ETRO as a New Oil-Based Drilling Fluid for High Pressure High Temperature and Deepwater Well

by

Afiq Hanafi Bin Mohd Ramli
11856
Petroleum Engineering

Supervisor
Dr. Sonny Irawan

A project dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Petroleum Engineering)

SEPT 2012

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
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CERTIFICATION OF APPROVAL

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Approved by,

……………………..
(Dr. Sonny Irawan)

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.

Regards,

…………………………………………

(Afiq Hanafi Bin Mohd Ramli, 11856)

ABSTRACT

Base oil is the base fluids used in an invert emulsion drilling fluids system. Instead of using water as the base fluid, base oil is used in order to minimize the clay swelling problem in drilling applications. However, each base oils has different physical and chemical properties which may affect the properties of the drilling fluid. It is important to compare the performance of the base oil in order to select the most suitable and compatible base oil for a particular application. The purpose of this study is to evaluate the performance and compatibility of the new ETRO compared to others such as Saraline 185V, Sarapar 147, Escaid 110, and YK-D80N as the base oil in High Temperature High Pressure (HTHP) and deepwater condition and also to observe the effect of each base oils towards the drilling fluid properties. For this study, there are some aspects of the base oil that should be considered in selecting the best and most suitable base oil to be used in the drilling fluids like the physical properties, environmental toxicity and biodegradability, viscosity and stability of the fluid. For this study, besides comparing the performance of the base oils, we are more focusing on proving the compatibility of the new ETRO as the new base oil option for the industry especially for HPHT and deepwater drilling applications. Standard procedures of testing the mud is followed where the mud will be tested at before and after hot rolled for 16 hours at certain temperature which may differ depending on the particular application.

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ABBREVIATIONS AND NOMENCLATURES

HPHT	High pressure high temperature
TH-1	Testing of mud sample no 1 for HPHT system
TD-1	Testing of mud sample no 1 for deepwater system
ppg	Pound per gallon
C	Carbon
ASTM	American Standard Testing Method
GC	Gas Chromatography
PVC	Polyvinyl Chloride
PPM	Parts per million
RPM	Revolutions per minute
API	American Petroleum Institute
OWR	Oil Water Ratio
wt %	Weight percent
SG	Specific Gravity

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Drilling fluid is a fluid that used to aid the drilling operation. A proper and extensive design of drilling fluid system is important in facilitating an operation to reach the desired geological objective at the lowest overall cost with emphasizing on safety issue. Drilling fluid is applied with the objective of removing the cuttings from the well, maintaining wellbore stability, controlling downhole formation pressures and also as a lubricant to the bit and drill string. Nowadays, drilling operations had become more challenging when they start to intrude the High Pressure High Temperature (HPHT) and deepwater condition. In line with the situation, a very good performance of drilling fluid is demanded and this is where the Oil Based Mud (OBM) had become the preferred system as they provide an excellent thermal-stability characteristics.

In order to have a good drilling fluid system, the base fluid selection can be one of the main criteria to make it possible. In this study, we are basically comparing the performance of the base oils which are Saraline 185V, Sarapar 147, Escaid 110, YK-D80N and new ETRO in different drilling fluid system. As we all know, each base oils has different physical and chemical properties. So that, throughout this study we are actually observing on what is the effect of having different properties of base oil towards the drilling fluid. Apart from that, we also would like to measure on how critical the base oil will affect the drilling fluid properties such as plastic viscosity, yield point, emulsion stability, high temperature high pressure (HTHP) filtrate and etc. Besides that, we are more focusing on the new ETRO in showing its compatibility to be a good base fluid for drilling fluid especially in HTHP and deepwater application.

Each base oils will be tested for their rheological properties and filtration loss through maintaining the mud formulation and composition as the basic principle to compare the performance of the base oils. Besides that, we also give specifications for each system as a guideline for us in comparing the base oil performance. In addition, the temperature used for each system is different and this can also help us on comparing the performance of the base oil at different temperature. From this, we expect to have a result that can provide us with the best or the most suitable base oil to be used in particular drilling applications.

1.2 PROBLEM STATEMENT

Based on the current scenario and situation of more challenging drilling applications, Oil Based Mud (OBM) had become the most preferred drilling fluid system and widely used in the industry over Water Based Mud (WBM). This is because OBM has impressive performance that can suit for HTHP and deepwater well application which are out of WBM capability. So, in order to have a good OBM system, one of the most important parts is the selection of the base fluid. The organism of choice of the base fluid depends on the particular local conditions as well as the technical needs of the particular application. The following criteria should be considered in order to choose the best base fluid for a particular application:

a. Environmental toxicity and biodegradability.
b. Viscosity of synthetics base fluid.
c. Stability of the fluid.
d. Physical properties.

The selection criteria are important as every base fluid has different physical and chemical properties that may affect the drilling fluid properties. This clearly indicates a need for us to compare the base oils performance in selecting the most compatible base oil that suit the particular application besides also provide low impact to the environment. In this study, we have choose several base oils that are commonly used for Malaysia operation which are Saraline 185V, Sarapar 147, Escaid 110, and YK-D80N to be compared with ETRO.

Besides that, as PETRONAS is in their research on developing new base oil product to be used for their operation, we have taken the opportunity to also compare the very new base oil manufactured by PETRONAS namely ETRO which are planned to be commercialize by post 2015. So we are also focusing on testing the compatibility of ETRO as the new base oil for drilling fluids.

1.3 OBJECTIVES

The objectives of this project are as follows:

i. To formulate drilling fluids with ETRO base oil in two different mud system for HPHT and deepwater well application.
ii. To measure initial and after hot rolled rheological properties, emulsion stability, and filtration characteristics of drilling fluids formulated.
iii. To compare the performance of ETRO with other commercial base oil for HPHT and deepwater well application.

1.4 SCOPE OF STUDY

The scope of study for this project can be divided into three parts. The first part is mainly to study and understand the base oil properties that may affect the drilling fluids properties. Besides that, the critical properties of the base oil that should be considered for the application in high pressure high temperature (HPHT) and deepwater well is also determined. Apart from that, drilling fluid system formulation is also designed and determined in the first part. The methodology in testing the drilling fluid formulated is also need to be clarified during the first part before continuing to the experimental work.

The second part of the study is basically associated with the experimental or laboratory works. The experiments will be conducted with different types of base oil which are ETRO, Saraline 185V, Sarapar 147, Escaid 110, and YK-D80N. The technical performance of the drilling fluid which includes rheological properties, emulsion stability, and filtration characteristics are tested. The testing parameter is basically depending on the application of the drilling fluid system where it’s include a specific temperature, mud weight, additives concentration, and also oil water ratio.

Lastly, for the third part is about the results assessment of the base oil. In this project, our main scope is to test the compatibility of ETRO as a new oil-based drilling fluid especially for HPHT and deepwater well. A part from that, we will also compare the performance of ETRO with other base oil in term of the rheological properties, emulsion stability and filtration characteristics for the specific applications.

1.5 RELEVANCY OF THE PROJECT

The relevancy of this project is shown by the needs of having a better mud performance in order for us to deal with the challenging drilling operation. From that situation, Oil-based mud (OBM) had become the most preferred mud system over the water-based mud (WBM) and selection of base oil in oil-based mud (OBM) may become a very important criterion in order to design a good drilling fluids. So it is relevance to study on the new ETRO as a new oil-based drilling fluid for the industry. This is because in term of the properties, ETRO shows a very good potential to be used as a new oil-based drilling fluid.

1.6 FEASIBILITY OF THE PROJECT

Moving to the feasibility of this project, ETRO oil-based mud study can be said as feasible to be done for final year project because it is rheologically modified in the university laboratory and the facilities is also proved to be available. Besides that, the rheological properties test, emulsion stability test, and HPHT filtration characteristics test is also feasible as it is expected to be completed within the time frame as mentioned in the project gantt chart. In term of chemicals requirement for this project, we have got endorsement to have Scomi's chemical sample for the all the testing stated in the methodology part. For the economic feasibility of ETRO to the industry, it is the least expensive invert emulsion systems as it is a diesel type base fluid compared to other enhanced synthetic base fluid. We also have been informed by the PETRONAS Base Oil that the price for this new ETRO will be much more cheaper compared to other base oil that available in the industry. So we can say that this project is very feasible for the industry.

CHAPTER 2

LITERATURE REVIEW

2.1 DRILLING FLUID FUNCTIONS

A properly designed and formulated drilling fluid is very important as it is the main fluid that is used to drill a well and without it, it is impossible for us to do drilling work. The functions of drilling fluid can be divided into two categories which are primary and secondary functions. The primary functions are as follows:

i) Transport cuttings from the well to the surface

Cuttings are generated when we drilled a formation by the bit. Each cuttings need to be removed from the wellbore in order to make sure well can be drilled smoothly. Besides that, if cuttings cannot be removed from the wellbore it may cause problems such as stuck pipe, bit broke and etc. So this is where the present of drilling fluid is needed in order to clean the wellbore by transporting the cuttings up to the surface. Here drilling fluid will be circulated down the drillstring and through the bit and the cuttings will be transported to the surface through the annulus.

ii) Control formation pressures

As we start drilling a hole, it will cause in formation pressures disturbance. So, it is very important for us to control the formation pressures as it may lead to formation damage or even worse to formation collapse if we unable to control the pressure. Basically, drilling fluid play their roles in controlling the formation pressures is by its hydrostatic pressure. Hydrostatic pressure is the force exerted by a fluid column and depends on the mud density and true vertical depth (Scomi Oiltools Sdn Bhd, 2008, sec. 2, p. 3).

iii) Maintain wellbore stability

Wellbore instability can occur due to the stresses acting on the formation. In order to manage this problem, the stresses should be balanced. So, drilling fluid must be formulated with the weight within the range to balance the stresses. In determination of ideal mud weight for a particular condition, mud weight window is normally used as reference. Besides that, wellbore instability during drilling also may cause problems such as packoffs, stuck pipe, excessive trip and reaming time, mud losses, poor logging and cementing condition, and etc.

While for the secondary functions of drilling fluids are summarize as below:

Table 1. Secondary Functions of Drilling Fluid (Scomi Oiltools, 2008)

Secondary Functions	Explanation
Support weight of tubular.	Drilling fluid buoyancy supports part of the weight of the drill string or casing.
Cool and lubricate bit and drilling strings.	The drilling fluid will lubricate the bit tooth penetration through rock and serves as a lubricant between the wellbore and drill string thus reducing torque and drag.
Transmit hydraulic horsepower to bit.	The hydraulic horsepower will generate at the bit is actually the result of flow volume and pressure drop through the bit nozzles. This energy will then be converted into mechanical energy which removes cuttings from the bottom of the hole and improves the rate of penetration.
Provide medium for wireline logging	The drilling fluid will help and provide

	medium for wireline logging. However, different types of fluids will give different result of logging due to the differing physical characteristics.

2.2 OIL BASED MUD (OBM)

As shown by its name, Oil Based Mud (OBM) is a mud that used diesel or mineral oil as the continuous phase. In recent year, the industry has commercially and widely used OBM as the preferred mud system over the water based mud (WBM) especially in order to deal with the challenging drilling operation. Besides that, OBM is also categorized under the invert emulsion mud as it has water as the internal phase and diesel or mineral oil as the external phase. There are many advantages of using OBM such as it help in minimizing clay swelling problem, stable at high temperature, provide high rate of penetration (ROP), and also can be recycled or reused for other wells. Usually, the major concern in using OBM is the environmental impact of the diesel and mineral oil but however action has been taken by having mud toxicity test for every OBM formulated. Moreover, the criterion of the base fluid used is normally the one with aromatic content less than 0.1%.

2.3 ETRO

(i) Properties of ETRO

ETRO is a refinery extracted oil and also the first base oil developed by PETRONAS for their operations. It is actually planned to be commercialized by post 2015. Up to now, it is still under the research and development program in order to get the best base oil that is compatible for drilling fluid application. Basically, it is type of premium diesel that going through some processes such as vacuum distillation, hydrotreating, catalytic dewaxing, hydrofinishing, and fractionation. One of the best properties for this new base oil is that it has an extremely low pour point (typically less than -42°C) compared to other base oil available in the market. This is actually due to the process of catalytic dewaxing where paraffin molecules are isomerized into iso-paraffin. This is somehow gives an advantage to ETRO as low pour point property is the parameter that make it suitable to be used in deepwater and low temperature drilling operation. Up to now, PETRONAS has developed the wider cut or range of ETRO where it has wide range of initial and final boiling point. The problem with this wider cut of ETRO is that it has low flash point property. However, the narrow cut of ETRO is now in the process of development which will provide a base oil with higher flash point property. Besides that, ETRO also has good properties where it has low viscosity with aromatic content less than 0.1%.

Table 2. Physical and Chemical Properties of ETRO (PETRONAS, 2012)

Base Oil		**ETRO (Wider Cut)**	
Physical Properties	**Units**	**Result**	**Method**
Physical state		Liquid at ambient temperature	
Density at 15 deg C	kg/m^3	804.2	ASTM D 1298
Colour		Colourless	
Odour		Odourless	
Saybolt colour		+30	ASTM D156
Initial Boiling Point	deg C	190	ASTM D86
Final Boiling Point	deg C	320	ASTM D86
Kinematic viscosity at 40 deg C	mm^2/s	2.485	ASTM D445
Sulphur	PPM	< 3	ASTM D3120
Aromatics	% m	< 0.1	SMS 2728
Pour point	deg C	-63	ASTM D97
Flash point	deg C	76	ASTM D93
Aniline Point	deg C	73	ASTM D611
Solubility in water		Insoluble	
Chemical Properties			
C10 & Lower	% m/m	8.26	GC X GC
C11-C14	% m/m	41.70	GC X GC
C15-C18	% m/m	37.45	GC X GC
C19-C20	% m/m	11.94	GC X GC
C21 & Higher	% m/m	0.65	GC X GC

(ii) Production of ETRO

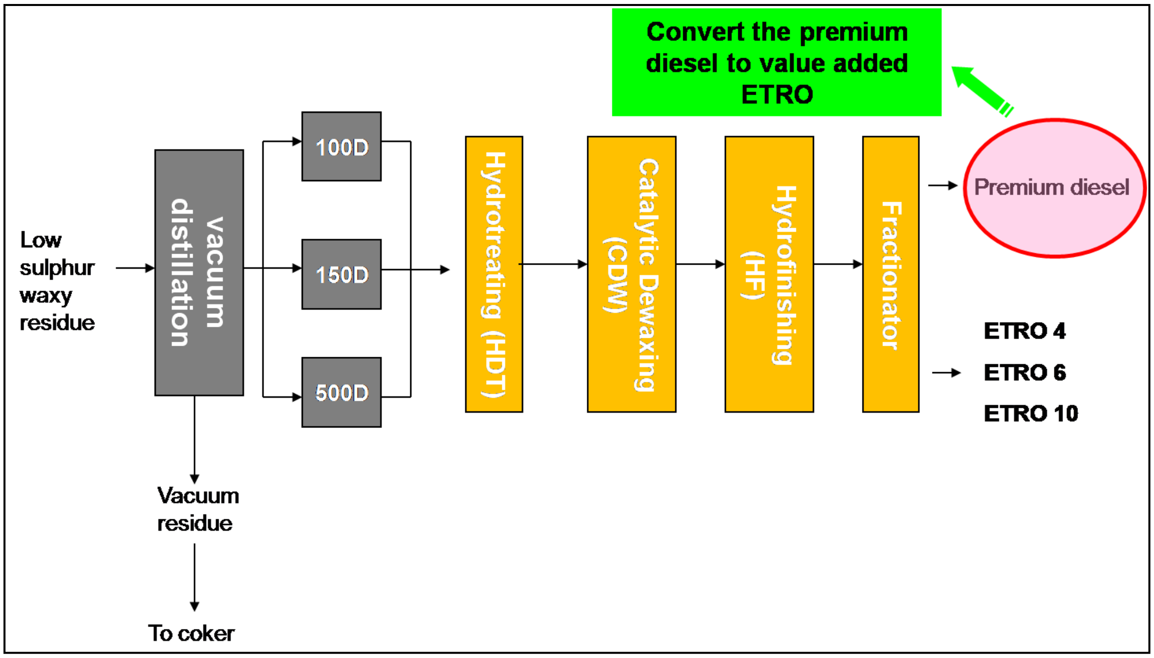


Figure 1. The process of ETRO production (PETRONAS, 2012)

Figure 1 show on how ETRO is produced which is actually going through some refinery units system. Basically, ETRO is produced from one of the PETRONAS base oil plant named as MG3 and it is a by-product base oil. Initially from a low sulphur waxy residue collected, it will go through the vacuum distillation unit where the product partial pressure is reduced via vacuum and stripping steam. Next, the process is done by batch, hence the base oil grade produce like ETRO 4, ETRO 6, and ETRO 10 will actually depend on which block there are on whether 100D, 150D, or 500D. Then they will go through the next unit which is hydrotreating unit (HDT). Basically, at this stage the main objective is actually to remove the contaminants and reduce aromatics in order to produce a clean product for further processing. After that, the product pour point is reduced through the process in the Catalytic Dewaxing Unit (CDW) where the paraffin molecules are isomerized into iso-paraffin molecules. This is where one of the critical stage of ETRO production where we want to have a very low pour point of product. After done with the CDW unit, the product will be processed in hydrofinishing unit (HF) in order to increase the stability of the product. Lastly, the last stage is going through the fractionators before the product is separated into ETRO categories and premium diesel. The base oil product is actually the most bottom draw of the fractionators and the premium diesel is then being converted to value added ETRO.

2.4 OTHER BASE OIL INVOLVED

(i) Saraline 185V

It is a mixture of hydrocarbons containing straight and branched chain of alkanes with chain length of predominantly C10 to C20 and produced by synthesis from natural gas and subsequent hydrotreatment. Saraline 185V is also a premium-quality of drilling fluid base oil that suitable to be used in deepwater drilling applications. This is as the result of having a low viscosity, a low pour point and relatively high flash point properties. Besides that, Saraline 185V is also a readily biodegrades fluids and contains virtually no aromatics and contaminants compound such as sulphur and amines. In addition, Saraline 185V is also classified as a synthetic base drilling fluid as it is produced from the reaction of a purified feedstock as opposed to highly refined or processed mineral oils, which are produced from the distillation or refining of crude oil. Nowadays, it has been widely used as a non-aqueous base fluid in an invert emulsion drilling fluid mostly in Malaysia, Thailand, Vietnam, Myanmar, Indonesia, Philippines, Bangladesh, India, Australia, New Zealand, and China.

(ii) Sarapar 147

For this base oil, it is also produced by synthesis from natural gas and subsequent hydrotreatment which contain straight chain of alkanes. Sarapar 147 is a premium-quality of drilling fluid base oil that suitable for high temperature high pressure (HTHP) wells but can only applicable for the use in shallow water drilling applications. Sarapar 147 is considered as clean base oil as it contains less sulphur and amines besides it also a readily biodegrades base oil. Besides that, it has a low viscosity, high flash point which making it ideal for HTHP wells. While for Sarapar 147, it is actually a mixture of normal paraffins (n-alkanes) of carbon chain length C14 to C17.

