FINAL YEAR PROJECT II

DISSERTATION REPORT

"Study on the Effect of Different Ratio of Primary and Secondary Emulsifier in Drilling Fluid"

Supervisor:

Miss Raja Rajeswary Suppiah

By:

Muhammad Zulhilmi bin Muhammad

12091

Bachelor of Engineering (Hons)

(Petroleum Engineering)

SEPTEMBER 2012

CERTIFICATION OF APPROVAL

Study on the Effect of Different Ratio of Primary and Secondary Emulsifier in Drilling Fluid

By:

Muhammad Zulhilmi bin Muhammad

A project dissertation submitted to the:

Petroleum Engineering Program

Universiti Teknologi PETRONAS

In partial fulfillment of the requirement for the:

Bachelor of Engineering (Hons)

(PETROLEUM ENGINEERING)

Approved by,

____

(Raja Rajeswary Suppiah)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

SEPTEMBER 2012

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.

____

(Muhammad Zulhilmi bin Muhammad)

ABSTRACT

Drilling fluid plays an important role in drilling operation. The main function of drilling fluid is to transport drilling cuttings from the well, control formation pressure and maintain the stability of the wellbore. Two main categories of drilling fluid are water-based mud and non-aqueous mud. In non-aqueous mud there are two types of mud which is the oil-based mud and synthetic based mud. For both non-aqueous muds, one of the most important chemical used is emulsifier. Emulsifier consists of two types which are primary and secondary emulsifier. The primary emulsifier function is to emulsify the water inside the oil so that there is no free water in filtrate and the secondary emulsifier is as the wetting agent. The efficiency of the emulsifier from the emulsion stability test using the electrical stability meter and from the filtration of the mud using the HTHP filter press. The performance of emulsifier in mud under different ratio of primary and secondary emulsifier can be predicted through the behaviour pattern. Moreover, the temperature of the down hole and performance of the mud are very significant. This project had been conducted at Baker Hughes Drilling Fluid Laboratory at Bangi by using their chemicals, equipment, and tools. In conclusion, the finding of this project is the best ratio of primary to secondary emulsifier for the temperature of 300°F and below is 1:2 while for the temperature of 300°F till 350°F the best ratio of primary to secondary emulsifier is 2:1.

ACKNOWLEDGEMENT

First and foremost, I thank and praise Allah for His guidance and blessing, definitely without it I would not have been able to complete my final year project lasting for two semesters. It was a long journey of studying, researching, analyzing, comparing and training, in which a lot has happened – many problems were faced and many solutions were implemented. I am infinitely thankful to a lot of people who has helped in the completion of this project. My deepest gratitude goes to Miss Raja Rajeswary Suppiah, my supervisor who has guided me through the whole process of project implementation and helped in suggesting the suitable approach and methods to solution of the problems and challenges encountered during the timeframe of the project.

My salutation would be incomplete without giving credit to Baker Hughes Incorporated, especially the Baker Hughes Drilling Fluid Laboratory's staffs at Bangi who has allowed me to use the laboratory, equipment, chemicals and assisting me in my project completion and its objectives fulfillment.

Thank you all for all the help and support in completing my final year project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLE

LIST OF CHART

1. INTRODUCTION

1.1. Background of the Project

Oil-based muds (OBM) and invert emulsion drilling fluids have been used for a number of years, primarily because of their superior performance when compared to water-based muds (WBM). Invert emulsion drilling fluids provide formation of a thinner filter cake, excellent lubricity, enhanced rate of penetration and superior hole stability. However, there are many disadvantages associated with oil retention on cuttings, toxicity to human health and marine environment and disposal of cuttings and used fluids. (Patel & Ali, 2003)

Since the inception of OBM, many attempts have been made to combat the environmental problems associated with OBM. Synthetic-based muds (SBM) were developed in 1990's in an attempt to balance the performance benefits of conventional oil-based muds and the pollution prevention characteristics of water-based muds. During past decades, the contribution of SBM in minimizing the environmental impact of discharges and improving health and safety condition on the rig has been well documented in literature. Despite the advantages of SBM, the extent of their environmental impact remains controversial. The primary focus to combat the environmental problems while balancing the performance characteristics of invert emulsion fluids, has been on the chemistry of base fluids (Burke & Veil, 1995), weight materials (Candler, Leuterman, Wong, & Stephens, 1990), and oil/water ratios (Daynes, Pratt, & Coates, 1987). Such changes are insignificant in either emulsifier chemistry (Clapper & Salisbury, 1984) or basic invert emulsion drilling chemistry even though invert emulsion technology has advanced in other areas of science. It is time to move on and look into new and existing emulsifier chemistries to bring a quantum leap in invert emulsion drilling fluid technology.

An emulsion is formed between two liquids by lowering the interfacial surface tension of one liquid to enable that liquid to form a stable dispersion of fine droplets in the other liquid. Lowering the interfacial surface tension and formation of an emulsion requires the presence of an agent possessing partial solubility in both phases. The class of chemicals, that represent these agents, generally possesses functional groups which confer bipolarity. Although, fatty acids, fatty alcohols and amines are good examples of bipolarity molecules, there exists a multitude of molecular variations of this type of polarity. (Patel & Ali, 2003)

In most regular emulsions, the oil phase is dispersed as fine droplets in the continuous water or aqueous phase. This is commonly known as an oil-in-water (O/W) emulsion. In an invert emulsion, the aqueous phase is the dispersed phase and continuous phase is oil phase. This is known as water-in-oil (W/O) emulsion. The present state of the art OBM's are invert emulsion drilling fluids. (Daynes, Pratt, & Coates, 1987)

Now days there are two types of emulsifiers used in the industry which is the primary and secondary emulsifiers. Their function is to emulsify the water-in-oil and to oil-wet the solid in the mud respectively.

1.2. Problem Statement

In order to enhance the technology of drilling fluids, the patterns of behaviour of emulsifier at various ratio of primary and secondary emulsifier in mud is very important. This is very important because the performance of emulsifier in mud under different ratio of primary emulsifier and secondary emulsifier can be predicted through the behaviour pattern.

Temperature of the down hole and performance of the mud are very significant. Therefore, advance evaluations on the testing temperature of the mud are very important for the drilling fluid enhancement.

1.3. Objective and Scope of Study

Objective of this project are:-

a) To compare and evaluate the effect of emulsifier at different ratio of primary and secondary emulsifier in the mud.
b) To compare and evaluate the effect of emulsifier at different temperature of testing in the mud.

The scope of study is focused on the composition of the mud. It must be the same for all the experimental period, usage of only primary and secondary emulsifier, given ratio of emulsifier and the experimental temperature in the testing procedure, constant dilution ratio throughout the experiment and chemicals used are from the same batch of packaging.

1.4. Relevancy of the Project

As mention in the problem statement and objective above, this project is mainly to study on the effect of primary and secondary emulsifier in the drilling fluid. The emulsifiers itself are very expensive. Therefore, the ratio of emulsifier has been included to get the optimum ratio to reach a certain performance.

1.5. Feasibility of the Project

The entire chemical for this project is supplied by Baker Hughes Drilling Fluid Laboratory. It has also been agreed that these experiments will be carried out in Baker Hughes Drilling Fluid Laboratory by using their equipment.

2. THEORY AND LITERATURE REVIEW

2.1. Drilling Fluids

The objective of a drilling operation is to drill, evaluate and complete a well that will produce oil and/or gas efficiently. Drilling fluid performs numerous essential functions that turn the objectives into reality. A properly designed drilling fluid will enable an operator to reach the desired geological objective at the lowest overall cost. A fluid should enhance penetration rates, reduce hole problems and minimise formation damage. Removing cuttings from the well, maintaining wellbore stability and controlling formation pressures are of primary importance on every well. Though the order of importance is determined by well design, conditions and current operations, the most common drilling fluid function are (SCOMI OILTOOLS SDN BHD, 2008):-

1. Transport cutting from the well
2. Control formation pressures
3. Maintain stable wellbore
4. Seal permeable formation
5. Suspend cuttings downhole and release them on the surface
6. Minimise reservoir damage
7. Cool, lubricate and support the bit and drilling assembly
8. Transmit hydraulic energy to tools and bit
9. Ensure good data recovery
10. Control corrosion
11. Facilitate cementing and completion
12. Minimise Health Safety and Environment risk

These are the reasons why drilling fluid is very important in drilling operation.

2.2. Chemistry of Emulsifier

The primary emulsifier is actually the calcium soap. It is made from the reaction of the lime and fatty acids in the mud with the specified time. The secondary emulsifier is an oil-wetting chemical extracted from wet solid prior to emulsion before the emulsions are formed. The emulsifiers are also used to prevent any water intrusion.

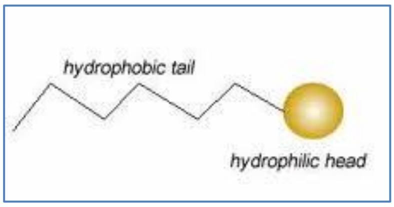

FIGURE 1: Emulsifier's fatty acid chain

The emulsifier is divided into two parts:-

a) *Hydrophobic tail* – does not like water
b) *Hydrophilic head* – like water

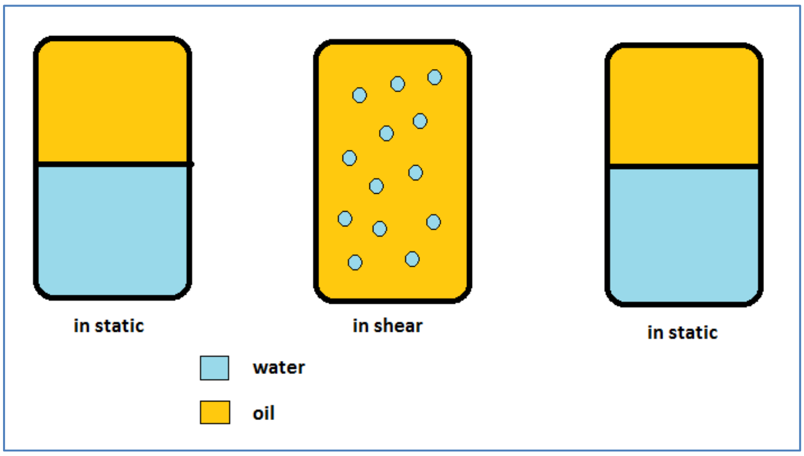

FIGURE 2: State of water in oil in static and in shear

When the water and oil is mixed together, the water or oil will not become as emulsion. Only when we shear the oil and water the water will emulsify in oil. However, oil and water will retain their original form when shearing is stopped. This signifies the importance of an emulsifier.

