INVESTIGATING THE VIABILITY OF LOCAL VEGETABLE OIL AS BASE FLUID FOR DRILLING HPHT FORMATION

by

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prepared for

Dr. Aliyu Adebayo Sulaimon

A dissertation report submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Petroleum Engineering)

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Universiti Teknologi PETRONAS

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Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

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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 have not been undertaken or done by unspecified sources or persons.

BUTSARO HAYISANI

ABSTRACT

The aim of this study is to investigate the properties of local vegetable oil and look into the possibility of using this fluid in the real drilling operation in high pressure and temperature by extracting the real drilling fluids with a long series of experiments in order to get their properties and compare to local vegetable fluids to meet standard requirement and select the best among candidates to use as base drilling fluid as answering the technical performance and sustainable development.

The scope of this study will focus deeply on the rheological properties of the available local vegetable oil through this semester. However, it will be shared some part of the research to the co-worker to achieve the optimum result.

Vegetable oil in this project – Coconut oil are renewable, highly biodegradable could be suitable candidate of a highly biodegradable oil-based mud to achieve the sustainable development. Thus, six mud samples were formulated with six different composition of base fluids which are Saraline, 100%, 80%, 70%, 60%, 50% Coconut oil based mud samples.

The results that obtained from this experiment will compared to the standard oil based mud in the drilling operation in high pressure and high temperature. The best among candidate will further research to replace diesel oil in the future.

This research will be the answer both technical performance and environmental concern when the selected oil sample will be extracted properties during the experiment. The sample will undergo the process to meet the standard requirement of oil based mud. Owing to The environmental concern will be reduced when there is no pollution to the marine environment, moreover, it will bring value to the local vegetable oil to the oil and gas industry. And this is how the research bridges the gap between both of them to reach real sustainable development in the future.

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Last but not least, I would like to express my deepest appreciation to University Technology PETRONAS, which provides this opportunity for student to expose their knowledge in this final year project and facilitate all required equipment for the experiment to fulfill the gap of becoming well-rounded student to the future.

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ABBRIVIATION

No.	Word	Meaning
1	HPHT	High Pressure & High Temperature
2	Rheology	Study the behavior of material
3	Deep well	The well drilled with 15,000 ft (or 15,000 psi & 350 °F) and above
4	Salinity	The saltiness or dissolved salt content of a body of water or in soil
5	Drilling Fluid	Used to aid the drilling of boreholes into the earth includes WBM & OBM
6	WBM	Water Based Mud
7	OBM	Oil-Based Mud
8	SBM	Synthetic-Based Mud
10	R300	Viscometer reading at 300 r/min
11	R600	Viscometer reading at 600 r/min
12	ES	Electric Stability
13	API	American Petroleum Institute

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Sustainable development of petroleum activities requires a strategy and management optimization. Most of the Company's projects are simply looking to improve performance and technology to achieve maximum profit with optimal cost. Thus, the ecological aspects of the project are carried out, designed and implemented for the development of a sustainable future.

Circulating a drilling fluid is a fluid used in the rotary drilling for various functions are required in drilling operations. When designing a drilling fluid includes the factors taken into account, good design, formation pressures and rock mechanics is provided, formation chemistry, temperature, environmental legislations and logistics. Fluid rheology determines its effectiveness in a wellbore (Veil, 1998).

Oil drilling fluids offer some advantages over drilling muds water-based in many situations, which make them particularly desirable for certain types of formation, it has the use of oil-based mud has increased in recent years, drilling with oil-based mud generally perform better in extremely hot or cold environment, very slate inhibition borehole stability, lubricity, thermal stability, corrosion resistance, tolerance to impurities and ease of maintenance. In addition, oil-based fluids causes less problems in drilling shale formations allow drilling areas with a minimum of salt dissolution of salt (Sterber & Herold, 1995).

Nevertheless, there are important issues that make it a poor choice for environmentally sensitive areas, which is higher than the potential problems of environmental pollution and cost. Mud varies in degrees of toxicity. It is difficult and expensive to dispose of safely for the environment (Akhtar, Adnan, et al., 2008).

While diesel showed a central role as the base oil to the introduction of the drilling mud and OBM on the study early 1980 for diesel fuel, diesel fuel is suitable for use as base oil because of the high toxicity and the aromatic content and influence of the environment (Yassin, Kamis & Abdullah, 1991). Because of the increasing environmental legislation against the disposal of oil based mud and greater environmental awareness of the effects of diesel oil led to strict regulations regarding the use of reverse-emulsion fluids. Regulation for offshore applications are particularly severe, even the most recent, less polluting mineral and synthetic oils in vogue today may be assigned inappropriate because of their non-biodegradability. In fact, today, in many parts of the world, such as USA, UK, Netherlands, Norway, Nigeria and Australia, the use of diesel and mineral oil based drilling fluids in offshore operations is already strictly regulated or banned because of their toxicity, persistence and bioaccumulation. The same type can generate between 1,000 – 1,500 tons of cuttings. With oil retention average of 15%, about 150-225 tons of oil drilling fluid is discharged into the sea for each wellbore, thus causing a wider area around the site of perforation may vary.

Cuttings produced during drilling should be cleaned with an expensive procedure before being thrown into the sea. Oil based mud itself must be transported to shore for disposal after use. The use of oil-based muds in some ecologically sensitive areas is strictly prohibited. Therefore drilling fluids based on vegetable oil and synthetic-based muds were introduced as environmentally friendly alternatives that do not involve any risk to the health of the oil workers and the host community (Neff, 1987).

Coconut oil is local vegetable oils are selected as candidate oil base mud of this project. Owing to its physical and chemical properties which assume that can replace diesel oil in OBM. However, diesel will be tested as base oil in oil based mud as a benchmark in this project. Since diesel oil has been proven to be a potential oil based mud and widely used in the industry. In this project the properties of coconut oil and sesame oil based mud will be measured and characterized to ensure their use as a replacement based oil.

1.2 Problem Statement

Today, with the greatly expanding environmental concerns, the use of oil-based mud is either banned or severely restricted in many countries. Environmental law restrict and prohibit the use of drilling fluid, the aquifers can contaminate soil and groundwater potential. The cost may be a problem if oil based mud is selected as base drilling fluid. First, the Cost containment, transportation, and can significantly increase the cost of disposal for the use of oil-based fluids. Second, the degree of biological activity of cuttings from oil based mud is harmful to marine environment.

Over the range of physical suffocation, the impact of oil-based mud cuttings can be organic enrichment of the sediment and / or toxicity of certain fractions of the oils used, such as aromatic hydrocarbons (Amani, 2012). The cuttings from oil base mud will require a special mud treatment before discharge to prevent contaminated water from oil-free (Veil, 1998).

Therefore, the local vegetable oils (coconut oil) as low aromatic and free of toxicity, which have been proposed as alternative fluids can introduce potentially use and replace diesel oil for drilling fluid in drilling operations in order to bridging the gap between technical performance and environmental problem.

1.3 Objectives

The main objective of this study is to investigate the properties of local vegetable oils and look into the possibility of using alternative base oil in real drilling fluid operations in high pressure and high temperature formations. Other objectives are;

1. To carry out the experimental study of alternatives oil based (coconut oil) follow the oil based and the properties of drilling fluids requirements.
2. To compare and evaluate the experimental result of alternative oil based (coconut oil) and Diesel oil based drilling fluid.
3. To clarify and summarize whether coconut oil can be an alternative oil-based for drilling fluid or not.

1.4 Scope of Study

This project will include the understanding of oil-based mud, its properties and application. At the end of the study, the experimental results will be evaluated to identify and determine the sesame oil and coconut oil as an alternative to oil based can be able to replace diesel or not.

For the study of the theory and definitions of terms related to the study, as well as for experiments that can provide the results of determining the conclusion that whether or not the alternative oil based (coconut oil) can be used as the oil-based mud are the main functions and objectives of this project.

CHAPTER 2
LITERATURE REVIEW

2.1 Oil-Based Mud

2.1.1 General description

Oil based mud may be defined as a drilling fluid having a hydrophobic fluid or natural or synthetic oil as the continuous or external phase is water and, if present, as a dispersed or internal phase. Oil based mud solids are an "oil" wet all additives are "oil" dispersible and mud filtrate is "oil". The water, if present, is emulsified in the phase of "oil”.

There are two basic classifications of oil based mud; invert emulsion oil based mud and free water oil based mud. The amount of water present will describe the type of oil based mud. The base fluids used can vary from crude oil, refined oils such as diesel, mineral oils, paraffins and olefins, to non-petroleum organic esters which are currently available and silicone oils. Type fluids above variously called inert fluids and synthetic fluids - are considered more environmentally acceptable than diesel or mineral oil-based mud.

Conventional all-oil-base muds (oil based mud without water) have a non-aqueous external phase, but they are designed to be free of water or when formulated in use. Since water is not present, the types of asphalt materials, polymers, or lignitic may be necessary to control loss and fluid viscosity. As there is no water added to the system in the formulation and additions of water are avoided if possible during drilling, there is only a minimum requirement for emulsifiers.

To all-oil muds, water-free oil based mud withstand small amounts of water, but if the water is a contamination effect, the mud should be converted to an invert emulsion. If the water is not emulsify quickly can cause the solids in the slurry of water and stability problems. The water-solids blind the shaker screens and loss of whole mud occur. Invert emulsions are formulated so as to contain oil based mud moderate to high concentrations of water which is an integral component of the invert emulsion, and a salt thereof are contained, often calcium or sodium chloride. In a mixture of water and oil, the interfacial tension between oil and water is very high, so that when they are mixed together, the liquids usually mechanically separated when the movement stops.

Any emulsion which is formed from this direct emulsion with water as the external continuous phase. Reduced surface tension, surface-active agent (surfactant) enables a liquid to form a stable dispersion of fine droplets in the other. Nevertheless, the two liquids are immiscible. The lower the interfacial tension, the smaller the droplets and the more stable the emulsion. Interfacial tension between water and mineral oil is about 50 dynes / cm^2, and a good emulsifier and less than about 10 dynes/cm^2.

Surfactants, emulsifiers consist of soluble, lipophilic oil-chain atoms attached to chain water soluble (hydrophilic). The lipophilic portion is dissolved in the oil side of the interface and hydrophilic on the water side. Whether the emulsion formed is direct (oil in water) or reverse (water in oil) depends on hydrophilic / lipophilic balance (HLB) which is the weight ratio of the hydrophilic part of the lipophilic molecule.

2.1.2 Oil-based mud application

Oil-based mud offer many advantages in comparison with water based muds. The high initial cost of oil-based mud can be a factor does not choose this type of mud system. However, if the total drilling costs consider costs accompanying the use of oil dirt, usually less than for water mud. Some applications of the oil-based mud will be described below.

1. **Shale stabilization**

   Oil based mud is best suitable for drilling water sensitive shales. Formulated with proper salinity, oil based mud can prevent the movement of water out of the mud in the shales.

2. **Optimize rate of penetration**

   Oil-based mud, as a rule, delivers faster ROP WBM while providing better stability shale. Filtering relaxed invert emulsions usually have high oil content of the water and some additives used to control fluid loss are omitted.

3. **High temperature wells**

   Oil base mud has the ability to drill formations where temperatures exceed downhole base mud tolerances, especially in the presence of contaminants.

4. **Drilling salts**

   Invert oil based mud provide the dipstick hole and do not leach salt. The addition of salt to the aqueous phase prevents the salt to dissolve in the aqueous emulsion phase.

5. **Lubricity in deviated wells**

   The high lubricity offered by oil based mud makes it particularly suitable for highly deviated and horizontal wells.

2.2 Alternative Vegetable Oil

2.2.1 Coconut oil

The refined coconut oil is the most widely used form of coconut oil in the world that we are usually rather tasteless and odorless, if not the purest and the best. It is also known as RBD coconut oil, which stands for refined, bleached and deodorized coconut oil. RBD oil is usually made us copra (dried coconut kernel).

The dried copra is placed in a hydraulic press with added heat and extracts the oil. This produces up practically all the oil present, amounting to more than 60% of the dry weight because this oil coconut “crude" is not suitable for consumption because it contains contaminants and must be refined with further heating and filtering.

Physical properties of coconut oil can be summarized as follows;

Color: Colorless at or above 30°C, white when solid.
Odor: Typical smell of Coconut (if not refined, bleached & deodorized).
Melting point: Melts at 25 C (76°F), solid below this temperature.
Smoking point: 177°C (350°F).
Flash point: 315°C (600°F)
Solubility in water: Insoluble in water.
Density: 0.920 to 0.924 at a temperature of 25 Celsius degree.

Chemical properties of sesame oil can be summarized as table below;

Table 1: Coconut oil is composed of following fatty acids

Name of fatty acid	Percentage	Remarks	Type of fat
Lauric acid	45% to 52%	Medium chain fatty acid	Saturated fat
Myristic acid	16% to 21%	Medium chain fatty acid	Saturated fat
Caprylic acid	5% to 10%	Medium chain fatty acid	Saturated fat
Capric acid	4% to 8%	Medium chain fatty acid	Saturated fat
Caproic acid	0.5% to 1%	Medium chain fatty acid	Saturated fat
Palmitic acid	7% to 10%	-	Saturated fat
Oleic acid	5% to 8%	-	Unsaturated fat
Palmitoleic acid	In traces	-	Saturated fat
Linoleic acid	1% to 3%	-	Unsaturated fat
Linolenic acid	Up to 0.2%	-	Unsaturated fat
Stearic acid	2% to 4%	-	Saturated fat

2.3 Selected Vegetable Oil

2.3.1 Coconut oil

Coconut oil has become alternatives oil based muds with its properties which are able to comply with the standard requirement of Oil based mud properties. From the tables shown below; Coconut oil has highest cloud and pour point (13.1 °C and 12.7 °C) among all the oil studied due to it contains short chain (6-8) carbon atom fatty acids (Akhtar, Adnan, et al., 2008). But they have the high flush point or smoke point of 350 °F (177 °C) at the same point. Viscosity also influences the pour and cloud points of the oils. As the viscosity of sesame oil and coconut oil is 54.37 mPa.s or 54.37 cP and 44.16 mPa.s or 44.16 cP, its Specific gravity (SG) is 0.9185 and 0.9138 respectively (Diesel oil has SG of 0.84 in 60’F (API, 1998), they have shown the possibility of coconut oil as the new alternative.

Table 2: Average value of different parameters of different oil

No.	Name of oils	Average Viscosity (mPs.s)	Mean of oils	Each oil different from mean	Total Standard deviation
1	Saraline Oil	2.66	151.88	-149.22	194.06
2	Coconut Oil	44.16		-107.72	
3	Almond Oil	65.68		-86.20	
4	Castor Oil	686.24		534.36	
5	Sesame Oil	54.37		-97.51	
6	Sunflower Oil	58.19		-93.69	

Newtonian or Non-Newtonian behavior play important role in this physical property of the oils. In Newtonian liquids; if the viscous stresses that arise from its flow, at every point, are proportional to the local strain rate ,the rate of change of its deformation over time. The shear stress and shear rate are directly proportional to each other which will give a straight line in the profile of shear stress versus shear rate. However, the flow index value of coconut oil is 0.9 deviating from 1 approaching the Non-Newtonian behavior as shown in table 2.

2.4 Saraline Oil

2.4.1 Chemical identity

Saraline 185V is a synthetic wax up with a low viscosity, low pour point and a relatively high flash point, use as synthetic drilling fluid, the appropriate application of pure natural deepwater exploration (Shell MDS, 2009) is produced. There is virtually no aromatic and impurities such as sulfur and amines which contain Saraline 185V easily removed non-toxic water and a source of low rainfall toxicity. It is generally regarded as a non-aqueous liquid in the drilling fluid emulsion is used. SARALINE 185V contains the reaction of purified, unlike the highly purified mineral oils / processed by distillation or refining (UCP, 2003), which produced by Shell MDS.

It is easily decomposed, non-toxic in the water and has a low toxicity precipitation. It has a viscosity of low flow low and a relatively high flash point, it is ideal for underwater exploration. It is commonly used as a non-aqueous liquid inverse emulsion drilling mud in the exploration and production of oil and gas industry. Saraline 185V and / or its variants and related products have been used at different times in Malaysia, Thailand, Vietnam, Myanmar, Indonesia, Philippines, Bangladesh, India, Australia, New Zealand, China and the Caspian Sea since 1997 .

