Optimum Composition of Nanosilica in Synthetic Based Mud (SBM) For High Pressure High Temperature (HPHT) Wells Application

by

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Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Petroleum)

JANUARY 2015

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Universiti Teknologi Petronas
in partial fulfilment of the requirements for the
BACHELOR OF ENGINEERING (Hons)
(PETROLEUM)

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

ADRYAN

ABSTRACT

The depleted of easy oil reservoir and followed by the decreasing of production rate of the existing field enforce drilling operation to find the reservoir in challenging environment condition which contain high pressure and high temperature (HPHT) to accommodate the global energy demand which continue to grow over the years. This HPHT environment tends to give some troublesome during drilling operation, particularly drilling fluid. Prolonged exposure of drilling fluid in HPHT condition will change the drilling fluid desired properties due to degradation of the chemical component. Although Synthetic Based Mud (SBM) is well known as the most suitable drilling fluid for most wellbore environment, but it still has some problem with chemical degradation while exposed to HPHT condition. Recently, as the early stage of research by conducting series laboratory experiments, the utilization of nanosilica has been introduced to the SBM as an additive and it has been proven to enhance SBM performance in HPHT. However, the optimum composition of nanosilica in SBM need to be determined to meet the performance and economical viable, thus will make this utilization applicable in the real condition. Therefore, this study focused to find the optimum composition of nanosilica in SBM for HPHT wells application. Nanosilica is categorized into two different sizes which are 5-15 nanometers (nm) and 10-20 nm and exposed into HPHT conditions which are 350°F and 450°F system. The concentration of nanosilica is manipulated within range 1-3 wt. %. From this experiment, the optimum composition of nanosilica size 10-20nm in SBM has been determined to give better performance of SBM formulation in HPHT conditions in term of rheological properties, electrical stability and cost, while the enhanced nanosilica size 5-15nm in SBM has shown lower performance as compared to nanosilica size 10-20nm.

ACKNOWLEDGEMENT

First and foremost, the author would like to express sincere gratitude to the supervisor Mr. M. Aslam Md. Yusof, lecturer Faculty of Geoscience and Petroleum Engineering, Department of Petroleum Engineering, Universiti Teknologi PETRONAS for his patience, continuous support, motivation and guidance during this project.

Thanks to the Drilling Fluid Lab technician, Mr. Jukhairi Selamat for the assistance, training and guidance for the lab sessions.

Last but not least, special thanks to author family members and friends for their continuous support and encouragement during this project.

TABLE OF CONTENTS

CERTIFICATION OF APPROVAL i

CERTIFICATION OF ORIGINALITY ii

ABSTRACT iii

ACKNOWLEDGEMENT iv

TABLE OF CONTENTS v

LIST OF FIGURES vii

LIST OF TABLES viii

INTRODUCTION 1

- 1.1 Background 1
- 1.2 Problem Statement 2
- 1.3 Objective 3
- 1.4 Scope of Study 3

LITERATURE REVIEW 4

- 2.1 High Pressure High Temperature Well 4
- 2.2 SBM 5
- 2.3 Nanotechnology 6
- 2.4 Nanosilica 8

METHODOLOGY 11

- 3.1 Methodology 12
- 3.2 Drilling Fluid Formulation 12
- 3.3 Mixing Sample 14
- 3.4 Rheological Properties Test for the Sample 17
- 3.5 Electrical stability of Emulsion Test 18
- 3.6 Hot Rolling Samples 18

3.7 HPHT Filtration Test..19
3. 8 Project Gantt-Chart..20
3.9 Key Milestone 21
RESULT AND DISCUSSION..22
4.1 Sample Result and Discussion 23
4.1.1 Nanosilica size 5-15nm, temperature 350°F and mud weight 13.5 ppg. ..23
4.1.2 Nanosilica size 5-15nm, temperature 450°F and mud weight 17 ppg. 26
4.1.3 Nanosilica size 10-20nm, temperature 350°F and mud weight 13.5 ppg. 29
4.1.4 Nanosilica size 10-20nm, temperature 450°F and mud weight 17ppg. 33
CONCLUSION AND RECOMMENDATION 39
REFERENCES..41

LIST OF FIGURES

FIGURE 1: Methodology of the project 11

FIGURE 2: Rotational speed vs dial reading for 5-15nm, 13.5ppg, 350°F...............24

FIGURE 3: Plastic viscosity comparison BHR vs AHR for 5-15nm, 13.5ppg, 350°F 24

FIGURE 4: 10 sec/10 min gel strength & yield point comparison BHR vs AHR for 5-15nm, 13.5ppg, 350°F 25

FIGURE 5: Electrical Stability BHR vs AHR for 5-15nm, 13.5ppg, 350°F 26

FIGURE 6: Rotational speed vs dial reading for 5-15nm, 17ppg, 450°F..................27

FIGURE 7: Plastic viscosity comparison BHR vs AHR for 5-15nm, 17ppg, 450°F 28

FIGURE 8: 10 sec/10 min gel strength & yield point comparison BHR vs AHR for 5-15nm, 17ppg, 450°F 28

FIGURE 9: Electrical Stability BHR vs AHR for 5-15nm, 13.5ppg, 350°F 29

FIGURE 10: Rotational speed vs dial reading for 10-20nm, 13.5ppg, 350°F...........31

FIGURE 11: Plastic viscosity comparison BHR vs AHR for 10-20nm, 13.5ppg, 350°F...31

FIGURE 12: 10 sec/10 min gel strength & yield point comparison BHR vs AHR for 10-20nm, 13.5ppg, 350°F 32

FIGURE 13: Electrical Stability BHR vs AHR for 10-20nm, 13.5ppg, 350°F 33

FIGURE 14: Rotational speed vs dial reading for 10-20nm, 17ppg, 450°F..............36

FIGURE 15: Plastic viscosity comparison BHR vs AHR for 10-20nm, 17ppg, 450°F 36

FIGURE 16: 10 sec/10 min gel strength & yield point comparison BHR vs AHR for 10-20nm, 17ppg, 450°F 37

FIGURE 17: Electrical Stability BHR vs AHR for 10-20nm, 17ppg, 450°F 37

LIST OF TABLES

TABLE 1: required performance of drilling fluid properties in HPHT well 5
TABLE 2: chemical properties of nanosilica 8
TABLE 3: Physical properties of nanosilica 8
TABLE 4: Thermal properties of nanosilica 8
TABLE 5: Result from previous experiment for nanosilica size 10-20nm, 350°F, 13.5ppg 9
TABLE 6: Base Mud formulation 13
TABLE 7: Standard performance of SBM base formulation for 350°F & 450°F 13
TABLE 8: Mud formulation for Temperature 350°F and Mud weight 13.5ppg 14
TABLE 9: Mud formulation for Temperature 450°F and Mud weight 17ppg 15
TABLE 10: Mud formulation for Temperature 350°F and Mud weight 13.5ppg 16
TABLE 11: Mud formulation for Temperature 450°F and Mud weight 17ppg 16
TABLE 12: Gantt-chart of the project for FYP I & FYP II 20
TABLE 13: Project key milestone 21
TABLE 14: Mud samples properties for nanosilica size: 5-15nm, Temperature 350°F and mud weight 13.5 ppg 23
TABLE 15: Mud samples properties for nanosilica size: 5-15nm, Temperature 450°F and mud weight 17 ppg 26
Table 16: Mud samples properties for nanosilica size: 10-20nm, Temperature 350°F and mud weight 13.5 ppg 29
TABLE 17: Mud samples properties for nanosilica size: 10-20nm, Temperature 450°F and mud weight 17 ppg 34

CHAPTER 1
INTRODUCTION

1.1 Background

British Petroleum in their Energy Outlook (2014) stated that the global demand energy is growing by 41% between 2012 and 2035. Among the sources of energy being produced, hydrocarbon still playing the role as main source despite the increasing of the utilization of renewable energy (Kong and Ohadi, 2010). Unfortunately, oil and gas industry currently has entering the phase where the easy hydrocarbon reservoirs are decreasing and also followed by the declining production of existing fields. This condition will force oil and gas industry to expand the operations into unconventional and challenging environment such as under High Pressure and High Temperature (HPHT) to meet the global demand (Cocuzza et al., 2011). Thus, drilling technology must be developed to deal with the problems which may arise during the operation in HPHT condition to ensure the safety of the people and equipment. It is make drilling operation cost effective due to it is comprising 80% percent of total well cost (Shah et al., 2010).

In HPHT condition, which can be defined as the bottom hole where the pressure and temperature exceed 10,000 psi and 300°F, drilling operation might face some problem due to this type of well normally being drilled with slow rate of penetration (ROP) (Amani and Shadravan; Witthayapanyanon et al., 2014). Prolonged exposure of drilling fluid in HPHT resulted in the discrepancy of its ability caused by the degradation of the chemical component of the drilling fluid. Godwin et al. (2010) stated that HPHT wellbore will cause static and dynamic barite sag and increase the risk of well control loss due to it can degrade the solid carrying capacity of conventional mud. Another well control issue caused by HPHT wellbore is the mud will absorb large volume of gas if the mud stays static in hole for certain period and this influx of gas inside the mud makes the mud formulation unstable.

As one of important parts in drilling operation, drilling fluid also need to be developed and customized according to HPHT condition (Shah et al., 2010). The Synthetic based Mud (SBM) has been proven as the most compatible drilling based mud for most well condition. Among the abilities of SBM are no shale swelling, excellent fluid loss control, good cutting carrying, high rate of penetration (ROP), low torque and drag force and also this type of mud more environmentally friendly due to the less toxic in synthetic material (Herzhaft et al., 2001; Rojas et al., 2007).

However, although all of the advantages of SBM as mention above, SBM still has the limitation associated with chemical degradation when it’s exposed in HPHT condition. The needs of rheologically stable and filtration performance of drilling fluid make the drilling fluid steps into the next level of drilling fluid called “smart fluid” by introducing nanotechnology in the drilling fluid (Amanullah et al., 2011). Nanoparticle in drilling fluid system are expected to enhance the performance of drilling fluid, also to reduce the total solids and chemical content and hence will reduce the overall cost of drilling fluid system development (Apaleke et al., 2012).

The utilization of nanosilica as additive in SBM formulation for HPHT application has been confirmed capable to enhance SBM properties such as rheology, electrical stability and fluid loss (Wahid, 2014). For that reason, to make the formulations economically viable, this project intended to find the optimum composition of nanosilica in SBM formulation for HPHT well application.

1.2 Problem Statement

Unstable mud properties due to HPHT conditions can cause drilling operation troublesome and the utilization of nanosilica in SBM has been proven to solve it. However, from the economical point of view, the combination between SBM and nanosilica will make drilling operation costly. Thus by performing laboratory experiment, the optimum composition of nanosilica in SBM formulations in HPHT condition need to be determined as one of applicable solutions in drilling fluid and also economically viable.

1.3 Objective

The overall objective of this project is to find the optimum composition of nanosilica as an additive in SBM formulations for HPHT application at temperature 350°F and 450°F. Therefore, to accomplish the overall objective, this project will be focused on these specific objectives which are:

- To identify the optimum composition of nanosilica in SBM formulations with size 10-20nm within range 35% - 45% of nanosilica concentration under HPHT condition.
- To investigate the performance of SBM formulations with smaller size of nanosilica which is 5-15 nm under HPHT condition and compare the result with SBM formulations with nanosilica size 10-20nm in term of rheological properties, electrical stability and fluid loss control.

