Usage of Nano Silica at Different Concentration in Synthetic Based Mud (SBM): A Comparison Study for High Temperature High Pressure (HTHP) Well

by

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13896

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

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

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May 2014

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.

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NORAZWAN BIN WAHID

ABSTRACT

Synthetic based mud (SBM) is proven to be the optimum mud for almost all drilling operations, for example in high temperature high pressure (HTHP) well, deepwater, unconventional and long extended reach directional (ERD) well. However, at certain conditions, the good performance of SBM will degrade, particularly due to effect of chemical instability under high temperature. In the light of aforesaid concern, the study on nano-particles as a smart-fluid in drilling operations has been gaining attention worldwide. The study focuses on improve performance of SBM with nano-silica at different concentration, the ability of nano-silica in fluid loss agent and to perform comparison studies in HTHP applications. The involving parameters in this study included the manipulation of nano-particles concentration by total mud weight between 0 to 3 wt. %, and performance at different temperature (275°F and 350°F). The enhanced formulation showed positive result such that better fluid loss control capability and act as the rheology modifier in HTHP condition. Therefore, this study has tested the formulation of base mud and enhanced mud up to the extent of HTHP condition.

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Norazwan bin Wahid

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ABBREVIATION AND NOMENCLATURE

AHR	-	After Hot Rolled
API RP	-	American Petroleum Institute Recommended Practice
BHR	-	Before Hot Rolled
BM	-	Base Mud
CBM	-	Coal Bed Methane
CNT	-	Carbon Nano Tube
EDS	-	Elemental Dispersive Spectroscopy
e-HTHP	-	Extreme High Temperature High Pressure
EM	-	Enhanced Mud
ERD	-	Extended Reach Directional
ES	-	Electrical Stability
GO	-	Graphene Oxide
HTHP	-	High Temperature High Pressure
LAO	-	Linear Alpha Olefin
MW	-	Mud Weight
N_2	-	Nitrogen Gas
O	-	Oxygen
OBM	-	Oil Based Mud
OWR	-	Oil Water Ratio
PAO	-	Poly Alpha Olefin
PV	-	Plastic Viscosity
ROP	-	Rate of Penetration
RPM	-	Rotation per Minute
SBM	-	Synthetic Based Mud
SEM	-	Scanning Electron Microscopy
Si	-	Silica

SiO_2 - Silicon Dioxide
u-HTHP - Ultra High Temperature High Pressure
WBM - Water Based Mud
YP - Yield Point

cP - centipoise, unit for viscosity measurement
g/mL - gram per milliliter, unit for density measurement
in - inch, unit for length measurement
mL - milliliter, unit for volume measurement, 10^{-3}
mm - millimeter, unit for length measurement, 10^{-3}
nm - nano meter, unit for length measurement, 10^{-9}
ppb - pound per barrel, lb/bbl
ppg - pound per gallon, lb/gal
psi - pound per square in, unit measurement for pressure
psi/ft - pound per square in per foot, unit measurement for pressure gradient
sg - specific gravity, dimensionless
wt. % - weight percentage

°C - degree Celsius, unit measurement for temperature
°F - degree Fahrenheit, unit measurement for temperature
ϑ_{600} - dial reading at 600 RPM, lb/100ft^2
ϑ_{300} - dial reading at 300 RPM, lb/100ft^2

CHAPTER 1
INTRODUCTION

1.1 PROJECT BACKGROUND

In drilling operations, the success is heavily dependent on the drilling fluid, or always called as drilling mud [1]. Its various functions have proven that the best and optimum selection of drilling fluid play an important role for successful operations. Nowadays, drilling operations have become more challenging from time to time as explorations go towards harsher environment, such that deepwater, HTHP, ERD to extreme ERD and unconventional play such as coal bed methane (CBM), tight gas reservoir, and shale oil/gas reservoir [2-5]. The design of the drilling mud itself must consider the economic value, safety (to the rig crews and environment) and functionally wise depending on the type of operations.[6]

There are many types of drilling mud that have been classified, for instance, water based mud (WBM), oil based mud (OBM) and SBM. However, from all different types of drilling mud offered by the drilling fluid companies, SBM is known as the most optimum mud for almost every drilling environment [7]. SBM is another type of OBM but it uses a better base fluid which result in lesser environmental issue. It various advantages, are, higher rate of penetration (ROP), good wellbore stability particularly in shale formation, and lower torque/drag for drill string rotation, has made this mud preferable [8-10].

However, at some condition, there is still an issue related to chemical degradation and instability when drilling through HTHP formation. This problem may cause mud instability which will lead to drilling and completion problems [5]. It is supported in different sources that various conventional polymeric and surfactant additives that have been tested for the best performance of drilling muds have expensive cost and degrade at HTHP conditions, which lead to unwanted changes in rheological properties [11]. To encounter this, researches to use nano technology to design smart fluids which consist of nano particles have been conducted recently [12-15]. This enhanced formulation with nano particles in the system is intended to become system optimizer, particularly to enhance filtration performance and provide better rheological behavior. In addition, controlling the rheology of the drilling muds is one of the key issues to resolve frequently occurring and harsh drilling problems [11]. The use of nano particles as to be the system optimizer is in line with the fact that nano particles have better thermal stability (good for HTHP conditions) [13, 14, 16], able to perform as bridging agent in fluid loss system to control loss circulation [1, 17, 18] and pickering emulsion for the stabilizer system [19, 20].

1.2 PROBLEM STATEMENT

There are two reasons that justify the need to conduct this study: Firstly, inconsistent rheology of the mud when exposed to HTHP condition will result in poorer performance in drilling operations such as lower ROP, pipe sticking and higher torque and drag. Secondly, the fluid loss control in the mud system will degrade and become unstable in HTHP condition where this will lead to multiple problems to the well. Therefore, there is a need to enhance the current formulation with better one, particularly in fluid loss control and stable mud rheology, with the introduction of nano particles in the formulation. A comparison study in HTHP environment has to be done between current SBM formulations and SBM formulations with nano particles enhancement.

1.3 PROJECT OBJECTIVE

The overall objective of this study is to highlight the effect of nano particles, and to be exact the effect of nano silica, on the performance of SBM to the extent of HTHP conditions. Therefore, the objectives are, specifically:

- To improve performance of SBM formulations with nano silica at different concentration.
- To investigate the ability of nano silica in fluid loss control agent.

- To perform comparison studies under HTHP condition for constant rheology and better fluid loss control.

1.4 SCOPE OF STUDY

The first part of this study is primarily to focus on the performance of nano silica in base mud system where the testing temperature is at 275°F in order to understand its behavior at lower temperature.

The second part of this study is to evaluate the performance of enhanced SBM formulations with nano silica at HTHP conditions (350°F). The concentration of nano silica will become the modifying parameter in the analysis, which vary from 1 to 3 wt. %.

For overall, the study will be focused on mud properties: mud weight (MW), plastic viscosity (PV), yield point (YP), gel strength, electrical stability (ES) and HTHP fluid loss volume.

1.5 RELEVANCY OF THE STUDY

The relevancy of the study is shown by the need to have an optimum design for the mud system which is capable of performing at the very challenging environment. To this, SBM had become the preferred solution over OBM and WBM. Therefore, the approach on using nano silica in the formulations is relevant to this project, where enhanced mud formulations with nano particles, for example nano silica, could be the future smart drilling fluids of choice.

1.6 FEASIBILITY ANALYSIS

This project is feasible to be conducted as final year project because it could be finished within the given timeline. The experiments can be done in the university's laboratory and all equipment are available. The laboratory is also capable to conduct HTHP filtration test which is required as part of the analysis in this study. In term of chemicals, collaboration with drilling fluid company to supply particular chemicals for use in this study have also been endorsed. The requirement for advanced laboratory and testing can be performed via external facilities from servicing companies, when necessary. The supply for nano silica also can be received in time although special order and process are needed. In the end, this project is feasible for academia and industry.

CHAPTER 2

LITERATURE REVIEW

2.1 DRILLING FLUIDS

Drilling fluid system, commonly known as the “mud system”, is the single component of the well-construction process that remains in contact with the wellbore throughout the entire drilling operation [21]. By definition, the term drilling fluid means “a liquid, gas or gasified liquid circulating continuum substance used in the rotary drilling process to perform any or all of the various functions required in order to successfully drill a usable wellbore at the lowest overall cost” [22].

The drilling fluid is expected to perform multiple tasks concurrently, for example, to cool the bit, to lubricate the rotating part of the drill string, and effective hole cleaning, but if the designed fluid failed to provide any of the functional requirements, this could lead to severe problems [11]. Such problems are, lost circulation, formation damage, pipe-sticking, wellbore erosion (poor hole), poor wellbore cleaning, and high torque and drag that significantly reduces the drilling efficiency [3, 9, 23].