Table 3. Physical and Chemical Properties of Saraline 185V (Shell MDS, 2006)

Base Oil			**Saraline 185V**	
Physical Properties		**Units**	**Result**	**Method**
Physical state			Liquid at ambient temperature	
Density at 15 deg C		kg/m^3	778	ASTM D 1298
Colour			Colourless	
Odour			Odourless	
Saybolt colour			+30	ASTM D156
Boiling range	IBP	deg C	206	ASTM D86
	90% recovered	deg C	308	ASTM D86
	FBP	deg C	318	ASTM D86
Vapour pressure @ 40 deg C		kPa	< 0.1	Calculated
Kinematic viscosity at 40 deg C		mm^2/s	2.66	ASTM D445
Vapour density (air=1)			> 5	
Sulphur		PPM	< 3	ASTM D3120
Aromatics		% m	< 0.1	SMS 2728
Pour point		deg C	-27	ASTM D97
Flash point		deg C	89	ASTM D93
Aniline Point		deg C	95	ASTM D611
Auto-ignition point		deg C	216	ASTM E659
Solubility in water			Insoluble	
Fire point		deg C	114	ASTM D92
Copper Corrosion, 3hr at 100 deg F			1B	ASTM D130
Chemical Properties				
	C10 & Lower	% m/m	1.8	GC X GC
	C11-C14	% m/m	28.5	GC X GC
	C15-C18	% m/m	40.8	GC X GC
	C19-C20	% m/m	21.1	GC X GC
	C21 & Higher	% m/m	7.8	GC X GC
	Total n-parafin	% m/m	99.2	GC X GC

Table 4. Physical and Chemical Properties of Sarapar 147 (Shell MDS, 2005)

Base Oil			Sarapar 147	
Physical Properties		**Units**	**Result**	**Method**
Physical state			Liquid at ambient temperature	
Density at 15 deg C		kg/m^3	774	ASTM D 1298
Colour			Colourless	
Odour			Odourless	
Saybolt colour			+30	ASTM D156
Boiling range	IBP	deg C	255	ASTM D86
	90% recovered	deg C	285	ASTM D86
	FBP	deg C	295	ASTM D86
Vapour pressure @ 40 deg C		kPa	< 0.1	Calculated
Kinematic viscosity at 40 deg C		mm^2/s	2.67	ASTM D445
Vapour density (air=1)			> 5	
Sulphur		PPM	< 3	ASTM D3120
Aromatics		% m	< 0.1	SMS 2728
Pour point		deg C	9	ASTM D97
Flash point		deg C	124	ASTM D93
Aniline Point		deg C	94	ASTM D611
Auto-ignition point		deg C	216	ASTM E659
Solubility in water			Insoluble	
Chemical Properties				
	C13 & Lower	% m/m	0.4	GC X GC
	C14	% m/m	24.8	GC X GC
	C15	% m/m	24.5	GC X GC
	C16	% m/m	23.3	GC X GC
	C17	% m/m	21.6	GC X GC
	C18 & Higher	% m/m	5.4	GC X GC
	Total n-parafin	% m/m	93.2	GC X GC
	Total Methyl-branched Paraffin	% m/m	6.1	GC X GC
	Total Ethyl-branched Paraffin	% m/m	0.5	GC X GC

(iii) Escaid 110

It is another base oil that serves as a premier base fluid product for drilling fluids in deepwater and extended-reach drilling applications. It lies under the category of dearomatised hydrocarbon. It has very low viscosity feature compared to other base oil. Besides that, it is also compatible with varies emulsifiers and can be used in combination with any other filtration products used in oil-based muds.

Table 5. Physical and Chemical Properties of Escaid 110 (ExxonMobil, 2007)

Base Oil		**Escaid 110**	
Physical Properties	**Units**	**Result**	**Method**
Physical state		Liquid at ambient temperature	
Density at 15 deg C	kg/m^3	806	ASTM D 1298
Colour		Colourless	
Odour		Mild Petroleum	
Saybolt colour		30	ASTM D156
Initial Boiling Point	deg C	201	ASTM D86
Final Boiling Point	deg C	237	ASTM D86
Vapour pressure @ 38 deg C	mm HG	2.6	
Kinematic viscosity at 40 deg C	mm^2/s	1.68	ASTM D445
Vapour density (air=1)		6.2	
Sulphur	PPM	< 1	ASTM D3120
Aromatics	% m	< 0.2	SMS 2728
Pour point	deg C	-39	ASTM D97
Flash point	deg C	75	ASTM D93
Aniline Point	deg C	72	ASTM D611
Auto-ignition point	deg C	251	ASTM E659
Solubility in water		Insoluble	
Chemical Properties			
C11	% m/m	7.7	GC X GC
C12	% m/m	33.9	GC X GC
C13	% m/m	37.6	GC X GC
C14	% m/m	19.4	GC X GC
C15	% m/m	1.4	GC X GC
Total n-parafin	% m/m	53.3	GC X GC

(iv) YK-D80N

It is a base oil which originated from South of Korea. It has high boiling points and high stability with bio degradation capabilities. Besides that, it can also be used for resin sol such as PVC sol as it has high flash point properties. It also provides an excellent cleaning capability for metal and plastics.

Table 6. Physical and Chemical Properties of YK-D80N (SK Energy, 2004)

Base Oil			**YK-D80N**	
Physical Properties		**Units**	**Result**	**Method**
Physical state			Liquid at ambient temperature	
Density at 15 deg C		kg/m^3	827.4	ASTM D 1298
Colour			Colourless	
Odour			Odourless	
Saybolt colour			30	ASTM D156
Boiling range	IBP	deg C	210	ASTM D86
	90% recovered	deg C	259	ASTM D86
	FBP	deg C	270	ASTM D86
Kinematic viscosity at 40 deg C		mm^2/s	2.097	ASTM D445
Sulphur		PPM	0.001	ASTM D3120
Aromatics		% m	0.0166	UV
Pour point		deg C	< -49	ASTM D97
Flash point		deg C	85	ASTM D56
Aniline Point		deg C	71.6	ASTM D611
Solubility in water			Insoluble	
Chemical Properties				
	C10 & Lower	% m/m	0.16	GC X GC
	C11-C14	% m/m	70.01	GC X GC
	C15-C18	% m/m	29.74	GC X GC
	C19-C20	% m/m	0.07	GC X GC
	C21 & Higher	% m/m	0.02	GC X GC
	Total n-parafin	% m/m	5.68	GC X GC

2.5 HIGH PRESSURE HIGH TEMPERATURE DRILLING

From time to time, worldwide demand for energy continues to increase rapidly and gives impact to all energy sources. Projections of continued growth in hydrocarbon demand are driving the oil and gas industry to explore new or under-explored areas which lead to more challenging drilling operations. This is where they start to explore and seek for the hydrocarbon sources at the more extreme conditions that deal with high depth, high pressures, and also high temperature. High pressure high temperature (HPHT) well is formally defined as a well having an undisturbed bottomhole temperature of greater than 300°F (149°C) and a pore pressure of at least 0.8 psi/ft (~15.3 lbm/gal) or requiring a blowout preventer (BOP) with a rating in excess of 10,000 psi (Schlumberger Oilfield Glossary). Since HPHT drilling operation is inherently expensive, the choice of drilling fluids system becomes one of the most criteria that require careful evaluation to successfully handle the challenges presented. The challenges that may arise include elevated well temperature and pressure, downhole lost circulation, low penetration rates and etc. Nowadays, invert emulsion drilling fluids or SBM have been the systems of choice for HPHT well application over WBM. So as seen from the definition of HPHT condition, it actually gives the specifications that a drilling fluid system should perform. A drilling fluid with higher temperature and density stability is basically required to be applied in HPHT drilling application. This is because as we go deeper into the downhole, the temperature increase with depth and may range above 400°F. Selection of base fluid with high range of boiling and flash point is also important to overcome this condition. Since the well condition is having quite high pore pressure condition, so here we need to have higher density of drilling fluid system in order to provide pressure stability to the formations. As high density is required, the system should also has excellent suspension properties where it exhibits minimum density differentiation (barite sagging) properties.

2.6 DEEPWATER DRILLING

Nowadays, oil and gas industry has become incredibly more challenging than previous decades. New shallow well has now become very hard to be found and they are moving to be minority well categories. In oil and gas exploration, the industry has largely intruded the deepwater oil exploration. By definition, deepwater drilling is the exploration activity located in offshore areas where water depths exceed approximately 600 feet (200m) (Schlumberger Oilfield Glossary). The great challenge of producing hydrocarbons from deepwater environment begins with identifying viable prospects. Geoscientists and engineers have built an enviable record of successes in deepwater exploration. Similarly, the drilling community can point to its own technological developments for deepwater drilling.[1] Drilling fluid also has become one of the most important key parameter in making deepwater drilling successful. Therefore, there are of course some parameters that should be considered in designing the drilling fluid to suit this challenging application. A flat rheological drilling fluid system is needed for deepwater drilling application where the system provides rheological properties, yield point, and gel strength that are consistent over a wide range of temperatures. This is because as in the deepwater environment, a seawater temperature of 39°F (4°C) is measured while the formation temperature may range up to 212°F (100°C) or more. In conventional drilling fluid systems, this variation in temperature will causes in wide fluctuation of rheological properties which may lead to problems in drilling operations and there is where the need of special flat rheological system arise for deepwater drilling application. Besides that, the drilling fluid system also should apply a low pour point of base fluid due to the wide range of temperature application which also consists of very low seabed temperature. The growth of this deepwater drilling application start to become a peak when the oil prices increases and has been economically feasible for the companies to invest. As the demand on oil and gas is expected to grow in the future, investment from oil companies as well as advanced technology have the potential of being the key elements to fulfill the demand but with conditions of deepwater drilling has to be widely operated. Basically, the key point on making deepwater drilling is extensively applied in the industry, the oil prices is said need to be higher and only then it become economical for the companies to invest.

[1] Carre, G., Pradie, E., Christic, A., Delabroy, L., Greeson, B., Watson, G., … Taylor, G. (2002). Oilfield Review. *High Expectations from Deepwater Wells, 14*(4), 36-51. Retrieved from http://www.slb.com/~/media/Files/resources/oilfield_review/ors02/win02/p36_51.ashx

CHAPTER 3

THEORY

3.1 BASE OIL PROPERTIES

There are several properties of the base oil which may have a significant effect on the mud properties:

Flash point - It is an indicator of the volatility of the base oil. The higher the flash point of the base oil, the less likely the oil-based mud will catch fire. The flash point of the base oil will vary along with age as its volatile components start to vaporize into the atmosphere. Besides that, addition of water into the oil-based mud will result in higher flash point of the mud which is beyond the flash point of the base oil. Usually, the preferred requirement of the base oil flash point should be greater than 150°F.

Pour point - The lowest temperature (in °F or °C) at which a liquid remains pourable (meaning it still behaves as a fluid) or generally known as the temperature where a fluid start to stop flowing[16]. Ideally, the good base fluid should have a low pour point as much as possible. Typically, if the drilling condition is not cold, this issue will be not a problem. However, drilling at very cold climate such as in Alaska, Russia, etc, attention should be given on the pouring point of the base oil. Moreover, another drilling condition that really need closely look about the pour point of the base fluid is the deepwater operation where temperature of the seabed is very cold approximately 4°C[17].

Aniline point - It is an indication of the relative aromatic content of the base oil. Generally, the aromatic components are particularly detrimental to the rubber parts of the circulation system. Good base oil should at least have the aniline point of 140°F. Certain oil-based mud products such as the organophilic clay viscosifiers are affected by the amount of aromatic components in the base oil. As the aromatic content is decreased, more viscosifier will generally be required or a different viscosifier will have to be used.

Viscosity - It is commonly described as the degree of internal friction which associated with the resistance of two adjacent layers of fluid that moving relatively to each other. In the base oil side of view, addition of brine and solids to the base oil will increases its viscosity substantially. Besides that, the viscosity of oil-based mud is generally proportional to the viscosity of the base oil. Having lower viscosity of oil-based muds will generally lead to an increase in penetration rates.

Aromatic content - It is basically the measure of toxicity of the base oil which indicates by the quantity of benzene-like compounds in the base oil. Actually, these are the compounds that will affect the toxicity of the base oil with the higher content of aromatics, the more toxic the oil-based mud will be. On the other hand, the toxicity of the mud is relatively important where it depends on the environmental sensitivity of the area and the governmental regulations. Usually, base oil with low aromatic contents less than 1% by its weight is a compulsory requirement in selecting the base oil that fulfills the environmental regulations.

3.2 PLASTIC VISCOSITY

Plastic Viscosity is proportional to rate of shear, thus largely reflects the resistance to flow. This resistance is actually due to mechanical friction that caused by solids concentration, size and shape of solids, and viscosity of the fluid phase content in the mud. For practical field applications, plastic viscosity is regarded as a guide to solids control. Its value increases if the volume percent of solids increases or if the volume percent remains constant, and the size of the particle decreases. Besides that, plastic viscosity is also said as the theoretical minimum viscosity a mud can have because it is the effective viscosity as shear rate approaches infinity.[2] The value of plastic viscosity is obtained by subtracting the 300rpm reading from the 600rpm reading of viscometer. Below is the formula to determine plastic viscosity:

$$\textit{Plastic Viscosity (PV)} = \textit{600 rpm reading} - \textit{300 rpm reading} \qquad (3.1)$$

[2] Styles, S., Ledgister, H., Singh, A. K., Meads, K., Schlemmer, R., Tipton, P., et al. (2006). *Drilling Fluid Engineering Manual.* Kuala Lumpur: Scomi Group.

3.3 YIELD POINT

Yield Point is a parameter of Bingham plastic model where in the straight line plot of the model, it is the yield stress extrapolated to a shear rate of zero (Schlumberger Oilfield Glossary: Yield Point). Besides that, yield point can also be defined as the initial resistance to flow that caused by electrochemical forces between the particles. This electrochemical force is due to changes on the surface of the particles dispersed in the fluid phase. Yield point can be calculated by subtracting the 300rpm dial reading of viscometer with plastic viscosity calculated. Below is the formula to determine yield point:

$$\text{Yield Point (YP)} = \text{300 rpm reading} - \text{Plastic Viscosity (PV)} \qquad (3.2)$$

3.4 GEL STRENGTH

Gel strength is the indication of the attractive strength forces (gelation) in a drilling fluid under the static condition. It is basically measured through letting the mud in the static mode for 10 second and 10 minutes time before the viscometer dial readings are taken. The gelation of mud should not be allowed to be more than its necessary to perform the function of suspension of cuttings and weight material. Usually, excessive gelation is mainly caused by high solids concentration that leads to flocculation to occur.

3.5 HPHT FILTRATE ANALYSIS

This analysis will be done by using the HTHP filter press that being set up with pressure differential of 500psi at specific temperature for 30 minutes period of time. The specified temperature is basically temperature that reflect the expected bottom hole temperature and thus there is no standardized temperature. This analysis is a static filtration procedure recommended by the API 13B standard procedures for testing drilling fluids at elevated temperature and pressures (Scomi Oiltools Sdn Bhd, 2008, sec. 3a, p. 11). The outcomes for this analysis is mainly the filtrate and also filter cake build by the mud. The rate of loss through the cake is mostly dependent upon the particle size distribution in the mud and the incorporation of droplets of water and oil in the openings between the solids. For OBM system, mud that gives lowest filtrate without any water droplet is considered to be the most preferred one.

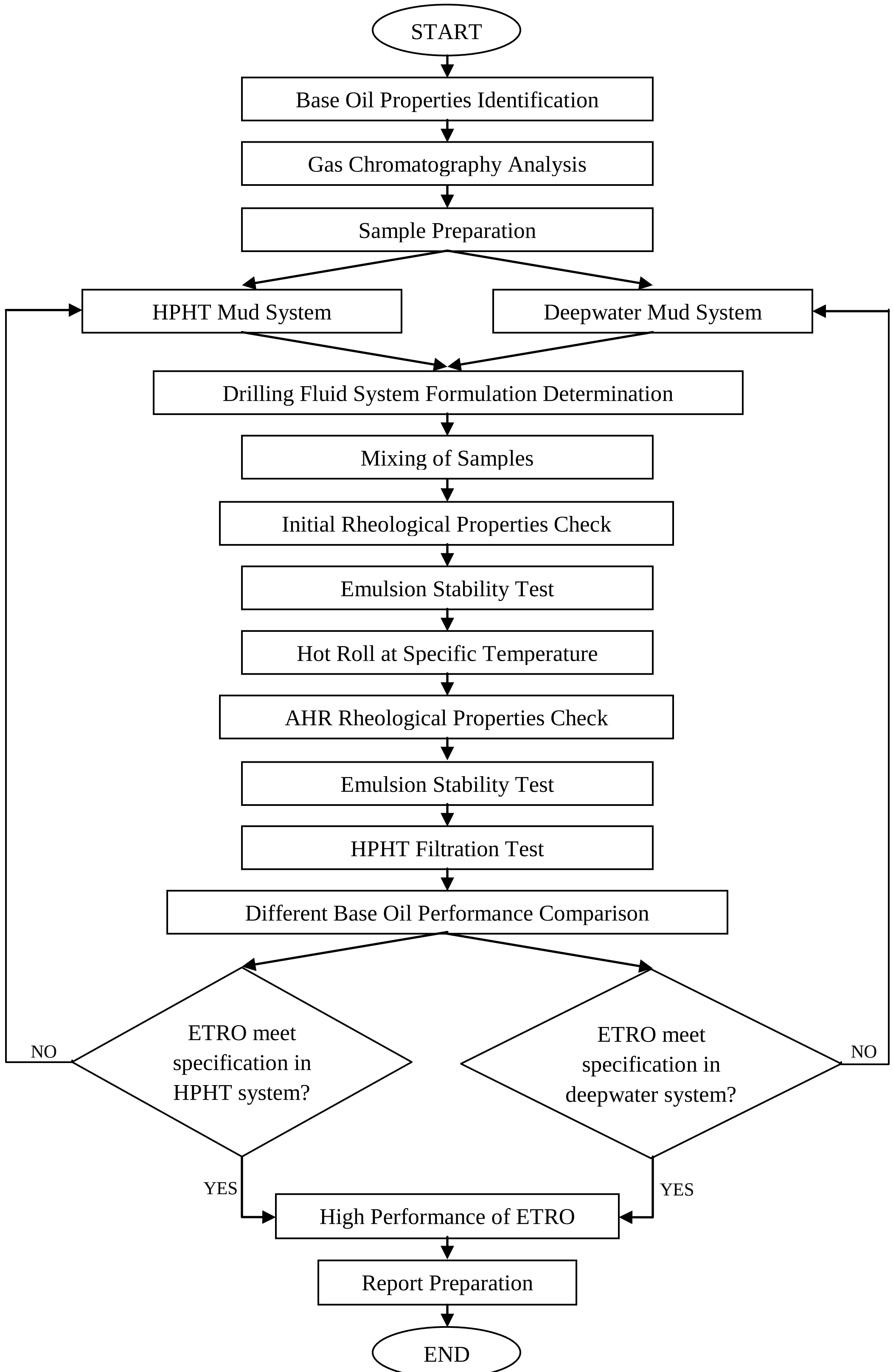
3.6 EMULSION STABILITY TEST

It is a test for oil-base and synthetic-base muds that indicates the emulsion and oil-wetting qualities of the sample (Schlumberger Oilfield Glossary: Electrical Stability Test). Besides that, electrical stability test is also considered as the measurement of the emulsion stability of the mud. The test will be carried out at 120°F (48.9°) and the ES voltage will be measured as the maximum voltage that the mud will sustain across the electrode gap before start conducting the current.[3]

[3] Growcock FB, Ellis CF and Schmidt DD: "Electrical Stability, Emulsion Stability, and Wettability of Invert Oil-Based Muds," *SPE Drilling & Completion* 9, no. 1 (March 1994): 39-46.