1.4 Scope of Study

This project is a laboratory experiment project. The utilization of nanosilica as an additive in SBM formulations under HPHT condition at different concentrations, sizes and temperatures will be observed and compared to find the optimum composition of nanosilica.

In order to observe the performance of nanosilica in SBM under HPHT condition, therefore this study will be focused on the drilling fluid properties of the samples which are the rheology, electrical stability and fluid loss volume under HPHT conditions.

CHAPTER 2

LITERATURE REVIEW

2.1 High Pressure High Temperature Well

Generally, HPHT well condition can be defined as the wellbore condition where the pressure and temperature exceed 10,000psi and 300°F. United Kingdom Continental Shelf Operations Notice stated that “High Temperature well condition can be defined as when the undisturbed bottom hole temperature is greater than 149C (300°F) and High Pressure can be defined as either the maximum pore pressure of any porous formation that exceeds a hydrostatic gradient of 0.18 bar/m (0.8 psi/ft) (representing an equivalent mud weight (EMW) of 1.85 SG or (15.4 ppg) or, needing deployment of pressure control equipment with a rated working pressure in excess of 690 bar (69 MPa, 10000 psi)”.

Some other authors tried to classify the HPHT into different categories based on lower and upper limit of the pressure and temperature. As one of the examples of the classification, Amanullah and Ramasamy (2014) stated that HPHT wells can be divided into three categories which are:

a. HPHT environment, with bottom hole pressure greater than 10,000psi & less than 15,000psi and Temperature greater than 300°F & less than 350°F.
b. Ultra HPHT environment, with bottom hole pressure greater than 15,000psi & less than 20,000psi and Temperature greater than 350°F & less than 400°F.
c. Extreme HPHT Environment, with bottom hole pressure greater than 20,000psi and Temperature greater than 400°F.

Under these conditions, the drilling fluid properties will drastically change due to the chemical, physical and thermal instability. Shrivastav (2012) stated that the chemical components of the drilling fluid begin to degrade in HPHT environment and the drilling fluid will be forced out of the well as reservoir fluid rapidly expands. This condition will decrease hydrostatic pressure of the formation, allowing the reservoir fluid to enter inside the well and will cause a blowout. Knut et al. (2004) said that the drilling fluid used in HPHT well tends to exhibit sagging behaviour and it also exhibits syneresis where the liquid is expelled from gel structure.

Despite the problems that may occur during drilling operation in HPHT well, the interest of this type of well continues growing and remains high. Thus, formulating stable drilling fluid in HPHT condition will be challenging task and required suitable additive to withstand against HPHT condition (Witthayapanyanon et al., 2014). According to (Adamson 1998) the required performance for drilling fluid properties in HPHT well can be shown on below table:

TABLE 1: Required performance of drilling fluid properties in HPHT well

Drilling Fluid Property	Required Performance in HPHT Wells
Plastic Viscosity	As low as reasonably possible to minimize Equivalent Circulating Density (ECD)
Yield stress and gels	Sufficient to prevent sag but not cause gelation and also to prevent high surge and swab pressure
HPHT fluid loss	As low as reasonably possible to prevent formation damage and differential sticking
HPHT rheology	Predictable in order to control sag, gelation and ECD

2.2 SBM

SBM has been chosen for this project due to its ability for both performance and environment. In term of ability this type of fluid has the same abilities with OBM which are well bore stability, stable in high temperature, good cutting carrying ability, adequate lubricant to drill bits and no shale swelling. It also be able to overcome OBM limitation in environmental side due to its hazardous material from the oil by providing less toxic and environmental friendly (Shah et al., 2010).

This SBM drilling fluid is an invert emulsion which mean it consists of synthetic hydrocarbon/oil on the external phase and water/brine on the internal phase. The fluid obtains the stability by adding surfactant. The first generation of SBM was made by using polypha-olefin, ester or ether which had a high kinematic viscosity, thus need high pressure to pump the drilling fluid. To improve this SBM, linear alpha olefins, linear paraffins and isomerized olefins were introduced as second generation of SBM and it successfully decrease the kinematic viscosity and can be operated by a low pump pressure (Friedheim, 1997).

As conventional drilling fluid, SBM has limitations when exposed to HPHT conditions due to its thermal and chemical instability which will change drilling fluid properties, therefore the utilization of nanoparticle in SBM to replace conventional drilling fluid additive need to be formulated to support drilling operations in HPHT.

2.3 Nanotechnology

For the past 20 years, nanotechnology has been successfully applied in various industries such as aerospace, textile, biology and food (Cocuzza et al., 2011). Nanotechnology is the technology which focus on the application and development of tools, devices and materials with size less than 100nm and the important properties are not related to macro scale or atomic properties. In oil and gas industry, this technology has entered in past 7-9 years and it has been utilized for drilling, EOR, production and refining.

Nanotechnology has brought drilling fluid to the next level, often called “smart fluids” which will add benefits in the area of rheology, shale stability, thermal conductivity, fluid loss, torque and drag reduction (Freidheim et al., 2012; Kong and Ohadi, 2010; Cocuzza et al., 2011). The physical properties of nanomaterial such as chemical and thermal stability and biodegradable make it has been considered as promising material as additive in drilling mud to support the drilling operations for almost type of wells.

Some experiments have been conducted to add nanoparticles in drilling fluid. One of the examples is the utilization of Carbon nanotubes (CNT) as stabilizers for ultra-HPHT non-aqueous inverts. The experiment is conducted by selecting two CNT for final formulations at 600°F and base fluid. CNT materials have shown positive results in stabilizing the rheological profile, but it is unable handle fluid loss control.

The second example is the utilization of graphene oxide (GO) as an additive to a freshwater slurry of bentonite and barite to study its effect for both rheology fluid loss. It is observed that GO has a relatively effective effect for fluid loss and rheology (Friedheim et al., 2012).

Another experiment is by using the Finite Element method (FEM) and nickel-based nanoparticles is added to the drilling mud. The result showed the friction coefficient from the drilling mud is decreased hence provide benefit in horizontal or extended drilling (Hareland et al., 2012).

Paiaman and Al-Anazi (2009) stated that the addition of nano-carbon black particles into drilling mud reduced the thickness of the mud cake with increasing pressure and temperature, hence be able to prevent stuck pipe problem. Lee et al. (2009) investigated the use of iron dioxide magnetic nanoparticles offer drilling fluid viscosity control.

On the other hands, the utilization of nanoparticle in drilling fluids also brought some issue. Friedheim et al. (2012) stated that due to the size of nanoparticle, it begins to show an attractive force one another, hence will result in the increasing of viscosity and gel strength of the fluids at low concentrations.

One of critical issues of using nanoparticle is from Health, Safety and environment (HSE) point of view. Friedheim et al. (2012) stated that the limitation of the recent toxicology and ecotoxicology data of nanoparticles make broad statements of health and ecological effects will insufficient. Low solubility even insoluble nano particles bring concern as the previous research have indicated that nano particles can enter tissues of living organisms and will spread into the organs.

2.4 Nanosilica

Silicon dioxide (SiO_2) nanoparticles or silica nanoparticles or nanosilica are the particles with high surface area, size 5-100nm, low toxicity and ability to be functionalized with a range molecules and polymers. Nanosilica appear in the form of a white powder and have properties as shown by below tables:

TABLE 2: chemical properties of nanosilica

Chemical Data	
Chemical symbol	SiO_2
Group	Silicon 14
	Oxygen 16
Chemical Composition	
Element	Content (%)
Silicon	46.83
Oxygen	53.33

TABLE 3: Physical properties of nanosilica

Physical Properties	
Density	0.086 lb/in^3
Molar mass	59.96 g/mol

TABLE 4: Thermal properties of nanosilica

Thermal Properties	
Melting point	2912°F
Boiling point	4046°F

The experiment done by Sensoy et al. (2009) on nanosilica stated that it is used to plug nano-size pores in the shale to provide shale stability. Hoelscher et al. (2010) also confirmed the finding from nanosilica experiment in drilling mud that nanosilica can physically plug shale at low loading levels. Agarwal et al. (2011) observed the improvement of rheological effect from nanoclay and nanosilica for HPHT invert emulsion based drilling fluids. Javeri et al. (2011) claimed that the ability of nanosilica in drilling fluid to reduce loss circulation.

Wahid (2014) have proved that utilization of nanosilica size 10-20nm in SBM for HPHT has enhanced the performance. Below tables are the result form the experiment:

TABLE 5: Result from previous experiment for nanosilica size 10-20nm, 350°F and 13.5ppg

Before Hot Rolled Properties				
	0% nanosilica	20% nanosilica (0.35 wt. %)	40% nanosilica (0.71 wt. %)	60% nanosilica (1.06 wt. %)
OWR	80:20	80:20	80:20	80:20
Rheology Property (120°F) at:				
600 rpm	130	108	108	95
300 rpm	83	63	64	56
200 rpm	56	47	48	42
100 rpm	34	29	30	27
6 rpm	12	20	11	10
3 rpm	10	14	9	9
Plastic viscosity, cP	43	45	44	39
Yield point, lb/100ft2	24	18	20	17
10 sec gel strength, lb/100ft2	12	16	14	14
10 min gel strength, lb/100ft2	17	22	44	42
ES (120°F), volt	768	617	542	578
After Hot Rolled Properties				
OWR	80:20	80:20	80:20	80:20
Rheology Property (120°F) at:				
600 rpm	145	132	133	109
300 rpm	86	75	79	65
200 rpm	63	55	59	49
100 rpm	35	32	37	31
6 rpm	17	7	10	11
3 rpm	11	4	8	9

Plastic viscosity, cP	59	57	54	44
Yield point, lb/100ft2	27	18	25	21
10 sec gel strength, lb/100ft2	24	22	21	12
10 min gel strength, lb/100ft2	14	39	47	43
ES (120°F), volt	890	880	636	778
HPHT filtrate (500 psi), ml	5.6	4.4	4	4.4
Filter cake, mm	4	2	2	2

As the summary, it has been proven that nanosilica enhanced the drilling fluid ability. However, in the current market, according to US Research Nanomaterial, Inc. nanosilica cost $156/kg. Therefore, due to its price, the optimum composition of nanosilica in SBM need to be determined to make it economically viable and applicable for drilling operation under HPHT conditions.