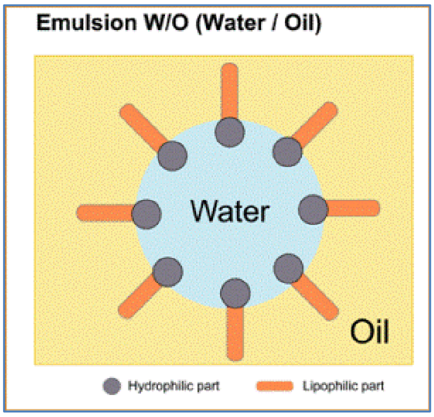

FIGURE 3: Emulsifier condition in mud

When we place the emulsifier in the mixture of water and oil the fatty acid will act as in the picture above to emulsify the water-in-oil. The hydrophilic head will hold the water molecule so that the water will be emulsifier in the oil even without shear.

2.3. Parameter of Emulsion Stability

Check the alignment for a stable emulsion to take place, there are a few parameters that contribute to emulsion stability. This can be divided into surfactant dosage, oil/water ratio, stirring intensity, mixing temperature and mixing time.

2.3.1. Effect of Surfactant Dosage

Investigations have demonstrated that emulsifier concentration has a significant impact on emulsion stability. When the dosage of surfactant increases, the emulsion stability increases, but only up toa certain point. When the dosage is too high the stability decreases due to a rapid coalescence and too low of surfactant dosage also destabilize the emulsion due to agglomeration of the oil droplets.

2.3.2. Effect of Oil/Water Ratio

Emulsion type is dependent on the relative phase volume. It is crucial to determine the best water/oil ratio to make sure the emulsion is stable. If we use high water ratio, the amount of primary emulsifier need to be increase.

2.3.3. Effect of Stirring Intensity

Emulsification needs energy to disperse one immiscible liquid towards other liquid. Firstly, the interface of the two phases is deformed to such an extent that large droplets are formed. The large droplets will be broken up into smaller ones. During emulsification, the interfacial area between two liquids increases. It is the properties of the liquids which tend to minimize the surface area; hence there is a need for mechanical energy for emulsification process to take place. Increasing local dissipation of energy in breaking zone due to the rise of circulation consumption through mixer zone is found to be most effective way for diameter decrease. The main objective of stirring is to form a stable emulsion; basically breaking large liquids drops into smaller drops. High intensity does not necessarily mean better emulsion; too intense stirring will lead to the emulsifier to break away from oil-water interface.

2.3.4. Effect of Temperature

The temperature is one of the significant factors in producing stable emulsion. The surface tension of most liquids decreases with increasing temperature. This is caused by increased kinetic energy imparted to the surface molecules at high temperature will tend to overcome the net attractive force of the bulk liquid. As the temperature increase towards critical value, the cohesive force between molecules approaches zero. Normally with increase temperature, it will be easier for emulsification to take place but if too high, there will be a chance that it will coagulate the particles which cause the deterioration of the emulsions. The interfacial adsorption of the emulsifier is adversely affected to some extent by increasing temperature. Affect will also be on the surfactant which is loosely adsorbed on the oil-water interface and will separate out from the emulsion. This will increase in collision and coalescence, thus destabilize the emulsion.

2.3.5. Effect of Mixing Time

Mixing time plays an important role in making a stable emulsion. Mixing will decrease the radii of droplets in the emulsion with increasing emulsifying time. Emulsifier becomes more effective with increased mixing time. Nevertheless, too long of mixing will decrease the emulsifier effectiveness as it will cause the emulsifier to drop out from oil-water interface.

2.4. Literature Review

There are numbers of research papers have been done in the past few months on the fundamental of drilling fluids, chemistry of emulsifiers, and mud testing. All of them were reviewed and studied by me.

TABLE 1: List of Studied and Analysed Papers

No.	Title of Paper / Research / Work	Author	Date
1	**A new emulsified acid to stimulate wells in carbonate reservoir.**	M.A. Sayed, H.A. Nasr-El-Din, J. Zhou, S. Holt, and H. Al-Malki	15 January 2012
2	**An Analytical Method for Emulsifier Concentration in an Oil-Base Drilling Fluid**	R. Matherly	August 1981
3	**Droplet size analysis of emulsified acid**	S.H. Al- Mutairi, H.A. Nasr-El-Din, A.D. Hill	9 May 2009
4	**Effect of droplet size, emulsifier concentration, and acid volume fraction on the rheological properties and stability of emulsified acids**	S.H. Al- Mutairi, H.A. Nasr-El-Din, A.D. Hill	30 May 2007
5	**Effect of droplet size, emulsifier concentration, and acid volume fraction on the rheological properties and stability of emulsified acids 2**	S.H. Al- Mutairi, H.A. Nasr-El-Din, A.D. Hill	November 2008
6	**High performance emulsifiers for synthetic based muds**	Nigel Evans, Bruno Langlois, Annie Audibert-Hayet, Christine Dalmazzone, Eric Deballe	1 October 2000
7	**Improved stability of invert emulsion fluids**	Ryan Van Zanten, Jeff J. Miller, Chris Baker	6 March 2012
8	**New opportunities for the drilling industry through innovative emulsifier chemistry**	Arvind Patel, Syed Ali	5 February 2003
9	**Special non-polluting emulsifier for non-aqueous drilling fluids in deep offshore drilling**	A Audibert, C Dalmazzone, D Dalmazzone, C Dewattines	26 September 2004
10	**Study of water in diesel emulsion stabilized by**	Ahmad Nizar bin Yunus	May 2011

	surfactant		
11	**A Solid Emulsifier Used to Improve the Performance of Oil-in-Water Drilling Fluids**	Jiennian Yan, Fuhua Wang, Guancheng Jiang, SPE	February 1997
12	**Advances in Invert Emulsion Performance Through Novel Emulsifier Chemistry**	Steve Young, Guindo De Stefano, John Lee	March 2012
13	**Emulsion Drilling Fluid**	Doyne L Wilson	Not stated
14	**Fighting Wellbore Instability-Customizing Drilling Fluids Based on Laboratory Studies of Shale-Fluid Interactions**	Sandra Gomez, Wenwu He	July 2012
15	**Formation Damage Caused by Emulsions During Drilling With Emulsified Drilling Fluids**	Ingebret Fjelde	June 2009
16	**New Advancements in Emulsifier Technologies**	N. Rife, S. Young	March 2011
17	**New Drilling Fluid Technology Mineral Oil Mud**	R. B. Bennet	Not stated
18	**Operational Limits of Synthetic Drilling Fluids**	FB Growcock, TP Frederick	September 1996
19	**Physicochemical Properties of Synthetic Drilling Fluids**	FB Growcock, TP Frederick, SL Andrews	February 1994

2.4.1. A New Emulsified Acid to Stimulate Wells in Carbonate Reservoir (M. A. Sayed, 2012)

The high temperature of deep wells requires a special formulation of emulsified acid that can be stable and effective at such high temperature. At these temperatures, both the reaction and rate between acid and rock, corrosion rate of tubular are high. This fact makes reaction of tubular and reducing the reaction rate between rock and acid challenging. At temperature 200°F, there is a need to add more corrosion inhibitor and corrosion inhibitor intensifier, which increases the cost of the treatment too much.

2.4.2. An Analytical Method for Emulsifier Concentration in an Oil-Base Drilling Fluid (Matherly, 1981)

Invert emulsion fluids contain special surfactant that permit the formation of the water-in-oil emulsion and maintain its stability. The internal water phase of the emulsion typically is a sodium chloride or calcium chloride brine. Only a small quantity of emulsifier is required for an invert emulsion. Overtreatment with emulsifiers is costly. Under treatment is even more costly if it results in failure of the emulsion and consequent water-wetting and settling of barite and drilled solids. Heretofore, there has been no procedure for determining the emulsifier content in invert emulsion drilling fluids. Interferences by the oil itself precluded determination.

2.4.3. Droplet size analysis of emulsified acid (S. H. Al-Mutairi, Droplet Size Analysis of Emulsifier Acid, 2009)

The droplet has a practical impact on the performance of emulsified acid. Good understanding and characterization of the emulsified acid by its size distribution will lead to better understanding of its stability, rheology and reactivity. In this paper, they showed that:

a) Coarse or fine emulsions can be produced by selecting the mode of mixing and speed of shearing.
b) Simple mixing and low shearing produced coarse emulsions whereas atomizing and high shearing produced fine emulsions.
c) The droplet size decreased with increasing emulsifier concentration and acid volume fraction.
d) Average droplet size decreased with increasing emulsifier concentration and increased with increasing acid volume fraction.

The specific surface area of the droplets increased with increasing emulsifier concentration and decreased with increasing acid volume fraction.

2.4.4. Effect of droplet size, emulsifier concentration, and acid volume fraction on the rheological properties and stability of emulsified acids & Effect of droplet size, emulsifier concentration, and acid volume fraction on the rheological properties and stability of emulsified acids 2 (S. H. Al- Mutairi, 2007) (S. H. Al- Mutairi, 2008)

These two papers examined the impact of the droplet size and acid volume fraction in the characteristics of emulsified acids. The following conclusions were obtained:

a) Fine emulsions are more stable than coarse emulsions.
b) Emulsions with acid volume fraction close to 0.7 are more stable than others.
c) The viscosity of emulsified acid decreases with increasing droplet size of the emulsion system. Fine emulsions have higher viscosity than coarse ones.
d) The viscosity decreases with widening the size distribution of the emulsion.
e) Monodisperse emulsions have higher viscosity than polydisperse emulsions that are generated by mixing those monodisperse emulsions.
f) The viscosity of emulsified acid was found to increase as the acid volume fraction increases.

2.4.5. High performance emulsifiers for synthetic based muds (Nigel Evans, 2000)

The main characteristics of oil-based muds (OBM), i.e. high lubricity, low fluid loss, stability in adverse conditions and thin filter-cake, make them particularly suitable for HPHT wells and reservoir drilling. Nonetheless, as HP/HT conditions become more severe, problems of fluid stability start to occur in particular:

a) Loss of emulsion stability
b) Loss rheology control
c) Increased fluid loss leading to reservoir damage

These problems are generally related and often enhanced in certain parts of the well due to the geothermal gradient. In such conditions, hole cleaning problems and increased invasion of the reservoir by the lost fluid occur. Moreover, when the emulsion is destabilised, lost fluid consists in separate oil and water phases which can induce severe formation damage. Emulsion stability is due not only to the chemical stability of the emulsifier itself but also to different interface properties. OBM's are water-in-oil emulsions stabilised by emulsifier systems and colloid particles such as barite and clay mixture. The solids can be organophilic or wetted by a co-emulsifier and play an important role in emulsion stability due to their oil/water interfacial properties. When the emulsion is stable, the filter-cake is composed of colloid particles and water droplets dispersed in an oil phase. The water droplets are distorted with pressure but plug the cake pores and reduce its permeability. HP/HT reservoir conditions as well as increasingly stringent environmental regulations have led to the need for improved emulsifier systems.