CHAPTER 4

METHODOLOGY



4.1 FORMULATION OF DRILLING FLUID SYSTEM

Below is the suggested formulation for both HPHT and deepwater mud system:

- For HPHT mud system:
    - Mud density = 14.0 lb/gal
    - Oil water ratio = 85:15
    - Hot roll temperature = 392 °F
    - Hot roll period = 16 hours
    - Calcium Chloride content = 25%

Table 7. List of Chemicals Used for HTHP Mud System

Chemical/Additive	Function
ETRO, Saraline 185V, Sarapar 147. Escaid 110, YK-D80N	Base fluid
Emulsifier 019	Single emulsifier
Liquid Fluid Loss Control	Fluid loss additive
Organophilic Clay HT	Viscosifier
Organophilic Clay XHT	Viscosifier
Fluid Loss Control 450	Fluid loss additive
Fluid Loss Control XHT	Fluid loss additive
Lime	Alkalinity
Fresh Water	Brine
Calcium Chloride	
Barite	Weighting agent

- For deepwater mud system:
    - Mud density = 10.5 lb/gal
    - Oil water ratio = 75:25
    - Hot roll temperature = 250 °F
    - Hot roll period = 16 hours
    - Calcium Chloride content = 25%

Table 8. List of Chemicals Used for Deepwater Mud System

Chemical/Additive	Function
ETRO, Saraline 185V, Sarapar 147. Escaid 110, YK-D80N	Base fluid
Emulsifier Deep	Emulsifier
Emulsifier 022	Rheological Modifier
Organophilic Clay HT	Viscosifier
Fluid Loss Control HT	Fluid Loss Additive
Lime	Alkalinity
Fresh Water	Brine
Calcium Chloride	
Barite	Weighting Agent
Rev Dust	Simulated Drill Solids

4.2 SAMPLES PREPARATION AND MIXING PROCEDURES

Equipments: Digital Balance, Hamilton Beach Mixer, stopwatch, thermometer, and 1 lab barrel mud cup.

Figure 2. Digital Balance

Figure 3. Hamilton Beach Mixer

Procedures: The chemical samples are weighted according to the mud formulation concentration. Then the samples are mixed by using Hamilton Beach mixer at high speed of 18,000 rpm for 60 minutes. The order of additive addition is as below:

Table 9. Mixing order and time for OBM/SBM

Additives	Mixing 1 lab barrel of OBM/SBM on Hamilton Beach Mixer		
	Mixing Order	**Speed**	**Mixing Time (min)**
Base Oil	1	High (18,000 rpm)	-
Emulsifier	2	High (18,000 rpm)	2
Organophilic Clay	3	High (18,000 rpm)	5
Fluid Loss Additive	4	High (18,000 rpm)	2
Lime	5	High (18,000 rpm)	2
Brine	6	High (18,000 rpm)	15
Weighting Agent	7	High (18,000 rpm)	2
Other Contaminants	8	High (18,000 rpm)	2
		Additional mixing time	30
		Total mixing time	60

4.2.1 HPHT Mud Formulation Composition

Part 1: HPHT System Composition for Optimizing Test

Table 10 shows the mud formulation composition for optimizing test in HPHT mud system. Basically, there are total of seven (7) mud samples prepared with different in some parameters. TH-1 is marked as a benchmark mud sample where the other mud samples will have the same composition with TH-1 but different in selected parameters. In TH-2, the mud density is increased from 14 to 16 ppg and oil water ratio (OWR) of 85:15 to 90:10. On the other hand, for TH-3 and TH-4, the mud samples are tested with different types of weighting agent which is grinded barite instead of normal barite like in TH-1 but also with different mud density of 14 and 16 ppg, for TH-3 and TH-4 respectively. All mud are tested with the hot rolling temperature of 392°F, except for TH-5 where the hot rolling temperature is reduced to 300°F with the composition is remained constant as in TH-1. Next, for TH-6, the mud sample is actually being added with additional organophilic clay content compared to the benchmark mud sample in TH-1. Lastly, the concentration of the emulsifier used is increased for TH-7 mud sample.

Table 10. Optimizing Test Mud Formulation Composition for HPHT System

Products	SG	TH-1	TH-2	TH-3	TH-4	TH-5	TH-6	TH-7
Hot Roll Temperature (°F)		**392**	392	392	392	300	392	392
Mud density, lb/gal		**14.0**	16.0	14.0	16.0	14.0	14.0	14.0
OWR		**85/15**	90/10	85/15	90/10	85/15	85/15	85/15
ETRO	0.8042	**159.38**	151.54	159.23	151.33	159.38	158.78	158.69
Emulsifier 019	0.95	**15.00**	15.00	15.00	15.00	15.00	15.00	16.00
Liquid Fluid Loss Control	0.98	**2.00**	2.00	2.00	2.00	2.00	2.00	2.00
Organophilic Clay HT	1.70	**2.00**	2.00	2.00	2.00	2.00	3.00	2.00
Organophilic Clay XHT	1.70	**3.35**	3.35	3.35	3.35	3.35	4.35	3.35
Fluid Loss Control 450	1.05	**8.00**	8.00	8.00	8.00	8.00	8.00	8.00
Fluid Loss Control XHT	1.03	**2.00**	2.00	2.00	2.00	2.00	2.00	2.00
Lime	2.30	**15.00**	15.00	15.00	15.00	15.00	15.00	15.00
Fresh Water	1.00	**34.97**	20.94	34.94	20.91	34.97	34.84	34.82
Calcium Chloride	3.40	**12.67**	7.59	12.66	7.58	12.67	12.62	12.62
Barite	4.39	**333.86**	444.86			333.86	*332.65*	*333.76*
Grinded Barite	4.38			334.05	445.10			

Part 2: HPHT System Composition for Performance Comparison Study

Table 11 shows the mud formulation composition for performance comparison study test in HPHT mud system. Basically, there are four (4) other base oils that used to compare with ETRO performances which are Saraline 185V, Sarapar 147, Escaid 110 and YK-D80N. In this performance comparison study, the additives composition is maintained for all mud samples. Only the composition of the base oil, calcium chloride brine and barite are varies as they are depending on the specific gravity (SG) of the base oil. So, as the SG for each base oils is different, so that the composition of those parameter will also different for each mud samples.

Table 11. Performance Comparison Mud Formulation Composition for HPHT System

Products	ETRO	Saraline 185V	Sarapar 147	Escaid 110	YK-D80N
Hot Roll Temperature (°F)	392	392	392	392	392
Mud density, lb/gal	14.0	14.0	14.0	14.0	14.0
OWR	85/15	85/15	85/15	85/15	85/15
ETRO	159.38				
Saraline 185V		153.23			
Sarapar 147			152.30		
Escaid 110				157.92	
YK-D80N					164.84
Emulsifier 019	15.00	15.00	15.00	15.00	15.00
Liquid Fluid Loss Control	2.00	2.00	2.00	2.00	2.00
Organophilic Clay HT	2.00	2.00	2.00	2.00	2.00
Organophilic Clay XHT	3.35	3.35	3.35	3.35	3.35
Fluid Loss Control 450	8.00	8.00	8.00	8.00	8.00
Fluid Loss Control XHT	2.00	2.00	2.00	2.00	2.00
Lime	15.00	15.00	15.00	15.00	15.00
Fresh Water	34.97	34.76	34.72	34.92	35.17
Calcium Chloride	12.67	12.59	12.58	12.65	12.74
Barite	333.86	340.30	341.28	335.39	328.14

4.2.2 Deepwater Mud Formulation Composition

Part 1: Deepwater System Composition for Optimizing Test

Table 12 shows the mud formulation composition for optimizing test in deepwater mud system. Same as in HPHT mud system, there are also total of seven (7) mud samples set for deepwater mud system. TD-1 is selected as the benchmark mud sample for this system where the other mud samples' composition will be based on this benchmark but varies in some parameters. For TD-2 and TD-3, there are basically tested with different mud density of 12.5 and 14 ppg respectively. OWR also change with the mud density changes where TD-2 and TD-3 have OWR of 80:20 and 85:15. Besides that, for TD-4 and TD-5, they are varies in term of the hot roll temperature where for TD-4 is where the temperature is increased to 300°F and TD-5 is 392°F instead of 250°F as in the benchmark sample TD-1. In TD-6, additional of organophilic clay is added to the mud sample from 3 to 4 grams. Lastly, in TD-7, the concentration of the emulsifier used is increased.

Table 12. Optimizing Test Mud Formulation Composition for Deepwater System

Products	SG	TD-1	TD-2	TD-3	TD-4	TD-5	TD-6	TD-7
Hot Roll Temperature (°F)		**250**	250	250	300	350	250	250
Mud density, lb/gal		**10.5**	12.5	14.0	10.0	10.0	10.0	10.0
OWR		**75/25**	80/20	85/15	75/25	75/25	75/25	75/25
ETRO	0.8042	**169.91**	165.86	163.95	169.91	169.91	169.65	167.51
Emulsifier-Deep	0.95	**10.00**	10.00	10.00	10.00	10.00	10.00	12.00
Emulsifier 022	0.98	**2.00**	2.00	2.00	2.00	2.00	2.00	4.00
Organophilic Clay HT	1.70	**3.00**	3.00	3.00	3.00	3.00	4.00	3.00
Fluid Loss Control HT	1.05	**6.00**	6.00	6.00	6.00	6.00	6.00	6.00
Lime	2.30	**8.00**	8.00	8.00	8.00	8.00	8.00	8.00
Fresh Water	1.00	**70.43**	51.56	35.98	70.43	70.43	70.32	69.43
Calcium Chloride	3.40	**25.52**	16.68	13.03	25.52	25.52	25.48	25.16
Barite	4.39	**121.32**	235.11	321.28	121.32	121.32	120.74	121.08
Rev Dust	2.60	**25.00**	*25.00*	*25.00*	25.00	25.00	*25.00*	*25.00*

Part 2: Deepwater System Composition for Performance Comparison Study

Table 13 shows the mud formulation composition for performance comparison study test in deepwater mud system. Same as in the HPHT mud system, deepwater also test and compare ETRO with four (4) different base oils which are Saraline 185V, Sarapar 147, Escaid 110 and YK-D80N. All the additives composition is remained constant for each mud samples. As some components are calculated highly dependent on the SG of the base oils, they will vary depending on the SG of the base oil. Those components are including the volume of base oil used, calcium chloride brine content and weight of barite.

Table 13. Performance Comparison Mud Formulation Composition for Deepwater System

Products	ETRO	Saraline 185V	Sarapar 147	Escaid 110	YK-D80N
Hot Roll Temperature (°F)	250	250	250	250	250
Mud density, lb/gal	10.5	10.5	10.5	10.5	10.5
OWR	75/25	75/25	75/25	75/25	75/25
ETRO	169.91				
Saraline 185V		163.48			
Sarapar 147			162.50		
Escaid 110				168.39	
YK-D80N					175.62
Emulsifier-Deep	10.00	10.00	10.00	10.00	10.00
Emulsifier 022	2.00	2.00	2.00	2.00	2.00
Organophilic Clay HT	3.00	3.00	3.00	3.00	3.00
Fluid Loss Control HT	6.00	6.00	6.00	6.00	6.00
Lime	8.00	8.00	8.00	8.00	8.00
Fresh Water	70.43	70.04	69.98	70.34	70.77
Calcium Chloride	25.52	25.38	25.36	25.48	25.64
Barite	121.32	128.28	129.34	122.97	115.14
Rev Dust	25.00	25.00	25.00	25.00	25.00

4.3 MUD RHEOLOGICAL PROPERTIES TEST

Equipments: Fann 35 Viscometer, heating jacket, thermo cup, stopwatch, and thermometer.

Figure 4. Fann 35 Viscometer

Procedures:

i. Stir the sample at 600 rpm while the sample is heating to 120°F (48.9°C).

ii. Once the temperature reach 120°F, start noting the result of dial reading at 600, 300, 200, 100, 6, and 3 rpm speeds. Ensure the dial reading has stabilized at each speed before noting the value.

iii. After done with 3 rpm reading, stir the sample at 600 rpm for 30 seconds before taking the 10-second gel. The gel is taken by stopping the motor and left the mud in static mode for 10 seconds. Then initiate the mud with 3 rpm speeds and take the highest deflection of the dial reading.

iv. Restir the sample at 600 rpm for 30 seconds and leave it undisturbed for 10 minutes in order to measure the 10-min gel.

Calculations: Determine Plastic Viscosity (PV) and Yield Point (YP) using formula 3.1 and 3.2 in Chapter 3.

4.4 EMULSION STABILITY TEST

Equipments: Electrical Stability Meter

Figure 5. Electrical Stability Meter

Procedures:

i. Place the clean probe of ES meter in the sample at 120°F (48.9°C) and use it to stir the fluid to ensure homogeneity.

ii. Position the probe so it does not touch the bottom or sides of the heated cup in order to get more accurate result and ensure that the tip of the electrode is completely immersed.

iii. Press the button to initiate the voltage ramp and holding the probe still until the end point is reached and a steady reading is seen in the digital display.

iv. Note the reading and repeat the test for three times for calculating average value.

4.5 HOT ROLLING THE SAMPLES

Equipments: Roller oven and aging cells

Figure 6. Roller Oven

Figure 7. Aging Cells

Procedures:

i. The oven must be preheated first to the required temperature.

ii. The sample is stirred for 5 minutes on Hamilton Beach Mixer.

iii. Then, the sample is transferred into aging cell container. The aging cell is tightened.

iv. The aging cell is pressurized according to the specific pressure that depending on the temperature tested.

v. The aging cell is then placed in the roller oven and start rolling the sample. The sample is rolled for 16 hours.

4.6 HPHT FILTRATION TEST

Equipments: HPHT Filter Press, HPHT Filtration Cells (Diameter 3'' x Height 3''), Filter paper (Diameter 2.5''), High Pressure CO_2 supply, Stopwatch, and measuring cylinder.

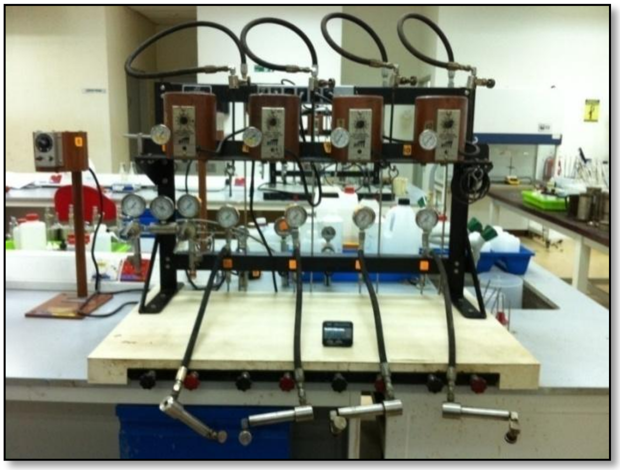


Figure 8. HTHP Filter Press

Procedures:

i. The heating jacket is preheated to the required temperature.
ii. Tighten the bottom valve stem and fill the cell to about 0.5 inch from the rim.
iii. Place a filter paper on the rim and put the lid on the cell. Ensure the lid stem is open while doing this to avoid damaging the filter paper.
iv. Tighten the six studs in the cell and close the lid stem.
v. Place the cell in the heating jacket with the lid facing downwards. Rotate the cell until it seats on the locking pin.
vi. Place CO_2 cartridge in each regulator and tighten up the retainers.
vii. Place the top regulator on the stem and engage the locking pin. Close the bleed off valve and turn the regulator clockwise until 100 psi is showing on the gauge.
viii. Repeat the process with the bottom regulator.
ix. Turn the top valve stem ¼ to ½ turn anti clockwise to pressure up the cell to 100 psi.

x. When the cell reach required test temperature, open the bottom stem with ½ turn and then increase the pressure on the top regulator to 600 psi. Start the stopwatch timing.

xi. After 30 minutes, close the top and bottom valve stems. Slack off the regulator on the bottom collection vessel. Bleed off the filtrate into the graduated cylinder. Disconnect bottom collection vessel, fully open the bleed off valve and tip any residual filtrate into the graduated cylinder.

xii. Bleed the pressure off the top regulator.

xiii. Disconnect the top regulator and remove the cell from the heating jacket, allowing it to cool in water bath.

xiv. When the cell has cooled, bleed off the trapped pressure by slowly opening the top valve with the cell in an upright position. With the residual pressure bled off, loosen the six studs and remove the lid.

xv. Examine the filter paper and report the thickness of cake built in millimeter and the filtrate produced in milliliter.

Calculations: The total filtrate volume should be doubled as the standard API filter press is twice the area of the HPHT cell.

CHAPTER 5

RESULTS AND DISCUSSIONS

In this project, there was two main systems were tested namely HPHT and deepwater mud system. Basically, both systems were divided into two main testing parts where the first part is the mud optimizing test and the second part is the performance comparison test. In the first part, it is called as optimizing test as the ETRO-based mud was actually formulated and tested under several conditions. There was a basic ETRO-based formulation as the benchmark before the mud were tested under variations of condition which were comprised of mud density & Oil-Water ratio (OWR) variations, different organophilic clay and emulsifier concentration, changing of hot rolled temperature condition, and also different types of weighting agent used. There were total of seven (7) mud samples were tested during the first part.

Moving to the second part of the testing, it is actually comprised of comparing the performance of four different base oils with ETRO-based mud. The other four base oils are Saraline 185V, Sarapar 147, Escaid 110 and YK-D80N. Basically, all four different base oils were formulated in both two different mud system which are HPHT and deepwater system by having the same mud composition or formulation as the ETRO-based mud. For both parts, each of the mud formulated was tested for their performances in term of rheological properties, emulsion stability and filtration characteristics.

5.1 HPHT SYSTEM

5.1.1 Results of Optimizing Test for HPHT System

Table 14. Results of Optimizing Test for HPHT System

Properties Initial:	**TH-1**	**TH-2**	**TH-3**	**TH-4**	**TH-5**	**TH-6**	**TH-7**
Mud density, lb/gal	14.0	16.0	14.0	16.0	14.0	14.0	14.0
Hot Roll Temperature (°F)	392	392	392	392	300	392	392
Rheological properties at	*120 °F*	*120 °F*	*120 °F*	*120 °F*	*120 °F*	*120 °F*	*120 °F*
600 rpm dial reading	85	117	84	124	79	117	89
300 rpm dial reading	50	68	50	73	46	72	53
200 rpm dial reading	37	50	37	55	34	55	40
100 rpm dial reading	24	31	24	35	22	37	26
6 rpm dial reading	7	8	7	10	6	12	7
3 rpm dial reading	6	7	6	8	5	10	6
Plastic viscosity, cP	35	49	34	51	33	45	36
Yield point, lb/100ft2	15	19	16	22	13	27	17
10" gel strength, lb/100ft2	7	8	8	10	7	11	7
10' gel strength, lb/100ft2	9	10	10	14	9	13	10
ES, volt at 120 °F	1233	1373	914	1261	1940	1380	1367
OWR	85/15	90/10	85/15	90/10	85/15	85/15	85/15
Properties AHR, 16 hr:	**TH-1**	**TH-2**	**TH-3**	**TH-4**	**TH-5**	**TH-6**	**TH-7**
Mud density, lb/gal	14.0	16.0	14.0	16.0	14.0	14.0	14.0
Rheological properties at	*120 °F*	*120 °F*	*120 °F*	*120 °F*	*120 °F*	*120 °F*	*120 °F*
600 rpm dial reading	130	131	149	141	148	146	140
300 rpm dial reading	77	75	89	81	91	89	85
200 rpm dial reading	58	56	67	60	69	68	65
100 rpm dial reading	37	33	41	37	44	44	41
6 rpm dial reading	10	7	10	10	10	13	11
3 rpm dial reading	8	5	8	8	9	11	9
Plastic viscosity, cP	53	56	60	60	57	57	55
Yield point, lb/100ft2	24	19	29	21	34	32	30
10" gel strength, lb/100ft2	10	7	12	10	10	13	11
10' gel strength, lb/100ft2	12	9	16	13	22	15	14
ES, volt at 120 °F	1579	1678	1703	1831	1999	1583	1911
OWR	85/15	90/10	85/15	90/10	85/15	85/15	85/15
CaCl2, % wt.	25	25	25	25	25	25	25
HTHP (500 psi, 350 °F), ml	4.4	3.9	9.5	8.4	6.4	3.6	48
HTHP (Filter cake), mm	1	1	2	2	4	1	1

5.1.2 Rheological Behavior of ETRO-Based Mud in HPHT System

5.1.2.1 Effect of mud density and OWR changes

In HPHT system, there were actually two mud density and oil water ratio (OWR) being tested, 14 ppg with 85:15 OWR and 16 ppg with 90:10 OWR, respectively for TH-1 and TH-2, as shown in mud formulation at Table 10. This increment in mud density from 14 to 16 ppg testing is actually to study the capability of the ETRO base oil in withstanding such a high mud density. This study is very important as having a high capable density mud is basically one of the main criteria or parameter to be a good mud for HPHT well application. The mud density was increased as the OWR increased by adding more barite as the main weighting agent and also reducing the calcium chloride brine content.