CHAPTER 3

METHODOLOGY

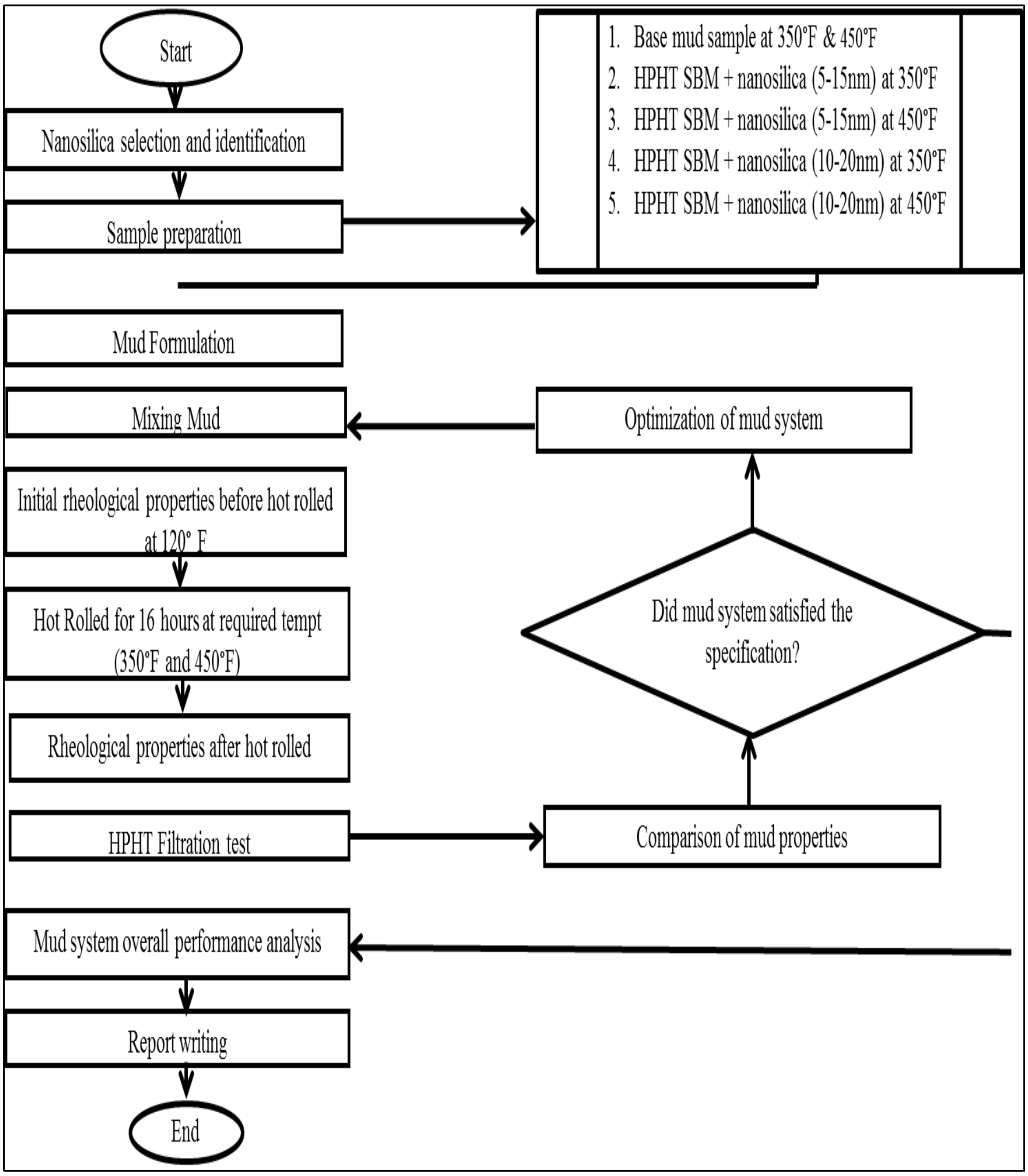

FIGURE 1: Methodology of the project

3.1 Methodology

In this project, the methodology is divided into below steps:

Step 1: Sample preparation.

Nanosilica with size range 5-15nm and 10-20nm are used for this project.

During the experiment the samples are divided into these categories:

1. HPHT SBM + nanosilica (5-15nm) at 350°F
2. HPHT SBM + nanosilica (5-15nm) at 450°F
3. HPHT SBM + nanosilica (10-20nm) at 350°F
4. HPHT SBM + nanosilica (10-20nm) at 450°F

Step 2: Testing the sample.

The tests were conducted for the sample to determine:

1. Rheological properties before hot rolled (120°F)
2. Hot rolled for 16hrs at 350°F and 450°F
3. Rheological properties after hot rolled (350°F and 450°F)
4. HPHT filtration pass

Step 3: Analysing the result.

The data obtained from the experimental results were compared with the based temperature to determine whether there is improvement of the enhanced SBM formulation by using nanosilica. Otherwise, the sample will be repeated and the content nanosilica will be added to find the optimum composition and performance.

Step 4: Preparing the report

All the data obtained from the result were analysed and discussed.

3.2 Drilling Fluid Formulation

The samples in this project were tested in High Temperature conditions which are at 350°F and 450°F. Nanosilica with different concentrations and sizes were added for both systems to generate the optimum amount of nanosilica.

TABLE 6: Base Mud formulation

Materials	**350°F System**	**450°F System**
Base oil	143.86	122.46
Primary emulsifier	13.80	15.60
Secondary emulsifier	11.00	1.90
Viscosifier	2.50	0.10
Other (XHT Viscosifier)	1.30	1.00
Fluid loss agent (FLA)	9.90	1.50
Lime	11.30	18.50
Drill water	46.71	39.76
Calcium Chloride	16.5	9.40
Barite (4.2 SG)		482.39
Barite (4.39 SG)	297.80	
Drill Solids	20	20
Oil water ratio (OWR)	80:20	85:15
Mud weight (ppg)	13.5	17

Below table is the standard performance of SBM formulations for both 350°F and 450°F systems:

TABLE 7: Standard performance of SBM base formulation for 350°F & 450°F

Mud Type	HPHT SBM 350°F	HPHT SBM 450°F
Hot Roll Temp °F	350	450
Mud density, ppg	13.5	17
Plastic viscosity, cP	< 45	< 65
Yield point, lb/100 sq ft	15-30	15-30
Initial gel strength, lb/100 sq ft	6-12	6-12
6rpm fann reading	8-12	8-12
HPHT fluid loss, cc/30min	< 4 (275°F/500psi)	< 4 (275°F/500psi)
HPHT filter cakes, 32nd inch	≤ 2	≤ 2
Electrical stability, volts	>500	>500

Nanosilica is added to the formulation based on the designed concentration within the range 0 to 3% of total wt.

Below testing procedures are following API standard which is API RP 13b-2

3.3 Mixing Sample

Digital balance, Hamilton Beach mixer, stop watch, thermometer and one barrel mud cup will be used to mix the sample.

Procedure for mixing the sample:
The material for samples will be weighted by digital balance based on mud formulation. Total time of mixing time for all samples will be 60 minutes. Including designated mixing time and additional time. Hamilton Beach mixer will be used for mixing at 18000 (rpm).

Nanosilica size: 5-15nm

TABLE 8: Mud formulation for Temperature 350°F and Mud weight 13.5ppg

Material	**Trade Name**	**Mixing Order**	**Time (Min)**	**20% Nanosilica (ppb)**	**40% Nanosilica (ppb)**	**60% Nanosilica (ppb)**
Base oil	Sarapar 147	1	4	144.59	145.32	146.05
Primary emulsifier	CONFI MUL HT	2		13.80	13.80	13.80
Secondary emulsifier	CONFI TEC HT	3		1.00	1.00	1.00
Vicosifier	CONFI GEL HT	4	2	2.50	2.50	2.50
XHT Viscosifier	CONFI GEL XHT	5	2	1.30	1.30	1.30
Fluid loss agent	CONFI TROL HT	6	2	7.92	5.94	3.96
Nanosilica	Nanosilica	7	2	1.98	3.96	5.94
Lime	Ca(OH)2	8	2	11.30	11.30	11.30
Drill water		9	15	46.95	47.18	47.42
Calcium	Calcium			16.50	16.50	16.50

chloride	chloride					
Barite (4.39 SG)	DRILL BAR XP	10	2	296.81	295.83	294.85
Drill solids	REV DUST	11	2	20.00	20.00	20.00

TABLE 9: Mud formulation for Temperature 450°F and Mud weight 17ppg

Material	**Trade Name**	**Mixing Order**	**Time (Min)**	**20% Nanosilica (ppb)**	**40% Nanosilica (ppb)**	**60% Nanosilica (ppb)**
Base oil	Sarapar 147	1	4	122.57	122.69	122.81
Primary emulsifier	CONFI MUL XHT	2		15.60	15.60	15.60
Secondary emulsifier	CONFI TEC HT	3		1.90	1.90	1.90
Vicosifier	CONFI GEL HT	4	2	0.10	0.10	0.10
XHT Viscosifier	CONFI GEL XHT	5	2	1.00	1.00	1.00
Fluid loss agent	CONFI TROL XHT	6	2	1.20	0.90	0.6
Nanosilica	Nanosilica	7	2	0.30	0.60	0.9
Lime	Ca(OH)2	8	2	18.50	18.50	18.50
Drill water		9	15	39.80	39.83	39.87
Calcium chloride	Calcium chloride			9.40	9.40	9.40
Barite (4.39 SG)	DRILL BAR	10	2	482.23	482.07	481.91
Drill solids	REV DUST	11	2	19.50	19.50	19.50

Nanosilica size: 10-20nm

TABLE 10: Mud formulation for Temperature 350°F and Mud weight 13.5ppg

Material	**Trade Name**	**Mixing Order**	**Time (Min)**	**35% Nanosilica (ppb)**	**37.5% Nanosilica (ppb)**	**42.5% Nanosilica (ppb)**	**45% Nanosilica (ppb)**
Base oil	Sarapar 147	1	4	145.08	145.2	145.50	145.60
Primary emulsifier	CONFI MUL HT	2		13.80	13.80	13.80	13.80
Secondary emulsifier	CONFI TEC HT	3		1.00	1.00	1.00	1.00
Vicosifier	CONFI GEL HT	4	2	2.50	2.50	2.50	2.50
XHT Viscosifier	CONFI GEL XHT	5	2	1.30	1.30	1.30	1.30
Fluid loss agent	CONFI TROL HT	6	2	6.43	6.19	5.70	5.45
Nanosilica	Nanosilica	7	2	3.47	3.71	4.20	4.45
Lime	Ca(OH)2	8	2	11.30	11.30	11.30	11.30
Drill water		9	15	47.12	47.15	47.24	47.3
Calcium chloride	Calcium chloride			16.50	16.50	16.50	16.50
Barite (4.39 SG)	DRILL BAR XP	10	2	296.07	295.95	295.83	295.58
Drill solids	REV DUST	11	2	20.00	20.00	20.00	20.00

TABLE 11: Mud formulation for Temperature 450°F and Mud weight 17ppg

Material	**Trade Name**	**Mixing Order**	**Time (Min)**	**35% Nanosilica (ppb)**	**37.5% Nanosilica (ppb)**	**42.5% Nanosilica (ppb)**	**45% Nanosilica (ppb)**
Base oil	Sarapar 147	1	4	122.75	122.78	122.81	122.84
Primary	CONFI	2		15.60	15.60	15.60	15.60

emulsifier	MUL XHT						
Secondary emulsifier	CONFI TEC HT	3		1.90	1.90	1.90	1.90
Vicosifier	CONFI GEL HT	4	2	0.10	0.10	0.10	0.10
XHT Viscosifier	CONFI GEL XHT	5	2	1.00	1.00	1.00	1.00
Fluid loss agent	CONFI TROL XHT	6	2	0.97	0.94	0.86	0.83
Nanosilica	Nanosilica	7	2	0.53	0.56	0.64	0.67
Lime	Ca(OH)2	8	2	18.50	18.50	18.50	18.50
Drill water		9	15	39.81	39.82	39.84	39.85
Calcium chloride	Calcium chloride			9.40	9.40	9.40	9.40
Barite (4.39 SG)	DRILL BAR	10	2	482.11	482.09	481.95	481.97
Drill solids	REV DUST	11	2	19.50	19.50	19.50	19.50

3.4 Rheological Properties Test for the Sample

Fann 35, heating jacket, thermo cup, stopwatch and thermometer were used to test the rheological properties of the sample.