The basic functions of a drilling mud are [21]:

- Transport cuttings to surface.

  This is the most basic function of a drilling mud. To accomplish this, the fluid should have adequate suspension capability to help ensure that cuttings and any commercially added solids such as barite will be suspended, particularly in static intervals. Successful cuttings transport is important to help avoid pipe sticking problem and bit balling.
- Prevent well control issues.

  The fluid column will exert hydrostatic pressure to the wellbore, and normally the pressure exerted should balance or exceed the natural formation pressure to help prevent an influx of gas or other formation fluids. As the pressure increases, the mud density required also increases to help maintain a safe margin and prevent “kicks” or “blowout”. Therefore, maintaining appropriate mud density is necessary to help avoid any well control issue.

- Preserve wellbore stability
  Maintaining the optimal drilling fluid density not only helps contain formation pressures, but also helps prevent hole collapse and shale destabilization. The wellbore should free from any obstruction and tight spot to help ensure the drill string can be run freely. Therefore, the mud program will be designed based on the given pore and fracture pressure chart of the respective formation to provide the best results for a given interval.

Other functions of drilling mud are, but not limited to, as the lubricating and cooling mechanism, minimizing formation damage, providing information about the wellbore, reducing torque and drag, and minimizing risk to personnel, environment and drilling equipment [4, 10, 18, 21].

There are many types of drilling muds available to serve various operations in drilling, such as WBM, OBM, SBM, drill-in fluids, pneumatic-drilling fluids and all-oil fluids [21]. All of these have its own functionality, advantages and disadvantages, depending upon the requirements and the needs of its specific operations.

2.2 Synthetic Based Mud (SBM)

SBM were developed out of an increasing desire to reduce the impact on environment of offshore drilling operations, but without sacrificing the cost-effectiveness of oil-based system [21]. It has almost the same properties as OBM but SBM is commonly known with its advantage of having low toxicity level and environmental friendly. This is also supported in different literature such that SBM is the combination of technical advantages of OBM with low persistence and toxicity of WBM [24]. In offshore environment where discharge of cuttings drilled with OBM is strictly prohibited, however it is not imposed on the use of SBM due to its advantages as aforementioned.

The chemical structures for base oils used in synthetic drilling fluids may vary widely from esters, ethers, linear-alpha-olefins (LAO), poly-alpha-olefins (PAO), n-alkanes and acetal derivatives [10].

Among advantages that have been discussed by many authors of using SBM, but not limited to, are faster completion of wells, lower drilling costs, gas hydrate suppression, high ROP, suit to drill long open hole section (due to excellent lubricating properties), wellbore stability, and lower overall well costs [7, 8, 10, 25].

2.3 HTHP

In HTHP conditions, the physical definition of this term can be referred to a well that requires a higher density fluid which typically requires high solids loading (reflecting higher pressure) [2]. In different sources, the term HTHP operation is defined as wells that have an initial reservoir temperature greater than 300°F and a reservoir pressure greater than 10000 psi or an initial reservoir overpressure greater than 3000 psi [26], and the definition as given by the United Kingdom Continental Shelf Operations Notice, as any well having undisturbed bottomhole temperature of above 300°F and pore pressure gradient exceeding 0.80 psi/ft.

This condition can be classified into three tiers to simulate the HTHP environment, as shown in the ***Table 1***:

Table 1: Classification of three tiers of HTHP environment [27]

	Pressure, psi	**Temperature, °F**
HTHP	10000 to 15000	300 to 350
Extreme-HTHP (e-HTHP)	15000 to 20000	≤ 400
Ultra-HTHP (u-HTHP)	20000 to 30000	≤ 500

The current trend of drilling is moving towards HTHP where the drilling fluids design must help to meet the very challenging environment and ***Figure 1*** below shows the distribution of some HTHP wells located around the world. In such harsh environment (extremes in temperature and pressure), problems are likely to occur and this may result in drilling inefficiency.

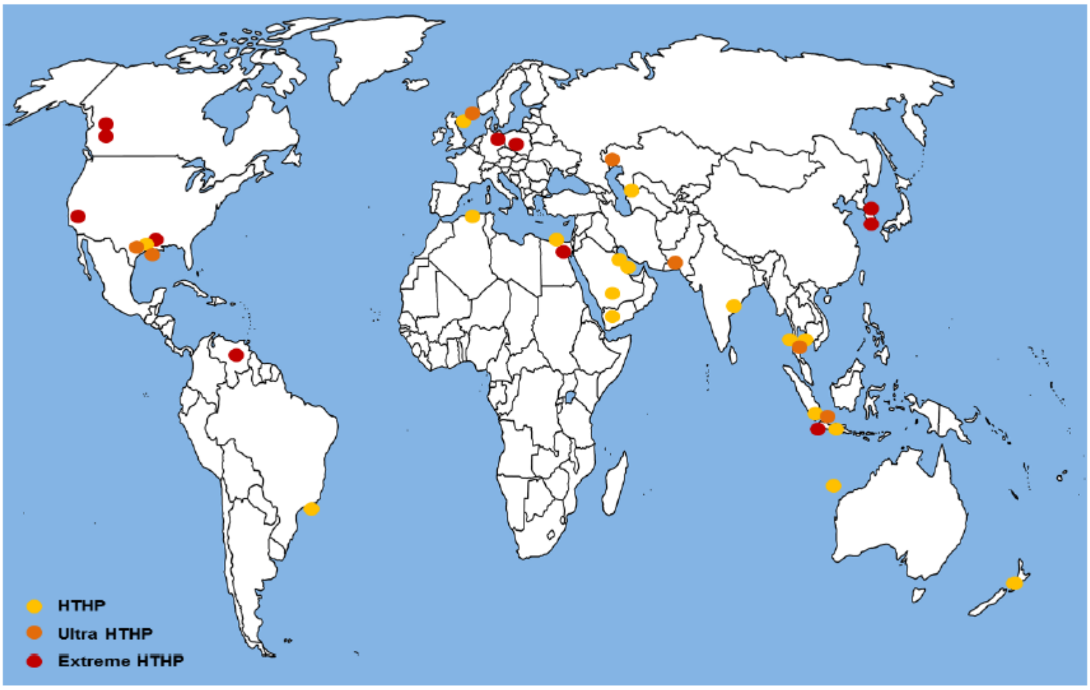


Figure 1: HTHP wells around the world [25]

In order to perform in this environment, the fluids must have special performance [5], for example:

- Superior suspension properties in order to reduce or eliminate barite sag.
- Good additives to minimize fluid losses into formation
- Better control over the potential of different sticking
- Improve borehole stability

For this, invert drilling fluid is often used over water-based drilling fluid to drill challenging HTHP wells due to its inherited thermal stability. However, when the temperature exceeds 400°F, the chemicals used in the formulation can become unstable and thermal degradation can occur over a short period of time resulting drastic changes in rheology and other fluid properties [25].

For this reason, some modification or enhancement should be done to help ensure the selected fluids are able to perform in HTHP environment.

2.4 NANO TECHNOLOGY AND NANO PARTICLES

Nano technology has been widely applied in a variety of products including circuitry, medical, material composites and even consumer goods [14, 15], however its application in oil and gas industry is still at its new stage [12, 13, 28]. In some studies [29], the definition of nano technology is described as "a field of applied science and technology whose unifying theme is to control of matter on the atomic and molecular scale, generally 100 nm or smaller, and the fabrication of devices with critical dimensions that lie within that size range".

Research in the use of nano particles in drilling fluid has started gaining attention worldwide. ***Table 2*** below shows the summary of different studies on different nano particles in drilling fluid application.

Table 2: Summary of different studies on different nano particles in drilling fluid application [14]

Type of Study	Type of Nano Particle	Remarks
Rheology and fluid loss control	Graphene Oxide (GO)	GO added to freshwater slurry of bentonite and barite, to study the effect of viscosity
HTHP rheology and fluid loss control	Carbon Nanotubes (CNT)	CNT showed positive result in stabilizing rheological profile, but it extent to fluid loss control was still an issue
Shale stability	Nano silica	Nano silica showed positive result, given that suitable nano particles size was taken into consideration

A positive study was conducted to test the ability of nano silica to decrease water invasion in shale formation [30]. However, the tests were carried out between nano silica and WBM, instead of testing the combination with SBM or OBM. ***Table 3*** and

Figure 2 describe the effect on nano silica concentration at different size with the permeability reduction.

