F and the friction coefficient f, and it does not vary with velocity. The axial component decreases as the circumferential component increases since the magnitude of the vector sum of these components is a fixed quantity. As drill string rotation speed increases, it increases the circumferential component, which decreases axial friction.

To reduce drag and torque, it is compulsory to eliminate or reduce any of the components in the equation. There are four ways to reduce drag and torque;

1) Reducing the normal forces,

2) Reducing the coefficient of friction,

3) Increasing dynamic vs static conditions and

4) Increasing system capabilities [23].

This project will emphasize on reducing the coefficient of friction to reduce the drag and torque by implying the minimum coefficient of friction possessed by WBM and OBM.

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CHAPTER 3

METHODOLOGY

This project serves as a continuation to the previous project being held by Azrul Azwar bin Samsuddin, Petroleum Engineering graduate from Universiti Teknologi PETRONAS. His project emphasized more on friction and wear behavior of drill string where he was only used two types of drilling mud (Normal WBM and Normal WBM with nut plug) as the samples [18].

3.1 Laboratory Experiments

This project will focus more on different types of drilling muds where other kinds of WBM and OBM which are being left out, to be included in this project. This study is divided into three sequences of lab experiments; mud experiment which also includes mud preparation, Multispecimen Wear Tester (MWT) experiment (including material preparation) and topography experiment. Four different compositions of WBM and four for OBM will be formulated as the samples.

3.1.1 Materials Preparation

Few modifications on the existing MWT components such as the pin and rotating disk need to be done because the materials used in this project differ from the existing tribology test.

i) Pin

For this experiment, the drill string will be in pin form, and it is in cylinder shape, with dimension of 4mm diameter and 12mm height (Figure 3.1). The material used for the pin is mill steel and it resembles the drill string in the well bore and steel is chosen because steel drill pipe is widely used in the industry.

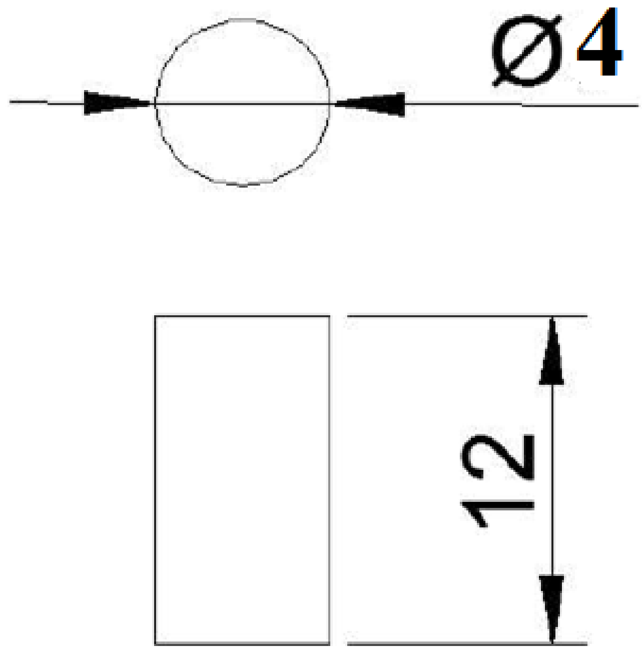


FIGURE 3.1: Drawing for pin

FIGURE 3.2: Pin

FIGURE 3.3: Plan View Pin

ii) Pin Holder

A pin holder (Figure 3.4) which resembles the drill collar is required to hold the pin (drill string). The pin holder used in this research is already available in the laboratory. So, there is no need to fabricate a new pin holder since the pin holder in the laboratory can fit together with the pin.

FIGURE 3.4: Pin Holder

iii) Disc Plate

Disc plate made of granite is needed to be used to simulate the actual actions that happened on the wellbore by using Multispecimen Wear Tester (MWT). Disc plate resembles the well bore formation. The disc that is being used is the Granite rock which contains quartz, feldspar, mica, and iron ore. The granite is cut into disc form with dimension of 52mm diameter, and 2mm thick as shown in Figure 3.5. The disc is prepared by using the machine that is provided in the Geology Lab at building 16, Universiti Teknologi PETRONAS.

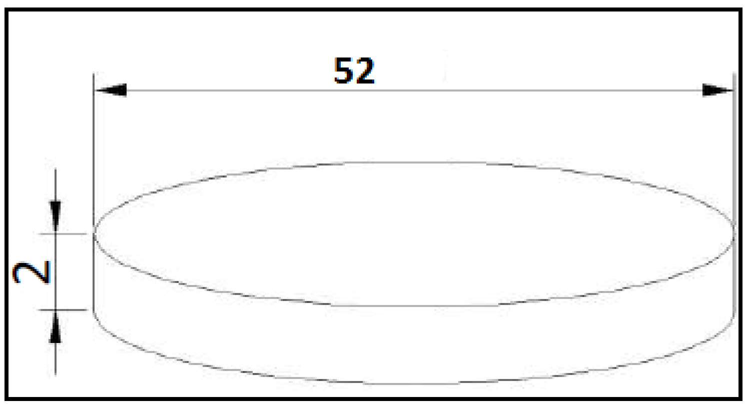


FIGURE 3.5: Drawing Disc Plate

FIGURE 3.6: Granite Disc Plate

iv) Drilling Fluid Cup

The drilling fluid cup is a component that will be used to hold the disc and the drilling fluid. Its function is to ensure the disc to be merging into the drilling fluid, and also to ensure the area of contact between the pin and the disc to be lubricated all the time. Based on Figure 3.8, at the side of the component, there are 4 holes with Screw size of M2. The function of the screw is to tighten up the disc in place, so that it will not move together with the pin during the experiment.

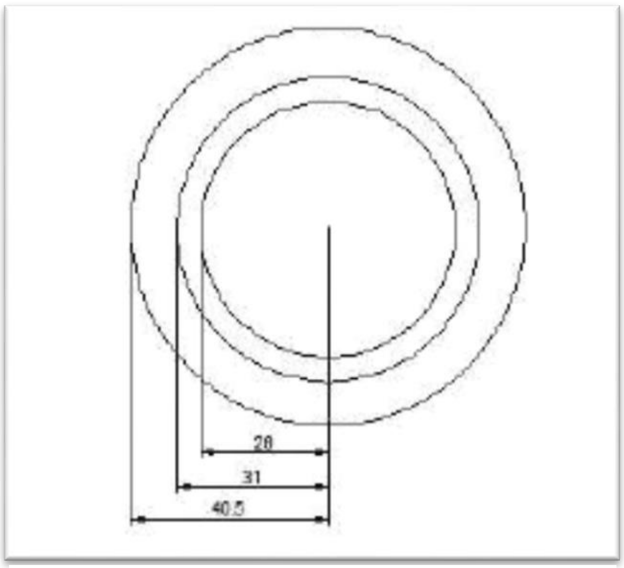


FIGURE 3.7: Plan View Drilling Fluid Cup

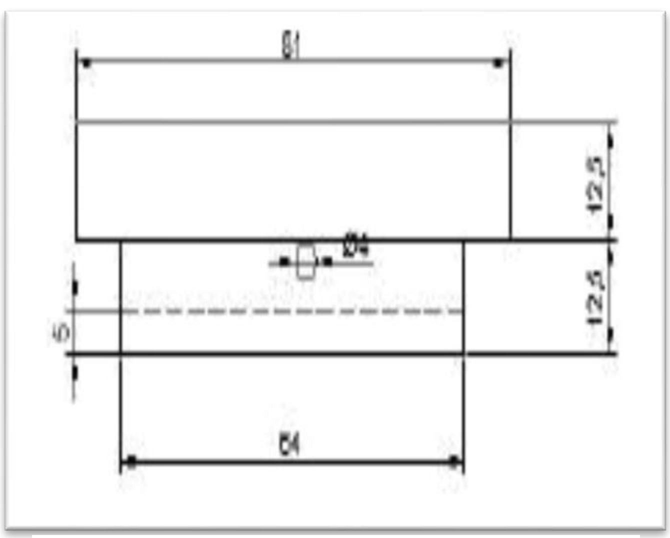


FIGURE 3.8: Side View Drilling Fluid Cup

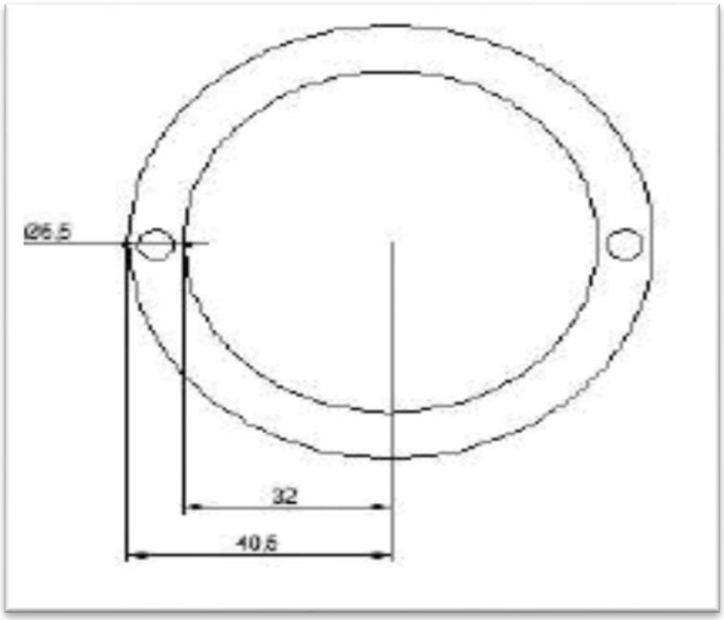


FIGURE 3.9: Background View Drilling Fluid Cup

FIGURE 3.10: Drilling Fluid Cup

3.1.2 Mud Samples Preparation and Testing

In mud preparation, each drilling muds will be examined and tested on mud weight or density test, rheology, gel strength, plastic viscosity, and apparent viscosity. The tools that will be used in this experiment are mud balance and FANN Viscometer. Then, the mud samples will be stored and used for the second work process.

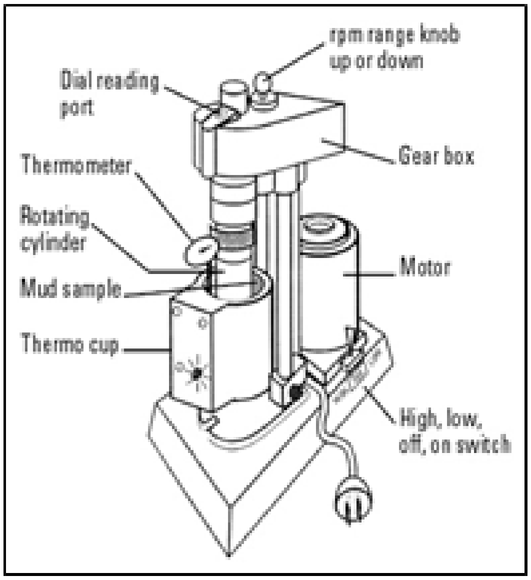


FIGURE 3.11: Viscometer [24]

FIGURE 3.12: Mud balance [25]

Viscometer (Figure 3.11) is used to determine the plastic viscosity, apparent viscosity, yield point, and gel strength while mud balance (Figure 3.12) is used to determine the mud density. Formulations of WBM and OBM are collected from past studies which tested drilling muds for lubrication purposes. All mud samples will be prepared with reference to American Petroleum Institute API Series 13 Standard. Mud samples will be prepared in the Drilling Laboratory at Universiti Teknologi PETRONAS at Block 16. The composition of the drilling fluids and additives will be different for each experiment in order to find the difference in wearing effect on pin and disc plate. The composition of the muds are shown in Table 3.1 and 3.2.

Water-based Muds (WBM)

TABLE 3.1: Samples of WBM

MUD #ID	SAMPLE #1	SAMPLE #2	SAMPLE #3	SAMPLE #4
Water (ml)	330	330	330	330
Soda Ash (g)	0.3	0.3	0.3	0.3
Caustic Soda (g)	0.2	0.2	0.2	0.2
HYDRO-ZAN (g)	1.25	1.25	1.25	1.25
Potassium chloride (g)	45.0	45.0	45.0	45.0
Calcium Carbonate (g)	20.0	20.0	20.0	20.0
Barite (g)	68.0	68.0	68.0	68.0
HYDRO-PAC LV (g)	4.00	-	-	-
HYDRO-PAC R (g)	-	4.00	-	-
Calcium Chloride (g)	-	-	4.00	-
HYDRO-PAC UL (g)	-	-	-	4.00

Oil-based Muds (OBM)

TABLE 3.2: Samples of OBM

MUD #ID	SAMPLE #5	SAMPLE #6	SAMPLE #7	SAMPLE #8
Saraline 185 V (g)	188.37	188.37	188.37	188.37
CONFI-MUL P (g)	5.00	5.00	5.00	5.00
CONFI-MUL S (g)	7.00	7.00	7.00	7.00
CONFI-GEL (g)	7.00	7.00	7.00	7.00
CONFI-TROL (g)	8.00	-	-	-
VG-69 (oranophilic clay) (g)	-	8.00	-	-
VG Plus (g)	-	-	8.00	-
ECOTROL RD (g)	-	-	-	8.00
Lime (g)	8.00	8.00	8.00	8.00
Fresh Water (g)	81.05	81.05	81.05	81.05
Calcium Chloride	29.36	29.36	29.36	29.36
Barite (g)	190.66	190.66	190.66	190.66

Below are the procedures to examine the rheology of the drilling mud.

1. WBM Mixing

    1.1 The materials in Table 3.1 were prepared first.

    1.2 Soda ash, potassium chloride and fresh water were mixed first with magnetic stirrer for 2 minutes.

    1.3 HYDRO-PAC LV was mixed in mud mixer for 5 minutes.

    1.4 HYDRO-ZAN was added slowly and mixed for another 5 minutes.

    1.5 Barite was added slowly and mixed for another 10 minutes.

    1.6 Caustic soda is added slowly and mixed for another 2 minutes.

    1.7 Calcium carbonate was added slowly and mixed for another 30 minutes.

    1.8 Steps 1.1 until 1.7 are repeated by replacing HYDRO-PAC LV with HYDRO-PAC R, Calcium Chloride and HYDRO-PAC UL.

2. OBM Mixing

    2.1 The materials in Table 3.2 were prepared first.

    2.2 Calcium chloride and fresh water were mixed first with magnetic stirrer for 10 minutes.

    2.3 Saraline, CONFI-MUL P were mixed in mud mixer for 4 minutes.

    2.4 CONFI-TROL was added slowly and mixed for another 2 minutes.

    2.5 Lime was added slowly and mixed for another 15 minutes.

    2.6 Calcium chloride is added slowly and mixed for another 15 minutes.

    2.7 Barite was added slowly and mixed for another 33 minutes.

    2.8 Steps 2.1 until 2.7 are repeated by replacing CONFI-TROL with VG 69, VG Plus and ECOTROL RD.

3. Mud Weight or Density Test
    3.1 The mud weight test will be using typical mud balance.
    3.2 The lid from the cup is removed and completely fills the cup with the mud to be tested.
    3.3 The lid is replaced and rotated until firmly seated, make sure some mud is expelled through the hole in the cup.
    3.4 The mud is washed or wiped from outside the cup.
    3.5 The balance arm is placed on the base, with knife edge resting on the fulcrum.
    3.6 The rider is moved until the graduated arm is level, as indicated by the level vial on the beam.
    3.7 At the left hand edge of the rider, the density is read on either side of the lever in all desired units without disturbing the rider.
    3.8 Mud temperature is noted down corresponding to density.