2.4.6. Improved stability of invert emulsion fluids (Ryan Van Zanten, 2012)

The emulsifier content also impacts the rheological profile of invert emulsion fluids by bolstering the strength of the interface and providing oil-wetting tendencies to the surfaces of any hydrophilic solids present. Simple plot test have been done in this paper to propose previously to optimize the emulsifier content by a series of additions and rheological measurements. Below is the example of optimum emulsifier concentration test:

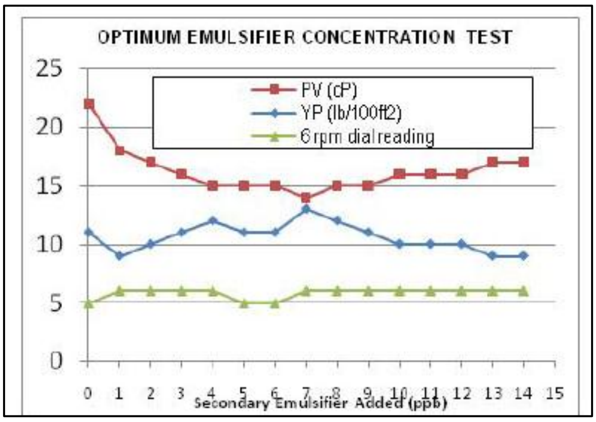

FIGURE 4 : Effect of emulsifier concentration on rheological properties

2.4.7. New opportunities for the drilling industry through innovative emulsifier chemistry (Patel & Ali, 2003)

A number of novel invert emulsion drilling fluids, including negative alkalinity and reversible invert emulsion drilling fluids have been developed through manipulation of surfactant chemistry. Negative alkalinity invert emulsion drilling fluids technology offers various advantages over conventional reserve alkalinity invert emulsion drilling fluids. The advantages include stable, lime-free OBM to combat the problems associated with acidic gases encountered during drilling.

2.4.8. Special non-polluting emulsifier for non-aqueous drilling fluids in deep offshore drilling (A. Audibert, 2004)

Oil based muds, generally formulated as invert emulsion, are difficult to stabilize over a large range of pressure and temperature conditions and especially at low temperature and high pressure where the formation of hydrate compounds may induce a destabilization of the emulsion and loss of well control. We developed a special non-polluting surfactant system that can be used whatever the oil phase composition.

2.4.9. Study of water in diesel emulsion stabilized by surfactant (Yunus, 2011)

The parameters that contribute towards stability are studied which includes the effect of water/diesel ratio, type of emulsifier, emulsifier dosage, stirring speed, stirring time and temperature .It is proven that this parameters have a great affect towards emulsion stability and each of the emulsion need to be tailor made with optimal parameters to produce a stable emulsion.

2.4.10. A Solid Emulsifier Used to Improve the Performance of Oil-in-Water Drilling Fluids (Jiennian Yan, 1997)

The types of emulsions formed are largely dependent on the wetting behaviour of particles. Oil-wet particles tend to stabilize water-in-oil emulsions, while water-wet particles tend to stabilized oil-in-water emulsions. Particles used for emulsion stabilization are typically a few micrometres or smaller in size. The coarse particles used in this study could not form emulsions. Particle concentration is also important factor affecting the stability of emulsions formed. In some cases, phase reversion may occur when the particle concentration changes to some extent. A suitable combination of solids and surfactants is beneficial to form more emulsions.

2.4.11. Advances in Invert Emulsion Performance Through Novel Emulsifier Chemistry (Steve Young, 2012)

There are many challenges to extending and improving the performance of invert emulsion fluids. This paper illustrates some of the new advancements in emulsifier technologies and how they can be used to tackle these challenges, overcoming some of the performance and usage issues that have either complicated or even prevented use of invert emulsions in the past. One common thread through these developments has been that the improved surfactants have allowed for an improvement in engineering understanding and control, resulting again in a step improvement in the consistency of performance of these systems. These new surfactants impart a better ability to tolerate solids and maintain rheological control and a low gel structure. Furthermore these emulsifiers are able to tolerate extreme temperatures, both hot and cold, as individual products and as a part of a formulated drilling fluid.

2.4.12. Emulsion Drilling Fluid (Wilson, not stated)

Emulsion drilling fluids are very flexible in their composition, preparation and properties. They are particularly well suited for top hole drilling in troublesome areas where formations wash badly or where tight hole conditions exist with normal claywater fluids. It has been demonstrated by Graham that “TO obtain a 75 percent reduction in water loss of the fluid, emulsion would be the most economical, followed by starch and sodium carhoxymethyl cellulose.” The use of emulsion drilling fluids is continuing to increase, and operators seem to agree that in troublesome areas their effectiveness lias been proven. Although some manufacturers recommend the use of their emulsions for completion work, it is the opinion of the author that these fluids are not ideal for drilling a pay zone due to the fact that the filtrate from all emulsions is essentially water, or aqueous solutions, which may materially reduce the productivity of the well. However, if an emulsion fluid is to be used for drilling the pay zone judicious care should be taken to select one that has the least blocking action on the formation, in which the emulsifier is chemically stable in the presence of contaminants, is easy to use, and economical to maintain.

2.4.13. Fighting Wellbore Instability-Customizing Drilling Fluids Based on Laboratory Studies of Shale-Fluid Interactions (Sandra Gomez, 2012)

Understanding the mineral composition, rock structure, and deformation feature of shale is an essential step in the design of drilling fluids which would help minimize the potential fluid-rock interaction and fracture development. These fluids can be further customized and selected through laboratory tests. Immersion test is one of the most efficient methods of evaluating fluid-rock interaction and fracture development. The physical and chemical changes observed in the immersion tests reflect the comprehensive effects of the rock properties (composition, structure, and deformation) on potential wellbore instability. This method has been successfully applied in selecting the proper drilling fluid with appropriate chemical additives for shale drilling.

2.4.14. Formation Damage Caused by Emulsions During Drilling With Emulsified Drilling Fluids (Fjelde, 2009)

Formation damage caused by emulsions has been studied for consolidated low-to-medium-permeability outcrop sandstone. Two types of emulsified drilling fluids were used one with MB oil and one with SB oil. Two STOs with different concentration of asphaltenes were used in the study. Macroemulsions have the potential to cause formation damage during drilling with emulsified drilling fluid. The emulsions in the studied mud systems were found to be stabilized by emulsifiers and particles (organoclay and drilled solids). The potential for emulsion invasion will highest during the spurt period and will increase with filtration pressure. Formation of emulsions inside oil reservoirs is also easiest at high shear rates. High concentrations of emulsifier in MF and/or reservoir oil will increase the potential. The risk for emulsion invasion and creation of emulsion during drilling can be reduced by avoiding high overbalanced pressure and minimizing the fluid loss, if the potential for creation of emulsions during production start is high, the mud components should be back produced al low drowdown. Formation damage caused by emulsion can be nonpermanent because they are thermodynamically unstable. The potential for permanent damage caused by emulsions is, therefore, lower at higher temperatures. Emulsions can also be destabilized by the reservoir oil. In bulk experiments, the stability of emulsions formed was found to depend on the compositions of both the emulsified drilling fluids and the crude oils. Emulsions were found to cause severe formation damage in corefloods at 90°C. This damage was partly removed during aging at higher temperatures. Emulsion stability appeared to be different in bulk systems and in corefloods. Used of synthetic oil instead of crude oil in laboratory experiments can give a wrong estimate of the potential for formation damage caused by emulsions. This is because the composition of reservoir oil can be important for formation and removal of emulsions. Short laboratory experiments can also give exaggerated potential estimates for formation damage caused by emulsions.

2.4.15. New Advancements in Emulsifier Technologies (N. Rife, 2011)

There are many issues with emulsifier packages that are extremely difficult to handle, some even unavoidable. This paper illustrates the new advancements in emulsifier technologies and how they are used to tackle these conventional problems of the previous generations of emulsifier packages. The emulsifier packages illustrated here are easier to engineer, and have better ability to handle solids and maintain low gel structure. Furthermore these emulsifiers are able to handle extreme temperatures, both hot and cold, as individual products and as a part of a drilling fluid. Lastly, with one emulsifier we are no longer bound to a 60:40 or lower oil: water ratio but can now raise the oil: water ratio as far as a 20/80.

2.4.16. New Drilling Fluid Technology Mineral Oil Mud (Bennet, not stated)

All these applications offer significant advantages of mineral-oil-based fluids over conventional water-based fluids. However, the conventional diesel-oil-based fluids offer the same advantages. Conventional oil-based fluids are formulated with diesel oil as the continuous oil phase. Diesel oil causes environmental problems because it is extremely toxic to marine life. Additionally, the cuttings must be specially treated to prevent discharge or separation of free oil in water. Diesel oil can also cause skin irritation; attack rubber parts, and produce a definite offensive odour. Mineral-oil-based fluids formulated with the specially refined paraffinic-based mineral oil and less-toxic additives provide an environmentally acceptable system, do not require the expensive cuttings-handling equipment and rig modifications, do not damage rubber components, and do not irritate the skin. They have a pleasant odour and are far less toxic to marine life.

2.4.17. Operational Limits of Synthetic Drilling Fluids (F. B. Growcock T. P., 1996)

Commercial synthetic fluids currently cost 3 to 6 times more than low-toxicity mineral oils. However, with good solids control equipment, SBM's can be used repeatedly tu such an extent that their net cost is not very different that the net cost of an LTMO-based mud. Nevertheless, loss of synthetic fluid is much more detrimental to the economics of a drilling operation than is loss of an LTMO, and it is prudent to avoid the use of an SBM in an area where high losses are expected. All of the synthetic fluids discussed here are stable at temperatures of up to at least 425°F. On the other hand, most conventional emulsifiers begin to chemically degrade at 150 to 300°F. Nevertheless, it is possible to formulate SBM's for all the synthetic fluids in the laboratory so that possess satisfactory emulsion stability and sufficient carrying capacity to at least 300 to 350°F. Field muds of the same compositions are expected to have higher emulsion stability and carrying capacity than lab muds because of the stabilizing effects of added solids and circulation of the mud through the drill bit. Consequently, in the field it may be possible to extend the temperature range of the SBM's further.