2.4.2 Physical and Chemical Properties

Physical and chemical properties as summarized as below.

Color: Colorless

Odor: Odorless

Pour point: -27'C (-16'F)

Flash point: > 85'C (185'F)

Soluble in water: Insoluble in water

Density: 0.77 at a temperature of 25'C.

When manipulating Saraline 185V, do not eat, drink or smoke. User use only in well-ventilated areas and take precautions against static discharge and kept at room temperature. Storing Saraline is located away from heat and other sources of ignition, do not keep useless contains unlabeled or mislabeled containers.

2.5 Base Oil Properties Requirements

Guidelines of the basic requirements had been discussed. This is detailed by Johanscvik and Grieve who have summarized as follow (Yassin, Kamis & Abdullah, 1991).

1. **Non-toxic and low aromatic content**

Base oil must have a total aromatic hydrocarbon content is less than 5%. It should be non-acute toxicity in a standard toxicity test 96 hr LC 50, carried out using 100% of the water soluble fraction of the base oil.

2. **Stable emulsion**

The base oil should be able to form a stable emulsion.

3. **Kinematic viscosity**

It should be as low as possible. This allows the oil based mud was formulated into the oil / water ratio lower and allows a better rheology (less plastic viscosity), especially at low temperature of the mud.

4. **Flash point**

There should be greater than 100 ° F. Higher flash point will minimize the risk of fire because we expect less hydrocarbon vapors to produce above the mud.

5. **Pour point**

It should be below ambient temperature to allow the pumping capacity of mud from storage tanks.

6. **Aniline point**

It is the temperature at which an equivalent mixture of aniline and oil are not soluble in each other. In general, less saturated hydrocarbon (usually having lower heating value) mix readily with low aniline point also.
To minimize the deterioration of the rubber component to the test, the oil should base have an aniline point of about 65 °C.

7. Non-fluorescent

Fluorescence base oil is undesirable because it inhibits the ability of well site geologist native to detect hydrocarbons in evaluating drill cuttings.

2.6 Rheology Study

It can be defined as the science of the deformation and/or flow of solids, liquids and gases under applied stress. In essence, the science deals with the stress-strain-time relationships of any matter.

The rheological characteristics of materials form a continuous spectrum of behavior ranging from that of the perfectly elastic solid at one extreme to that of the purely viscous Newtonian fluid at the other. Between these extremes lies the behavior of fluids which possess varying degrees of the character of both extreme materials, such materials are termed visco-elastic.

Certain rheological measurements made on fluids, such as viscosity, gel strength and etc. The information gathered from this experiment can help in the design of circulating systems required to accomplish certain desired objective in drilling operations, circulating pressures, surge and swab pressures and hole cleaning ability. In this project, the rheological study comprises of plastic viscosity, yield point, electric stability and gel strength. Each study is so significant to choose a better base fluid.

2.6.1 Viscosity

Viscosity can be described as the resistance to flow and is defined as the ratio of shear stress to shear rate.

The units of Poise are too large for drilling fluid studies and viscosity is reported in centipoises or millipascal.second (1cP = 1 mPa.s).

Since viscosity is dependent on shear rate and shear stress, one or the other must be specified when a viscosity measurement is stated. Shear rate is the usual variable defined, either as an actual shear rate in reciprocal seconds or as speed in rpm from a concentric cylinder viscometer. There are two types of fluid characterization which are;

1. Newtonian fluids

In these fluids the shear stress is directly proportional to the shear rate. When the shear rate is doubled the shear stress is doubled i.e. when the circulation rate is doubled the pressure required to pump the fluid is doubled. Such fluids have a constant viscosity.

2. Non-Newtonian fluids

The shear rate / shear stress ratio of non Newtonian fluids is not constant, which is true of most drilling fluids. The two most popular mathematical models for describing non-Newtonian drilling fluids are called the Bingham Plastic model and Power Law model.

2.6.2 Plastic viscosity

Drilling muds are usually composed of a continuous fluid phase in which solids are dispersed. Plastic viscosity is that part of the resistance to flow caused by mechanical friction. The friction is caused by:

1. Solid concentration.
2. Size and shape of solids.
3. Viscosity of the solid phase.

PV of a mud is the theoretical minimum viscosity a mud can have because it is the effective viscosity as shear rate approaches infinity. The highest shear rate occurs as the mud passes through the bit nozzles; therefore, PV will approximate the mud's viscosity at the nozzles.

2.6.3 Yield point

The yield point is the initial resistance to flow caused by electrochemical forces between the particles. This electrochemical force is due to charges on the surface of the particles dispersed in the fluid phase. Yield point is a measure of these forces under flow conditions and is dependent upon:

1. The surface properties of the mud solids.
2. The volume concentration of the mud solids.
3. Ionic environment of the liquid surrounding the solids.

A low Plastic Viscosity indicates that the mud is capable of drilling rapidly in the other hands, High Plastic Viscosity is caused by a viscous base fluid and by excess colloidal solids. However, the difference between the Plastic Viscosity and Apparent Viscosity of a drilling fluid is Plastic Viscosity is the viscosity of a mud when extrapolated to infinite shear rate while The Apparent Viscosity is the viscosity of a fluid measured at a given shear rate at a fixed temperature.

2.6.4 Gel strength

Gel strengths, 10-second and 10-minutes, measured on the VG meter, indicate strength of attractive forces (gelation) in a drilling fluid under static conditions. Excessive gelation is caused by high solids concentration leading to flocculation.

Signs of rheological trouble in a mud system often are reflected by a mud's gel strength development with time. When there is a wide range between the initial and 10-minute gel readings they are called "progressive gels".

This is not a desirable situation. If initial and 10-minute gels are both high, with no appreciable difference in the two, these are "high-flat gels", also undesirable. The magnitude of gelation with time is a key factor in the performance of the drilling fluid. Gelation should not be allowed to become much higher than is necessary to perform the function of suspension of cuttings and weight material. For suspension “low-flat gels” are desired.

2.6.5 Electrical stability

Electric Stability is a test for oil-base muds that indicates the emulsion and oil-wetting qualities of the sample. ES is tested by applying a voltage ES probe into a cup of 120°F mud then the ES meter automatically applies increasing voltage (from 0 to 2000 volts) across an electrode gap in the probe.

Maximum voltage that the mud will sustain across the gap before conducting current is displayed as the ES voltage. This threshold voltage is referred to as the Electric Stability of the mud and is defined as the voltage. Specification value: > 600volts.

2.6.6 Filtration

Fluid loss is defined as the loss of a mud filtrate (Liquid phase) into a permeable formation. It is controlled by the filter cake formed of the solid constituents in the drilling fluid. The test consist of volume measurement of the forced liquid through the mud cake into the drilled formation in 30 minutes time under given pressure and temperature using standard size cell.

2.6.6.1 Mud cake

Mud cake formation in drilling is very important. It is defined as the residue deposited on the borehole wall as mud loses filtrate into porous, permeable formation. One important characteristic of mud cake is its low permeability which retard further fluid loss to the formation. As this can be related to the thickness of the mud cake which may leads to many problems such as: tight hole condition, stuck pipe, formation damage and etc. Thus, it is very important for the mud engineers to control the thickness of the mud cake and at the same time, the fluid loss into the formation.

This can be achieved by adding fluid-loss additives into the mud recipe such as: Bentonite, Starch, Lignites and etc.

2.7 HPHT Formation

According to the SPE E & P Glossary, where the temperature is high temperature (total depth of the prospective reservoir or depth) is greater than 300 °C, or 150 ° C. For high pressure, this definition is met if the maximum expected pore pressure of the formation to be drilled porous exceeds a hydrostatic gradient 0.8 psi / ft, or equipment for controlling the pressure and the pressure necessary for during nominal operation 10,000 psi or 69 MPa.

CHAPTER 3
METHODOLOGY

The study will be divided into two phases for FYP I and FYP II as follows:

3.1 Final Year Project I

Searching, reviewing of the literature to obtain information and efficient methodology to design the experiment of turning the cutting process water-based drilling in the organic material environmentally.

3.1.1 Design and plan the drilling fluid experiment.

1. Plenty information preparation for alternative information-based drilling fluid oil.
2. Preparation of the experimental setup, look for the place to buy base oil, additives, materials, laboratory equipment, etc.
3. Having conversations and get recommendations from bioremediation of specialized companies and organizations.

3.2 Final Year Project II:

To carry out and investigate the experiments which resulting the most suitable solution passing on contaminate. And other objectives as below;

3.2.1 Experimental stage and analyze the results.

1. To prepare the refined Coconut oil as based drilling fluid.
2. To formulate the suitable mud formulation for refined Coconut oil.
3. To prepare the lab equipment and measure the Plastic Viscosity, Yield point, Electric Stability, Gel Strenght and Filtration.
4. To compare and analyze the Rheology result of Coconut oil and Saraline oil.

3.2.2 Research methodology

The consideration of this investigate is to extend new oil base mud to achieve mud properties which required by industry:

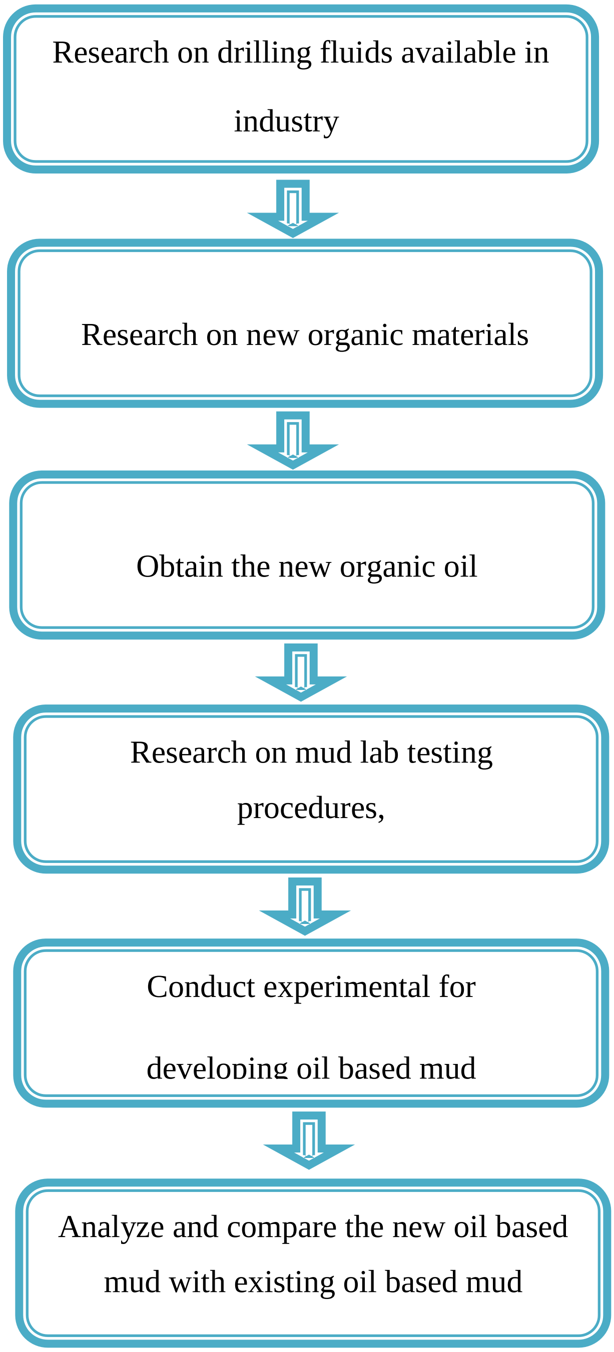

Figure 1 : Research Methodology

Table 3: Project Timeline Fyp I

Activities in FYP I	W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W 10	W 11	W 12	W 13	W 14	W 15	W 16	W 17
Selection of project topic															Study week	Final Examination Week	Semester Break
Preliminary research work																	
a) Literature review: *Investigating the viability of local vegetable oils as base drilling fluid HPHT formation.*																	
Submission of extended proposal																	
Proposal defense																	
Project work continues																	
Finding, Literature review, Experiment design																	
Submission of Interim Draft Report																	
Submission of Interim Report																	

Table 4: Project Timeline Fyp II

Activities in FYP II	W 1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W 15	W 16	W 17
Prepare Lab equipment and material for experiment															Study week	Final Examination Week	Semester Break
Rheology study of coconut oil and Saraline oil																	
Submission of Progress report																	
Analysis of obtained result																	
Pre-EDX and poster submission																	
Final Report Submission																	
EDX																	
Final Oral Presentation																	

3.3 Mixing Procedure

A systematic mixing process is planned and conducted to prevent premature mixing of the drilling fluid. Premature mixing would result in massive forming, which provides a fail mud system. The mixing method comprises mixing the active sequence and its mixing time. Table 5 shows the mixing process for the mixing of oil-based mud (OBM) and vegetable oil based mud respectively.

Table 5: Mixing procedure for formulated mud

Product	Mixing order	Mixing Time (Min)
Base oil	1	4
Coconut oil		
Toluene		
CONFI-MUL P		
CONFI-GEL	2	5
CONFI-TROL	3	2
Lime	4	2
Water	5	15
$CaCI_2$		
DRILL-BAR	6	33

The above ingredients are presence at different quantity in the OBM and vegetable oil based mud on the total mud weight. Table 7 shows the individual ingredients contained in the mud formulation for OBM and vegetable oil based mud respectively.

3.4 Base Mud Formulation

Oil-Based Mud (OBM) and Vegetable Oil Based Mud are selected as drilling fluids for this study. OBM and Vegetable Oils are formulated with the following ingredients.

1. Base oil (Coconut oil)
2. Toluene
3. CONFI-MUL P
4. CONFI-GEL
5. CONFI-TROL
6. Lime
7. Fresh water
8. Calcl2
9. DRILL-BAR

3.5 Mud Test

Mud test performed to test the performance of the formulated mud. The result of the test to obtain mud test be able to provide an analysis of mud details regarding the performance of mud. Then, improvements are to be carried out to its formulation, if necessary. Both synthetic based mud and oil based mud test coconut based mud like different from the viscosity reduction of coconut oil are conducted. Mud tests carried out as the following.

3.5.1 Mud density test

Mud density test is performed to analyze the mud weight of the formulated mud. It is often carried out by the engineer of the mud during the drilling operation to control the mud weight drilling fluids before and after distribution. Any change in the weight of the mud, it would weight up procedure to be performed in order to avoid interrupting the drilling operation.

A mud balance kit is used to check the weight of mud drilling fluids. The procedure was based on the American Petroleum Institute (API) 13B-2 standards (HIS Store Standards, 2012). The kit consists of mud balance cup of mud disposal is attached to the beam kit mud. A movable weight is attached to the beam kit mud, which conforms to counter balance the mud sample. There are two types of mud balance kit that are standard mud balance kit and pressurized mud balances kit. Pressurize mud balance kit is used for drilling fluids contained entrained gas. To avoid inaccuracies in reading, the pressurized mud balance kit is able reduces the entrained gas by creating a pressurized system.

The calibration is performed before running the test to avoid measurement errors. Distilled water is used to calibrate the mud balance kit. During the calibration reading of 8.345 pounds / gal is indicated the density of water. Figure 2 shows the kit of the balance of the standard mud balance kit that used in this study.