4. Viscosity
    4.1 Viscosity will be measured using FANN Viscometer.
    4.2 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.
    4.3 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.
    4.4 Stir the sample for about 5 seconds at 600 rpm, and then select the RPM desired for the best.
    4.5 Wait for the dial reading to stabilize.
    4.6 Record the dial reading and RPM.

5. Gel Strength

   5.1 Stir the sample at 600 rpm for about 15 seconds.

   5.2 Turn the RPM knob to stop position.

   5.3 Switch the RPM knob to GEL position.

   5.4 Record the maximum deflection recorded on the dial.

3.1.3 Multispecimen Wear Tester (MWT) Experiment

The second work process is friction/wear study by using DUCOM Multispecimen Wear Tester (MWT) which is available in Block 17, Universiti Teknologi PETRONAS. MWT is the equipment used to test various kinds of tribology properties such as friction and wearing behavior. The pin which acts as drill string is installed fix at one place, and a disc plate which acts as wellbore formation will be placed under it. The pin will rotate where the velocity and rotation per minute can be manipulated. The results from this experiment will read by the software installed and graphs of coefficient of friction (COF) versus time and wear versus time will be produced.

The prepared mud samples will be poured in the space between the pin and the disc. The drilling mud will act as the lubricator to reduce the friction between the pin and the disc. Below are the procedures of using Multispecimen Wear Tester (MWT):

1. Data recording will be done using computer connected to the rig. The RPM, disc, pressure, force are constants. For trial, the data used was:

   Rotational speed – 120 rpm

   Applied load – 10N

   Time –30 minutes per run

   Disc Plate – Granite

2. First, the disc plate will be weighed to get the initial weight before the experiment. The weight taken should be accurate, with at least 4 decimal places, as the expected wearing behavior to be small.
3. Then, the pin will also need to be weighed. Same as the disc, the accuracy of the weight recorded should be at least 4 decimal places.

4. The initial weight of both disc and pin will be used later in the result part to calculate, and record the wearing activity that happen on these two contact surfaces; in gram.
5. As for the pin, make sure there is no oil/fluid on it. Any other fluid will affect the experiment's result. To solve this, the pin is clean up the surface of the pin with methanol, and dries it up with dry cloth.
6. After that, install the pin into the holder by placing the pin inside the holder, and tighten up with the screw inside the holder. The pin must be tight enough so that no rotation of pin within, inside the holder will occur. Then, install the holder inside the MWT.
7. On the other side, the disc plate will be put into the drilling fluid cup as shown in Figure 3.13. The disc is put into the cup, and tighten up so that no rotation of the disc to occur; disc stay still, fix position. After tighten up, drilling fluid will be filled into the cup, until the disc is submerged into the fluid. Then, place the cup into the rig.

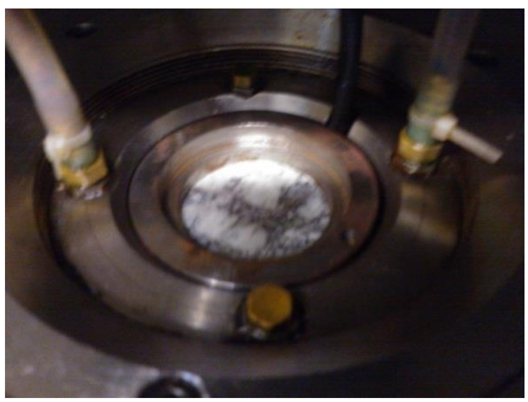


FIGURE 3.13: Drilling fluid cup in MWT

8. After set up all the components inside the rig, set up in the software will be done. Using the software, the parameters for rotational speed, time taken and others are keyed in through the computer.
9. Then, the load will start to be put on to the lever. The first load will only be used for the pin and the disc to be in contact; no applied load. As this is only used to let the contact between the pin and disc occur, only small load will be put onto the lever. At the same time, the applied load in the software will be set to zero.

FIGURE 3.14: MWT lever

FIGURE 3.15: MWT lever with load

10. Only by then, the applied load will be loaded. Based on Figure 3.14, there are 2 places to place the load. The ratio of the lever is 2:6. Means, if you put 5N load on the left, it will time by 2, and if you put on the right place, it will time by 6. That's how the applied load on this MWT works. As for this experiment, 5N load is placed on the left place as shown in Figure 3.15.
11. Then, the experiment is started by clicking start in the software. Through the software, the graph of the experiment is plotted, and the trend of the experiment can be observed.
12. When the experiment ended, take out the disc, as well as the pin from the rig and also from their holder/cup.
13. The pin will then be weighed to find the final weight, after the experiment. But as for the disc, it will need to be left for one day in order to dry it up and remove all drilling fluid inside the granite disc. This is to ensure that the final weight recorded will have the same condition as the initial weight; dry weight.
14. Data for the calculation of volume loss is acquired from the worn region of the sample and from the intact region around it. A reference plane is constructed for the intact surface. Volume loss is calculated from the differences between the interpolated reference plane and the actual worn surface.
15. All the steps of using MWT are repeated by replacing the drilling mud sample with other samples.

FIGURE 3.16: MWT equipment

3.1.4 Friction and Wear Topograhy Experiment

The pin and disc plate will be polished and used in the third and final work process which is the study of topography of the materials. The disc plate after the friction and wear testing will be observed and magnified image of wearing activity on the disc plate like Figure 3.17 will be displayed.

FIGURE 3.17: Magnified image of granite disc plate

3.2 Research Plan

3.2.1 Gantt Chart

TABLE 3.3: Gantt chart for FYP I and II semesters

No	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	Topic Selection / Proposal		√																										
2	Preliminary Research Work						√																						
3	Submission of Extended Proposal						•																						
4	Proposal Defense																												
5	Mud Rheology Preparation													√															
6	Submission of Interim Draft Report													•															
7	Submission of Interim Report														•														
8	Mud Samples Preparation																		√										
9	MWT Material Fabrication																√												
10	MWT Experiment																												
11	Submission of Progress Report																						•						
12	(cont.) Mud Samples and MWT Experiment																								√				
13	Topography Observation																								√				
14	Results and Discussion																									√			
15	Pre-SEDEX																									•			
16	Submission of Final Draft Report																										•		
17	Submission of Technical Paper																										•		
18	Oral Presentation																											•	
19	Submission of Dissertation																												•

- Important dates for FYP 1 and II semesters

√ Key milestones for FYP 1 and II semesters

3.2.2 Project Deliverables

TABLE 3.4: Project deliverables for research

Event or Deliverable	Target Date	Responsibility
Project charter/draft preparation	Week 1-2	Discuss the suitability and feasibility of the project title
Project plan completed	Week 3-7	Draft the project planning and project activities
Project plan approved	Week 8-9	Proposal defense presentation to the UTP supervisor and panel examiners
Project execution initiated	Week 10	Conduct all the project activities as planned in the project charter
Project execution completed	Week 26	Complete the final documentation and ready for project deliverable
Project results presentation	Week 27-28	Oral presentation and simulation of the project title and evaluation from UTP and panel examiners (Pre-SEDEX)
Project completion	Week 28	Hand in the final documentation for further reference to UTP and panel examiners

3.2.3 Project Activities

Preliminary Research
- Study on research papers and journals
- Understand concepts, theories and apparatus will be used
- Literature review

Mud Preparation & Test
- Finding suitable mud additives
- Mud characteristics evaluation (rheology, density, plastic, apparent viscosity, yield point)

Friction&Wear
- Multispecimen Wear Tester (MWT) preparation
- Multispecimen Wear Tester (MWT) experiment
- Coefficient of friction and wear vs time graphs

Topography
- Pin and Disk Plates preparation
- Topography experiment
- Magnified images recording

Output testing
- Tabulation of coefficient of friction (COF) and wear values

Correlation to Industry
- Compare the results to existing range of friction table in the industry

Discussion
- Discuss the findings and results

Report Wrting
- Compile all related results and produce in hardcopy and softcopy form

FIGURE 3.18: Project activities for the research

3.2.4 Flowchart/Workflow Process

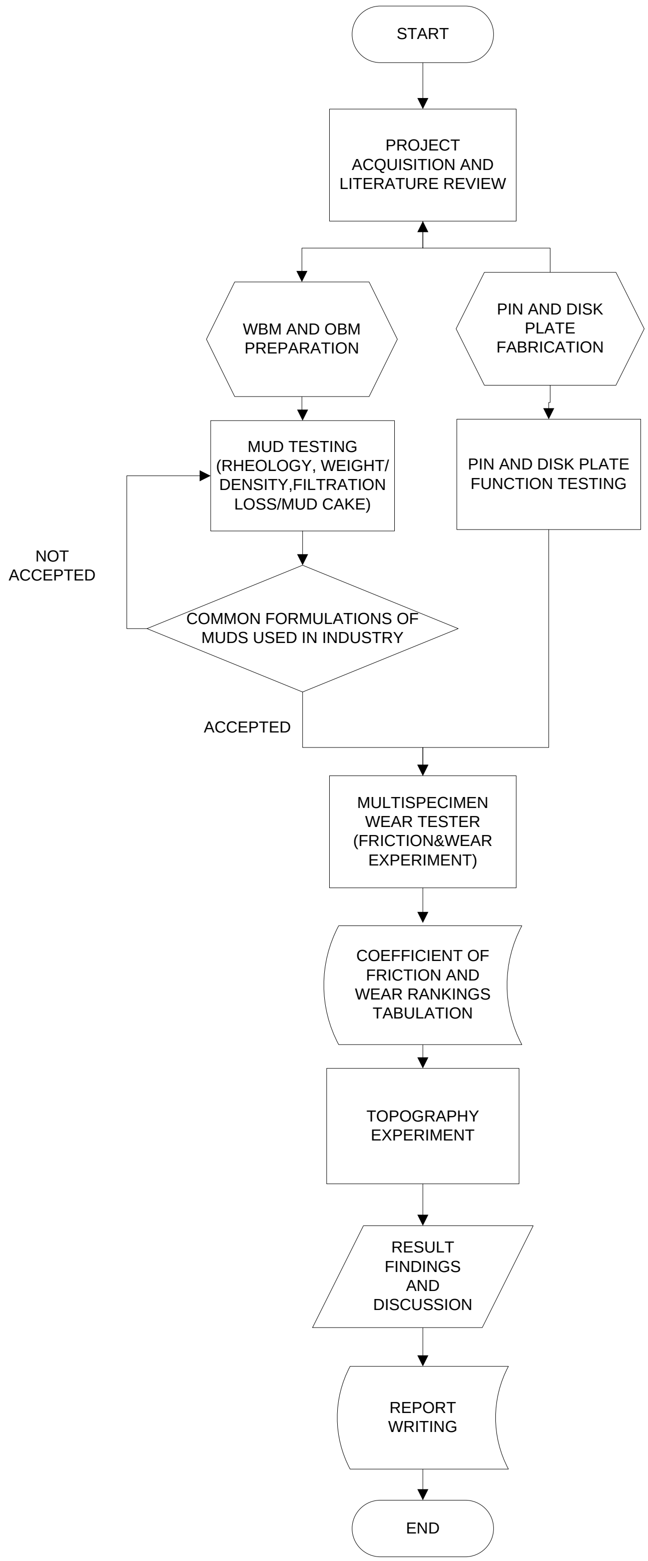


FIGURE 3.19: Research flowchart

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

Four (4) samples of WBM and four (4) samples of OBM have been prepared. According to API Standard series 13, the ratio for WBM and OBM is 80/20. All samples have already been tested for mud rheology, friction and wear testing and also topography observation.

4.1.1 Mud Rheology

Calculation for plastic viscosity, apparent viscosity, and yield point:

$$\textit{Mud Weight (psi/100ft)} = \textit{Mud Weight (ppg)}\ X\ 5.195$$

$$\textit{Gel strength (dynes/cm}^2\textit{)} = \textit{Gel strength (lb/100ft}^2\textit{)} \times 5.077$$

$$\textit{Plastic viscosity} = \mu_p = \textit{600 RPM reading} - \textit{300 RPM reading}$$

$$\textit{Apparent viscosity} = \mu_a = \textit{600RPM reading} \div 2$$

$$\textit{Yield Point} = \textit{300 RPM reading} - \textit{Plastic viscosity}$$

Water-based Muds

TABLE 4.1: WBM rheology data

Sample	**#1**	**#2**	**#3**	**#4**
Mud weight (ppg)	10.0	10.0	10.0	10.0
Mud weight (psi/100ft)	51.95	51.95	51.95	51.95
600 rpm reading	100	123	29	75
300 rpm reading	70	99	20	55
Plastic viscosity, μ_p (cp)	30	24	9	20
Apparent viscosity, μ_a (cp)	50	61.5	14.5	37.5
Yield point (lb/100ft^2)	40	75	11	35
Gel strength, 10sec (lb/100ft^2)	10	18	5	6
Gel strength, 10min (lb/100ft^2)	13	20	5	6

Oil-based Muds

TABLE 4.2: OBM rheology data

Sample	**#5**	**#6**	**#7**	**#8**
Mud weight (ppg)	11.5	11.5	11.5	11.5
Mud weight (psi/100ft)	59.7	59.7	59.7	59.7
600 rpm reading	112	185	150	175
300 rpm reading	77	140	121	110
Plastic viscosity, μ_p (cp)	35	45	29	65
Apparent viscosity, μ_a (cp)	56	92.5	75	87.5
Yield point (lb/100ft^2)	42	95	92	45
Gel strength, 10sec (lb/100ft^2)	20	95	11	28
Gel strength, 10min (lb/100ft^2)	21	95	12	26

4.1.2 Friction and Wear Testing

Based on the observation on the trend of the graph and MWT lever which has shaken too much during the experiment, it indicates that the surface of the disc is not flat, irregular and rough. The result is imperfect due to this error, as same applied load (10N) should be applied to all surface points of the granite disc plate. Observation on the plate after the experiment shows that the residues of the mud, especially oil-based muds increase the after-weight of the disc plate. Therefore, the weight of the granite disc plate is heavier after the experiment. For the pin's result, during rotational movement to the disc plate, it has resulted on the decrease of weight. The loss is not much, between 0.001g to 0.002g and it is invisible to the naked eyes.

There are quite differences of COF and wear values for OBM and WBM. WBM shows higher values of COF and wear compared to OBM. The values of COF and wear trending graphs are shown in Figure 4.1 until 4.4.