Steps:

a. Fill the mud sample into measuring cup
b. Stir the sample using Fann 35 viscometer at 600rpm.
c. Heat the sample until reach 120°F, take reading of dial at 600, 300, 200, 100, 6 and 3 rpm. Before take the reading, ensure the dial has stabilized at each speed.
d. After finish take all the reading above step, stir mud sample at 600 rpm for 30 seconds to take 10 seconds gel by stopping the motor and leave the mud in static mode for 10 seconds. Then, conduct the dial at 3 rpm and take the highest deflection of the dial reading.

e. For measuring 10 minutes gel, stir the mud sample at 600 rpm for 30 seconds and leave the mud in static mode for 10 minutes.

From the reading at 600rpm and 300rpm, plastic viscosity and yield point can be calculated by using:

1. PV (cP) = reading at 600 rpm – reading at 300 rpm
2. YP (lb/100 ft^2) = reading at 300 rpm – PV

3.5 Electrical stability of Emulsion Test

Electrical stability (ES) meter was used to test electrical stability of the sample(s)

Steps:

a. Ensure the probe of ES meter is cleaned and place it in the sample (120°) and to ensure the homogeneity, use the probe to stir the sample.

b. Ensure the probe so that it will not touch the heated cup to get more accurate result and also electrode tip has to completely immerse.

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

d. Record the reading and repeat the test three times to get average value.

3.6 Hot Rolling Samples

Roller oven and aging cells were used during this process.

Steps:

a. Preheat the oven to the designated temperature.

b. Stir the sample for 5 minutes using Hamilton Beach mixer.

c. Put the sample into aging cell container and close it tightly.

d. The aging cell is pressurise to the specific pressure to reach designated temperature.

e. Place the aging cell in the roller oven and start rolling the sample for 16 hours.

3.7 HPHT Filtration Test

HPHT filter press, HPHT filtration cells, filter paper, high pressure CO2 supply, stopwatch and measuring cylinder were used during this test

Steps:

a. The heating jacket is preheated to the required temperature.
b. Tighten the bottom valve stem and fill the cell to about 0.5-in from the rim.
c. Place the filter paper and put the lid on the cell. Ensure the lid stem is open while doing this to help avoid damaging the filter paper.
d. Tighten the six studs in the cell and close the lid stem.
e. Place the cell in the heating jacket with the lid facing downwards. Rotate the cell until it seats on the locking pin.
f. Place CO2 cartridge in each regulator and tighten up the retainers.
g. Place the top regulator on the stem and engage the locking pin. Close the bleed off valve and turn regulator clockwise until 100 psi.
h. Repeat the process with the bottom regulator.
i. Turn the valve stem ¼ to ½ turn, anti-clockwise to pressure up the cell to 100 psi.
j. When the cell reach the required temperature, open the bottom stem with ½ turn and then increase the pressure on the top regulator to 600 psi. Start the stopwatch timing.
k. 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.
l. Bleed the pressure off for the top regulator.
m. Disconnect the top regulator and remove the cell from the heating jacket, allowing it to cool in water bath.
n. When the cell has cooled, bleed off the trapped pressure by slowing 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.
o. Examine the filter paper and check the thickness of cake built (measured in millimetre (mm)) and filtrate produced (millilitre).

3. 8 Project Gantt-Chart

TABLE 12: Gantt-chart of the project for FYP I & FYP II

No	Activity	Week																									
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	Project title selection	■	■																										
2	Literature review			■	■	■	■																						
3	Nanoparticle selection				■	■	■	■																					
4	Study on SBM formulations				■	■	■	■	■																				
5	Study on research methodology						■	■	■	■																			
6	SBM final formulations								■	■	■																		
7	Continuation of the project									■	■	■	■	■															
8	Submit laboratory booking request												■	■															
9	Check chemicals availability														■														
10	Continuation of project															■	■	■	■	■	■	■	■						
11	Mud mixing and testing (5-15nm)																■	■	■	■									
12	Mud mixing and testing(10-20nm)																			■	■	■	■						
13	Analyse result from sample(s)																				■	■	■	■	■	■			
14	Project report compilation																									■	■	■	

3.9 Key Milestone

TABLE 13: Project key milestone

No	Description	Week No.
1	Received the approval of FYP project topic. Literature Review to make the title of project to be specified	2
2	Nanosilica with size 10-15 nm and 10-20 nm have been selected for this project.	7
3	Mud formulations study. The SBM is tested on 350°F and 450°F	9
4	Laboratory training prior to conduct the experiment and submission of laboratory booking request form	12
5	Check all chemicals availability	14
6	Mixing and testing based mud for 350°F and 450°F conditions as benchmarks	18
7	Mixing and testing mud sample(s) for nanosilica size 5-15nm and 10-20nm at temperature 350°F	19
8	Mixing and testing mud sample(s) for nanosilica size 5-15nm and 10-20nm at temperature 450°F	21
9	All the experiments have been completed	23
10	The results obtained have been analysed	24
11	Final report submission	26

CHAPTER 4

RESULT AND DISCUSSION

The project is started by made the base mud samples for 350°F and 450°F systems to set the benchmark (SBM standard performance) before the mud samples are enhanced with nanosilica.

In this report, the result shown below tables are the data taken before and after hot rolled from laboratory experiment for base mud, enhanced SBM with nanosilica size 5-15nm at different concentration (0%, 20% and 40%) and nanosilica size 10-20nm at different concentration (35%, 37.5%, 42.5% and 45) with temperature 350°F and 450°F for both sizes.

The aim for the enhanced SBM formulation with nanosilica size 5-15nm is to compare it’s performance with nanosilica 10-20nm while for enhanced SBM with nanosilica size 10-20nm is to determine the optimum composition of nanosilica in SBM formulation based on amount of nanosilica vs performance.

The quantity of nanosilica used in experiment is still within the economical range (0 to 3 wt. %) which is from 0 to 1.06 wt. %. Nanosilica is playing role as an additive in the formulation.

4.1 Sample Result and Discussion

4.1.1 Nanosilica size 5-15nm, temperature 350°F and mud weight 13.5 ppg.

TABLE 14: Mud samples properties for nanosilica size: 5-15nm, Temperature 350°F and mud weight 13.5 ppg

Before Hot Rolled Properties				
	0% nanosilica Base Mud	20% nanosilica (0.35 wt. %)	40% nanosilica (0.71 wt. %)	60% nanosilica (1.06 wt. %)
OWR	80:20	80:20	80:20	80:20
Rheology Property (120°F) at:				
600 rpm	120	140	145	149
300 rpm	72	80	83	85
200 rpm	51	58	59	61
100 rpm	32	35	36	38
6 rpm	12	10	12	14
3 rpm	10	8	9	11
Plastic viscosity, cP	48	60	62	64
Yield point, lb/100ft2	24	20	21	21
10 sec gel strength, lb/100ft2	12	17	19	24
10 min gel strength, lb/100ft2	17	55	48	59
ES (120°F), volt	768	610	561	448
After Hot Rolled Properties				
OWR	80:20	80:20	80:20	80:20
Rheology Property (120°F) at:				
600 rpm	145	168	168	167
300 rpm	86	96	98	96
200 rpm	63	75	79	78
100 rpm	38	47	47	44
6 rpm	17	17	19	17
3 rpm	11	17	16	15

Plastic viscosity, cP	59	72	70	71
Yield point, lb/100ft2	27	24	28	25
10 sec gel strength, lb/100ft2	24	32	30	28
10 min gel strength, lb/100ft2	14	72	67	76
ES (120°F), volt	890	850	682	723
HPHT filtrate (500 psi), ml	-	-	-	-
Filter cake, mm	-	-	-	-

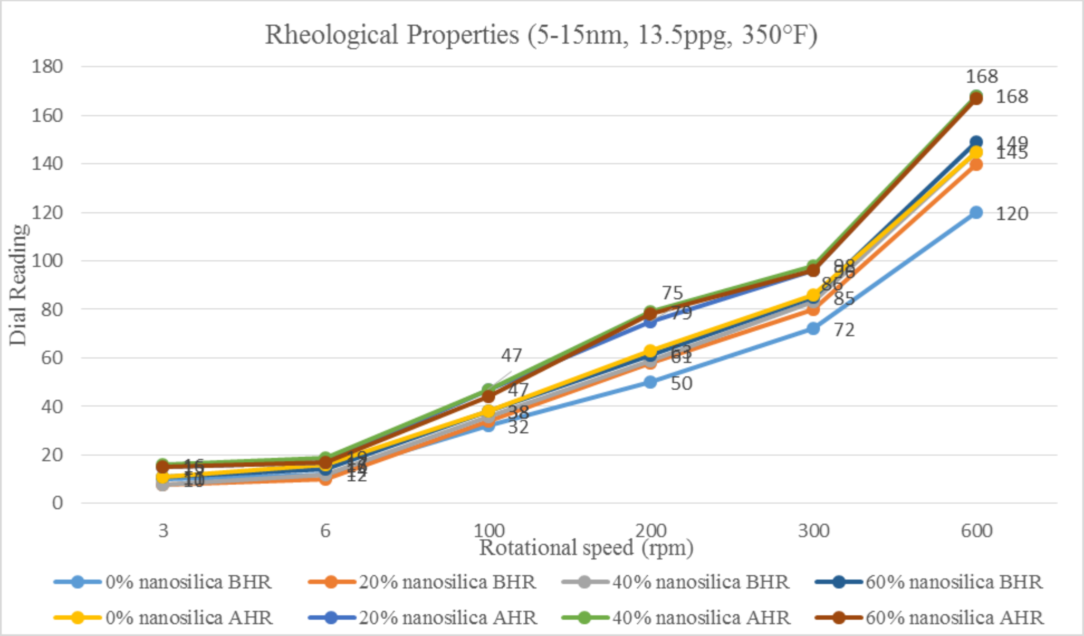

FIGURE 2: Rotational speed vs dial reading for 5-15nm, 13.5ppg, 350°F

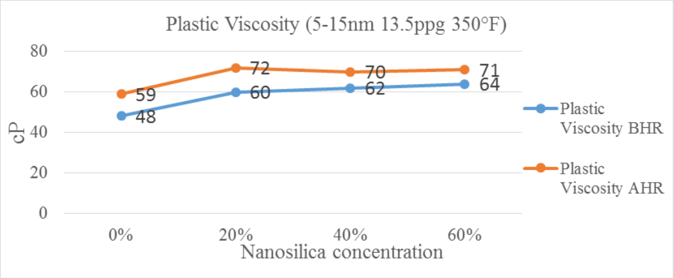

FIGURE 3: Plastic viscosity comparison BHR vs AHR for 5-15nm, 13.5ppg, 350°F

Figure 3 showed that the plastic viscosity (PV) from enhanced nanosilica size 5-15nm in SBM formulation BHR tends to increase and exceed the PV from base mud. The author found that one of the factors is due to the smaller nanosilica size increased the viscosity of the mud. According to Fletcher and Hill (2015), maintaining constant volume/mass fraction while reducing the particle size will increase the number particle itself. As the result, interaction between particles will also increase and it leads to an overall increase in viscosity. It is expected that the PV AHR increased due to the degradation of chemical properties of SBM when exposed in HPHT condition.