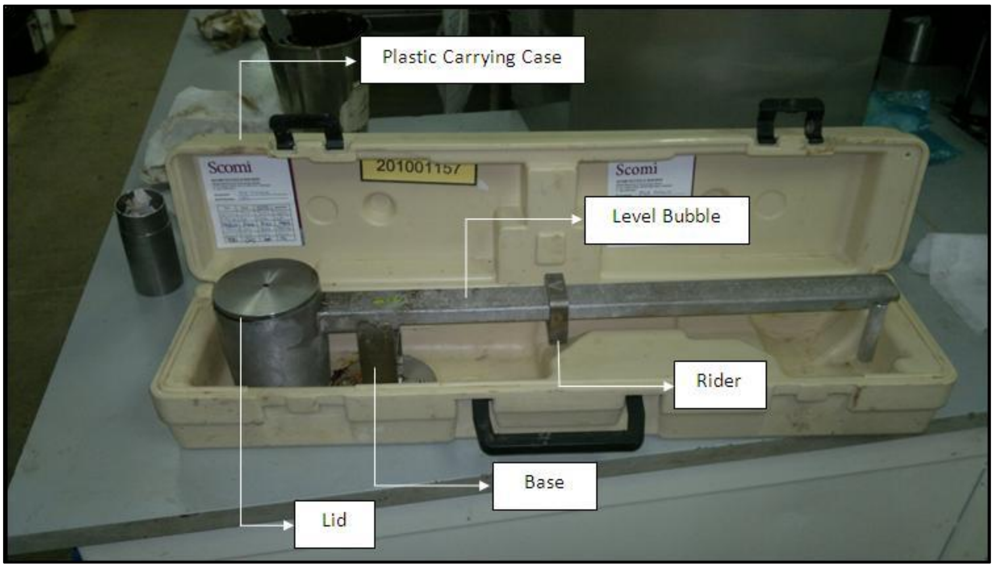

Figure 2: Typical Mud Balances Kit

The test is carried out on a flat surface to avoid incorrect measurements. The cup of mud is separated mud balance kit, and is filled with mud sample. It is important that the mud cup is filled to the brim, to get an accurate reading.

The lid is placed back in the mud cup, and the mud cup is attached back to the mud balance kit. The weights on the mud balance kit move to counter the weight of the mud. Reading is performed when the bubble is under the center line.

3.5.2 Rheology test

Rheology test is carried out to observe the flow properties of the mud sample. This is a standard procedure in experimental API-13B. Fann Model 35A, which is a six-speed viscometer driven motor is used to run the test. Figure 3 shows the description of the viscometer used in this test.

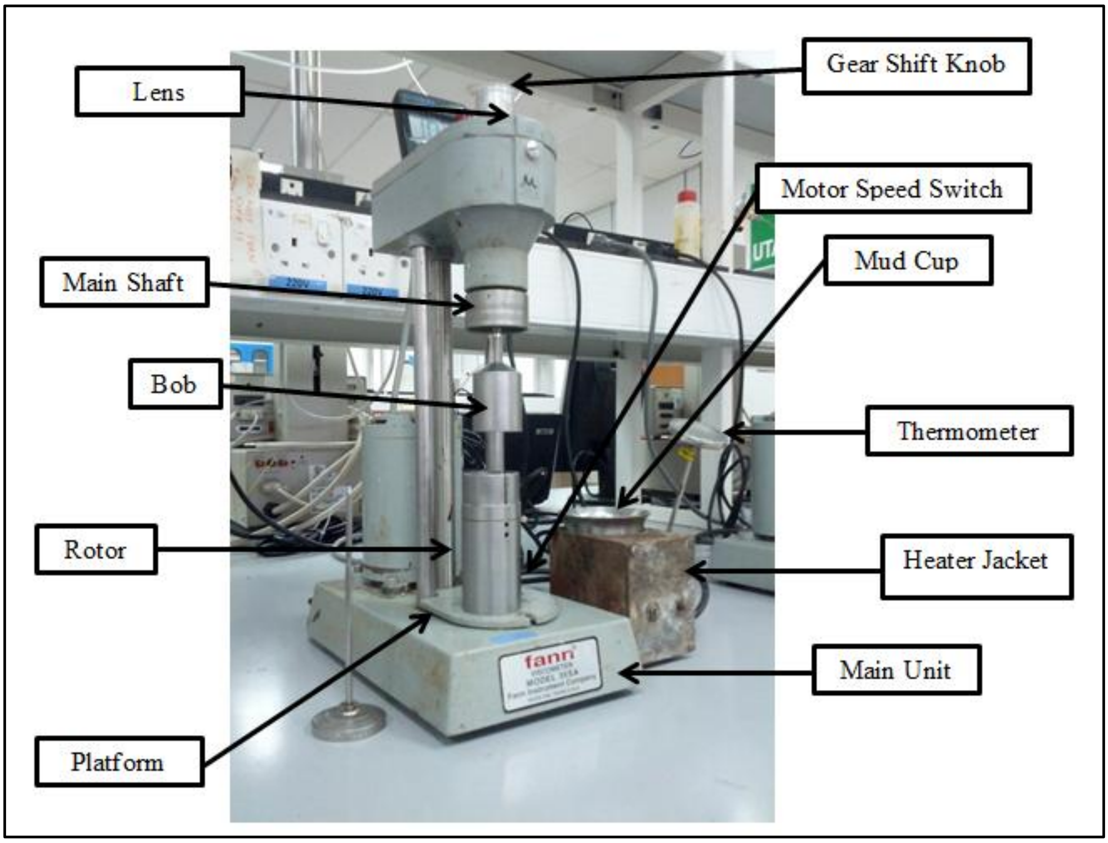

Figure 3: Variable Speed Viscometer

Rheology test consists of three sub-tests are: test Plastic Viscosity (PV), Yield point (YP) and gel strength of the mud. The shear stress of the mud flow properties is carried out in six different rotations (600 rpm, 300 rpm, 200 rpm, 100 rpm, 6 rpm and 3 rpm). The motor speed switch is used to set the speed, either high or low with corresponding to the position of the gear shift knob. Table 6 shows the list of position for the viscometer speed switch engine and gear shift knob.

Table 6: Six speed testing combinations for Fann 35A Viscometer

[Source: Model 35 Viscometer Instruction Manual]

Speed RPM	Motor Speed Switch	Gear Shift Knob
600	High	Down
300	Low	Down
200	High	Up
100	Low	Up
6	High	Centre
3	Low	Centre

PV represents the mud viscosity under dynamic flow condition, and YP represent the force need to initiate the flow of mud. PV and YP can be calculated based on E 3.1 and E 3.2:

E 3.1

PV = 600 rpm reading – 300 rpm reading

E 3.1

YP = 300 rpm reading – PV

Finally, the mud gel-strength is tested to observe the mud sample ability to suspend drill cuttings under static condition. The mud gel strength is measured at 10 second interval and 10 minute interval.

3.5.3 Electrical Stability test

The electrical stability was measured by applying a sinusoidal alternating voltage increases regularly through a pair of parallel flat-plate electrodes immersed in the oil base drilling fluid. The resulting residue voltage to a very low threshold current is reached. At this voltage, the conduction between the electrodes occurs, which causes a rapid increase in current. When this current reaches 61μA, the peak voltage is measured and expressed as the electrical stability of the drilling fluid or other material. The drilling fluid compositions at all power control stability based oil volume in a complex manner. Several properties affect the electrical stability of a given drilling fluid, such as

1. Resistivity of the continuous phase (typically oil)
2. Conductivity of the non-continuous phase (typically water droplets with dissolved salts)
3. Properties of suspended solids
4. Temperature
5. Droplet size
6. Type of emulsifier
7. Dielectric properties of the fluids
8. Shear history of the sample

Therefore, the interpretation of the condition of the oil-wet condition from one ES measurement is not necessarily representative of the mud. Since many factors affect the measurement of the absolute value of a single measurement is not very significant. Recommend several readings to be taken to establish a trend. These measurements will reflect the exact state of the mud and provide a basis for the treatment of mud. Figure 4 shows the description of the Electrical Stability Tester used in this test.

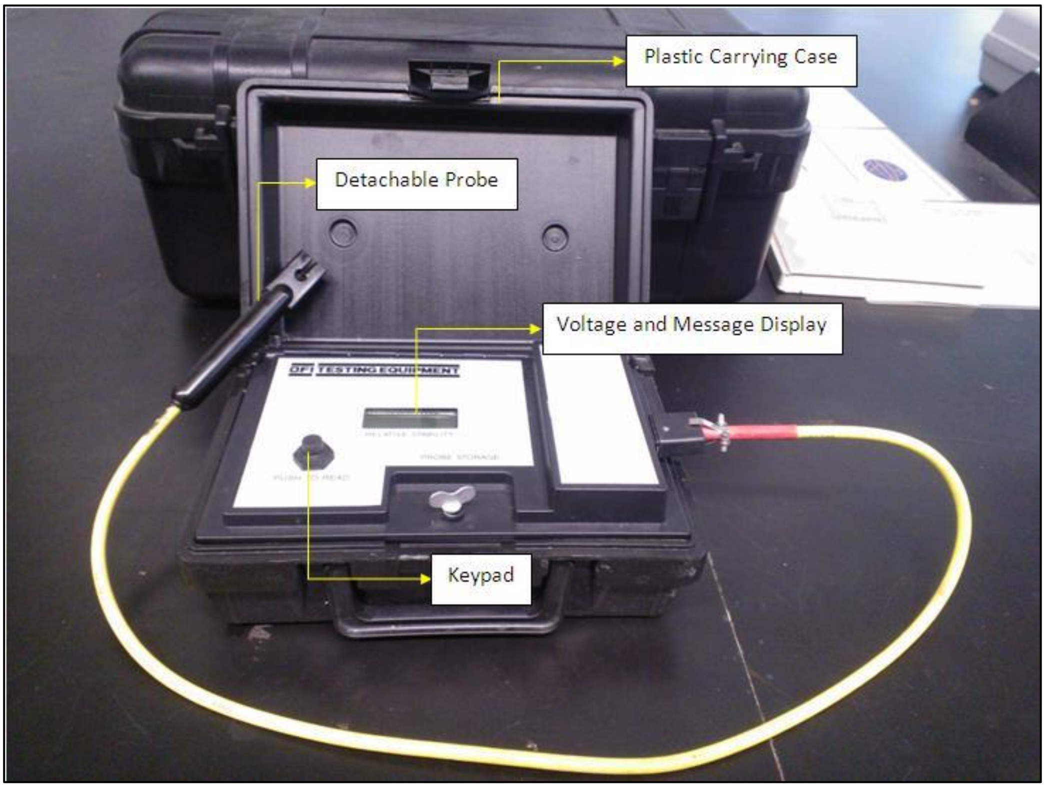

Figure 4: Fann emulsion and Electrical Stability Tester

3.5.4 High Temperature High Pressure (HTHP) filtrate test

Filtered control is another parameter to measure the performance of drilling fluids. It has the ability of drilling fluids to form of quality mud cakes that strengths and secure the formation during drilling operation. High Temperature High Pressure (HTHP) filter control are carried out for measuring the amount of filtrate obtained from the formulated mud. The test is also carried out to monitor the quality of the mud cake. HTHP filter press is used for analysis. Figure 5 shows the HTHP filter press is used for testing HTHP filtrate.

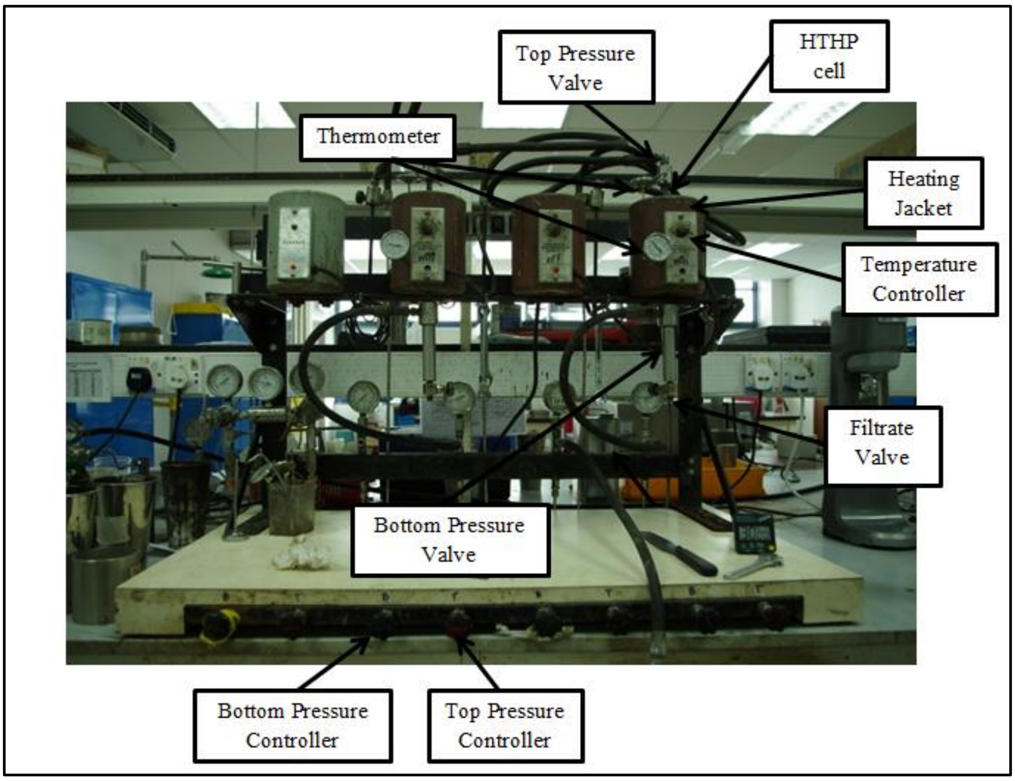

Figure 5: HTHP filter press unit

The test starts with heating the HTHP filter press heater jacket to the desired temperature of 250 ˚ F. In anticipation of the heater to warm up jackets, mud sample is poured into the HTHP cell. HTHP cell used is shown in Figure 6. Mud is poured to about 1 inch from the cell O-ring groove. A filter paper is placed on the grove and the cell gap is closed.

When the desired temperature is obtained, the cell is inserted into the jacket. Pressure applied to the top of the cell at 100 psi, while the upper die slightly open valve. The cell is then left to heat up to 250 ˚ F. A Thermometer is placed into the cell slot to observe the temperature. When the temperature reaches 250 cells ˚ F, top pressure is set to 600 psi and bottom pressure set to 100 psi. The bottom stem valve is slightly open and the timer is switch on.

The filtrate is taken at 5 minutes, 10 minutes, 15 minutes, 20 minutes, 25 minutes and 30 minutes. This is necessary to avoid filter build up in the stem valve. A cylinder is used to collect the form filtrate. At the end of 30 minutes, all stem valves are closed and the pressure is released before removing the HTHP cell. The cell is placed in a cold bath to cool down in the cell.

When the cell is cool down, the cell stem valve is slightly opened to release trap pressure in the cell before removing the cell cap. This step is performed to prevent the pressure from forcing the cell cap when the cap is removed. The mud cake forms filter cake on the filter paper is careful removed. The thickness is measured and observation is made.