Water-based Muds

TABLE 4.3: WBM friction and wear testing data

Sample	**#1**	**#2**	**#3**	**#4**
Time (hr)	0.5	0.5	0.5	0.5
Rotational speed (rpm)	120	120	120	120
Applied load (N)	10	10	10	10
Initial weight of pin (g)	3.245	3.230	3.228	3.224
Final weight of pin (g)	3.243	3.228	3.226	3.222
Loss weight of pin (g)	-0.002	-0.002	-0.002	-0.002
Initial weight of disc (g)	15.085	15.355	16.359	19.971
Final weight of disc (g)	15.086	15.356	16.361	19.974
Loss weight of disc (g)	+0.001	+0.002	+0.002	+0.003

Oil-based Muds

TABLE 4.4: OBM friction and wear testing data

Sample	**#5**	**#6**	**#7**	**#8**
Time (hr)	0.5	0.5	0.5	0.5
Rotational speed (rpm)	120	120	120	120
Applied load (N)	10	10	10	10
Initial weight of pin (g)	3.2550	3.250	3.248	3.224
Final weight of pin (g)	3.2545	3.248	3.245	3.220
Loss weight of pin (g)	-0.0005	-0.002	-0.003	-0.004
Initial weight of disc (g)	16.142	16.736	16.265	23.547
Final weight of disc (g)	16.155	16.746	16.275	23.559
Loss weight of disc (g)	+0.013	+0.010	+0.010	+0.012

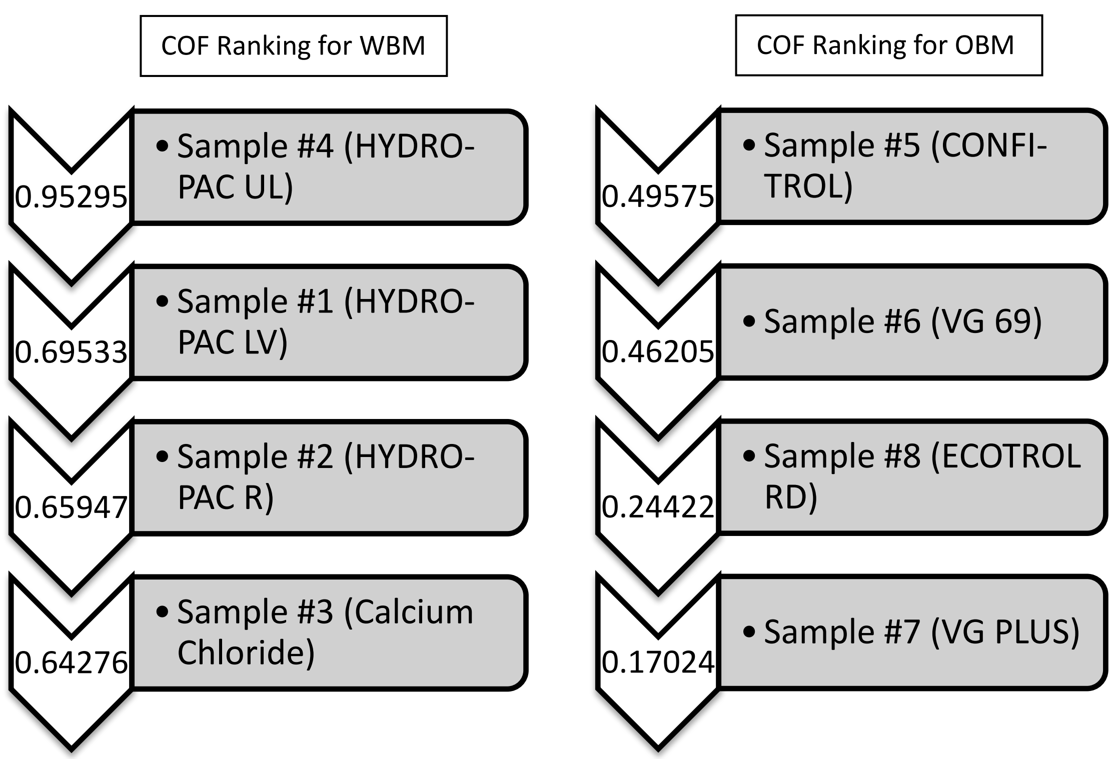


FIGURE 4.1&4.2: COF Ranking for WBM and OBM

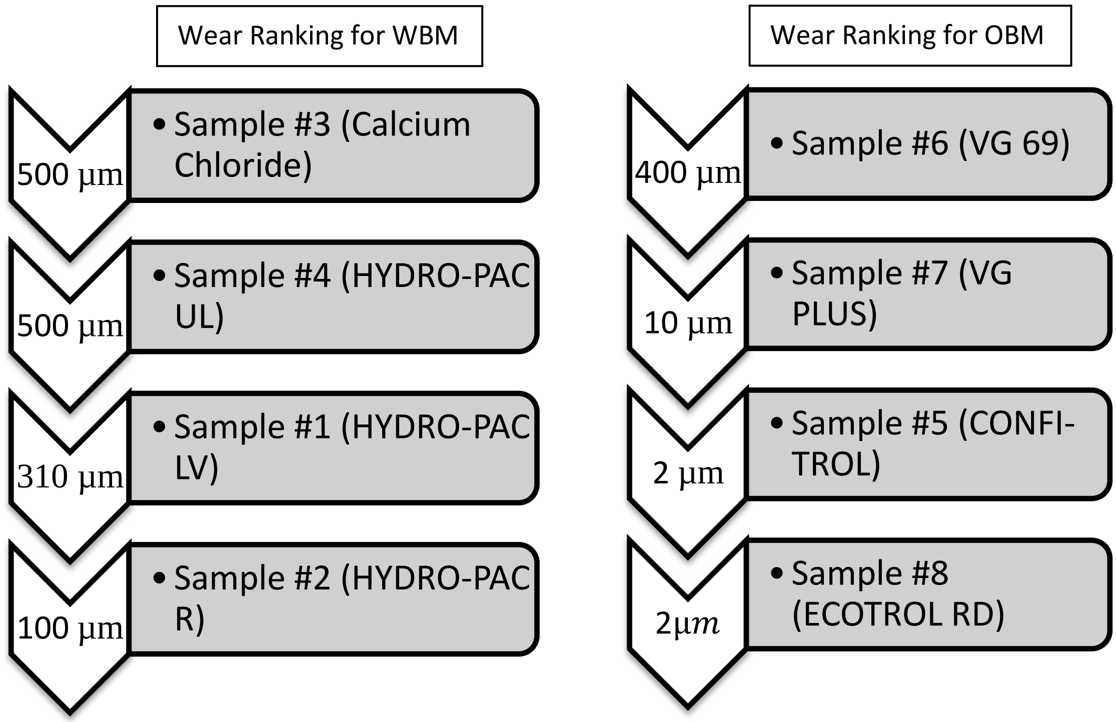


FIGURE 4.3&4.4: Wear Ranking for WBM and OBM

The wear ranking shown in Figure 4.3 and 4.4 is not applicable because MWT only detects the wearing activity between two identical minerals. Since the project involves two different minerals, which are mill steel (drill string) and granite (wellbore formation), the values for wear ranking cannot be trusted.

Sample #1

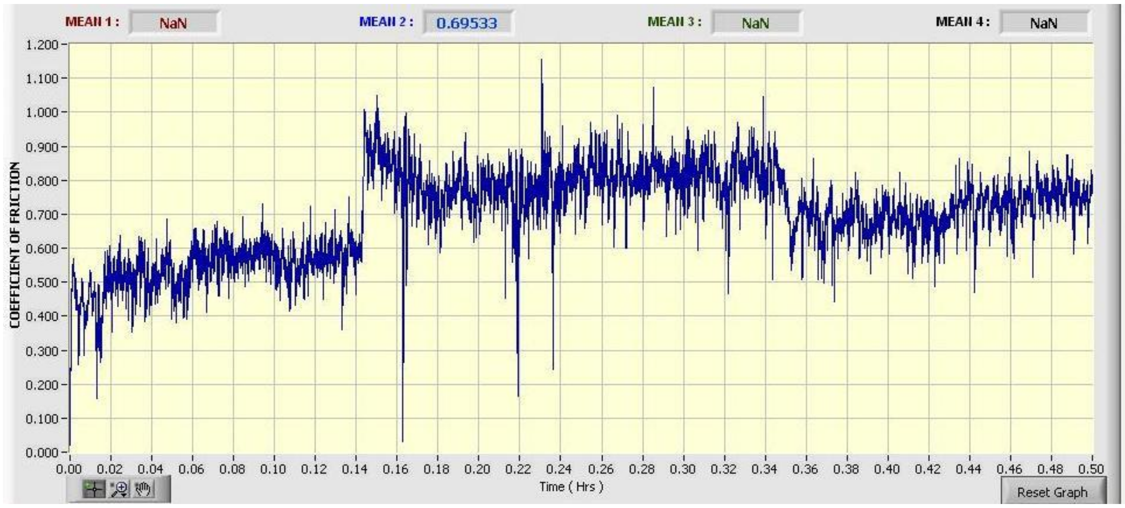


FIGURE 4.5: COF graph for Sample #1 (Additive: HYDRO-PAC LV)

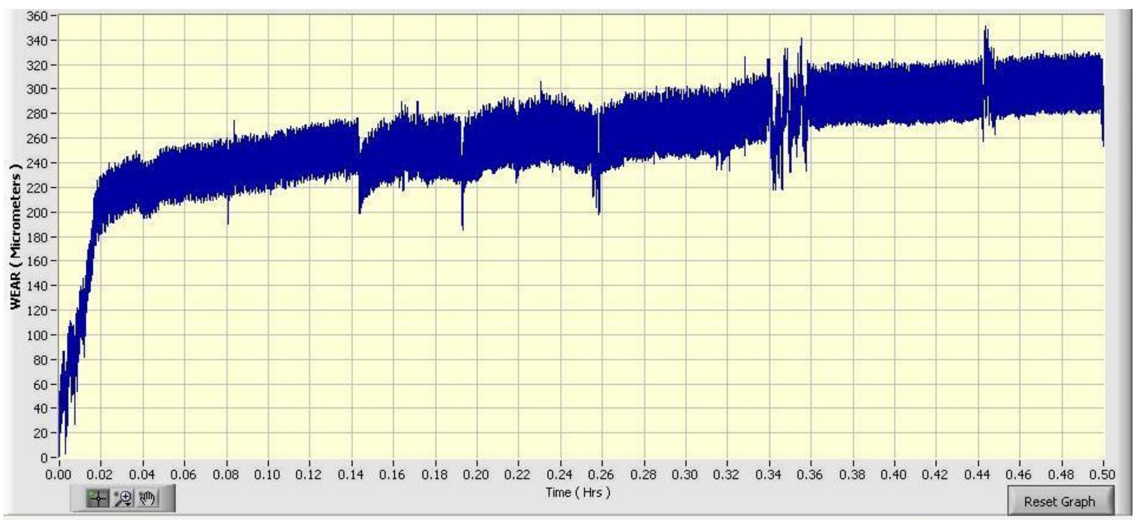


FIGURE 4.6: Wear graph for Sample #1 (Additive: HYDRO-PAC LV)

Figure 4.5 shows the coefficient of friction (COF) graph for water-based mud using HYDRO-PAC LV as the additive. The mean value of coefficient of friction (COF) for the mud is 0.69533. Figure 4.6 shows the wear graph for water-based muds using HYDRO-PAC LV as the additive. The wear value for the mud is 310µm.

Sample #2

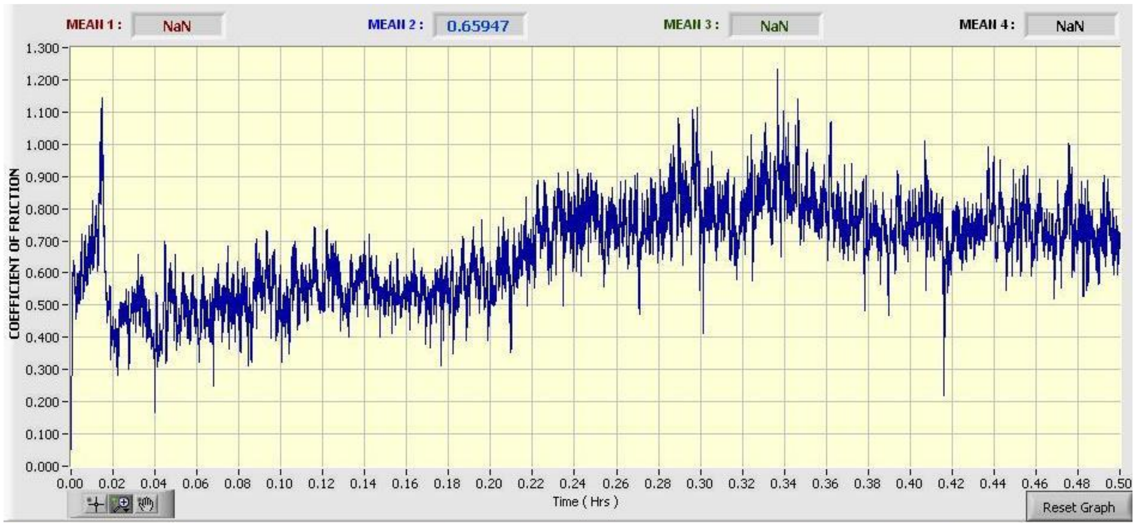


FIGURE 4.7: COF graph for Sample #2 (Additive: HYDRO-PAC R)

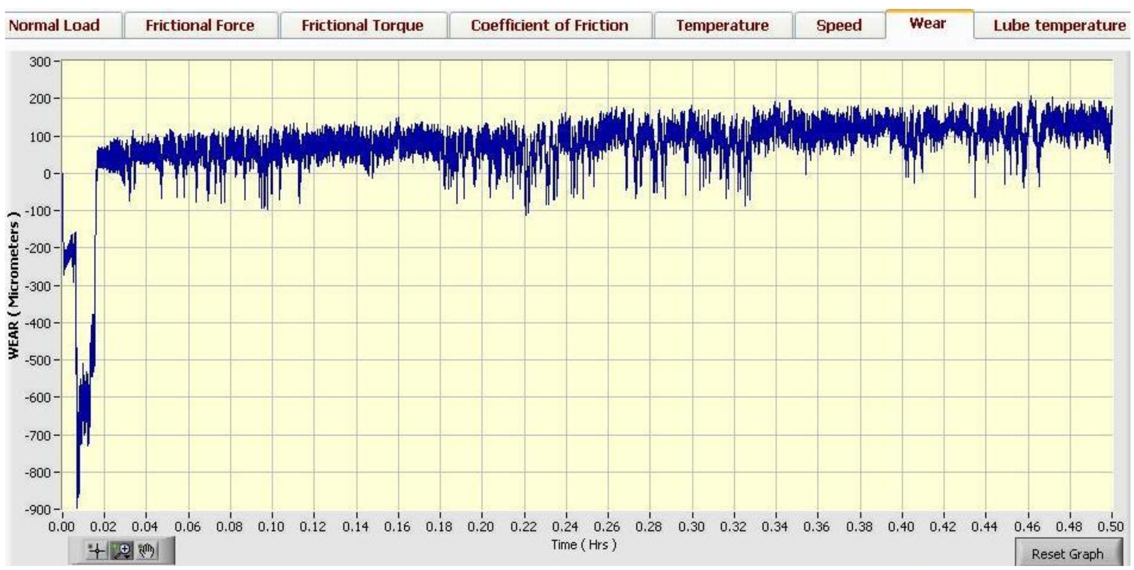


FIGURE 4.8: Wear graph for Sample #2 (Additive: HYDRO-PAC R)

Figure 4.7 shows the coefficient of friction (COF) graph for water-based mud using HYDRO-PAC R as the additive. The mean value of coefficient of friction (COF) for the mud is 0.65947. Figure 4.8 shows the wear graph for water-based muds using HYDRO-PAC R as the additive. The wear value for the mud is 100µm.

