UNIVERSITI TEKNOLOGI PETRONAS

FYP FINAL REPORT

OPTIMISING DRILLING FLUID TO MAINTAIN MUDSTONE FORMATION STABILITY

Course: FYP II

Supervisor: Dr Sonny Irawan

Name: Calvin Lowrans, 11905

Programme: Petroleum Engineering

Date: December 5, 2012

CERTIFICATION OF APPROVAL

OPTIMISING DRILLING FLUID TO MAINTAIN MUDSTONE FORMATION STABILITY

By

CALVIN LOWRANS

A project dissertation submitted to

the Petroleum Engineering Programme

University Teknologi PETRONAS

in partial fulfilment of the requirement for the

BACHELOR OF ENGINEERING (Hons)

(PETROLEUM ENGINEERING)

Approved by,

____

Dr Sonny Irawan

UNIVERSITY TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2012

CERTIFICATION OF ORIGINALITY

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

____

(CALVIN LOWRANS)

ABSTRACT

This project is aimed to study the effects of drilling fluids on mudstone strength. The project presents the instability mechanism and stability methodology of mudstone formation. Wellbore stability has been a detrimental and serious issue in drilling. Its costly effects has led to many research and technology development to curb and manage instability in the borehole efficiently Most of the drilling problems occur in mudstone and clay type formation. Main factors identified are related to the mechanical and chemical factors. Clay content in the mudstone causes instability generally by hydration, swelling and hydration in the presence of water phase. Counter measures that were taken against the highlight clay proble

m were to include characteristics such as sealing and inhibition in the drilling fluid design. Fundamental concepts, processes, models and novel test are adopted in this project to formulate the findings of the effects of using water based drilling fluid on the mudstone mechanical properties and how to increase its performance. Over 4 drilling fluids were examined for their effects on mudstone formation strength

TABLE OF CONTENT

LIST OF FIGURE

CHAPTER 1

INTRODUCTION

1. BACKGROUND OF STUDY

This thesis is an important study in the drilling fluids industry because current and previous practice has not been able address the mudstone instability problem in a holistic manner. Instead of solving a problem by treating its root cause which is the mudstone formation failure mechanism, current and previous practices dealing with mudstone instability only attends to mudstone instability symptoms which is a short term solution.

Thus the reason of this project is to manage mudstone instability by using the principles of rock mechanics in the drilling fluid design. This study would revolve around the key parameters which are as below.

Key Project Parameters:

1. Mudstone and Mudstone Instability
2. Rock Mechanics
3. Drilling Fluid

Parameter 1: Mudstone and Mudstone Instability

Mudstone is a fine-grained, clastic sedimentary rock composed of mud that is a mix of flakes of clay minerals and tiny fragments (silt-sized particles) of other minerals, especially quartz and calcite. The ratio of clay to other minerals is variable. Mudstone is characterized by breaks along thin laminae or parallel layering or bedding less than one centimeter in thickness, called fissility.

Mudstone instability has been a recognized problem in the petroleum industry especially in development drilling for exploration phase and its costly effects has led to many research and technology development to curb and manage mudstone instability in the borehole efficiently. Mudstone constitutes 75% of major drilled formations and 70% of the borehole problem are related to mudstone instability. Briefly, mudstone instability is caused by many factors and largely contributed by the nature of mudstone itself which is chemically active and reacts with incompatible drilling fluids.

Mudstone instability Symptoms:

- Pressure Loss
- Mud Strength Reduction
- Loss Circulation
- Sloughs and Caving In

Short term techniques adopted in current and previous practice of drilling fluid design in managing mudstone instability:

- Defaulting to the Use of Oil Based Mud
- Increasing Mud Weight
- Ignores Mudstone Stress and Tensile regime

Parameter 2: Rock Mechanics

The key element that rock mechanics principles has to contribute to this thesis of drilling fluid design is that, rock mechanics enables the prediction of mudstone formation behavior under applied stress and tensile regime through the pumped drilling fluid.

Rock Mechanics principles which are included in this project deals main with two rock principles which are:

- Stress
- Tensile
- Shear

Parameter 3: Drilling Fluids

Drilling fluids is the key conduit to drilling in mudstone formation, physically only drilling fluid is means or medium of introducing corrective changes for better mudstone stability management.

The key element that drilling fluid has to contribute to this thesis of managing mudstone instability is that combining the appropriate drilling fluid properties to produce and optimized mud for a particular mudstone which suitable and maintains proper mudstone wellbore stability. The drilling properties focused in this project are as follows:

- Mud Weight
- Mud Type
- Mud Chemistry Composition

Thus in this thesis the Drilling Fluids (Parameter 3) and Rock Mechanics (Parameter 2) are integrated to provide better solution for mudstone instability management

2. PROBLEM STATEMENT

To simplify the problems that precede mudstone instability and drilling fluids design 2 major problem statement is put forth:

1. The absence of an optimized drilling fluid design for the water based mud drilling fluid to manage mudstone instability.
2. The inability to manage mudstone instability using current water based mud drilling mud

Mudstone formation failure coupled with an incompatible drilling fluid is the most prevalent root cause of mudstone instability leading to an increase drilling cost by many individual preceding wellbore problems. A common and effective solution to mudstone instability would be an optimized drilling fluid design and selection, however in order to select an optimized drilling fluid design the complex drilling fluid-mudstone interaction need to be well understood and developed in an integrated manner which involves an holistic approach in the area of rock mechanics and drilling fluid design.

Although there many published model studies, laboratory techniques and study the key drilling fluid-mudstone interaction has been understood comprehensively. The lab testing techniques and model developed are capable and intended to characterize or evaluate a single attribute to key drilling fluid-mudstone interaction thus being a qualitative rather than quantitative solution.

Thus a pragmatic utilization of clay inhibition and sealing agent additives is required to design an optimal water based drilling fluid which will be achieved in this project through experimental test which will discussed in detailed in the methodology section.