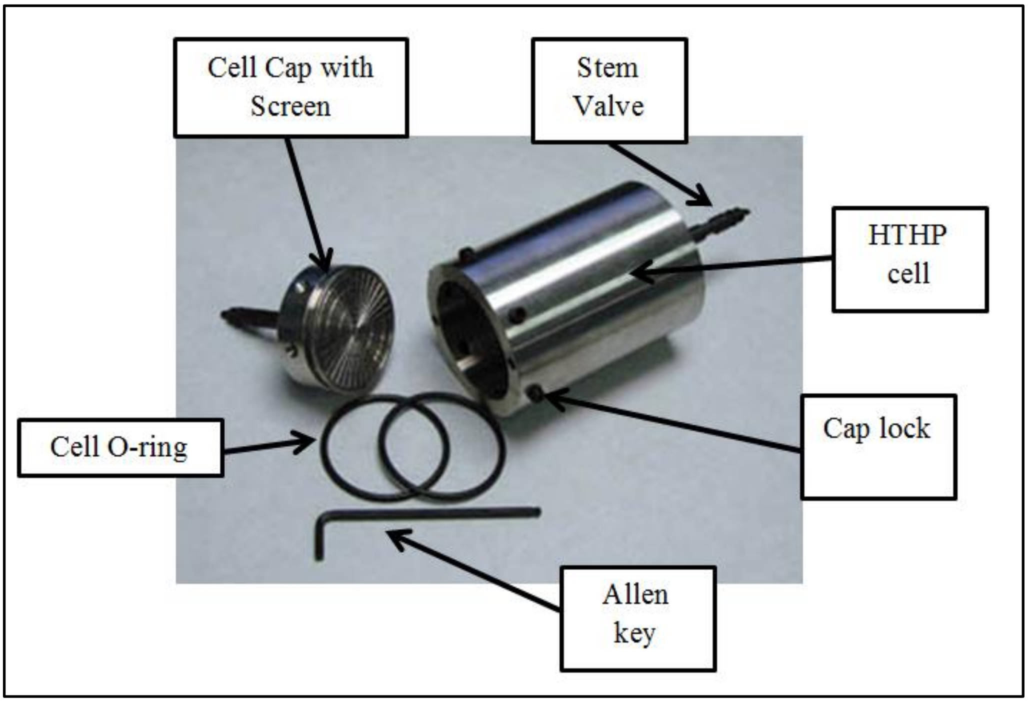

Figure 6: HTHP Cell

Table 7 : OBM mud formulations sheet

Ingredient	Composition (gram)					
	100% Saraline oil	100% Coconut oil	80% Coconut oil	70% Coconut oil	60% Coconut oil	50% Coconut oil
Saraline 185V	183.63	-	-	-	-	-
Coconut oil	-	241.18	168.83	168.83	144.71	120.59
Toluene	-	-	48.24	72.35	96.47	120.59
CONFI-MUL P	8.00	8.00	8.00	8.00	8.00	8.00
CONFI-GEL	7.00	7.00	7.00	7.00	7.00	7.00
CONFI-TROL	8.00	8.00	8.00	8.00	8.00	8.00
Lime	4.00	4.00	4.00	4.00	4.00	4.00
Water	59.00	67.31	67.31	67.31	67.31	67.31
$CaCl_2$	20.93	12.64	12.64	12.64	12.64	12.64
DRILL-BAR	129.46	1.88	1.88	1.88	1.88	1.88
Density (ppg)	10.80	9.15	9.05	9.00	8.95	8.90

3.6 Toluene

Toluene, formerly known as toluol, is a clear liquid, insoluble in water. Is a mono-substituted benzene derivative, i.e. one in which a single hydrogen atom from a group of six atoms of the benzene molecule has been replaced by a monovalent group, in this case CH3.

It is widely used as an industrial raw material and as a solvent. As other solvents, toluene is also sometimes used as an inhalant drug for its intoxicating properties; however, inhalation of toluene has the potential to cause severe neurological impairment. Toluene is a major organic solvent, but is also able to dissolve a number of notable inorganic chemicals such as sulfur, iodine, bromine, phosphorus and other non-polar covalent substances.

Toluene is a low kinematic viscosity of 0.68 cSt at 20degC and miscible with alcohol, it can be used as diluents to reduce the viscosity of the base oil. To save time and costs, so that toluene is the most suitable solvent for this study.

CHAPTER 4
RESULT & DISCUSSION

The comparative study is carried out through analyzing the OBM and coconut drilling fluids performances in term of Rheology, Filtrate Control, and Electrical Stability. Each analysis consists of two sets of results which obtained before hot roll and after hot roll. The hot roll temperature is 250˚F. By comparing the obtained results, a suitable drilling fluid would be selected based on SBM and coconut oil based mud formulated mud composition.

In this experiment, there are six samples that tested different base oil compositions: Saraline oil, 100% Coconut oil, 80% Coconut oil, 70% Coconut oil, 60% coconut oil and 50% coconut oil are. In addition, there are two conditions in this experimental project including before hot rolling and after hot rolling.

4.1 Base Oil Physical Properties

The first tests of the base mud systems are currently being conducted. The objective is to measure the basic properties of each oil-based, the use as a parameter to produce a suitable formulation, and is the comparative test on the mud properties by using different samples of mud.

Mud rheology helps determine the ability of drilling fluids to suspend and remove cuttings from the wellbore. Table 8 shows the rheological results for the Synthetic-based mud and Coconut oil-based mud drilling fluids while Figure 7-8 shows the comparison graph of their properties. The high pour point of coconut oil is not critical in hot climates such as South East Asia region. However, it would be the undesirable oils for use in cold climates. Another undesirable feature is the low aniline point value where there could be the possibility of a deterioration of the rubber to the test. Special care should be severely contoured to eliminate this problem. All rubber parts in the drilling system should be replaced by neoprene or similar components in order to avoid a possible default by rubber degradation.

Table 8: Base oil properties

Properties	100% Saraline	100% Coconut	80% Coconut	70% Coconut	60% Coconut	50% Coconut
600 rpm	6.0	94.5	58.8	43.8	35.5	23.5
300 rpm	3.3	50.3	31.4	23.4	18.9	12.5
Viscosity (cP)	2.7	44.2	27.4	20.4	16.6	11.0
Yield Point (lb/100 ft^2)	0.6	6.1	4.0	3.0	2.3	1.5

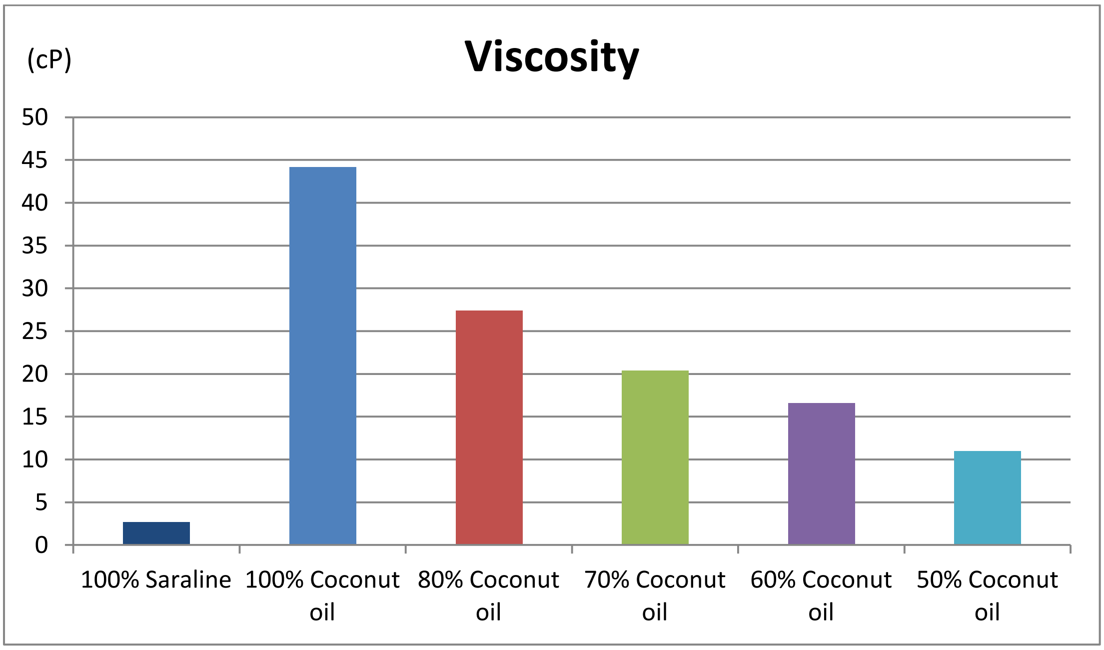

Figure 7: Viscosity of each base oil

As discussed above, the viscosity of vegetable oils is very high (about 44.6 cP). The application of this oil can cause a high PV in the mud system, especially at low temperature drilling. The problem can be solved by the following method (Yassin, Kamis, and Abdullah, 1991).

1. Dilution by mixing with thin mineral oil.
2. Find other low-viscosity Coconut oil.

3. Emulsification a portion of oil in water.
4. Thinning with appropriate thinner.

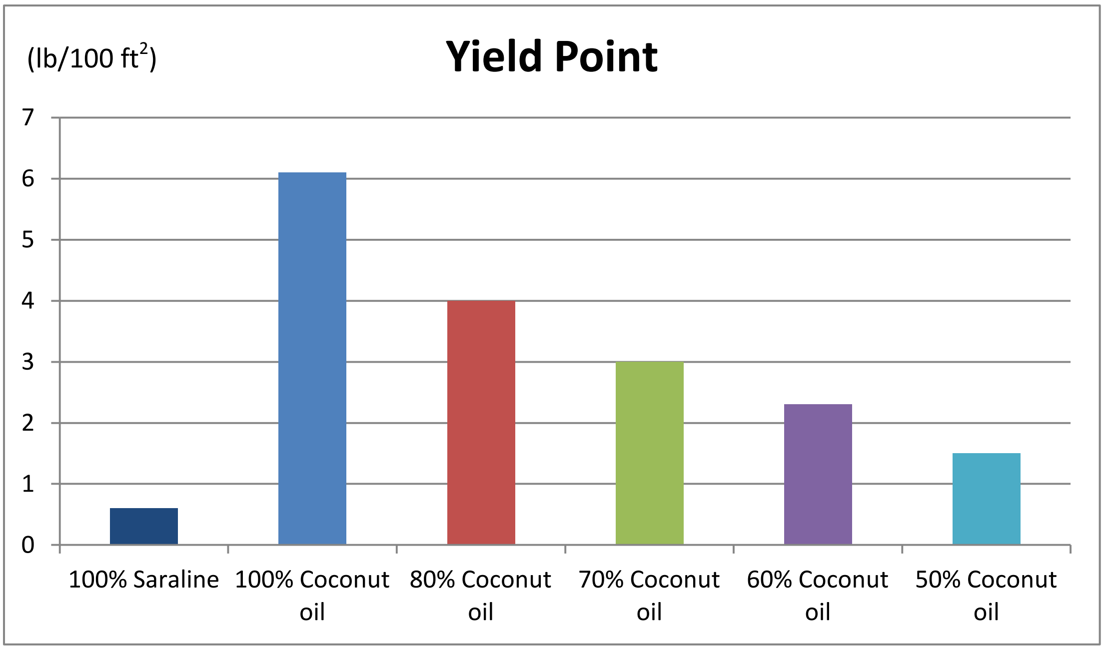

Figure 8: Yield Point of each base oil

4.2 Mud Test Result

4.2.1 Before hot rolling

The process of formulating the mud starts to create each sample according to the formula that was conducted by the calculation software mud and consult with a laboratory technician. The results of the before hot rolling are presented in Table 9 and 10.

Table 9: Mud properties result – Before hot rolling

Properties	100% Saraline oil	100% Coconut oil	80% Coconut oil	70% Coconut oil	60% Coconut oil	50% Coconut oil
600 rpm	31.5	170.5	137.0	117.5	75.8	67.8
300 rpm	17.8	106.5	81.8	72.1	47.0	41.8
Viscosity (cP)	13.7	64.0	55.2	45.4	28.8	26.0
Yield Point (lb/100 ft^2)	4.1	42.5	26.6	22.7	18.2	15.8
Gel St.@10 s (lb/100 ft^2)	5.0	23.0	22.0	21.0	20.0	19.0
Gel St @10 min (lb/100 ft^2)	7.0	35.0	25.0	24.0	23.0	22.0
Electric Stability(Volt)	345.0	1159.0	876.0	570.0	478.0	314.0
Mud Weight (ppg)	10.8	9.3	9.1	9.0	8.9	8.8

Table 10: Filtration fluid loss at 250 'F – Before hot rolling

Time Period (Min)	100% Saraline oil	100% Coconut oil	80% Coconut oil	70% Coconut oil	60% Coconut oil	50% Coconut oil
	Fluid Loss (ml)					
5	2.0	3.0	2.5	2.5	3.0	2.1
10	3.0	4.2	3.9	3	3.6	3.6
15	3.8	4.9	5.1	3.5	4.0	4.0
20	4.0	6.3	5.5	3.8	4.1	3.9
25	4.5	6.7	5.8	4.3	4.2	4.2
30	5.0	7.4	6.2	4.7	4.5	4.3

More graphs are shown in Figure 9-14, the properties of the comparison. The graphs show the coconut oil mud has a much higher viscosity, yield point, gel strength and electrical stability. However, the more diluted from coconut oil, less various properties of viscosity and yield point. However, there is also no significant change in Gel Strength. Larger amounts of filtration and thicker filter mud cakes are also been observed.