Sample #3

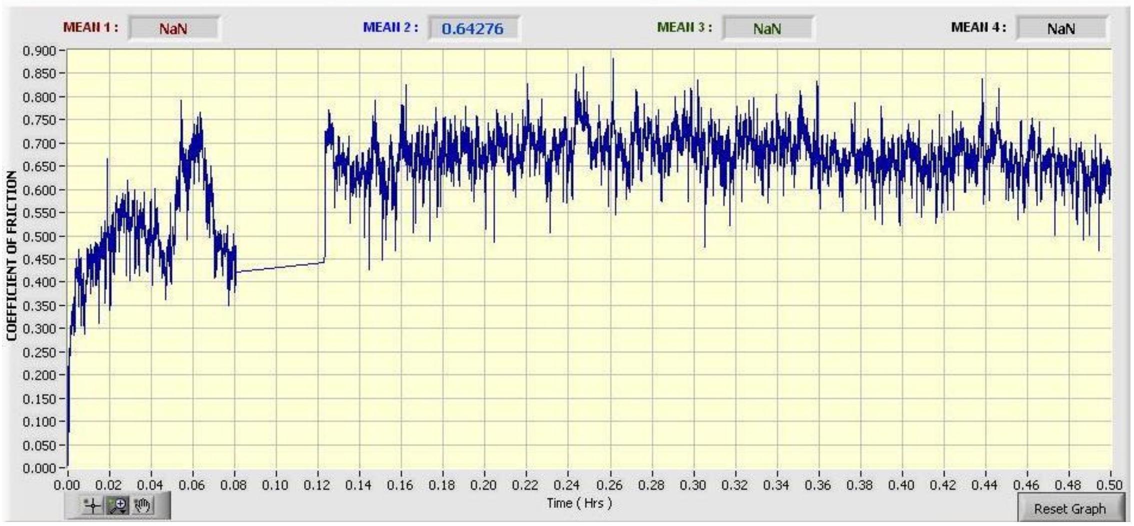


FIGURE 4.9: COF graph for Sample #3 (Additive: Calcium Chloride)

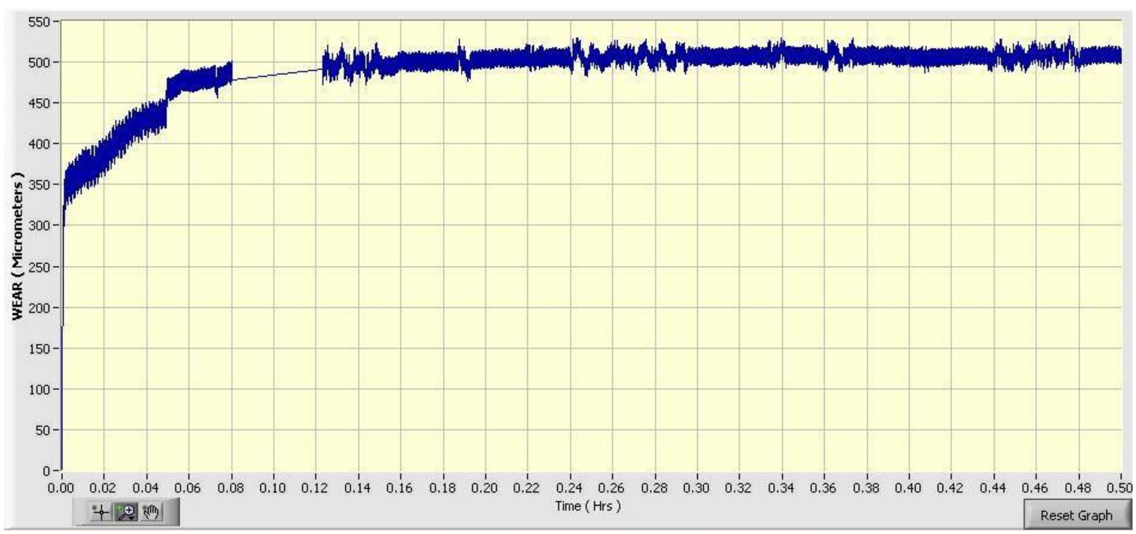


FIGURE 4.10: Wear graph for Sample #3 (Additive: Calcium Chloride)

Figure 4.9 shows the coefficient of friction (COF) graph for water-based mud using Calcium Chloride as the additive. The mean value of coefficient of friction (COF) for the mud is 0.64276. Figure 4.10 shows the wear graph for water-based muds using Calcium Chloride as the additive. The wear value for the mud is 500μm.

Sample #4

FIGURE 4.11: COF graph for Sample #4 (Additive: HYDRO-PAC UL)

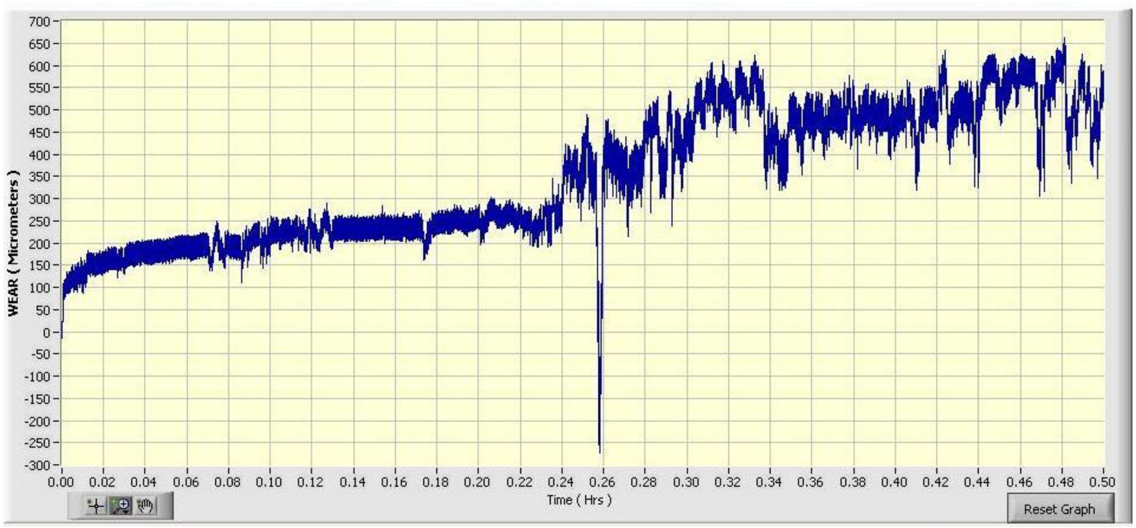


FIGURE 4.12: Wear graph for Sample #4 (Additive: HYDRO-PAC UL)

Figure 4.11 shows the coefficient of friction (COF) graph for water-based mud using HYDRO-PAC UL as the additive. The mean value of coefficient of friction (COF) for the mud is 0.95295. Figure 4.12 shows the wear graph for water-based muds using HYDRO-PAC UL as the additive. The wear value for the mud is 500µm.

Sample #5

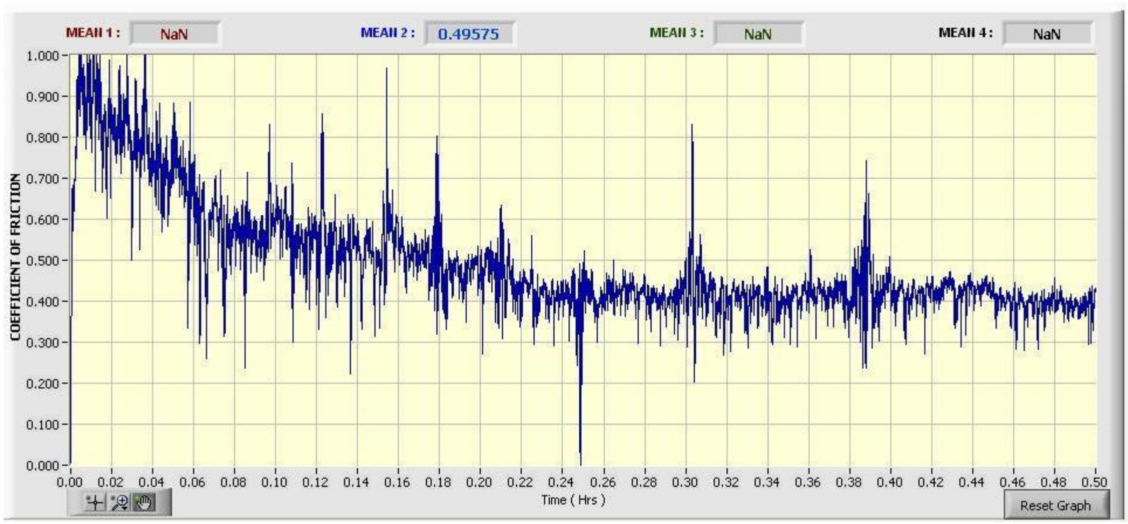


FIGURE 4.13: COF graph for Sample #5 (Additive: CONFI-TROL)

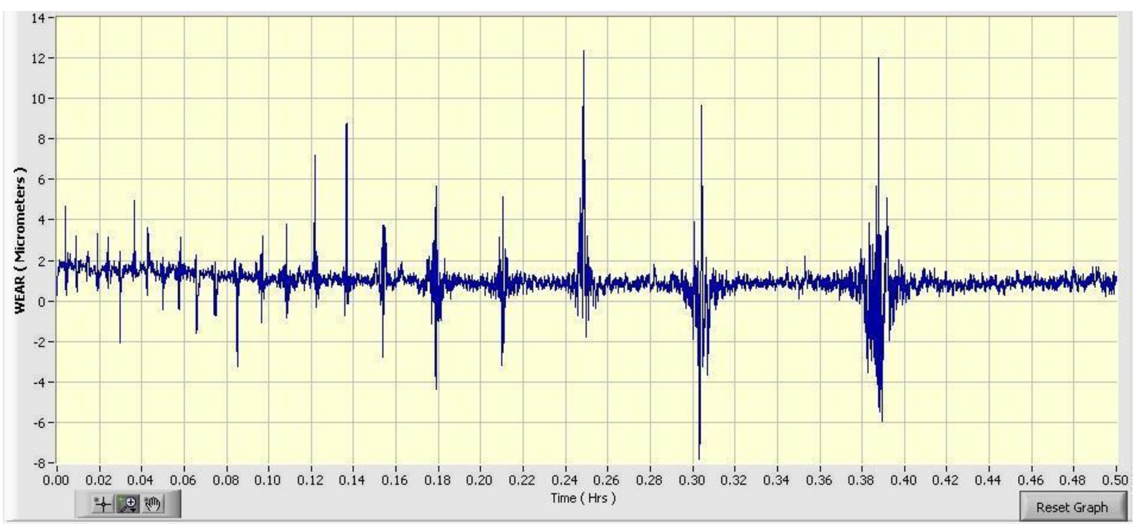


FIGURE 4.14: Wear graph for Sample #5 (Additive: CONFI-TROL)

Figure 4.13 shows the coefficient of friction (COF) graph for oil-based mud using CONFI-TROL as the additive. The mean value of coefficient of friction (COF) for the mud is 0.49575. Figure 4.14 shows the wear graph for oil-based muds using CONFI-TROL as the additive. The wear value for the mud is 2μm.

Sample #6

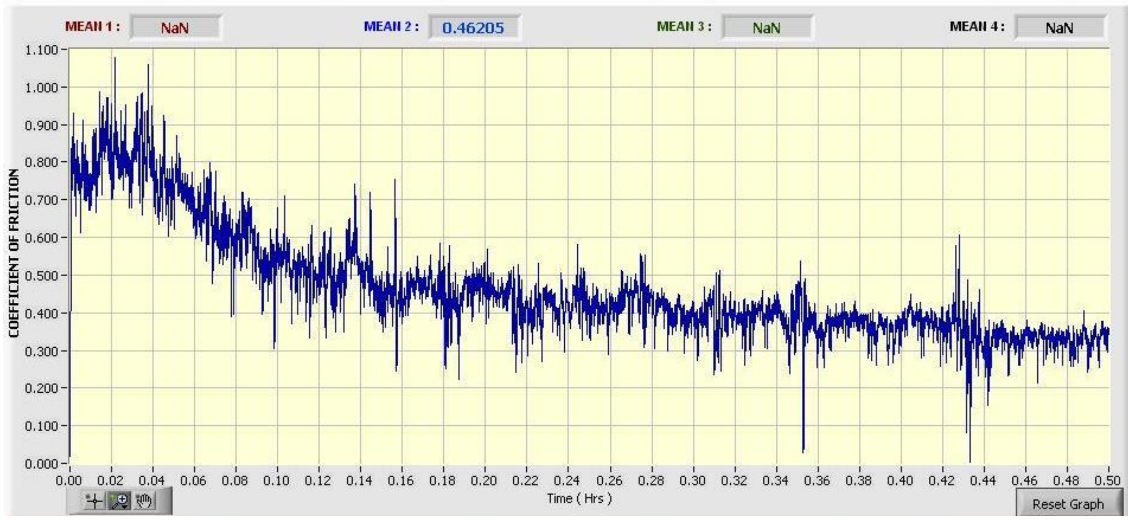


FIGURE 4.15: COF graph for Sample #6 (Additive: VG 69)

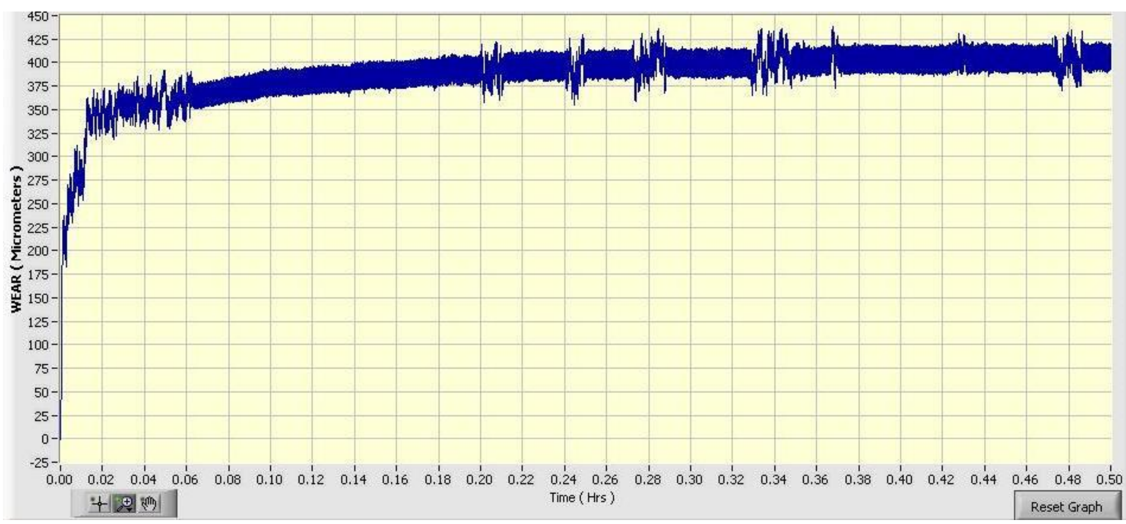


FIGURE 4.16: Wear graph for Sample #6 (Additive: VG 69)

Figure 4.15 shows the coefficient of friction (COF) graph for oil-based mud using VG 69 as the additive. The mean value of coefficient of friction (COF) for the mud is 0.46205. Figure 4.16 shows the wear graph for oil-based muds using VG 69 as the additive. The wear value for the mud is 400µm.