2.4.18. Physicochemical Properties of Synthetic Drilling Fluids (F. B. Growcock T. P., 1994)

Synthetic fluids and SBM's appear to be more biodegradable and more dispersible in seawater than mineral oils and mineral OBM's. Synthetic fluids and SBM's are more viscous at ambient temperatures than conventional OBM's, but they also thin more readily with increasing temperature. Standard low-shear rheology modifiers flatten the temperature profile to enable formulation of muds that provide good suspension characteristics at elevated temperatures, yet are thin enough to pump at low temperatures. SBM's can be formulated with conventional emulsifiers so as to give acceptable emulsion stability (HTHP fluid loss and electrical stability) at 300 to 350 F. However, to keep fluid loss < 10 cc/30 min, high emulsifier concentrations are needed (as high as 20 Ib/bbl) along with an asphaltic/coal product and a low-shear rheology modifier. The temperature limits of SBM's are not imposed by the synthetic fluids, which are shown to be quite stable even after long exposure to 425 F. Many of the emulsifiers, however, show signs of chemical degradation at temperatures as low as 200 F. SBM's do not hydrate or dehydrate shale as well as conventional OBM's, but water transport can be increased by decreasing the emulsifier concentration or using a less efficient emulsifier. Thermal stability and dispersibility in seawater are affected in opposite ways by most emulsifiers; to formulate SBM's which exhibit optimum thermal stability and dispersibility in seawater, both *W/O*- and OIW-stabilizing emulsifiers may be needed.

3. METHODOLOGY

Research and study have been done in order to mix the oil or synthetic based mud. For this project there are primary emulsifier and secondary emulsifier. All the emulsifier will be test at the ratio as below:-

TABLE 2: Ratio of Combinations for Testing

Ratio of combinations for testing		Primary emulsifier	
		4	8
Secondary emulsifier	4	4:4	8:4
	8	4:8	8:8

So the testing ratio will be at 4:4, 4:8, 8:4, and 8:8. The testing temperature for this project will be at 275°F, 300°F, and 325°F. For the rheology testing, the test temperature will be only at 120°F.

For this project, it includes two main processes which are mud preparation and mud testing.

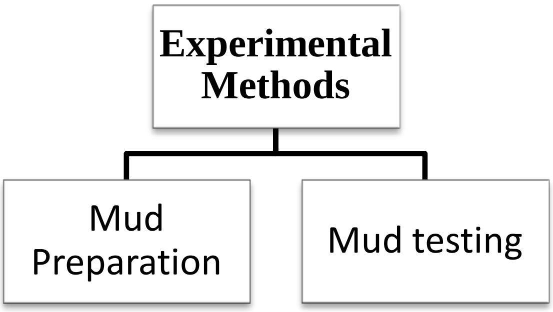

CHART 1: Experimental Methodology

3.1. Mud Preparation

The addition of components in their proper sequence mixing an oil mud will optimise the performance of each product. The order of addition as listed below is the most common procedure for preparation of oil or synthetic-based mud. (SCOMI OILTOOLS SDN BHD, 2008)

1. Add the required quantity of based fluid to the mixing cup.
2. Add the primary emulsifier and secondary emulsifier as required.
3. Add organophilic viscosifier as required.
4. Add lime as required.

5. Add required amount of water and salt powder to make brine and add after the lime additions.
6. Mix above for 20 minutes to ensure a good emulsion is formed.
7. Add weighting material as required for the desired density.

TABLE 3: Mixing Procedure

<table>
<tr><th rowspan="2">Products</th><th rowspan="2">Specific Gravity</th><th colspan="2">Beach Mixer</th></tr>
<tr><th>Order</th><th>Time, min</th></tr>
<tr><td>Saraline 185 V</td><td>0.77</td><td>1</td><td>0</td></tr>
<tr><td>Primary Emuslifier</td><td>0.92</td><td>2</td><td rowspan="2">5</td></tr>
<tr><td>Secondary Emusifier</td><td>0.92</td><td>3</td></tr>
<tr><td>Viscosifier</td><td>1.70</td><td>4</td><td>5</td></tr>
<tr><td>Lime</td><td>2.30</td><td>5</td><td>3</td></tr>
<tr><td>Water</td><td>1.00</td><td rowspan="2">6</td><td rowspan="2">20</td></tr>
<tr><td>CaCl2</td><td>2.15</td></tr>
<tr><td>Barite</td><td>4.2</td><td>8</td><td>2</td></tr>
<tr><td>Rev Dust</td><td>2.6</td><td>7</td><td>25</td></tr>
<tr><td></td><td></td><td>total</td><td>60</td></tr>
</table>

3.2. Mud Testing

After the mixing procedure is done the mud testing that need to be done (SCOMI OILTOOLS SDN BHD, 2008):-

1. Rheology: used the Motor Driven Fann 6 speed Viscometer to get the rheological properties of the mud at temperature 120°F.
2. HTHP filtrate: used the HTHP Filter Press to get the filtrate amount of the mud at the temperature of testing.
3. Emulsion stability: used the Electrical Stability Meter to get the emulsion stability of the mud at temperature 120°F.
4. Hot rolled: used the oven to hot roll the mud at desired temperature to indicate the drilling process in field.
5. Repeat the test from step 2 till step 4 for after hot-rolled mud.

Make sure all the equipment had been calibrated before used to get the precise data.

3.3. Tools, Equipment and Chemicals

The tools and equipment that are needed for the whole experiment are (SCOMI OILTOOLS SDN BHD, 2008):-

1. Mixing cup
2. Weighing machine
3. Silverson Mixer
4. Fann 35, 110 volt or 120 volt, powered by two speed synchronous motor to obtain speeds of 3, 6, 100, 200, 300 and 600 rpm.
5. Mud cup
6. Thermometer
7. Electrical stability meter
8. HTHP Filter Press
9. HTHP Filtration Cell – Diameter 3" x Height 3"
10. OFI specially hardened filter paper – diameter 2.5" / filtration area 4.91 sq.in
11. High pressure CO_2 supply (more than 600 psi – 4138 kPa)
12. Stop clock
13. 10 and 25 ml measuring cylinders

The chemicals that are required for the whole experiment are (SCOMI OILTOOLS SDN BHD, 2008):-

1. Based oil
2. Brine
3. Viscosifier
4. Emulsifier
5. Lime
6. Weighting agents
7. Water
8. Salt

The water and salt is mixed first to become brine before add to the mud.

3.4. Project Activities and Key Milestones

Several targets have been set for the FYP I and FYP II. The schedule is as below:-

TABLE 4: Project Activities and Key Milestones for FYP I

No	Detail / Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of project topic								M							
2	Preliminary research work								I							
3	Literature review								D							
4	Submission of extended proposal															
5	Proposal defence								S							
6	Project planning								E							
7	Submission of interim draft report								M							
8	Submission of interim report															

Legends:-

Project activities

Key milestones

TABLE 5: Project Activities and Key Milestones for FYP II

No	Detail / Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Project work continues								M								
2	Submission of progress report								I								
3	Project work continues								D								
4	Pre-SEDEX																
5	Submission of draft report								S								
6	Submission of dissertation (soft bound)								E								
7	Submission of technical paper								M								
8	Oral presentation																
9	Submission of dissertation (hard bound)																

Legends:-

Project activities

Key milestones

4. RESULT AND DISCUSSION

4.1. Rheological Changes Analysis at All Ratio and Temperature

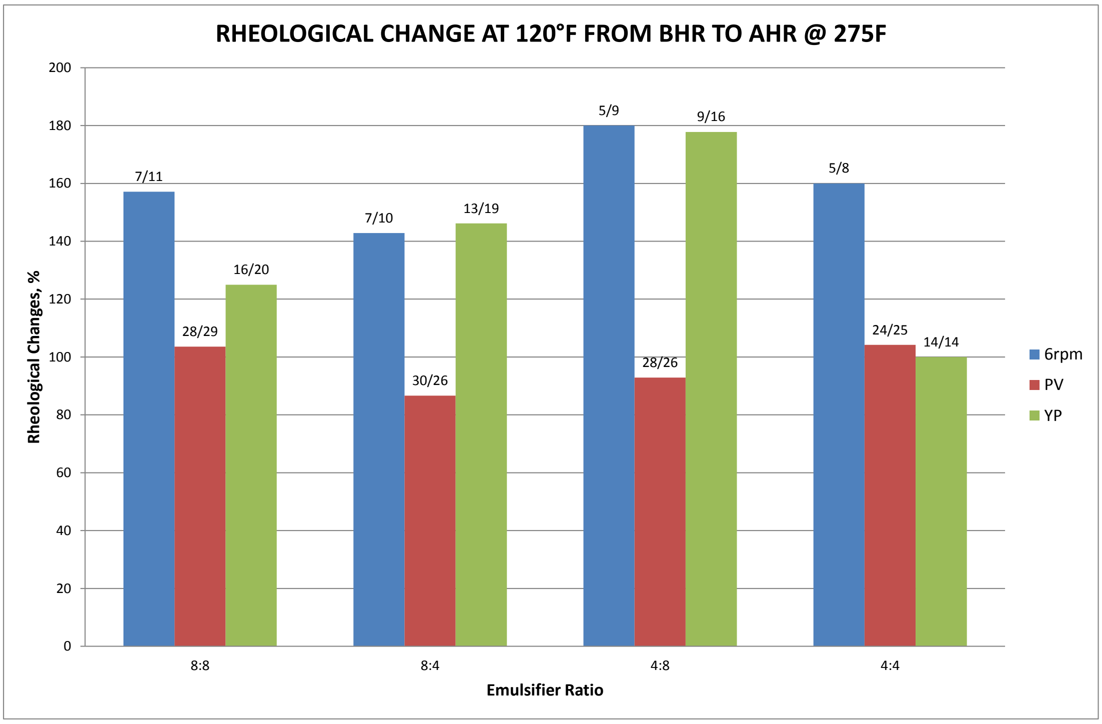

FIGURE 5: Rheological Change @ 120°F from Before Hot Rolled to After Hot Rolled Mud @ 275°F

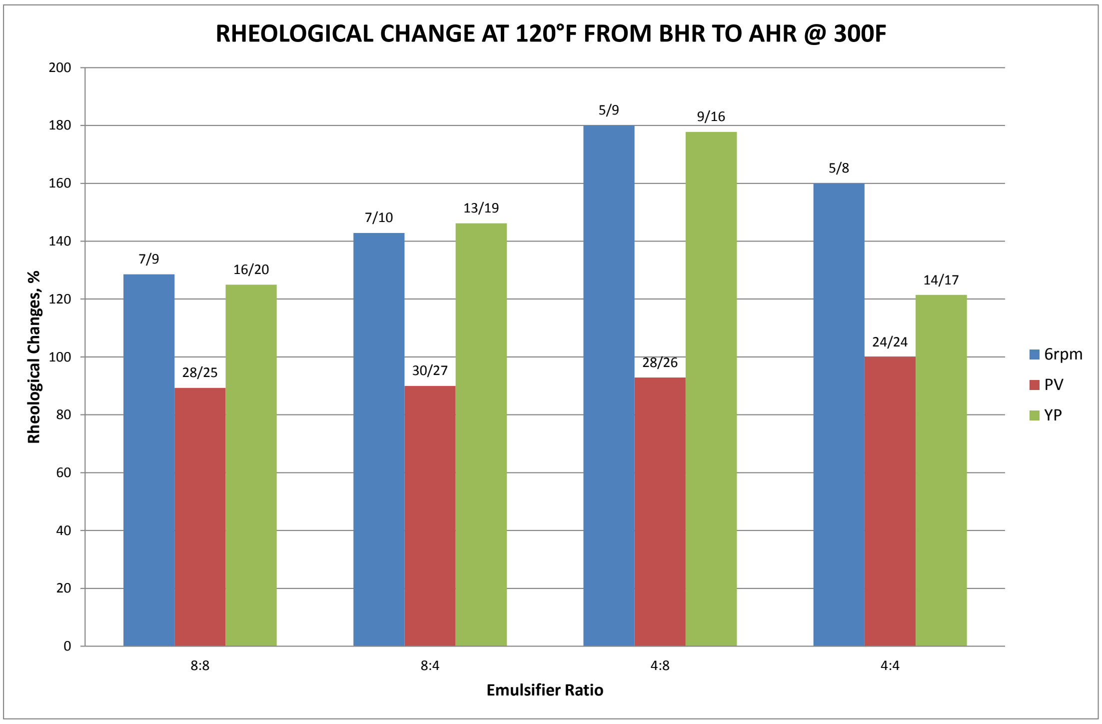

FIGURE 6: Rheological Change @ 120°F from Before Hot Rolled to After Hot Rolled Mud @ 300°F