Table 15 summarized the results of before hot rolled (BHR) and after hot rolled (AHR) for TH-1 and TH-2 with some important parameter to be considered. It indicates that in TH-1 and TH-2, from 14 to 16 ppg mud density increment, the 6 rpm reading, yield point (YP) and gel strength were slightly decreased while the plastic viscosity (PV) and emulsion stability (ES) were increased significantly. After hot rolling at 392°F, PV in both TH-1 and TH-2 increased from 35 to 53 cp and 49 to 56 cp which clearly signify for more stable mud emulsion. This indication may also be proved by having increased in the ES value BHR to AHR (Figure 9 & Figure 10). A part from that, emulsion stability test was also reported as stable for both TH-1 and TH-2 with the ES value of more than 400 volts BHR and AHR. Based on the results in Table 15, ETRO-based mud was shown as capable to maintain and withstand its rheological behavior over various mud density and OWR. This may become one of the criteria that will contribute in proving ETRO as suitable base oil for HPHT well application later on.

Table 15. Rheological properties results of TH-1 and TH-2

Parameter	**TH-1**		**TH-2**	
Mud Density, lb/gal	14.0		16.0	
Oil Water Ratio	85:15		90:10	
Properties AHR, 16 hr:	**BHR**	**AHR**	**BHR**	**AHR**

6 rpm dial reading	7	10	8	7
Plastic viscosity, cP	35	53	49	56
Yield point, lb/100ft2	15	24	19	19
10sec gel strength, lb/100ft2	7	10	8	7
10min gel strength, lb/100ft2	9	12	10	9
ES, volt at 120 °F	1233	1579	1373	1678

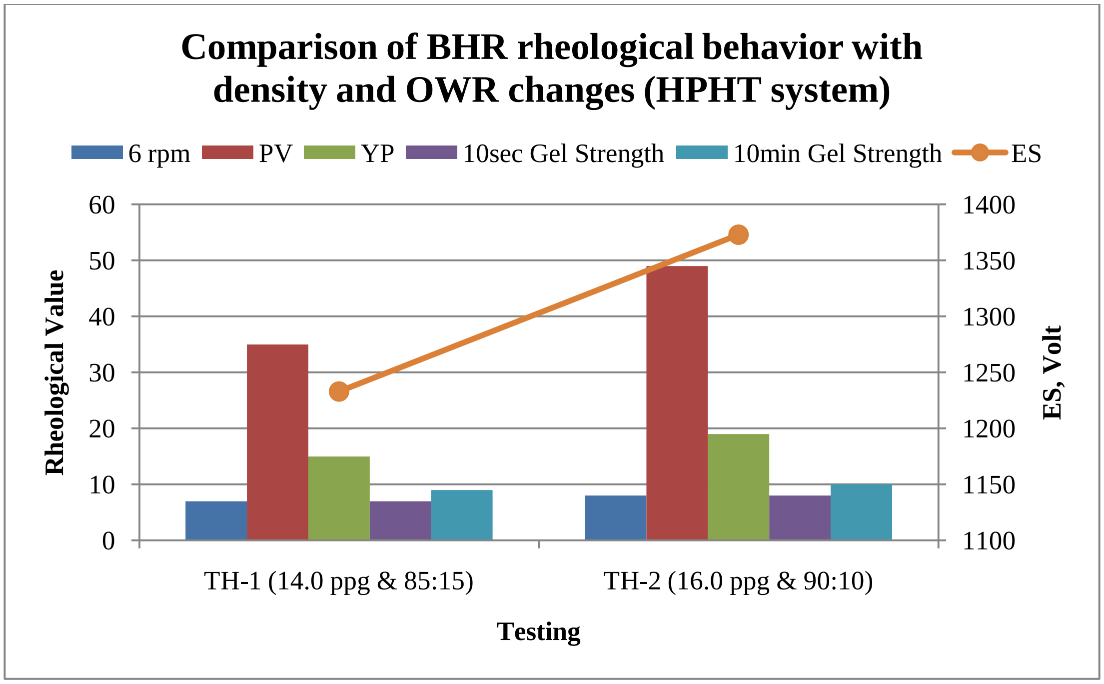


Figure 9. BHR Properties of TH-1 and TH-2

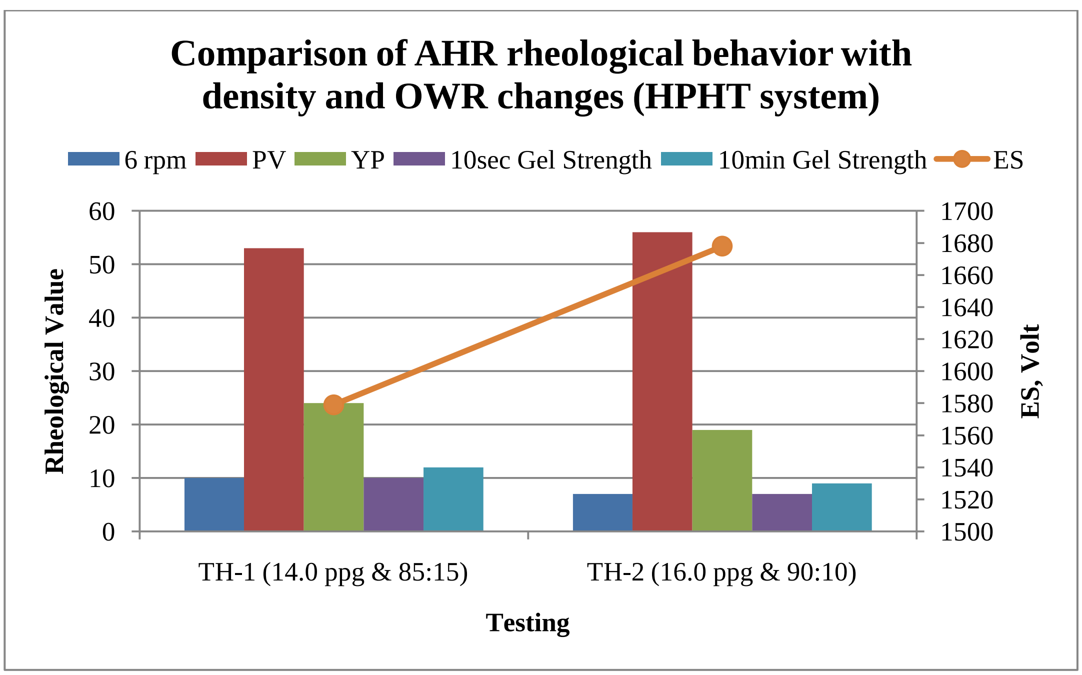


Figure 10. AHR Properties of TH-1 and TH-2

5.1.2.2 Effect of organophilic clay concentration variations

The main role of organophilic clay in drilling fluid is to act as viscosifier which will help in improving the ability to remove and suspend cuttings and also as weight materials during periods of noncirculation. Two different organophilic clay concentrations were examined in TH-1 and TH-6 with total clay content of 5.35 and 7.35 grams respectively. Basically, for this HPHT mud system, there were two types of organophilic clay used which are Organophilic Clay HT and Organophilic Clay XHT which have different temperature range compatibility.

Table 16 shows the result of rheological behavior of TH-1 and TH-6 at BHR and AHR condition with five parameters that may experience the prime effect of having different concentration of organophilic clay. Based on Figure 11, it shows that the additional of 2 grams from TH-1 to TH-6 has resulted in increased of 6 rpm reading, PV, YP and also gel strength. This clearly indicates that the mud cuttings suspension ability has been enhanced with addition of organophilic clay and this is also has been explained by Ghalambor, et al. that which state that the addition of organophilic clay will linearly increase the ability of cutting lifting[8]. 6 rpm reading and YP value is very important parameters in determining the hole cleaning ability of the mud where the value should not be too low or too high where low value will results in poor cutting lifting while too high value will cause hard to break the gelling mud.

Table 16. BHR and AHR rheological properties results of TH-1 and TH-6

Products	TH-1		TH-6	
ORGANOPHILIC CLAY HT	2.00 g		3.00 g	
ORGANOPHILIC CLAY XHT	3.35 g		4.35 g	
TOTAL Organophilic Clay	**5.35 g**		**7.35 g**	
Properties	**BHR**	**AHR**	**BHR**	**AHR**
6 rpm dial reading	7	10	12	13
Plastic viscosity, cP	35	53	45	57
Yield point, $lb/100ft^2$	15	24	27	32
10 sec gel strength, $lb/100ft^2$	7	10	11	13
10 min gel strength, $lb/100ft^2$	9	12	13	15

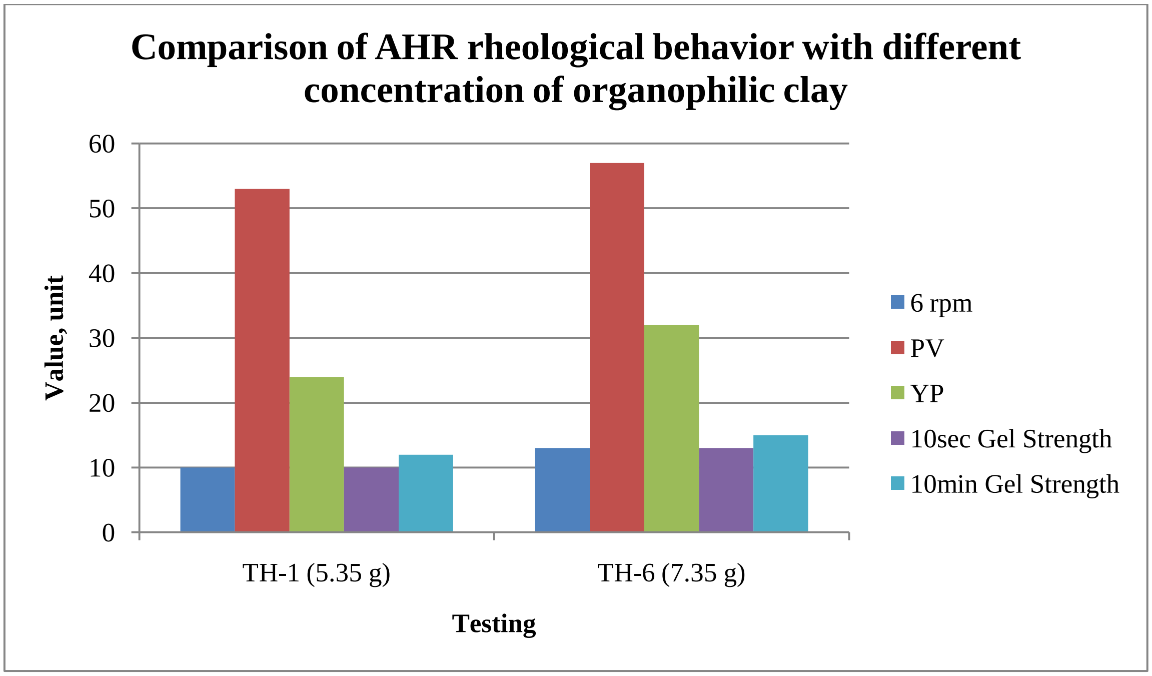


Figure 11. Comparison of AHR rheological behavior of TH-1 and TH-6 with different concentration of organophilic clay

5.1.2.3 Effect of hot rolled temperature changes

Mud can be aged statically and dynamically according to the needs and purpose of testing. In this project, all muds is rolled in a pressurized cell at 392°F which considered to be very high temperature condition in order to simulate the mud under drilling conditions at high temperature well. Theoretically, over time, high temperatures can degrade the components of a mud and alter its performance. However, since the tested temperature of 392°F is already high temperature condition, the mud was then tested with lower temperature which is 300°F on TH-5 in order to see the effect of changing the temperature condition.

Table 17 shows the results of TH-1 and TH-5 after been rolled at different temperature for 16 hours. As the temperature is lowered from 392 to 300°F, TH-1 to TH-5 respectively, it is observed that instead of the mud will be degraded, the mud stability had been significantly improved as it exposed to much lower temperature. This can be clearly seen in Figure 12 where the ES value increased from 1579 to 1999 volts after rolled with lower temperature.

Table 17. AHR rheological properties results of TH-1 and TH-5

Parameter	TH-1	TH-5
Hot Roll Temperature (°F)	392	300
Properties AHR, 16 hr:	**TH-1**	**TH-5**
6 rpm dial reading	10	10
Plastic viscosity, cP	53	57
Yield point, lb/100ft2	24	34
10min gel strength, lb/100ft2	12	22
ES, volt at 120 °F	1579	1999

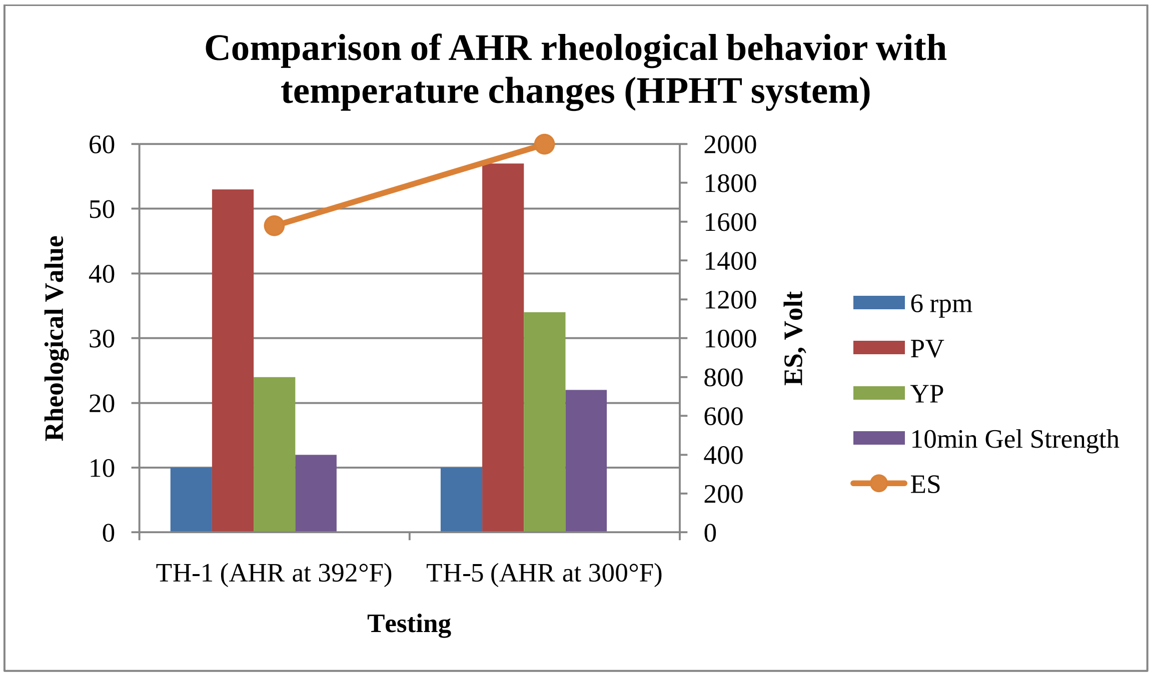


Figure 12. Comparison of AHR rheological behavior of TH-1 and TH-5 with temperature variations

5.1.2.4 Effect of emulsifier concentration variations

Two different emulsifier concentrations were tested on TH-1 and TH-7, 15 and 16 grams respectively. The main function of emulsifier used especially in an invert-emulsion drilling fluids is actually to lower the interfacial tension between oil and water which will allows more stable emulsion with small drops to be formed[9]. Basically this study is actually to examine the effect of emulsifier towards mud's electrical stability (ES) value which high ES value indicates a better emulsion and stable mud while low value is vice versa.

Table 18 shows the result for TH-1 and TH-7, BHR and AHR condition after adding emulsifier from 15 to 16 grams. The results of ES value has been plotted in Figure 13 where it shown that TH-7 has higher value of ES compared to TH-1 which clearly indicates that TH-7 has better emulsion stability. So, this finding is strongly support and explained that addition of emulsifier will enhanced the mud emulsion stability between oil and water.

Table 18. BHR and AHR electrical stability results of TH-1 and TH-7

Products	TH-1		TH-7	
Emulsifier 019	15.00 g		16.00 g	
Properties AHR, 16 hr, (392 °F):	BHR	AHR	BHR	AHR
ES, volt at 120 °F	1233	1579	1367	1911

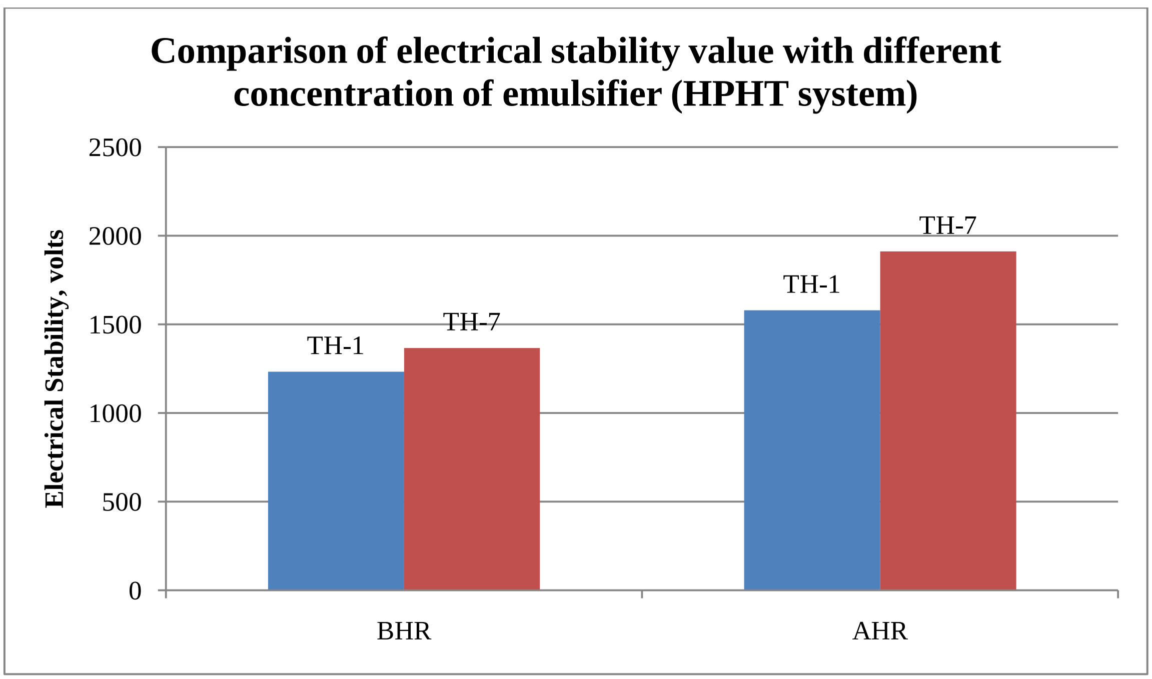


Figure 13. Comparison of electrical stability value of TH-1 and TH-7

5.1.2.5 Effect of using different types of weighting agent

There were two types of weighting agent used in this study which are barite and grinded barite. This two weighting agent is in fact distinguished by their size of particle where grinded barite has a lower particle size. As one of the criteria for HPHT mud system is to have high density properties, this study of using grinded barite as weighting agent is important in order to examine the effect of having low size particle of weighting agent. In fact, by having lower particle size of weighting agent can actually helps in enhancing barite sag problem.