Sample #7

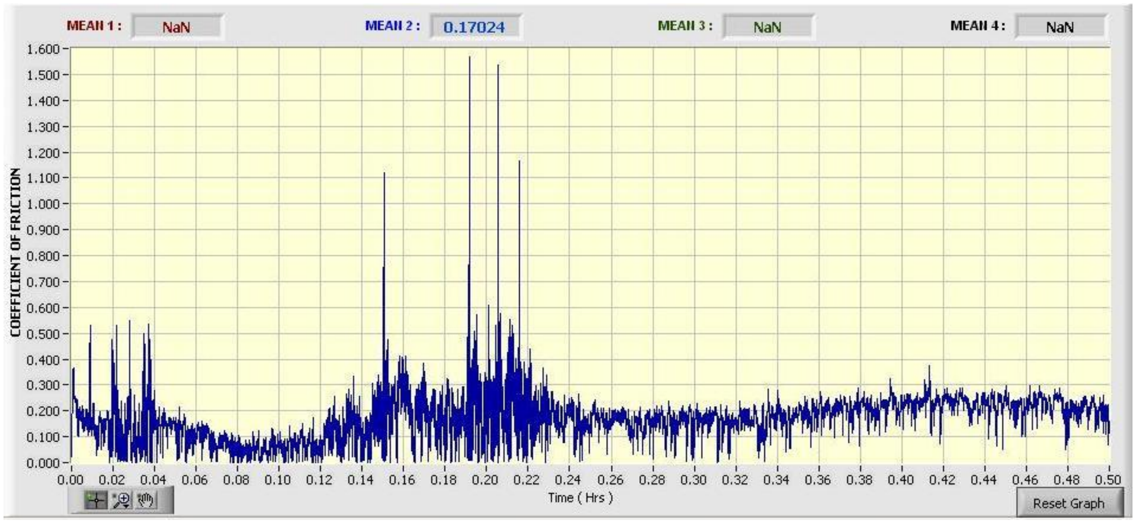


FIGURE 4.17: COF graph for Sample #7 (Additive: VG Plus)

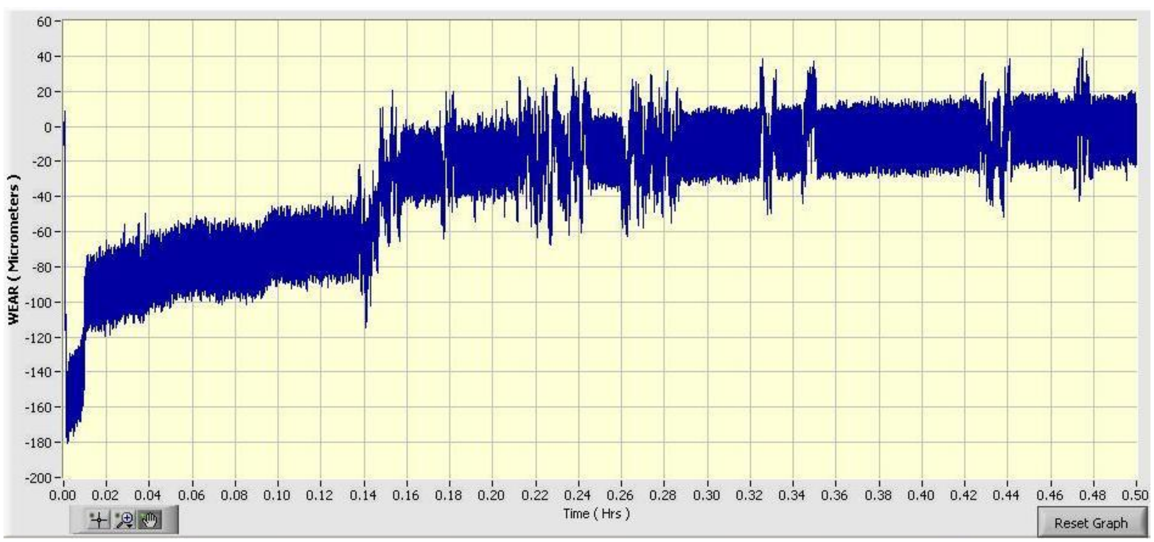


FIGURE 4.18: Wear graph for Sample #7 (Additive: VG Plus)

Figure 4.17 shows the coefficient of friction (COF) graph for oil-based mud using VG Plus as the additive. The mean value of coefficient of friction (COF) for the mud is 0.17024. Figure 4.18 shows the wear graph for oil-based muds using VG Plus as the additive. The wear value for the mud is 10µm.

Sample #8

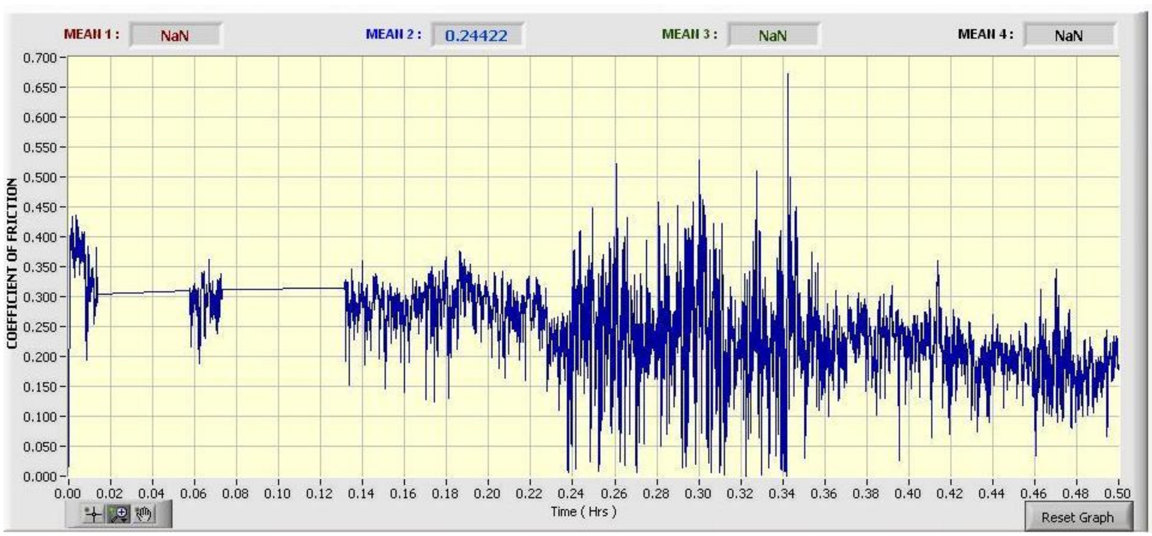


FIGURE 4.19: COF graph for Sample #8 (Additive: ECOTROL RD)

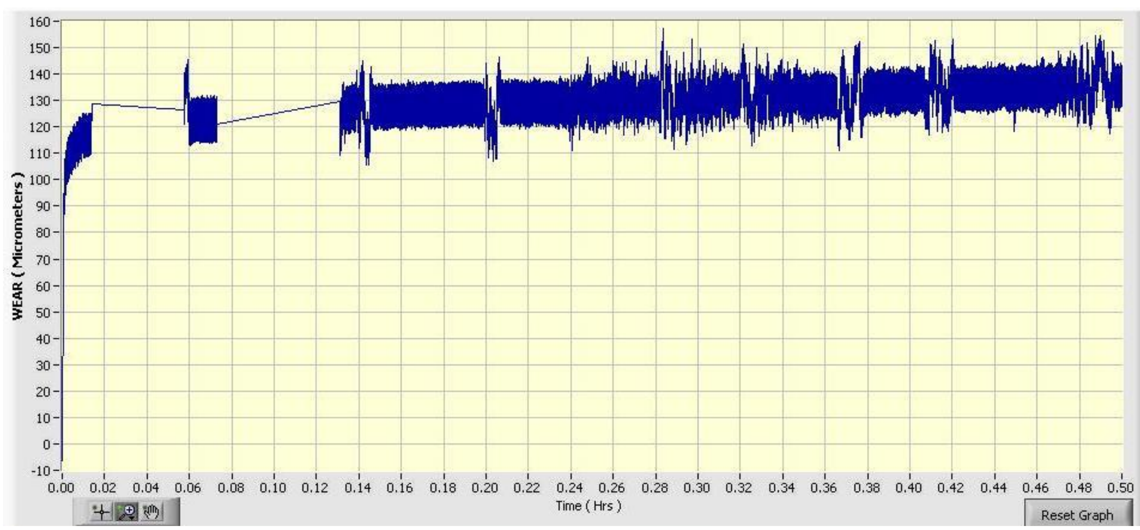


FIGURE 4.20: Wear graph for Sample #8 (Additive: ECOTROL RD)

Figure 4.19 shows the coefficient of friction (COF) graph for oil-based mud using ECOTROL RD as the additive. The mean value of coefficient of friction (COF) for the mud is 0.24422. Figure 4.20 shows the wear graph for oil-based muds using ECOTROL RD as the additive. The wear value for the mud is 2µm.

4.1.3 Topography observation

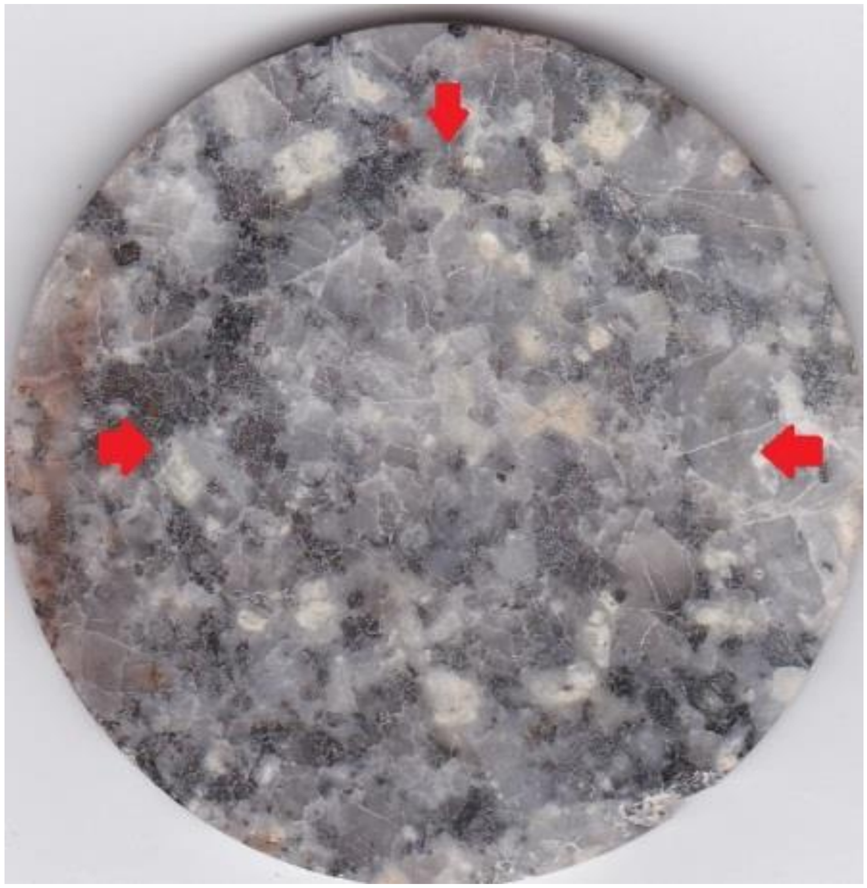


FIGURE 4.21: Magnified image of granite plate Sample #1

Based on Figure 4.21, the wear effect on the disc plate is not too visible. Only certain fragments become “shiny” due to the rotational movement of the pin to the disc plate. Red arrows show the parts which the wear effects occur most. Based on this observation, HYDRO-PAC LV additive can reduce the wear effect to the wellbore formation.

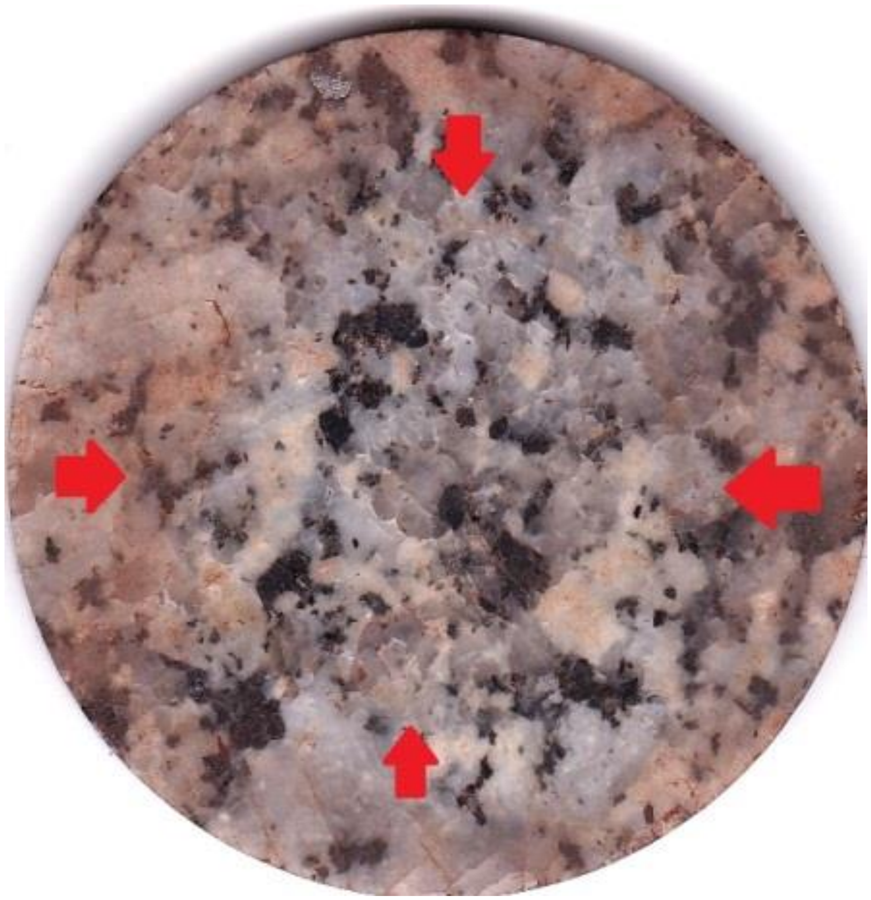


FIGURE 4.22: Magnified image of granite plate Sample #2

Based on Figure 4.22, the wear effect on the disc plate is visible to naked eyes. A visible circle can be observed on the disc plate surface. Red arrows show the parts which the wear effects occur most. Based on this observation, HYDRO-PAC R additive wears the wellbore formation most compared to the other three WBM.