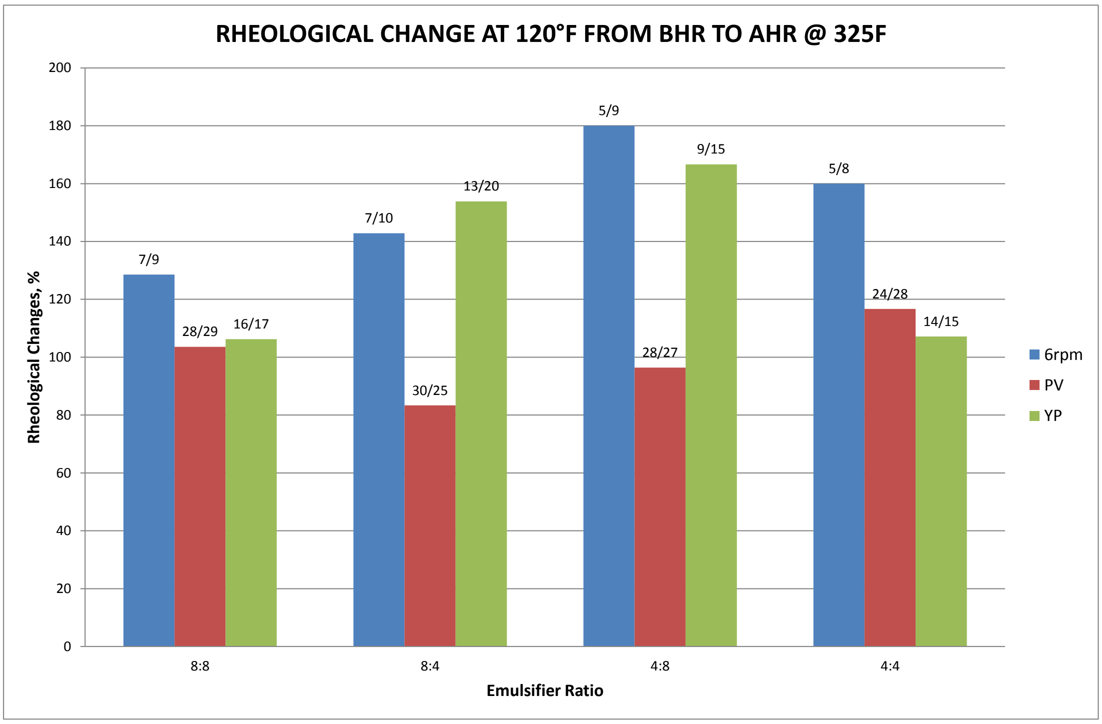

FIGURE 7: Rheological Change @ 120°F from Before Hot Rolled to After Hot Rolled Mud @ 325°F

From the rheological change analysis, the changes of all the value for 6 rpm, Plastic Viscosity (PV), and Yield Point (YP) is not so much change. The biggest change is 80% which also made by the 4:8 emulsifier ratio. Even though 4:8 emulsifier ratio has the biggest changes but the change is not so much which is acceptable in industry.