Based on Table 19, it shows that there was not much different in term of rheological properties such as 6 rpm reading, PV and YP for mud using grinded barite in TH-3 and TH-4 respectively. Figure 14 shows that the major differences that were observed are related to ES value and HPHT filtrate volume. For both TH-3 and TH-4 resulted in higher ES but also have quite high filtrate volume. Higher in ES value is believed because of better emulsion due to presence of small size particle of grinded barite compare to the normal barite. However, the risk when dealing with small particle size arises when it come to the filtration loss ability of the mud as shown in Table 19 and Figure 14, that the HPHT filtrate resulted in higher volume. This demonstrates that more fluid loss agents are needed in order to be able to provide better filtration loss ability when grinded barite used.

Table 19. Rheological properties results of TH-1, TH-2, TH-3 and TH-4

Products	**TH-1 (14.0 ppg)**	**TH-2 (16.0 ppg)**	**TH-3 (14.0 ppg)**	**TH-4 (16.0 ppg)**
Barite	333.86 g	444.86 g		
Grinded Barite			334.05 g	445.10 g
Properties AHR, 16 hr, (392 °F):	**TH-1**	**TH-2**	**TH-3**	**TH-4**
6 rpm dial reading	10	7	10	10
Plastic viscosity, cP	53	56	60	60
Yield point, lb/100ft2	24	19	29	21
10min gel strength, lb/100ft2	12	9	16	13
ES, volt at 120 °F	1579	1678	1703	1831
HTHP Filtrate, ml	4.4	3.9	9.5	8.4

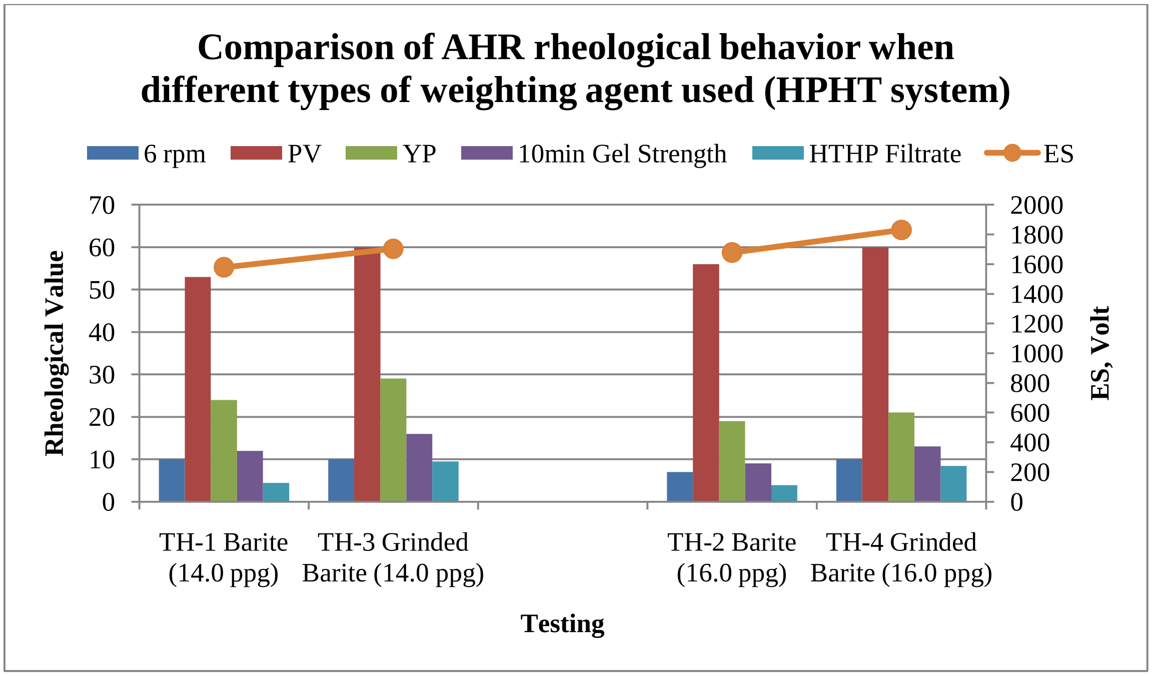


Figure 14. Comparison of AHR rheological behavior of TH-1 to TH-4 with different types of weighting agent

5.1.3 Filtration Characteristics of ETRO-Based Mud in HPHT System

Table 20 shows the results of filtration characteristics for all tested HPHT system mud (TH-1 till TH-7) which include the filtrate volume and filter cake thickness. The results were obtained after the mud samples were subjected to hot rolling test for 16 hours at 392°F and 300°F for TH-5 only. The HPHT filtration tests were carried out according to the API standard procedures where the mud samples were exposed to 500 psi pressure differential at 350°F for 30 minutes of total running test period.

As illustrated in Figure 15, all mud samples resulted in filtrate volume which below the API recommended value of 15 ml [API 13A, (1993)] except for TH-7 with much higher value, at 48 ml after subjected to addition of emulsifier. In this case, the mud sample TH-7 required to has additional of fluid loss agent in order to balance up with the addition of emulsifier applied. Besides that, it is also observed that there is no water droplet presence in the filtrate for all the mud samples which clearly indicates that the emulsion of the mud samples were very stable towards thermal degradation and high pressure condition. This can be supported by the results of high electrical stability value shown in Table 14.

As can be seen in Table 20, TH-1 to TH-2 resulted in decreasing of filtrate volume, from 4.4 to 3.9 ml after subjected to increase of mud density, 14 to 16 ppg respectively. This pattern is expected as increasing the weighting agent concentration, barite, resulted in better filtration loss control and also better emulsion stability as shown in Table 19.

Moving to the filter cake thickness, having low cake thickness is very important as thick cake in the wellbore may cause drilling problem such as stuck pipe, high torque and etc. Table 20 shows that all mud samples (TH-1 to TH-7) resulted in low thickness of less than 2 mm which indicates a good filter cake layer. However, TH-5 resulted in much higher filter cake thickness as also for the filtrate volume after being exposed to lower aging temperature, 300°F. This result is believed to happen as the mud sample contain different fluid loss agent, Fluid Loss Control 450 and Fluid Loss Control XHT, which will be activated at different temperatures. As for the Fluid Loss Control XHT, its activation temperature is actually above 350°F and having low hot rolling temperature of 300°F for TH-5 will cause the Fluid Loss Control XHT to be not activated. So this will cause the filtrate and filter cake to be much higher due to lack of fluid loss agent.

Results in Table 20 and Figure 15 also clearly illustrate the increase in filtrate volume with increasing water content in the emulsion system in TH-2 to TH-1 with OWR 90:10 and 85:15 respectively. When water content increases, in TH-1, water droplets in the invert emulsion system are within the vicinity of each other and associate to form large water droplets in the system. Since the filter cake is partly formed by the water droplets, an increase in water droplet size will increases the pore volume and permeability of the filter cake thus resulted in much higher filtrate volume.

Table 20. Filtration characteristics results of TH-1 to TH-7

Parameter	TH-1	TH-2	TH-3	TH-4	TH-5	TH-6	TH-7
Hot Roll Temperature, °F	392	392	392	392	300	392	392
HTHP Filtrate @500psi, ml	4.4	3.9	9.5	8.4	6.4	3.6	48.0
HTHP Filter Cake, mm	1	1	2	2	4	1	1

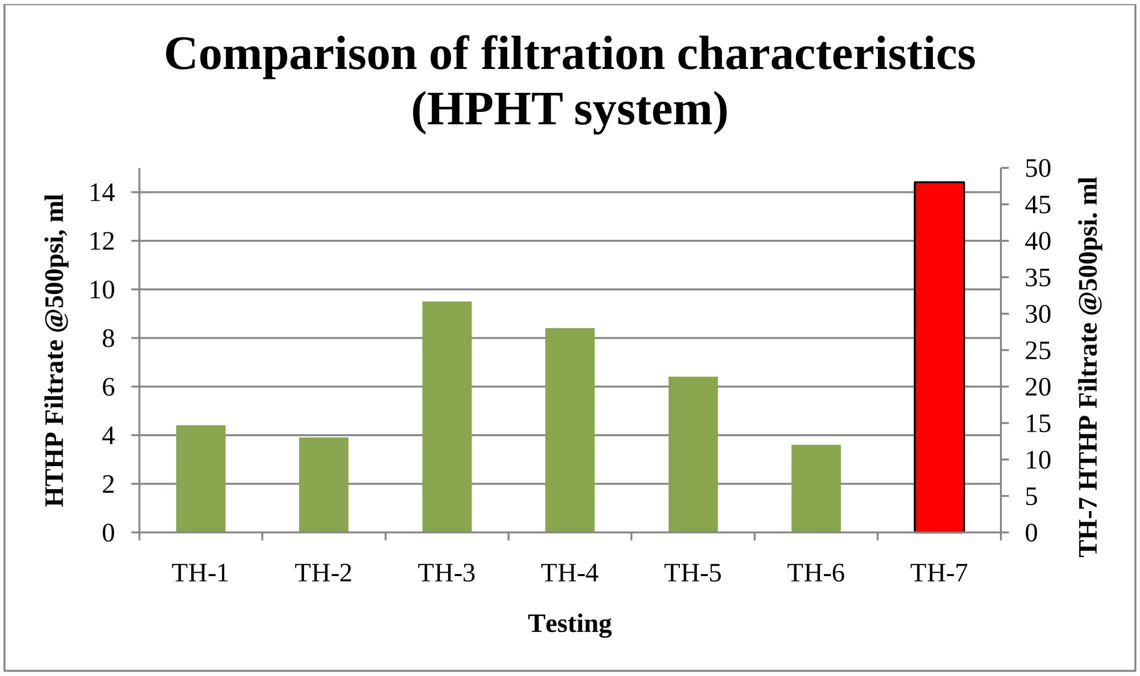


Figure 15. Comparison of filtration characteristics of TH-1 to TH-7

5.1.4 Performance Comparison Study of ETRO-Based Mud with Saraline 185V, Sarapar 147, Escaid 110, and YK-D80N in HPHT System

5.1.4.1 Results of Performance Comparison Test for HPHT System

Table 11 shows the mud formulation for performance comparison study between ETRO-based mud with other base oil such as Saraline 185V, Sarapar 147, Escaid 110, and YK-D80N. All muds were formulated with the same composition of additives, mud density of 14 ppg, OWR 85:15, calcium chloride content of 25% and hot rolling temperature of 392°F. This study is actually to compare the performance of the drilling fluids in term of rheological properties, emulsion stability and fluid loss characteristics with different base oils formulated. Each base oils has different physical and chemical properties, thus it is important to examine the effect towards the drilling fluid performances.

Table 21. Results of Performance Comparison Test for HPHT System

Properties Initial:	**Escaid 110**	**YK-D80N**	**Saraline 185V**	**Sarapar 147**	**ETRO**
Mud density, lb/gal	**14.0**	**14.0**	**14.0**	**14.0**	**14.0**
Rheological properties at	**120 °F**	**120 °F**	**120 °F**	**120 °F**	**120 °F**
600 rpm dial reading	76	92	105	104	85
300 rpm dial reading	45	55	63	64	50
200 rpm dial reading	34	41	48	49	37
100 rpm dial reading	22	26	32	33	24
6 rpm dial reading	7	8	9	11	7
3 rpm dial reading	6	7	8	10	6
Plastic viscosity, cP	31	37	42	40	35
Yield point, lb/100ft2	14	18	21	24	15
10" gel strength, lb/100ft2	7	9	9	10	7
10' gel strength, lb/100ft2	9	11	13	15	9
ES, volt at 120 °F	976	1158	1351	1211	1233
OWR	85/15	85/15	85/15	85/15	85/15
Properties AHR, 16 hr, (392 °F):	**Escaid 110**	**YK-D80N**	**Saraline 185V**	**Sarapar 147**	**ETRO**
Mud density, lb/gal	**14.0**	**14.0**	**14.0**	**14.0**	**14.0**
Rheological properties at	**120 °F**	**120 °F**	**120 °F**	**120 °F**	**120 °F**
600 rpm dial reading	87	93	166	146	130
300 rpm dial reading	52	54	108	93	77
200 rpm dial reading	39	40	87	73	58
100 rpm dial reading	25	25	61	50	37
6 rpm dial reading	8	7	26	19	10
3 rpm dial reading	7	6	25	18	8
Plastic viscosity, cP	35	39	58	53	53
Yield point, lb/100ft2	17	15	50	40	24
10" gel strength, lb/100ft2	7	7	27	22	10
10' gel strength, lb/100ft2	9	9	43	32	12
ES, volt at 120 °F	330	220	697	594	1579
OWR	85/15	85/15	85/15	85/15	85/15
CaCl2, % wt.	25	25	25	25	25
HTHP (500 psi, 350 °F), ml	4.2	3.8	1.6	2.4	4.4
HTHP (Filter cake), mm	3	3	2	2	1

Table 21 shows the results of the performance comparison for HPHT mud system at BHR and AHR condition. Some parameters have been determined as the key parameters to be compared in order to establish or decide on which base oils that most suitable for HPHT well condition. The parameters include of 6 rpm dial reading of Fann 35 Viscometer, plastic viscosity, yield point, gel strength, electrical stability value, HTHP filtrate volume, and also mud cake thickness.

5.1.4.2 Rheological Comparison Charts

Figure 16 shows the result of BHR rheological behavior for each base oils formulated in the HPHT system. As can be seen in Figure 16, the value of 6 rpm reading for ETRO-based mud is 7, which actually nearly the same as the other base oils formulated with value range of 7-11. It is also observed that at BHR condition, the value for 6 rpm reading and gel strength of ETRO-based mud is similar with Escaid 110 formulated mud. This can be one of the factors to show that ETRO can be said as comparable with the existing industrial base oil like Escaid 110. A part from that, all the base oil formulated mud resulted in high value of ES where ETRO with 1233 volts, is the second highest reading after Saraline 185V with 1351 volts. This clearly indicates that ETRO resulted in very stable invert emulsion mud as same as the other commercial base oils before being exposed to hot rolling temperature.

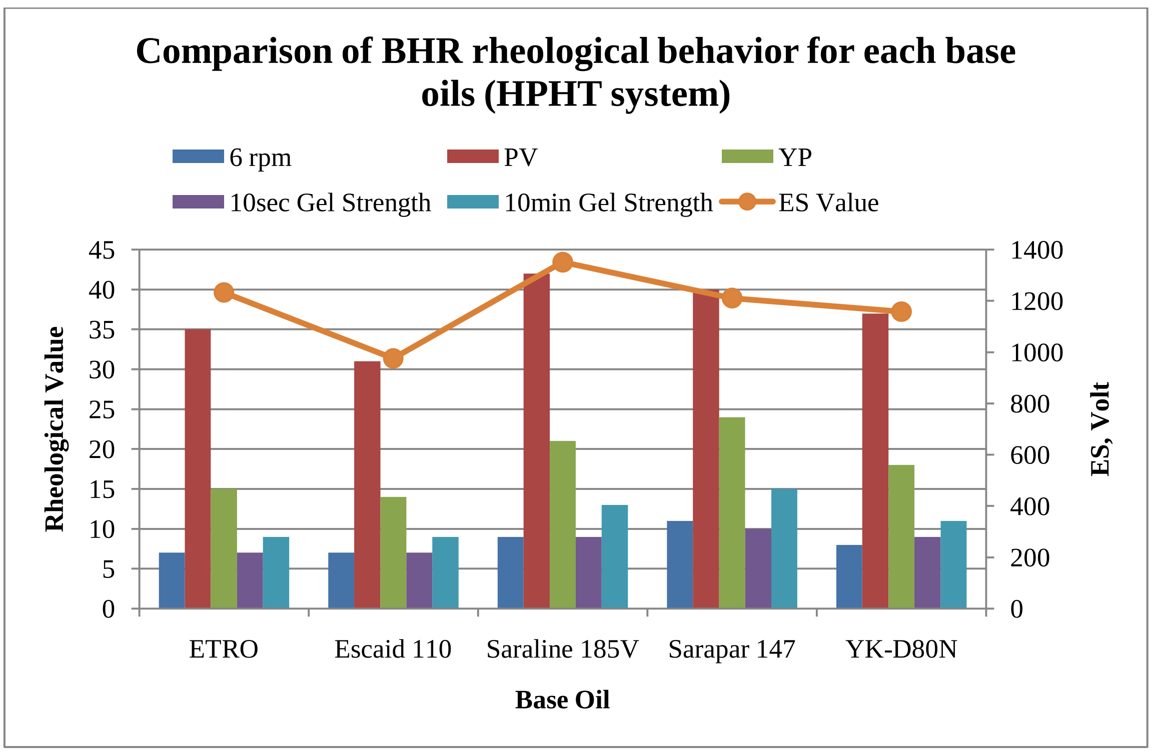


Figure 16. Comparison study of BHR rheological behavior for each base oils formulated in HPHT system

The results of rheological behavior comparison for each base oils formulated in HPHT system after being subjected to hot rolling temperature of 392°F for 16 hours are illustrated in Figure 17. As mentioned above, some key parameters will be compared between the base oils and these AHR rheological properties are very important points as the mud already simulated to the real condition of high temperature and pressure condition. As for the 6 rpm reading, ETRO-based mud is considered to has quite good and relevant result with the value of 10 where it is important to has 6 rpm reading value that not too high or too low. This is because 6 rpm is very important indicator for cutting transport ability of the mud. Saraline 185V gave quite high value of 6 rpm reading which is not preferable as more pump power will be required to circulated the mud while for the Escaid 110 and YK-D80N, they came up with low value of 6 rpm reading which also not preferable as it will result in poor cuttings transport ability.

Moving to the second parameter of plastic viscosity (PV), low value of PV is more preferable for the mud as it will help in reducing the risk of having drilling problems like differential sticking, low rate of penetration and etc. Even though the ETRO-based mud resulted in quite high PV value of 53 cp compared to Escaid 110 and YK-D80N, the value is considered as acceptable because of the high density mud applied. In term of PV, ETRO is observed to have quite similar value with Saraline 185V and Sarapar 147.

Yield point (YP) is actually used to evaluate the ability of mud to lift cuttings to the surface. High YP value indicates in better carries cuttings ability but too high value of YP is also not preferable as the frictional pressure loss is actually directly related to the YP. So that, having high YP will leads to high pressure loss while the drilling mud is being circulated. Drilling a large hole diameter will also requires on having high YP value in order to help hole cleaning efficiency. For this HPHT system, ETRO-based mud can be considered to have the most relevant YP value of 24 lb/100ft^2 for 14 ppg mud density compared to the other base oils formulated mud where low YP for Escaid 110 and YK-D80N while Saraline 185V and Sarapar 147 resulted in too high YP value.

The gel strength is another important parameter to be compared as it actually demonstrates the ability of the mud to suspend cuttings and other weighting materials when circulation is ceased. It is observed in Figure 17 that ETRO together with Escaid 110 and YK-D80N resulted in low 10 seconds and 10 minutes gel strength while Saraline 185V and Sarapar 147 gave quite high gel strength values. If the mud formulated has high gel strength, it will causes in high pump pressure required in order to break circulation after the mud is left static for a certain period of time. So, mud with low gel strength is much preferable and this gives ETRO an advantage as it has low 10 seconds and 10 minutes gel strength, 10 and 12 lb/100ft^2 respectively compared to Saraline 185V and Sarapar 147.

Figure 17 clearly illustrates the value of electrical stability (ES) of each base oils formulated where it is observed that after being subjected to hot rolling temperature of 392°F, ETRO resulted in highest ES value of 1579 volts which well ahead of others. This indicates that ETRO has the most stable emulsion between the water droplet and oil phase compared to the other base oils formulated in HPHT system.

For the filtration loss characteristics comparison, it is observed that ETRO resulted in quite high HTHP filtrate volume of 4.4 ml compared to other base oils. However, although the filtrate volume of ETRO is the highest among the base oils evaluated, it is still fulfilling the API standard requirement of having less than 15 ml volume of filtrate. Besides that, ETRO also has an advantage of having very low mud cake thickness, 1 mm compared to the other base oils (Table 21).

