Performance Comparison and Optimization of PFAD based Drilling Fluid

by

Tharmaraj Magathevan

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Petroleum Engineering)

MAY 2013

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

Petroleum Engineering Programme

Universiti Teknologi PETRONAS

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(PETROLEUM ENGINEERING)

Approved by,

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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.

(THARMARAJ MAGATHEVAN)

ACKNOWLEDGMENTS

First and foremost, I would like to express my utmost gratitude to AP Dr. Suzana bt Yusup, my Final Year Project Supervisor for her constant guidance and help in aiding my completion of this project. This Final Year Project course has really brought me to a phase where I have grown up to being more full-fledged, self-governing and decisive. Irrefutably this cumulative 28 week course has also brought about positive changes in my attitude and this has helped me a lot in developing myself and always being prepared for any challenge that may come in a little while.

Moreover, , I must say a big thank you to Mr Erwin Ariyanto, Technical Laboratory Manager of Scomi Oiltools GRTC for allowing me to use the laboratory facilities and guiding me for the completion of the project's second phase. I would also like to thank everyone that I have seek help in Scomi Oiltools GRTC lab during my brief time there.

Next I would like to thank Mr Junaid and Mr. Awais Ali for their aid in preparing the biodiesel samples and blending of those samples. They really helped me a lot in guiding and providing scholastic articles of my topic.

Thanks to this opportunity, now I have a deep understanding of how the biodiesel and drilling fluid functions and this is really great for me as I plan to venture in this industry in the future. Lastly, I would like to thank UTP Petroleum Engineering department for coordinating and aiding the evaluation milestones of this course and the continuous support.

ABSTRACT

At present, there exist a shift towards the development of sustainable drilling fluids. Researches in this field have been conducted using non-toxic, edible vegetable grade oils, and plant seed oil as the continuous fluid phase in the development of non-toxic, sustainable and biodegradable oil-based mud systems. This paper addresses the suitability and the usage of palm fatty acid distillate as the continuous phase for the development of bio-based drilling fluid with subsequent comparison of formulation performances and further optimizations. The project is done with the purpose of preparation and characterization of biodiesel to be suitable as continuous phase for drilling fluid based on physical properties comparison with conventional oil. Apart from that, a bio-based drilling fluid formulation is required which is compatible with the required specification, tested with various drilling fluid tests and evaluated based on its plastic viscosity, yield point, low end rheology, gel strength, ES reading, HTHP fluid loss and free water . With reference with the limited time span of the project, the project scope for the first phase is limited to the testing of physical properties for suitability of biodiesel as base fluid and the second phase is a mud formulation of 12.0 ppg density and testing of mud samples at 275F. The project was conducted by mixing 11 different mud formulations with varying lime and primary emulsifier concentrations from to obtain the required data by conducting rheology, Emulsion stability, HTHP filter press and retort test. The most suitable 3 was analyzed and its performance were compared and assessed based on the specification of the data criteria such as plastic viscosity, yield point, low end rheology, ES reading. gel strength, HTHP fluid loss and free water. Based on the findings, mud formulation 1 - PFAD sample with 0 conc. lime and 0 ppb. CONFI-MUL P (primary emulsifier), 2 - PFAD sample with 0 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier) and 3 - PFAD sample with 1 conc. lime and 1 ppb CONFI-MUL P(primary emulsifier must be further optimized to satisfy all the data criteria requirements in terms of reducing the viscosifier concentration or increasing the fluid loss agent concentration and even both. Although mud sample 3 satisfies most of the data analysis, it still cannot be deduced as the best formulation until further optimization are carried out.

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1.0 INTRODUCTION

1.1 Background

Drilling fluid is used to aid the drilling of boreholes into the earth. Often used while drilling oil and natural gas wells and on exploration drilling rigs, drilling fluids are also used for much simpler boreholes, such as water wells. Liquid drilling fluid is often called drilling mud. The three main categories of drilling fluids are water-based mud(which can be dispersed and non-dispersed), non-aqueous mud, usually called oil-based mud, and gaseous drilling fluid, in which a wide range of gases can be used.

Oil-based mud (OBM) can be a mud where the base fluid is a petroleum product such as diesel fuel. Oil-based mud are used for many reasons, some being increased lubricity, enhanced shale inhibition, and greater cleaning abilities with less viscosity. Oil-based mud also withstand greater heat without breaking down. The use of oil-based mud has special considerations. These include cost and environmental considerations. Synthetic-based fluid (SBM) (Otherwise known as Low Toxicity Oil Based Mud or LTOBM is a mud where the base fluid is a synthetic oil. This is most often used on offshore rigs because it has the properties of an oil-based mud, but the toxicity of the fluid fumes are much less than an oil-based fluid.

In the past, the usage of oil especially diesel oil as the continuous phase of oil-based drilling mud was widespread when drilling through sensitive producing formations and troublesome shale zones. However due to the adverse environmental effects caused by oil usage, extensive legislation exists in regulating the oil pollution. Subsequently, various types of LTOBM were introduced as alternative to replace the more toxic mineral oils or diesel oil-based drilling mud. (Abdullah, 2012) At present, the use of bio oil can be considered as an suitable alternative base fluid that poses no harm to the environment. The bio oil is synthesized by interesterification and have the potential of replacing mineral diesel as it is environmental friendly, good safety performance and renewable. (Wang, Sun, Shang, Fan, Liu, & Liu, 2012)

The vital factor that affects the performance of a non-aqueous fluid drilling mud is the emulsion which is defined as the mixture of two immiscible liquids in which one liquid exists in the form of small droplets dispersed throughout the other liquid. In order for this two liquid to coexist as an emulsion, emulsifiers are needed to be added into the drilling fluid. The role of the emulsifier is to stabilize a physical emulsion once it is formed. Therefore, the emulsifier's performance will directly affect the performance of the drilling fluid. Apart from that, the lime concentration in the drilling fluid is also significantly important as lime, calcium hydroxide, $Ca(OH)_2$ is used as a source of calcium and alkalinity in both water- and oil-based drilling fluids. Lime is used to increase pH, to provide excess lime as an alkalinity buffer, to flocculate bentonite slurries (spud mud) for improved hole cleaning, for removing soluble carbonate ions, for controlling corrosion; and for activating fatty-acid, oil-based drilling fluids additives. Emulsifier and lime work hand in hand as lime is needed to activate the fatty acids in the emulsifier which will react to ensure a proper water in oil emulsion is achieved. The project comprises of two main parts, first part is the development of the biodiesel to ensure its suitability and eligibility in being used as the continuous phase of drilling fluids The latter part consists of the selection and optimization of suitable formulation of the bio-diesel based drilling mud in order to ensure it meets all required specifications and be on par with conventional drilling fluid in terms of performance.

1.2 Problem Statement and Significance of Project

The problem statement for the project is also divided into two parts which are firstly bio-based drilling fluids have the potential to be an effective alternative replacing conventional oil-based drilling fluid as it possesses all the advantages of OBM and none of the drawbacks. Therefore, the biodiesel is tested beforehand for its eligibility and suitability to be utilized as the continuous phase of a drilling fluid. The latter part is the further selection and optimization of suitable formulation of the bio-based drilling fluid which in hand can is required to meet all required specifications.

As per the problem's first part, the development of a bio-based drilling fluid as an alternative for the conventional diesel-based drilling fluid addresses the need of creating an sustainable drilling fluid. (Apaleke, Al-Majed, & Hossain, 2012) The advantages of oil-based drilling fluid system including excellent lubrication performance, shale expansion inhibition, good borehole stability and high temperature resistance. On the other hand, the drawbacks of environmental pollution, easily inflammable and higher preparation cost poses a limit to the use of oil-based drilling fluids. However, these problems can be solved when bio oil is used to replace crude oil or mineral diesel in oil-based drilling fluids. Bio-based drilling fluid not only exceeds the performances of conventional oil-based drilling fluids but also show excellent environmental compatibility such as environmental friendly, good safety performance and renewable which meet the requirements of the strategy of sustainable development. (Wang, Sun, Shang, Fan, Liu, & Liu, 2012).

The second part of the problem that can be identified is the emulsifier which is basically divided into primary and secondary will help in maintaining a stable emulsion and oil wetting the drill cuttings and other solids in the drilling fluid to avoid fluid loss. However, many emulsifiers tend to be weak or not strong enough to maintain a stable water in oil emulsion during static or dynamic conditions. This will be problematic as when the emulsifier fails, the oil and water emulsion in the drilling fluid will separate due to differing densities and cause formation damage. Therefore this product must be examined closely and thoroughly before utilizing it massively in the drilling of oil wells. There lie a serious problem with emulsifier and the performance of the biodiesel drilling mud as the proposed bio fuel must be compatible with the emulsifier and the effect of lime is very temperamental in the biodiesel drilling mud as biodiesel has fatty acid naturally within it unlike conventional mineral oil. Typically, lime or calcium hydroxide, $Ca(OH)_2$ is introduced as they are considered as one of the essential component in oil based drilling fluids. The lime is used to neutralize the fatty acids in the fluid, activate the emulsifiers or fatty acids, stabilizes the emulsion when present in excess, and controls alkalinity. In the field, it also neutralizes acid gases such as (H2S and/or CO_2). The bio fuel or biodiesels usually contains a significant amount of fatty acids in them naturally. Thus, the reaction of lime with different concentrations would have different impact on the drilling fluid. Thus, in general the second phases of this project focuses on the performance of biodiesel drilling fluid with varying lime and emulsifier concentrations to conduct comparative study for further optimization.

The project is very significant as it will help address the three main factors that help justify the purpose of pursuing the project. The factors are in terms of cost, time and effort. In terms of cost, a suitable formulation of bio-based drilling fluid will save in cost as the green drilling fluid is biodegradable and environmentally friendly which makes easy disposal of the used drilling fluid. For example, the bio-based drilling fluid can be channeled out to the sea in offshore drilling as it is biodegradable. Time also plays an important factor. If the bio-based drilling fluid formulation is stable, it would be able to withstand differing wellbore conditions whilst drilling and reduce the time taken for treating the mud that comes up to the surface after being pumped into the well. Apart from that, this will also greatly reduce the cost of mud treatment and effort required to constantly monitor the mud properties. However in the event of clogged pipeline or mud contamination, there would be a need of specialized mud engineers to address and rectify the problem. Hence, it is significant to choose the suitable emulsifier as it would prevent unnecessary or unforeseen threats in terms of cost, time and effort.

The project will be beneficial for many as it would help address the problems above which pose a serious threat in the environment and formation damage during drilling. Based on the project, the development of bio-based drilling fluid and the study of emulsifiers will help improve and enhance the performance of the drilling fluid that will in hand help in drilling operations.

1.3 Objective and Scope of Study

1.3.1 Objective

The development of bio-based drilling fluid and the study of performance and the optimization of the suitable bio-based drilling fluid formulation to be reviewed off for research and development benefit. The formulation of bio-based drilling fluid must be suitable and meet all required specifications and the emulsion stability of the drilling fluid should be strong as it will determine the overall feasibility of the drilling fluid. There are several objectives to choose this highly prospect project. Project was chosen wisely as the development of a green drilling fluid still in its infant phase and this provides an opportunity explore and reinvent better prospects of drilling fluid function. Main project objective are:-

1. Preparation and characterization of biodiesel to be suitable as continuous phase for drilling fluid.
2. Formulate a bio-based drilling fluid which is compatible with the required specifications and test it with various drilling fluid tests
3. Study and evaluate the effectiveness of formulated bio-based drilling fluid in terms of its low plastic viscosity, low yield point, low end rheology, gel strength, ES reading, low HTHP fluid loss and zero free water
4. Compare the results from bio-based drilling fluid with results obtained to assess its performance.

1.3.2 Scope of Study

The project focuses on the development and the optimization of bio-based drilling fluid. However, this general purpose is too wide of a scope to investigate as there are too many variables to be accounted for and the duration and expertise in conducting this research is limited. The scope of the project's first phase was designed to test the suitability of the biodiesel to be used as continuous phase of the drilling fluid by measuring its kinematic viscosity, pour point, flash point, cloud point, density, acid value and specific gravity.

The second phase assesses the performance of the bio-based drilling fluid formulations and compares it with each other for further optimization.

In terms of the base oil, bio oil is used from Palm Fatty Acid Distillate (PFAD). The density of the drilling fluid is set to be 12.0ppg and the temperature of experimentation was set at 275F. The properties or aspects focused when performing data analysis was based on the low end rheology reading, HTHP fluid loss, Gel strength, Emulsion Stability, Plastic Viscosity and Yield Point.

1. To identify the best formulation of biodiesel-based drilling fluid in terms of low end rheology (6rpm)
2. To investigate biodiesel-based drilling fluid in terms of High Temperature High Pressure fluid loss.
3. To analyze the best formulation of biodiesel-based drilling fluid in terms of Plastic Viscosity and Yield Point.
4. To investigate the strength of formulation in terms of Emulsion Stability reading.
5. To identify the best formulation in terms of gel strength.

1.4 Relevancy of The Project

The relevancy of this project can be construed in three important criterias or level of focus. Firstly, it is my personal interest that drives me to pursue this project as it would set a pathway for my career in future and would expand my horizon in terms of my expertise as it would be more diversed. Apart from that, it is also very relevant with my course of study and enables me to master the key syllabus in addition to providing real time experience to deepen my understanding about this project. In terms of the Petroleum industry as whole, this project mainly comprises of the research and development aspect . It sets the foundation in assessing the strength and performance of the bio-based drilling fluid. The project will determine the most suitable formulation of the Palm Fatty Acid Distillate (PFAD) based drilling fluid and will be taken account as a possible alternative drilling fluid compared to conventional diesel based mud. The study of the capability of Palm Fatty Acid Distillate (PFAD) as an alternative option for drilling fluid can open opportunity for a environmentally friendly drilling operations.