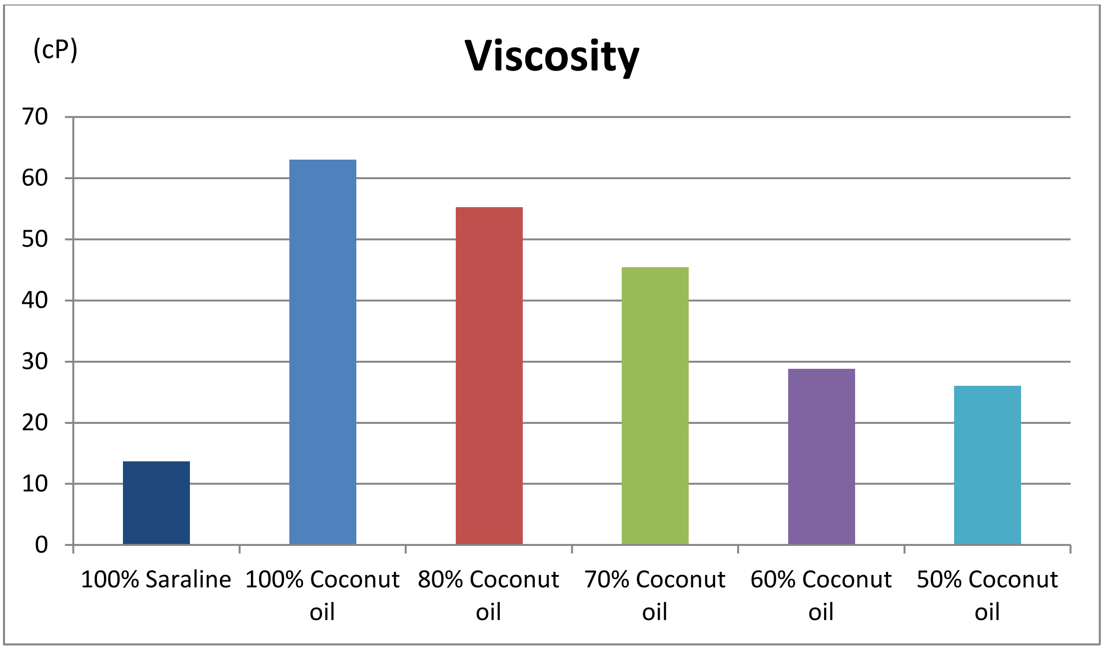

Figure 9: Viscosity of each mud – Before hot rolling

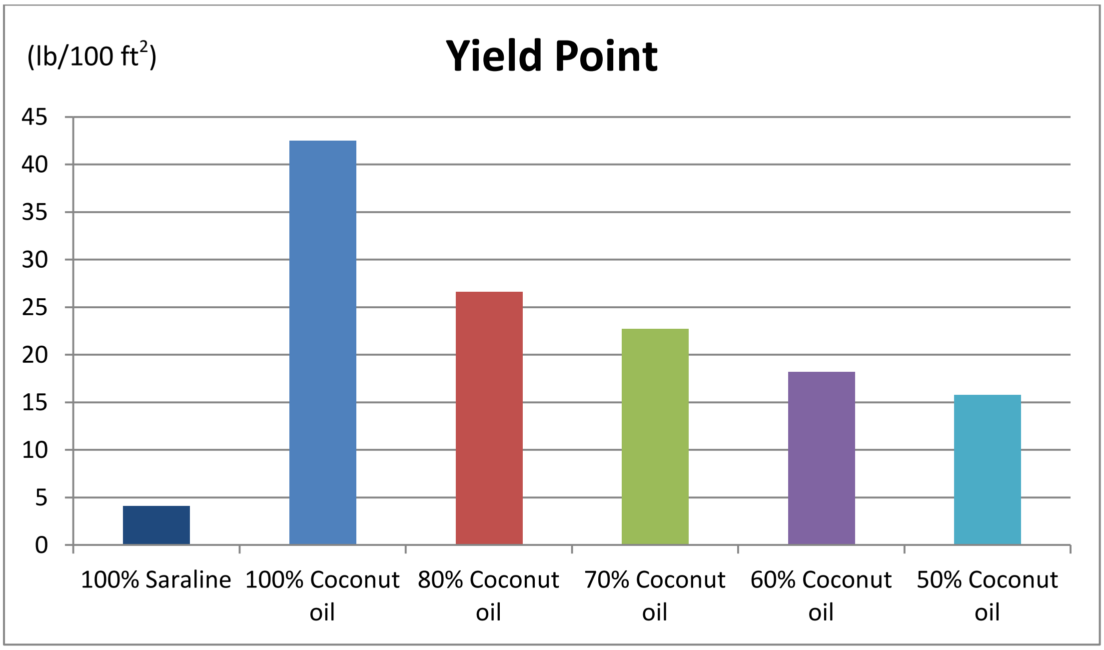

Figure 10: Yield point of each mud – before hot rolling

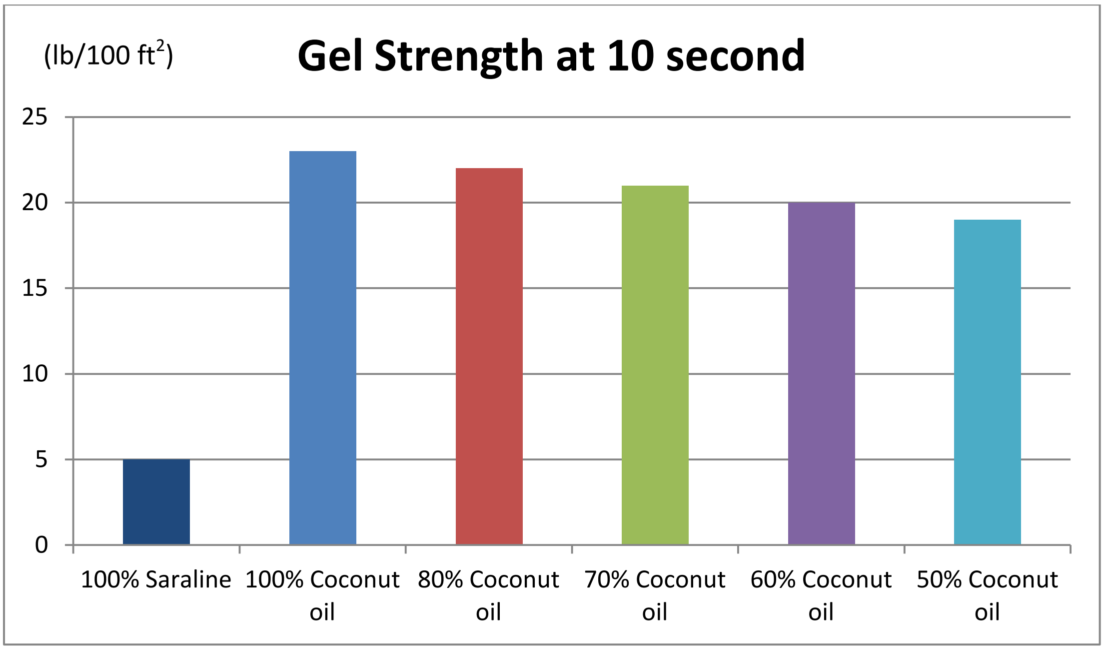

Figure 11: Gel strength at 10 second of each mud – Before hot rolling

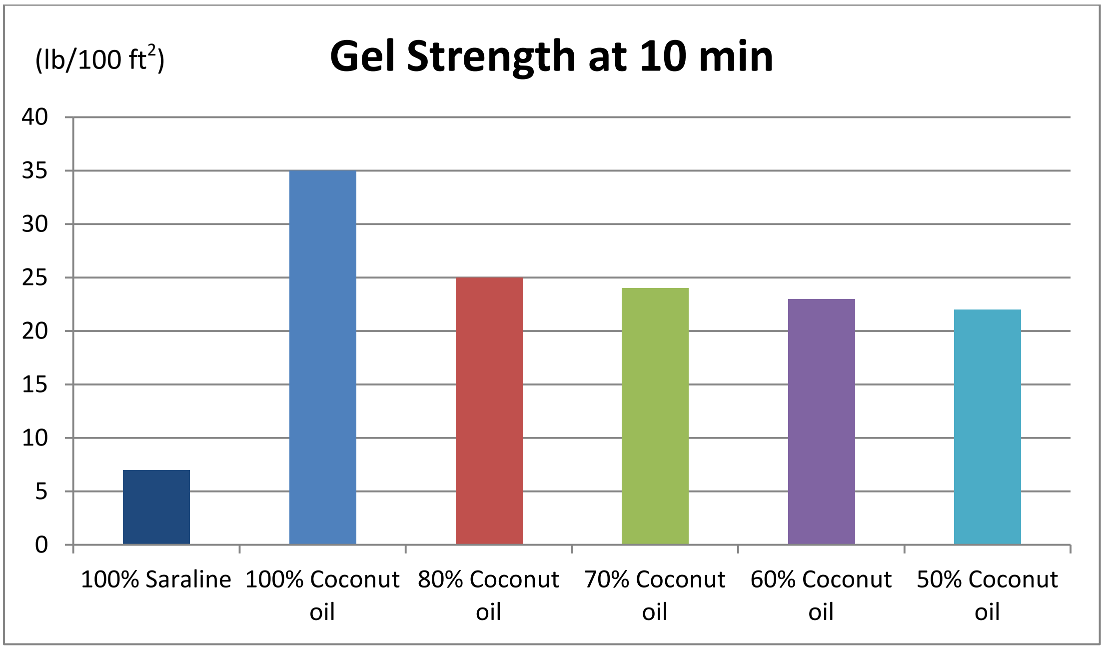

Figure 12: Gel Strength at 10 minutes of each mud – Before hot rolling

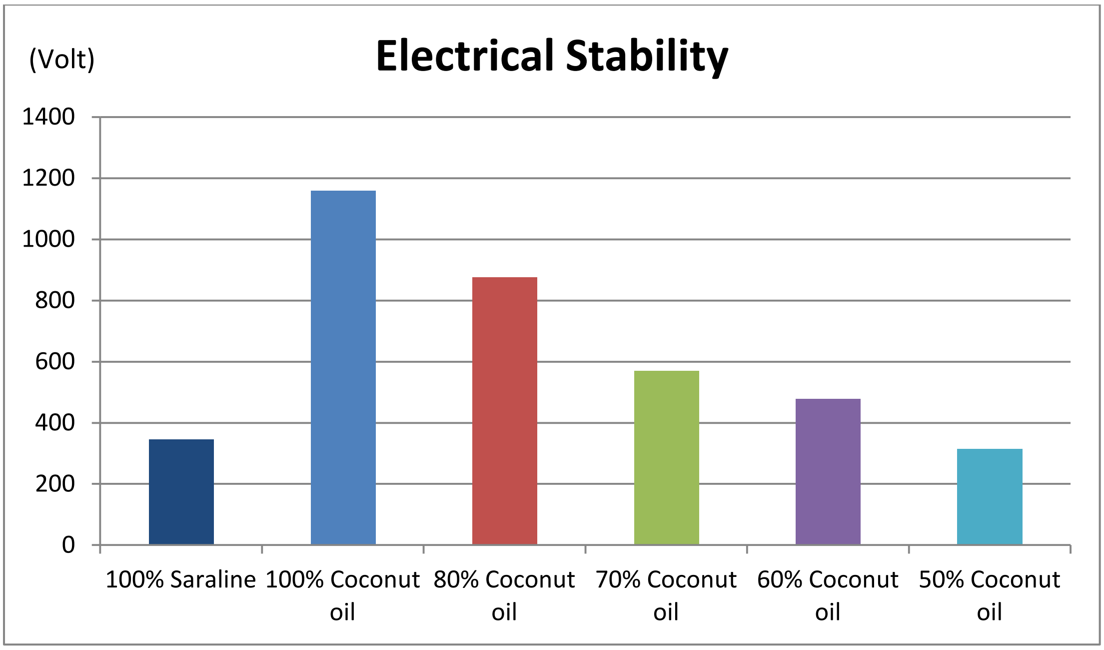

Figure 13: Electrical Stability of each mud – Before hot rolling

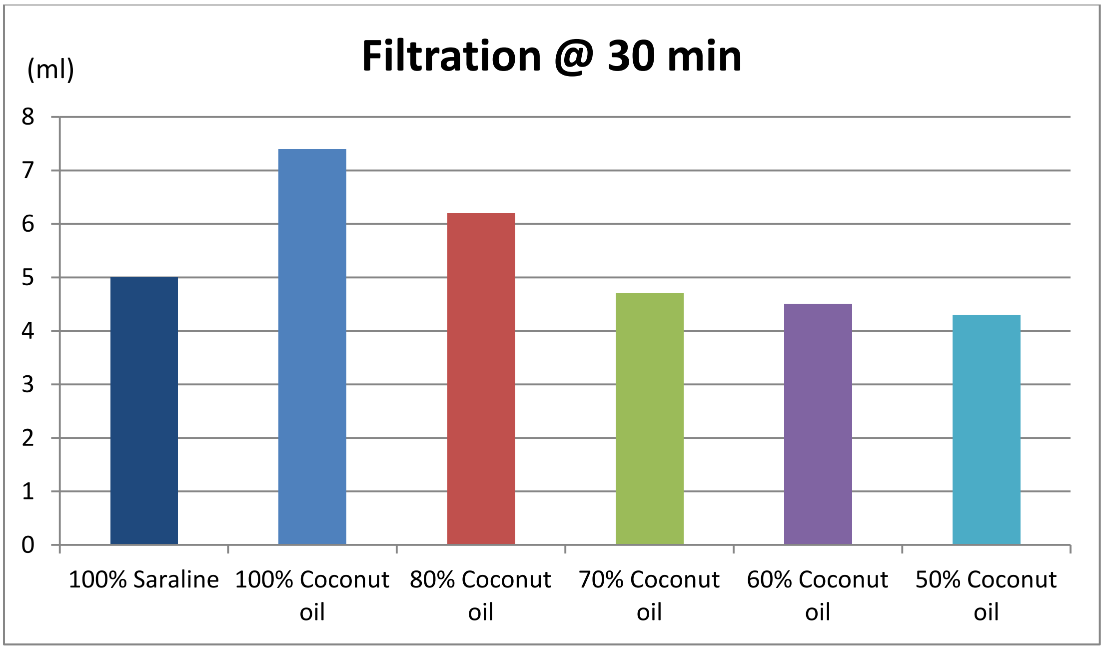

Figure 14: Filtration fluid loss at 30 minutes of each mud – Before hot rolling

4.2.2 After hot rolling

Moreover, the justification of the rheological properties of mud was also carried out by placing in hot rolling to simulate downhole conditions.

Table 11 shows the rheology results after hot rolling has been changed slightly to the result before the hot rolling.

Table 11: Mud properties result – After hot rolling

Properties	100% Saraline oil	100% Coconut oil	80% Coconut oil	70% Coconut oil	60% Coconut oil	50% Coconut oil
600 rpm	30.5	163.8	132.2	.116.8	71.7.	61.2.
300 rpm	16.5	104.2	84.8	75.8	48.7	40.2
Viscosity (cP)	13	59.6	47.4	41.0	23.0	21.0
Yield Point (lb/100 ft^2)	4	44.6	37.4	34.8	25.7	19.2
Gel St. @10 s (lb/100 ft^2)	4.7	21.0	20.0	19.0	18.0	17.0
Gel St.@10 min (lb/100 ft^2)	8	34.0	24.0	23.0	21.0	19.0
Electric Stability(Volt)	354	1249.0	893.0	596.0	484.0	374.0
Mud Weight (ppg)	11.6	10.5	10.3	10.2	10.1	10.0

Table 12: Filtration fluid loss result at 250 'F– After hot rolling

Time Period (min)	100% Saraline oil	100% Coconut oil	80% Coconut oil	70% Coconut oil	60% Coconut oil	50% Coconut oil
	Fluid Loss (ml)					
5	2.3	8.6	7.6	5.0	5.1	5.3
10	3.2	10.4	9.7	7.1	6.5	7.2
15	3.4	11.3	10.3	8.5	7.2	7.6
20	4.1	12.3	11.2	9.6	8.4	7.9
25	4.3	13.1	12.1	10.4	8.8	8.2
30	4.6	14.5	12.6	11.5	9.7	8.5