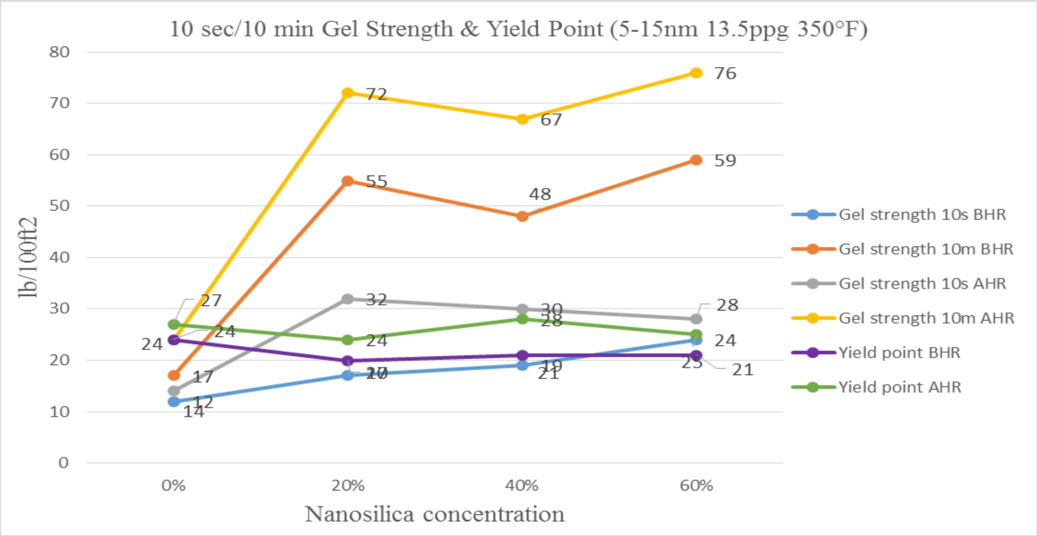

FIGURE 4: 10 sec/10 min gel strength & yield point comparison BHR vs AHR for 5-15nm, 13.5ppg, 350°F

Yield point AHR for enhanced SBM formulations showed a good result as shown in Figure 4 which means the YP increased but not too far from yield point BHR. This indication is a good sign to transport the drilling cutting from annulus. There is significantly increasing in 10minutes gel strength BHR and AHR. The increasing gel strength could be a good indicator for cutting suspension during static condition of wellbore, normally this condition happened while tripping operation to add more joints of drill pipe as drilling job goes deeper. But in this case, the increment is too high which could make the mud difficult to be circulated to the surface and requires more mud pump power to transport the mud out of hole.

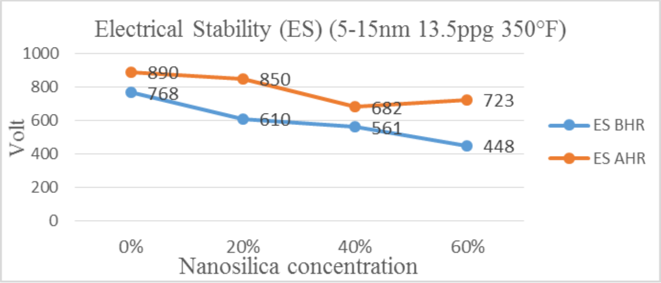

FIGURE 5: Electrical Stability BHR vs AHR for 5-15nm, 13.5ppg, 350°F

From Figure 5 it can be shown that the electrical stability is increased AHR, it reflects the stability of emulsion of SBM means that the water is dispersed well in oil phase and increase the resistivity of drilling fluid.

4.1.2 Nanosilica size 5-15nm, temperature 450°F and mud weight 17 ppg.

TABLE 15: Mud samples properties for nanosilica size: 5-15nm, Temperature 450°F and mud weight 17 ppg

Before Hot Rolled Properties				
	0% nanosilica Base Mud	20% nanosilica (0.042 wt. %)	40% nanosilica (0.082 wt. %)	60% nanosilica (0.13 wt. %)
OWR	85:15	85:15	85:15	85:15
Rheology Property (120°F) at:				
600 rpm	151	156	156	157
300 rpm	85	88	86	87
200 rpm	66	69	67	69
100 rpm	41	45	43	48
6 rpm	10	12	11	14
3 rpm	9	10	9	12
Plastic viscosity, cP	66	68	70	70
Yield point, lb/100ft2	19	20	16	17
10 sec gel strength, lb/100ft2	14	19	22	26
10 min gel strength, lb/100ft2	24	58	61	63
ES (120°F), volt	989	977	896	921

After Hot Rolled Properties				
OWR	85:15	85:15	85:15	85:15
Rheology Property (120°F) at:				
600 rpm	184	218	203	194
300 rpm	105	132	123	112
200 rpm	77	101	95	78
100 rpm	47	64	61	58
6 rpm	12	24	20	17
3 rpm	11	18	16	15
Plastic viscosity, cP	79	86	80	82
Yield point, lb/100ft2	26	46	43	30
10 sec gel strength, lb/100ft2	22	32	30	34
10 min gel strength, lb/100ft2	32	78	84	89
ES (120°F), volt	930	850	682	723
HPHT filtrate (500 psi), ml	-	-	-	-
Filter cake, mm	-	-	-	-

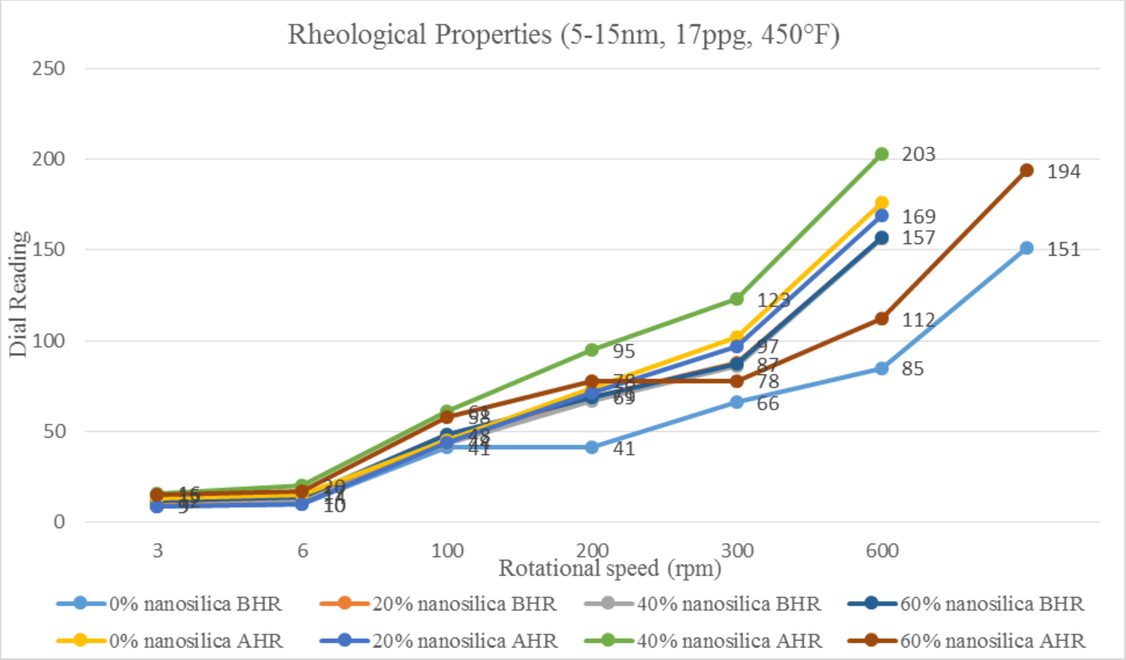

FIGURE 6: Rotational speed vs dial reading for 5-15nm, 17ppg, 450°F

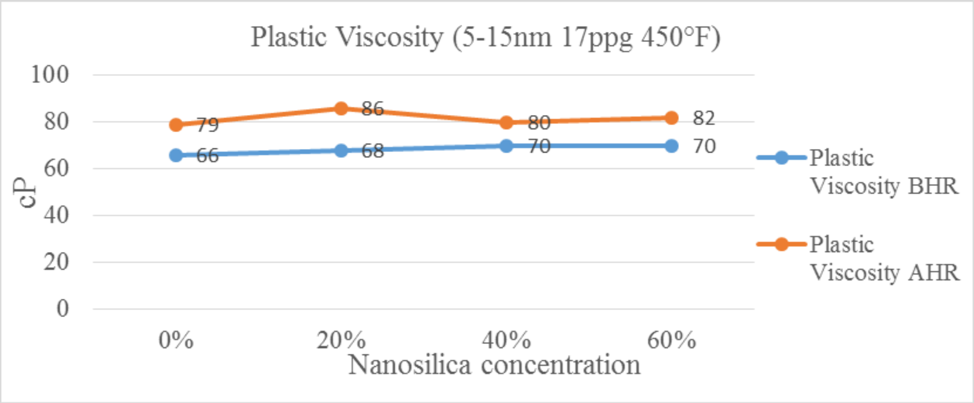

FIGURE 7: Plastic viscosity comparison BHR vs AHR for 5-15nm, 17ppg, 450°F

The same effect also occurred for 450°F system, it can be shown from Figure 7 the plastic viscosity BHR tends to increase beyond the plastic viscosity of base mud as benchmark and PV AHR also increase due to chemical degradation. YP increased has AHR and it is a good indicator for cutting transport. The gel strength AHR result as shown in Figure 8 is too high that could cause problem in wellbore which is the mud and drill cutting will be hard to be transferred to the surface after static condition.

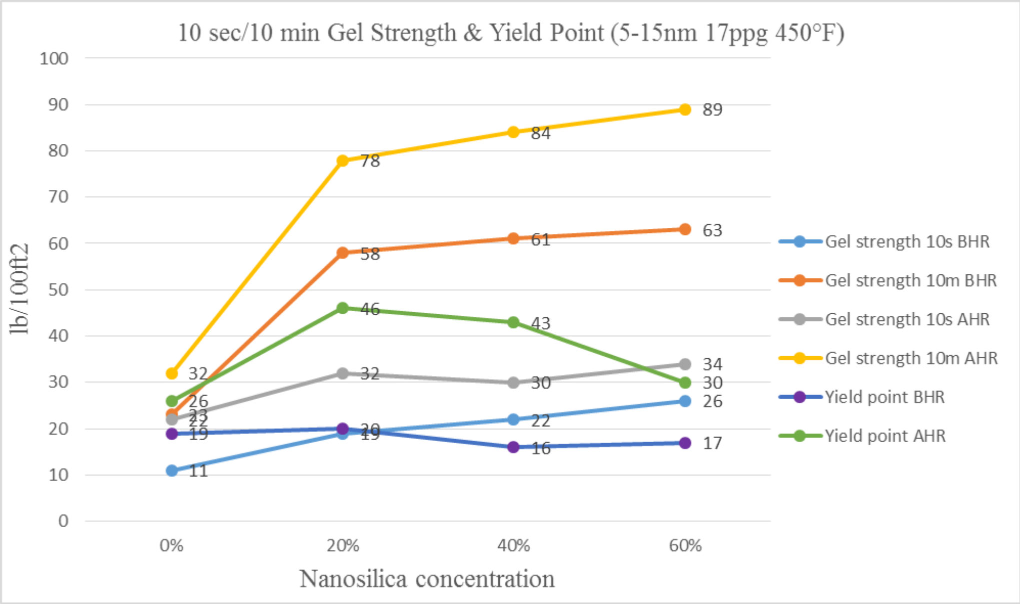

FIGURE 8: 10 sec/10 min gel strength & yield point comparison BHR vs AHR for 5-15nm, 17ppg, 450°F

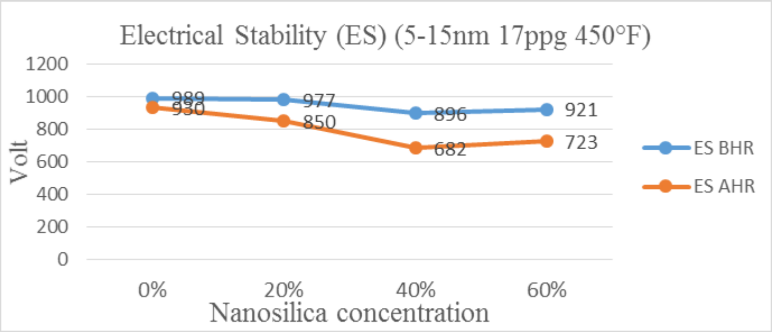

FIGURE 9: Electrical Stability BHR vs AHR for 5-15nm, 17ppg, 450°F

From Figure 9, it can be shown that the electrical stability trend is still above 500 Volt which is the standard electrical stability for SBM in 450°F environment. It shows a good stability of emulsion which mean the water is dispersed well in oil phase to increase the conductivity of SBM since oil is nonconductive material.