1.5 Feasibility of the project within the Scope and Time Frame

The project's feasibility within the scope is mainly to be set as a guideline for preliminary exclusion of the unsuitable biodiesel and formulations. The time frame of 28 weeks can only provide a guideline whether Palm Fatty Acid Distillate (PFAD) can be used as continuous phase. However, the whole prospect of full mud formulation study is very comprehensive and through and would require a larger time frame to provide a definite alternative bio-based drilling fluid. Since this project is the 1st phase in the study of biodiesel suitability and formulation, the biodiesel compatibility can be identified based on the scope of data analysis. The project will be feasible in terms of assessing the performance of bio-based drilling fluids and recommendations for further optimizing the formulations to be feasible and compared with conventional drilling fluids.

2.0 LITERATURE REVIEW AND THEORY

2.1 Drilling Fluid

In geotechnical engineering, drilling fluid is used to aid the drilling of boreholes into the earth. Often used while drilling oil and natural gas wells and on exploration drilling rigs, drilling fluids are also used for much simpler boreholes, such as water wells. Liquid drilling fluid is often called drilling mud. The three main categories of drilling fluids are water-based mud (which can be dispersed and non-dispersed), non-aqueous mud, usually called oil-based mud, and gaseous drilling fluid, in which a wide range of gases can be used. The main functions of drilling fluids include providing hydrostatic pressure to prevent formation fluids from entering into the well bore, keeping the drill bit cool and clean during drilling, carrying out drill cuttings, and suspending the drill cuttings while drilling is paused and when the drilling assembly is brought in and out of the hole. The drilling fluid used for a particular job is selected to avoid formation damage and to limit corrosion. (Apaleke, Al-Majed, & Hossain, 2012)

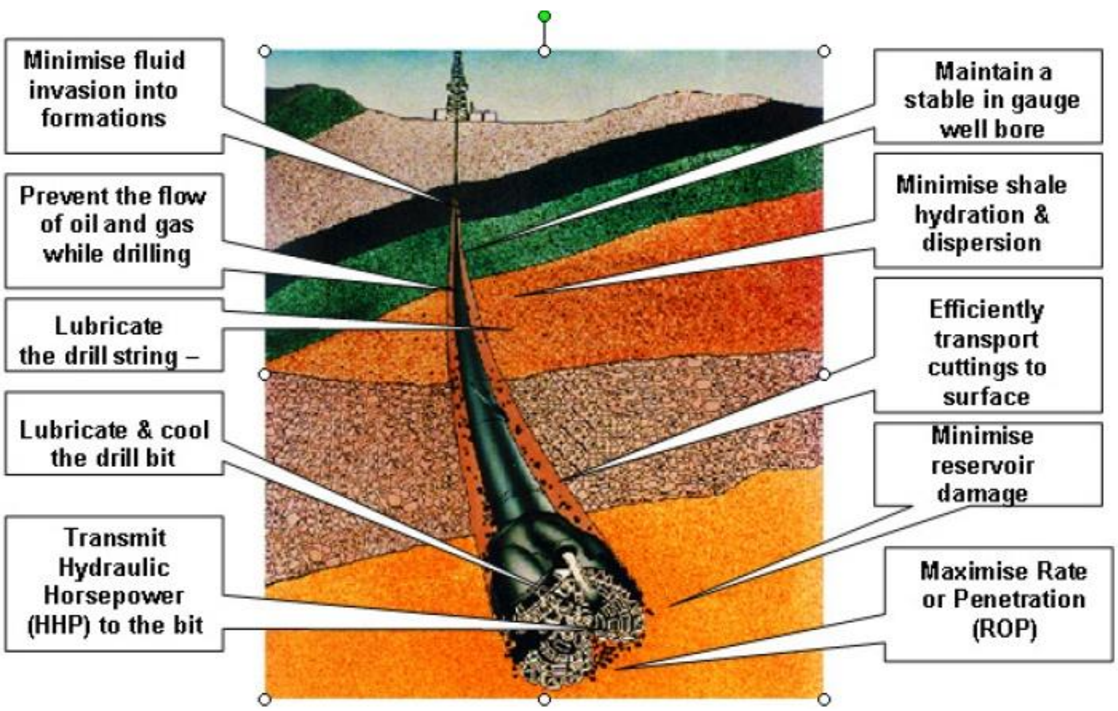


Figure 1: Drilling Fluid Functions

Many types of drilling fluids are used on a day-to-day basis. Some wells require that different types be used at different parts in the hole, or that some types be used in combination with others. In this project, priority will be only given to Oil Based Mud (OBM) and Synthetic Based Mud (SBM). Oil-based mud can be a mud where the base fluid is a petroleum product such as diesel fuel. Oil-based mud are used for many reasons, some being increased lubricity, enhanced shale inhibition, and greater cleaning abilities with less viscosity. Oil-based mud also withstand greater heat without breaking down. The use of oil-based mud has special considerations. These include cost and environmental considerations. Synthetic-based fluid (SBM) (Otherwise known as Low Toxicity Oil Based Mud or LTOBM) is a mud where the base fluid is a synthetic oil. This is most often used on offshore rigs because it has the properties of an oil-based mud, but the toxicity of the fluid fumes are much less than an oil-based fluid. This is important when men work with the fluid in an enclosed space such as an offshore drilling rig.

Synthetic based mud are often regarded as the ultimate drilling fluid due to its base fluid which is oil and its non-polar attributes which hinders the reaction with water sensitive clays and shales. Clay and shale formations remain stable in a SBM environment provided that the salinity of the SBM brine phase is higher than the salinity of the in situ shale pore fluid, to maintain osmotic backflow from the shale to the SBM. This rectifies and avoids shale hydration problem which poses a serious threat in drilling operations.

At present environmental protection plays a vital role worldwide. Thus, there exist a shift towards the development of sustainable drilling fluids. The research area of the development of environmentally green mud system is relatively still new, infant phase. Researches in this field have been conducted using non-toxic, edible vegetable grade oils, and plant seed oil as the continuous fluid phase in the development of non-toxic, sustainable and biodegradable oil-based mud systems. An oil based drilling fluid based on vegetable oil derived from palm oil and ground nut oil was developed which did not only satisfy environmental standards but promoted crop growth when disposed into farm lands (Dosunmu & Ogunrinde, 2010). The use of vegetable oil as an alternative to the use of mineral and diesel oil as the base fluid was proposed in the formulation of high performance drilling fluids for HTHP application. This particular formulation was eco-friendly, inexpensive and vastly available due to large volume of waste vegetable oil generated annually worldwide. (Amanullah & Mohammed, 2010). Another similar research was conducted using canola oil as the continuous phase of the drilling fluid and it was proven to be suitable at room temperature (BHR) and under stimulated down-hole conditions (AHR) too. (Apaleke, Al-Majed, & Hossain, 2012)

2.2 Current Researches

Vegetable oils are undoubtedly becoming a promising alternative to replace diesel fuel due to their renewable nature and environmentally friendly combustion as well. They have little to none sulphur content, offer no storage difficulty and excellent lubrication properties. Due to their abundance of waste vegetable oil generated annually, developing countries can use this to their advantage to solve their ecological problems and hence improve their economy. (Ramadhas, Jayaraj, & Muraleedharan, 2005). Some of the on-going research into finding more suitable crops and improving oil yield especially in replacing the conventional oil based mud are jatropha oil, palm oil, groundnut oil and rubber seed oil which will be discussed extensively as it is the proposed bio-oil utilized in this project.

Jatropha is a plant originated from the family Euphorbiacea. Its native plant was first in Central America and now it is being produced in India, Africa and North America. The advantages of Jatropha is its seeds can contain up to 30-40% of oil content. The seed is crushed for oil extraction to be used as biodiesel and the remaining will be used as biomass for powering electricity. (Jatropha Cultivation, Production, Properties and Uses, 2010). In Nigeria, a study from Covenant University focused on environmental safe drilling mud using this plant seed called jatropha. The oil was extracted from the jatropha seed and added to mud samples to study its stability for drilling operation as well as its toxicity, filtration, pH, viscosity, density and degree of safety to the environment. (Adesina, Anthony , Gbadesign , Eseoghene, & Oyakhire, 2012). Based on the latest research that has been conducted, it has been found out that jatropha oil-based mud (JOBM) has an undesirably high apparent viscosity at ambient temperature caused by the inherently high viscosity of the base fluid-jatropha oil. In addition, temperature and salinity give a negative impact on the rheological properties of oil-based drilling fluids. However, JOBM shows better adaptability under these condition and also exhibit better results for pH and density variation with temperature (Fadairo, Tozunku, Kadiri, & Falode O.A, 2012).

Palm oil and groundnut oil were examined to determine their capabilities in the development of environmentally friendly oil based mud. Tests were conducted between these bio-oils against conventional oil based mud. The comparisons mounted to several conclusions whereby palm oil is very viscous and demonstrates strong progressive gel strength before hot rolling. The oil exhibited thermal degradation after hot rolling for 16 hours which proves the fatty acid components of the oil are broken down. However, palm oil and groundnut oil are proven to have better eco-toxicological properties. Therefore, these preliminary tests indicate that additive chemistry must be employed in the formulation of the vegetable oil-based mud to provide functionality in drilling operations. (Dosunmu P. A., 2010)

2.3 Proposed Bio-oil

Palm Fatty Acid Distillate (PFAD) is a by-product from refining crude palm oil. PFAD is a light brown semi-solid at room temperature melting to a brown liquid on heating. Palm Fatty Acid Distillate (PFAD) comprise mainly of free fatty acid (FFA) (>80%) with palmitic acid and oleic acid as the major components. The remaining components are triglycerides, partial glycerides and unsaponifiable matters, e.g. vitamin E, sterols, squalenes and volatile substances. It is generally used in the soap industries, animal feed industries and as raw materials for oleochemical industries. Other applications include their use as food emulsifiers, an aid in rubber processing, in flavours and fragrance industries as well in pharmaceutical products. Vitamin E has been extracted commercially from PFAD for encapsulation (Gapor et.al., 1988). Gapor (2000) also developed a process to produce squalene from PFAD with purity over 90%. Squalene is a valuable compound used in health foods, cosmetics and in the pharmaceutical industry. Palm Fatty Acid Distillate (PFAD) is potentially a valuable, low-cost raw material for bio-diesel production. Palm Fatty Acid Distillate (PFAD) also a “food vs. fuel” argument that is much debated non-issue since Palm Fatty Acid Distillate (PFAD) is generally sold as a industrial fatty acids source for non-food requests.

PFAD (Palm Fatty Acid Distillated)

Figure 2: Crude and biodiesel palm fatty acid distillate

PFAD also provides a source of value-added co-products for the biodiesel producer. PFAD contains 72.7–92.6% FFA, with a small amount of unsaponifiable components (1–2.5%) and the remainder neutral oil. The figure below shows some of the general characteristics of Malaysian PFAD. (Source: Bonnie, T.Y.B., and Y. Mohtar, Characteristics and properties of fatty acid distillates from palm oil, *Oil Palm Bulletin 59*:5–11 (2009).

TABLE 1. *General characteristics of Malaysian PFAD*[a]

	Mean	Range
FFA—palmitic (%)	86.4	72.7–92.6
Unsaponifiable matter (%)	1.61	1.0–2.5
Saponification value (mg KOH/g)	209.5	200.3–215.4
Titer (°C)	46.7	46.0–48.3
Specific gravity @ 50°C (g/cc)	0.8725	0.8640–0.8880
Water content (%)	0.104	0.03–0.24
Iodine value, Wijs (g/100 g)	54.8	46.3–57.6

[a]PFAD, palm fatty acid distillate; FFA, free fatty acids. Source: Bonnie and Mohtar (2009).

Table 1: General Characteristics of Malaysian PFAD

PFAD biodiesel is an alternative fuel similar to conventional fuel which is produced from vegetable oil, and animal oil/fats. The largest possible source of suitable oil comes from oil crops such as rapeseed, soybean or palm. Biodiesel is a completely natural, renewable fuel applicable in any situation where conventional petroleum diesel is used without any modifications on engine are needed. It is 100% fatty acid based and reduces tailpipe emissions, visible smoke and obnoxious odors. Besides that, biodiesel can also be used in blends with conventional diesel while still achieving substantial reductions in emissions. Production of fatty acid methyl ester (FAME) from palm fatty acid distillate (PFAD) having high free fatty acids (FFA) was investigated (Chongkong, Tongurai, Chetpattananondh, & Bunyakan, 2007). The PFAD biodiesel has similarity in properties with diesel fuels.

However, biodiesel production cost (Ekeoma, 2010) is not economical as compared to petroleum based fuels. This paper generally describes the potential of palm fatty acid distillate (PFAD), a byproduct from production of consumable palm oil, with free fatty acid (FFA) content of 93% wt to be used as feedstock for a continuous production of biodiesel. The figure below shows the fuel properties of PFAD biodiesel.