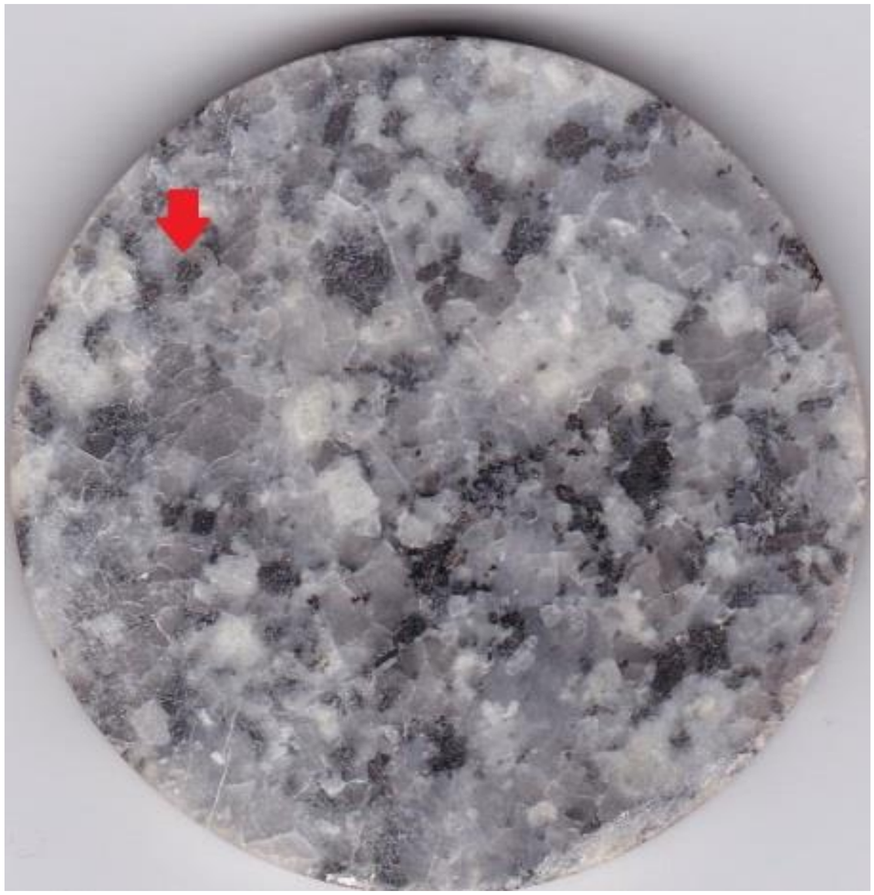


FIGURE 4.23: Magnified image of granite plate Sample #3

Based on Figure 4.23, the wear effect on the disc plate is the least visible compared to others. Only one part becomes “shiny” due to the rotational movement of the pin to the disc plate. Red arrow shows the part which the wear effect occurs. Based on this observation, calcium chloride additive can reduce the wear effect to the wellbore formation the most compared to the other three samples (WBM).

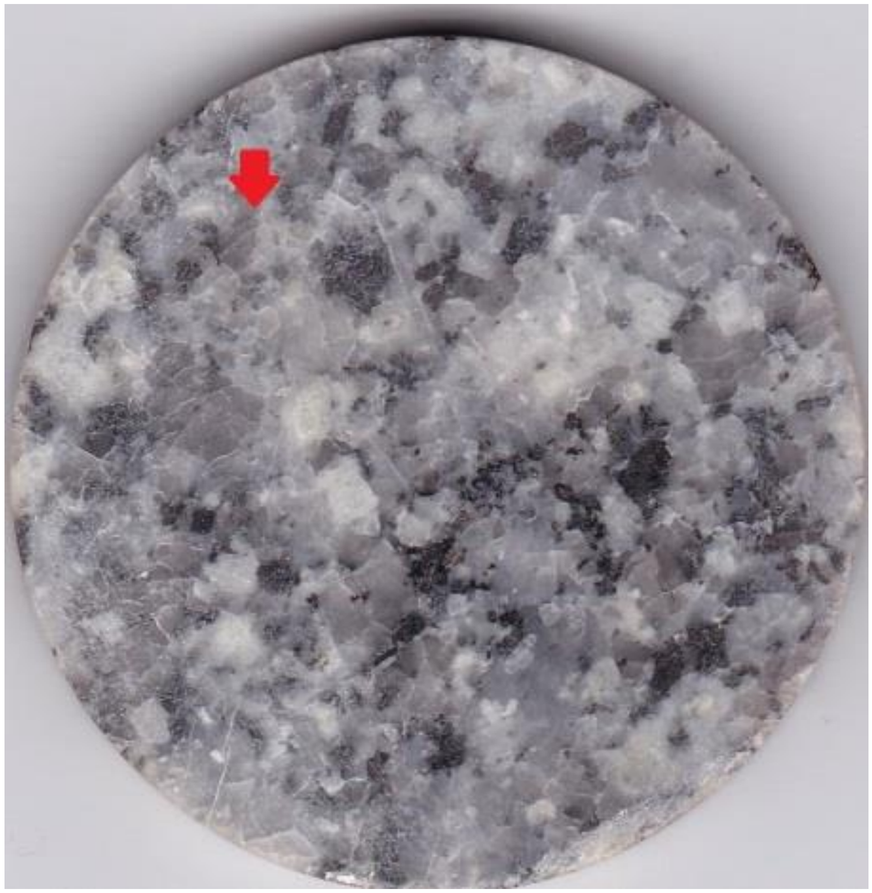


FIGURE 4.24: Magnified image of granite plate Sample #4

Based on Figure 4.24, the wear effect on the disc plate is not too visible compared to others. Only one part becomes “shiny” due to the rotational movement of the pin to the disc plate. Red arrow shows the part which the wear effect occurs. Based on this observation, HYDRO-PAC UL additive can also reduce the wear effect to the wellbore formation.

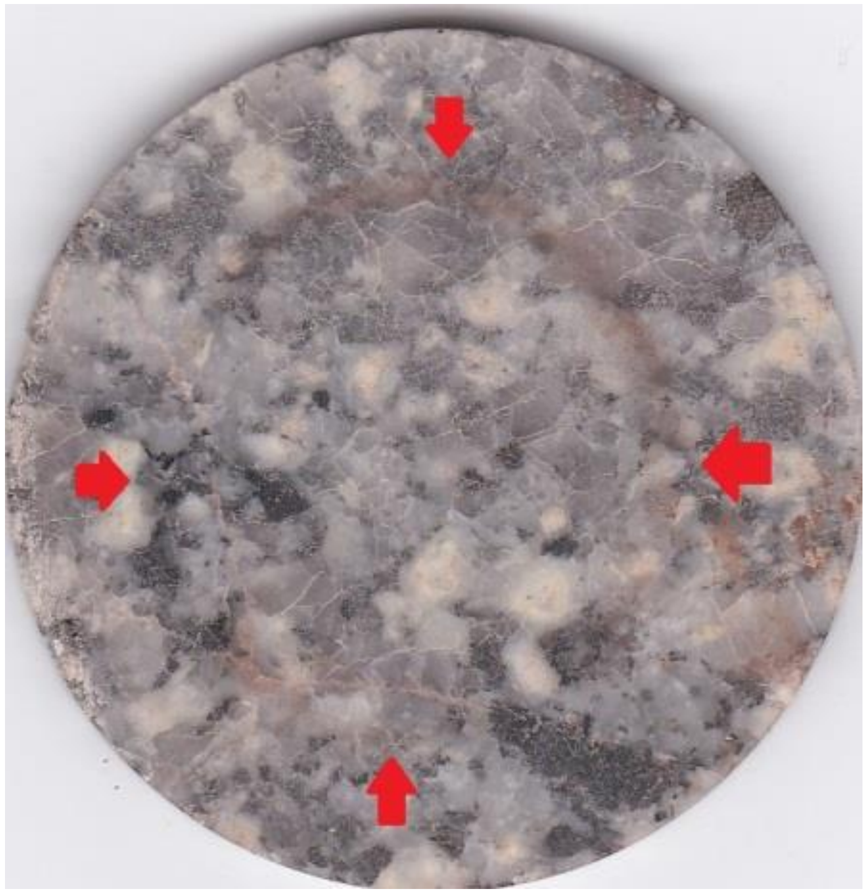


FIGURE 4.25: Magnified image of granite plate Sample #5

For OBM, based on Figure 4.25, the wear effect on the disc plate is visible to naked eyes. A visible circle can be observed on the disc plate surface. Red arrows show the parts which the wear effects occur most. Based on this observation, CONFI-TROL additive wears the wellbore formation the most compared to the other three OBM.

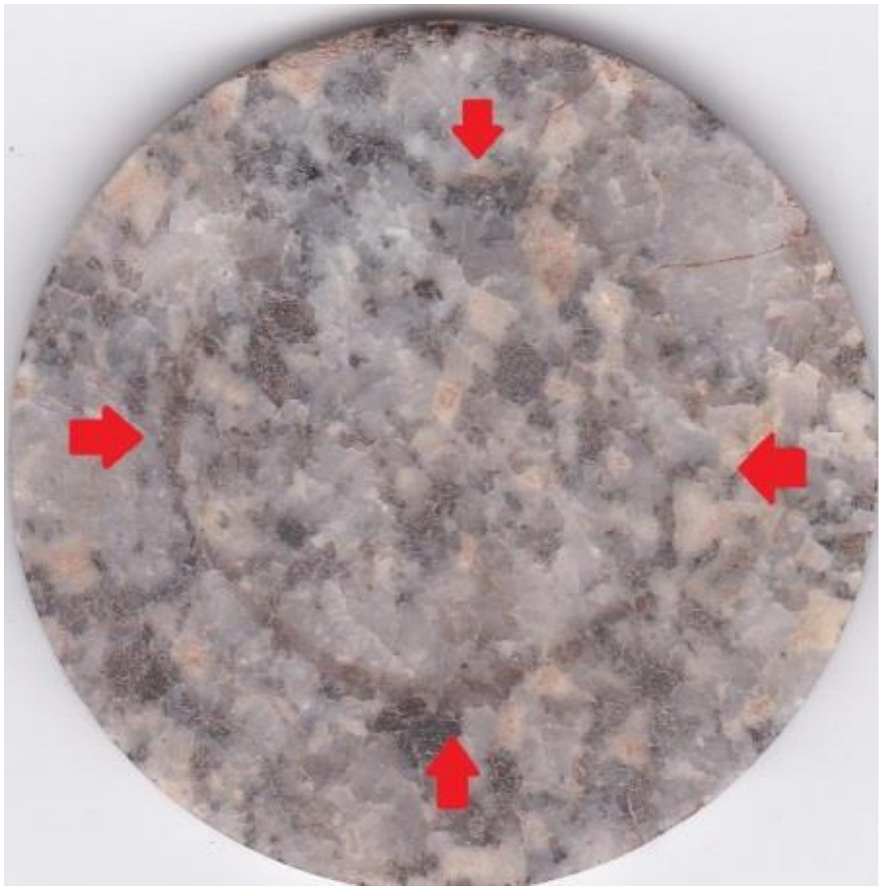


FIGURE 4.26: Magnified image of granite plate Sample #6

Based on Figure 4.26, the wear effect on the disc plate is visible to naked eyes. A visible circle can be observed on the disc plate surface. Red arrows show the parts which the wear effects occur most. Based on this observation, VG 69 additive wears the wellbore formation.

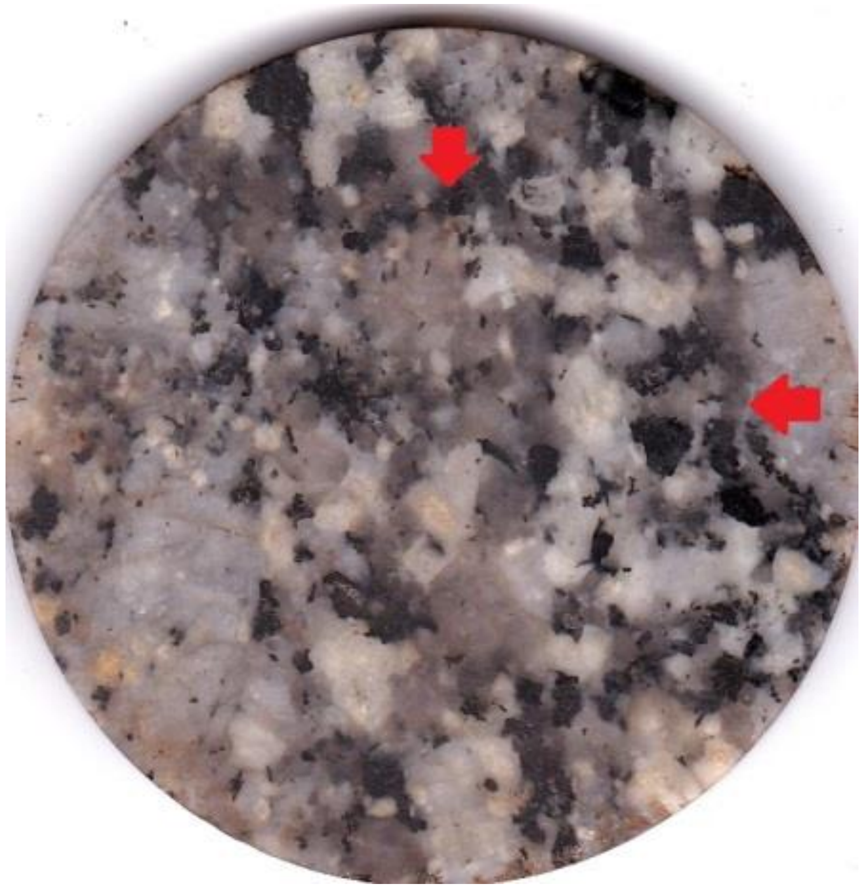


FIGURE 4.27: Magnified image of granite plate Sample #7

Based on Figure 4.27, the wear effect on the disc plate is the least visible compared to other OBM. Only two parts were wearied due to the rotational movement of the pin to the disc plate. Red arrows show the parts which the wear effects occur. Based on this observation, VG Plus additive can reduce the wear effect to the wellbore formation the most compared to the other three samples (OBM).