4.2. Gel Strength at All Ratio and Temperature

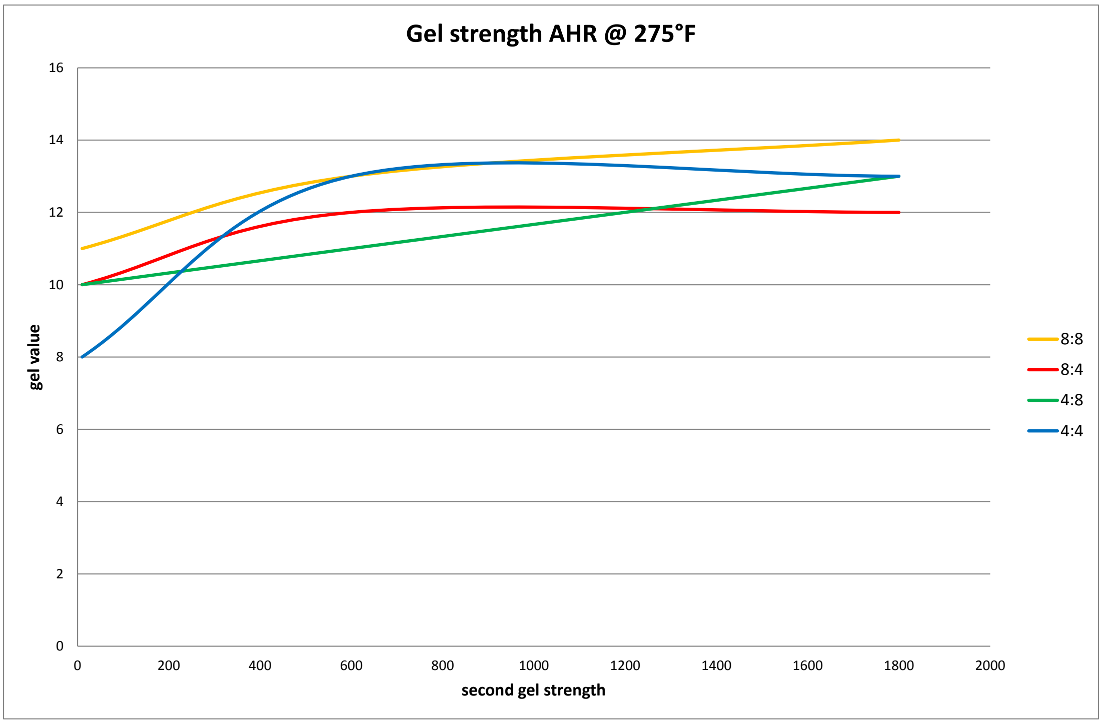

FIGURE 8: Gel Strength @ 275°F

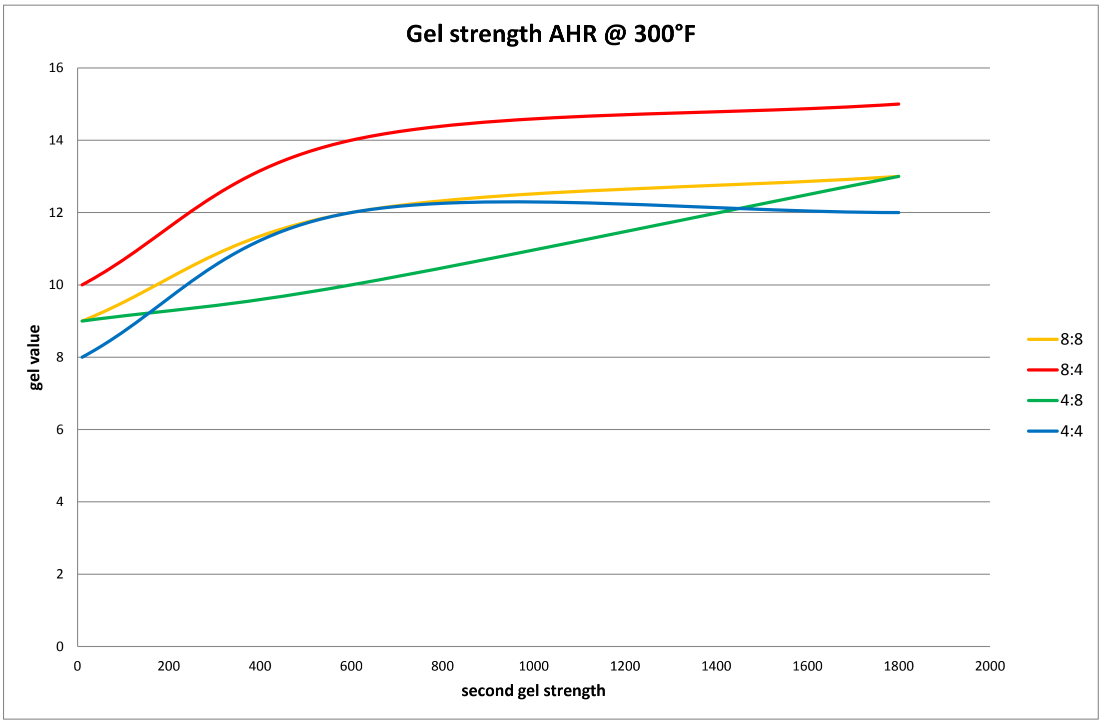

FIGURE 9: Gel Strength @ 300°F

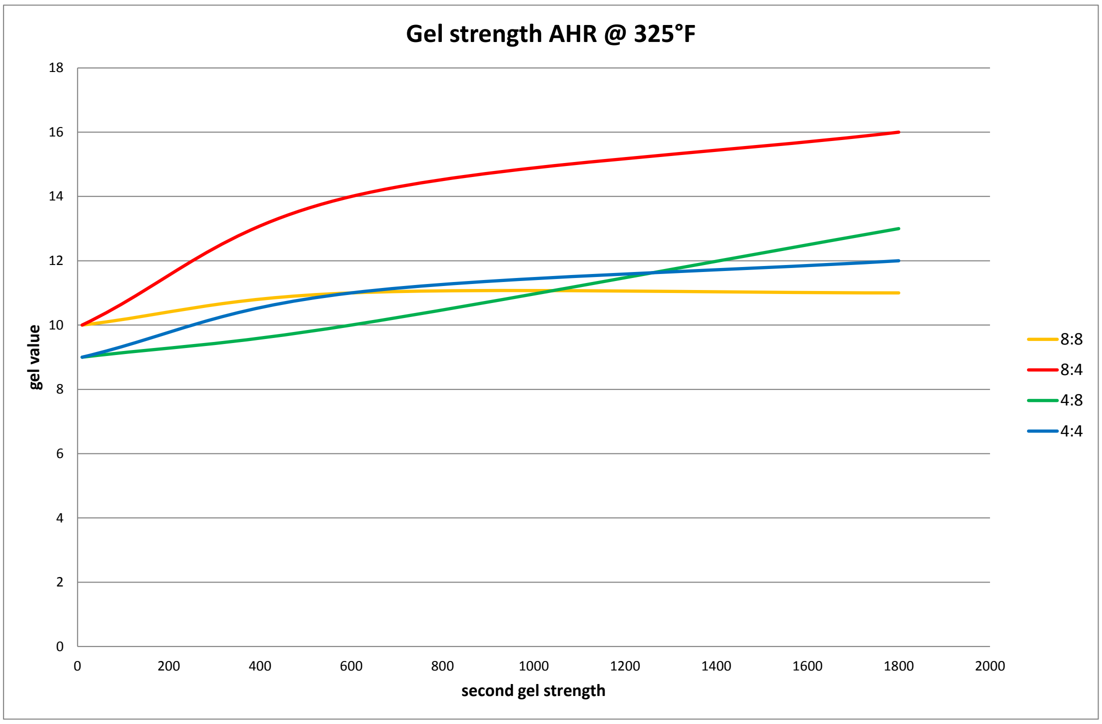

FIGURE 10: Gel Strength @ 325°F

From the experiment results, it shows that the 8:8, 8:4, and 4:4 emulsifier ratio's gel strength is stable which the gel strength does not increase extremely or can be said as not progressive. For the 4:8 emulsifier ratios' gel strength it is more progressive than the other. This can be seen from the Graph 1, Graph 4, and Graph 7 where the green line is increase more rapid than the other line. But it still can be accept because the increasing gel strength value is still not so rapid and controllable.

4.3. Electric Stability Test and Filtration at All Ratio and Temperature

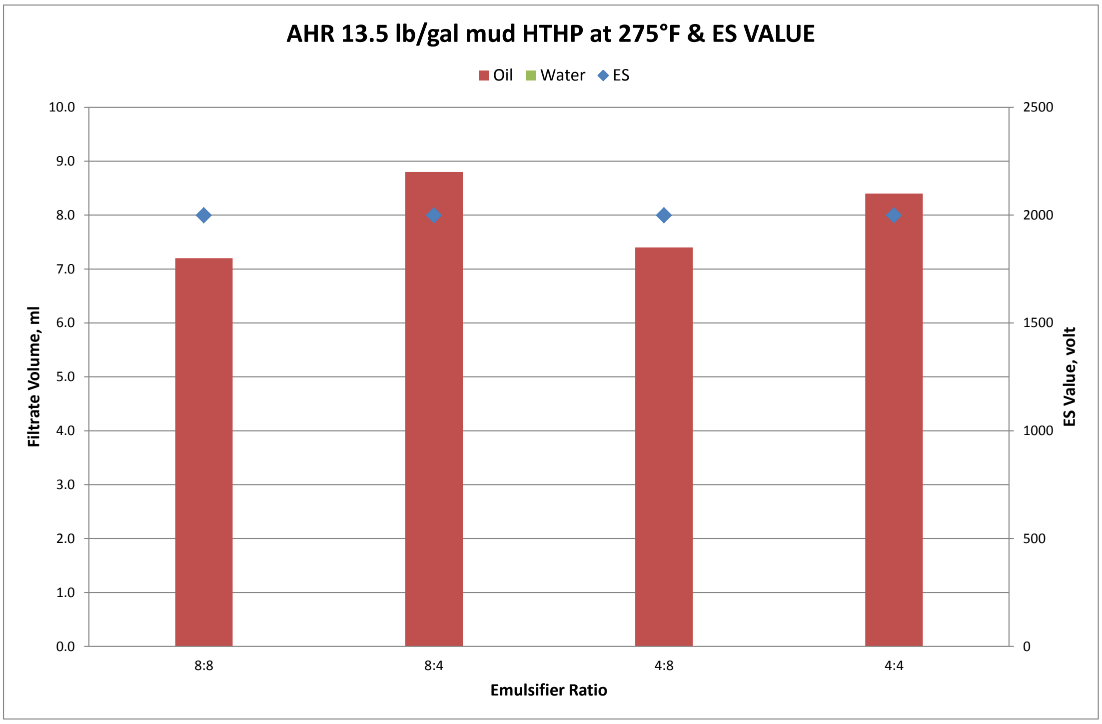

FIGURE 11: HTHP @ 275°F and ES Value for After Hot Rolled Mud

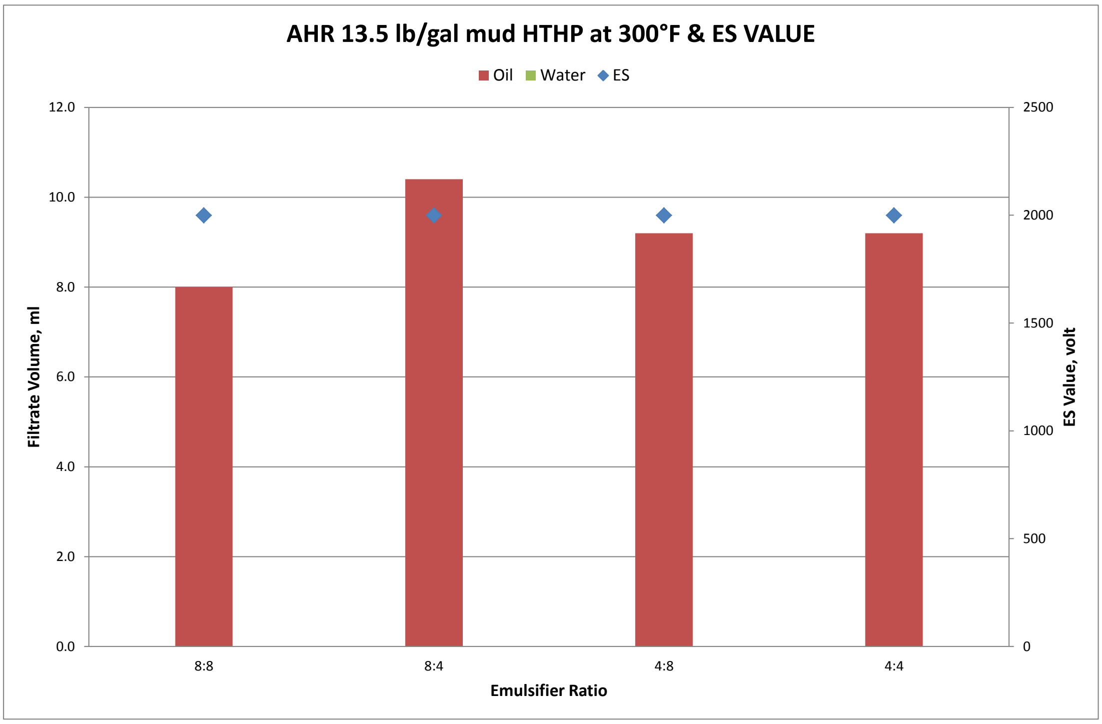

FIGURE 12: HTHP @ 300°F and ES Value for After Hot Rolled Mud

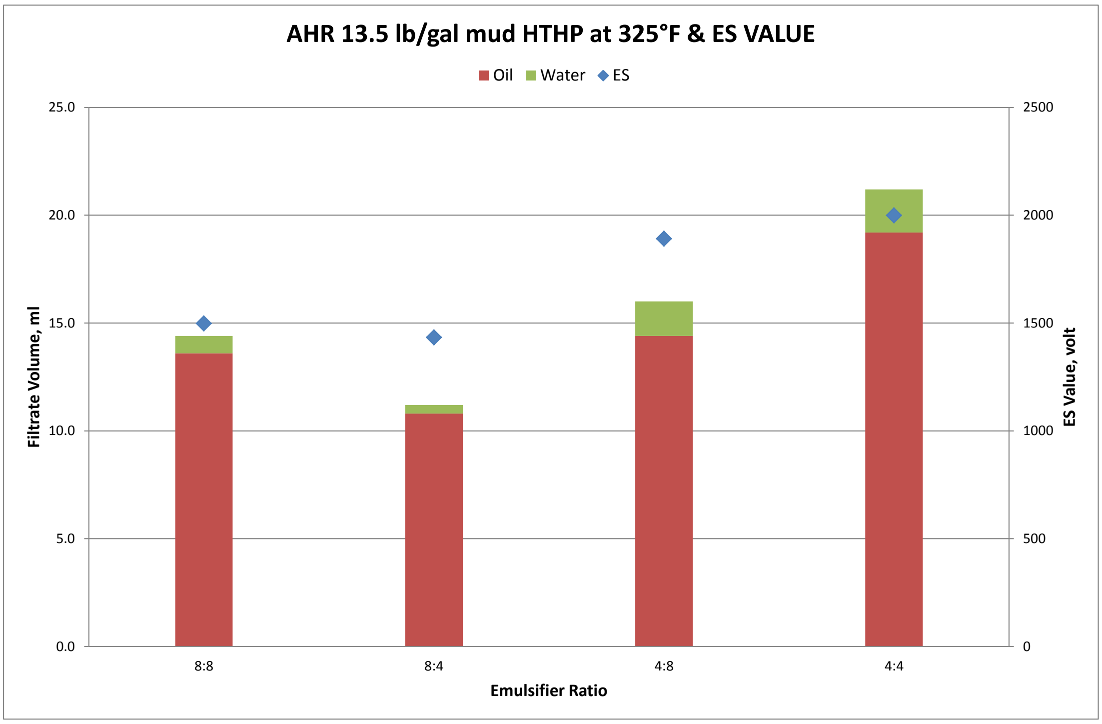

FIGURE 13: HTHP @ 325°F and ES Value for After Hot Rolled Mud

The Electrical Stability Test show a very good result where the values are all maximum accept at temperature 325°F where the value is drop accept for the 4:4 emulsifier ratio. The things that need to be realised is even though the Electric Stability value had drop but the drop is not too big where the value still above 1000 volt.

Filtrate that had been collect is good because there is no water inside the filtrate at 275 and 300°F which so that the primary and secondary emulsifier working well in the mud. For the testing at 325°F, the filtrates start to show free water in the filtrate. This shows that the emulsifier start to degrade caused by the high temperature.

As we can see for the temperature 300°F and below, when the amount of primary emulsifier is decrease, the filtrate is increase a little bit. This is because the primary emulsifier has a secondary function to oil wet the solid in mud. When the amount of secondary emulsifier is decrease the filtrates goes up so much because of the primary function of secondary emulsifier is to oil wet the solid in mud.