Fuel properties of PFAD biodiesel

Properties	Unit	Test method	PFAD biodiesel[a] in this work	Biodiesel specification	
				Thai standard	ASTM D6751-02
Density at 15 °C	kg/m^3	ASTM D4052	879.3	860–900	870–900
Viscosity at 40 °C	mm^2/s	ASTM D445	4.865	3.50–5.00	1.9–6.0
Flash point	°C	ASTM D93	181	120 min	130 min
Cloud point	°C	ASTM D2500	15	–	−3 to 12
Pour point	°C	ASTM D97	14	–	−15 to 10
Distillation 95%	°C	ASTM D86	335	360 max	360 max
Water content	wt%	ASTM D6304	0.03	0.05 max	0.03 max
Ash content	wt%	ASTM D874	0.0066	0.02 max	0.02 max
Carbon residue	wt%	ASTM D4530	0.07	–	–
Acid value	mg KOH/g	ASTM D664	0.33	0.50 max	0.80 max
Copper corrosion	Number	ASTM D130	1	1 max	3 max
Ester content	wt%	TLC	99.480	96.5 min	–
Triglyceride	wt%	TLC	0.000	0.2 max	–
Diglyceride	wt%	TLC	0.058	0.2 max	–
Monoglyceride	wt%	TLC	0.462	0.8 max	–

[a]PFAD biodiesel from neutralization with 1.83 v/wt% of 3 M $NaOH–H_2O$ solution at 65 °C for 15 min followed by transesterification process using 3.85 wt% of 0.396 M NaOH–MeOH solution at 80 °C for 15 min.

Figure 3: Fuel properties of PFAD biodiesel

Another report on the esterification of palm fatty acid distillates was reviewed to produce fatty acid methyl esters which is the biodiesel in a batch reactor, using 98 % concentrated tetraoxosulphate (VI) acid catalyst. The optimum requirement of ratio of reactants, catalyst, reaction time, and temperature was studied. (Ekeoma, 2010)

2.4 Emulsifier Study

The key point that enables oil-based drilling fluid to be the ultimate drilling fluid remains to be its emulsion stability. Emulsion can be defined as a mixture of two immiscible liquids in which one liquid exists in the form of very small droplets dispersed throughout the other liquid.

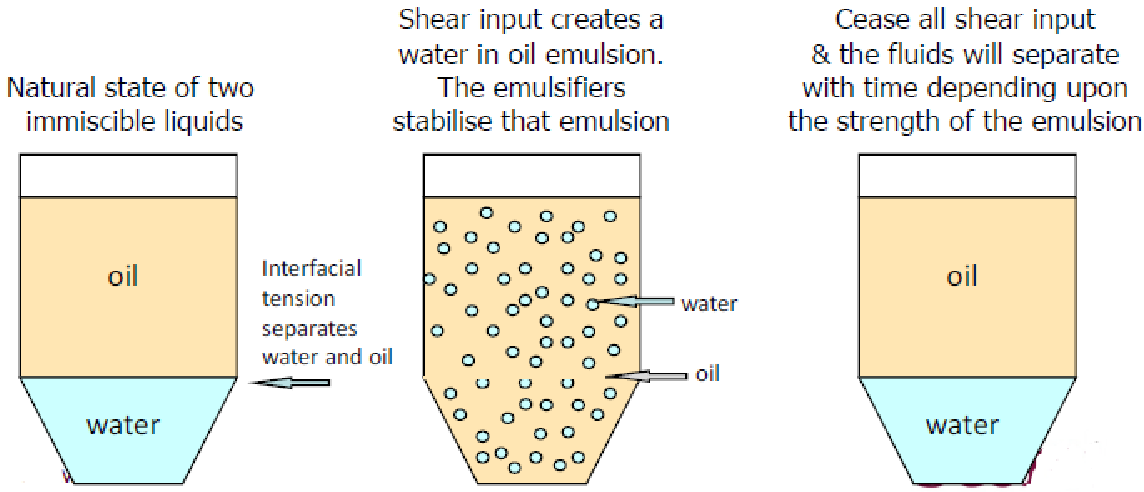


Figure 4:Emulsion principle

In order to obtain small droplets of uniform size, energy or work must be applied in the form shear. Sufficient shear can be achieved through turbulent agitation by special high-shear devices of when circulating through the bit jets, mud gun or with some centrifugal pumps.

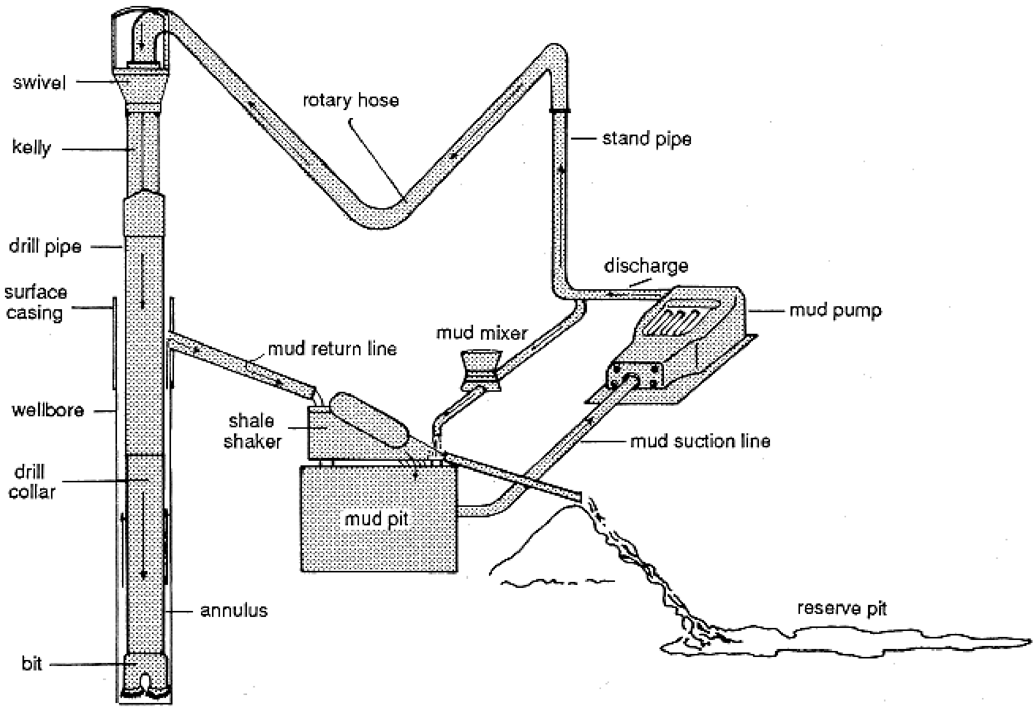


Figure 5: Drilling assembly

This then raises the question of how an emulsion can be formed and stabilized once formed. Emulsifiers are regarded as chemicals used in preparation and maintenance of an oil-base or synthetic-base drilling fluid that forms a water-in-oil emulsion (invert emulsion) (Oilfield Glossary, 2012). It also can be basically understood as chemicals that stabilize a physical emulsion once it is formed. It can be said that emulsifiers are categorized as a hydrophilic head with a lipophilic tail.

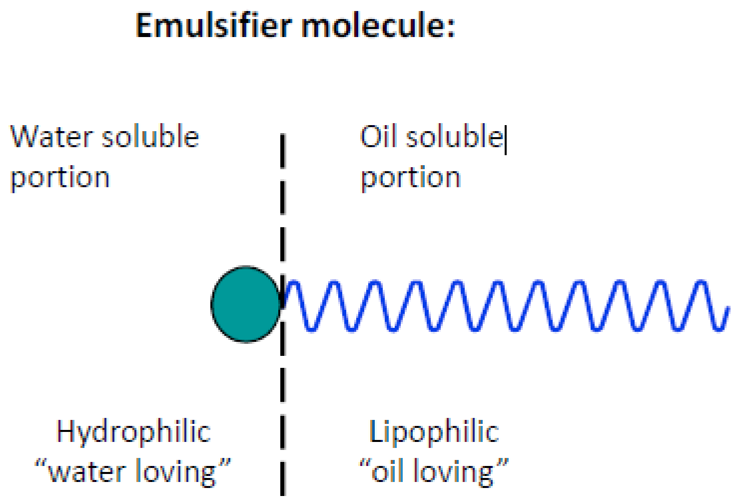


Figure 6: Emulsifier characteristics

Emulsifier stands on the boundary between the continuous oil phase and water droplet (primary emulsifier) Scientifically, an oil-mud emulsifier lowers the interfacial tension between oil and water, which allows table emulsions with small drops to be formed. The emulsifiers surround water droplets, like an encapsulating film, with the fatty acid component extending into the oil phase. Emulsifier molecules that cannot fit around drops form clusters (miscelles) in the oil phase or adsorb onto solids. Oil-mud emulsion drops each behave like a small osmotic cell. The emulsifier around the drops acts like a semi permeable membrane through which water can move but ions cannot pass. Thus oil mud have the special capability to control water transfer to and from the drops simply by adjusting salinity within the water phase of the oil mud. (Oilfield Glossary, 2012)

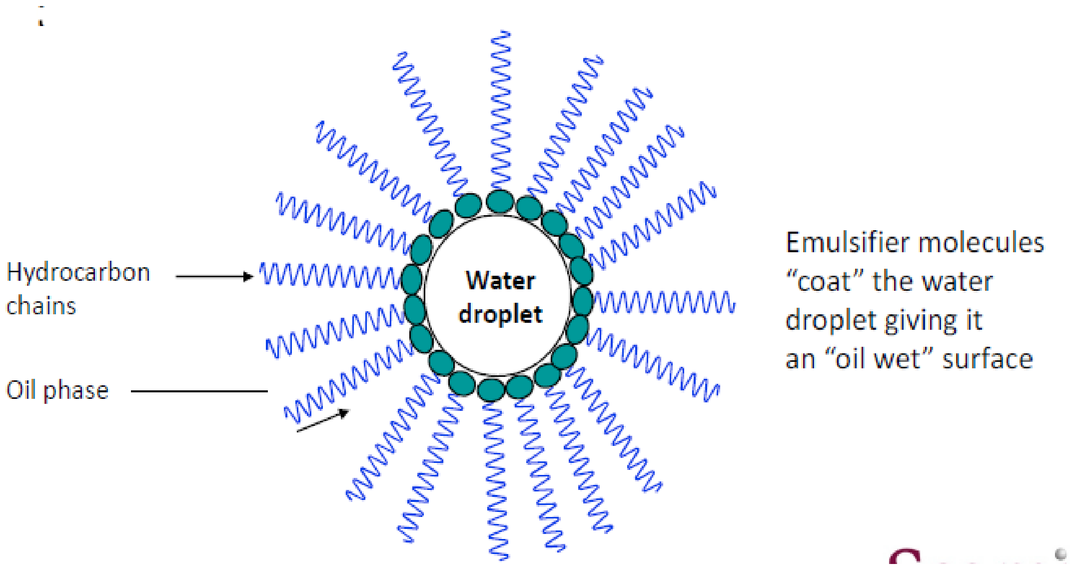


Figure 7: Primary emulsifier principle

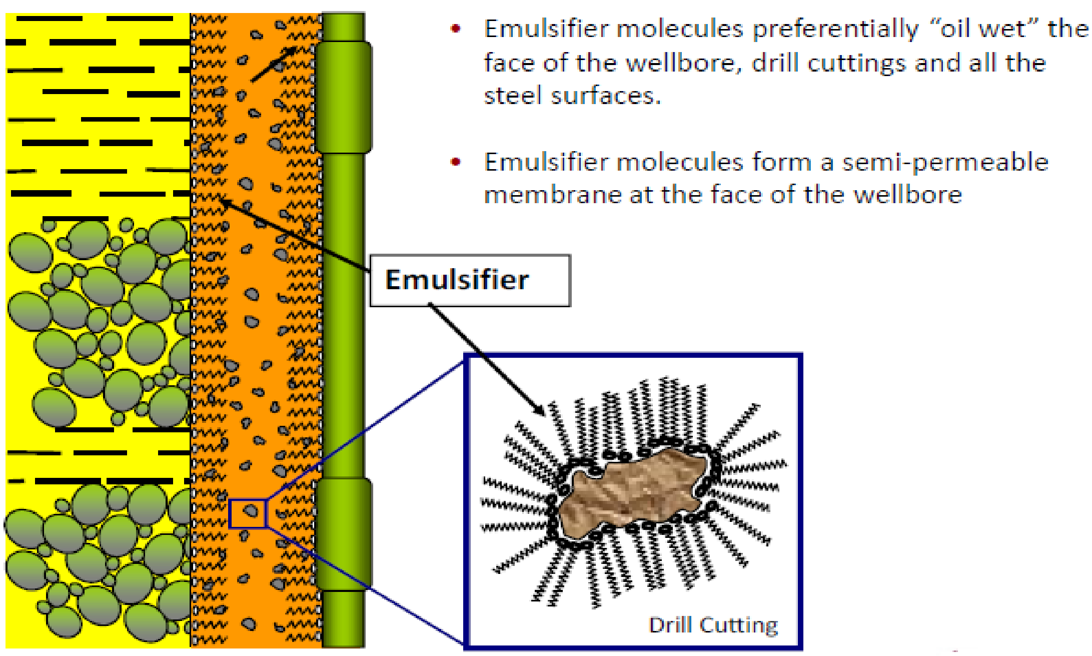


Figure 8: Secondary emulsifier principle

Most oil based mud use a system of two emulsifiers to ensure a stable emulsion as the mud is contaminated by cuttings and formation fluids.