3. OBJECTIVES AND SCOPES OF PROJECT

OBJECTIVES

The purpose of this study is to investigate the use of rock mechanic principles in drilling fluids design criteria to manage mudstone instability. The specific objectives of this work are as follows:

- To determine appropriate water based mud drilling fluid for the particular mudstone to manage mudstone instability
- To determine the optimum water based mud drilling fluid that maintains mudstone formation strength.

In order to address the complexity of drilling fluid-mudstone interaction for efficient mudstone instability management two levels of property interaction models are required.

The design criteria for optimal drilling fluid which can be used for quick and reliable parametric assessment of the drilling fluid design is required and needs to incorporate all mudstone and drilling fluid properties which are critical to key drilling fluid-mudstone interaction mechanism.

SCOPE OF STUDY

The scope of study in the project extends to the study of mudstone rock mechanics and also drilling fluids properties which laboratory test will verify findings on the relationship correlations that could show proper interactions between drilling fluid and mudstone this will in turn pave way for the criteria that drives decision on choosing the right drilling fluid for the right mudstone. Below show the list of model study and laboratory test that is within the scope of study of this project:

1. Core Sampling and Preparation
2. Water based Mud Mixing
3. Point load Test

4. SIGNIFICANT AND RELEVANCY OF THE PROJECT

The project is significant as upon completion of this project, it could become the optimised solution and option for current and existing drilling fluids design selection criteria by having a complex model which addresses the key drilling fluid-mudstone interaction mechanism. Through the 3 main drilling fluid-mudstone interaction mechanism which includes mud pressure penetration, chemical potential and swelling-hydrational stress as discussed earlier we are able to select an optimal drilling fluid to effectively manage mudstone instability.

This project is relevant to the author as the author is an Petroleum Engineering student which already completed most of major and core courses in Electrical and Electronics Engineering. Besides that, the knowledge regarding Drilling fluids and Rock mechnanics during drilling operation is one of core courses offered and this help the author to have more understanding in theory.

This project also could widen up the view of people regarding this technology and in the same time introducing a more integrated approach in manage mudstone instability efficiently

5. FEASIBILITY OF THE PROJECT WITHIN THE SCOPE AND TIME FRAME

Author had been given full two semesters of studies to complete the final year project which divided into Final Year Project I and Final Year Project II. The time given is almost 8 months and sufficient for the author to complete the project. During Final Year Project I, the author will spend more time for research and do background studies for materials which are related to the project and during Final Year Project II, the author will implement all the theories and knowledge he obtain from his research and completing the drilling fluid design charts and correlated mudstone property database.

CHAPTER 2

LITERATURE REVIEW AND THEORY

1. MUDSTONE AND MUDSTONE INSTABILITY

Mudstone is a fine-grained, clastic sedimentary rock composed of mud that is a mix of flakes of clay minerals and tiny fragments (silt-sized particles) of other minerals, especially quartz and calcite. The ratio of clay to other minerals is variable. Mudstone is characterized by breaks along thin laminae or parallel layering or bedding less than one centimeter in thickness, called fissility.

Key Mudstone Properties that contribute to mudstone instability:

- Low permeability
- Slightly porous
- Water Saturated
- Mixture of mud and clay particles

Figure 1: Mudstone (Drannablog, Sedimentary Process)

Mudstone instability has been a recognized problem in the petroleum industry especially in development drilling for exploration phase and its costly effects has led to many research and technology development to curb and manage mudstone instability in the borehole efficiently. Mudstone constitutes 75% of major drilled formations and 70% of the borehole problem are related to mudstone instability. Briefly, mudstone instability is caused by many factors and largely contributed by the nature of mudstone itself which is chemically active and reacts with incompatible drilling fluids.

Among the common problems caused by the incompatibilities of drilling fluid-mudstone interactions are as follows:

- Washouts
- Poor Penetration rates
- Increased solids handling cost
- Borehole encroachment
- Hole collapse
- Tight hole
- Stuck pipe
- Lost circulation and;
- Well control

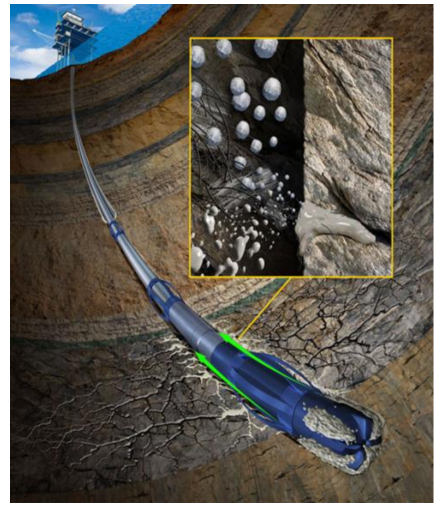


Figure2: Mudstone Instability (Oilonline.com)

Thus problems faced above eventually increases drilling cost leading to an uneconomic exploration and production.

Therefore the mudstone instability nature requires a timely-dependent mud support change which concerns the mud penetration pressure evidently the mud strength during drilling. However this single acting mud strength alteration sol

ution is not comprehensive to solve the mudstone instability and poses as a short term solution in the drilling fluid design.

On the other hand, an effective option for solving and managing mudstone instability would be concerning the drilling fluid design by focusing unto the instability mechanisms due to the interaction between drilling fluid and mudstones and the means to apply the solution based on proven rock mechanics principles and optimal drilling fluid design criteria as opposed to the current drilling practice.