5. CONCLUSION AND RECOMMENDATION

From the result, I conclude that the best emulsifier ratio for the temperature 300°F and below is 8:8 or also can be considered as 1:1 ratio. Even though this ratio is the best, we still need to consider on the economical part. When come to economical part, the best ratio for temperature 300°F and below is 4:8 emulsifier ratio or 1:2 ratio. This is because the result for 8:8 and 4:8 emulsifier ratios is not so much different or can be said as almost the same. For example, the filtrate volume for 8:8 emulsifier ratios is 7.2 ml while 4:8 emulsifier ratios are 7.4 ml.

For the temperature above 300°F, the best emulsifier ratio is 8:4 or also can be said as 2:1 ratio. This is because this ratio shows the good result at this temperature.

TABLE 6: Best Ratio for Each Temperature of Testing

Testing Temperature	The Best Ration for Primary and Secondary Emulsifier
275°F	1:2
300°F	1:2
325°F	2:1

Below is my recommendation for the future of this project:-

1. I hope that later there will be someone who can advance this experiment with more temperature variation.
2. I hope that one day there a person that can do some research on the emulsifier amount between the lab scale and field scale.
3. Hope that someday there will be a manual just to indicate the amount of emulsifier at specific temperature, condition (field or lab) and the ratio between them.

REFERENCES

[1] A. Audibert, C. D. (2004). *Special Non-Polutting Emulsifier for Non-Aqueous Drilling Fluids in Deep Offshore Drilling.*

[2] Bennet, R. B. (not stated). *New Drilling Fluid Technology Mineral Oil Mud.*

[3] Burke, C., & Veil, J. (1995). Synthetic-Based Drilling Fluids Have Many Environmental Pluses. *Oil & Gas Journal*, 59.

[4] Candler, J., Leuterman, A., Wong, S., & Stephens, M. (1990). Sources of Mercury and Cadmium in Offshore Drilling Discharges. *SPE Annual Conference* (p. 279). New Orleans: SPE.

[5] Clapper, D., & Salisbury, D. (1984). New Emulsifier are Finding Used in Oil-Based Muds. *World Oil*, 125.

[6] Daynes, R., Pratt, S., & Coates, J. (1987). *50/50 Oil/Water Ratio Invert Oil Emulsion Mud - A Useful Tool or a Sales Gimmick?* Offshore Europe: SPE.

[7] F. B. Growcock, T. P. (1994). *Physicchemical Properties of Synthetic Drilling Fluids.*

[8] F. B. Growcock, T. P. (1996). *Operational Limits of Synthetic Drilling Fluids.*

[9] Fjelde, I. (2009). *Formation Damage Caused by Emulsions During Drilling with Emulsified Drilling Fluids .*

[10] Jiennian Yan, F. W. (1997). *A Solid Emulsifier Used to Improve the Performance of Oil-in-Water Drilling Fluids.*

[11] M. A. Sayed, H. A.-E.-D.-M. (2012). *A New Emulsified Acid to Stimulate Wells in Carbonate Reservoir.*

[12] Matherly, R. (1981). *An Analytical Method for Emulsifier Concerntration in an Oil-Based Drilling Fluid.*

[13] N. Rife, S. Y. (2011). *New Advancements in Emulsifier Technologies.*

[14] Nigel Evans, B. L.-H. (2000). *High Performance Emulsifiers for Synthetic Based Muds.*

[15] Patel, A., & Ali, S. (2003). *New Oppotunitites for the Drilling Industry Through Innovative Emulsifier Chemistry.* Houston, Texas: SPE.

[16] Ryan Van Zanten, J. J. (2012). *Improved Stability of Invert Emulsion Fluids.*

[17] S. H. Al- Mutairi, H. A.-E.-D. (2007). *Effect of Droplet Size, Emulsifier Concentration, and Acid Volume Fraction on the Rheological Properties and Stability of Emulsified Acids.*

[18] S. H. Al-Mutairi, H. A.-E.-D. (2008). *Effect of Droplet Size, Emulsifier Concentration, and Acid Volume Fraction on the Rheological Properties and Stability of Emulsified Acids 2.*

[19] S. H. Al-Mutairi, H. A.-E.-D. (2009). *Droplet Size Analysis of Emulsifier Acid.*

[20] Sandra Gomez, W. H. (2012). *Fighting Wellbore Instability-Customizing Drilling Fluids Based on Laboratory Studies of Shale-Fluid Interaction.*

[21] SCOMI OILTOOLS SDN BHD. (2008). *Drilling Fluid Engineering Handbook.*

[22] Steve Young, G. D. (2012). *Advances in Invert Emulsion Performance Through Novel Emulsifier Chemistry.*

[23] Wilson, D. L. (not stated). *Emulsion Drilling Fluid.*

[24] Yunus, A. N. (2011). *Study of Water in Diesel Emulsion Stabilized by Surfactant.*

APPENDICES

FIGURE 14: Viscometer

FIGURE 15: Electric Stability Meter

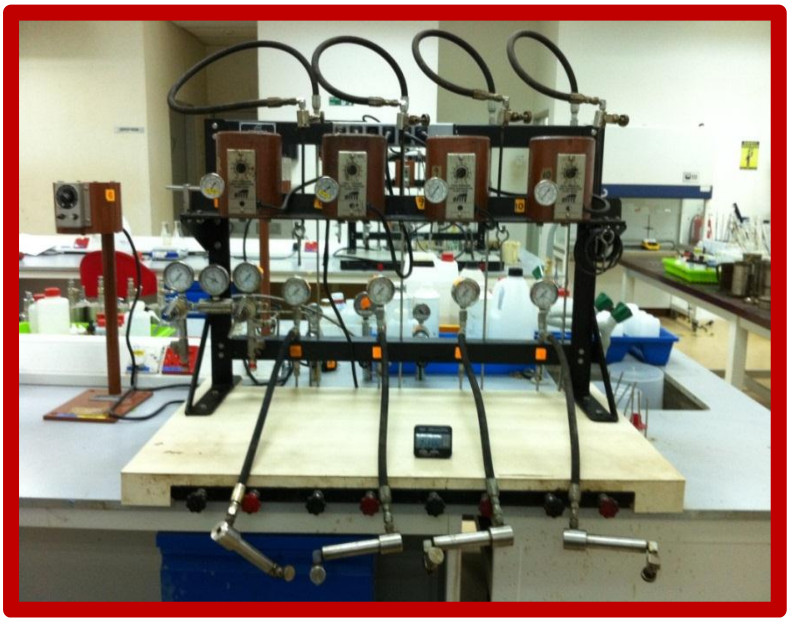

FIGURE 16: HTHP Filter Press

FIGURE 17: Oven

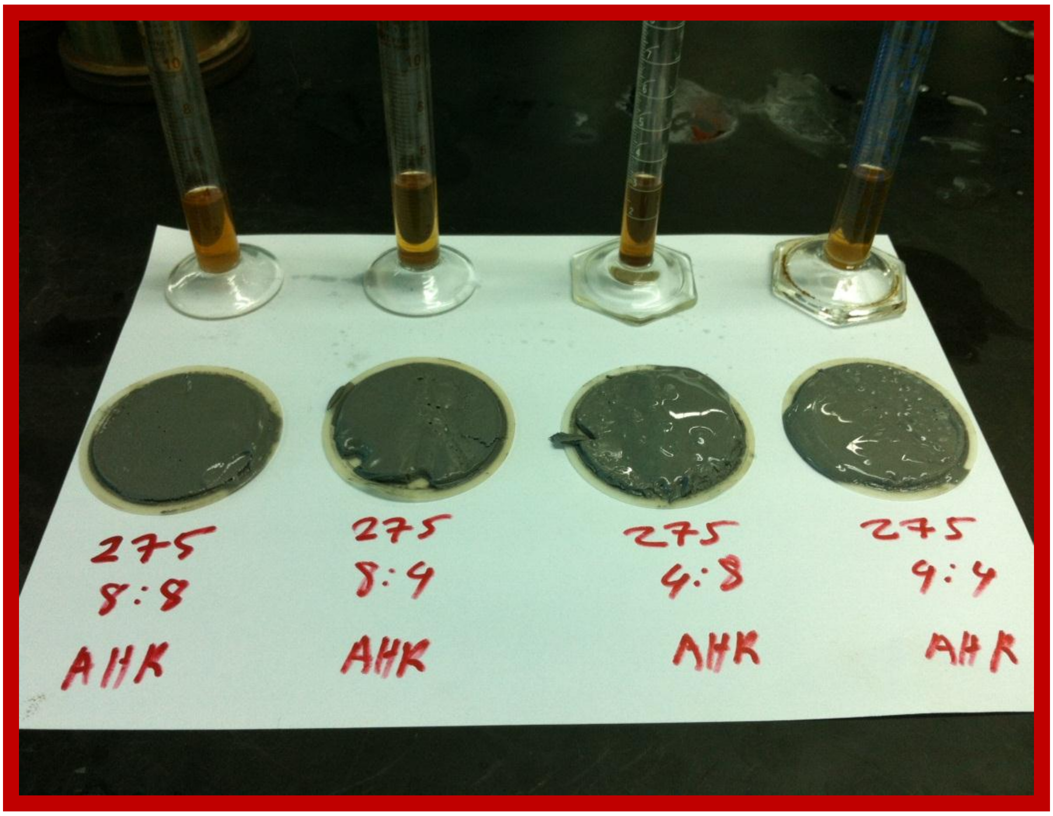

FIGURE 18: HTHP Result (filtrates and mud cake) @275F

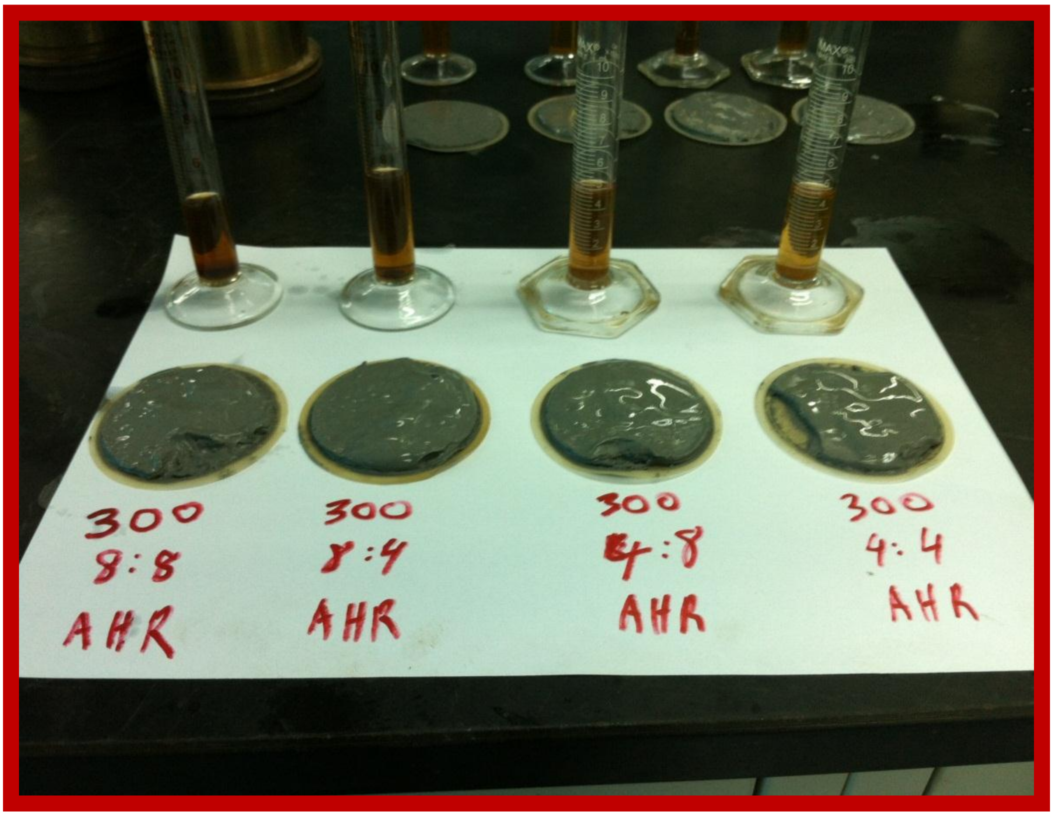

FIGURE 19: HTHP Result (filtrates and filter cake) @300F

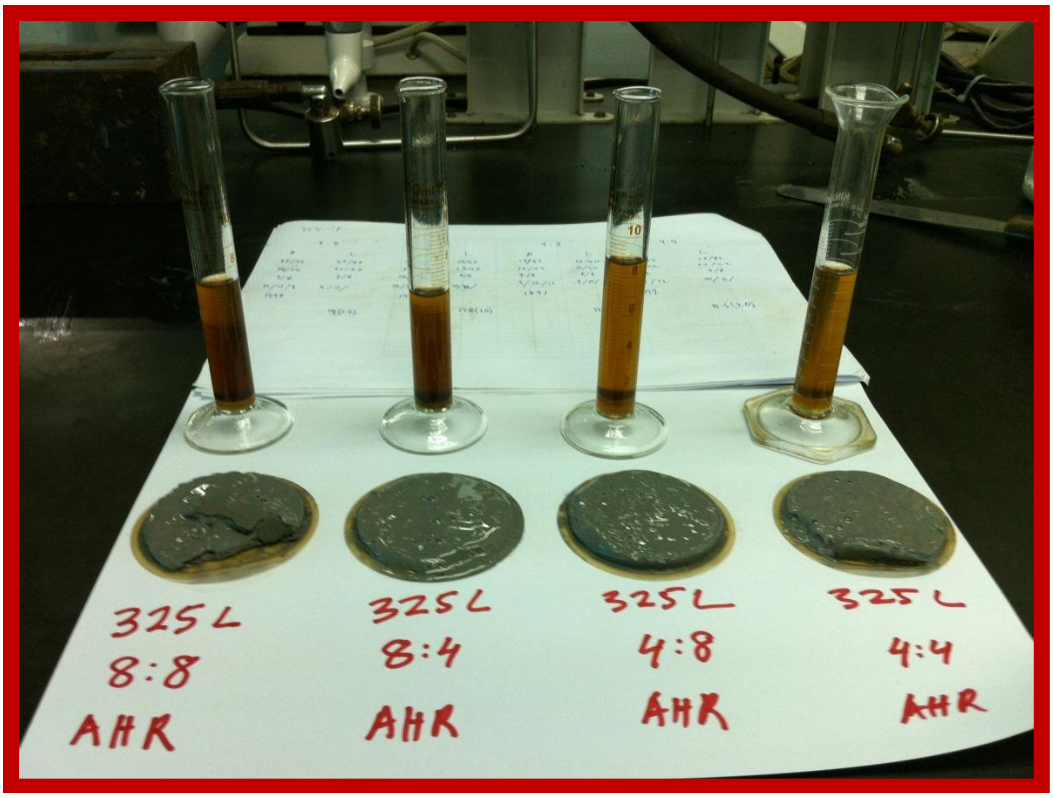

FIGURE 20: HTHP Result (filtrates and mud cake) @325F

		Emulsifier (8 : 8)		Emulsifier (8 : 4)		Emulsifier (4 : 8)		Emulsifier (4 : 4)	
Products	**SG**	**1**		**2**		**3**		**3**	
Saraline 185 V	0.77	151.12		154.45		154.45		157.78	
Primary Emulsifier	0.92	8.00		8.00		4.00		4.00	
Secondary Emulsifier	0.92	8.00		4.00		8.00		4.00	
Viscosifier	1.70	5.00		5.00		5.00		5.00	
Lime	2.3	10.00		10.00		10.00		10.00	
Fresh Water	1	51.27		51.24		51.24		51.21	
CaCl2	2.15	17.99		17.98		17.98		17.97	
Rev Dust	2.6	20.00		20.00		20.00		20.00	
Barite	4.2	295.61		296.33		296.33		297.04	
Properties Initial Properties AHR, 16 hr, 275 °F	**Spec Base**	**BHR**	**AHR**	**BHR**	**AHR**	**BHR**	**AHR**	**BHR**	**AHR**
Mud density, lb/gal	**13.50**								
Rheological properties at									
600 rpm dial reading		72	78	73	71	65	68	62	64
300 rpm dial reading		44	49	43	45	37	42	38	39
200 rpm dial reading		33	38	33	35	28	32	26	30
100 rpm dial reading		21	26	21	24	17	22	17	20
6 rpm dial reading		7	11	7	10	5	9	5	8
3 rpm dial reading		6	10	6	9	4	8	4	7
Plastic viscosity, cP		28	29	30	26	28	26	24	25
Yield point, lb/100ft2		16	20	13	19	9	16	14	14
10" gel strength, lb/100ft2		9	11	9	10	6	10	7	8
10' gel strength, lb/100ft2		15	13	8	12	14	11	14	13
30' gel strength, lb/100ft2		19	14	22	12	16	13	16	13
ES, volt at 120 °F		1999	1999	1999	1999	1999	1999	1999	1999
HTHP (500 psi, 275 °F)		6	7.2	8.4	8.8	8	7.4	10.4	8.4
Mud cake thickness, mm		1.5	3	2	3	2	2	3	2
OWR	**80:20**								

FIGURE 21: Testing Result @ 275°F

		Emulsifier (8 : 8)		Emulsifier (8 : 4)		Emulsifier (4 : 8)		Emulsifier (4 : 4)	
Products	**SG**	**1**		**2**		**3**		**3**	
Saraline 185 V	0.77	151.12		154.45		154.45		157.78	
Primary Emulsifier	0.92	8.00		8.00		4.00		4.00	
Secondary Emulsifier	0.92	8.00		4.00		8.00		4.00	
Viscosifier	1.70	5.00		5.00		5.00		5.00	
Lime	2.3	10.00		10.00		10.00		10.00	
Fresh Water	1	51.27		51.24		51.24		51.21	
CaCl2	2.15	17.99		17.98		17.98		17.97	
Rev Dust	2.6	20.00		20.00		20.00		20.00	
Barite	4.2	295.61		296.33		296.33		297.04	
Properties Initial Properties AHR, 16 hr, 300 °F	**Spec Base**	**BHR**	**AHR**	**BHR**	**AHR**	**BHR**	**AHR**	**BHR**	**AHR**
Mud density, lb/gal	13.50								
Rheological properties at									
600 rpm dial reading		72	70	73	73	65	68	62	65
300 rpm dial reading		44	45	43	46	37	42	38	41
200 rpm dial reading		33	34	33	35	28	33	26	32
100 rpm dial reading		21	23	21	25	17	22	17	21
6 rpm dial reading		7	9	7	10	5	9	5	8
3 rpm dial reading		6	8	6	9	4	8	4	7
Plastic viscosity, cP		28	25	30	27	28	26	24	24
Yield point, lb/100ft2		16	20	13	19	9	16	14	17
10" gel strength, lb/100ft2		9	9	9	10	6	9	7	8
10' gel strength, lb/100ft2		15	12	8	14	14	10	14	12
30' gel strength, lb/100ft2		19	13	22	15	16	13	16	12
ES, volt at 120 °F		1999	1999	1999	1999	1999	1999	1999	1999
HTHP (500 psi, 300 °F)		7.2	8	8.8	10.4	8.4	9.2	10.4	9.2
Mud cake thickness, mm		3	3	2.5	3	3	2	3	2
OWR	80:20								

FIGURE 22: Testing Result @ 300°F

		Emulsifier (8 : 8)		Emulsifier (8 : 4)		Emulsifier (4 : 8)		Emulsifier (4 : 4)	
Products	**SG**	**1**		**2**		**3**		**3**	
Saraline 185 V	0.77	151.12		154.45		154.45		157.78	
Primary Emulsifier	0.92	8.00		8.00		4.00		4.00	
Secondary Emulsifier	0.92	8.00		4.00		8.00		4.00	
Viscosifier	1.70	5.00		5.00		5.00		5.00	
Lime	2.3	10.00		10.00		10.00		10.00	
Fresh Water	1	51.27		51.24		51.24		51.21	
CaCl2	2.15	17.99		17.98		17.98		17.97	
Rev Dust	2.6	20.00		20.00		20.00		20.00	
Barite	4.2	295.61		296.33		296.33		297.04	
Properties Initial Properties AHR, 16 hr, 325 °F	**Spec Base**	**BHR**	**AHR**	**BHR**	**AHR**	**BHR**	**AHR**	**BHR**	**AHR**
Mud density, lb/gal	13.50								
Rheological properties at									
600 rpm dial reading		72	75	73	70	65	69	62	71
300 rpm dial reading		44	46	43	45	37	42	38	43
200 rpm dial reading		33	36	33	35	28	33	26	32
100 rpm dial reading		21	24	21	24	17	22	17	22
6 rpm dial reading		7	9	7	10	5	9	5	8
3 rpm dial reading		6	8	6	9	4	8	4	7
Plastic viscosity, cP		28	29	30	25	28	27	24	28
Yield point, lb/100ft2		16	17	13	20	9	15	14	15
10" gel strength, lb/100ft2		9	10	9	10	6	9	7	9
10' gel strength, lb/100ft2		15	11	8	14	14	10	14	11
30' gel strength, lb/100ft2		19	11	22	16	16	13	16	12
ES, volt at 120 °F		1999	1498	1999	1433	1999	1891	1999	1999
HTHP (500 psi, 325 °F)		8.4	13.6(0.8)	9.2	10.8(0.4)	9.2	14.4(1.6)	12.8	19.2(2.0)
Mud cake thickness, mm		3	3	3	3	3	3	3	3
OWR	80:20								

FIGURE 23: Testing Result @ 325°F