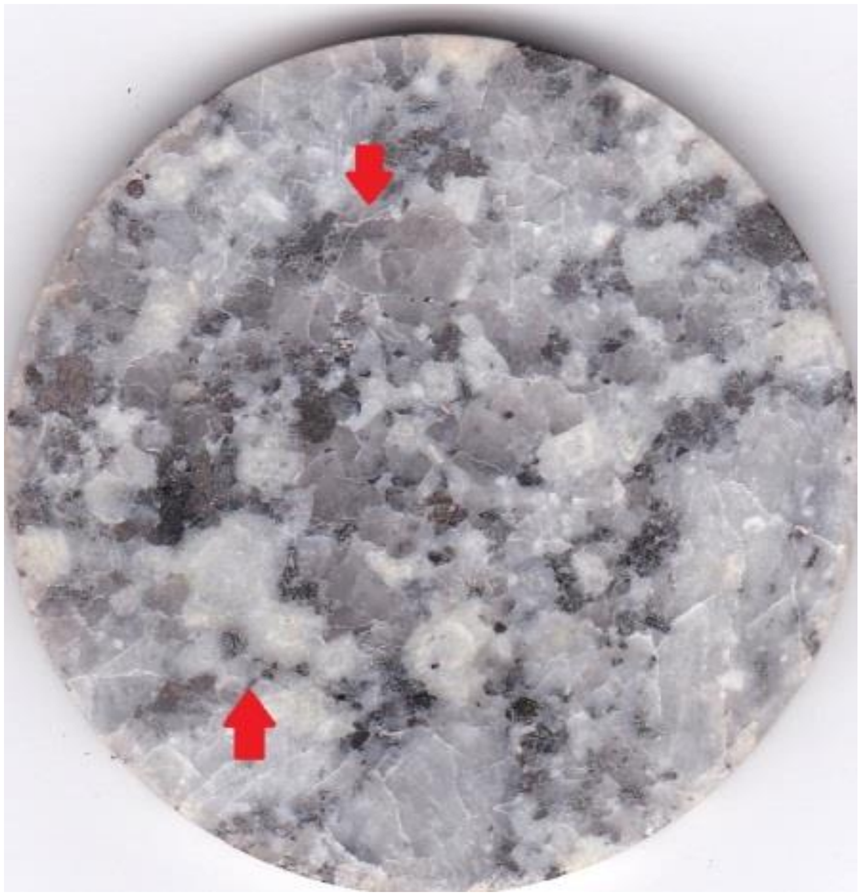


FIGURE 4.28: Magnified image of granite plate Sample #8

Based on Figure 4.28, the wear effect on the disc plate is not too visible. Only certain fragments were wearied due to the rotational movement of the pin to the disc plate. Red arrows show the parts which the wear effects occur most. Based on this observation, ECOTROL RD additive can reduce the wear effect to the wellbore formation.

4.2 Discussion

4.2.1 Mud Rheology

Plastic viscosity is important since it will indicate how easy or hard for the bit to drill. Low plastic viscosity will make the drill bit to drill easier and faster compared to high plastic viscosity. Apparent viscosity is the viscosity if a fluid measured at a given shear rate at a fixed temperature. Yield point indicates how better it can lift the cuttings out to the annulus. High yield point value shows that it can easily lift the cuttings from the drilling operation from the annulus compared to low value of yield point. Gel strength if possible, should be as low as possible because if the gel strength is high, it means that the bit would has problem to start drilling again after drilling activity is stopped for a certain of time. For example is tripping out. High gel strength would make the bit difficult to rotate again while low gel strength indicates that the bit can be easily rotated after tripping out. It means that a good drilling fluid must possesses low plastic viscosity, low apparent viscosity, high yield point, and low gel strength.

Water-based Muds

TABLE 4.5: Function of mud ingredients in WBM [26]

No	Item	Function
1	Fresh Water	Base water
2	Soda Ash	Source of carbonate ions, to reduce soluble calcium
3	Caustic Soda	Increase and maintain pH and alkalinity
4	HYDRO-ZAN	Optimize hydraulics with maximized rates of penetration
6	Potassium chloride	For drilling water-sensitive shales, especially hard, brittle shales
7	Calcium Carbonate	Bridging agent
8	Barite	Primary weight material
	Additives	
1	HYDRO-PAC LV (Sample #1)	Filtration controller and minimal viscosifier
2	HYDRO-PAC R (Sample #2)	Excellent thermal stability

	Additives	
3	Calcium Chloride (Sample #3)	Reduces clay swelling
4	HYDRO-PAC UL (Sample #4)	Filtration control agent

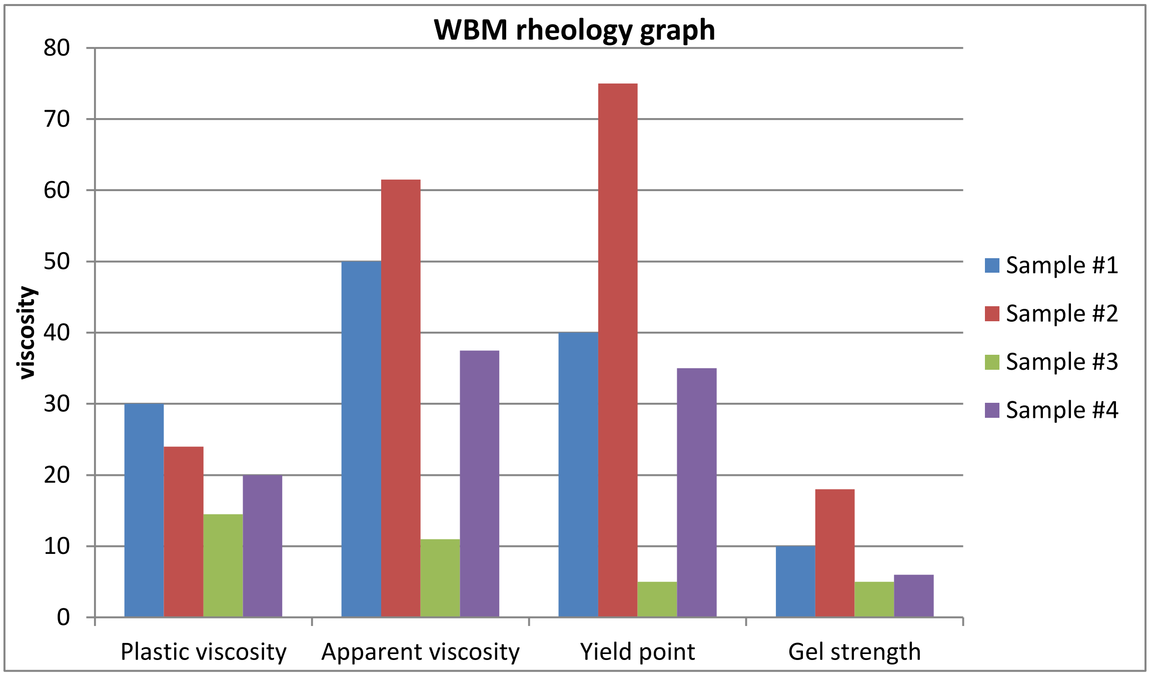


FIGURE 4.29: Mud rheology graph for WBM

Table 4.5 shows all the functions of mud ingredients in each sample. The main ingredients for WBM are fresh water, soda ash, caustic soda, HYDRO-ZAN (xantham gum), potassium chloride, calcium carbonate and barite. Different additive gives different effects to the mud as different mud shows different values of plastic and apparent viscosity, yield point and gel strength. From Figure 4.29, it shows that Sample #3 is the best drilling fluid composition among all four samples as it comprises low plastic viscosity, low apparent viscosity, and low gel strength compared to others. Although the yield point for Sample #3 is the lowest, but it is still acceptable as the range for yield point for WBM is around 5-20. According to Table 4.5, Sample #3 contains calcium chloride as the additive as it provides clay swelling reduction. Calcium chloride added to the water phase of the mud generates osmotic force and may be used to dehydrate formation clays [26]. Calcium chloride is also mainly used for completion fluid and also to control the degree of acidity or alkalinity of a fluid.

Oil-based Muds

TABLE 4.6: Function of mud ingredients in OBM [27]

No	Item	Function
1	Saraline 185V	Base oil
2	CONFI-MUL P	Emulsifier which is resistant to high temperatures
3	CONFI-MUL S	Improve emulsion stability and wetting agent
4	CONFI GEL	Viscosifier and increase the carrying capacity and hole cleaning
6	Lime	Activate the emulsion, provide tight fluid loss control
7	Water	Drill hard, compacted, near-normally pressured formation
8	Calcium Chloride	Reduces clay swelling
9	Drill-Bar	Primary weight material
	Additives	
1	CONFI TROL (Sample #5)	Cause minimal viscosity increase and is effective in controlling HPHT filtration
2	VG 69 (Sample #6)	Provide good ventilation
3	VG Plus (Sample #7)	Filtration control
4	ECOTROL RD (Sample #8)	Fluid loss reducer

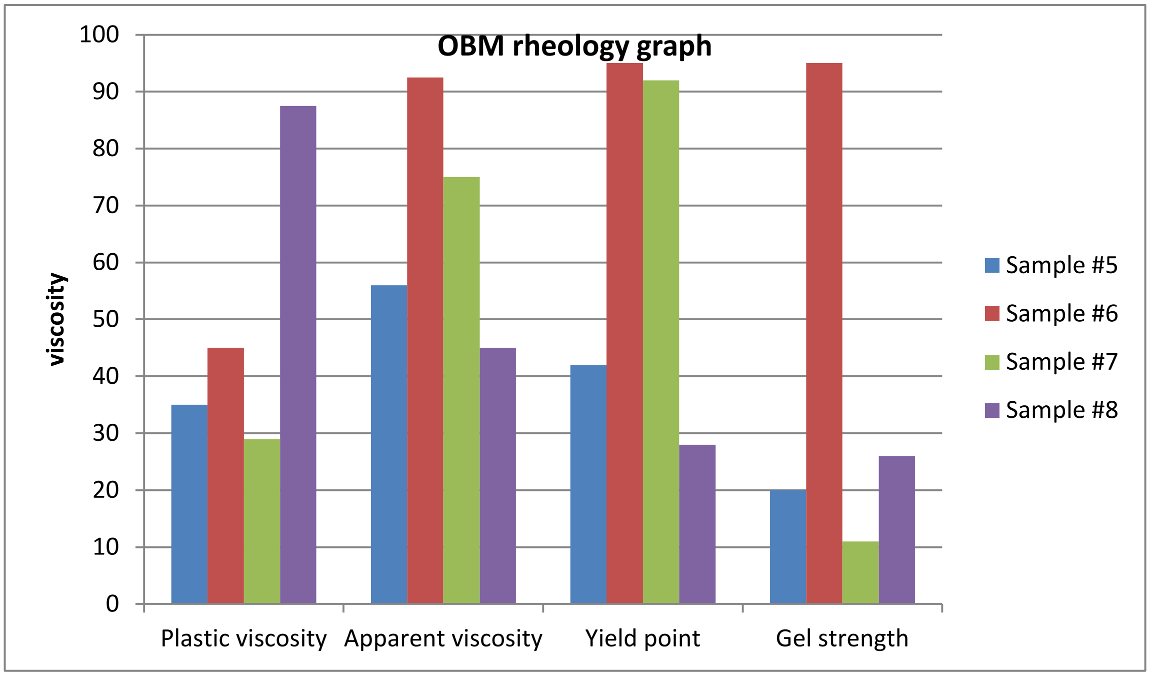


FIGURE 4.30: Mud rheology graph for OBM

Table 4.6 shows all the functions of mud ingredients in each sample. The main ingredients for OBM are Saraline, CONFI-MUL P, CONFI-MUL S, CONFI GEL, lime, water, calcium chloride and Drill-Bar (barite). Different additive gives different effects to the mud as different mud also shows different values of plastic and apparent viscosity, yield point and gel strength. From Figure 4.30, it shows that Sample #7 is the best drilling fluid composition among all four samples as it comprises low plastic viscosity, high yield point, and low gel strength compared to others. Although the apparent viscosity for Sample #7 is among the highest, but it is still acceptable. According to Table 4.6, Sample #7 uses VG Plus as the additive as it provides clay swelling reduction. VG Plus additive is effective in mineral oil-base drilling, coring, workover, and completion fluids [27]. It can also be used in specialty fluids such as casing packs, packer fluids, lost-circulation pills, and spotting fluids where viscosity required. This additive can improve the carrying capacity, gel strength and suspension of weight material. It also assists in improving filter-cake quality and filtration control.

4.2.2 Friction and Wear Testing

The wearing behavior happened on all samples (WBM and OBM) can be considered as a huge wear effect as in the real situation although the test for each sample was conducted for only 30 minutes. The drilling operations are done for hours and it shows that, with the many hours of time consuming, the wearing effect is a major effect in determining the selection of drilling muds to be used.

For drilling operation, a huge wearing effect on formation is a huge concern as it shows that, by using the drilling fluid, the wearing effect or the penetration rate of the drill string through the formation is high. Increment in weight for granite disc plate which symbolizes the wellbore formation is a huge concern as it shows that wellbore formation is plugged in with drilling fluid. In the other hand, the pin weight is decreases and as the pin symbolizes the drill string, with the decrement in pin's weight, it indicates that the wear effect occurs at drill string is a huge setback. The drill string will be having a high rate of damage as it penetrates the formation. Thus, the selection of the least COF and wear values is a must in order to decrease the frictional and wearing effects.