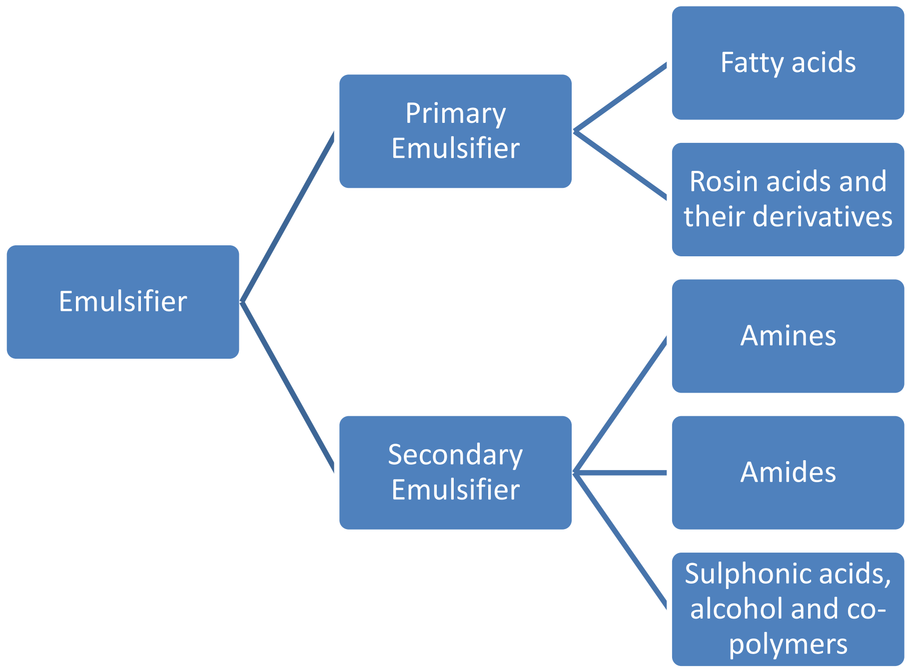


Figure 9: Emulsifier classification

Secondary emulsifiers act to preferentially oil wet drill solids and barite, They also act to improve emulsion stability, particularly at high temperature. Fatty acid emulsifiers are tall oils which are complex mixtures of oxygenated hydrocarbons, anionic in nature. They require activation by a metal ion usually calcium derived from LIME to be saponifyed. Imidazoline emulsifiers are divided into cationic and anionic in nature. The anionic imidazolines require LIME for activation but their thermal stability are generally inferior. Polyamide / polyester emulsifiers are non-ionic emulsifiers which do not require LIME for activation. They are highly resistant to salt contamination, high thermal stability and possess good oil wetting capability.

Therefore, a good emulsifier package will achieve a stable emulsion of water in oil, preferentially oil wet all particulate matter, preferentially oil wet steel surfaces, good oil wetting characteristics without significant impact on low shear rheology, remain stable at anticipated bottom hole temperatures. Below are figures to illustrate the impact of stable and unstable water-in-oil emulsion at dynamic and static conditions.

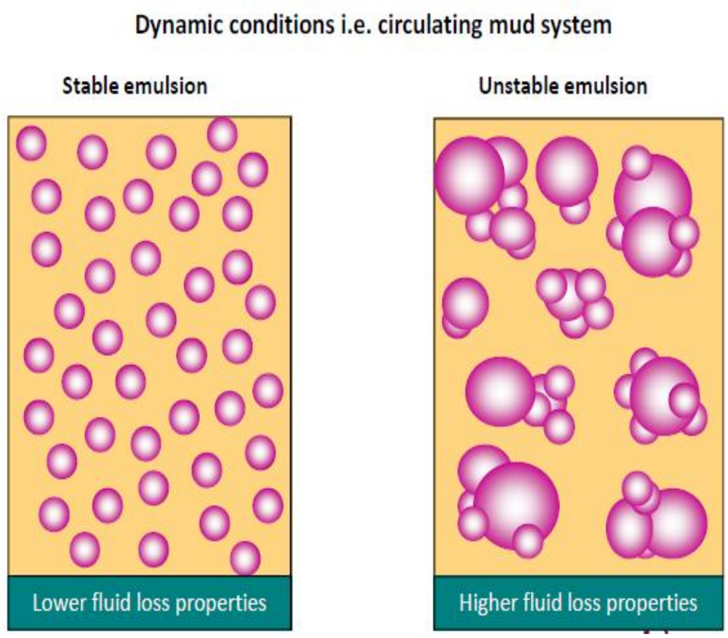


Figure 10: Emulsion at dynamic conditions

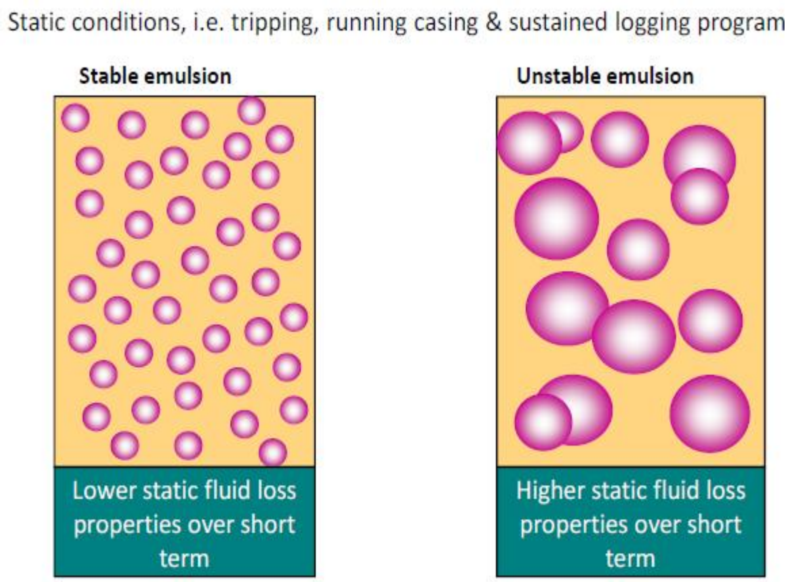


Figure 11: Emulsion at static conditions

This explains the importance and vital role played by emulsifiers in making SBM and OBM the ultimate drilling fluid.

2.5 Lime

Lime or better known as hydrated lime and slaked lime are all common names for calcium hydroxide $Ca(OH)_2$. It is used as a source of calcium and alkalinity in both water- and oil-base drilling fluids. Drilling fluid applications for lime include:

- increasing pH
- providing excess lime as an alkalinity buffer
- flocculating bentonite muds
- removing soluble carbonate (CO3 2–) ions
- controlling corrosion
- activating fatty-acid for oil-base mud

A sufficiently optimum lime value used to activate the emulsifiers is often essential factors for the successful performance of a drilling fluid. The activation of fatty acids in the emulsifiers aids in soap building in drilling mud's, directly related to sufficient emulsion formation and stability. Limiting the lime value can also impede the performance of the drilling fluid as it affects the emulsion stability and consequently causes more free water loss during HTHP filtration test.

An alkaline pH which is buffered by excess lime will prevent acidic conditions from occurring which can lead to accelerated corrosion from acid gases. The solubility of lime increases with increased salinity, but decreases with increased calcium, increased pH and increased temperature. Normal treatments for lime depend on the system. The three levels of lime concentration are often described as:

- Low Lime: 0.5 – 2.0 lb/bbl → (1.43 – 5.7 kg/m3)
- Medium Lime: 2.0 – 5.0 lb/bbl → (5.7 – 14.3 kg/m3)
- High Lime: 5.0 - 15.0 lb/bbl → (14.3 - 43.0 kg/m3)

Lime precipitates soluble carbonate ions as calcium carbonate (CaCO3) as follows:
Ca(OH)2 + CO32– ® CaCO3 ¯ + 2(OH–) ………. (at pH >10.3)

Lime (lb/bbl) = CO32– (mg/l) x 0.000432 x Fw
Water-base: Excess Lime (lb/bbl) =0.26 [Pm - (Fw x Pf)]
Oil-base: Excess Lime (lb/bbl) = POM x 1.3

Where:
Fw = Water fraction from retort
analysis (% water/100)

3.0 METHODOLOGY

3.1 Research Methodology

The role of emulsifier and lime in Oil based and bio-based drilling fluid is vital and comprehensive. The study of bio-based drilling fluid formulation must be carried out in order to set a basis for comparison between different types of formulations and rate their performance based on the agreed upon criteria. In order to further the research, three methods will be practiced:

1. Quantitative method
2. Qualitative method
3. Evaluative method

Quantitative data is best explained as data containing numerical significant whereby qualitative is subjective, meaning it is subject to interpretation and evaluative method describes the standards required for evaluation to be done. This helps in this research project as it provides a basis for decision making. All these methods are used in this project in order to get the best possible reasoning for this problem. Quantitative method is important for this project to have accurate data. Below are the quantitative methods utilized:

1. Calculation
   - ✓ This was done to prepare the formulation of mud samples with the correct measurement of each individual products.
2. Tabulation
   - ✓ Tabulation is done on the results obtained through findings, monitoring and experiments.
   - ✓ It is visually convenient to analyze the data.
   - ✓ Tables were presented to record the data obtained based on the tests performed.

Qualitative method is also an important method which have to use in this project to obtain certain crucial data. Some of the qualitative method which used in order to retrieve data is:

1. Survey
    - ✓ Survey were done on both the emulsifier sets from their source to know their perceived strength and conditions deemed suitable for the usage of the emulsifiers.
2. Interview
    - ✓ An interview or a talk session was held between supervisor in order to know the study and address the required parameters.
3. Flowchart and Gantt Chart
    - ✓ Flowchart and Gantt chart is important to keep track and monitor the stage and to progress of project from time to time. This would serve as the schedule for project.
4. Discussion
    - ✓ Some discussion session took place with my supervisor to update the progress of the project..
    - ✓ Suggestions are also given by my supervisor on how to handle to project.

Evaluative method is very much needed as well in this type of research project as it will help serve as a basis for decision making. Below are the evaluative methods performed:

1. Data Analysis Criteria
    a. Necessary criteria to be used as basis for comparison of formulation performance was chosen beforehand to aid in performing the necessary tests and obtaining the required data
2. Acceptable Range of Values
    a. The results obtained were compared based on the range applicable by standard products to further eliminate unsuitable formulation.

3.2 Project Methodology

The methodology covers the experimental works which starts from the identification and characterization of palm fatty acid distillate in terms of its physical properties followed by the blending of the biodiesel with pure palm olein at varying ratios for economic considerations. The second phase of the project comprises of the formulation of bio-based drilling fluid and the performance comparison between formulations for further optimization.

3.2.1 1st Stage: Project Planning

The problems related to the project are identified and the importance of the project is determined. The objective and also the scope of study are outlined and the feasibility of the project work is making sure to be within the time frame given. The solution to the problem statement is studied and the types of materials and tools used for the experiment are also indentified through literature review.

3.2.2 2nd Stage: Determining Physical Properties of PFAD

The palm fatty acid distillate used in this experiment is identified and characterized. The physical properties which are analyzed include the density, specific gravity, kinematic viscosity, flash point, pour point and acid value. This serve as a preliminary basis to rate the suitability of the PFAD sample as continuous phase for drilling fluid. The palm fatty acid distillate used in this experiment is obtained from Research and Development Department of Universiti Teknologi PETRONAS.

3.2.3 3rd Stage: Blending of Palm Fatty Acid Distillate - Palm Olein

The palm fatty acid distillate is blended in varying ratios with palm olein for economic considerations. The kinematic viscosity of different blending of palm fatty acid distillate and palm olein are determined as it will be set as the deciding factor whether to blend the oils and use as drilling mud base fluid.

3.2.4 4th Stage: Development of PFAD Drilling Fluid Formulation

The palm fatty acid distillate drilling fluid formulations are prepared. The equipment and chemicals required for the experiments are indentified with a clear experimental procedure outlined and planned. The equipment and methods needed to analyze the properties samples are also indentified. After that, the experimental works will be conducted in the laboratory of Scomi Oiltools Sdn. Bhd to obtain the data and results.

3.2.5 5th Stage: Comparative study on performance of formulations

The effect of lime and emulsifier on the newly developed palm fatty acid distillate drilling fluid are analyzed. Varying lime and emulsifier concentration are used to aid in this study. The comparative study of the different formulations are analysed and its performance are assessed for further optimization.

3.3 Flow Chart of Project Methodology

Prototype

Sample Preparation

- PFAD as project base fluid
- Blending of PFAD and palm olein
- Chemical Additives

↓

Parameters

Sample Testing

- Physical properties.
  - Yield point
  - Plastic viscosity
  - Density
  - Gel strength
  - Filtration
- Performance comparison

↓

Theory

- Wide range of differences expected to be seen between different formulations of PFAD based drilling fluid
- The effect of lime and emulsifier is expected to have major differences on the behaviour of PFAD based drilling fluid

↓

Outcome

Result

- Comparison between the efficiency and properties of PFAD based drilling fluid formulations and optimization.
- Comparison with conventional drilling fluid.

3.4 Project Activities

Beginning of Project

↓

Project Title Selection:
Obtain the title from project supervisor and understand the title and its requirement.

↓

Problem Statement and Objective of the Project:
Understand the purpose of this research and list down all the objectives of the

↓

Literature Review:
Gather information on the related topics from various sources to further understand on the topic.