As summary, for enhanced SBM formulation with nanosilica size 5-15nm for both temperature 350°F and 450°F, it could be not suitable to be used as additive in SBM for HPHT wells conditions due to it will increase the PV and gel strength. The are several factors could be affecting the results, one of the factors is the smaller size of nanosilica will increase the interaction between the particles hence has increased the plastic viscosity.

4.1.3 Nanosilica size 10-20nm, temperature 350°F and mud weight 13.5 ppg.

Table 16: Mud samples properties for nanosilica size: 10-20nm, Temperature 350°F and mud weight 13.5 ppg

Before Hot Rolled Properties				
	35% Nanosilica (0.62 wt. %)	37.5% nanosilica (0.64 wt. %)	42.5% nanosilica (0.73 wt. %)	45% nanosilica (0.79 wt. %)
OWR	80:20	80:20	80:20	80:20
Rheology Property (120°F) at:				
600 rpm	111	109	106	104

300 rpm	67	64	63	63
200 rpm	53	50	51	49
100 rpm	32	31	35	33
6 rpm	14	12	11	12
3 rpm	10	9	9	10
Plastic viscosity, cP	44	45	43	41
Yield point, lb/100ft2	23	19	20	22
10 sec gel strength, lb/100ft2	18	17	18	20
10 min gel strength, lb/100ft2	37	45	43	46
ES (120°F), volt	593	579	526	568
After Hot Rolled Properties				
OWR	80:20	80:20	80:20	80:20
Rheology Property (120°F) at:				
600 rpm	137	139	135	138
300 rpm	81	82	79	83
200 rpm	60	64	59	62
100 rpm	34	39	37	41
6 rpm	14	12	11	13
3 rpm	11	9	9	11
Plastic viscosity, cP	56	57	56	55
Yield point, lb/100ft2	25	25	23	28
10 sec gel strength, lb/100ft2	22	20	21	22
10 min gel strength, lb/100ft2	42	47	45	48
ES (120°F), volt	688	661	621	762
HPHT filtrate (500 psi), ml	-	-	-	-
Filter cake, mm	-	-	-	-

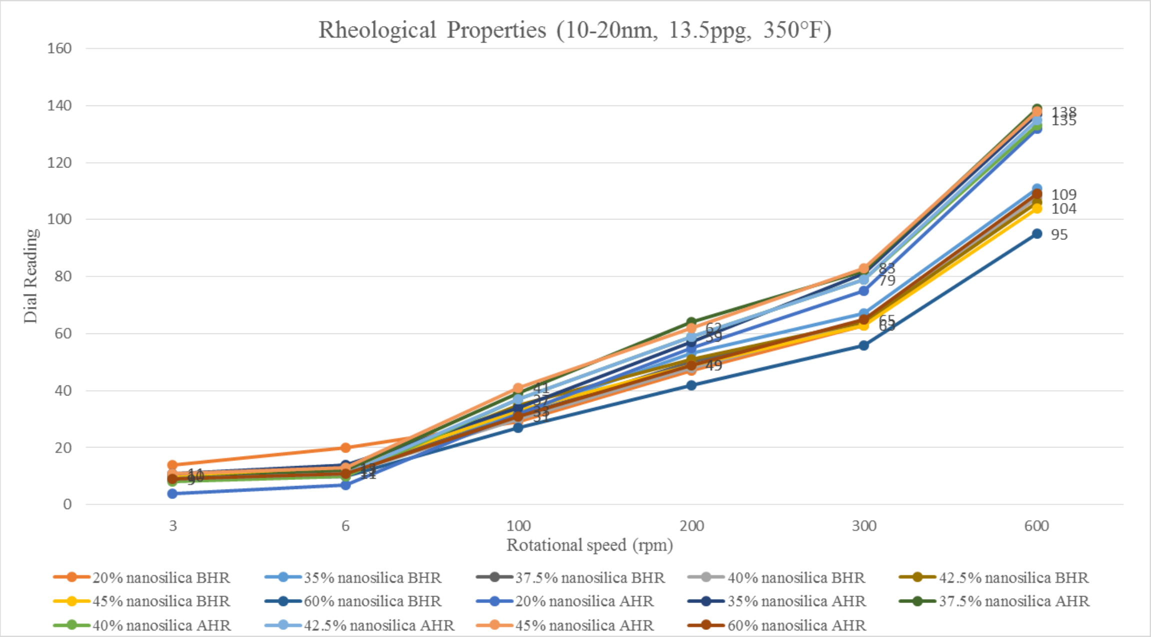

FIGURE 10: Rotational speed vs dial reading for 10-20nm, 13.5ppg, 350°F

Figure 10 shows the rpm vs dial reading which can be used to check the rheological properties (PV, YP and gel strength) of SBM performance with nanosilica size 10-20nm at temperature 350°F. The data has been combined from the author result and from previous experiment done by Wahid (2014) to get the trend.

It has been proven that the utilization of nanosilica in SBM at 350°F system improves the rheological performance of the SBM. Below figures will describe the performance of nanosilica in SBM and later the optimum composition of nanosilica can be determined.

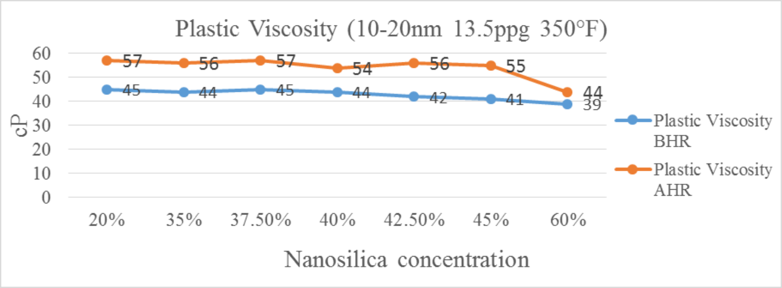

FIGURE 11: Plastic viscosity comparison BHR vs AHR for 10-20nm, 13.5ppg, 350°F

Figure 11 describes that the utilization of nanosilica size 10-20nm has been proven to improve the Plastic Viscosity of SBM since based on the standard performance for 13.5ppg at 350°F PV should be less than 45cP. It will make the drilling fluid easily to transfer by mud pump from mud pit to the bottom hole. PV increases after hot rolled process due to the chemical degradation when the samples are exposed to the HPHT environment. The increment of PV AHR also can be a good indicator to transport the drilling cutting from bottom hole to the surface, provided the PV is not too high or else it will require more pressure from mud pump to push the fluid out of hole.

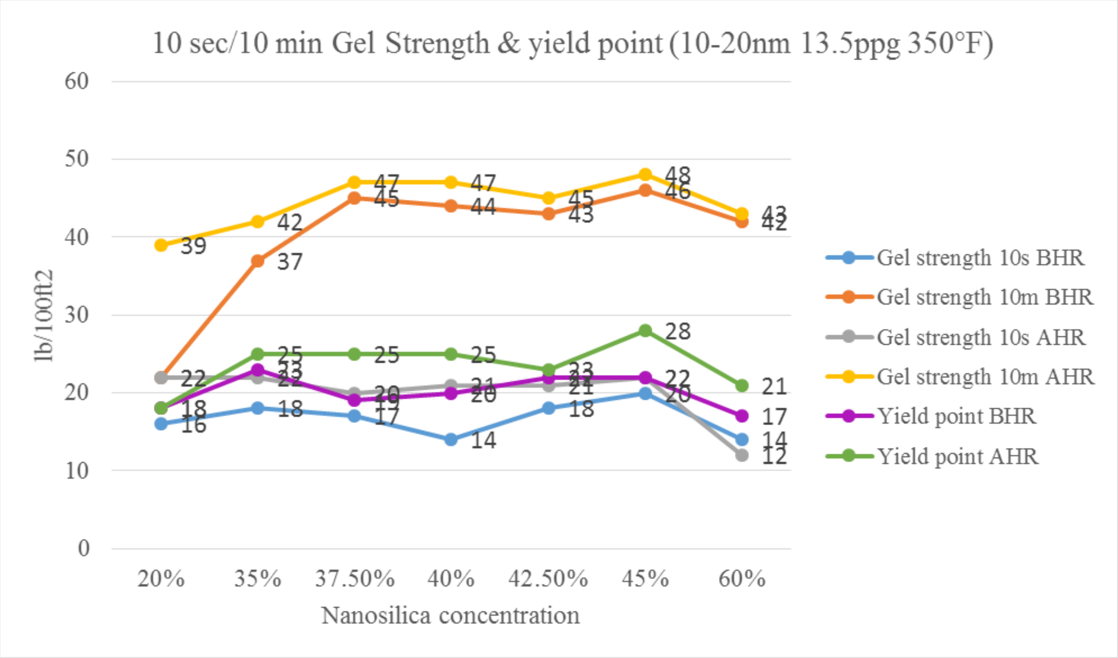

FIGURE 12: 10 sec/10 min gel strength & yield point comparison BHR vs AHR for 10-20nm, 13.5ppg, 350°F

From Figure 12 yield point of enhanced SBM with also increases after 16 hours in hot rolled oven at 350°F. It is a good indicator that this enhanced mud will perform better wellbore clean up to transport the drill cutting out of hole. The gel strength has increased AHR and not too high, as an indicator of good cutting suspension during static condition of the wellbore.

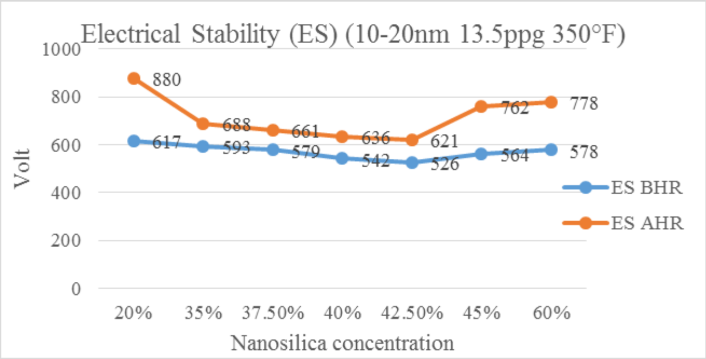

FIGURE 13: Electrical Stability BHR vs AHR for 10-20nm, 13.5ppg, 350°F

From Figure 13, it can be shown that the electrical stability trend is still above 500 Volt which is the standard electrical stability for SBM in 450°F environment. It shows a good stability of emulsion which mean the water is dispersed well in oil phase to increase the conductivity of SBM since oil is nonconductive material.

As summary of the enhanced SBM with nanosilica 10-20nm, it can be stated that the optimum nanosilica composition in SBM for 10-20nm and 350°F system is under 42.5% concentration (0.73 wt. %) by looking at the rheological properties, electrical stability and amount of nanosilica.

4.1.4 Nanosilica size 10-20nm, temperature 450°F and mud weight 17ppg.

TABLE 17: Early investigation mud samples properties for nanosilica size: 10-20nm, Temperature 450°F and mud weight 17 ppg

Before Hot Rolled Properties			
	0% Nanosilica Base Mud	20% nanosilica (0.042wt. %)	40% nanosilica (0.084 wt. %)
OWR	85:15	85:15	85:15
Rheology Property (120°F) at:			
600 rpm	151	147	145
300 rpm	85	83	83
200 rpm	66	62	59
100 rpm	41	36	36

6 rpm	10	9	10
3 rpm	9	7	8
Plastic viscosity, cP	66	64	62
Yield point, lb/100ft2	19	19	21
10 sec gel strength, lb/100ft2	14	15	16
10 min gel strength, lb/100ft2	24	27	30
ES (120°F), volt	989	1022	973
After Hot Rolled Properties			
OWR	85:15	85:15	85:15
Rheology Property (120°F) at:			
600 rpm	184	176	169
300 rpm	105	102	98
200 rpm	77	74	73
100 rpm	47	45	45
6 rpm	12	15	12
3 rpm	11	13	11
Plastic viscosity, cP	79	74	71
Yield point, lb/100ft2	26	28	27
10 sec gel strength, lb/100ft2	22	23	25
10 min gel strength, lb/100ft2	32	39	59
ES (120°F), volt	930	821	782
HPHT filtrate (500 psi), ml	-	-	-
Filter cake, mm	-	-	-

TABLE 18: Further investigation mud samples properties for nanosilica size: 10-20nm, Temperature 450°F and mud weight 17 ppg

Before Hot Rolled Properties				
	35% Nanosilica (0.074 wt. %)	37.5% nanosilica (0.078wt. %)	42.5% nanosilica (0.090 wt. %)	45% nanosilica (0.094 wt. %)
OWR	85:15	85:15	85:15	85:15
Rheology Property (120°F) at:				

600 rpm	148	146	146	143
300 rpm	85	83	84	58
200 rpm	64	61	60	58
100 rpm	39	37	37	34
6 rpm	10	12	11	11
3 rpm	9	10	9	9
Plastic viscosity, cP	63	63	62	61
Yield point, lb/100ft2	22	20	22	21
10 sec gel strength, lb/100ft2	22	18	17	17
10 min gel strength, lb/100ft2	34	33	34	34
ES (120°F), volt	962	948	954	968
After Hot Rolled Properties				
OWR	85:15	85:15	85:15	85:15
Rheology Property (120°F) at:				
600 rpm	169	170	171	168
300 rpm	97	98	100	97
200 rpm	71	74	76	72
100 rpm	44	47	47	45
6 rpm	10	11	12	12
3 rpm	9	9	10	11
Plastic viscosity, cP	72	72	71	71
Yield point, lb/100ft2	25	26	26	29
10 sec gel strength, lb/100ft2	22	24	24	22
10 min gel strength, lb/100ft2	48	51	53	56
ES (120°F), volt	741	716	723	739
HPHT filtrate (500 psi), ml	-	-	-	-
Filter cake, mm	-	-	-	-

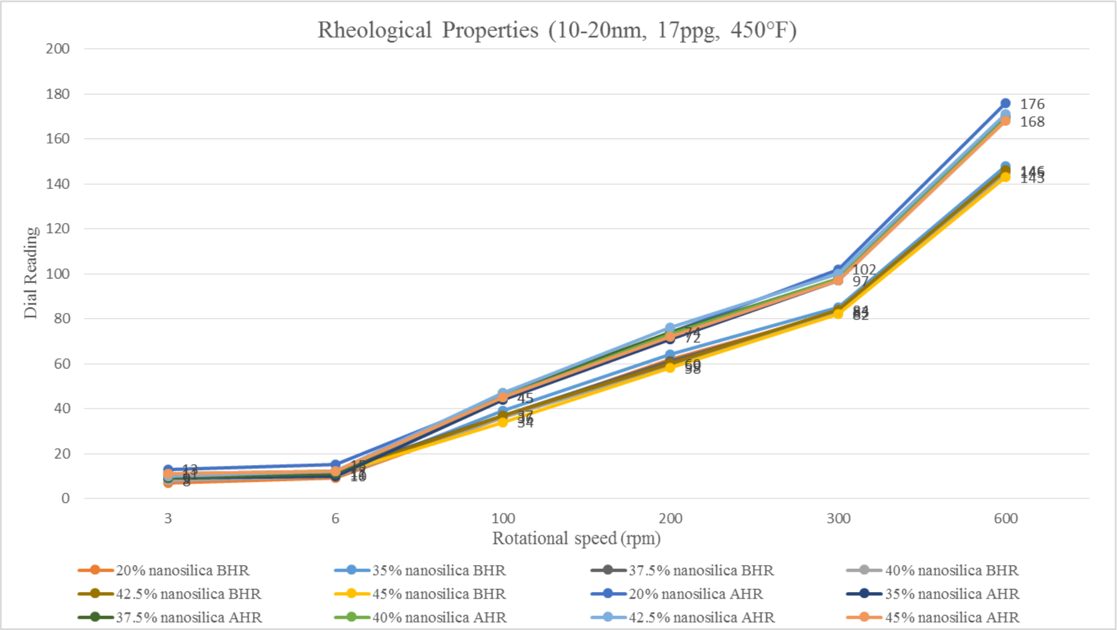

FIGURE 14: Rotational speed vs dial reading for 10-20nm, 17ppg, 450°F

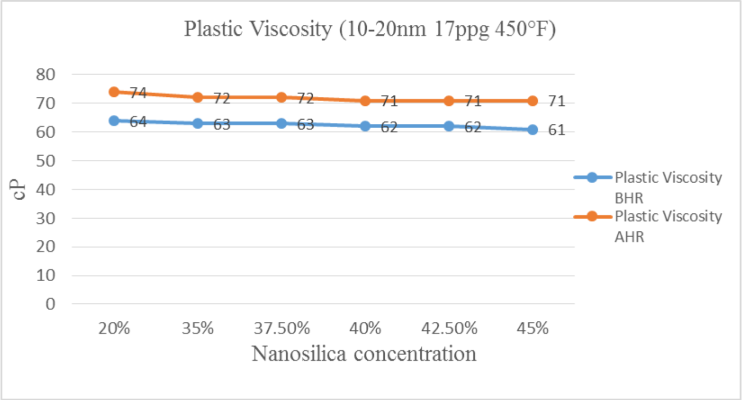

FIGURE 15: Plastic viscosity comparison BHR vs AHR for 10-20nm, 17ppg, 450°F

Figure 15 describes that the PV of enhanced mud BHR decreases as nanosilica concentration increases. The PV BHR from enhanced SBM formulation with nanosilica is below the benchmark which is 66cP which has a good effect to the SBM formulation. The increment of PV AHR is inevitable due to the chemical degradation in the SBM formulations. The lowest viscosity produced by enhanced SBM is under 45% of nanosilica concentration.

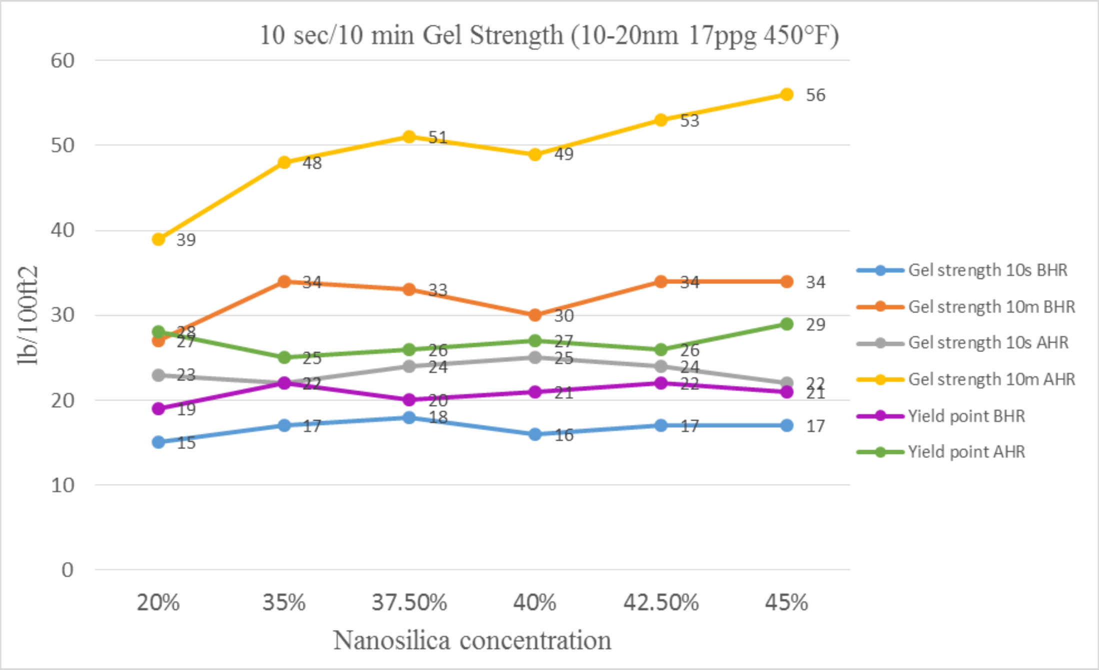

FIGURE 16: 10 sec/10 min gel strength & yield point comparison BHR vs AHR for 10-20nm, 17ppg, 450°F

Figure 16 has shown that the gel strength and YP AHR have increased as a good indicator for wellbore clean up and cutting suspension. The highest gel strength and yield point value is under 45% nanosilica concentration.

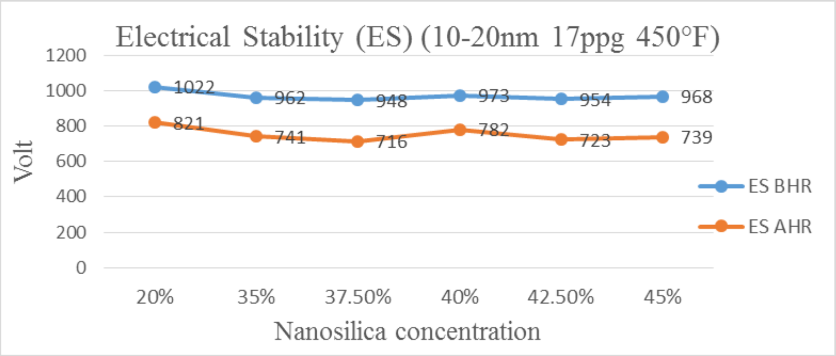

FIGURE 17: Electrical Stability BHR vs AHR for 10-20nm, 17ppg, 450°F

From Figure 17, it can be shown that despite the electrical stability trend is decreasing but still above 500 Volt which is the standard electrical stability for SBM in 450°F environment. It shows a good stability of emulsion which mean the water is dispersed well in oil phase to increase the conductivity of SBM since oil is nonconductive material.

As summary for enhanced SBM formulation with nanosilica size 10-20nm at 450°F, the optimum composition is under 45% concentration (0.094 wt. %) by looking at the rheological properties, electrical stability and amount of nanosilica.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

Different sizes of nanosilica has been shown have different effect on SBM performance. From this experiment, it can be stated that nanosilica 5-15nm has lower performance as compared to nanosilica size 10-20nm in SBM formulation due to the smaller size of nanosilica has increased the plastic viscosity of SBM for both 350°F and 450°F temperature systems and it is also affect the gel strength, yield point and electrical stability of the SBM

On the other hand, nanosilica size 10-20nm showed a good result to enhance SBM performance for HPHT condition for 350°F and 450°F temperature systems. Therefore in term of economical reason and performance, the optimum composition of nanosilica for 350°F system (13.5ppg) is 42.5% (0.73 wt. %) while for 450°F temperature system (17ppg), the optimum composition is 45% (0.094 wt. %).

There are some limitation found during the project which the major limitation is the experiment unable to perform HPHT filtration test due to the only HPHT Filter pass equipment is broken. The technician already made requisition but the new equipment will be arrived beyond the project schedule. Other limitation is the Fann 35 viscometer is not equipped with heating jacket and thermo cup, so that it is difficult to maintain the required temperature which is 60°F during collecting the data. The author came with the solution which is to stir the sample little longer (10minutes) after mixing and then put it into water bath cementing test equipment and set the temperature to 60°F. Yet it has significant effect on the reading of 10 minutes gel strength.

For further study, here is the recommendation from author point of view:

- The enhancement of nanosilica for other additives (e.g viscosifier) need to be analysed to observe the effect of nanosilica in SBM.
- Due to only small amount of nanosilica is used in SBM formulation for 450°F, the concentration of nanosilica size 10-20nm in this formulation could be extended until 80% or 90% for optimization purpose.

REFERENCES

1. Amani, M., and Shadravan, A. (2012). HPHT 101 – What Petroleum Engineers and Geoscientist should Know about High Pressure and High Temperature Wells Environment. Energy Science and Technology, CSCanada. 4(2): 36-60.
2. Amanullah, M., & Al-Tahini, A. M. (2009, January 1). Nano-Technology - Its Significance in Smart Fluid Development for Oil and Gas Field Application. Society of Petroleum Engineers. doi:10.2118/126102-MS
3. Amanullah, M., & Ramasamy, J. (2014, November 10). Nanotechnology Can Overcome the Critical Issues of Extremely Challenging Drilling and Production Environments. Society of Petroleum Engineers. doi:10.2118/171693-MS
4. Amanullah, M., AlArfaj, M. K., & Al-abdullatif Ziad Abdullrahman. (2011, January 1). Preliminary Test Results of Nano-based Drilling Fluids for Oil and Gas Field Application. Society of Petroleum Engineers. doi:10.2118/139534-MS
5. Apaleke, A. S., Al-Majed, A. A., & Hossain, M. E. (2012, January 1). Drilling Fluid: State of The Art and Future Trend. Society of Petroleum Engineers. doi:10.2118/149555-MS
6. Bland, R. G., Mullen, G. A., Gonzalez, Y. N., Harvey, F. E., & Pless, M. L. (2006, January 1). HPHT Drilling Fluid Challenges. Society of Petroleum Engineers. doi:10.2118/103731-MS
7. Cai, J., Chenevert, M. E., Sharma, M. M., & Friedheim, J. E. (2012, March 1). Decreasing Water Invasion Into Atoka Shale Using Nonmodified Silica Nanoparticles. Society of Petroleum Engineers. doi:10.2118/146979-PA
8. Cocuzza, M., Pirri, F., Rocca, V., & Verga, F. (2011, January 1). Is The Oil Industry Ready For Nanotechnologies? Offshore Mediterranean Conference.

9. Dudley, Bob. (2014, January). BP Energy Outlook [Online]. Available: http://www.bp.com/content/dam/bp/pdf/Energy-economics/Energy-Outlook/Energy_Outlook_2035_booklet.pdf
10. El Sherbeny, W., Al-Baddaly, H., Rahal, A., Said, M., Hardman, D., & Henry, T. (2014, April 21). Nanotechnology Applications To Minimize Geo-Mechanical Related Challenges While Drilling Intercalated Sediments, Western Desert, Egypt. Society of Petroleum Engineers. doi:10.2118/172242-MS
11. El-Diasty, A. I., & Ragab, A. M. S. (2013, April 15). Applications of Nanotechnology in the Oil & Gas industry: Latest Trends Worldwide & Future Challenges in Egypt. Society of Petroleum Engineers. doi:10.2118/164716-MS
12. Fletcher, Jamie., Hill, Adrian. Chemeurope (2015). Retrieved April 1, 2015: http://www.chemeurope.com/en/whitepapers/61207/making-the-connection-particle-size-size-distribution-and-rheology.html
13. Friedheim, J. E., Young, S., De Stefano, G., Lee, J., & Guo, Q. (2012, January 1). Nanotechnology for Oilfield Applications - Hype or Reality? Society of Petroleum Engineers. doi:10.2118/157032-MS
14. Hareland, G., Wu, A., Lei, L., Husein, M. M., & Zakaria, M. F. (2012, January 1). Innovative Nanoparticle Drilling Fluid and Its Benefits to Horizontal or Extended Reach Drilling. Society of Petroleum Engineers. doi:10.2118/162686-MS
15. Herzhaft, B., Audibert-Hayet, A., Sandford, R., & Freche, P. (2001, January 1). Optimization of SBM Formulations for Minimum Damage. Society of Petroleum Engineers. doi:10.2118/64981-MS
16. Hobbulovich, Z. T., & Abdulaevna, M. L. (2013, March 26). Applications of Bio and Nanotechnologies in the Oil and Gas Industry. Recent Progress. International Petroleum Technology Conference. doi:10.2523/16638-ABSTRACT
17. Hoelscher, K. P., De Stefano, G., Riley, M., & Young, S. (2012, January 1). Application of Nanotechnology in Drilling Fluids. Society of Petroleum Engineers. doi:10.2118/157031-MS
18. Javeri, S. M., Haindade, Z. M. W., & Jere, C. B. (2011, January 1). Mitigating Loss Circulation And Differential Sticking Problems Using

Silicon Nanoparticles. Society of Petroleum Engineers. doi:10.2118/145840-MS

19. Kapusta, S., Balzano, L., & Te Riele, P. M. (2011, January 1). Nanotechnology Applications in Oil and Gas Exploration and Production. International Petroleum Technology Conference. doi:10.2523/15152-MS
20. Kong, X., & Ohadi, M. (2010, January 1). Applications of Micro and Nano Technologies in the Oil and Gas Industry - Overview of the Recent Progress. Society of Petroleum Engineers. doi:10.2118/138241-MS
21. Lee, J., Cullum, D. D., Friedheim, J., & Young, S. (2012, January 1). A New SBM for Narrow Margin ERD Drilling. Society of Petroleum Engineers. doi:10.2118/151469-MS
22. Li, G., Zhang, J., Zhao, huaizheng, & Hou, Y. (2012, January 1). Nanotechnology to Improve Sealing Ability of Drilling Fluids for Shale with Micro-cracks During Drilling. Society of Petroleum Engineers. doi:10.2118/156997-MS
23. Nwaoji, C. O., Hareland, G., Husein, M., Nygaard, R., & Zakaria, M. F. (2013, March 5). Wellbore Strengthening- Nano-Particle Drilling Fluid Experimental Design Using Hydraulic Fracture Apparatus. Society of Petroleum Engineers. doi:10.2118/163434-MS
24. Paiaman, M.A., Al-Anazi, D.B., 2009. Feasinility of Decreasing Pipe Sticking. NAFTA Sci. J 60 (12), 645-647.
25. Pourafshary, P., Azimpour, S. S., Motamedi, P., Samet, M., Taheri, S. A., Bargozin, H., & Hendi, S. S. (2009, January 1). Priority Assessment of Investment in Development of Nanotechnology in Upstream Petroleum Industry. Society of Petroleum Engineers. doi:10.2118/126101-MS
26. R. API, "13B-2: Recommended Practice for Field Testing Oil-Based Drilling Fluids," ed: API, Washington DC, 2005.
27. Riley, M., Young, S., Stamatakis, E., Guo, Q., Ji, L., De Stefano, G., … Friedheim, J. (2012, January 1). Wellbore Stability in Unconventional Shales - The Design of a Nano-Particle Fluid. Society of Petroleum Engineers. doi:10.2118/153729-MS
28. Rojas, J. C., Daugherty, W. T., Irby, R. D., Bern, P. A., Romo, L. A., Dye, W. M., … Trotter, R. N. (2007, January 1). New Constant-Rheology

Synthetic-Based Fluid Reduces Downhole Losses in Deepwater Environments. Society of Petroleum Engineers. doi:10.2118/109586-MS

29. Sensoy, T., Chenevert, M. E., & Sharma, M. M. (2009, January 1). Minimizing Water Invasion in Shales Using Nanoparticles. Society of Petroleum Engineers. doi:10.2118/124429-MS
30. Shah, S. N., Shanker, N. H., & Ogugbue, C. C. (2010, April 7). Future Challenges of Drilling Fluids and Their Rheological Measurements. American
31. Sharma, M. M., Chenevert, M. E., Guo, Q., Ji, L., Friedheim, J., & Zhang, R. (2012, January 1). A New Family of Nanoparticle Based Drilling Fluids. Society of Petroleum Engineers. doi:10.2118/160045-MS
32. Shrivastav, P. (2012, April 30). An Integrated Approach Towards Well Control of a HPHT Well. Offshore Technology Conference. doi:10.4043/22885-MS
33. Singh, S. K., Ahmed, R. M., & Growcock, F. (2010, January 1). Vital Role of Nanopolymers in Drilling and Stimulations Fluid Applications. Society of Petroleum Engineers. doi:10.2118/130413-MS
34. Stamatakis, E., Young, S., & De Stefano, G. (2012, January 1). Meeting the Ultra HTHP Fluids Challenge. Society of Petroleum Engineers. doi:10.2118/153709-MS
35. Van Oort, E., Lee, J., Friedheim, J., & Toups, B. (2004, January 1). New Flat-Rheology Synthetic-Based Mud for Improved Deepwater Drilling. Society of Petroleum Engineers. doi:10.2118/90987-MS
36. Witthayapanyanon, A., Chandramouleeswaran, K., Bin Dollah, A., Clapper, D., Bland, R., Kongsawast, A., Abshar, M. (2014, March 25). Ultra-HPHT Drilling Fluid Design for Frontier Deep Gas Exploration in South Malay Basin. Offshore Technology Conference. doi:10.4043/24830-MS
37. Witthayapanyanon, A., Chandramouleeswaran, K., Bin Dollah, A., Clapper, D., Bland, R., Kongsawast, A., … Abshar, M. (2014, March 25). Ultra-HPHT Drilling Fluid Design for Frontier Deep Gas Exploration in South Malay Basin. Offshore Technology Conference. doi:10.4043/24830-MS
38. Xu, Z. (2012, January 1). Application of Nanotechnology on Borehole Wall Stability in Gas-Liquid Medium Transition during Gas Drilling. Society of Petroleum Engineers. doi:10.2118/160906-STU

39. Zakaria, M., Husein, M. M., & Harland, G. (2012, January 1). Novel Nanoparticle-Based Drilling Fluid with Improved Characteristics. Society of Petroleum Engineers. doi:10.2118/156992-MS
40. N. Wahid, *"Usage of Nano Silica at Different Concentration in Synthetic Based Mud (SBM): A Comparison Study for High Temperature High Pressure (HTHP) Well,"* Bachelor dissertation, Department Petroleum Engineering, Universiti Teknologi PETRONAS, Perak, 2014.