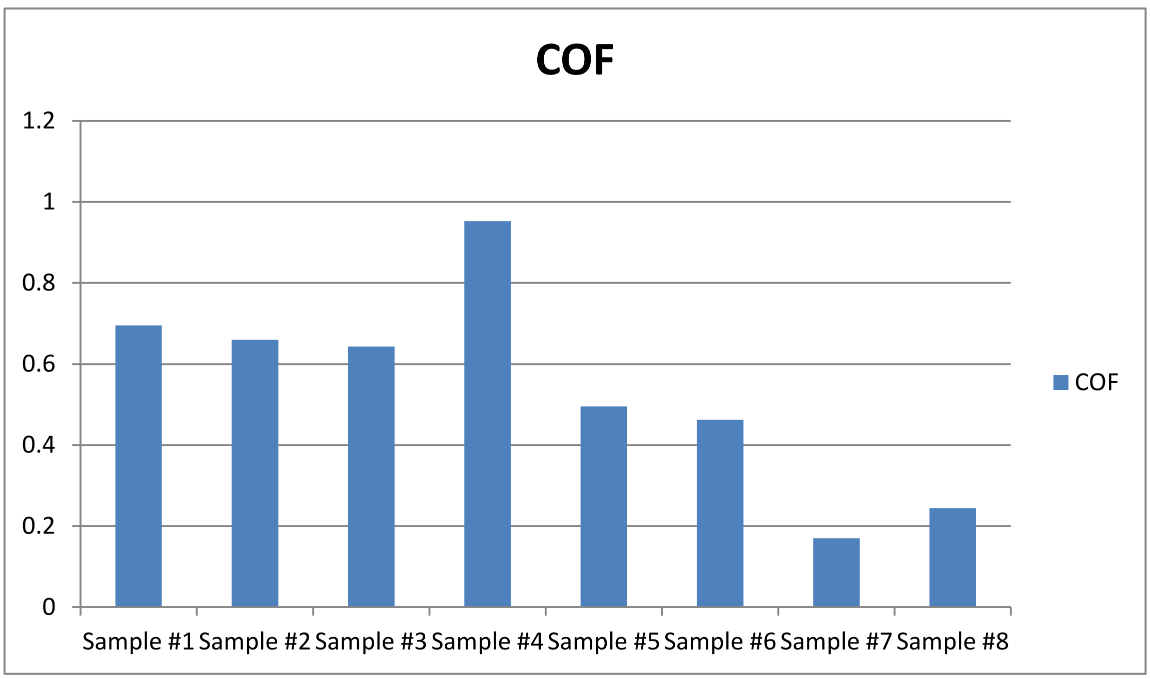
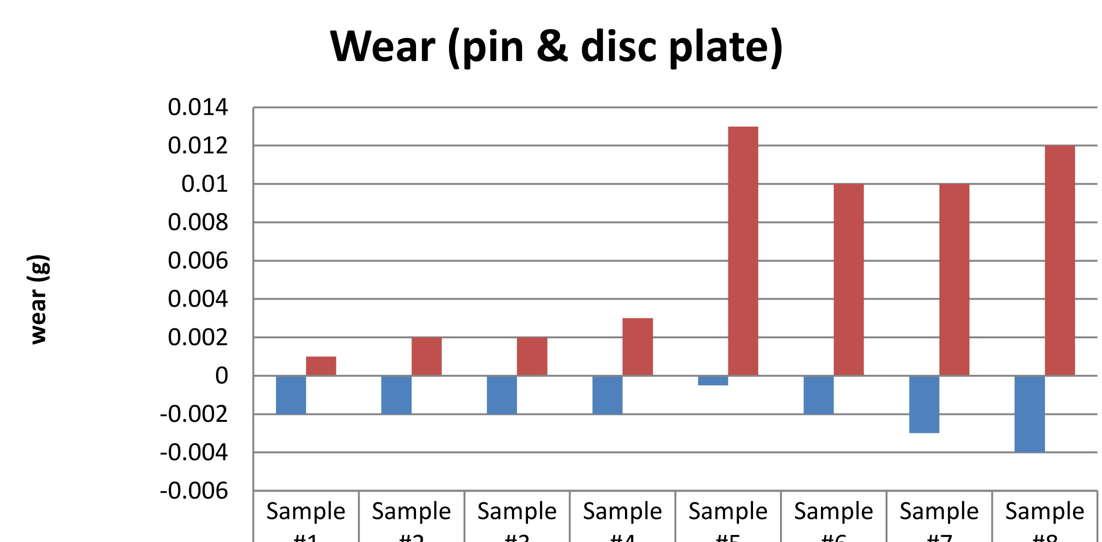


FIGURE 4.31: COF graph for all samples

Based on Figure 4.31, Sample #3 has the least value of COF for WBM while Sample #7 has the least value of COF for OBM. Calcium chloride which is used to reduce clay swelling can also reduce the frictional activity between the drill string and the wellbore formation. VG Plus which is widely used as the filtration control is proven to have the least COF value. Filtration control can minimize fluid invasion damaging permeable zones. The properties of the resultant mud cakes should prevent sticking of the drill string against the wall due to differential-pressure.

For the wear testing, MWT cannot measure wear effect between two different minerals (mill steel and granite). The wear effect is examined by the difference in weight of pin before and after the experiments.

The ranges of values of COF by Mud Lubricity Tester is 0.25 to 0.40 for WBM and 0.17 to 0.25 for OBM are relatively different compared to the results achieved by Multispecimen Wear Tester (MWT). The reason is because the accuracy of the experiment is low and also the equipment errors (lever shakes too much, irregular disc plate, and inconsistent applied load).



	Sample #1	Sample #2	Sample #3	Sample #4	Sample #5	Sample #6	Sample #7	Sample #8
Wear(pin)	-0.002	-0.002	-0.002	-0.002	-0.0005	-0.002	-0.003	-0.004
Wear (disc plate)	0.001	0.002	0.002	0.003	0.013	0.01	0.01	0.012

FIGURE 4.32: Wear for pin and disc plate graph for all samples

All pins have decreased in weight while disc plates' weights are increased. WBM has low wearing effect compared to OBM. There is a significant difference of weight decrease in granite disc plate between WBM and OBM. Increase amount of weight at disc plate shows that mud plugged in to the disc plate (wellbore formation) and decrease amount of weight at pin indicates that pin (drill string) has eroded. The testing was only executed for 30 minutes for each sample and it is expected that huge wearing effect will happens in actual drilling hours of operations.

From Figure 4.32, for WBM, Sample #3 shows the less weight change for both pin and disc plate. Although the least weight change is Sample #1 but the difference of weight between Sample #3 and Sample #1 is only 0.001g, which is not significant. For OBM, Sample #7 shows the less weight change for both pin and disc plate. Sample #6 is the least weight change for OBM but the difference in weight change between Sample #6 and Sample #7 is not too significant (0.001g). In conclusion, calcium chloride and VG Plus is still the best additive to reduce the wearing effect between the drill string and the wellbore formation.

4.2.3 Topography Observation

For WBM, there is no visible wear effect on the disc surface. A "shiny" circle resulted at the disc plate after friction and wear testing. For OBM, there is visible wear effect occurred on the disc plate due to the viscosity of the mud. A brown circle is clearly resulted from the experiment on every OBM's disc plate samples.

Sample #3 and Sample #7 of disc plates show the least visible of wear effect compared to the other samples. These indicate that calcium chloride and VG Plus is the best additive used to reduce the wear effect between the drill string and wellbore formation.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusions, the objectives of this research are achieved and well delivered. Different types of WBM and OBM were prepared as types of additives have been kept as the manipulating variable to differ between each sample. The density and the mud rheology of each sample were studied and to keep the prepared mud samples under standard, API 13 series was being the main reference for the procedure.

For friction and wear study, reference tables which show COF and wear ranking for WBM and OBM is plotted and the least COF and wear values of each mud samples have been identified. Sample #3 and #7 show the least COF value for WBM and OBM respectively. Calcium chloride is a good WBM additive to decrease the frictional and wear activity between the drill string and wellbore formation while VG Plus is a good OBM additive to reduce the friction and wear as well. The wear graphs are not too reliable to discuss because MWT assumes the values for two same materials, while in fact there are two different materials (mill steel and granite). Therefore, before and after weights of each pin and disc plates are weighted and the difference of weight is taken as the source of wearing behavior.

Images of wearing effect to the disc plates (wellbore formation) were observed and analyzed. The wearing effect can also be identified by measuring the weight of the disc plate and pin before and after the experimental run. From the images, they show that OBM initiates wear more frequently compared to WBM. Loss of weight in pin and additional weight inherited in granite disc plates are much bigger in OBM compared to WBM. Sample #3 and 7 show the least wear behavior occurred between the drill string and wellbore formation.

5.2 Recommendation

1) Various types of drilling fluid can be tested to get the complete references for all types of drilling fluid. Instead of water-based and oil-based muds, this project can be expanded to include synthetic-based muds (SBM) and its friction and wear ranking. Different types of additives can also be included to WBM and OBM types in order to study the friction and wearing activities as well to compute the friction and wear values as future reference.

2) Multispecimen Wear Tester (MWT) is not the perfect or the most trusted equipment to be used for friction and wear study. MWT can only tested under room temperature and atmospheric pressure, which are quite not reliable. A testing simulation needs to include variation of temperature and pressure values because drilling operations presents at high temperature and pressure.

3) Different sizes, shapes and types of pin, load, and disc can be adjusted as well. Drilling operations require different types, sizes and shapes of drill bits for different well formation. Instead of using mill steel for cylindrical pin and granite for round disc plate, other shapes and types of ingredient should be used in order to get variety of results.

4) The experiment should be run two (2) times for one disc in order to get more reliable result because the first run indicates that the disc surface is in contact, regular and flat. The 2^{nd} run will be used as the experimental result as the disc plate is placed correctly.

5) Conduct filtration loss and mud cake build experiments after friction and wear testing. These tests cannot be done because of the limited volume of mud prepared during mud preparation.

6) Use high viscosity of drilling fluid in order to reduce the probability of leakage in the drilling fluid "cup" or holder.

Although there are only eight (8) samples tested, this paper should be a kick-start to the other projects to study the COF and wear values in other types of drilling fluids as friction and wear plays a major effect in drilling operations especially in horizontal drilling.

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APPENDIX

AMC Saraline 185V Composition Table

an imdex limited company

AMC OIL & GAS

AMC SARALINE 185V

BASE OIL FOR OIL BASED MUD

Description

SARALINE 185V is a quality drilling fluid sourced from clean natural gas, it contains virtually no aromatics and contaminants such as sulphur and amines. SARALINE 185V is classified as a synthetic base drilling fluid as it is produced from the reaction of a purified feedstock as opposed to highly refined/processed mineral oils. SARALINE 185V readily biodegrades, is non-toxic in the water column and has low sediment toxicity. It has a low viscosity, a low pour point and relatively high flash point making it ideal for deepwater exploration. It is widely used as a non-aqueous base fluid in an invert emulsion drilling mud. SARALINE 185V is manufactured by Shell MDS.

Application

SARALINE 185V is used as a synthetic oil base fluid. This is compatible with all AMC emulsifiers and can be used in combination with any other AMC filtration products for use in oil based muds. It is also ideal for use in deep water applications.

Advantages

- Has a low viscosity
- Has a low pour point
- Has a relatively high flash point
- Has low toxicity.

Typical Properties

Boiling range: 90% recovered °C 308:	IBP °C 206 FBP °C 318
Vapour pressure @40°C:	<0.1 kPa
Density @ 15°C:	778 kg / m³
Kinematic viscosity @ 40°C:	2.66 mm²/s
Vapour density (air=1):	> 5
Sulphur ppm:	< 3
Aromatic %m:	< 0.1
Pour point °C:	-27
Cloud point °C:	-14
Flash point °C:	89
Auto-ignition point °C:	216
Fire point °C:	114

Recommended Treatment

It is widely used as a non-aqueous base fluid in an invert emulsion drilling mud.

Packaging

Supplied in IBC (international bulk container)

200 L drum

Calcium Chloride (WBM Additive) Description

Scomi
Scomi Oiltools

Calcium Chloride (Dry) Product Data Sheet

Product Description

Calcium chloride, $CaCl_2$ is used as a completion, workover, gravel packing, perforating and packer fluid. It is also used as an osmotic generator in non-aqueous systems. It is available in a variety of purities varying from 74 – 95+ %.

Typical Properties

COMMON NAME	Calcium chloride	CHEMICAL FORMULA	$CaCl_2$
APPEARANCE	Powder	SOLUBILITY IN WATER @ 20 °C	74.5g/100 ml
SG (Anhydrous)	2.15		

Applications/ Functions

The amount of Calcium chloride added to the mud is dependent on the water activity and or density of the fluid that is required.

Advantages

- Readily available.
- High purity product.
- Economically viable.
- Common oil field usage.

Recommended Treatment

As a brine Calcium chloride can be used to formulate single salt brines to 11.67 lb/gal (1398 kg/m^3) or in combination with other salts to form brines of the required density. The most common combination is with Calcium Bromide brines to densities up to 15.1 lb/gal (1812 kg/m^3) For details of concentrations required check brine tables. In non aqueous fluids, treatments will depend on the required degree of osmotic activity required.

Limitations

- The use of Calcium chloride may be restricted by local HSE rules.
- If combined with monovalent salts it may cause precipitation in solution.
- Compatibility with work over chemicals should be confirmed prior to use.
- Compatibility with various rubber drilling components should be confirmed prior to contact.
- The crystallisation point of brines must be carefully checked to ensure they are not too low.

Recommended Handling

Consult MSDS before use and use personal protective equipment as advised.

Packaging

Calcium chloride is packaged in 25 kg (55 lbs) and 50 kg (110 lb) sxs and 1.0 MT Bulk Bags. Keep in location away from moisture and use all when opened.

September 2007

VG Plus (OBM Additive) Description

VG-PLUS

VG-PLUS* organophilic clay is an improved viscosifier and gelling additive for all synthetic-base and VERSACLEAN* mineral oil-base systems.

VG-Plus clay is an amine-treated bentonite that improves the carrying capacity, gel strength and suspension of weight material. It also assists in improving filter-cake quality and filtration control.

VG-Plus clay has particular application in mixing plants. The product provides viscosity for building new fluids that have not been exposed to shear and temperature.

Typical Physical Properties

Physical appearance	Off-white to tan powder
Specific gravity	1.57
Bulk density	33 lb/ft³ (528 kg/m³)

Applications

VG-Plus additive is an effective viscosifier in mineral oil- and synthetic-base drilling, coring, workover and completion fluids. It can also be used in specialty fluids such as casing packs, packer fluids, lost circulation pills and spotting fluids where viscosity is required.

The VG-Plus product is used to increase gel strength and viscosity in mineral oil and synthetic-base muds. It is especially useful in blending plants where high shear and temperature are not available to obtain full dispersion and hydration. Although it provides more viscosity in these situations than other organophilic clays, even the VG-Plus clay will not fully yield. For this reason, caution should be used to avoid overtreatment until the fluid can be circulated through the wellbore.

Typical concentrations range from 2 to 10 lb/bbl (5.7 to 28.5 kg/m³) for most drilling applications, depending on the base fluid and water content. For maintenance, occasional treatments should be added as needed to maintain the flow properties and gel strengths in the desired ranges. Specialty applications such as casing packs and packer fluids generally require concentrations in the range of 10 to 15 lb/bbl (28.5 to 43 kg/m³).

Advantages

- High-performance viscosifier for all mineral oil- and synthetic-base fluids
- Especially effective when mixing new fluids in low-shear, low-temperature situations such as in mud plants
- Increases viscosity for improved hole cleaning and weight-material suspension
- Improves filter-cake quality for reduced fluid loss
- Provides efficient gelling capabilities for blending casing packs and packer fluids

Toxicity and Handling

Bioassay information is available upon request.

Handle as an industrial chemical, wearing protective equipment and observing the precautions described in the Material Safety Data Sheet (MSDS).

Packaging and Storage

VG-Plus viscosifier is packaged in 50-lb (22.7-kg), multi-wall, paper sacks.

Store in a dry, well-ventilated area. Keep container closed. Store away from incompatibles. Follow safe warehousing practices regarding palletizing, banding, shrink-wrapping and/or stacking.