↓

Hardware/Experimental Setup:

- Material Identification: Bio oil as base oil, water,soda ash, bentonite, flowzan, barite, caustic soda (mud formulation).
- Apparatus Design: Prepare mud balance, marsh funnel, viscometer, HTHP filter press, screen set and pH meter.

↓

Experimental Work:
Part 1 - Determine the physical properties of PFAD sample and subsequent blending with palm olein.

Part 2 - Developing the formulations of PFAD drilling mud and the assessment of its performance for further optimization.

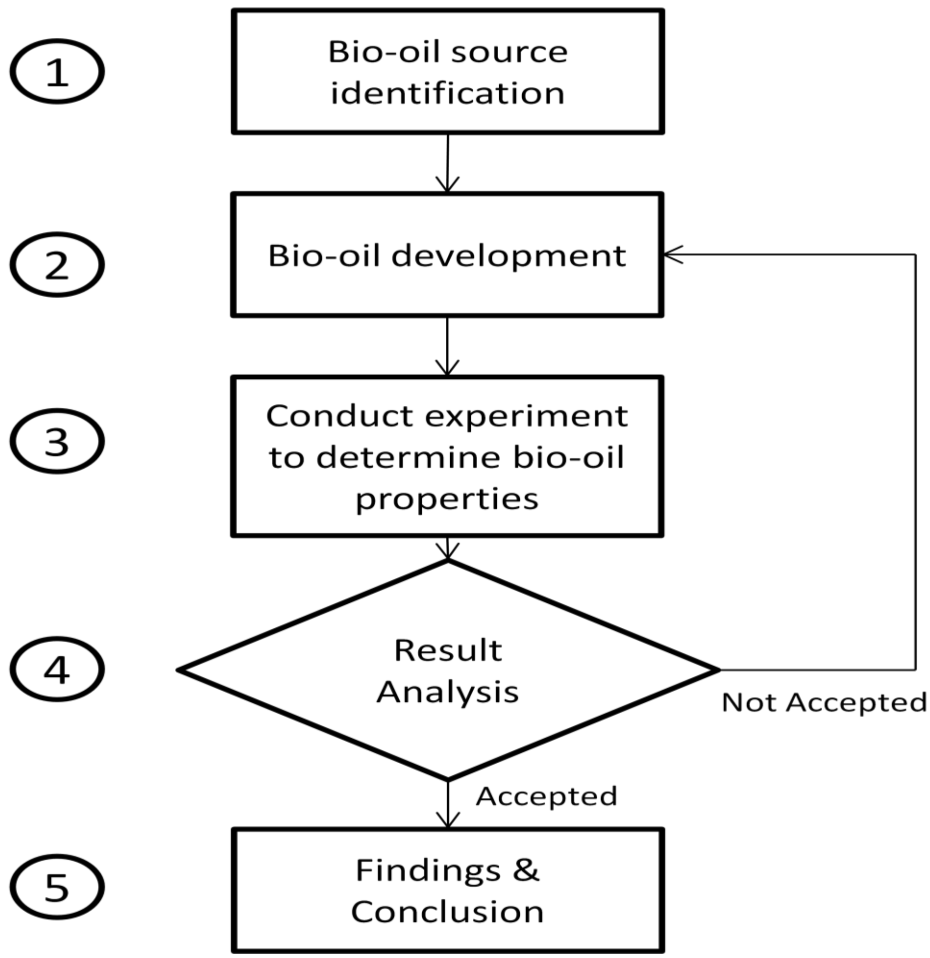
↓

Analysis and Interpretation of Result:
Data gathered are analyzed and interpreted critically .

↓

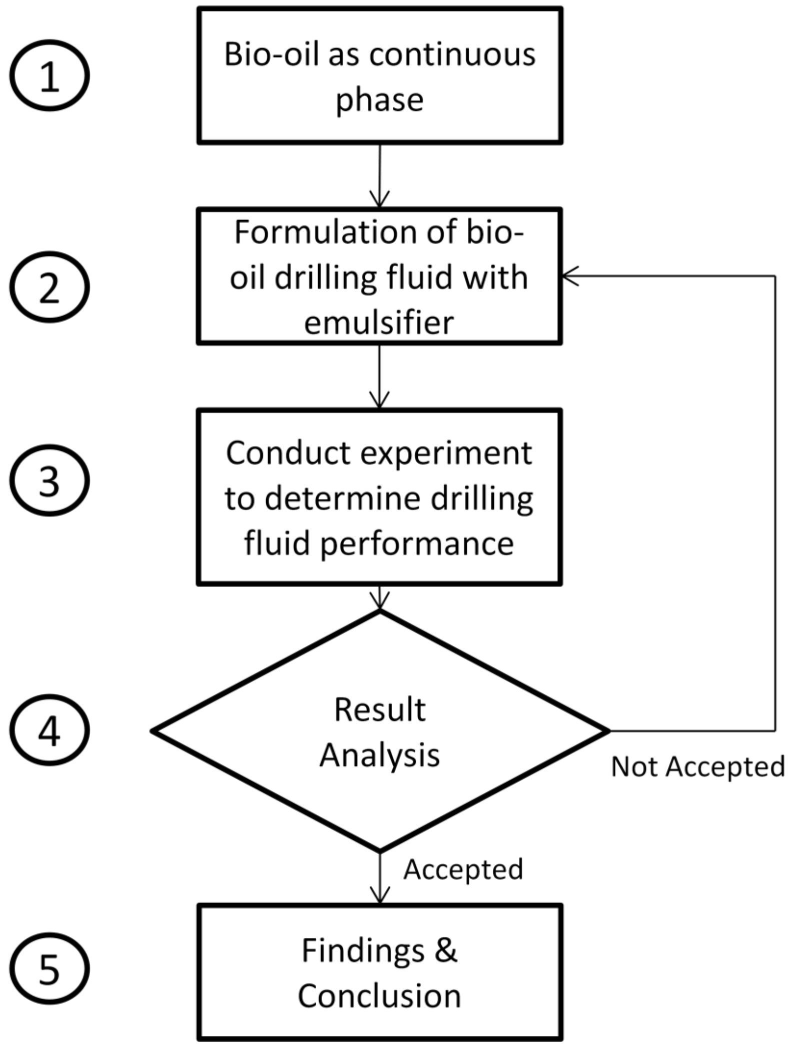
Documentation and Reporting:
Research will be documented and reported in detail. Recommendation and further improvements will be discussed.

Since the project experiment is divided into two parts. Individual flow charts are used.



This flow chart is used to determine the palm fatty acid distillate physical properties and the kinematic viscosity of the PFAD and palm olein blend. As if the kinematic viscosity is too high, it will not be accepted and a different ratio is tried.

The second phase is as follows:



3.5 Tools

Below are the summary of activities and tools required for the project.

Activities	Description	
PFAD Physical Properties	- Determining the PFAD sample's physical properties for determining its suitability as base fluid	
PFAD testing	Properties	Tools Required
	Density and Specific Gravity	Anton Paar DMA 4500 M
	Kinematic Viscosity	Koehler Kinematic Viscosity Bath equipment.
	Flash Point	Protest Cleveland Open Cup Instrument (CLA 5) with automated flash point analyzer
	- Cloud Point and Pour Point	1SL CPP 5Gs analyzer
	- Acid Value	Titration of potassium hydroxide (KOH)
PFAD Preparation	- Rotary Evaporator (consists of water bath as temperature controller, vacuum pump and distillation column) to heat up the biodiesel and remove methanol	
Blending with Palm Olein	- The PFAD sample is blended with palm olein at varying ratios for economic considerations - The kinematic viscosity is determined for each ratio.	

Table 2: Tools Required for Phase 1

<table>
<tr><th>Activities</th><th colspan="2">Description</th></tr>
<tr><td>Preparation of mud formulation</td><td colspan="2">- Prepare a mud formulation for the biofuel-based mud and diesel mud which will be used as reference
- Chemical Additives
- Tools required (mud formulator)</td></tr>
<tr><td rowspan="6">Mud to be tested with following parameters</td><td>Properties</td><td>Tools Required</td></tr>
<tr><td>Density</td><td>Mud Balance</td></tr>
<tr><td>Mud mixing</td><td>Hamilton Beach Mixer</td></tr>
<tr><td>Emulsion Stability</td><td>ES Meter</td></tr>
<tr><td>- Plastic Viscosity
- Gel Strength
- Yield Point</td><td>FANN (Model 35A) Viscometer</td></tr>
<tr><td>- Filtrate Volume
- Mud cake thickness</td><td>High Pressure High Temperature Filter press</td></tr>
<tr><td>Testing with HTHP</td><td colspan="2">- Study the emulsion stability of the newly formulated bio-based drilling fluid</td></tr>
</table>

Table 3: Tools required for Phase 2

3.6 Key Milestones

Some of the key events and activities that will take place during the Final Year Project is as follow:

1. Finalizing the project title from project supervisor.
2. Thorough background study on the topic given via online articles, journals and books.
3. Identification of the topic problem statement and objectives of the project.
4. Thorough research on the literature review.
5. Plan the methodology to be used in this project and the flow of the project.
6. Completion and submission of Extended Proposal to project supervisor.
7. Proposal defense with project supervisor and panel of examiners.
8. Completion and submission of FYP I Interim Report to be reviewed by project supervisor and panel of examiners.
9. Experimentation works continue and results are recorded
10. Submission of progress report to be reviewed by project supervisor.
11. Pre- SEDEX poster evaluation of project by panel of examiners.
12. Submission of dissertation (soft bound) and technical report to be reviewed by project supervisor and panel of internal and external examiner.
13. Oral presentation (VIVA) of project to be assessed by project supervisor and panel of internal and external examiner.
14. Submission of Project dissertation (hard bound) after critiqued by project supervisor and panel of examiners.

3.7 Gantt Chart

3.7.1 Project Gantt Chart

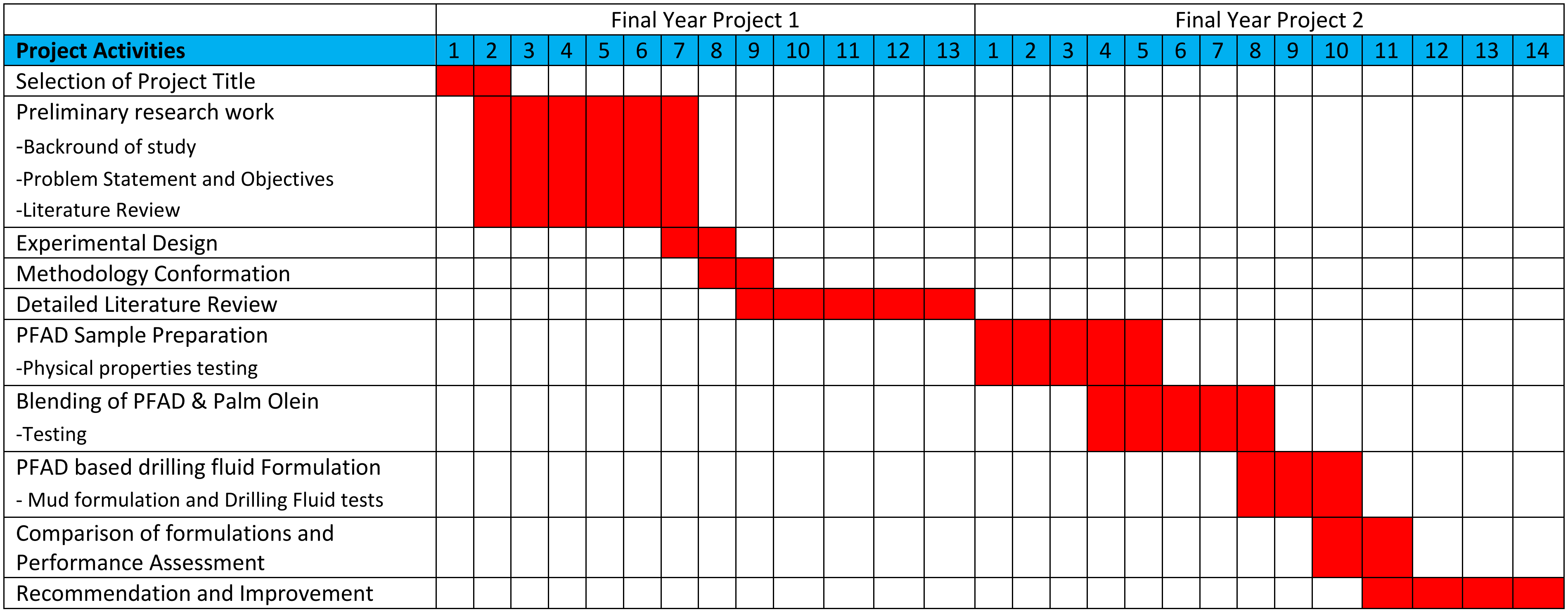


Table 4: Project Gantt chart

3.7.2 Final Year Project I Gantt Chart

Tasks	Week Number													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection of the Project Title														
Preliminary research work														
* Background study														
* Problem Statement and Objectives														
* Literature Review														
Submission of Extended Proposal							●							
Proposal Defense Preparation														
Proposal Defense Presentation														
Detailed Literature Review														
Simulation Design & Data Collection														
Preparation of Interim Report														
Submission of Interim Report Draft													●	
Submission of Interim Report														●

Table 5: Final Year Project I Gantt Chart

3.7.2 Final Year Project II Gantt Chart

Tasks	Week Number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Project Work Continues															
Submission of Progress Report							●								
Project Work Continues															
Pre-SEDEX										●					
Submission of Draft Report											●				
Submission of Dissertation (soft bound)												●			
Submission of Technical Paper												●			
Oral Presentation													●		
Submission of Project Dissertation (Hard Bound)															●

Table 6: Final Year Project II Gantt Chart

3.8 Project Procedures

Before Hot Roll

- 1. Mix 1 barrel of the PFAD mud formulation,12.0ppg for 60 minutes.
- 2. Record the rheological and gel strength properties of the mud sample.
- 3. Measure the ES reading of the mud sample.
- 4. Pour mud sample into aging cell and place in oven for 16 hours of hot rolling a 275F.