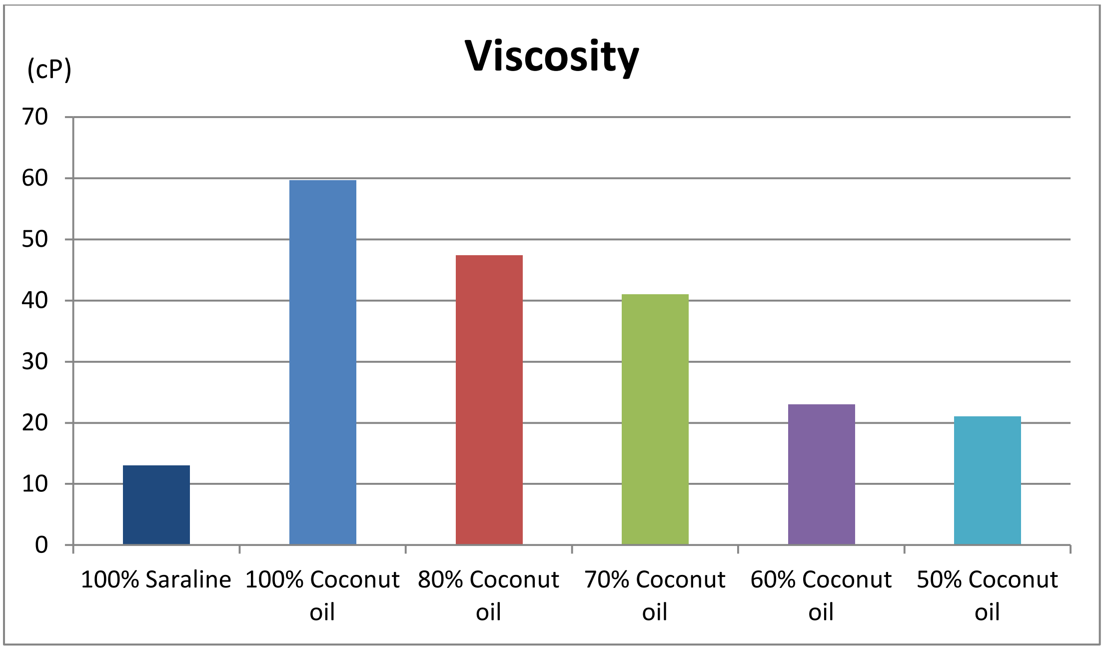

Figure 15: Viscosity of each base oil – After hot rolling

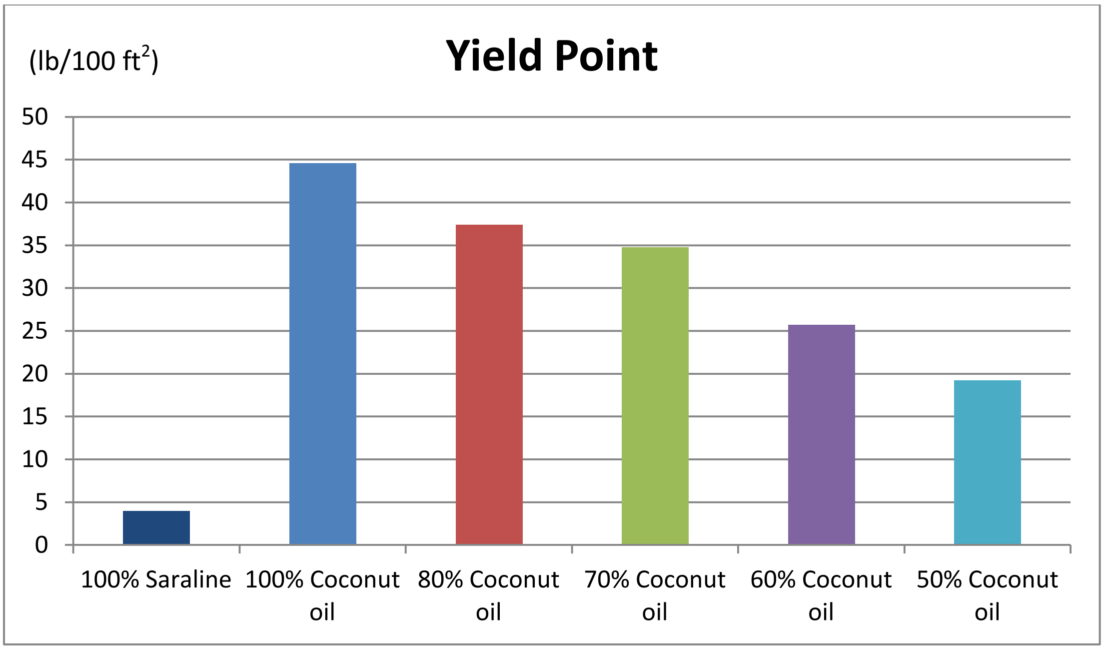

Figure 16: Yield point of each mud – After hot rolling

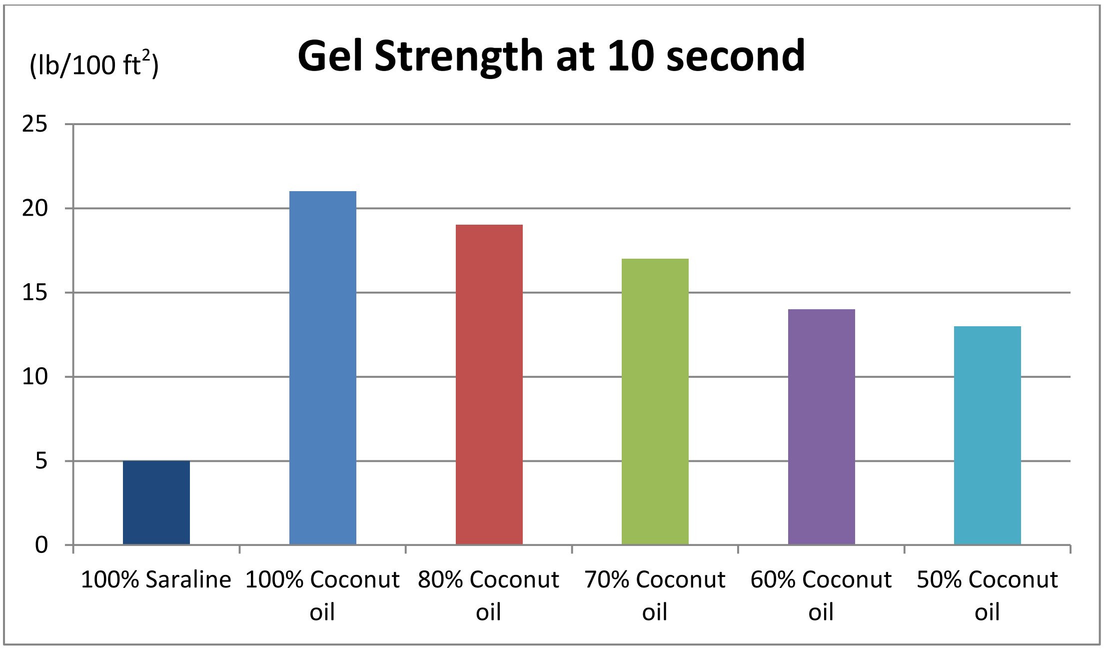

Figure 17: Gel strength at 10 second of each mud – After hot rolling

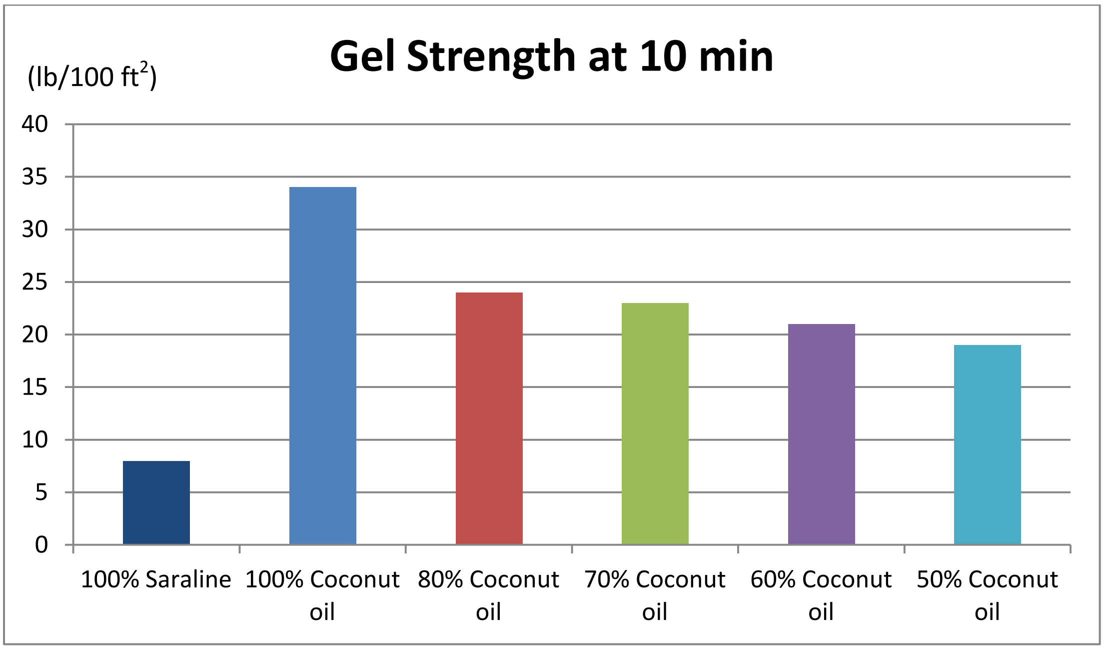

Figure 18: Gel strength at 10 minutes of each mud – After hot rolling

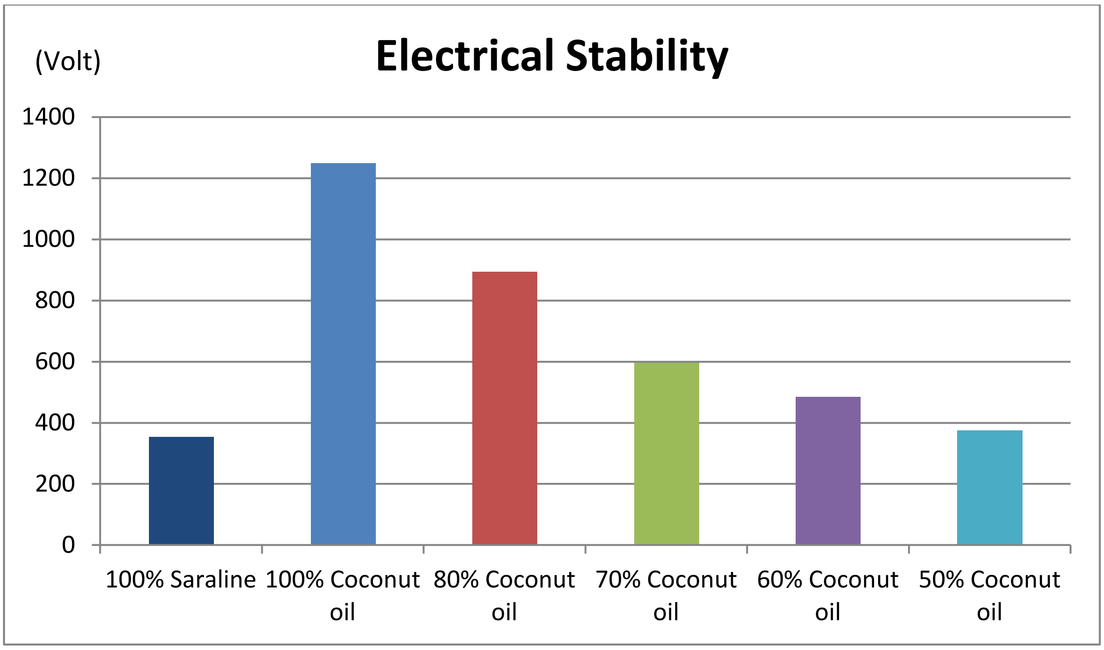

Figure 19: Electrical Stability of each mud – After hot rolling

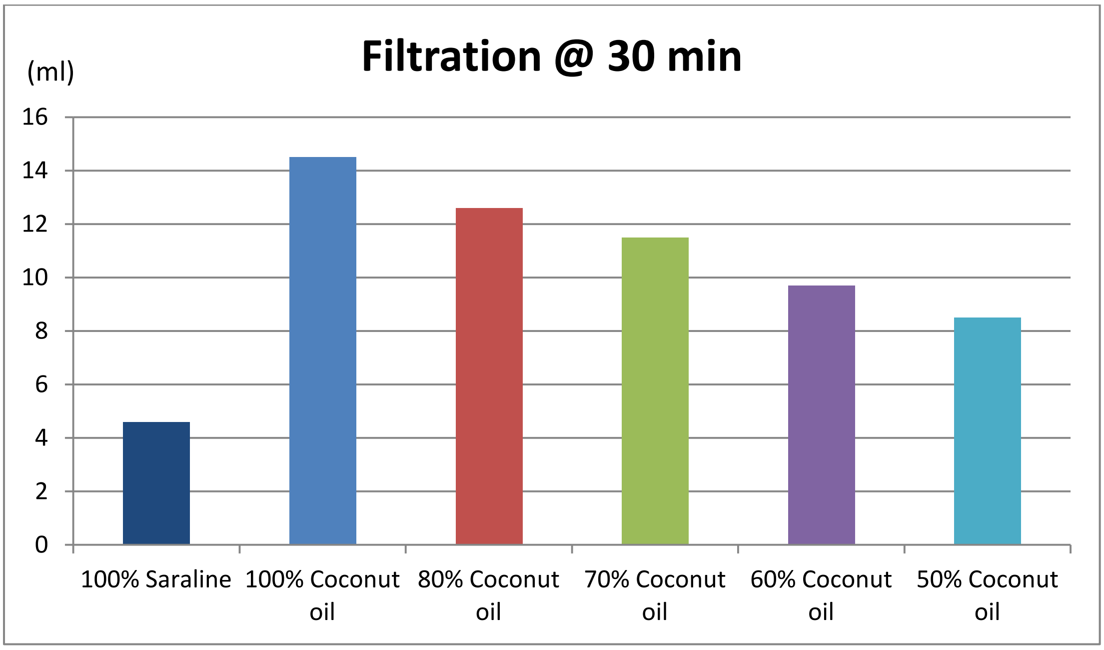

Figure 20: Filtration fluid loss at 30 minutes of each mud – After hot rolling

4.3 Comparison of the Conditions

Final step where comparisons between the properties of before hot rolling and after hot rolling (Fig. 21-22) have been conducted to observe the change, they have no significant change in the difference between the viscosities but they have reverse significant change in yield point.

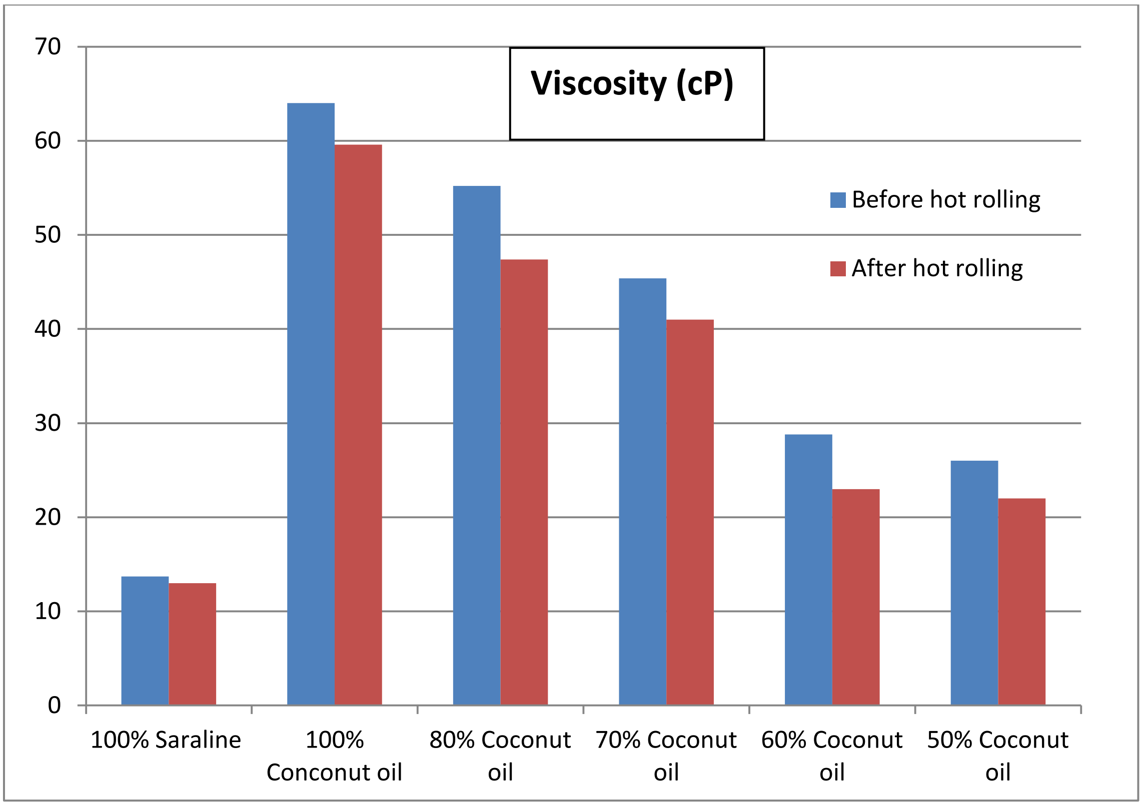

Figure 21: Comparison of Viscosity Before/After hot rolling

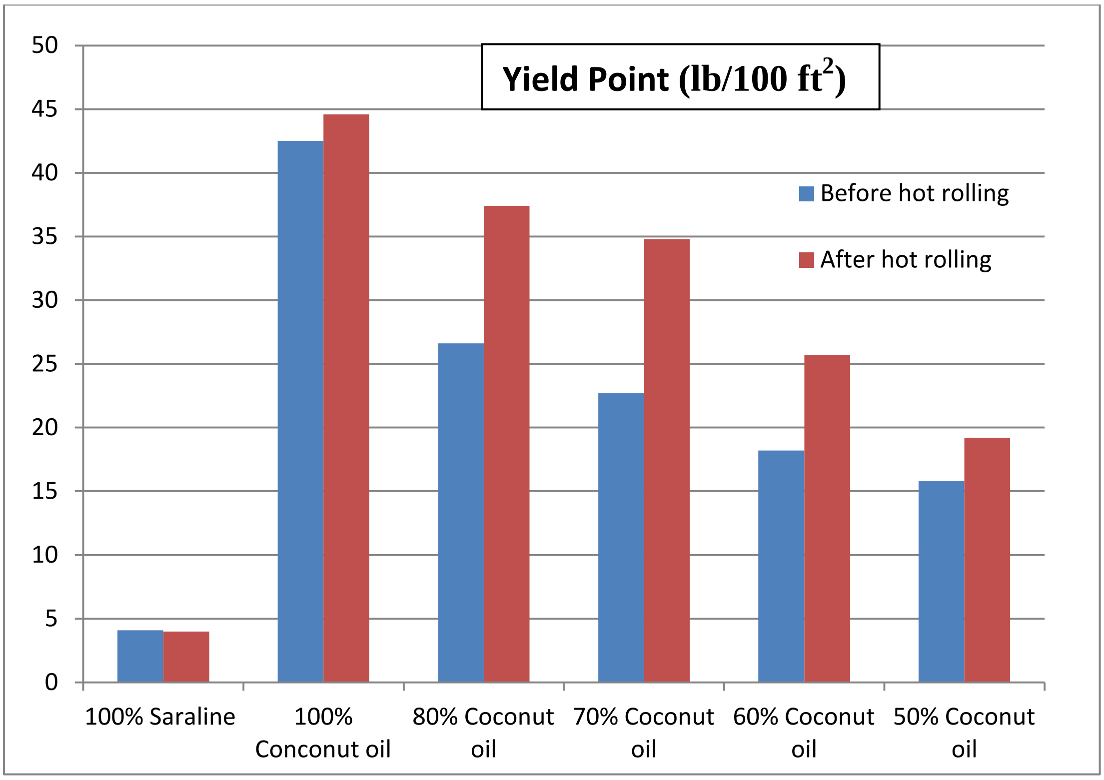

Figure 22: Comparison of Yield Point Before/After Hot Rolling

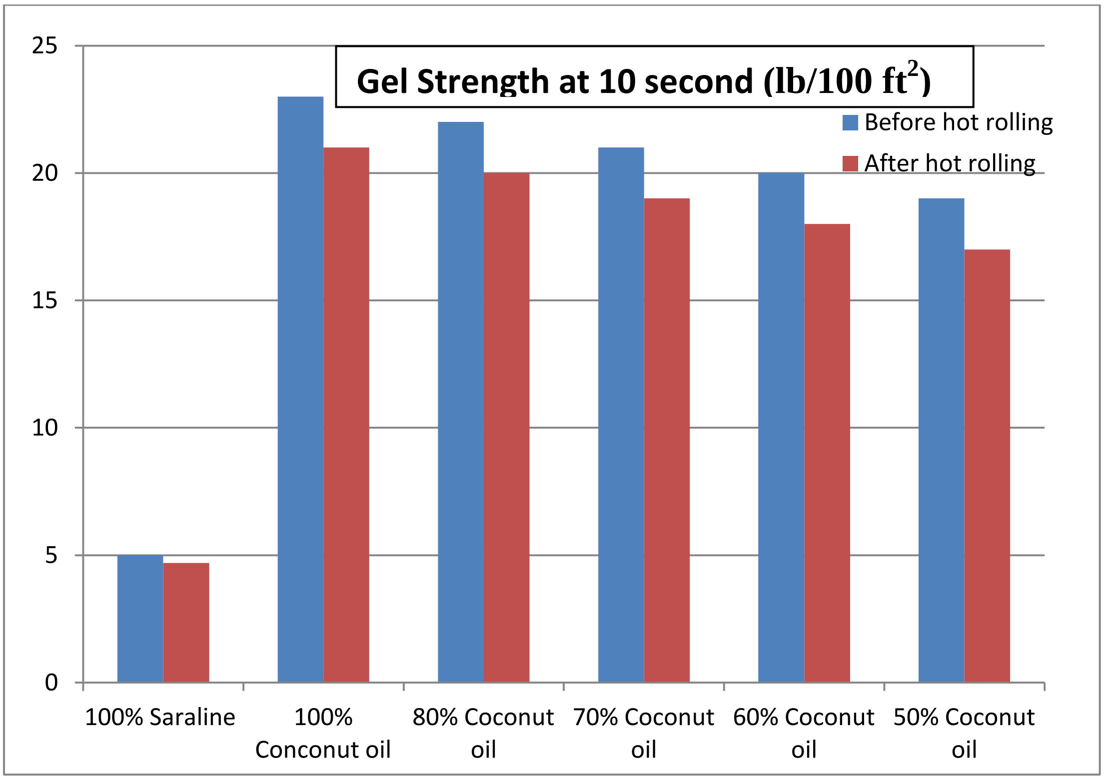

Figure 23: Comparison of Gel Strength at 10 second Before/After hot rolling

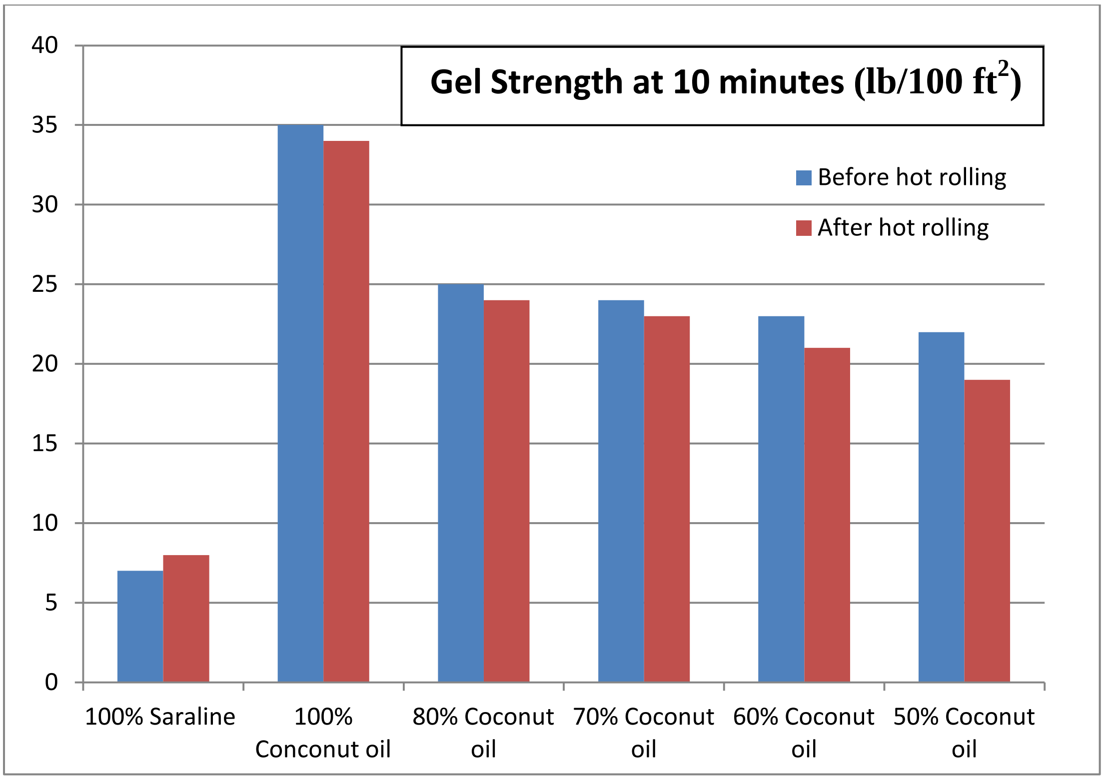

Figure 24: Comparison of Gel Strength at 10 minutes Before/After hot rolling

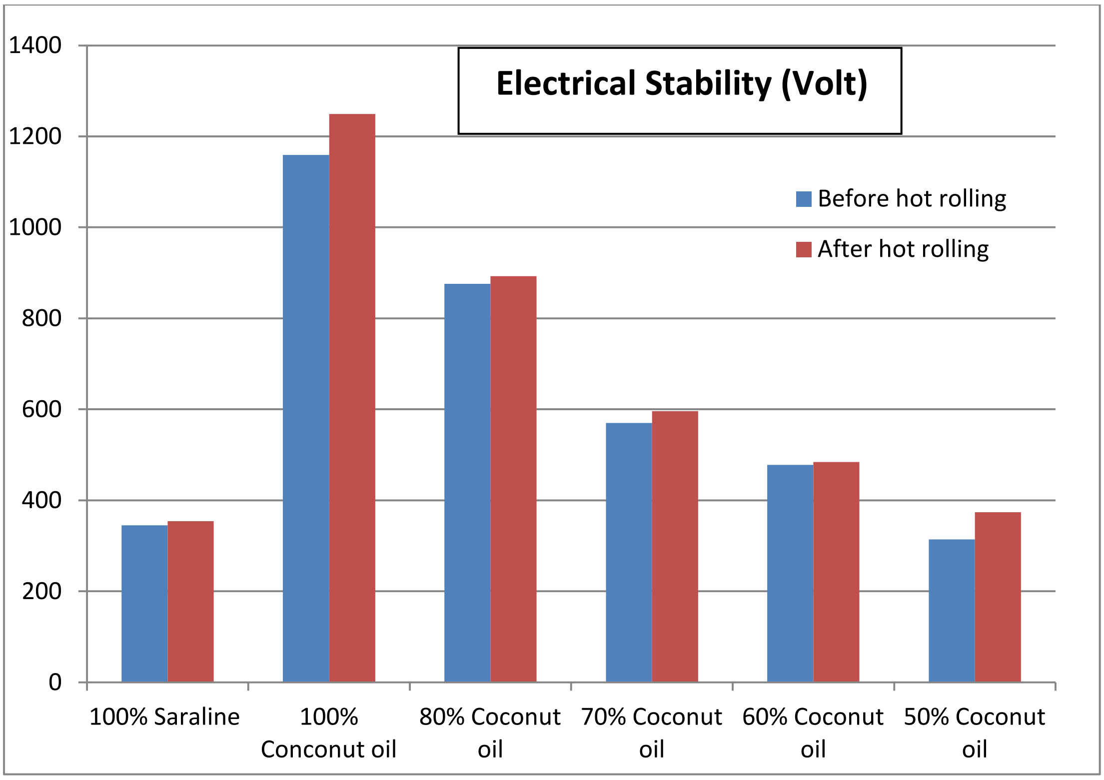

Figure 25: Comparison of Electrical Stability before/after hot rolling

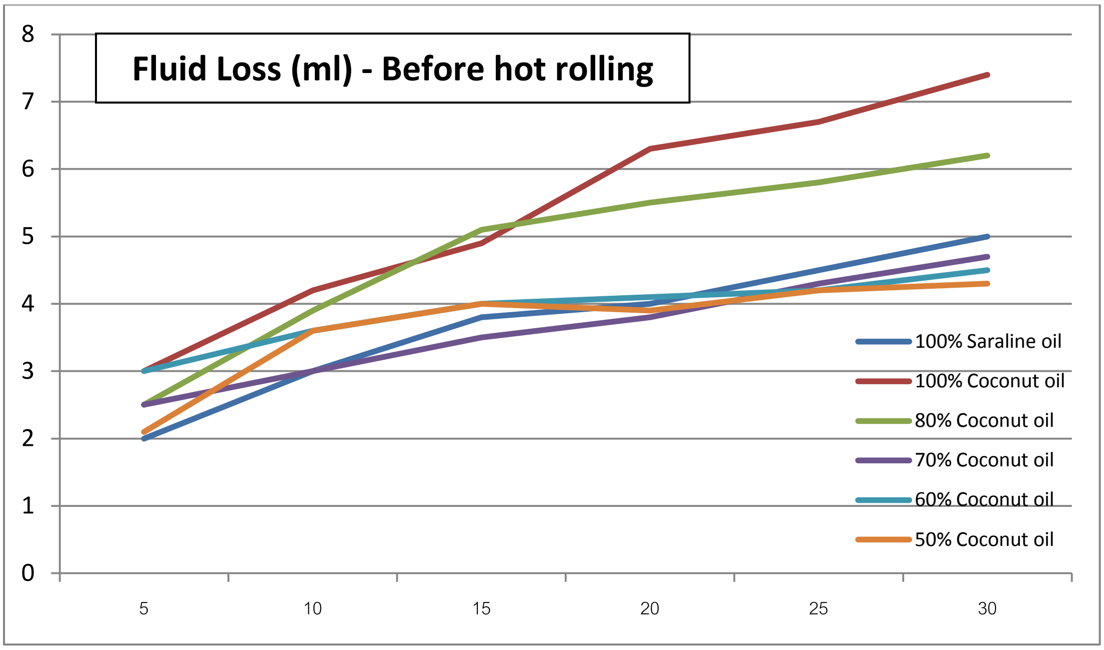

Figure 26: Filtration fluid loss of each mud – Before hot rolling

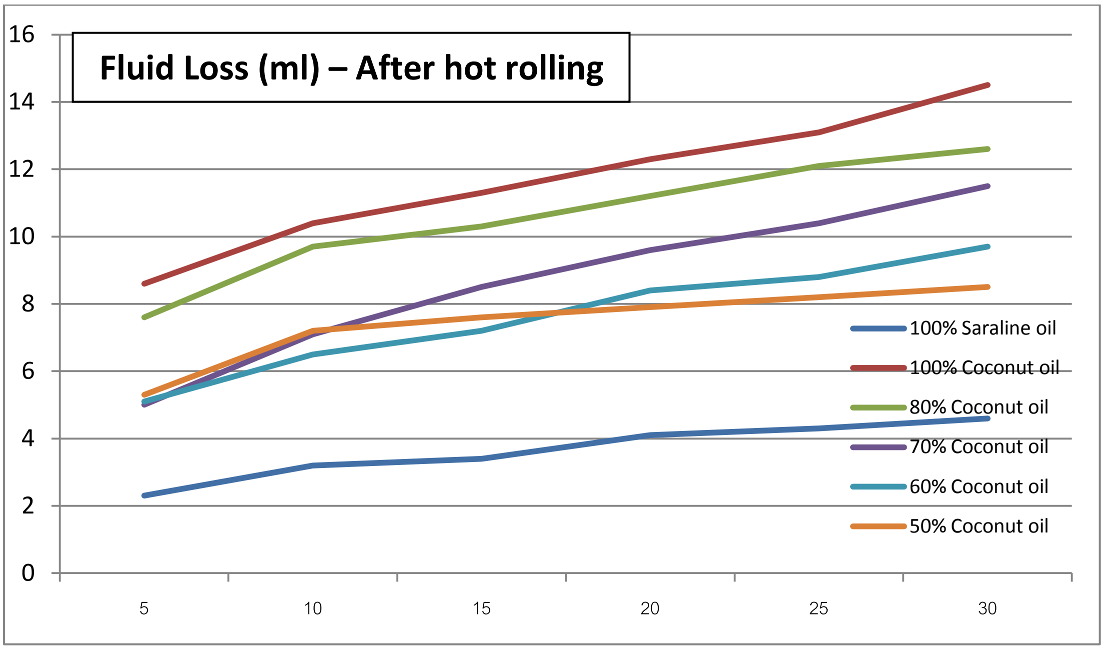

Figure 27: Filtration fluid loss of each mud – After hot rolling

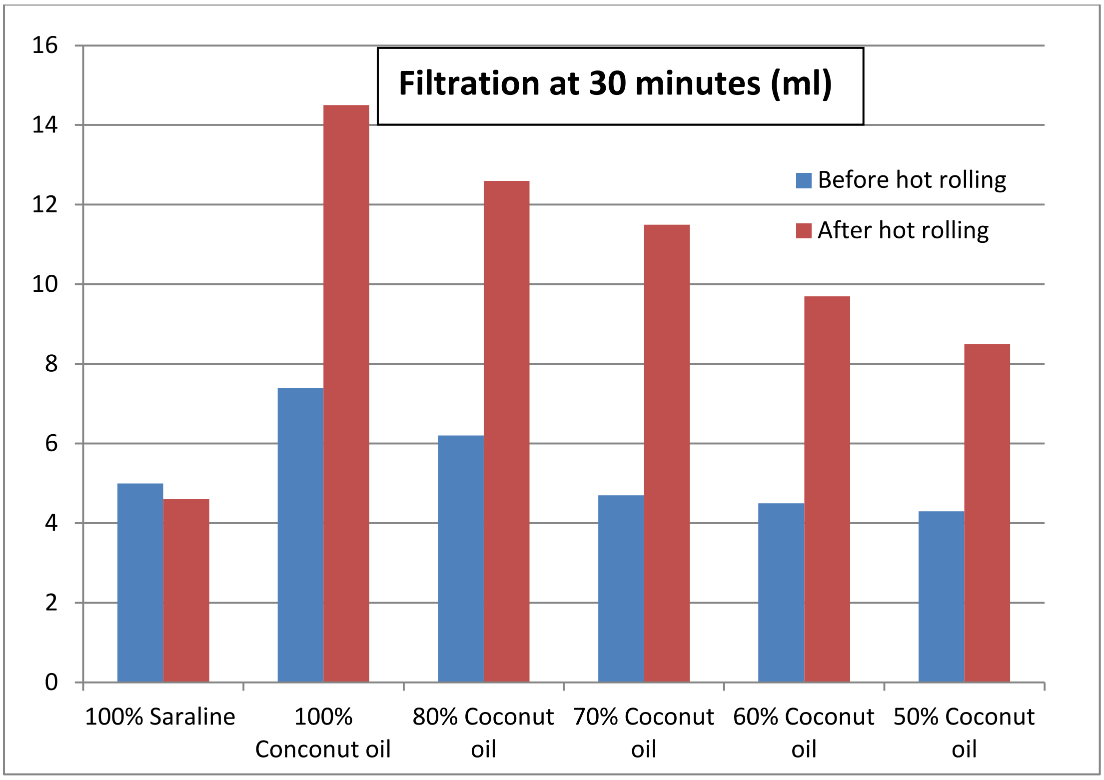

Figure 28: Filtration fluid loss at 30 minutes Before/After hot rolling

Comparing Figure 25 - 28 show that there is an even higher viscosity in Coconut oil, but decreasingly due to the dilution, but the result shows yield point in the opposite direction, where a dilute coconut oil, a wide range of differences. Although, the value of gel strength obtained appear to be just a little difference. Furthermore, high exterior fluid loss is still observed. Table12 shows the filtration after hot rolling which the significant in fluid loss can be observed.