Finally, for HPHT mud system application, ETRO has possessed very good rheological properties. It has resulted in low 6 rpm reading, relevant plastic viscosity value, low yield point and gel strength, very high electrical stability value, acceptable HTHP filtrate volume, and also very thin mud cake thickness. These parameters had lead ETRO to be verified as comparable base oil and also one of the most suitable base oil for HPHT well drilling application.

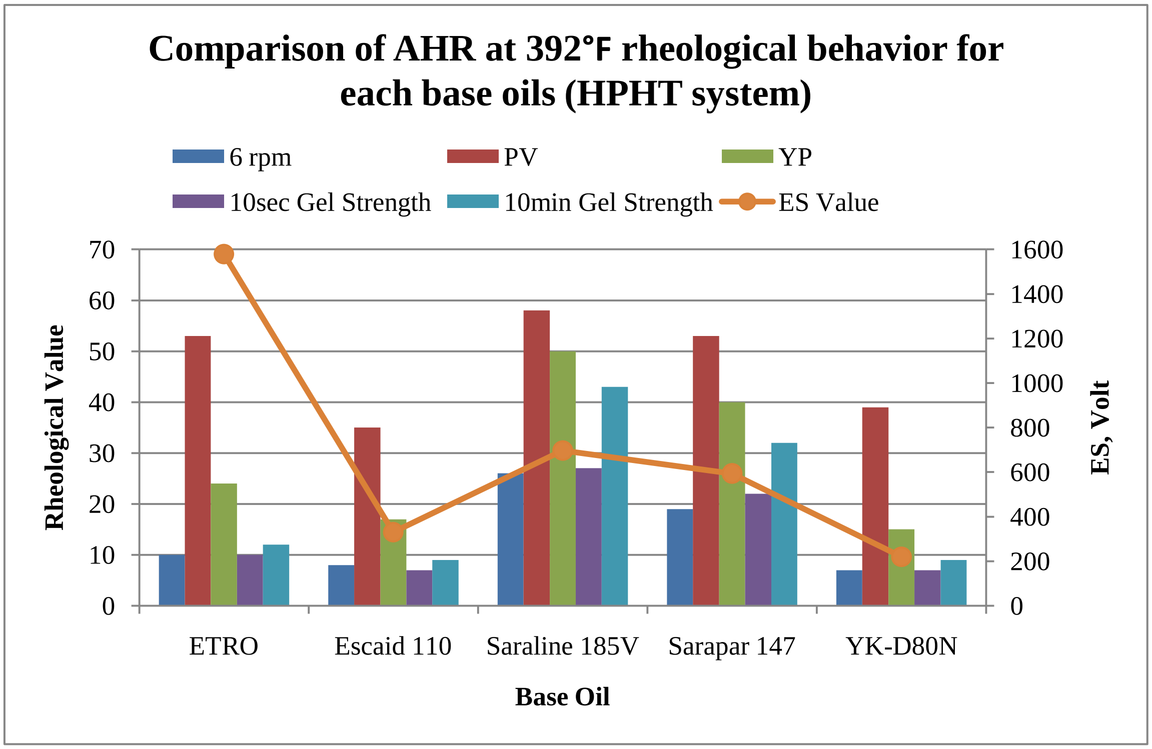


Figure 17. Comparison study of AHR rheological behavior for each base oils formulated in HPHT system

5.2 DEEPWATER SYSTEM

5.2.1 Results of Optimizing Test for Deepwater System

Table 22. Results of optimizing test for deepwater system

Properties Initial:	**TD-1**				**TD-2**				**TD-3**				**TD-4**				**TD-5**				**TD-6**				**TD-7**			
Mud density, lb/gal	**10.5**				**12.5**				**14.0**				**10.5**				**10.5**				**10.5**				**10.5**			
Hot Roll Temperature (°F)	**250**				**250**				**250**				**300**				**392**				**250**				**250**			
Rheological properties at	**40 °F**	**70 °F**	**120 °F**	**150 °F**	**40 °F**	**70 °F**	**120 °F**	**150 °F**	**40 °F**	**70 °F**	**120 °F**	**150 °F**	**40 °F**	**70 °F**	**120 °F**	**150 °F**	**40 °F**	**70 °F**	**120 °F**	**150 °F**	**40 °F**	**70 °F**	**120 °F**	**150 °F**	**40 °F**	**70 °F**	**120 °F**	**150 °F**
600 rpm dial reading	230	154	88	67	244	151	93	76	264	170	101	87	269	163	96	73	241	141	84	66	243	156	92	71	300	195	118	93
300 rpm dial reading	131	90	54	41	139	89	56	48	152	100	62	55	157	97	59	45	139	87	51	40	140	94	57	44	179	119	79	60
200 rpm dial reading	95	67	41	31	100	66	43	37	110	74	48	43	114	73	45	34	102	66	39	31	103	71	43	34	131	91	63	48
100 rpm dial reading	55	40	27	21	58	40	29	26	63	45	32	30	66	45	30	23	59	41	25	20	62	45	29	23	77	58	45	33
6 rpm dial reading	16	18	11	7	18	17	10	11	16	15	12	15	16	24	13	8	15	21	10	6	21	21	11	8	21	41	23	16
Variation 6 rpm (40°F & 120°F)	31.3%				44.4%				25.0%				18.8%				33.3%				47.6%				-9.5%			
3 rpm dial reading	14	16	10	6	15	15	9	10	14	14	11	13	14	21	11	7	13	19	9	5	19	20	10	7	20	37	21	15
Plastic viscosity, cP	99	64	34	26	105	62	37	28	112	70	39	32	112	66	37	28	102	54	33	26	103	62	35	27	121	76	39	33
Yield point, lb/100ft2	32	26	20	15	34	27	19	20	40	30	23	23	45	31	22	17	37	33	18	14	37	32	22	17	58	43	40	27
Variation YP (40°F & 120°F)	37.5%				44.1%				42.5%				51.1%				51.4%				40.5%				31.0%			
10" gel strength, lb/100ft2	26	33	15	11	23	27	17	18	19	27	22	22	30	42	17	13	24	35	14	11	35	40	16	13	59	68	32	23
10' gel strength, lb/100ft2	75	50	27	20	65	53	40	31	61	56	45	38	71	54	35	28	76	45	31	25	74	65	24	18	80	92	45	39
Variation 10' gel (40°F & 120°F)	64.0%				38.5%				26.2%				50.7%				59.2%				67.6%				43.8%			
ES, volt at 120 °F			1999				1999				1999				1999				1999				1785				1999	
OWR	75/25				80/20				85/15				75/25				75/25				75/25				75/25			
Properties AHR, 16 hr, (250 °F):	**TD-1**				**TD-2**				**TD-3**				**TD-4**				**TD-5**				**TD-6**				**TD-7**			
Mud density, lb/gal	**10.5**				**12.5**				**14.0**				**10.5**				**10.5**				**10.5**				**10.5**			
Rheological properties at	**40 °F**	**70 °F**	**120 °F**	**150 °F**	**40 °F**	**70 °F**	**120 °F**	**150 °F**	**40 °F**	**70 °F**	**120 °F**	**150 °F**	**40 °F**	**70 °F**	**120 °F**	**150 °F**	**40 °F**	**70 °F**	**120 °F**	**150 °F**	**40 °F**	**70 °F**	**120 °F**	**150 °F**	**40 °F**	**70 °F**	**120 °F**	**150 °F**
600 rpm dial reading	155	85	57	52	194	114	69	57	213	128	78	67	137	91	66	63	140	86	48	38	194	110	69	65	271	164	81	65
300 rpm dial reading	87	51	37	34	109	65	42	37	119	73	45	40	83	57	45	44	74	46	25	20	112	67	45	43	160	100	50	41
200 rpm dial reading	62	39	29	27	78	48	32	29	85	53	33	31	63	44	37	35	52	32	17	13	82	52	36	34	118	76	39	32
100 rpm dial reading	37	25	20	19	45	29	21	21	49	31	21	21	39	29	27	27	28	17	9	7	52	35	25	25	70	49	26	23
6 rpm dial reading	10	8	8	10	11	8	9	10	11	8	7	10	12	10	14	15	3	2	2	2	17	13	11	13	25	23	12	12
Variation 6 rpm (40°F & 120°F)	20.0%				18.2%				36.4%				-16.7%				33.3%				35.3%				52.0%			
3 rpm dial reading	9	6	7	9	10	7	8	9	9	7	6	9	10	9	13	13	2	1	1	1	15	11	9	12	23	21	11	11
Plastic viscosity, cP	68	34	20	18	85	49	27	20	94	55	33	27	54	34	21	19	66	40	23	18	82	43	24	22	111	64	31	24
Yield point, lb/100ft2	19	17	17	16	24	16	15	17	25	18	12	13	29	23	24	25	8	6	2	2	30	24	21	21	49	36	19	17
Variation YP (40°F & 120°F)	10.5%				37.5%				52.0%				17.2%				75.0%				30.0%				61.2%			
10" gel strength, lb/100ft2	14	12	11	13	16	15	15	14	13	14	14	14	18	15	18	16	3	3	3	3	24	20	16	17	38	35	20	18
10' gel strength, lb/100ft2	30	27	27	25	40	36	27	20	35	34	30	27	36	35	26	23	14	14	9	6	50	44	35	33	68	55	30	25
Variation 10' gel (40°F & 120°F)	10.0%				32.5%				14.3%				27.8%				35.7%				30.0%				55.9%			
ES, volt at 120 °F			1999				1999				1999				1946				1942				1999				1999	
OWR	75/25				80/20				85/15				75/25				75/25				75/25				75/25			
CaCl2, % wt.	25				25				25				25				25				25				25			
HTHP (500 psi, 250 °F)	2.8				2.4				4.6				7.6				Water-20, Oil-122 (SAG)				3.2				3.6			
HTHP (Filter cake), mm	1.0				1.0				2.0				2.0				5.0				2.0				2.0			

5.2.2 Rheological Behavior of ETRO-Based Mud in Deepwater System

5.2.2.1 Effect of mud density and OWR change

In deepwater system, three different mud density and oil water ratio (OWR) were tested which are TD-1, TD-2 and TD-3 for 10.5 ppg with 75:25 OWR, 12.5 ppg with 80:20 OWR and 14 ppg with 85:15 OWR respectively, as shown in mud formulation on Table 12. Deepwater drilling operation is also not spared from encountered operational problem like loss of circulation that may causes a drop in hydrostatic pressure in the wellbore besides also leads to high nonproductive time. Increase the drilling fluid density would be the best way in order to stop this loss of circulation problem to happen yet will also avoid the kick occurrence. So, the study on the capability of the deepwater mud system to withstand high density feature is very important in dealing with very challenging drilling operation.

During the test, barite was added to increase the mud weight while the calcium chloride brine content was reduced as the OWR increased. Figure 18 and Figure 19 respectively show the BHR rheological properties of TD-1, TD-2 and TD-3 at 120°F and AHR rheological properties of TD-1, TD-2 and TD-3 at 120°F. Both Figure 18 and Figure 19 indicate that the PV and 10 seconds gel strength keep increasing as the mud density increased from TD-1 to TD-3. This happened as the solid content in the mud increased. This trend is expected as the higher the mud weight, the higher PV will be. After being subjected to hot rolling temperature of 250°F, the YP is observed to be decreased as the mud density increased from TD-1 to TD-3 respectively.

Moving to 6 rpm reading properties, it is recorded has not changed much as the mud density increased for both BHR and AHR condition. This indicates that the mud has sustained its cuttings transport ability throughout the increment of density. For both BHR and AHR condition, the ES value is recorded to be very high at 1999 volts for all three muds which a clear indication of great mud emulsion stability.

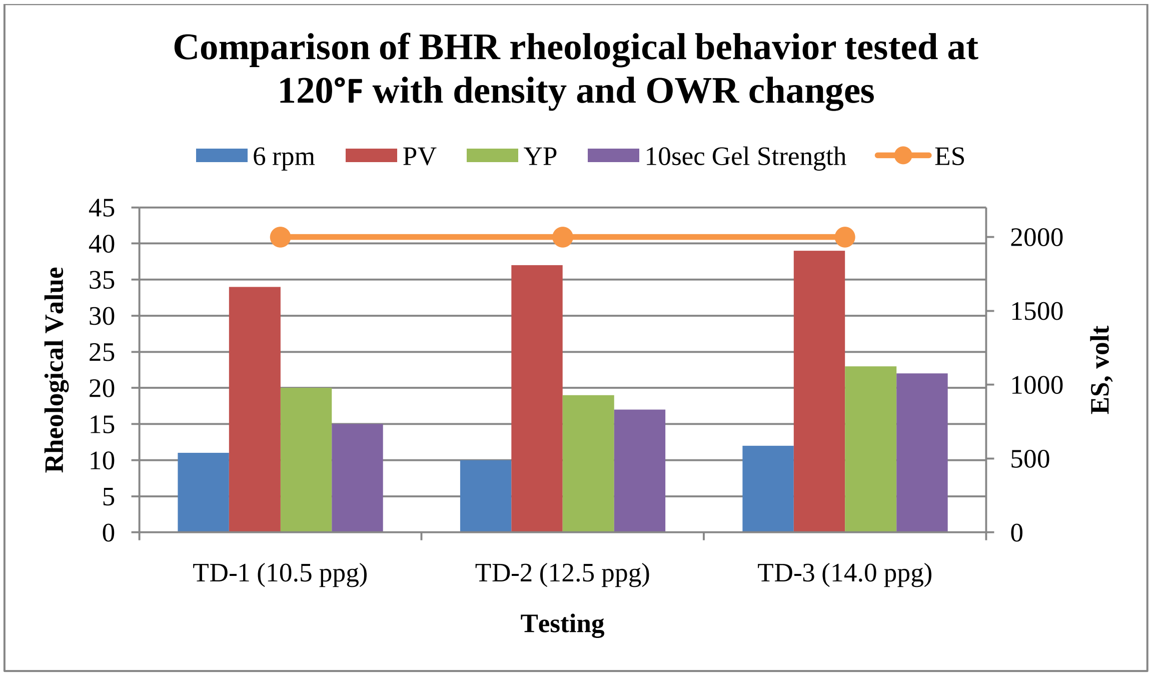


Figure 18. Comparison of BHR rheological behavior tested at 120°F with density and OWR changes

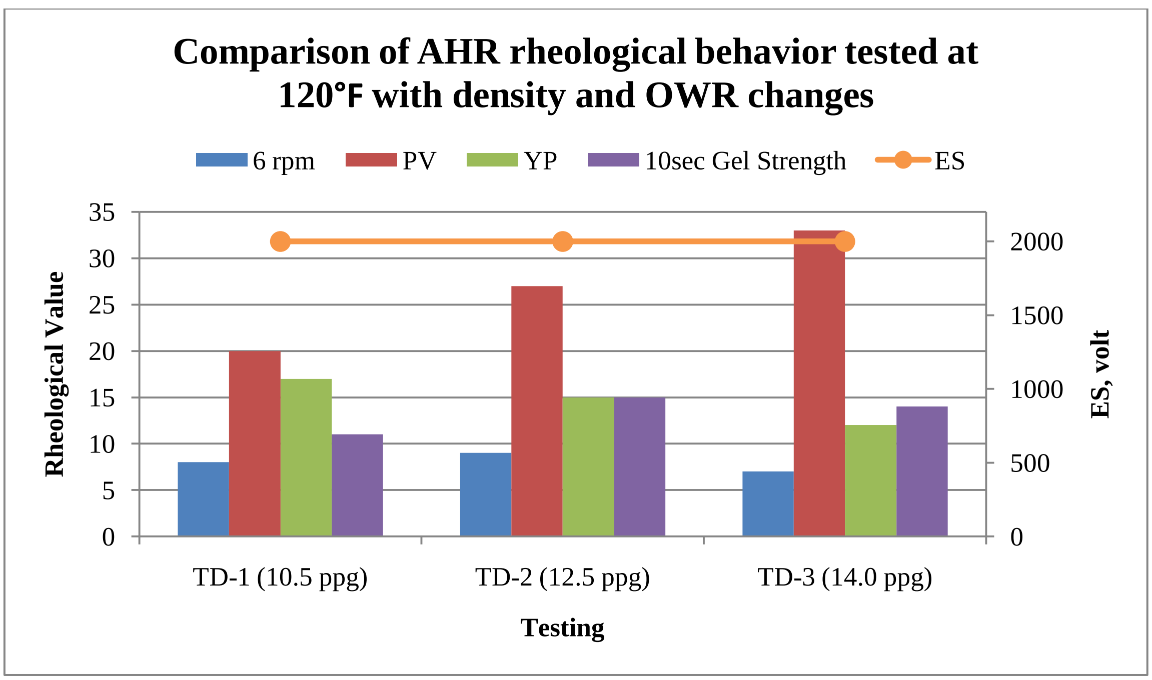


Figure 19. Comparison of AHR rheological behavior tested at 120°F with density and OWR changes

5.2.2.2 Effect of organophilic clay concentration variations

There were two different concentration of organophilic clay tested, 3 grams on TD-1 and 4 grams on TD-6 in order to study the effect of mud ability in suspending cuttings when subjected to increase in organophilic clay content. Figure 20 and Figure 21 respectively show the BHR and AHR rheological properties of TD-4 and TD-6 at 120°F. It is observed that the 6 rpm reading, PV, YP and also 10 seconds gel strength of the mud increased with increment of organophilic clay content from TD-1 to TD-6 respectively at both BHR and AHR condition. This clearly indicates that organophilic clay has played its role as viscosifier that enhances the ability of the mud to remove and suspend cuttings. Besides that, Figure 21 also shows that both muds, TD-1 and TD-6 were having very good emulsion stability with 1999 volts of ES value after being subjected to hot rolling temperature of 250°F. This signifies that the mud emulsion stability is maintained over the increment of organophilic clay concentration.