After Hot Roll

- 6. Take the mud sample out of the oven, cool and stir for 5 minutes.
- 7. Record the rheological and gel strength properties of the mud sample.
- 8. Measure the ES reading of the mud sample.
- 9. Run retort test at 950F and HTHP test at 275F on the mud sample..

Figure 12: Project Procedures

4.0 RESULTS AND DISCUSSIONS

4.1 Determining PFAD Physical Properties

The palm fatty acid distillate used in this project is obtained from UTP Research and Development Laboratory. The oil appears to be brown in colour. It is characterized by analyzing its properties such as density, specific gravity, kinematic viscosity, flash point, pour point, cloud point and acid value. However before doing so, the oil is heated at a temperature of 70^{o}C for about 30 minutes to remove methanol from the biodiesel. The test to see if the methanol is removed is to place a drop of the heated oil onto skin. If no cooling effect is felt, then the methanol is successfully removed. The results of the analysis are shown below.

Property	Unit	Testing Method	Value
Density	kg/m^3	ASTM D4052	908.25
Specific Gravity	-	ASTM D4052	0.910
Kinematic Viscosity (at 40'C)	cSt/ mm2/s	ASTM D445	4
Pour Point	^{0}C	ASTM D97	16
Cloud Point	^{0}C	ASTM D2500	17
Flash Point	^{0}C	ASTM D92	132
Acid Value	M KOH/g	AOCS (Cd 3d-63)	0.33

Table 7: Palm Fatty Acid Distillate physical properties

Based on the results obtained, it is then compared with the conventional diesel and mineral oils such as Saraline 200 and Sarapar 147.

Property	**Unit**	**Diesel**	**PFAD Sample**	**Sarapar 147**	**Saraline 200**
Specific Gravity	-	0.865	0.910	0.773	0.783
Kinematic Viscosity (at 40'C)	cSt/ mm2/s	2.0	4.8	2.5	3.0 - 4.0
Pour Point	^{0}C	-17.7	16	12	-18
Flash Point	^{0}C	37.8	132	120	95

Table 8: Comparison of PFAD and Conventional oil

It is observed that the PFAD sample satisfies most of the criteria needed for to be used as the base fluid for drilling mud. The most important criteria that needs to be satisfied are as follows:

- Kinematic viscosity
  - It should be as low as possible. This allows the oil based mud to be formulated at lower oil/ water ratios and gives better rheology (lower plastic viscosity), especially at low mud temperature.
- Flash point
  - It should be greater than 100F or 37.8^{o}C. Higher flash point will minimize fire hazards as less hydrocarbon vapour is expected to generate above the mud

- Pour point
    - It should be lower than ambient temperature to allow pumpability of mud from storage tanks

It is also observed that the PFAD sample values are close to the conventional oil used in drilling fluid. Therefore, it is acceptable to be carried forward and used as the continuous phase of the drilling fluid formulation.

4.2 Blending of Palm Fatty Acid Distillate with Palm Olein

For economic considerations, the palm fatty acid distillate was blended with pure palm olein at varying ratios . The kinematic viscosity of the blended samples were recorded and set as the benchmark in determining its suitability as continuous phase to be used as drilling fluid. The results are as follows.

No	**Mixing Ratio of PFAD - Palm Olein (%)**	**Kinematic Viscosity (cSt)**
1.	100 - 0	4.8
2.	90 - 10	6.42
3.	80 - 20	8.06
4.	70 - 30	11.34
5.	60 - 40	17.55
6.	50 - 50	21.85
7.	40 -60	26.15
8.	30 - 70	31.08
9.	20 - 80	35.38
10.	10 - 90	37.49
11.	0 - 100	39.04

Table 9: Kinematic viscosity of PFAD - Palm Olein ratio

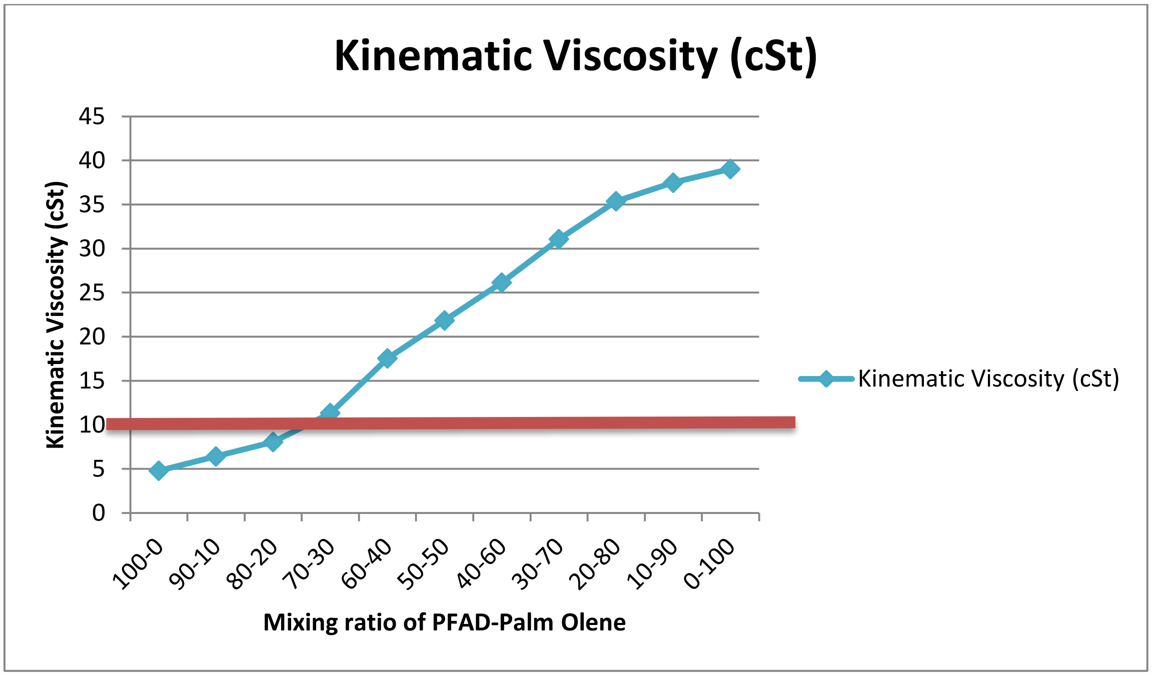


Figure 13: Graph-Kinematic Viscosity of PFAD - Palm Olein Ratio

Based on the results above, 100% of PFAD biodiesel records the lowest kinematic viscosity value and subsequently followed by the increasing palm olein ratios. Generally, any fluid with a kinematic viscosity of higher than 10 cSt is deemed fail as a base fluid for drilling mud as the oil itself is too viscous and higher oil/water ratios and this will result is bad rheological reading. Therefore, only three blending ratios were deemed suitable and feasible as base fluid which are:

- 100% PFAD Biodiesel
- 90% PFAD Biodiesel - 10% Palm Olein
- 80% PFAD Biodiesel - 20% Palm Olein

Since the kinematic viscosity of the conventional oil are below 5 cSt, the 100% PFAD biodiesel is chosen to be the best out of three blending to be used as the continuous phase of the drilling fluid. The 100% PFAD biodiesel will be further used in different formulations to assess its performance and efficiency as a bio-based drilling fluid. This does not mean the other two blending is unsuitable but it is unfavourable due to time constraint and the absence of a optimized formulation for the PFAD based drilling fluid. This two blending can be tried once the 100% PFAD sample is successfully optimized in a drilling fluid formulation as this formulation can be referred as the base formulation and further optimization based on the blending can be carried out. However, two blended oils should be tested for its physical properties beforehand to ensure its compatible to be used as a continuous phase in drilling fluid formulation.

4.3 Palm Fatty Acid Distillate Drilling Fluid

After the blending, the 100% PFAD biodiesel sample is chosen to be used as the continuous phase of the drilling fluid. The basic mud formulation is prepared and explained as follows.

4.3.1 Formulation Data

<table>
<tr><th>Products</th><th>Mixing Order</th><th>Mixing Time (Min)</th></tr>
<tr><td>Base oil - PFAD sample</td><td>1</td><td></td></tr>
<tr><td>Primary Emulsifier - CONFI-MUL P</td><td>2</td><td>2</td></tr>
<tr><td>Secondary Emulsifier - CONFI- MUL S</td><td>3</td><td>2</td></tr>
<tr><td>Viscosifier- CONFI-GEL HT</td><td>4</td><td>5</td></tr>
<tr><td>Fluid Loss Control Agent -
CONFI TROL HT</td><td>5</td><td>2</td></tr>
<tr><td>LIME</td><td>6</td><td>2</td></tr>
<tr><td>Fresh water</td><td rowspan="2">7</td><td rowspan="2">15</td></tr>
<tr><td>$CaCl_2$</td></tr>
<tr><td>Weighting Agent -Barite</td><td>8</td><td>5</td></tr>
</table>

Table 10: Formulation data

The table above is the framework of the formulation whereby all mud samples were mixed in accordance with the formulation above but with differing measurements for a total of 60 minutes. The products in the formulation can be explained as follows:

A. Base oil - PFAD sample
    - Biodiesel which is the base fluid used throughout this project.

B. Primary and Secondary Emulsifier - CONFI-MUL P / S
    - Emulsifier sets of primary and secondary emulsifiers which is the independent variable in this project.

C. Viscosifier - CONFI-GEL HT
    - Organophillic bentonite which plays the role of the viscosifier in this project
D. Fluid loss control agent - CONFI TROL HT
    - Fluid loss control agent that minimizes filtrate invasion and improves mud cake quality
E. LIME
    - Saponification reaction with fatty acid emulsifiers
    - Converting some additives to oil soluble forms
    - To maintain alkaline environment
F. Fresh water and $CaCl_2$
    - Premixed together as brine.
    - to reduce volume of oil and to hydrate organophillic clay viscosifier
G. Barite
    - Weighting agent

4.3.2 Results

This part of the project is mainly to compare and contrast the performance of 3 most acceptable formulations of the PFAD based drilling fluid that was obtained among all the formulations. The results were then further discussed and analyzed to recommend further optimization to ensure the three formulations can be improved in the future. The three formulations chosen are:

- 1 - PFAD sample with 0 conc. lime and 0 ppb. CONFI-MUL P (primary emulsifier)
- 2 - PFAD sample with 0 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier)
- 3 - PFAD sample with 1 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier
- Diesel formulation is also recorded to act as a reference and act as a base case.

MIXING FOR 60 MINUTES

Products	mixing time, min	1	2	3	Diesel
PFAD Sample		154.19	154.55	153.91	172.06
CONFI-MUL P	2	0.00	1.00	1.00	3.00
CONFI-MUL S	2	9.00	8.00	8.00	6.00
CONFI-GEL HT	5	3.75	3.75	3.75	3.75
CONFI-TROL HT	2	4.00	4.00	4.00	4.00
LIME	2	0.00	0.00	1.00	10.00
fresh water	15	71.75	71.75	71.75	69.30
CaCl2		26.14	26.14	26.14	25.06
Barite	5	193.18	193.18	193.18	229.00

Properties Initial:	Spec Base	1 (BHR)	1 (AHR)	2 (BHR)	2 (AHR)	3 (BHR)	3 (AHR)	Diesel (BHR)	Diesel (AHR)
Mud density, lb/gal (formulated)	**12.0**	**12.0**	**12.0**	**12.0**	**12.0**	**12.0**	**12.0**	**12.0**	**12.0**
Rheological properties		120 °F	120 °F	120 °F	120 °F	120 °F	120 °F	120 °F	120 °F
600 RPM		115	158	171	104	196	196	96	63
300 RPM		111	98	133	72	174	159	67	37
200 RPM		81	81	114	60	156	137	55	29
100 RPM		56	62	92	46	131	112	43	20
6 RPM	**8-12**	18	41	52	27	76	70	27	10
3 RPM		17	39	47	25	71	63	25	9

PV, cP	**<35**	4	60	68	32	22	37	29	26
YP, lb/100 ft^2	**15-25**	107	38	65	40	152	122	38	11
Gel 10 sec, lb/100 ft^2	**6-10**	31	40	44	23	64	51	27	10
Gel 10 min, lb/100 ft^2		32	39	46	26	67	61	33	15
ES, volts at 120 °F	**>500**	O/S	1690	676	531	O/S	1689	1267	847
OWR	**75:25**								
oil, ml			28.5		27		26		31
water, ml			6.5		10		8		8
solids, ml			15		13		16		11
HTHP (500 psi, 275°F), ml/30 minute	**5.0**		16.2		41		4.4		0.8
water, ml			0.2		0.0		0.0		0.0
oil, ml			7.9		20.5		2.2		0.4
total, ml			8.1		20.5		2.2		0.4

Table 11: Formulation Results

(BHR) - Before hot roll **(AHR) -** After hot roll for 16hrs at 275F

4.3.3Data Analysis

The results obtained were very comprehensive and provided with many factors that can be used as the basis of comparison in terms of the suitability of the formulation set. However, five main factors were identified as the basis of comparison which formed the scope of the project decision making criteria. Figure below illustrates the five main decision analysis criteria.

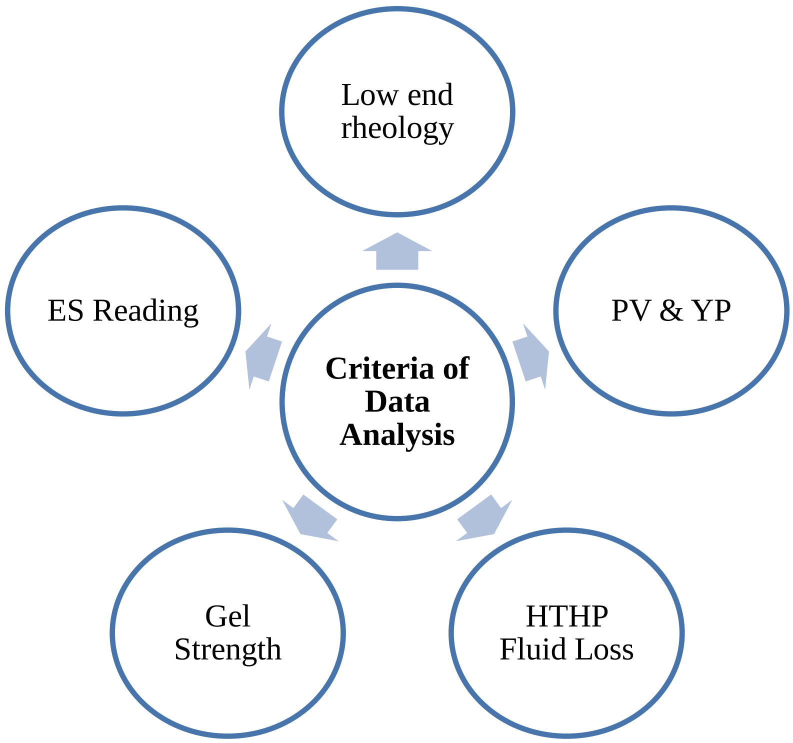


Figure 14: Data analysis criteria

To facilitate the analysis of results, more importance is given to the values of criteria after hot roll is taken into account as the hot rolling process simulates the drilling fluid circulating from the surface to the bit and back up. This gives a more clear picture of the formulation's performance. The diesel formulation will not be included as it is a existing base oil widely used in drilling fluid formulation. Therefore, it satisfies all required criteria and would be redundant to be compared with the new PFAD formulation samples.

Low End Rheology (6RPM)

The low end rheology was taken into account as one of the criteria because a good formulation must be able to achieve good 'oil wetting' characteristics without significant impact on 'low shear' rheology. This low end rheology directly affects the hole cleaning and Equivalent Circulating Density (ECD) of the mud. Therefore, the mud must not be too thick and at the same time not too thin. The rheology of the mud samples were recorded at 12.0ppg density before and after hot roll.

Acceptable range : 8 – 12

Mud Formulation	**1**	**2**	**3**
12.0ppg (BHR)	18	52	76
12.0ppg (AHR)	41	27	70

Table 12: Low end rheology (6rpm) results

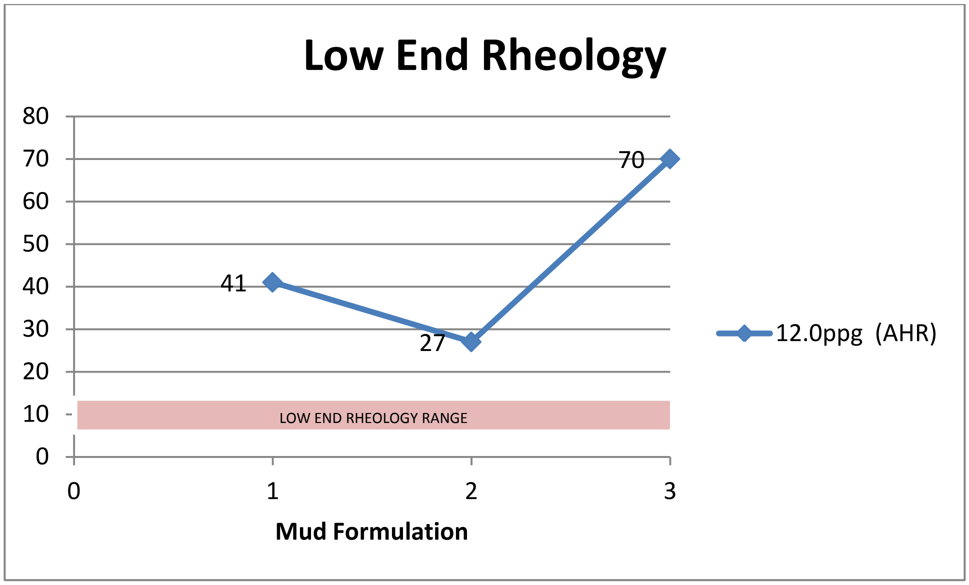


Figure 15: Graph- Low end rheology (6rpm) results

- 1 - PFAD sample with 0 conc. lime and 0 ppb. CONFI-MUL P (primary emulsifier)
- 2 - PFAD sample with 0 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier)
- 3- PFAD sample with 1 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier)

Based on the results, all three formulation does not satisfy the acceptable range of the low end rheology criteria. This shows the mud is too thick at low rpm and this can be caused by the viscosifier concentration. Lowering the viscosifier concentration will help in reducing the low end rheology reading.

Plastic Viscosity and Yield Point

Plastic viscosity is defined as the amount of solids present in the mud. A low PV indicates that the mud is capable of drilling rapidly because of the low viscosity of mud exiting at the bit. High PV is caused by a viscous base fluid and by excess collodial solids. To lower PV, a reduction in solids content can be achieved by dilution of the mud. Yield point is defined as the amount of reactive solids present in the mud. YP is used to evaluate the ability of the mud to lift cuttings out of the annulus. A high YP implies a non-Newtonian fluid, one that carries cuttings better than a fluid of similar density but lower YP. YP is lowered by adding deflocculant to a clay-based mud and increased by adding freshly dispersed flocculant such as lime. The calculations to obtain both values are as follows:

PV = 600RPM - 300RPM

YP = PV - 300RPM

The comparison is done for the three formulations before and after hot roll.

PV Acceptable range: < 35 YP Acceptable range: 15 - 25

Mud Formulation	**1**		**2**		**3**	
	BHR	**AHR**	**BHR**	**AHR**	**BHR**	**AHR**
PV	4	60	68	32	22	37
YP	107	38	65	40	152	122

Table 13: Plastic viscosity (PV) and Yield Point(YP) for 12.0ppg results

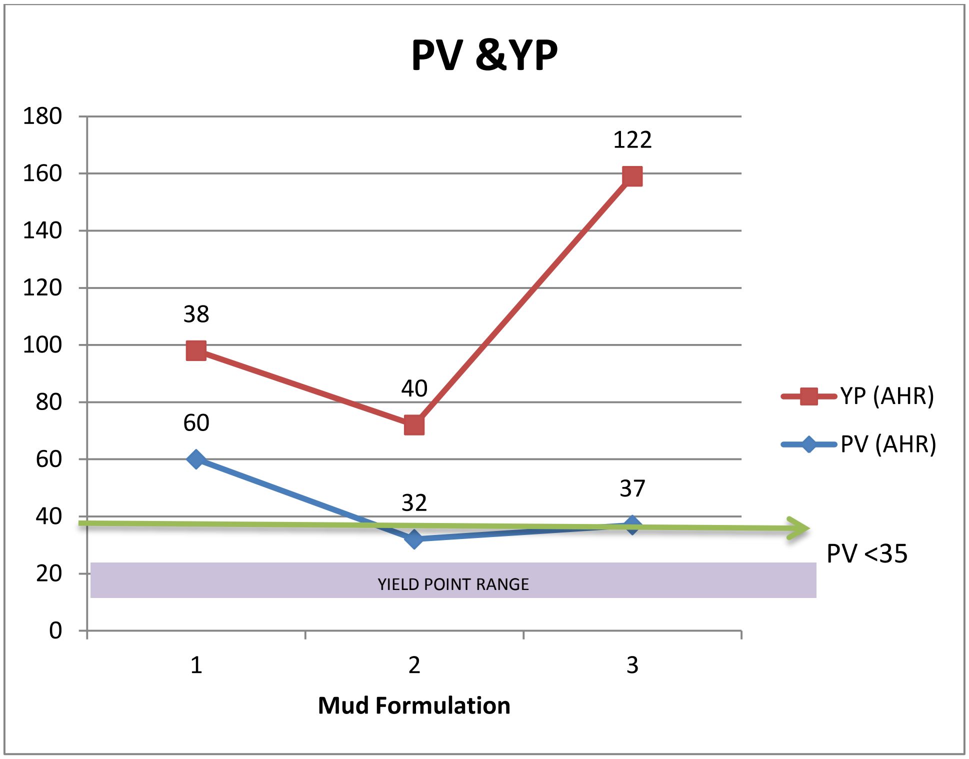


Figure 16: Graph-Plastic viscosity (PV) and Yield Point(YP) for 12.0ppg (AHR) results

- 1 - PFAD sample with 0 conc. lime and 0 ppb. CONFI-MUL P (primary emulsifier)
- 2 - PFAD sample with 0 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier)
- 3- PFAD sample with 1 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier)

Based on the results, all three mud formulations do not satisfy the requirement of the Plastic viscosity and Yield Point criteria. However, mud formulation:

- 2 - PFAD sample with 0 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier)
- 3- PFAD sample with 1 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier)

have both PV values close to the required criteria. In terms of YP, all formulations have values which are way above the acceptable range. This can be due to the viscosifier concentration. Lowering the viscosifier concentration will help in reducing the low end rheology reading.

Gel Strength

Gel strength is the shear stress of drilling mud that is measured at low shear rate after the drilling mud is static for a certain period of time. The gel strength is one of the important drilling fluid properties because it demonstrates the ability of the drilling mud to suspend drill solid and weighting material when circulation is ceased. If the mud has the high gel strength, it will create high pump pressure in order to break circulation after the mud is static for long time. Gel strengths at 10seconds and 10 minutes were recorded for this project. The comparison is done for the three formulations before and after hot roll.

Acceptable range, 10 sec : 6 - 10

Mud Formulation	1		2		3	
	BHR	AHR	BHR	AHR	BHR	AHR
10 sec	31	39	44	23	64	51
10 min	32	40	46	26	67	61

Table 14: Gel strength for 12.0ppg results

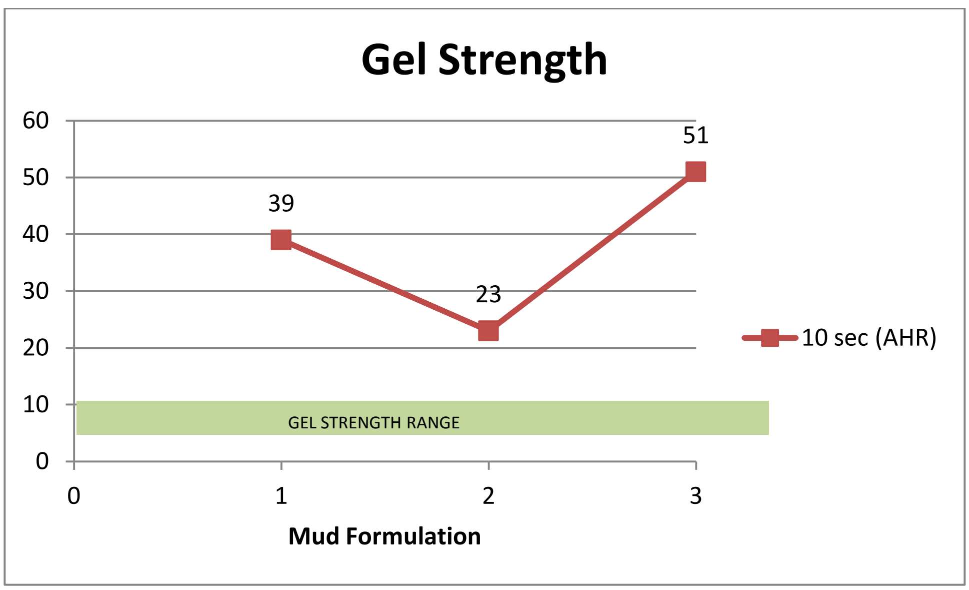


Figure 17:Graph- Gel strength 10sec for 12.0ppg (AHR) results

- 1 - PFAD sample with 0 conc. lime and 0 ppb. CONFI-MUL P (primary emulsifier)
- 2 - PFAD sample with 0 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier)
- 3- PFAD sample with 1 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier)

Based on the results, none of the formulation satisfies the acceptable range of the gel strength criteria. For the gel strength, more importance is given for 10 sec which explains the graph plotted. This can be caused by the viscosifier concentration. Lowering the viscosifier concentration will lower the gel strength values of the mud formulations.

Emulsion Stability

Emulsion stability test is attest for oil-base and synthetic-base mud that indicates the emulsion and oil-wetting qualities of the sample. The emulsion stability test basically records the amount of voltage needed to pass electricity from one electrode to the other. As oil is a non-conductor, the water droplets suspended in the oil will help to conduct the electricity from both electrodes.

Acceptable range : >500

Mud Formulation	1	2	3
12.0ppg (BHR)	O/S	676	O/S
12.0ppg (AHR)	1690	531	1689

Table 15: Emulsion stability results

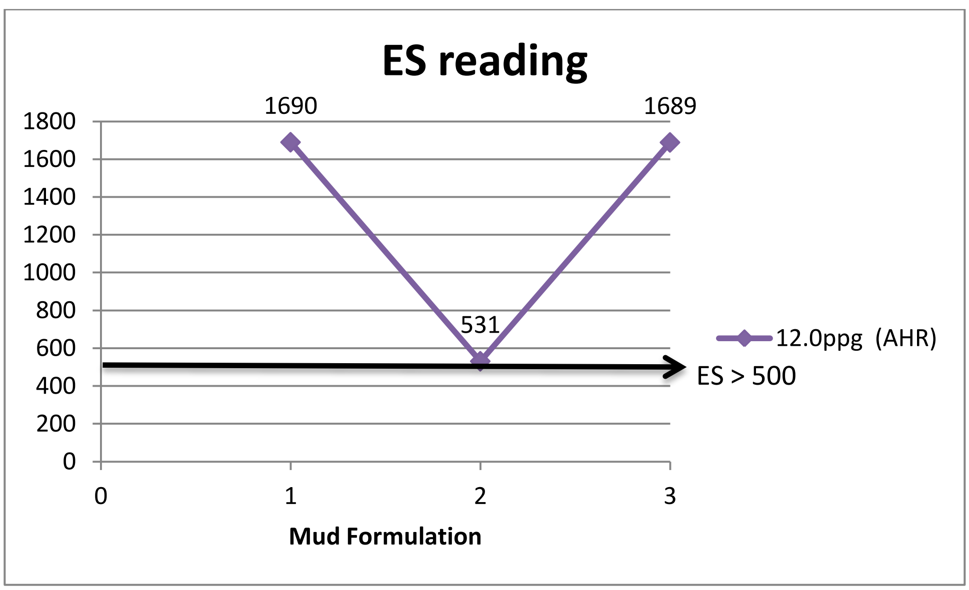


Figure 18: Graph -Emulsion stability for 12.0ppgf (AHR) results

- 1 - PFAD sample with 0 conc. lime and 0 ppb. CONFI-MUL P (primary emulsifier)
- 2 - PFAD sample with 0 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier)
- 3- PFAD sample with 1 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier)

Based on the results, all mud formulations satisfy the requirements of the Emulsion Stability criteria. This means the emulsifier is compatible with the base oil and provides a stable water in oil emulsion.

HTHP Fluid Loss

HTHP fluid loss test mechanism is basically a pressurized cell, fitted with a filter medium used for evaluating filtration characteristics of a drilling fluid while it is static in the test cell. Two main aspects are observed with this test. Those are the filtrate level and mudcake thickness. For the project, the mud cake thickness is omitted. The filtrate level however is interpreted for the 12.0ppg mud formulations after hot roll.

Acceptable range : < 5ml

Mud Formulation	**1**	**2**	**3**
HTHP filtrate	16.2	41.0	4.4
Free Water	0.2	0.0	0.0

Table 16: HTHP fluid loss results

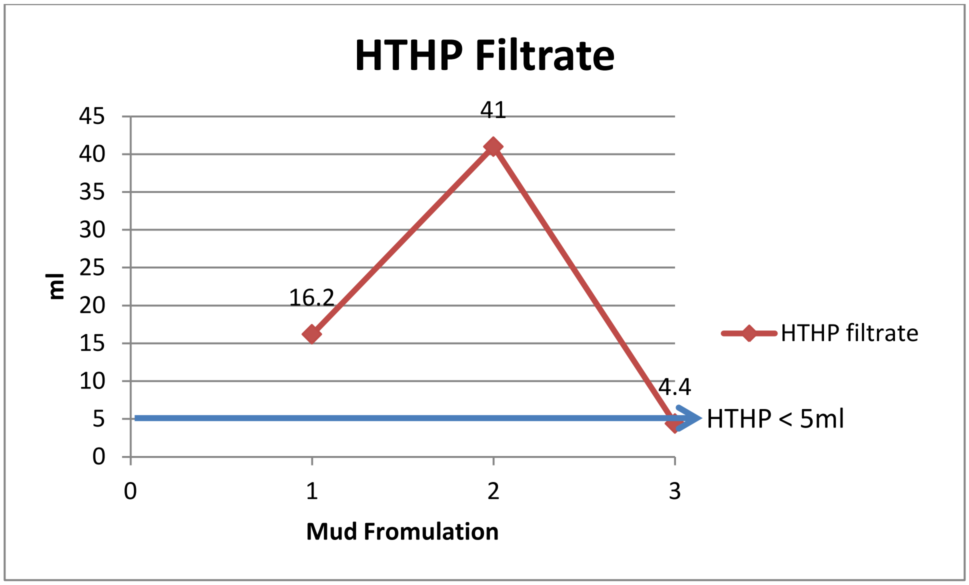


Figure 19: Graph-HTHP fluid loss results

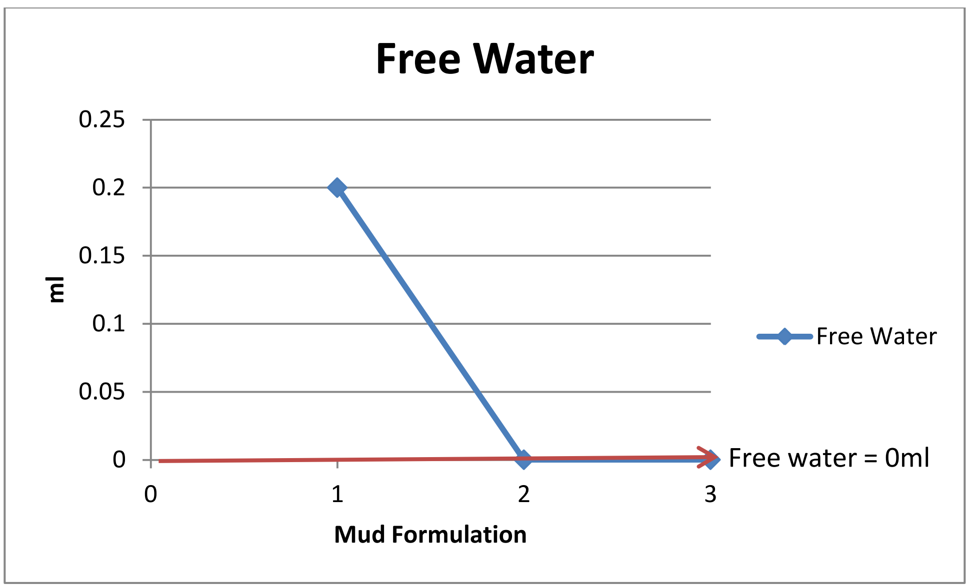


Figure 20: Graph- Free water results

- 1 - PFAD sample with 0 conc. lime and 0 ppb. CONFI-MUL P (primary emulsifier)
- 2 - PFAD sample with 0 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier)
- 3- PFAD sample with 1 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier)

Based on the results, mud formulation 3- PFAD sample with 1 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier) is the only one that satisfies the requirement for the HTHP Fluid loss criteria.

Mud formulation

- 1 - PFAD sample with 0 conc. lime and 0 ppb. CONFI-MUL P (primary emulsifier)
- 2 - PFAD sample with 0 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier)

did not satisfy the required criteria as excessive filtrate was produced during the test. However, mud formulation 2 does not have free water visible in the filtrate which means it has emulsion stability. Mud formulation 1 has very little visible free water. This can be due to the absence of primary emulsifier in the formulation. The failure or both formulation can be caused by the fluid loss control agent concentration. Increasing the fluid loss control agent concentration will reduce the filtrate produced by the formulation.

5.0 CONCLUSION AND RECOMMENDATION

The conclusion of the project should address the objectives intended to fulfill at the beginning of the project. A table is tabulated to illustrate the performance of the formulations of PFAD samples. As mentioned earlier, importance are given to the after hot roll values.

	1 - PFAD sample with 0 conc. lime and 0 ppb. CONFI-MUL P (primary emulsifier)	**2** - PFAD sample with 0 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier)	**3**- PFAD sample with 1 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier)
Low end rheology	–	–	–
Plastic Viscosity	–	+	+
Yield Point	–	–	–
Gel Strength	–	–	–
Emulsion Stability (ES)	+	+	+
HTHP Filtrate	–	–	+
Free Water	–	+	+

Table 17 : Mud samples vs. data analysis criteria

(+) - Meets Specification (-) – Does not meet specification

Based on the table above, it is understood that all three formulations require further optimization in order to improve its performance and efficiency of the PFAD based drilling fluid. Based on the comparison of the three formulation:

- 1 - PFAD sample with 0 conc. lime and 0 ppb. CONFI-MUL P (primary emulsifier)
    - has a high ES reading of 1690

- 2 - PFAD sample with 0 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier)
    - has a low Plastic Viscosity value of 32
    - has a high ES reading of 531
    - has zero free water in HTHP filtrate

- 3- PFAD sample with 1 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier)
    - has a relatively low Plastic Viscosity value of 37
    - has a high ES reading of 1689
    - has a low HTHP filtrate produced of 4.4ml
    - has zero free water in HTHP filtrate

Formulation sample 3 - PFAD sample with 1 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier) meets the most number of specification of all the criteria above. However, it can't be chosen as the optimum formulation as it fails few of the important criteria required in an effective drilling fluid. Therefore, further optimization must be done for the three formulations to ensure the reliability and suitability of the PFAD based drilling fluid. Another note is further retesting is required for Mud formulation 2 as it does not follow the trend of the results from various tests. This can be due to faulty equipment, human error or unforseen nature. Therefore, its results is wise to be repeated to prove its applicability.

For further optimization, the following mud formulations:

- 1 - PFAD sample with 0 conc. lime and 0 ppb. CONFI-MUL P (primary emulsifier)
    - It is observed that the mud formulation fails to meet requirement of all criteria except ES reading. However, its values recorded are close to the acceptable range of values. Therefore, the viscosifier concentration should be lowered as it will lower the yield point, gel strength and low end rheology value. For the HTHP fluid loss and free water, fluid loss control agent should be added to reduce the volume of filtrate and free water produced.

- 2 - PFAD sample with 0 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier)
    - It is observed that the mud formulation fails to meet the requirement of yield point, low end rheology and gel strength. The viscosifier concentration should be reduced as it will reduce the values of these three criteria. As for the HTHP fluid loss, fluid loss control agent should be added.
- 3- PFAD sample with 1 conc. lime and 1 ppb CONFI-MUL P (primary emulsifier)
    - It is observed that the mud formulation fails to meet the requirement of yield point, low end rheology and gel strength. The viscosifier concentration should be reduced as it will reduce the values of these three criteria.
- The base fluid comprised of PFAD biodiesel can be further treated to reduce its free fatty acid content. This will help stabilise the lime and primary emulsifier concentration as lime is vital in every drilling fluid to maintain an alkaline environment necessary for drilling operations.

After these optimization are done, then the optimum formulation of PFAD based drilling fluid can be identified and used as the base formulation for the PFAD sample. In conclusion, the objectives of the project were satisfied as the

1. PFAD sample was characterized and prepared to be suitable as continuous phase for drilling fluid in terms of physical properties comparison with conventional oil and the blending of PFAD sample with palm olein.

2. The PFAD dased drilling fluid was formulated and tested with various drilling fluid tests such as rheology, retort and HTHP fluid loss test.

3. The formulated PFAD based drilling fluid was studied and evaluated in terms of its low plastic viscosity, low yield point, gel strength, low end rheology, ES reading, low HTHP fluid loss and zero free water.

4. The results were compared and the formulation's performance were assessed for further optimization recommendations.

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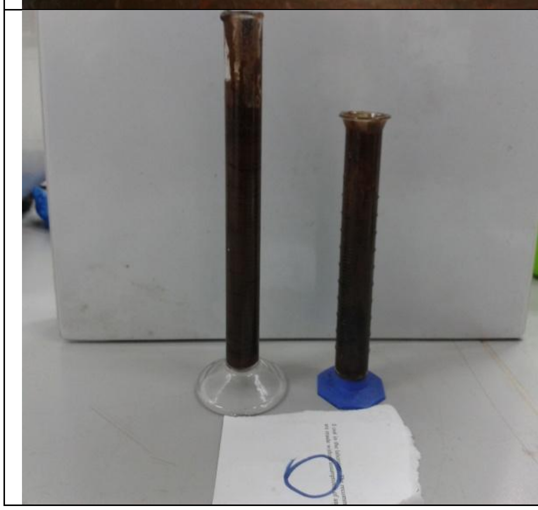
Appendix

Pictures	Description
	Retort test being run at 950F to determine the oil water ratio (OWR) using retort kit
	Mud formulation mixing using Hamilton Beach Mixer

	Rheological properties of mud tested using Viscometer Fann35
	Result of Retort test of PFAD drilling fluid sample
	Oven for placing formulation 16hours of hot rolling

	Mud sample after 16hours of hot rolling. The samples are placed in aging cells before placing into the oven.
	HTHP filtrate collected for PFAD sample