Owing to both conditions indicate a high volume filtration and thick mud filter cake, the addition of fluid loss control agent in the system was needed to achieve the same desired HPHT fluid loss value.

The result of electrical stability and filtration, Saraline oil-based mud showed only slightly different, although coconut oil-based mud, clearly showing the different means that because of their chemical compounds in the coconut oil itself suffered after exposure to heat. However, further studies are necessary to carry out this consequence.

CHAPTER 5

CONCLUSION & RECOMMENDATION

From both before / after hot rolling experimental results, coconut oil was found to have acceptable properties of base oils, even though not gain much ideal base fluids for use in drilling operations. Moreover, it shows some promise for use as oil -base drilling fluid, the more promising the quality ignition, non-toxic and good emulsion stability. However, coconut oil exhibits some undesirable properties that need further investigation, including high viscosity and high pour point. Therefore, further recommendations are followings;

1. To conduct research on the chemical bond of coconut oil in more detail to specify the most suitable additive.
2. Conducting the experiment with full function of standard test equipments & control 100% pure refined oil.
3. Seek for the better dilute agent and proper process for viscosity reduction.

However, within environmental concerns, the main advantage of coconut oil which generally is considered non-toxic and no aromatic content, and widely used in the food industry. Its flash point is higher than mineral oil. This value would reduce the possibility of setting up permanent extreme fire and will reduce the risk of oil vapor in the mud-processing area, thus providing a safer situation for the rig workers. In any case, the impact on the environment in coconut oil is needed to investigate in more detail.

In conclusion, from the overall results, it is possible to use coconut oil as oil-based with proper consideration of adding specific additive or changing the composition of material in mud formula. In this stage of experiment conclude that coconut oil is still not suitable to be oil-based for drilling fluid in drilling operation.

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APPENDICES

Appendix 1: Recommended Practice on the Rheology and Hydraulics of Oil-well Drilling Fluids.

1.1 Scope

1.1.1 The objective of this Recommended Practice (RP) is to provide a basic understanding of and guidance about drilling fluid rheology and hydraulics, and their application to drilling operations. The methods for the calculations used herein do not take into account the effects of temperature and compressibility on the density of the drilling fluid.

1.1.2 Rheology is the study of the deformation and flow of matter. Drilling fluid hydraulics pertains to both laminar and turbulent flow regimes.

1.1.3 For this RP, rheology is the study of the flow characteristics of a drilling fluid and how these characteristics affect movement of the fluid. Specific measurements are made on a fluid to determine rheological parameters of a fluid under a variety of conditions. From this information the circulating system can be designed or evaluated regarding how it will accomplish certain desired objectives. Drilling fluid rheology is important in the following determinations:

1. Calculating friction loss in pipe or annulus.
2. Determining the equivalent circulating density of the drilling fluid.
3. Determining the flow regime in the annulus.
4. Estimating hole cleaning efficiency.
5. Evaluating fluid suspension capacity.
6. Determining the settling velocity of drill cuttings in vertical holes.

1.1.4 The discussion of rheology in this RP is limited to single-phase liquid flow. Some commonly used concepts pertinent to rheology and flow are presented. Mathematical models relating shear stress to shear rate and formulas for estimating pressure drops, equivalent circulating densities and settling velocities of drill cuttings are included.

1.1.5 Conversion factors and examples are included for all calculations so that U.S. Customary units can be readily converted to metric (SI) units.

1.1.6 Where units are not specified, as in the development of equations, any consistent system of units may be used.

1.1.7 The concepts of viscosity, shear stress, and shear rate are very important in understanding the flow characteristics of a fluid. The measurement of these properties allows a mathematical description of circulating fluid flow. The rheological properties of a drilling fluid directly affect its flow characteristics and all hydraulic calculations. They must be controlled for the fluid to perform its various functions.

2. Basic Concepts

2.1 Flow Regimes

2.1.1 The behavior of a fluid is determined by the flow regime, which in turn has a direct effect on the ability of that fluid to perform its basic functions. The flow can be either laminar or turbulent, depending on the fluid velocity, size and shape of the flow channel, fluid density, and viscosity. Between laminar and turbulent flow, the fluid will pass through a transition region where the movement of the fluid has both laminar and turbulent characteristics. It is important to know which of the flow regimes is present in a particular situation to evaluate the performance of a fluid.

2.1.2 In laminar flow, the fluid moves parallel to the walls of the flow channel in smooth lines. Flow tends to be laminar when moving slowly or when the fluid is viscous. In laminar flow, the pressure required to move the fluid increases with increases in the velocity and viscosity.

2.1.3 In turbulent flow, the fluid is swirling and eddying as it moves along the flow channel, even though the bulk of the fluid moves forward. These velocity fluctuations arise spontaneously. Wall roughness or changes in flow direction will increase the amount of turbulence. Flow tends to be turbulent with higher velocities or when the fluid has low viscosity. In turbulent flow, the pressure required to move the fluid increases linearly with density and approximately with the square of the velocity. This means more pump pressure is required to move a fluid in turbulent flow than in laminar flow.

2.1.4 The transition between laminar and turbulent flow is controlled by the relative importance of viscous forces and inertial forces in the flow. In laminar flow, the viscous forces dominate, while in turbulent flow the inertial forces are more important. For Newtonian fluids, viscous forces vary linearly with the flow rate, while the inertial forces vary as the square of the flow rate.

2.1.5 The ratio of inertial forces to viscous forces is the Reynolds number. If consistent units are chosen, this ratio will be dimensionless and the Reynolds number (Re) will be:

$$Re = DV\rho / \mu$$

Where
D= diameter of the flow channel,
V=average flow velocity,
ρ = fluid density,
μ= viscosity.

2.1.6 The flow of any particular liquid in any particular flow channel can be laminar, transitional, or turbulent. The transition occurs at a critical velocity. For typical drilling fluids, it normally occurs over a range of velocities corresponding to Reynolds number between 2000 and 4000.

3. Equipment for Measurement of Rheological Properties

3.1 Orifice Viscometer-Marsh Funnel

3.1.1 Description

The Marsh funnel is widely used as a field measuring instrument. The measurement is referred to as the funnel viscosity and is a timed rate of flow, usually recorded in seconds per quart. The instrument is dimensioned so that by following standard procedures the outflow time of one quart of fresh water is 26 sec. ± 0.5 sec. at 70°F ± 5°F (21°C ± 2°C).

3.1.2 Uses

Funnel viscosity is a rapid, simple test that can be made routinely on a particular drilling fluid system. It is, however, a one-point measurement and, therefore, does not give any information as to why the viscosity may be high or low. No single funnel viscosity measurement can be taken to represent a consistent value for all drilling fluids of the same type or of the same density.

3.1.3 Operating Procedure

Refer to API RP 13B-1 Recommended Practice Standard Procedure for Field Testing Water-based Drilling Fluids, or RP 13B-2 Recommended Practice Standard Procedure for Field Testing Oil-based Drilling Fluids, Sections entitled "Marsh Funnel."

3.2 Concentric Cylinder Viscometer

3.2.1 Low-temperature, Non-pressurized instruments

3.2.1.1 Description

Concentric cylinder viscometers are rotational instruments powered by an electric motor or a hand crank. Fluid is contained in the annular space between two cylinders. The outer sleeve or rotor sleeve is driven at a constant rotational velocity. The rotation of the rotor sleeve in the fluid produces a torque on the inner cylinder or bob. A torsion spring restrains the movement. In most cases, a dial attached to the bob indicates displacement of the bob. Instrument constants have been so adjusted that plastic viscosity and yield point are obtained by readings from rotor sleeve speeds of 300 and 600 rpm. Instruments are also available that are not direct indicating but use x-y recorders to record the acquired data.

3.2.1.2 Selection of Instruments

Several models of low temperature, non-pressurized concentric cylinder viscometers are commonly used in testing drilling fluids. They differ in drive, available speeds, methods of readouts and measuring angles. All permit rapid calculation of plastic viscosity and yield point from readings at 300rpm and 600 rpm. their operating limits. Illustrations of instruments are found in Figures 24.

Figure 29: Model 280

3.2.1.3 Operating Procedures

Operating procedures for several models of concentric cylinder viscometers are detailed in API RP 13B-1 or API RP13B-2. Specific operating procedures for those instruments not included in API RP 13B-1 or API RP 13B-2 can be obtained from the manufacturer.

3.2.2 High-temperature, Pressurized Instruments

3.2.2.1 Description

Several instruments are used to measure flow properties of drilling fluids at elevated temperatures and pressures. Each instrument has differences in temperature and pressure limitations, and design variation.

1. Model 50SL Viscometer: This instrument is designed in the same fashion as the non pressurized viscometers. The upper operating limits are1000 psig and 500°F. Fluid is contained in the annular space between two cylinders with the outer sleeve being driven at a controlled rotational velocity. Torque is exerted on the inner cylinder or bob by the rotation of the outer sleeve in the fluid. This torque is then measured to determine flow properties. This instrument has infinitely variable rotor speeds from 1 rpm – 625 rpm with a viscosity range of 1 – 300,000 cP. The temperature range of 0 – 500°F is programmable. A computer interface provides real-time graphic display and data storage.

2. Model 70 HPHT Viscometer: The high-pressure, high-temperature instrument has upper operating limits of 20,000 psi and 500°F. It is a concentric cylinder viscometer that uses the same geometry as the non-pressurized viscometers. Rotor speeds are variable up to 600 rpm. The rotor has external flights to induce circulation. Temperature, pressure, rpm, and shear stress are obtained through digital readout. The digital temperature control has ramp and soak capacities.

3. Model 75 HPHT Viscometer: The high-pressure, high temperature instrument has upper operating limits of 20,000 psig and 500°F. It is a concentric cylinder viscometer that uses the same geometry as the non-pressurized viscometers. Rotor speeds are variable up to 600 rpm. The rotor has external flutes to induce circulation. Temperature, pressure, rotary speed, and shear stress are microprocessor controlled and digitally displayed. Interface to a computer allows for additional programming and manipulation of data.

4. RV20/D100: This instrument is a high-temperature, pressurized rotational viscometer with upper operating limits of 1400 psi and 572°F. It consists of concentric cylinders mounted in an autoclave. The outer cylinder is bolted to the autoclave top and supports the inner cylinder on a ball bearing. The inner cylinder (or rotor) is connected by a magnetic coupling to a Rotovisco RV20. Computer control is available for automatically plotting flow curves. The instrument is continuously variable between 0 and 1200 sec.-1 and provides automatic data analyses. The torque imparted on the rotor is measured by an electrical torsion bar, which provides rapid response. The angular movement of the torsion bar is a measurement of the transmitted torque; the shear stress is calculated from the torque value by means of an appropriate shear stress constant. A high-pressure, high-temperature version of this instrument is also available with upper operating limits of 14,000 psi and 662°F. (No photograph of this HPHT equipment is available.)

5. Model 7400: This instrument is a high-pressure, high-temperature, coaxial cylinder, coquette-type Rheometer. Testing limits are 20,000 psi and 400°F. Torque range is 0 – 540,000 dyne/cm, measured by a precision strain gauge sensor. There are twelve evenly-spaced preset rotor speeds as well as infinitely variable from 0 – 600 rpm. Temperature is microprocessor controlled. The unit is provided with a data acquisition system that displays temperature, pressure, torque, and rotor speed in real time on a computer monitor. The test fluid is continually circulated in the

sample container by the rotor design. The test fluid is separated from the pressurizing medium by a flexible piston to prevent contamination.

6. Model 1000 HPHT Viscometer: This instrument (shown in Figure 15) incorporates high-pressure up to 1000 psi and high temperatures up to 500°F. An optional chiller can be used for testing to 32°F. Low shear rates as low as 0.01 sec.-1 are possible. The instrument uses traditional bobs and rotor for measurements with shear stress ranges from 0 – 4000 dyne/cm2. The instrument is computer controlled using the ORCADA software system. Data is stored in an ASCII text format or in a Microsoft Excel file.

Figure 31: Model 70

Figure 30: Model 50SL

Figure 32: Model 75

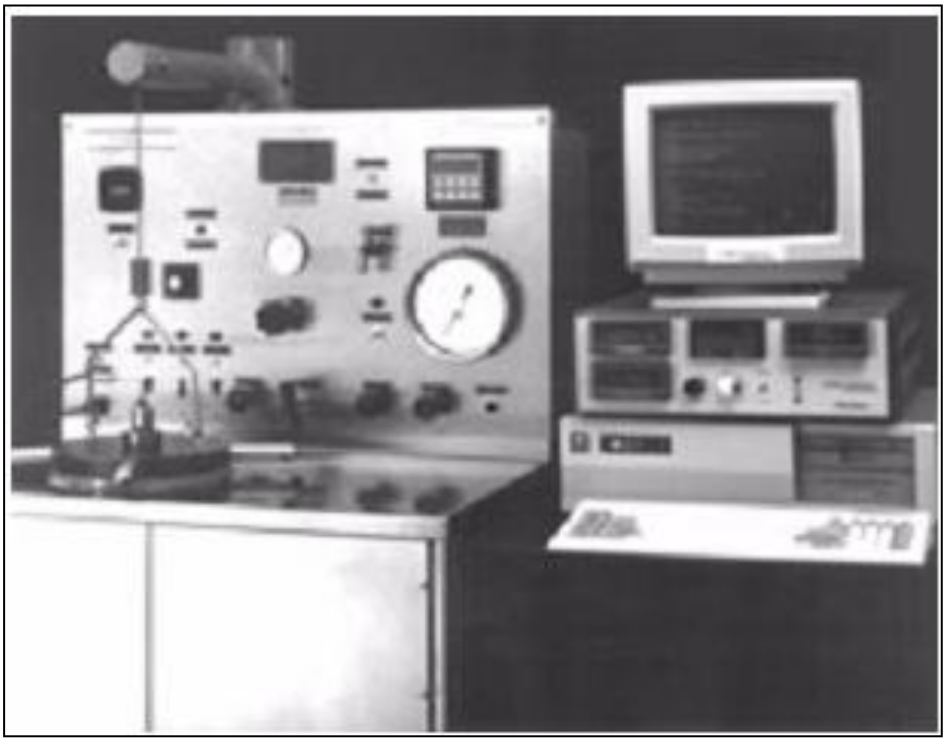

Figure 33: Model 7400

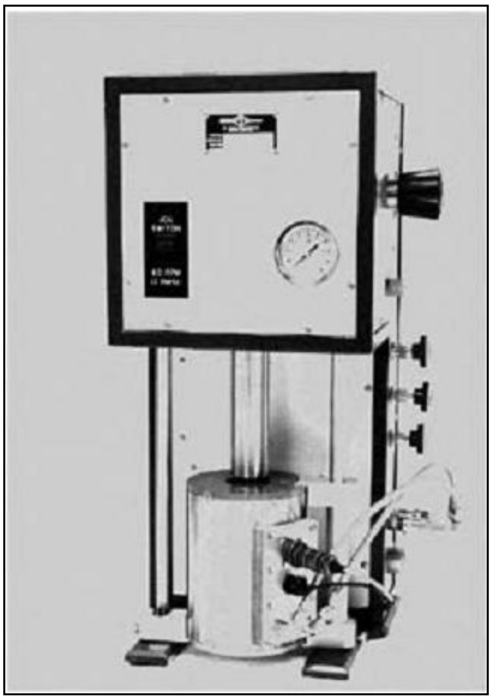

Figure 34: RV 20/D100 **Figure 35: 1000 HPHT Viscometer**