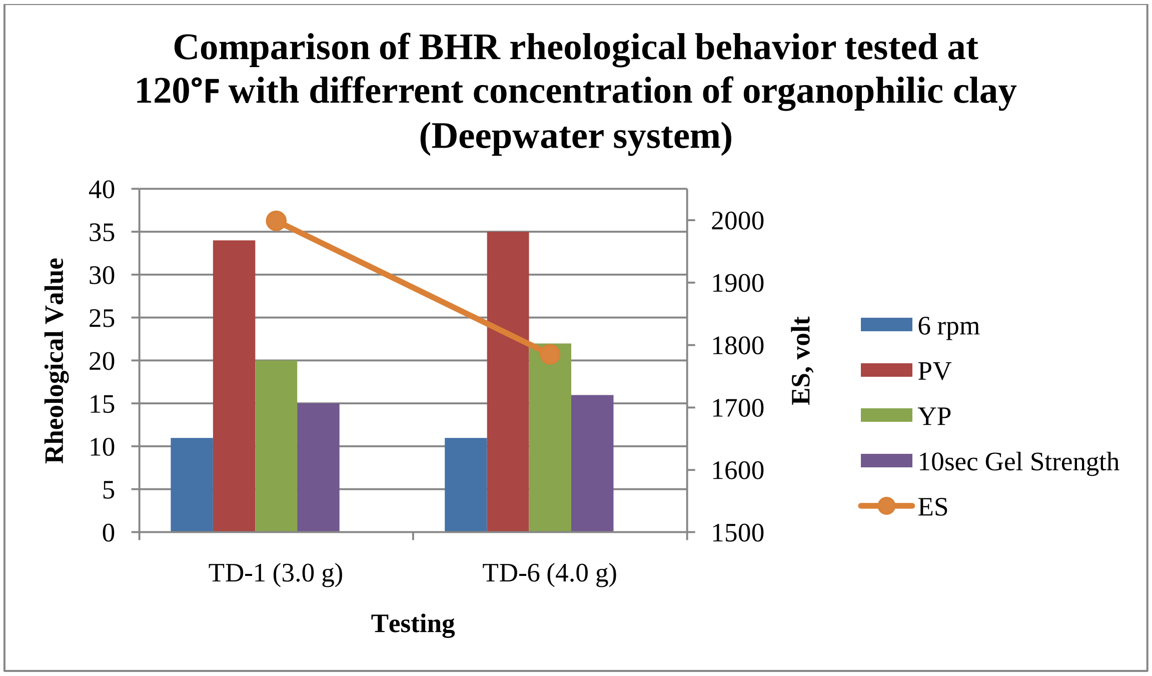


Figure 20. Comparison of BHR rheological behavior tested at 120°F with different concentration of organophilic clay in deepwater system

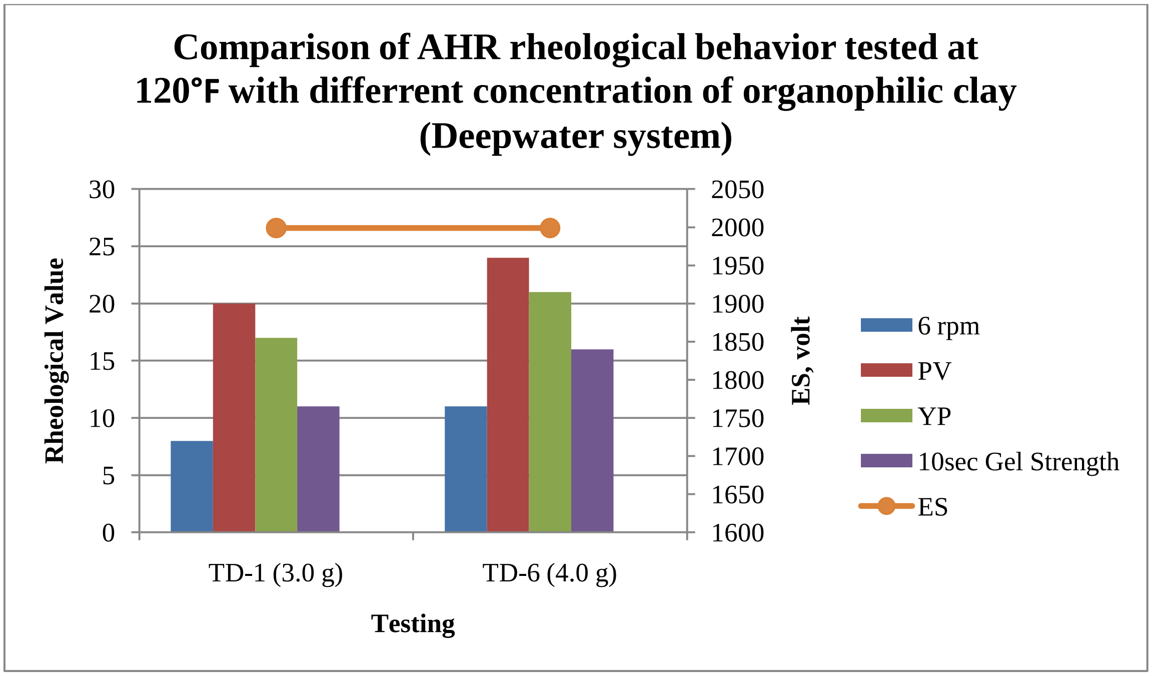


Figure 21. Comparison of AHR rheological behavior tested at 120°F with different concentration of organophilic clay in deepwater system

5.2.2.3 Effect of hot rolled temperature changes

Drilling deeper will leads to increase in downhole temperature. This is where the significant of studying the effect of mud rheological properties with increase in temperature appear. Each mud has been hot rolled in a pressurized cell for 16 hours. This hot rolling procedure is actually aimed to simulate the mud being exposed to the reservoir temperature condition.

Figure 22 shows the results of muds after being subjected to different hot rolling temperature of 250°F, 300°F and 392°F on TD-1, TD-4 and TD-5 respectively. It is observed that the emulsion stability of the mud decreased with increased in temperature. This is actually occurred due to the degradation of the emulsifier which cannot sustain high temperature condition. Besides that, the properties of 6 rpm reading, PV, YP and 10 seconds gel strength was recorded to be increased from TD-1 to TD-4 after being subjected to 250°F and 300°F. This situation is actually caused by the thermal flocculation effect on the clay contain in the mud as the clay starts to flocculate under high temperature.

However, as can be seen on the rheological properties of TD-5 shown on Figure 22, it resulted in very low value of 6 rpm reading, YP and 10 seconds gel strength. This is believed to happen because of the components of the mud that thermally degraded and cannot sustain at temperature up to 392°F. In order to overcome this problem, additives that have a good endurance at high temperature condition should be used in formulating the mud.

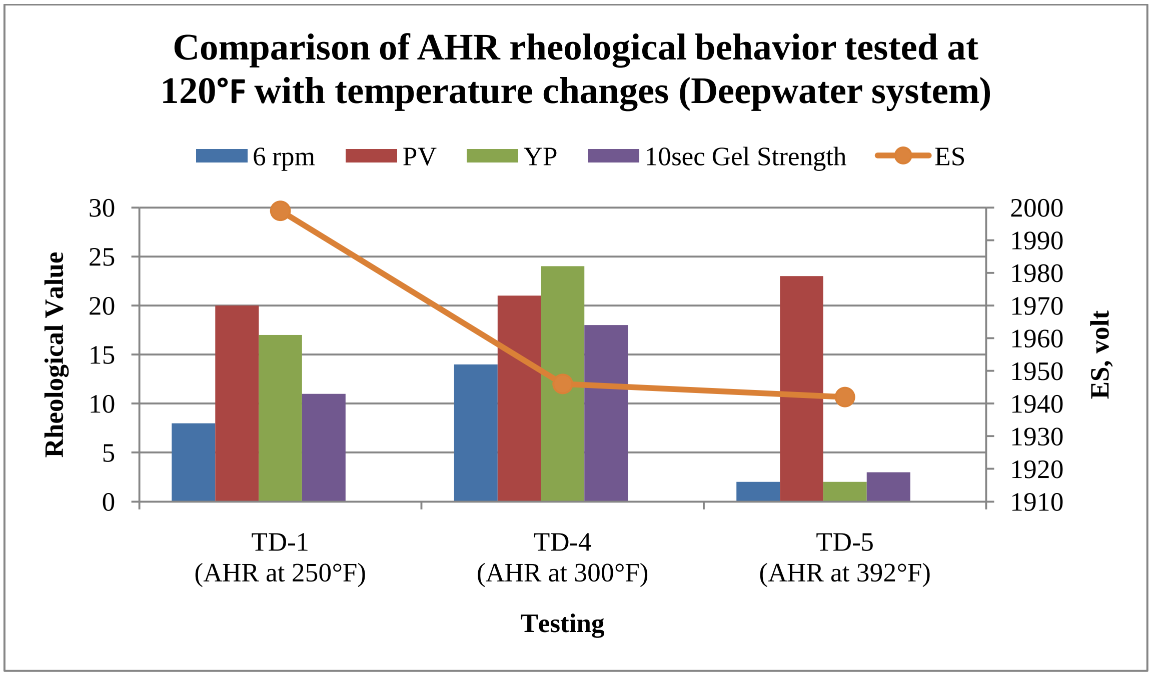


Figure 22. Comparison of AHR rheological behavior tested at 120°F with temperature changes in deepwater system

5.2.3 Filtration Characteristics of ETRO-Based Mud in Deepwater System

For filtration characteristics test in deepwater system, each mud samples were actually subjected to a specified hot rolling temperature for 16 hours where TD-1, TD-2, TD-3, TD-6, and TD-7 were tested at 250°F while TD-4 and TD-5 at 300 and 392°F respectively. After being hot rolled at respective temperature, the mud samples were then being tested for HPHT filtration test by using HPHT Filter Press where the mud samples were 500 psi pressure differential were applied at specified temperature for 30 minutes of total running test period. Table 23 shows the results of filtration characteristics for all tested deepwater system mud (TD-1 till TD-7) which include the filtrate volume and filter cake thickness.

Based on Figure 23, it shows that all mud samples resulted in filtrate volume which below the API recommended value of 15 ml [API 13A, (1993)] except for TD-5 which resulted in very high volume of filtrate, 142 ml after being subjected to high temperature of 392°F. In this case, the mud sample TD-5 loss its stability and this clearly indicates that this deepwater mud system cannot sustain at very high temperature condition. Even though the result for ES value is very high (shown in Table 22) for TD-5, it is proved that the mud loss its stability as there were water droplet presence detected in the filtrate with a volume of 20 ml of the total filtrate.

As can be seen in Table 23 and Figure 23, the volume of filtrate recorded increases from TD-1 to TD-4 and TD-5, with 2.8, 7.6 and 142 ml respectively, after the mud samples being exposed to different temperature. The results show that increase in hot rolling temperature will increase the volume of filtrate collected. This happens because of degradation effect of the additives as being subjected to higher temperature condition. Besides that, degradation effect of the additives will also cause the mud to be less stable as can be observed from the decreases in ES value of the mud as temperature increases. As for filter cake thickness, it is observed that all mud samples resulted in low cake thickness of less than 2 mm which indicates a good filter cake produced. However, TD-5 resulted in thicker filter cake of 5 mm after being subjected to higher temperature of 392°F. This is happened as the mud loss its stability besides the fluid loss agent used is degraded and cannot sustain at temperature 392°F.

Table 23. Filtration characteristics results of TD-1 to TD-7

Parameter	TD-1	TD-2	TD-3	TD-4	TD-5	TD-6	TD-7
Hot Roll Temperature, °F	250	250	250	300	392	250	250
HTHP Filtrate @500psi, ml	2.8	2.4	4.6	7.6	142.0	3.2	3.6
HTHP Filter Cake, mm	1	1	2	2	5	2	2

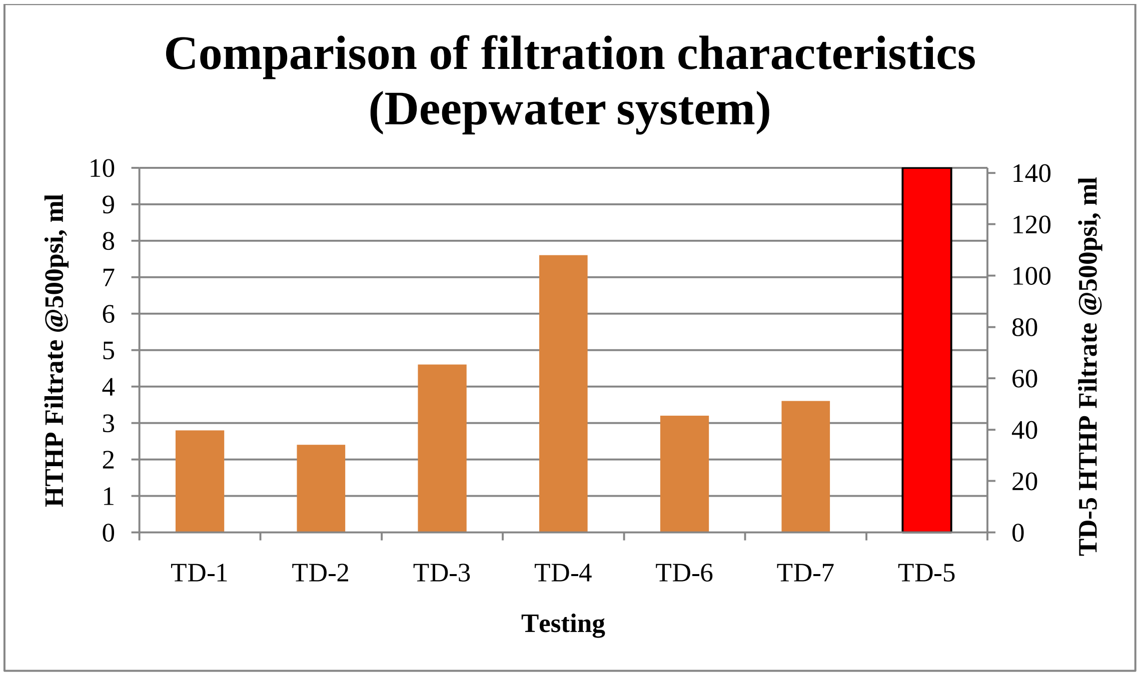


Figure 23. Comparison of filtration characteristics of TD-1 to TD-7

5.2.4 Performance Comparison Study of ETRO-Based Mud with Saraline 185V, Sarapar 147, Escaid 110, and YK-D80N in Deepwater System

5.2.4.1 Results of Performance Comparison Test for Deepwater System

Table 24. Results of Performance Comparison Test for Deepwater System

Properties Initial:	Escaid 110				YK-D80N				Saraline 185V				Sarapar 147				ETRO			
Mud density, lb/gal	10.5				10.5				10.5				10.5				10.5			
Rheological properties at	40 °F	70 °F	120 °F	150 °F	40 °F	70 °F	120 °F	150 °F	40 °F	70 °F	120 °F	150 °F	50 °F	70 °F	120 °F	150 °F	40 °F	70 °F	120 °F	150 °F
600 rpm dial reading	109	77	55	48	143	96	64	55	227	151	95	78	217	178	105	86	230	154	88	67
300 rpm dial reading	62	45	33	29	80	57	38	35	131	90	59	51	134	107	72	56	131	90	54	41
200 rpm dial reading	45	34	25	21	57	47	29	27	96	68	46	40	100	81	64	45	95	67	41	31
100 rpm dial reading	27	21	15	14	35	27	19	17	58	44	31	29	63	53	48	33	55	40	27	21
6 rpm dial reading	6	6	6	6	9	9	8	6	21	22	17	15	32	31	32	18	16	18	11	7
Variation 6 rpm (40 °F and 120 °F)	0.0%				11.1%				19.0%				0.0%				31.3%			
3 rpm dial reading	5	5	5	5	8	8	7	5	19	20	16	13	30	29	30	17	14	16	10	6
Plastic viscosity, cP	47	32	22	19	63	39	26	20	96	61	36	27	83	71	33	30	99	64	34	26
Yield point, lb/100ft2	15	13	11	10	17	18	12	15	35	29	23	24	51	36	39	26	32	26	20	15
Variation YP (40 °F and 120 °F)	26.7%				29.4%				34.3%				23.5%				37.5%			
10" gel strength, lb/100ft2	7	7	8	7	9	10	10	9	28	36	24	21	59	54	29	25	26	33	15	11
10' gel strength, lb/100ft2	20	18	12	11	22	20	16	18	54	46	35	32	77	64	41	32	75	50	27	20
Variation 10' gel (40 °F and 120 °F)	40.0%				27.3%				35.2%				46.8%				64.0%			
ES, volt at 120 °F			441				584				766				714				1999	
OWR	75/25				75/25				75/25				75/25				75/25			
Properties AHR, 16 hr, (250 °F):	**Escaid 110**				**YK-D80N**				**Saraline 185V**				**Sarapar 147**				**ETRO**			
Mud density, lb/gal	10.5				10.5				10.5				10.5				10.5			
Rheological properties at	40 °F	70 °F	120 °F	150 °F	40 °F	70 °F	120 °F	150 °F	40 °F	70 °F	120 °F	150 °F	50 °F	70 °F	120 °F	150 °F	40 °F	70 °F	120 °F	150 °F
600 rpm dial reading	104	63	45	42	114	68	49	44	173	96	66	59	194	121	71	63	155	85	57	52
300 rpm dial reading	59	37	28	27	64	40	31	29	98	57	43	41	110	71	44	42	87	51	37	34
200 rpm dial reading	43	28	21	20	47	31	23	22	71	43	34	33	79	53	34	33	62	39	29	27
100 rpm dial reading	27	18	14	14	29	20	15	15	42	28	23	24	47	33	24	24	37	25	20	19
6 rpm dial reading	9	6	6	7	9	6	6	8	13	10	10	14	19	15	12	15	10	8	8	10
Variation 6 rpm (40 °F and 120 °F)	33.3%				33.3%				23.1%				36.8%				20.0%			
3 rpm dial reading	7	5	5	6	7	5	5	7	12	9	9	13	17	14	11	14	9	6	7	9
Plastic viscosity, cP	45	26	17	15	50	28	18	15	75	39	23	18	84	50	27	21	68	34	20	18
Yield point, lb/100ft2	14	11	11	12	14	12	13	14	23	18	20	23	26	21	17	21	19	17	17	16
Variation YP (40 °F and 120 °F)	21.4%				7.1%				13.0%				34.6%				10.5%			
10" gel strength, lb/100ft2	11	9	9	10	11	9	9	10	21	16	15	17	33	28	22	20	14	12	11	13
10' gel strength, lb/100ft2	24	21	18	16	24	22	20	18	42	39	31	29	66	44	37	34	30	27	27	25
Variation 10' gel (40 °F and 120 °F)	25.0%				16.7%				26.2%				43.9%				10.0%			
ES, volt at 120 °F			786				852				908				541				1999	
OWR	75/25				75/25				75/25				75/25				75/25			
CaCl2, % wt.	25				25				25				25				25			
HTHP (500 psi, 250 °F)	1.8				2.0				0.4				0.4				2.8			
HTHP (Filter cake), mm	1				1				1				1				1			

Table 24 shows the results of the performance comparison for deepwater mud system at BHR and AHR condition. Each base oils was formulated with the same additives composition, hot roll at 250°F, density of 10.5 ppg, OWR 75:25, and being tested for rheological properties at 40, 70, 120 and 150°F. Some parameters have been determined as the key parameters to be compared in order to establish or decide on which base oil gives the best performances and most suitable for deepwater well condition. For deepwater mud system, there are some special parameters that a drilling fluid should possess in order to deal with the technical requirements of deepwater operation. The most important and critical parameter is that the mud should has flat rheological behavior over wide range of temperature. The flatness of the mud rheological behavior was tested and measured through calculating the variation percentage of 6 rpm reading, yield point and also 10min gel strength at 40 to 150°F.

Besides that, deepwater application also requires a drilling fluid system with very low pour point of base oil since the operation has to deal with very low temperature condition at the seabed with approximately 39°F (4°C). In this case, it is observed that Sarapar 147 is the one that failed to fulfill this requirement as it has high pour point of 48°F (9°C). As can be seen in Table 24, the rheological properties of Sarapar 147 can only be tested down to 50°F only as the mud start to solidify and loss its flow characteristics below the temperature. This clearly indicates that Sarapar 147 is not suitable to be used in deepwater drilling application.

5.2.4.2 Rheological Comparison Charts

Figure 24 and Figure 25 show the comparison of 6 rpm reading and yield point for each base oils at four different rheological temperatures of 40, 70, 120 and 150°F. A curve has been plotted in order to see the flatness of the parameter for each base oils. In figure 24, it is observed that ETRO together with Escaid 110 and YK-D80N show the most flat curve for 6 rpm reading compared to Saraline 185V and Sarapar 147. This means that ETRO, Escaid 110 and YK-D80N have consistent and stable rheological properties over a wide range of temperature changes. This flatness of 6 rpm reading indicates that the mud systems have maintained their cuttings transport ability regardless of temperature changes. This is very important parameter as deepwater application deals with wide range of temperature changes particularly from the seabed to the downhole condition and the muds should not loss their ability in transporting the cuttings to the surface within this range of temperatures. Losing capability of transporting cuttings will cause serious problems to the drilling operation like low rate of penetration, hole pack-off, bit broken and etc.

Maintaining yield point within temperature variation is also important to provide mud ability of lifting cuttings to the surface. Again, Figure 25 shows that ETRO, Escaid 110 and YK-D80N give the most flatness curve compared to Saraline 185V and Sarapar 147. In term of the yield point value, ETRO is observed to have a quite similar value with the others. This means that ETRO possess comparable properties with the other commercial base oils in deepwater mud system.