2. DRILLING FLUIDS

Drilling fluid was used in the mid-1800s in cable tool (percussion) drilling to suspend the cuttings until they were bailed from the drilled hole. With the advent rotary drilling in the water-well drilling industry, drilling fluid was well understood to cool the drill bit and to suspend drilled cuttings for removal from the well-bore. Clays were being added to the drilling fluid by the 1890s. At the time that Spindletop, near Beaumont, Texas, was discovered in 1901, suspended solids (clay) in the drilling fluid were considered necessary to support the walls of bore-bole. With the advent of rotary drilling at Spindletop, cuttings needed to be brought to the surface by circulating the fluid. Water was insufficient so mud from mud puddles, spiked with some hay, was circulated downhole to bring rock cuttings to the surface. Most of the solids in the circulating system (predominantly clays) resulted from the so-called disaggregation of formations penetrated by the drill bit. The term disaggregation was used to describe what happened to the drilled clays. Clays would cause the circulating fluid to thicken, thus increasing the fluid of viscosity. Some of the formation drilled would not disperse but remain as rock particles of various sizes commonly called cuttings. Drilling fluid was recirculated and water was added to maintain the best fluid density and viscosity for the specific drilling conditions. Cuttings that are not dispersed by water, required removal from the drilling fluid in order to continue the drilling operation. At the sole discretion of the driller or tool pusher, a system of pits and ditches were dug on site to separate the cuttings from the drilling fluid by gravity settling. This system included a ditch from well, or possibly a bell nipple, settling pits and a suction pit from which the clean drilling fluid was picked up by the mud pump and recirculated.

Drilling Fluids Capability

Drilling fluid must satisfy many needs in their capacity to do the following:

i. suspend cuttings (drilled solids), remove them from the bottom of the hole and the well-bore, and release them at the surface
ii. control formation pressure and maintain well-bore stability

iii. seal permeable formations
iv. cool, lubricate, and support the drilling assembly
v. transmit hydraulic energy to tools and bit
vi. minimize reservoir damage
vii. permit adequate formation evaluation
viii. control corrosion
ix. facilitate cementing and completion
x. minimize impact on the environment
xi. inhibit gas hydrate formation

Types of Drilling Fluid

Drilling fluids are classified according to the type of base fluid and other primary ingredients:

i. gaseous: Air, nitrogen
ii. aqueous: gasified – foam, energized (including aphrons)
clay, polymer, emulsion
iii. nonaqueous: oil or synthetic – all oil, invert emulsion

True foams contain at least 70% gas (usually N_2, CO_2, or air) at the surface of the hole, while energized fluids, including aphrons, contain lesser amount of gas. Aphrons are specially stabilized bubbles that function as a bridging or lost circulation material (LCM) to reduce mud losses to permeable and microfractured formations. Aqueous drilling fluids are generally dubbed water-based muds (WBMs), while non aqueous drilling fluids (NAFs) are often referred to as oil-based muds (OBMs) or synthetic-based muds (SBMs). OBMs are based on NAFs that are distilled from crude oil; they include diesel mineral oils, and refined linear paraffins (LPs). SBMs, which are also known as pseudo-oil-based muds, are based on chemical reaction products of common feedstock materials like ethylene; they include olefins, esters, and synthetic LPs. Above the concentration of a few weight percent, dispersed drilled solids can generate excessive low-shear-rate and high-shear-rate viscosities, greatly reduce drilling rates, and excessively thick filter cakes. As the drilling mud density increases (increasing concentration of weighting material), the high-shear-rate viscosity rises continuously even as the concentration of drilled solids with low-gravity is reduced.

3. ROCK MECHANICS

The key element that rock mechanics principles has to contribute to this thesis of drilling fluid design is that, rock mechanics enables the prediction of mudstone formation behavior under applied stress and tensile regime through the pumped drilling fluid (Figure 4).

Rock Mechanics principles which are included in this project deals main with 3 rock principles which are:

- Stress
- Tensile
- Shear

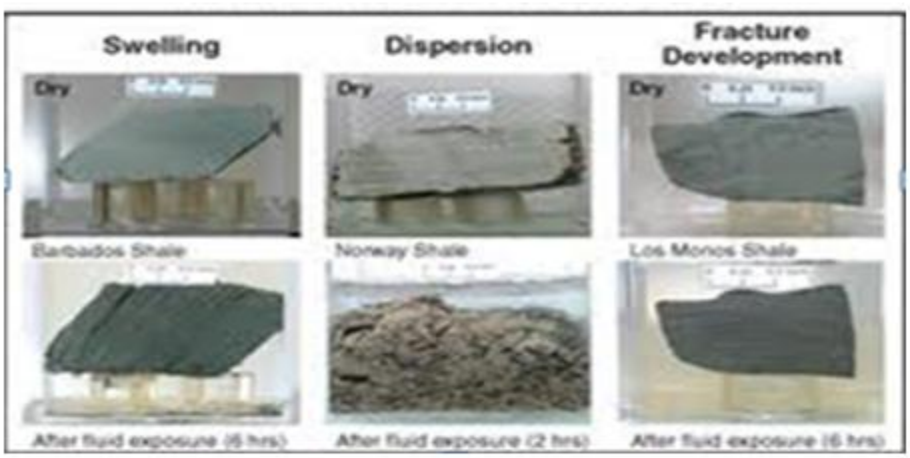


Figure 3: Mudstone Behaviour Under Stress and Tensile (*SPE 14347*)

Compressive Stress consists of two opposing forces acting on a rock which decreases the volume of the rock per unit area. Compressive strength is the maximum force that can be applied to a rock sample without breaking it. Units of stress are either reported in pounds per square inch (psi in English units) or Newtons per square meter (N/m^2in metric units). 1.0 Newton is equal to 1.0 $Kg\text{-}m/s^2$ and is derived by multiplying the mass by the gravity force, $9.81m/s^2$.

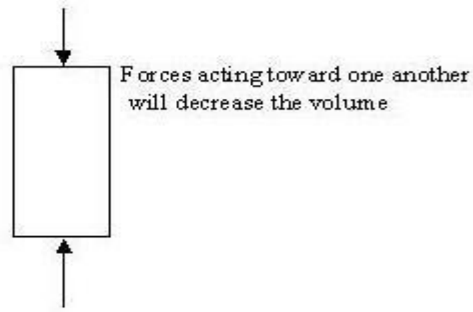


Figure 4: Compressive Stress (*sdsmt.edu,Basic Rock Mechanics)*

Tensile Strength occurs when rocks placed in tension will show a decrease in the total volume of the rock per unit area due to forces directed outward, opposite in action. Tensile strength for a rock is usually much lower than its compressive strength, i.e., rocks are most likely to fail under tension well before they would fail under compression. Thus, it is very important to know the stress regime a rock will be subjected to when used in an engineering project. Most rock materials are never placed in a situation where tension is the primary force.

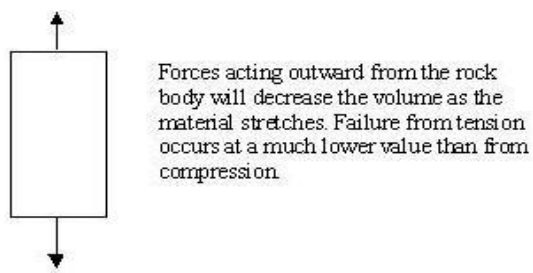


Figure 5: Tensile Strength (*sdsmt.edu,Basic Rock Mechanics)*

Shear Strength during shearing action is caused by two forces acting in opposite directions along a plane of weakness (fracture, fault, bedding plane, etc.) that is inclined at some angle to the forces. The result is a force couple which effectively tears the material. Rifting in tectonic environment is nothing more than a large shearing of the solid crust of the Earth where the actual rift itself is usually inclined at about 30^o to the tension forces. In the case of rifting, tension is generally supplied by the upwelling of mantle material below the crust.

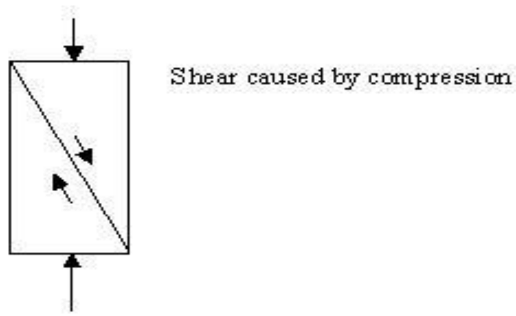


Figure 6: Shear Strength (*sdsmt.edu,Basic Rock Mechanics)*

Shear Rate in a simple flow, is the change in fluid velocity divided by the width of the

Channel through which the fluid is moving.

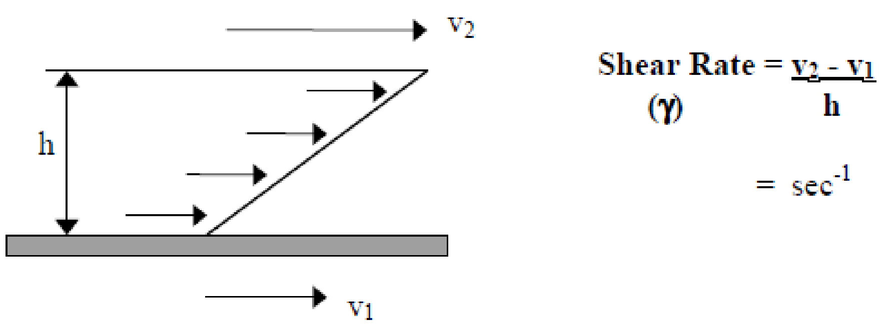
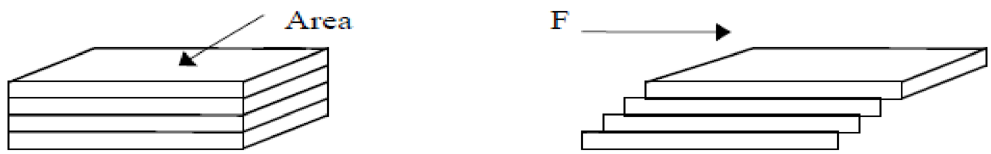


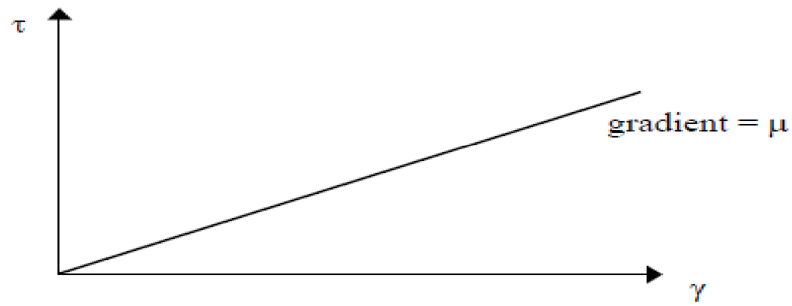
Figure 7: Shear Rate (*sdsmt.edu,Basic Rock Mechanics)*

Shear Stress is the force per unit area required to move a fluid at a given shear rate.



$$\text{Shear Stress } (\tau) = F/A \quad = \frac{\text{lb. ft}}{\text{in}^2} \quad \text{or} \quad \frac{\text{lb. ft}}{100\text{ft}^2} \quad \text{or} \quad \frac{\text{dynes}}{\text{cm}^2}$$

Figure 8: Shear *Stress* (*sdsmt.edu,Basic Rock Mechanics)*



I.e. A linear relationship exists between Shear Stress (t) and Shear Rate (g).

Figure 9: Shear Strees & Shear Rate (*sdsmt.edu,Basic Rock Mechanics)*

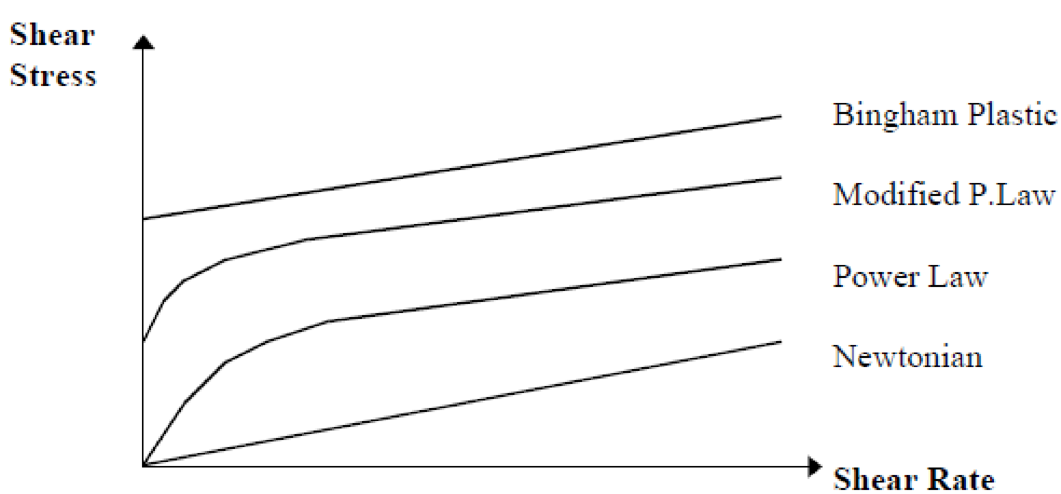


Figure 10: Fluid Models Shear Strees & Shear Rate (*sdsmt.edu,Basic Rock Mechanics)*

CHAPTER 3:

METHODOLOGY

Wellbore stability methodology adopted here is via direct testing method. Trial and Error testing of the drilling muds effect on the mudstone strength and strength as the key measure of stability.The experiment flow is as shown in Figure 1.After the particular drilling mud has been mixed, the core sample is inserted together with the mud in the aging cell. The pressure in the aging cell is confined to 100 psi, which is a standard pressure confinement to prevent the mud from boiling. The aging cell is left in the rolling oven for 24 hours under a temperature of 250 Degrees Fahrenheit to simulate borehole conditions.

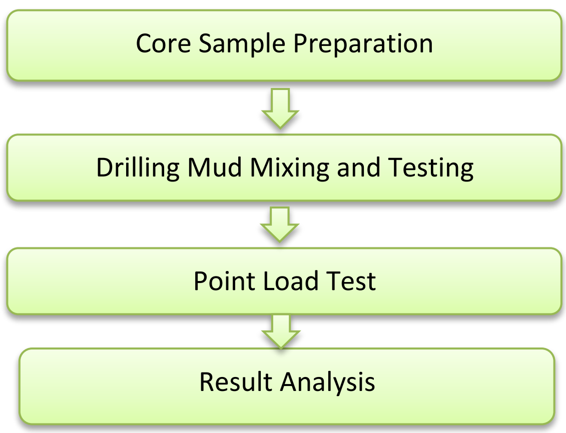


Figure 11: Methodology and Experiment Flow

1. Core Preparation Method

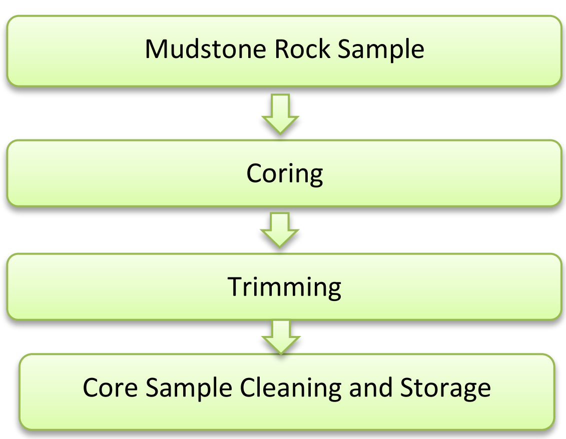


Figure 12: Core Preparation Workflow

Figure 1: Mudstone Rock Sample

Figure 1: Coring

Figure 1 : Core sample cleaning and storage

Figure 1 : Core sample Trimming

(UTP Rock Cutting Lab)

Figure XX show the core sample preparation flow and figure xx to xx show the process taken place and equipment used. The mudstone rock sample for cored to obtain 10 core sample and 5 core sample are selected based on quality control. Core sample which are cracked and fractured are omitted. As 4 core samples are required for the experiment one sample is used for replacement purposes.

Mudstone SEM scan

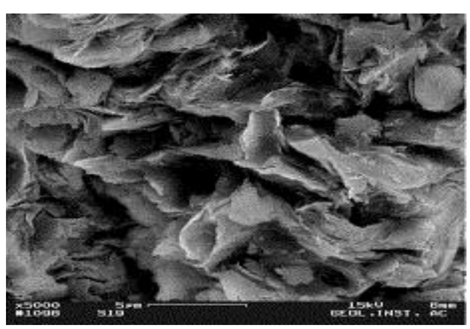


Figure 13: Mudstone SEM Scan

Quartz	K Feldspar	Plagiocase	Calcite	Ferroan Dolomite	Clay content
17.01	6.56	21.21	13.38	4.77	37.07

2. Drilling Mud Composition and Mixing

There were 4 different finalised water based drilling fluid formulated for testing. The first drilling fluid formulated was with the absence of additives ingredients include barite, bentonite, water, viscofier, filtration agent and caustic soda (Water Mud). The second mud has the same composition with an added 10% KCl solution into the mud(W.Mud + 10% KCl). The KCl solution here is intended to provide an inhibition characteristic. The third mud has the same composition with the second mud but with added clay control additives at 3% in volume and denoted as X. (W.Mud + 10% KCl + 3 % X). The final mud composition is the same as the 3rd mud but with an added sealing agent additives at 3 % in volume and denoted as Y (W.Mud + 10% KCl + 3 % X + 3% Y).

Mud Sample	Mud Composition
1	Water Mud + KCI (10%)
2	Water Mud
3	Water Based Mud + KCI (10%) + X (3%)
4	Water Based Mud + KCI (10%) + X (3%) + Y (3%)

Table 1: Mud Sample Summary List and Composition

2.1 Mud Formulation and Compostion

Formulation 1

Mud Weight, lb/gal **10.00 lb/gal** **Salinity, % Salt**

 # Lab bbls **1.0000**

Input Mixing Order	**Product**	**Product Concentration** bbl/bbl	**Product Concentration** lb/bbl	**Product to Build 1.000 bbls** Total bbl	**Product to Build 1.000 bbls** Total
1	**Water**	0.9281	325.31	0.928	325.31
2	**FLOWZAN**	0.0006	0.30	0.0006	0.30
3	**CAUSTIC SODA**	0.0033	2.50	0.0033	2.50
4	**MIL-BEN**	0.0137	12.00	0.0137	12.00
5	**MIL-BAR**	0.0543	79.89	0.0543	79.89
6	**Totals**	**1.0000**	**420.00**	**1.0000**	**420.00**

Formulation 2

Mud Weight, lb/gal 10.00 lb/gal **Salinity, % Salt**

 # Lab bbls 1.0000

Input Mixing Order		Product Concentration		Product to Build 1.000 bbls	
	Product	bbl/bbl	lb/bbl	Total bbl	Total
1	Water	0.9054	317.35	0.905	317.35
2	KCl	0.0413	35.26	0.041	35.26
3	FLOWZAN	0.0006	0.30	0.0006	0.30
4	CAUSTIC SODA	0.0033	2.50	0.0033	2.50
5	MIL-BEN	0.0137	12.00	0.0137	12.00
6	MIL-BAR	0.0357	52.59	0.0357	52.59
7	Totals	1.0000	420.00	1.0000	420.00

Formulation 3

Mud Weight, lb/gal 10.00 lb/gal **Salinity, % Salt**

 # Lab bbls 1.0000

Input Mixing Order		Product Concentration		Product to Build 1.000 bbls	
	Product	bbl/bbl	lb/bbl	Total bbl	Total
1	Water	0.8748	306.62	0.875	306.62
2	KCl	0.0399	34.07	0.040	34.07
3	FLOWZAN	0.0006	0.30	0.0006	0.30
4	CAUSTIC SODA	0.0033	2.50	0.0033	2.50
5	MIL-BEN	0.0137	12.00	0.0137	12.00
6	MAX-GUARD	0.0315	11.15	0.031	11.15
7	MIL-BAR	0.0363	53.37	0.0363	53.37
8	Totals	1.0000	420.00	1.0000	420.00

Formulation 4

Mud Weight, lb/gal **10.00 lb/gal** **Salinity, % Salt**

 # Lab bbls **1.0000**

Input Mixing Order	Product	Product Concentration		Product to Build 1.000 bbls	
	Product	**bbl/bbl**	**lb/bbl**	**Total bbl**	**Total**
1	**Water**	0.8501	297.98	0.850	297.98
2	**KCl**	0.0387	33.11	0.039	33.11
3	**FLOWZAN**	0.0006	0.30	0.0006	0.30
4	**CAUSTIC SODA**	0.0033	2.50	0.0033	2.50
5	**MIL-BEN**	0.0137	12.00	0.0137	12.00
6	**MAX-GUARD**	0.0315	11.15	0.031	11.15
7	**SHALE-BOND**	0.0261	10.05	0.026	10.05
8	**MIL-BAR**	0.0359	52.91	0.0359	52.91
9	**Totals**	**1.0000**	**420.00**	**1.0000**	**420.00**

3. Point Load

The point load test was chosen as the method to measure the residing strength of the core samples after exposed to drilling fluid because of its applicability and suitability because of the limitation of the core sample size available. Point load test provides the measurement of strength in Mpa unit of pressure. It is a simple index test for rock material which gives standard point load index $I_{s(50)}$. $I_{s(50)}$ is calculated from the point load at failure and the size of the specimen with size correction to an equivalent core diameter of 50mm.

Figure 14: Point Load Machine

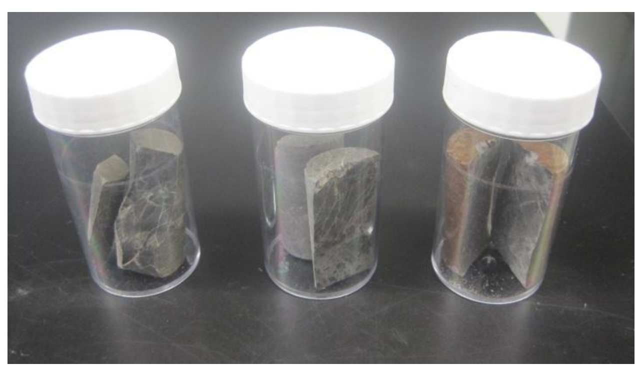


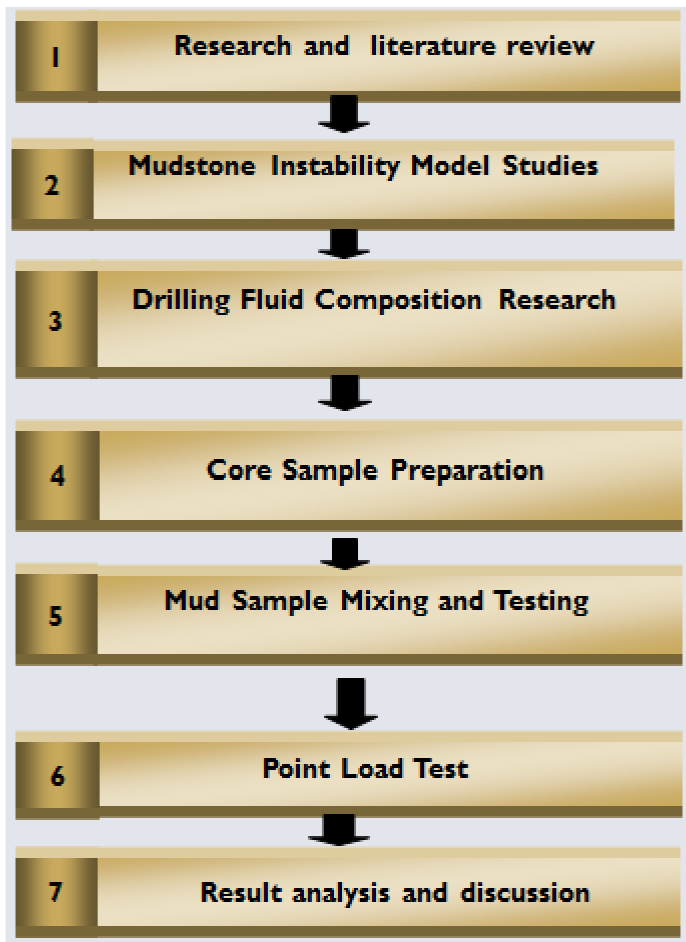
Figure 12: Crushed Core Sample After Point Load Test

The test was conducted diametrically where the rock core with diameter D was loaded between the point load apparatus across its diameter. Since the core diameter is not equivalent to 50 mm, the load calculation needs to be adjusted the equation used is showed below in equation 1 and 2:

$$I_s = P / D_e^{2}$$ .... Equation 1 *(ISRM, 1977)*

$$F = (D_e / 50)^{0.45}$$ .... Equation 2 *(ISRM, 1977)*

4. PROJECT ACTIVITIES AND WORK FLOW



5. EQUIPMENT AND TOOLS

All the necessary equipment and the information are available for the study and the project is expected to be finished within the time frame. The followings are essential for completion of this project.

Figure 16: Corex Coring Machine

Figure 13: Digital Weighed

Figure 14: Multi Mixer

Figure 5: Rolling Oven

Figure 20: HPTP press filter

Figure 21: Point Load Test Machine

CHAPTER 4

RESULTS AND DISCUSSION

The result and discussion presented includes the works and analysis that has been done according to the methodology adopted which includes the model study and technical parameter extraction for each mechanism. The point load test was the final stage of experimentation and the result obtain is summarized in graph 1 and table 1. The result can be divided into two categories, they are :

1. Drilling Fluid Composition
2. Mudstone Strength Test

4.1 Drilling Fluid Composition

There were four different finalised water based drilling fluid formulated for testing. The first drilling fluid formulated was with the absence of additives ingredients include barite, bentonite, water, viscofier, filtration agent and caustic soda (Water Mud). The second mud has the same composition with an added 10% KCl solution into the mud(W.Mud + 10% KCl). The KCl solution here is intended to provide an inhibition characteristic. The third mud has the same composition with the second mud but with added clay control additives at 3% in volume and denoted as X. (W.Mud + 10% KCl + 3 % X). The final mud composition is the same as the 3rd mud but with an added sealing agent additives at 3 % in volume and denoted as Y (W.Mud + 10% KCl + 3 % X + 3% Y).

Mud Sample	Mud Composition
1	Water Mud
2	Water Mud + KCl (10%)
3	Water Based Mud + KCl (10%) + X (3%)
4	Water Based Mud + KCl (10%) + X (3%) + Y (3%)

Table 2: Mud Sample Summary List and Composition

In this experiment, Mud samples is the base (Water Based Mud). Sample 1, 2, 3 and 4 are muds mixed with different or no additives. Every mud sample was prepared in order to measure the change in its properties. The additives used to form the formulation all have its specific function. Table 4.3 and 4.4 show the functions of additives in water based mud and mud formulations results, respectively.

Functions of additives in water based mud

Additive	Function
Water	Works as a solution medium to form water based mud
Xanthan-Gum	Increase viscosity of mud
Hydro-Pac LV	Acts as a filtration controller
Caustic Soda	Increase and maintain pH and alkalinity
Bentonite	To increase gel strength, density, yield point, viscosity and reduce fluid loss
Barite	To increase mud weight
X Agent	To provide clay inhibition characteristics
Y Agent	To provide sealing characteristics to bridge pore throats

Table 3: Functions of additives in water based mud

4.2 Mudstone Strength Test

Based on the experiment conducted, the strength measurement for all core sample is different and experience a strength reduction from the original condition.

SOLUTION	CORE	Pressure (MPA)
Original Condition	1	0.96
Water Mud	2	0.25
Water Mud + KCl (10%)	3	0.51
Water Based Mud + KCl (10%) + X (3%)	4	0.73
Water Based Mud + KCl (10%) + X (3%) + Y (3%)	5	0.82

Table 4: Mud Sample Composition and Core Strength Result

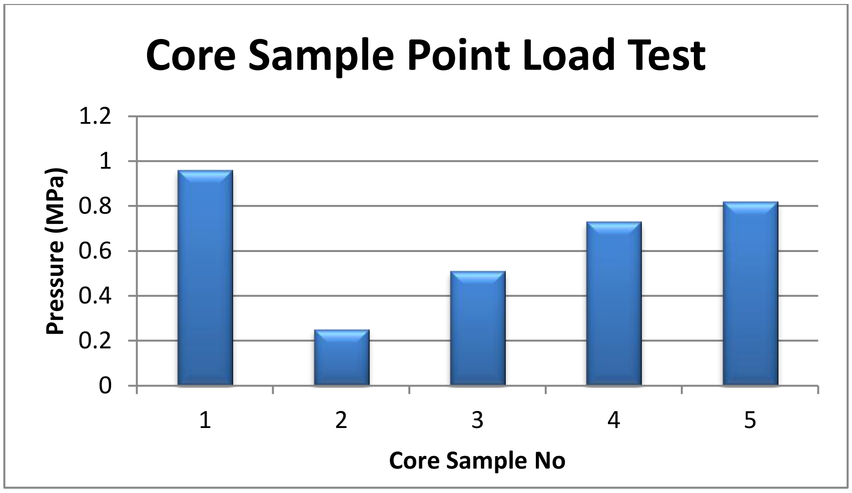


Figure 22: Core Sample Point Load Strength Result

Based on the point load experiment, the water based drilling fluid with 10% KCI, shows an increased strength in the mudstone core. Although the strength is reduced compared to the original strength which is expected due to the water content it is still a better performing mud than the water drilling fluid only

The reasoning why the water based drilling fluid with 10% KCI shows a better performance and is used is because potassium ions has clay inhibition characteristic whereby it provides attraction among clay platelets.

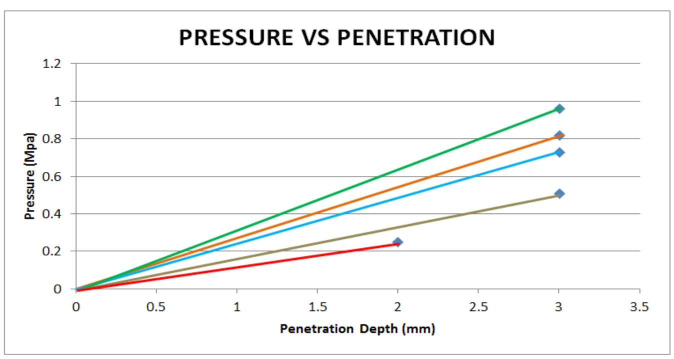


Figure 23: Pressure vs Penetration depth of Point Load Test

Original Condition	Original Condition
Mud 1	Water Mud + KCl (10%)
Mud 2	Water Mud
Mud 3	Water Based Mud + KCl (10%) + X (3%)
Mud 4	Water Based Mud + KCl (10%) + X (3%) + Y (3%)

Table 5: Summary of Mud Sample composition

Based on the point load experiment, the water based drilling fluid with 10% KCI, shows an increased strength in the mudstone core. Although the strength is reduced compared to the original strength which is expected due to the water content it is still a better performing mud than the water drilling fluid only

The reasoning why the water based drilling fluid with 10% KCI shows a better performance and is used is because potassium ions has clay inhibition characteristic whereby it provides attraction among clay platelets.

It is observed that the mudstone sample 3 shows a reduced strength over 70% from the original sample. This is due to the water content in mud and susceptible kaolinite in mudstone. Addition of X and Y additives have increased the performance of mud. This explains that sealing agent plays an important role in clay content formation stability

Sample	Strength Reduction (%)
1	0.0
2	74.0
3	46.9
4	24.0
5	14.6

Table 6: Strength reduction

CHAPTER 5

Conclusion and Recommendation

Even with the best drilling practices mudstone wellbore instability still occurs. Thus it is essential to optimize water based drilling fluid to minimize mudstone wellbore instability.The project is belief to be relevant to the study of drilling fluid design to manage mudstone instability in drilling engineering scope.

The performance of a drilling fluid can be optimized by monitoring and controlling the mud additives especially for high clay content formations. This can be done by modifying its components and additives. Overall, it is justified that clay inhibition additives, sealing agent additives and usage of salt solution is appropriate and has effectiveness in combating mudstone well bore instability problem,. However, further testing is still required before the product can be commercialized to the market. This is because the experiments conducted only covered the mud testing of intermediate sized core sample.

Extended experiments and evaluation are recommended, so that the project will be more considerable and reliable. Further work on analytical and experimentation study on this project is required. Special equipment to measure and experiment each drilling fluid-mudstone interaction is essential in obtaining accurate results. This project is preceded with a model study initially and later verified with result from experiments. Thus it vital to ensure the model used has been verified.

In order to obtain more accurate results, more tests should be conducted. These tests include the High Temperature High Pressure (HTHP) test, dynamic filtration test, formation damage system test, X-Ray fluorescence test, and solid-liquid content test. The chemical analysis of the fluid should also be tested. These include the calcium content, salt content, and others that affect the performance of the drilling fluid. All these tests should be able to prove the potential of modified water based drilling fluid in detail in maintaining mudstone formation strength.

CHAPTER 5

REFERENCES

1. Tan, C.P., Rahman, S.S., Richards, B.G., Mody, F.K., Integrated rock mechanics and drilling fluid design approach to manage shale instability. SPE 47259

2. Tan, C.P., Rahman, S.S., Richards, B.G., Managing physico-chemical wellbore instability in shale with the chemical potential mechanism. SPE 36971

3. Tan, C.P., Zeynaly-Andabily,M.E. and Rahman, S.S,: "A NoveI Method of Screening Drilling Muds Against Mud Pressure Penetration for Effective Borehole Wall Support," *Proc. IA DC/SPE Asia Pact~c Drilling Technology Conference,(1996),* Kuala Lumpur, MalaysiA 287-294.

4. Mody, F.K. and Hale, A.H.: "A Borehole Stability Model to Couple the Mechanics and Chemistry of Drilling Fluid Interaction, " *Proc. SPE/IADC Drilling Con$, (1993),* Amsterdam, The Netherlands, 473-490.

5. Xiangjun Liu, Pingya Luo, Hong Liu and Dachuan Liang : " Keeping Shale Formation Stability by Optimizing Drilling Fluids, in Yangta Oil Field,Western China ". *IPTC (2009), Doha, Qatar, SPE 13313-MS*

6. J. J. Azar and G. R. Samuel, "Chapter two – drilling fluids," in *Drilling Engineering* Tulsa, Okla.: PennWell Corp., 2007, pp. 37-82.

7. R. Caenn, H. C. H. Darley and G. R. Gray, "Chapter 3 - equipment and procedures for evaluating drilling fluid performance," in *Composition and Properties of Drilling and Completion Fluids (Sixth Edition)*Anonymous Boston: Gulf Professional Publishing, 2011, pp. 91-135.

8. S. Styles, K. Meads, M. Bonsack, A. Singh, and R. Schlemmer, "*KMC Oiltools Drilling Fluid Manual*," 2006

9. James P. Brill and Hemantha Mukherjee, (1999), "Non-Newtonian Fluids" and " Flow in an Annulus", Multiphase Flow in Wells (17): 9-11