Table 3: Overview of basic three step PP tests using various nano particles concentrations [30]

Shale number	NP name	wt% NP in muds	Permeability (nd)			Δk (%)
			Brine	LSM	LSM+NP	
Atoka 34C	NP-A	10	0.17	0.0258	0.0034	86.92
Atoka 39D	NP-A	5	5.0	0.216	0.168	22.22
Atoka 33C	NP-B	10	0.174	0.01	0.0015	85.00
Atoka 44D	NP-B	5	0.22	0.0136	0.007	48.53

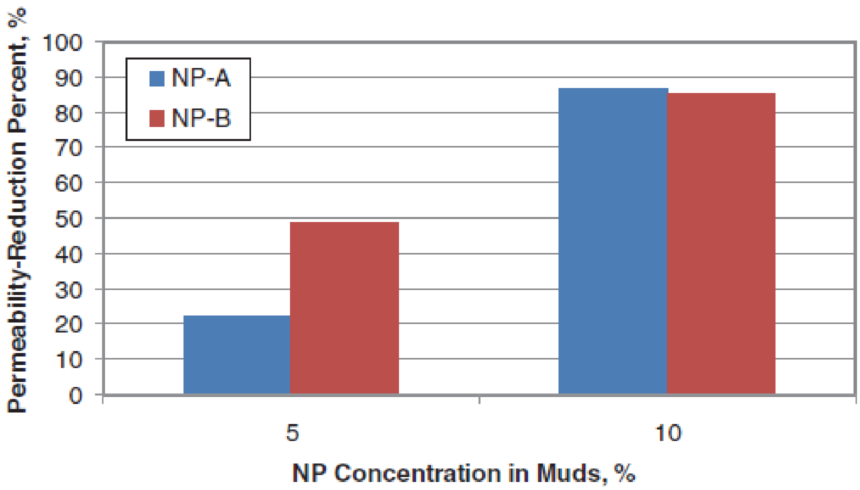


Figure 2: Effect of nano particles concentration in muds on permeability-reduction percent [30]

More studies have enlighten the possibility of nano drilling fluids to be commercially used in drilling operations. Some of its advantages, as described by several authors [17, 31-33], are:

- Reducing differential pipe sticking (decrease mud cake thickness)
- Filtration control additive to reduce formation damage (lower volume of fluid loss to the formation)
- Reduction in friction coefficient – more than 25% using nickel-based nano particles (suitable for ERD well)
- Enhancers of electrical and thermal conductivity
- Emulsion stabilizers
- Wellbore strength improvers, and to mention a few.

Therefore, through overall analysis from the literature, it is hoped that the study on the usage of nano silica in SBM could enhanced the formulation to the extent of HTHP.

CHAPTER 3

PROJECT METHODOLOGY

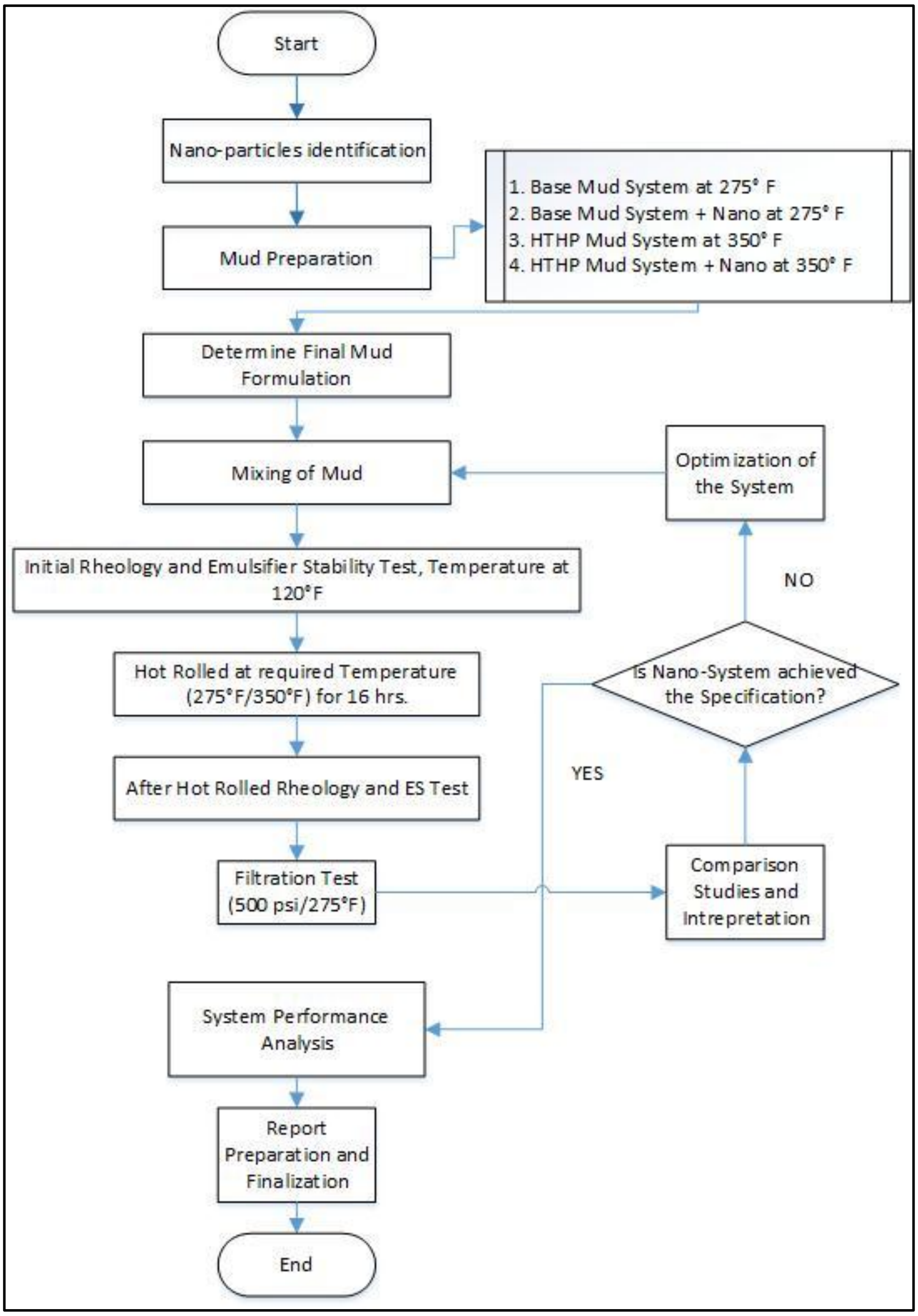


Figure 3: Process flowchart for nano SBM

3.1 THE FLOWCHART PROCESSES

Figure 3 shows the process flowchart for nano SBM. There are four main processes to be described based on the flowchart:

Process 1:

This process is where all the testing parameters were determined. The samples preparation will be based on:

- Base mud system at 275°F
- Base mud system + nano silica at 275°F
- HTHP mud system at 350°F
- HTHP mud system + nano silica at 350°F

Process 2:

In this process, the sample(s) were tested for:

- Initial rheology and emulsion stability test at ambient temperature
- Hot rolled at designated temperature (275°F and 350°F) for 16 hours
- Aging test on rheology and emulsion stability, after hot rolled
- HTHP filtration test

Process 3:

At this stage, the comparison studies were conducted based on the given benchmark for the required tests. An optimization process will take place, when the results obtained from the tests far beyond the benchmark.

Process 4:

The performance analysis on case by case basis were performed in this process. Each of the parameter will be analyzed in the discussion part. The data and result obtained were summarize in the report for documentation.

3.2 NANO SILICA SPECIFICATION

The specification of nano silica used in the experiment is given below, in ***Table 4***:

Table 4: Nano silica specification

Product name	**Silicon dioxide – nano powder, SiO_2**
Purity	99.5% trace metals basis
Size	10-20 nm particle size
Appearance	White, powder
Boiling point	2230°C
Melting point	>1600°C
Density	2.2-2.6 g/mL at 25°C

Figure 4 and ***Figure 5*** show Scanning Electron Microcopy (SEM) imaging and the Elemental Dispersive Spectroscopy (EDS) for elemental identification, respectively, of nano silica used in this experiment.

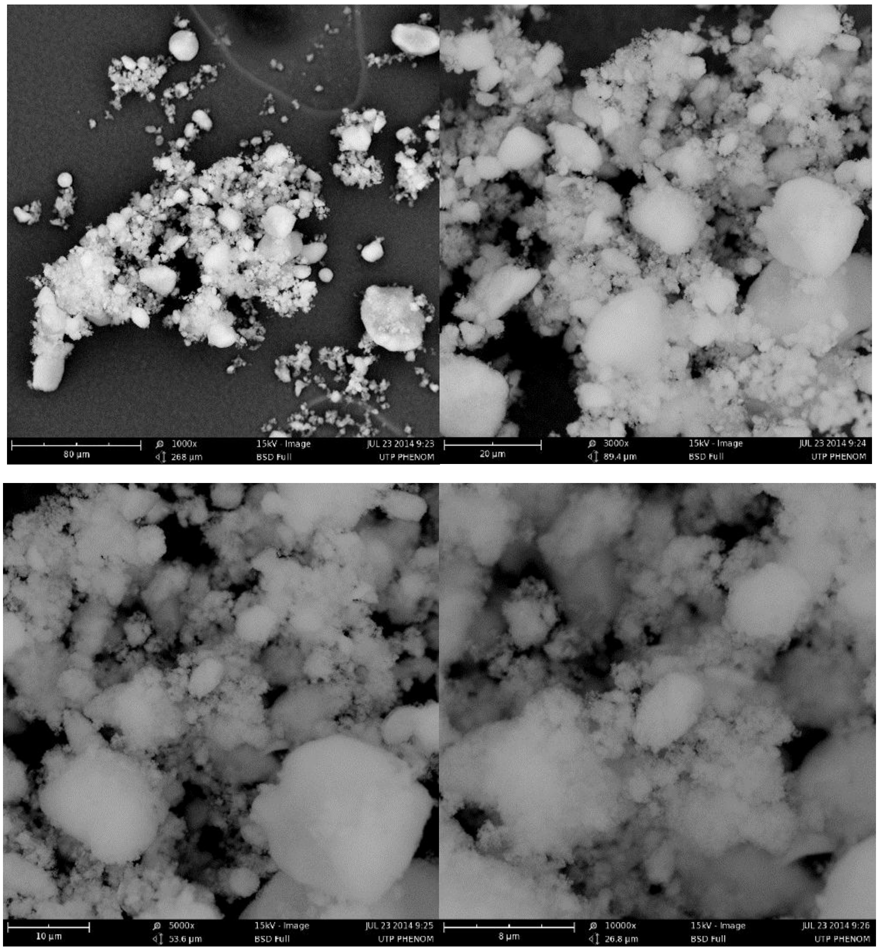


Figure 4: SEM images of nano silica, from top left: Magnification of 1000x, 3000x, 5000x, 10000x

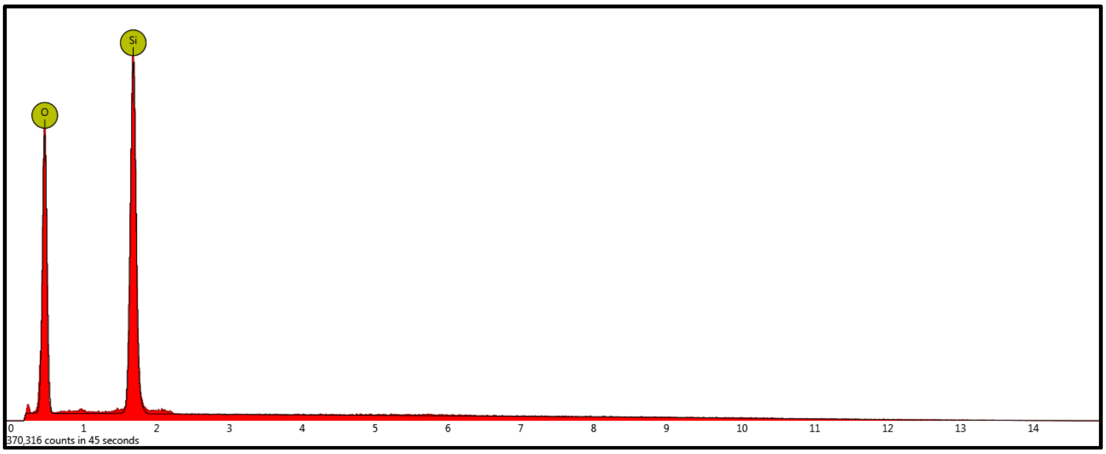


Figure 5: EDS analysis for nano silica elemental identification

Table 5: Elemental Identification of nano silica, SiO_2

Element Number	Element Symbol	Element Name	Confidence	Concentration	Error
14	Si	Silicon	100.0	23.9	0.3
8	O	Oxygen	100.0	76.1	0.4

Based on the ***Figure 4***, the sizes of nano silica used in this experiment has been confirmed while the purity of the nano silica is confirmed in the EDS result shown in ***Figure 5*** and ***Table 5***.

3.3 DRILLING MUD FORMULATIONS

In this project, the samples were tested at 275°F as the 'base temperature' and at 350°F as the 'high temperature'. The enhanced mud formulation with different concentration of nano silica also were performed for comparison studies on these two system.

The formulation can be seen in ***Table 6*** below:

Table 6: The formulation at different temperature system

Functional Materials	275°F System	350°F System
Base oil	✓	✓
Primary emulsifier	✓	✓
Secondary emulsifier	✓	✓
Viscosifier	✓	✓
Other (XHT Viscosifier)		✓
Fluid loss control	✓	✓
Lime	✓	✓
Calcium chloride	✓	✓
Barite (4.39 SG*)	✓	✓
Oil water ratio (OWR)	75:25	80:20
MW, ppg*	12.0	13.5
Nano silica concentration	0 to 3 of total wt. %	

**SG – Specific gravity*

**ppg – pound per gallon*

3.4 SAMPLE FORMULATION and MIXING PROCEDURES

Equipment:

Digital balance, Hamilton Beach mixer, stopwatch, thermometer and one lab barrel mud cup.

Procedure:

The chemical samples are weighted according to the mud formulation concentration. All samples will have a total of 60 minutes of mixing time, which include the additional time and the designated mixing time. The mixing is performed using Hamilton Beach mixer at high speed of 18000 rotation per minute (rpm).

Table 7 and ***Table 8*** below show the mixing order and time for 275°F and 350°F mud system, respectively.

Table 7: Mixing order and time for 275°F mud system

Functional Materials	Mixing Order	Time, min	Base Case Mud, ppb**	20 % (0.16 wt. %), ppb	40 % (0.32 wt. %), ppb	60 % (0.48 wt. %), ppb
Base oil	-	-	160.08	160.15	160.67	160.96
Primary emulsifier	1	2	3.00	3.00	3.00	3.00
Secondary emulsifier	2	2	6.00	6.00	6.00	6.00
Viscosifier	3	5	3.75	3.75	3.75	3.75
Fluid loss control	4	2	4.00	3.60	2.40	1.60
Nano silica*	5	2	-	0.80	1.60	2.40
Lime	6	2	10.00	10.00	10.00	10.00
Drill water /calcium chloride	7	15	51.97 / 25.06	52.00 / 25.06	52.16 / 25.06	52.26 / 25.06

Barite (4.39 SG)	8	2	217.49	216.98	216.69	216.30
Drill solids	9	2	20.00	20.00	20.00	20.00

**nano silica will be added for enhanced formulation system, according to its tested concentration*

***ppb is pound per barrel*

Table 8: Mixing order and time for 350°F mud system

Functional Materials	Mixing Order	Time, min	Base Case Mud, ppb	20 % (0.35 wt. %), ppb	40 % (0.71 wt. %), ppb	60 % (1.06 wt. %), ppb
Base oil	1	4	143.86	144.59	145.32	146.05
Primary emulsifier	2		13.80	13.80	13.80	13.80
Secondary emulsifier	3		1.00	1.00	1.00	1.00
Viscosifier	4	2	2.50	2.50	2.50	2.50
Other (XHT Viscosifier)	5	2	1.30	1.30	1.30	1.30
Fluid loss control	6	2	9.90	7.92	5.94	3.96
Nano silica*	7	2	-	1.98	3.96	5.94
Lime	8	2	11.30	11.30	11.30	11.30
Drill water /calcium chloride	9	15	46.71 / 16.50	46.95 / 16.50	47.18 / 16.50	47.42 / 16.50
Barite (4.39 SG)	10	2	297.79	296.81	295.83	294.85
Drill solids	11	2	20.00	20.00	20.00	20.00

**nano silica will be added for enhanced formulation system, according to its tested concentration*

3.5 MUD RHEOLOGICAL PROPERTIES TEST

Equipment:

Fann 35 viscometer, heating jacket, thermo cup, stopwatch and thermometer.

Procedure:

i. Stir the sample at 600 rpm while the sample is heating to 120°F.
ii. Once the temperature reach 120°F, start noting the result of dial 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 finished 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 leave the mud in static mode for 10 seconds. Then, initiate the mud with 3 rpm speed and take the highest deflection of the dial reading.
iv. Stir again the sample at 600 rpm for 30 seconds and leave it undisturbed for 10 minutes. This is to measure the 10-min gel.

The calculation of PV and YP will be performed using ***Equation 1*** and ***Equation 2***, respectively.

$$PV = \theta_{600} - \theta_{300} \quad (1)$$

$$YP = \theta_{300} - PV \quad (2)$$

3.6 ELECTRICAL STABILITY TEST

Equipment:

Electrical stability (ES) meter.

Procedure:

i. Place the clean probe of ES meter in the sample 120°F and use it to stir the fluid to help 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 hold 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 three times for calculating average value.

3.7 HOT ROLLING THE SAMPLES

Equipment:

Roller oven and aging cells.

Procedure:

i. The oven must be preheated to the required temperature.
ii. The sample is stirred for 5 minutes on Hamilton Beach mixer.
iii. The sample is transferred into aging cell container. The aging cell is tightly closed.
iv. The aging cell is pressurized to the specific pressure, depending on the tested temperature.
v. The aging cell is then placed in the roller oven and start rolling the sample. The sample is rolled for 16 hours.

3.8 HTHP FILTRATION TEST

Equipment:

HTHP filter press, HTHP filtration cells (Diameter 3-in x Height 3-in), filter paper (Diameter 2.5-in), high pressure N_2 supply, stopwatch and measuring cylinder.

Procedure:

i. The heating jacket is preheated to the required temperature.
ii. Tighten the bottom valve stem and fill the cell to about 0.5-in 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 help 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 N_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 regulator clockwise until 100 psi.
viii. Repeat the process with the bottom regulator.
ix. Turn the valve stem ¼ to ½ turn, anti-clockwise to pressure up the cell to 100 psi.
x. 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.
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 for 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 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.

xv. Examine the filter paper and check the thickness of cake built (measured in millimeter (mm)) and filtrate produced (in milliliter (ml)).

The calculation of the volume should be doubled as the standard API filter press is twice the area of the HTHP cell.

The testing procedure follows the API RP 13B-2 [34] and also from [35].

3.9 PROJECT GANTT-CHART

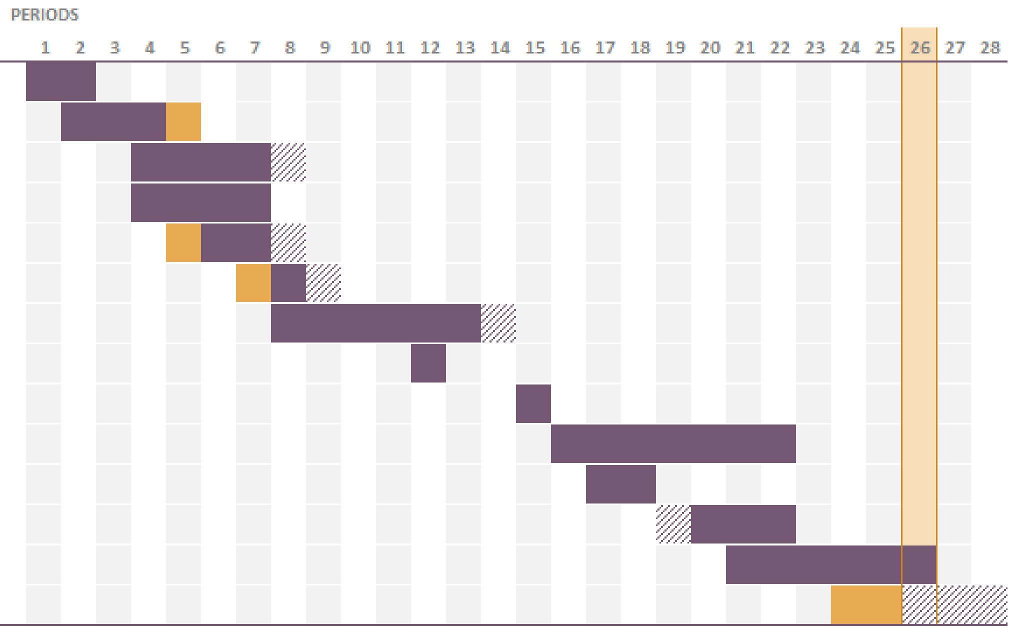
Table 9 shows the project timeline for the first part of the Final Year Project (FYP).

Table 9: Project timeline (Gantt-Chart) for FYP 1 and FYP 2

FYP I & FYP II Planner

Period Highlight: # | Plan | Actual | % Complete | Actual (beyond plan)

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Selection of project title	1	2	1	2	100%
Literature review and theory analysis	2	3	2	4	100%
SBM formulations studies	4	5	4	4	100%
Research methodology indentification	4	4	4	4	100%
Nano particles selection	6	3	5	3	100%
Final formulations	8	2	7	2	100%
Project work continuation (Phase 1)	8	7	8	6	100%
Laboratory booking submission	12	1	12	1	100%
FYP II Commencement	15	1	15	1	100%
Project work (Phase 2)	16	7	16	7	100%
Base mud sampling	17	2	17	2	100%
Enhanced mud sampling (nano silica)	19	4	20	3	100%
Project analysis	21	6	21	6	100%
Project work finalization	26	3	24	2	100%



3.10 KEY MILESTONE OF FYP 1 AND FYP 2

Table 10 describes the key milestone (to-date), achieved for the first part of this study.

Table 10: Key milestone

No.	Description	Week No.
1	The title for FYP is confirmed. Further studies on the title have been made to shape the project direction and scope.	2
2	The suitable nano particles has been decided (nano silica) and the sizing (5 to 15 nm, 10 to 20 nm) of nano silica also have been chosen.	6
3	Mud formulations have been confirmed. The SBM mud system will be for 275°F and 350°F.	8
4	Pre-laboratory studies on the testing procedure have been identified. The laboratory booking ticket has been submitted.	12
5	Received mud chemicals and additives.	14
6	Base mud samples were mixed and results were obtained for benchmarking purpose.	17
7	Nano silica was received and works on enhanced mud system were started.	20
8	All experimental works have been completed.	23
9	Analysis on the results have been performed.	26

CHAPTER 4

RESULT AND DISCUSSION

In this project, the comparison studies were performed based on the experimental results obtained for SBM without nano silica or base mud (BM) and SBM with nano silica or enhanced mud (EM), particularly focused on HTHP performance.

The variation in nano silica concentrations with respect to the commercial fluid loss control additive were the main experimental modifying parameter. The amount nano silica used were between zero to 1.78 by total weight percent (wt. %) of drilling mud formulation, and nano silica was treated as fluid loss control additive.

The study concentration of nano silica with respect to commercial fluid loss control additive varies from 20%, as the lower case study to the highest case study, which is 60%. In total, there will be eight samples which equally divided for the studies on 275°F and 350°F mud systems respectively – Base case, 20% nano silica, 40% nano silica, and 60% nano silica to weight of current fluid loss additive.

This section will discuss further on the experimental results for all cases which were described previously.

4.1 MUD DATA ANALYSIS

Table 11 provides the data obtained for all mud systems in this study. The experimental data were taken Before Hot Rolled (BHR) and After Hot Rolled (AHR) for the mud rheological properties and HTHP filtration test will only be performed AHR. The mud samples were left aging for 16 hours, at dynamic condition, depending on its study temperature.

Table 11: Experimental data result for both systems - 275°F and 350°F

Properties BHR:	BM275	EM275-20%	EM275 -40%	EM275 -60%	BM350	EM350 -20%	EM350 -40%	EM350 -60%
Mud density, ppg	12.0	12.0	12.0	12.0	13.5	13.5	13.5	13.5
Hot rolled temperature, °F	275	275	275	275	350	350	350	350
Rheological properties at, °F	120	120	120	120	120	120	120	120
600 rpm	78	48	48	45	131	108	108	95
300 rpm	46	29	28	27	76	63	64	56
200 rpm	36	22	21	21	55	47	48	42
100 rpm	24	14	13	13	35	29	30	27
6 rpm	9	5	5	5	16	20	11	10
3 rpm	9	4	3	4	12	14	9	9
PV, cP	32	19	20	18	55	45	44	39
YP, lb/100 ft^2	14	10	8	9	21	18	20	17
10 sec gel strength, lb/100 ft^2	8	12	11	8	11	16	14	14

10 min gel strength, lb/100 ft^2	11	17	16	13	16	22	44	42
ES, volt @ 120°F	623	588	539	594	782	617	542	578
OWR	75:25	75:25	75:25	75:25	80:20	80:20	80:20	80:20
Properties AHR, 16 hours:	**BM275**	**EM275-20%**	**EM275 -40%**	**EM275 -60%**	**BM350**	**EM350 -20%**	**EM350 -40%**	**EM350 -60%**
Mud density, ppg	12.0	12.0	12.0	12.0	13.5	13.5	13.5	13.5
Rheological properties at, °F	120	120	120	120	120	120	120	120
600 rpm	86	56	50	50	141	132	133	109
300 rpm	49	31	30	29	84	75	79	65
200 rpm	36	22	22	20	61	55	59	49
100 rpm	23	14	14	12	38	32	37	31
6 rpm	7	9	5	5	15	7	10	11
3 rpm	6	6	4	4	10	4	8	9
PV, cP	37	25	20	21	57	57	54	44
YP, lb/100 ft^2	12	6	8	8	27	18	25	21
10 sec gel strength, lb/100 ft^2	7	13	13	8	12	22	21	12
10 min gel strength, lb/100 ft^2	8	22	18	11	20	39	47	43
ES, volt @ 120°F	723	592	629	615	921	880	636	778
OWR	75:25	75:25	75:25	75:25	80:20	80:20	80:20	80:20

HTHP (500 psi, 275°F), ml	6.0	5.0	3.5	3.8	5.6	4.4	4	4.4
Filter cake thickness, x/32-in	4	2	2	2	4	2	2	2

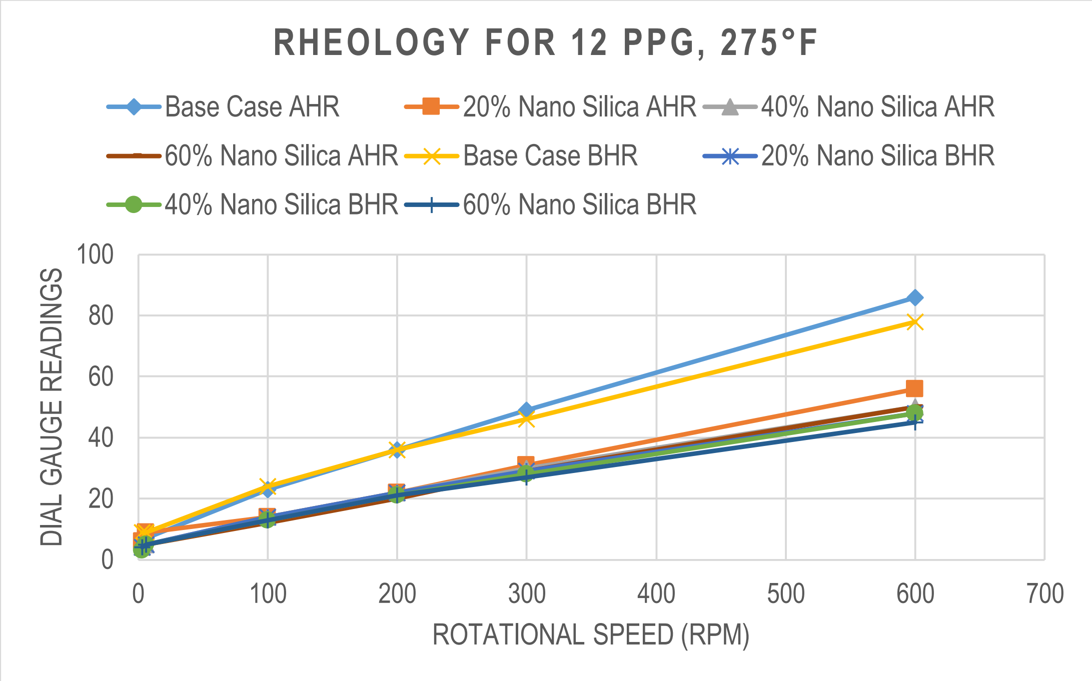


Figure 6: Dial readings vs. RPM for 12 ppg, 275°F mud system

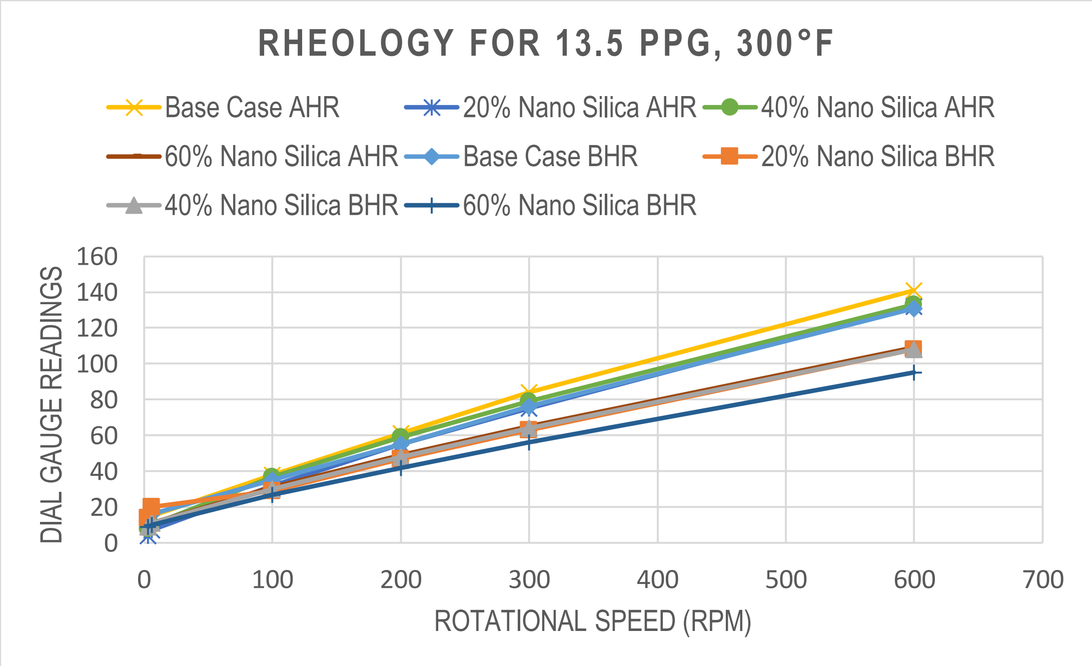


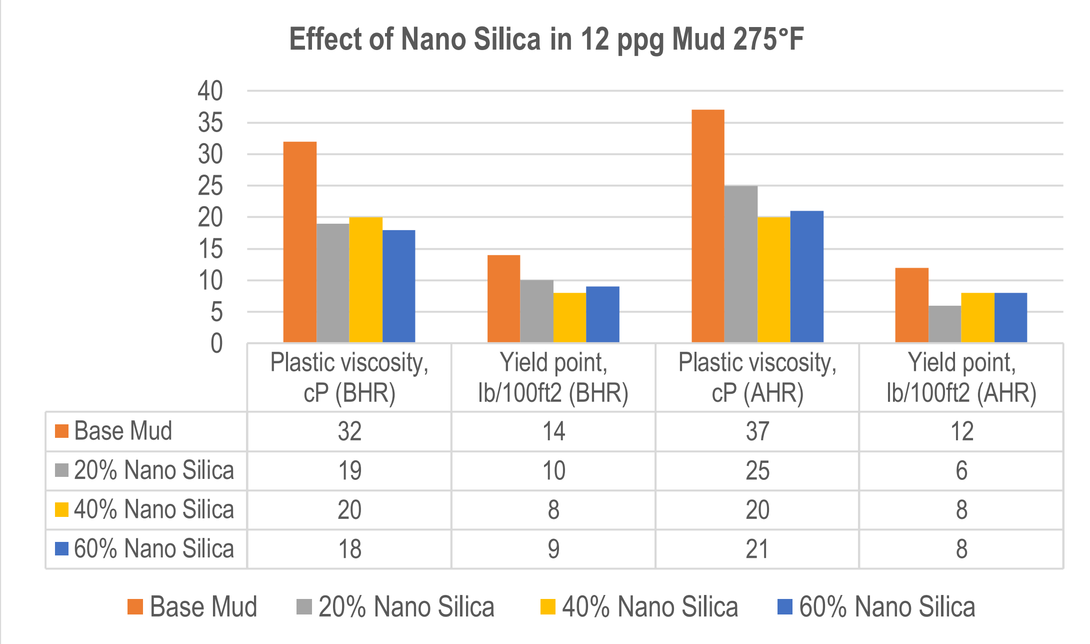
Figure 7: Dial readings vs. RPM for 13.5 ppg, 350°F mud system

Figure 6 and ***Figure 7*** represent the shear stress versus shear rate of the both mud systems. This rheological profile were discussed in the next sections for comparison studies on PV, YP, gel strength, and HTHP filtration.

4.2 RHEOLOGY PERFORMANCE COMPARISONS

Rheology performance of the mud systems can be discussed in term of PV, YP and 10 seconds/minutes gel strength. The performance analysis will be done between BHR and AHR to study the respective properties.

4.2.1 PV and YP Comparisons



	Plastic viscosity, cP (BHR)	Yield point, lb/100ft2 (BHR)	Plastic viscosity, cP (AHR)	Yield point, lb/100ft2 (AHR)
Base Mud	32	14	37	12
20% Nano Silica	19	10	25	6
40% Nano Silica	20	8	20	8
60% Nano Silica	18	9	21	8

Figure 8: PV and YP comparisons for 12 ppg, 275°F mud

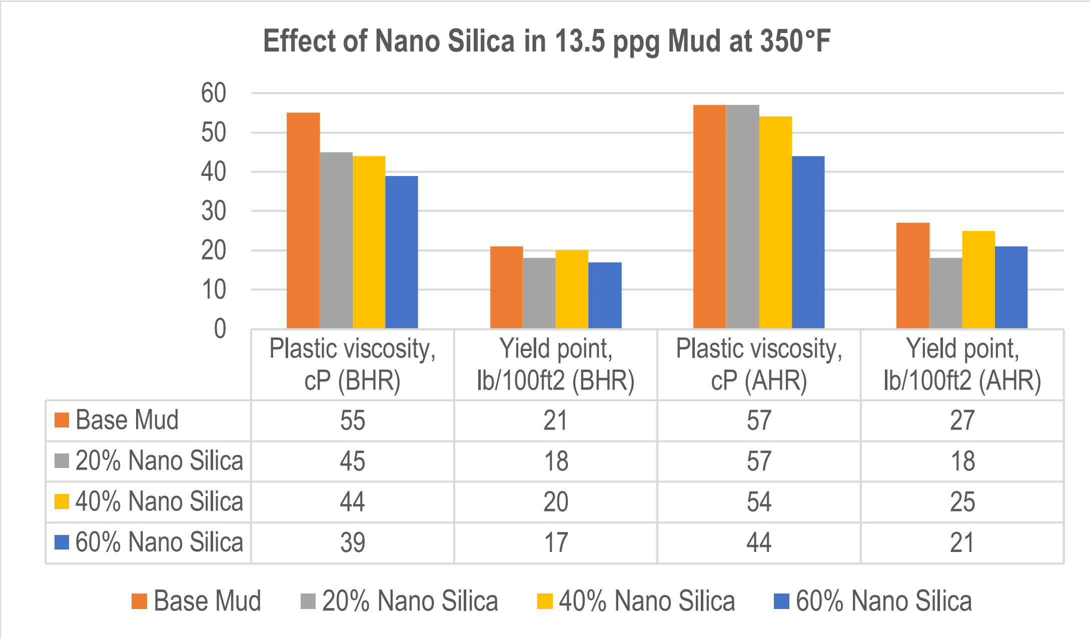


Figure 9: PV and YP comparison for 13.5 ppg, 350°F mud

Figure 6 and ***Figure 7*** show the PV and YP performance of both mud systems at BHR and AHR. The PV reflects as the resistances of the fluid to flow while YP is used to evaluate the mud ability to transport cutting in the annulus out to the surface.

PV and YP tend to increase after 16 hours of exposure to its desired temperature (275°F and 350°F) as to simulate the bottom hole condition. The increase in these parameters might be caused by the degradation of additives used when exposed to higher temperature, known as mud flocculation. However, the trend with the increase in nano silica concentration shows a decrease in PV and YP values when compared to base mud AHR. This can be well described as the nano silica is dispersed properly in the mud, thus making the mud less viscous when compared to the base mud. Another factors could be the effect of the reduction in amount of barite as nano silica concentration in the formulation increase, thus the mud is having lesser solid particles which reduce the interaction of clay mineral between it.

From the PV and YP results, balance intermolecular forces is obtained when the enhanced mud are showing lesser tendency to particles flocculation, thus giving a less viscous mud system which is good in term of hydraulics.

4.2.2 10 Seconds/Minutes Gel Strength Comparisons

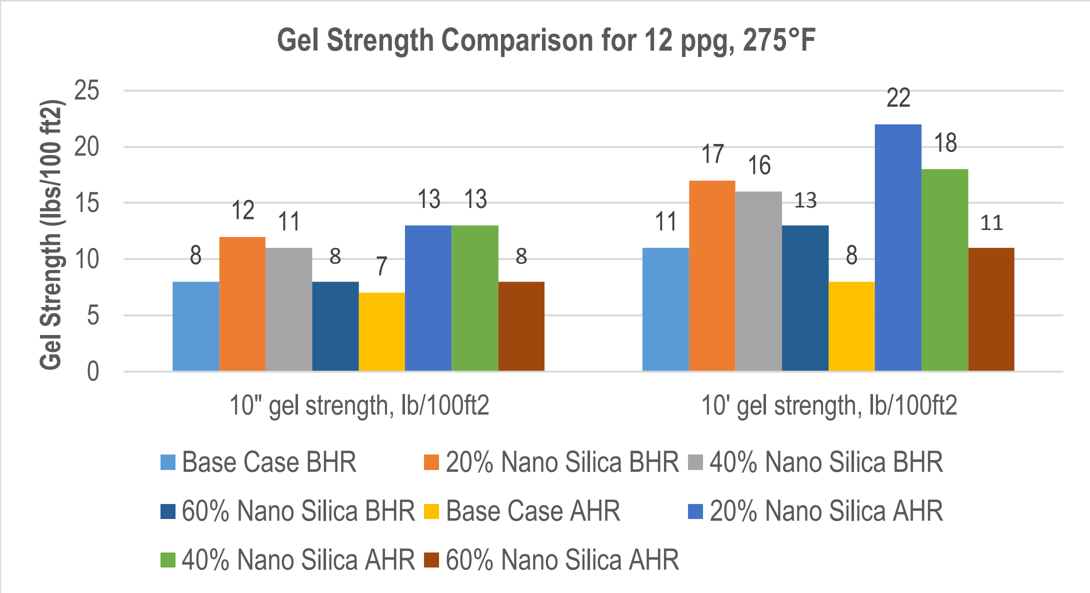


Figure 10: Gel strength comparison for 12 ppg, 275°F mud

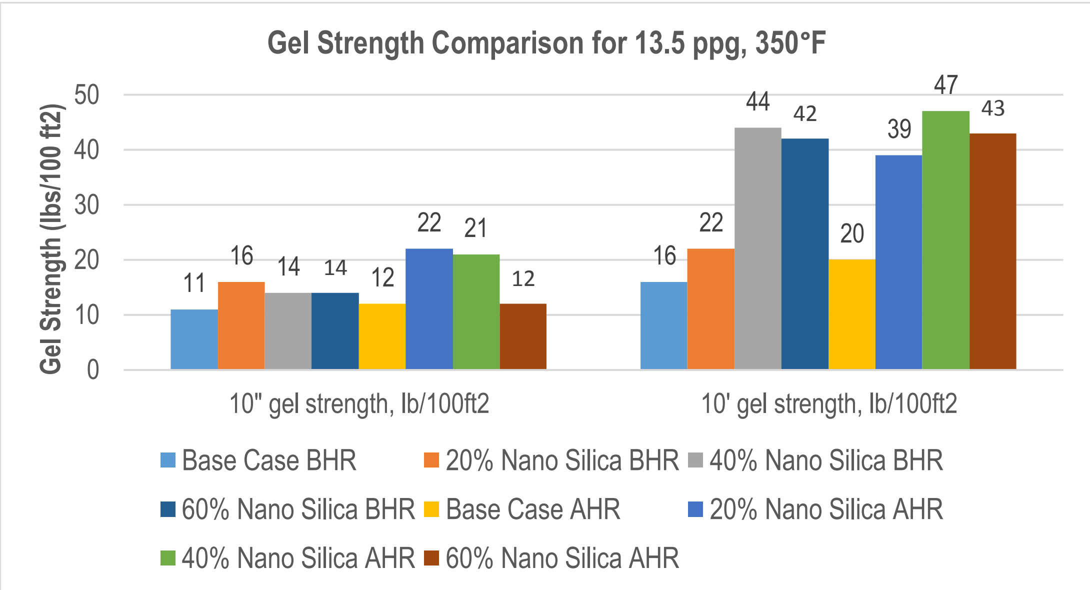


Figure 11: Gel strength comparison for 13.5 ppg, 350°F mud

Figure 8 and ***Figure 9*** show gel strength comparisons for both mud systems. It is the shear stress measured at low shear rate after the mud was left in static condition for certain period of time, normally measured at 10-second and 10-minute.

The enhanced mud for both systems showed comparatively higher gel strength values for 10-minute measurement when compared to the base mud. This is however a good indicator for better suspension of drill cuttings at static condition when drilling operation is halted, but too high of gel strength may require bigger force to break the gel.

Both YP and gel strength show the ability of the fluid to successfully remove drill cuttings to the surface and suspend it while drilling operation is halted. However, the major different in term of hydraulics is that once pipe is rotated and fluid is moving, the gelling will not be observed while the YP will not disappear when the fluid is moving.

Therefore, addition of nano silica helps improve the fluid PV, YP and gel strength for better drilling fluid performance.

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4.3 HTHP FLUID LOSS PERFORMANCE

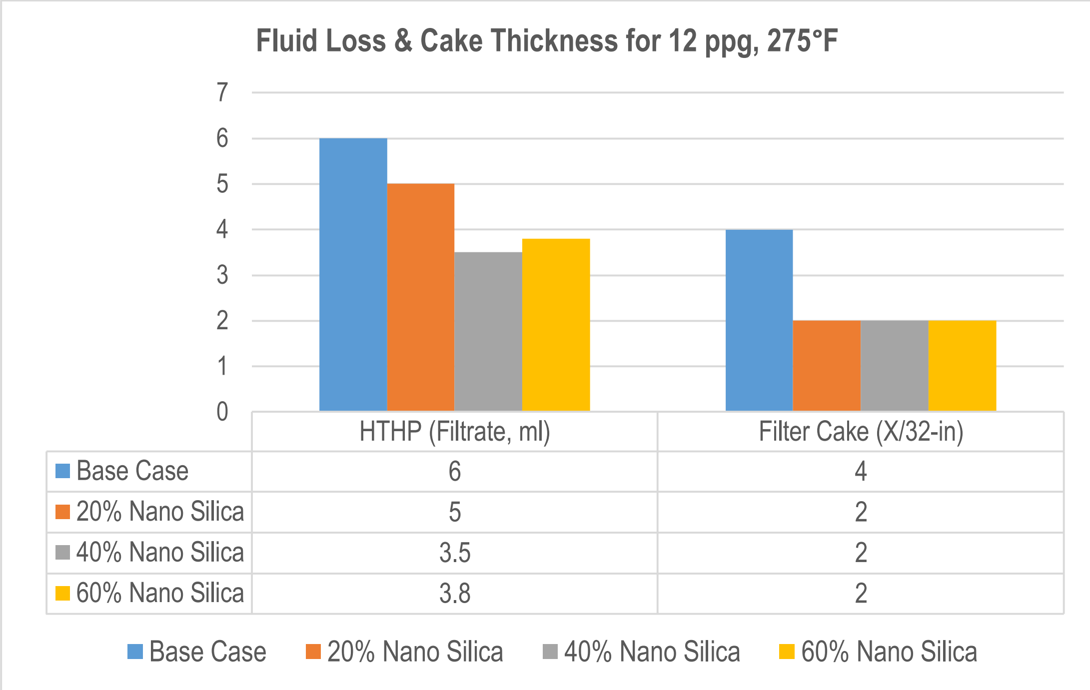

Figure 12: Fluid loss and mud cake thickness for 12 ppg, 275°F mud

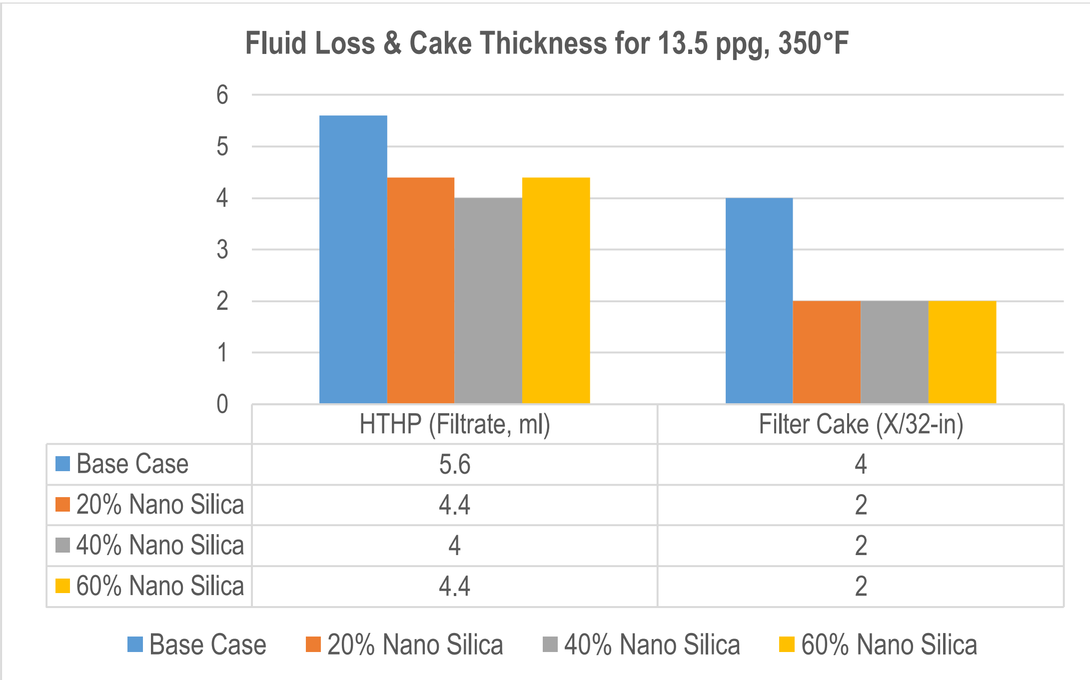

Figure 13: Fluid loss and mud cake thickness for 13.5 ppg, 350°F mud

Figure 10 and ***Figure 11*** show the result on the HTHP filtration for both mud systems. Nano silica is intended in this study to be used as a fluid loss control additive as to compare its performance to the commercially used fluid loss agent, which is gilsonite, an asphaltene based. Increasing nano silica concentration in the formulation helps reduce the amount of filtrate produced. However, an optimum range of combination should be studied for better formulation in order to have lower filtrate volume. It is seen that at 40% concentration of nano silica to gilsonite, the filtrate volume were decreased by 41.67% for 275°F mud system and by 28.57% for 350°F mud system, when compared to the based case.

The mud cake formed at the end of filtration test were thinner when compared to the base mud. Variation in concentration do not significantly affect mud cake formation in this study.

Lower filtrate will reduce problem of formation damage and thinner mud cake helps prevents tendency to pipe sticking which will later cause stuck pipe. Therefore, a 2 to 3 (2:3) ratio of nano silica to gilsonite could be the optimum range of combination for lower filtrate volume. It can be concluded that nano silica is good additive for reducing fluid loss problem, particularly at high temperature system.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

The SBM system with nano silica enhancement has proven to be good as fluid loss control. The comparison studies between the Base Case and enhanced mud up to 40% of nano silica show good reduction in filtrate volume and as well as the mud cake thickness in which technically speaking reflects to good performance of drilling operations.

The new formulation also works best at high temperature condition although it was only tested up to 350°F. It gives stable rheology in term of PV, YP, gel strength and ES values. Lower YP can be observed and it indicates good performance for cuttings transport to the surface. Lower overall rheological values were obtained when compared to Base Case at both systems for BHR and AHR.

There are few recommendations could be suggested for future work, which are:

- The current size of nano silica used ranges from 10-20 nm. Therefore, for future work, it can be suggested that to test the performance using smaller size of nano silica, ranging between 5-15 nm and comparison could be made between each case.
- In order to confirm optimum combination of nano silica to fluid loss additive, which in this case is gilsonite, a smaller scope of range between 35% and 45% should be performed. However, the total addition of nano silica in the formulation should not exceed more than 3% by weight of total mud system, should economic reasons are to be considered.
- The current test on HTHP formulations were performed before and after aging, to study its chemical stability particularly after aging and HTHP filtration, while the rheology test were not performed at in-situ condition. In order to test the ability of the mud at in-situ, the rheology test of the mud

is recommended to be tested using HTHP Viscometer. This could justify the performance of enhanced mud under variation of temperature and pressure.

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APPENDICES

List of equipment for the laboratory work. **Pictures taken from Scomi Oiltools laboratory*

Digital Balance

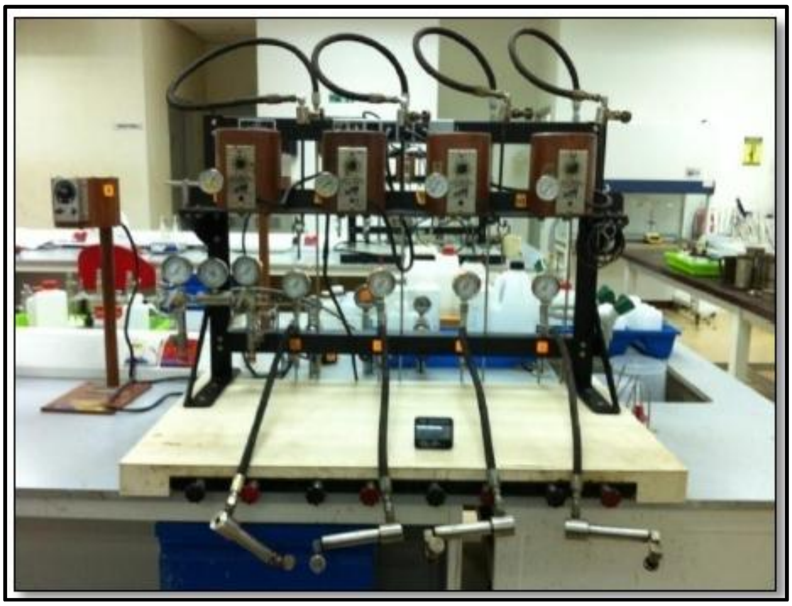
Hamilton mixer

Fann 35

ES meter

Aging cells


Roller Over


HTHP Filter Press

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