Figure 26 shows the comparison of 6 rpm reading, yield point, and 10 minutes gel strength variation in term of percentage and also ES value for each base oils tested. The lower the variation percentage, the more preferable the mud will be for deepwater application. This is because, low variation percentage of 6 rpm, YP and gel strength will indicate that the mud had successfully maintained its rheological properties over temperature changes. From Figure 26, it can be seen that ETRO-based mud resulted in the lowest variation percentage of 6 rpm reading and 10 minutes gel strength of 20% and 10% compared to the others. While for the variation of YP, ETRO resulted in 10.5% which is the second lowest after YK-D80N. In term of 6 rpm reading and 10 minutes gel strength, ETRO has the best results as it possess the lowest value.

Based on Figure 26, ETRO also has an advantage of having the highest ES value of 1999 volts compared to the other base oils. This indicates that ETRO has the most stable emulsion between the water droplet and oil phase compared to the other base oils formulated in deepwater system.

Moving to the filtration loss characteristics comparison, after being subjected to pressure differential of 500 psi and temperature of 250°F, it is observed that ETRO resulted in quite high HTHP filtrate volume of 2.8 ml compared to other base oils (shown in Table 24). However, although the filtrate volume of ETRO is the highest among the base oils evaluated, it is still fulfilling the API standard requirement of having less than 15 ml volume of filtrate. Besides that, in term of mud cake thickness, all mud samples resulted in the same thickness of 1 mm which is very good mud cake layer.

Finally, for deepwater mud system application, ETRO has possessed very good rheological flatness of 6 rpm reading, yield point and 10 minutes gel strength. It resulted in the lowest variation percentage of 6 rpm reading and 10 minutes gel strength. Even though YK-D80N is the one with the lowest variation of percentage for yield point, ETRO still has the advantage of being the second lowest when it resulted in highest ES value. These parameters have lead ETRO to be verified as the most suitable base oil for deepwater well drilling application.

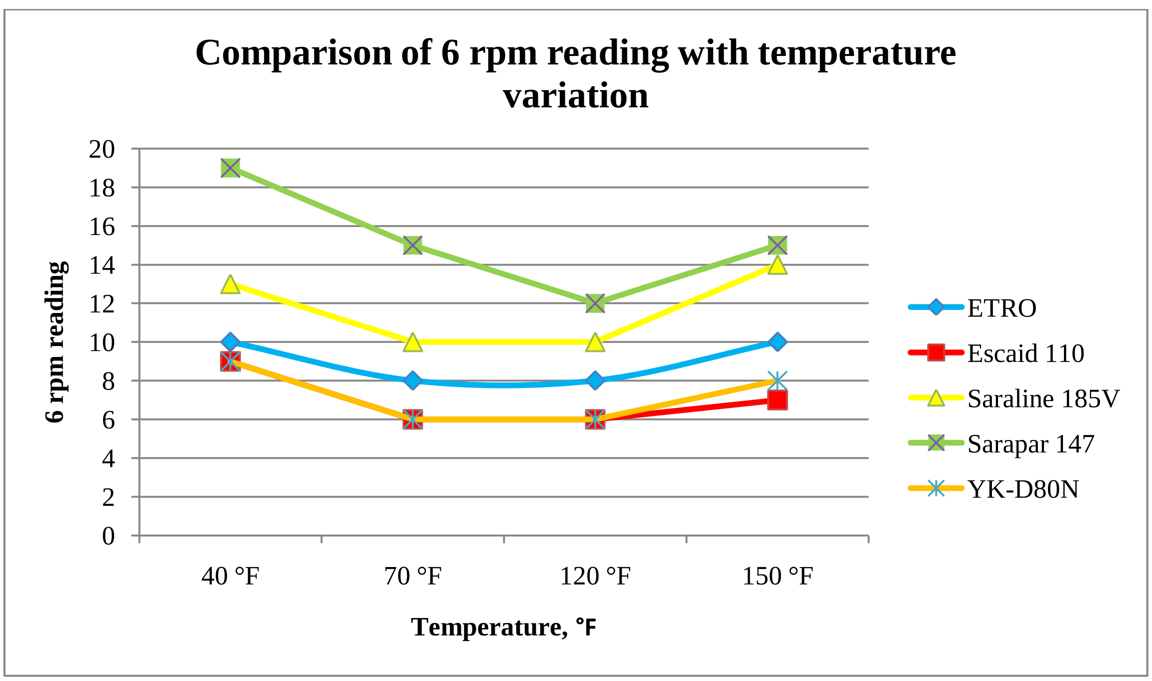


Figure 24. Comparison of 6 rpm reading of each base oils with temperature variation in deepwater system

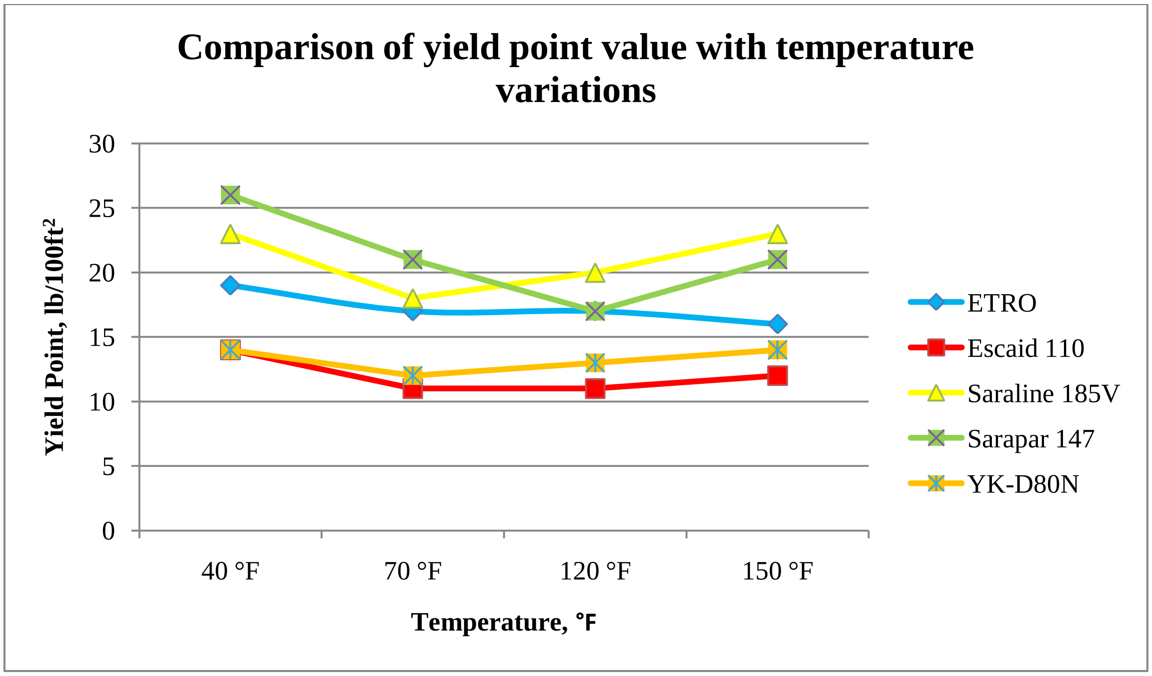


Figure 25. Comparison of yield point of each base oils with temperature variation in deepwater system

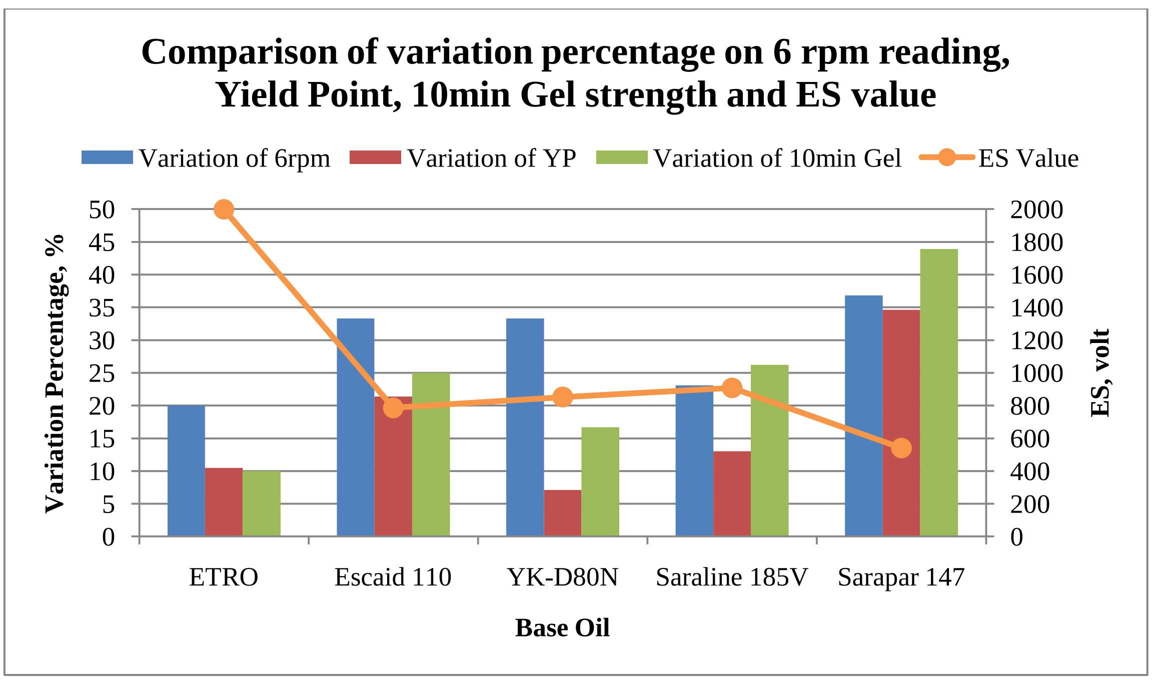


Figure 26. Comparison of variation percentage on 6 rpm reading, yield point, 10min gel strength and ES value of each base oils in deepwater system

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

- ***ETRO is suitable for high pressure high temperature (HPHT) and deepwater mud system.***

  Firstly, ETRO is very suitable to be used as a base oil in drilling fluids because it has good properties of low density and low aromatic and sulphur content. It is said as compatible to be used in HPHT mud system because it can sustain good rheological properties at very high temperature of 392°F and also high density of 16 ppg. High density mud is required in order to deal with high pressure well condition. While for deepwater mud system, it is said to be suitable because of its flat rheological behaviour where it has been proved that its 6 rpm reading, yield point and 10 minutes gel strength does not change much over wide range of temperature changes. Besides that, ETRO also has an extremely low pour point of -63°F compared to other common base oils that make it very suitable for deepwater application.

- ***ETRO offers more stable emulsion, low in yield point, plastic viscosity, 6 rpm reading and gel strength compared to other base oils but slightly higher in filtrate volume.***

  In term of rheological properties, it is observed that ETRO resulted in low yield point which is 24 and 17 lb/100 ft^2 for HPHT and deepwater mud system respectively. High YP value indicates in better carries cuttings ability but too high value of YP is also not preferable as it may cause high pressure loss while the drilling mud is being circulated. For plastic viscosity (PV) value, ETRO resulted in low value of 20 cp for deepwater mud system and acceptable value of 53 cp for high density of HPHT mud system. Low PV is very important in order to prevent drilling problem like differential sticking, low penetration rate and etc. Next, ETRO also resulted in low 6 rpm reading of 10 and 8 for HPHT and deepwater mud system which indicates good cuttings transport ability. Moving to gel strength, in HPHT mud system, ETRO resulted in low value for 10 seconds and 10 minutes of testing, 10 and 12 lb/100 ft^2 respectively. While for the deepwater mud system, ETRO resulted in low value for 10 seconds testing of 11 lb/100 ft^2 but slightly higher for 10 minutes with 27 lb/100 ft^2. Besides that, it is observed that ETRO is very good in term of its emulsion stability. This is because ETRO always resulted in very high value of electrical stability (ES) which is usually up to 1999 volts. However, one of the problems with ETRO is that it gives slightly higher in term of filtrate volume. This problem can be overcome by adding more fluid loss agent in order to help in reducing the filtrate volume.

- ***ETRO was proven to be technically comparable as other commercial base oils for the use in HPHT drilling application whiles it is demonstrated as the best base oil for deepwater drilling application.***

  In this project, ETRO was compared with other common commercial base oils like Escaid 110, Saraline 185V, Sarapar 147 and YK-D80N. As for the HPHT drilling application, ETRO resulted in quite similar rheological behaviour besides having an advantage of high in ES value compared to other base oils tested. While in deepwater drilling application, ETRO has been proved to be the best base oil among the other common base oils tested as it resulted in lowest variation percentage of 6 rpm reading, yield point and 10 minutes gel strength. Low in variation percentage indicates that ETRO had successfully maintained its rheological properties over a wide range of temperature changes. This flat rheological behaviour is very important as deepwater drilling application always need to deal with wide range of temperature from the seabed to the downhole temperature condition.

For the future works, it is recommended to:

- Conduct a stress test on ETRO-based mud by adding seawater, cement and more rev dust in order to study the effect towards its rheological behaviour. This is because, there is always a risk of some seawater encroaching or cement mixed into the mud while drilling. Besides that, study on having more rev dust also important in order to evaluate the capability of the mud to sustain high drill cuttings content.

- Conduct rheological test by using Fann 75 viscometer instead of Fann 35 viscometer especially for HPHT mud system. This is actually to better simulate the real reservoir condition with very high temperature and pressure testing. So, the result of rheological behaviour of the mud would be more accurate as it being exposed to real condition of the reservoir in Fann 75 viscometer.
- Conduct detailed research on the cost and economic analysis of the ETRO base oil in order to be compared with other commercial base oils.
- Add more fluid loss control additives in the formulation of ETRO-based mud in order to reduce the volume of filtrate collected.
- Check and calibrate the testing equipments prior to commence any experimental works in order to gain more accurate results.

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APPENDIX 1

GANTT CHART

Activities	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection and confirmation of FYP Topic														
Preliminary literature review and theory analysis														
Request ETRO sample from PETRONAS Base Oil														
ETRO sample analysis														
Understanding the methodology and details on base oil and drilling fluid system							•							
Submit Proposal Defense Report							•							
Proposal Defense (Oral Presentation)								•	•					
Determine formulation for each drilling fluid systems												•		
Submit Interim Draft Report												•		
Submit Interim Report													•	•

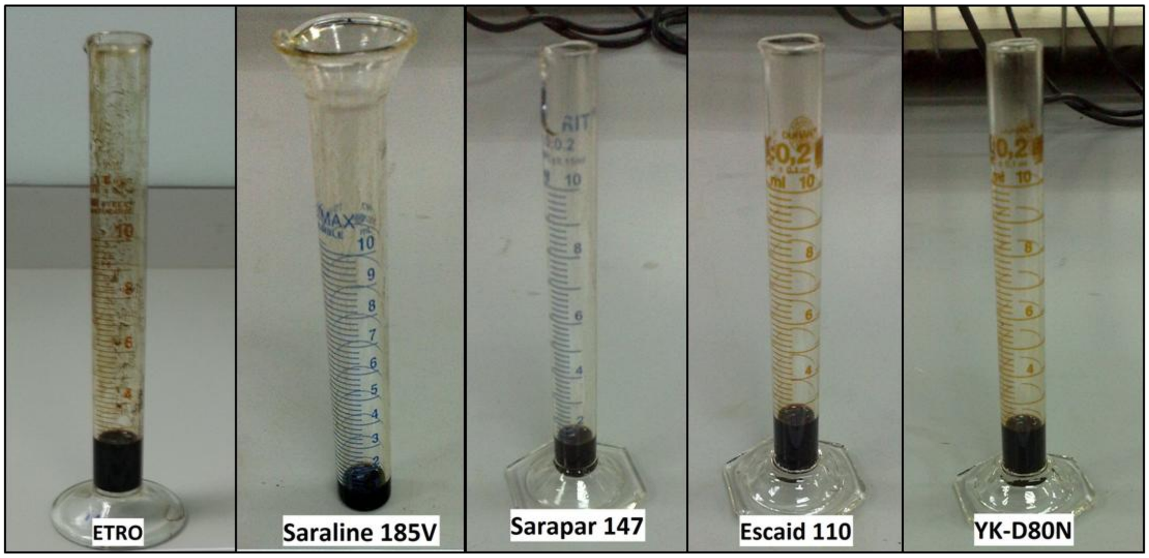
Activities	Week													
	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Acquire additives required		•												
Rheological properties measurement of HTHP mud system				•										
Emulsion stability and filtration characteristics test for HTHP mud system				•										
Rheological properties measurement of deepwater mud system						•								
Emulsion stability and filtration characteristics test for deepwater mud system						•								
Assessment of ETRO performance and comparison with other base oil														
Reporting and documentation of results														

APPENDIX 2

MILESTONES

No.	Activities	Date
1	Complete methodology identification and base oil properties analysis	Week 7
2	Submission of Proposal Defense Report	2nd July 2012 (Week 7)
3	Proposal Defense (Oral presentation)	9-20th July 2012 (Week 8-9)
4	Complete with determination of mud system formulation	Week 12
5	Submission of Interim Draft Report	9th August 2012 (Week 12)
6	Submission of Interim Report	16th August 2012 (Week 13)
7	Complete acquiring the additives required	Week 16
8	Done with rheological properties, emulsion stability and filtration characteristics test on HPHT mud system	Week 18
9	Done with rheological properties, emulsion stability and filtration characteristics test on deepwater mud system	Week 20
10	Final report submission (draft)	Week 23
11	Final report submission	Week 24-25

Figure of filtrate volume and mud cake thickness of mud samples in HPHT mud system:



APPENDIX 4

Figure of filtrate volume and mud cake thickness of mud samples in deepwater mud system:

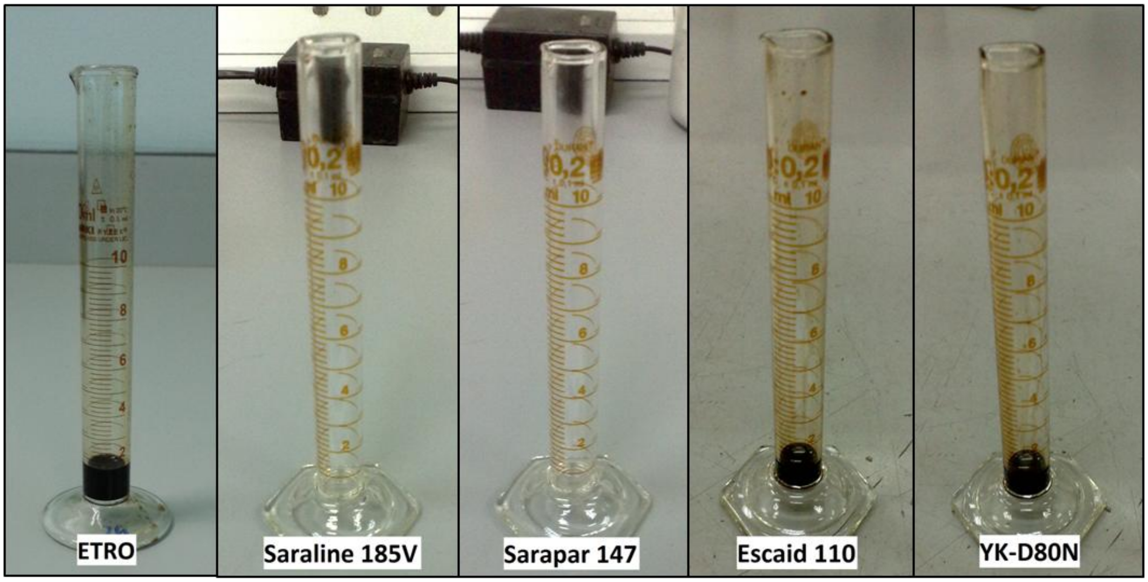


Figure of base oils involved: