Effect of Different Drilling Fluids on Reservoir Skin Factor

by

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CERTIFICATION OF APPROVAL

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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.

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ABSTRACT

Drilling operations and specially drilling fluids has big impact on formation damage leading to high skin values and low productivity due to permeability impairment. Even slight formation damage in a well can result in significant loss of revenue; hence it is from the essentials to reduce formation damage caused by drilling operation and specially drilling fluid.

Bentonite is the common material that used as base (gel) in Water Based Mud (WBM), hence this paper aims at reducing formation damage through investigating alternative drilling fluids by replacing Bentonite with milled Bentonite which has particle size less than 63µm in Water Based Mud. Different rheology and filtration tests under different conditions have been conducted to asses filter cake performance of each mud.

Results from the experiments shows that milled Bentonite mud performance in HPHT conditions is much better than its performance in LPLT conditions and is also better than the performance of normal Bentonite under both conditions.

In the LPLT conditions, milled Bentonite based mud results in 12% less filtration rate compared to normal Bentonite, this percentage raises dramatically up to 65% in the HPHT conditions. As milled Bentonite mud produces less filtrate volume, it is expected to result in higher filter cake quality and hence less skin factor compared to the normal Bentonite based mud.

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ABBREVIATIONS AND NOMENCLATURES

FDS	= Formation Damage System
GNPOC	= Greater Nile Petroleum Operating Company
OBD	= Oil Based Mud.
UTP	= Universiti Teknologi PETRONAS
WBM	= Water Based Mud.
HPHT	= High Pressure High Temperature.
LPLT	= Low Pressure Low Temperature.
ppg	= Pound Per Gallon.

CHAPTER 1:

INTRODUCTION

1.1 Project Background.

It is well recognized that during overbalanced drilling operations near-wellbore flow properties are altered by drilling-fluid invasion as most drilling fluids contain weighting solids (Ding et al, 2004). The pressure over balance required between the drilling fluid and reservoir pressure to keep the well under control will force the weighting solids to enter the formation and cause damage.

According to Engineering manual nearly all of the Corps of Engineers drilling and sampling is accomplished using one or more of four general types of drilling fluid: compressed air, foam, clear water, and water-based mud. Air and water generally satisfy the primary functions of a drilling fluid. However, additives must often be added to these fluids to overcome specific downhole problems. Air with additives is referred to as "foam." A freshwater- or saltwater-based drilling fluid with additives is commonly called "drilling mud." A fifth type of drilling fluid is the oil-in-water emulsion or oil-based mud. Water-based muds are the primary element of most geotechnical drilling and sampling operations. The most common additive to form a water-based mud is bentonite, although polymers have been developed and perform well for most drilling operations.

Bentonite is an absorbent aluminium phyllosilicate consisting mostly of montmorillonite and is considered the most commonly used drilling fluid additive. When mixed with water, the resulting slurry has a viscosity greater than water, possesses the ability to suspend relatively coarse and heavy particles, and tends to form a thin, very low permeability cake on the walls of the borehole. Because of these attributes, Bentonite drilling mud is superior to water as a drilling fluid for many applications.

Drilling muds have four basic properties that determine the behavior of the mud as a drilling fluid: viscosity, density, gel strength, and filtration. Several other properties, although of lesser importance, need to be checked, especially if problems are anticipated or encountered. These properties include sand content, pH (alkalinity or acidity), and calcium content.

Viscosity is defined as the resistance offered by a fluid to flow. The thicker a particular fluid is the higher its viscosity. Accurate measurement of the viscosity of drilling mud is dependent on a number of factors and requires special equipment. The basic factors which affect the viscosity of a mud are the viscosity of the base fluid (water); the size, shape, and number of suspended particles; and the forces existing between particles as well as between particles and the fluid.

Weight per unit volume of drilling fluid is referred to as fluid density. It is commonly reported as kilograms per cubic meter (kg/m3) as well as pounds per gallon (lb/gal or ppg) or pounds per cubic foot (pcf). The desired density, which is frequently incorrectly called weight, for most drilling situations is usually less 9.0 ppg and can be easily determined by a mud balance.

Gel strength is the measure of the capability of a drilling fluid to hold particles in suspension after flow ceases. Gel strength results from the electrical charges on the individual clay platelets. The positively charged edges of a platelet are attracted to the negatively charged flat surfaces of adjacent platelets. In a bentonite mud in which the particles are completely dispersed, essentially all the bonds between particles are broken while the mud is flowing. When the mud pump is shut off and flow ceases, the attraction between clay particles causes the platelets to bond to each other, this coming together and bonding is termed flocculation.

Filtration is the ability of the drilling fluid to limit fluid loss to the formation by deposition of mud solids on the walls of the hole. The drilling fluid tends to move from the borehole into the formation as a result of hydrostatic pressure which is greater in the hole than in the formation during drilling operations. As the flow of drilling fluid filtrate occurs, the drilling fluid solids are deposited on the walls of the borehole and thereby significantly reduce additional fluid loss. The solids deposit is referred to as a filter cake. The ideal filter cake is thin with minimal intrusion into the formation. The thickness of the filter cake for a particular mud is generally a function of the permeability of the formation. For example, the filter cake in a clay interval of the borehole would be thinner than in a sand interval.

1.1.1 Formation Damage Impact on Productivity losses

Dearing and Ali (1996); and Bennion et al (1996) stated that substantial reductions in oil and gas productivity may occur in many reservoirs due to formation damage caused by drilling-fluid invasion. Alfenore et al (1999) added that Productivity losses are especially critical for long horizontal wells which are often "openhole" completed. In many cases perforations does not bypass near-wellbore damage and may lead to very large skin values, hence prevention of formation damage generated by a drilling fluid may not always be possible specially for horizontal wells because first, the drilling time of the horizontal well is usually many times greater than that of a typical vertical well, leading to a much deeper filtrate invasion; and second, the viscous forces available to cleanup near-wellbore damage is reduced because of the very low drawdown pressure that is needed to produce from a typical horizontal well. Shaw and Chee (1996) claimed that the data obtained from production logging of many horizontal wells show severe damage across a large portion of the horizontal wellbore.

1.1.2 Formation Damage Mechanisms

Smith et al (1996) said that formation damage mechanisms can generally be categorized into two groups: firstly, physical reduction in pore or pore throat size and, secondly, changes in relative permeability. The degree of formation damage depends upon many parameters, such as nature and characteristics of the drilling fluid, operating conditions, and formation properties (Ding et al, 2004).

Two types of drilling fluids are normally used in drilling operations which are Oil Based Mud (OBM) and Water Based Mud (WBM). In case of WBM, two main damaging mechanisms are caused by both particulate invasion during the initial spurt loss period and by filtrate invasion through filter cakes (Ding et al, 2004).Al-Yami et al (2008) defined the mud spurt as the rush of filtrate that occurs in the first minute after the pressure is applied and before the filtrate volume becomes proportional to the square root of time.

1.2 Problem Statement.

Drilling fluids are the primary causes of formation damage during well construction and especially during work-over operations. Unfortunately there is no safe drilling fluid. Menouar et al 2000 said that an unpublished study by a major oil company has shown that even slight formation damage in a well can result in significant loss of revenue. For instance, the loss of production rate is in the range of 8 to 10% for mild formation damage with a skin of approximately 1, while severe formation damage with a skin of 20 could result in the loss of more than 80% of the production rate (Menouar et al 2002).

Formation damage can occur during drilling, casing and cementing, completion, well servicing, well stimulation and production operations. However drilling operation is considered as the primary initiator of formation impairment, as virgin formation comes first time in contact with a foreign fluid. Ding et al (2004) claimed that as soon as the drilling bit comes in contact with the reservoir, spurt loss takes place because there is no filter cake to prevent fluid solid particles from entering into the pay zone. Internal filter cake is formed during this period due to progressive deposition of these particles. Most of the solid particles are retained outside the formation when the internal filter cake is well established, creating a thin external filter cake, which mainly controls the rate of filtrate invasion. High wetting-phase saturation is generated due to the displacement of oil-in-place with a WBM filtrate as an imbibition process in the invaded zone. In addition, WBM filtrate is mainly formed from polymer molecules that can deeply invade the reservoir even if the larger molecular weight species are retained in the filter cake (Audibertet al 1999 and Argillier et al 1999). They added that the polymer chains can be stretched by the flow, go through the filter cake, adsorb within the porous media, and even plug rock pores depending on their molecular weight and filtration conditions. After oil backflow, polymer chains associated with water increase the capillary retention of water, leading to residual wetting-phase saturation, higher than the initial ones. This induces an additional damaging effect (water blocking) caused by drastic reduction of oil relative permeability leading to high values of skin factor (Bennion et al 1993).

Various conventional polymeric and surfactant additives that have been tested for superior performance of the drilling fluids have high cost and degrade at high temperature high pressure (HTHP) conditions, which lead to unwanted changes in rheological properties (Abdo and Haneef 2012). They added that "in the light of functional requirements of drilling fluids, it is thus a topic of utmost interest for the researchers and drilling industry to develop tailored made drilling fluids that could be able to perform the job with best level of agreement and maintain their paramount functionality over a wide range of variables like temperature, pressure, types of formations, and drilling environments".

1.3 Objectives.

This project aims at investigating skin factor values resulting from using different drilling fluid systems and consequently its impact on productivity, hence the objectives of this project could be stated as:

i. Investigate possibility of replacing Bentonite with milled Bentonite in WBM.
ii. Study and compare Rheological properties of Bentonite based mud and milled Bentonite mud.
iii. Investigate the effect of Bentonite particle size on filter cake quality (Skin).

1.4 Feasibility of the Study.

This project requires execution a number of laboratory tests that could be done at Universiti Teknologi PETRONAS (UTP) laboratories (Block 15) or at any other drilling fluid laboratory outside the university, in addition field data could be provided by oil companies such as Greater Nile Petroleum Operating Company (GNPOC) in Sudan. Moreover calculations could be done in order to generate clear graphs and pictures of the results. All these methods and equipments needed are feasible and available to achieve objectives of the project within the proposed time.

CHAPTER 2

LITERATURE REVIEW

2.1 Formation Damage:

The primary focus of research has been on evaluation and minimization of formation damage ever since van Everdingen and Hurst introduced the concept of a skin factor (Jilani et al 2001). Jilani et al (2001) defined formation damage as a process that results in a reduction of the flow capacity of oil, water, or gas bearing formation, the zone of altered permeability is referred to as a skin and the resulting effect as a skin effect.

Jilani et al (2001) claimed that presently, drilling fluids are being designed in such a way to minimize solid and fluid invasion into the formation by building a quick mud cake on the formation face, however it is during the first few seconds before the appearance of mud cake that the drilling fluids are in direct contact with formation causing major solid and fluid invasion. It is before mud cakes have a significant contribution in the overall severity of formation impairment that these early spurt losses occur. Solid particles in drilling fluid start bridging the pores and form a mud cake on the formation face after the early spurt losses. Solid invasion and filtration rate are essentially reduced by the mud cake. Even the invading filtrate plays a critical role as it reacts with formation rock and cause clay swelling and dispersion and produce precipitation of salt in the pore, which also reduces formation permeability.

The filtrate generated by WBM may cause physical and chemical reaction with in situ reservoir fluid and rock, and a severe damage could be induced. Part of the formation damage may be permanent. Once the mud particles have invaded the rock, it is difficult to remove them by back flow. The severity of formation damage or skin is directly related to the permeability impairment and depth of that impairment around the well bore and it is well understood from the published literature that the skin is a function of overbalance pressure, pore sizes in the formation and particle size distribution in the drilling fluid, formation permeability and the nature of the drilling fluid used.

Jilani et al (2001) stated that the best way to control formation damage is to minimize particle and filtrate invasion by building a fine-quality, low-permeability and high strength mud cake around the well bore. Such external mud cakes are a function of the average pore size in the formation, median particle size of bridging additive materials and their concentrations as well as drilling operation conditions, such as overbalance pressure. Smith et al (1996) claimed that although some solids invasion and formation damage are inherent to all drilling fluids, it is possible to minimize both damage caused by solids invasion, and the depth of this damage, by correctly sizing the bridging particles in the drilling fluid.

Peng and Peden (1992) reported that theoretical and experimental studies on static and dynamic filtration of water based drilling fluids have been done to evaluate the effects of fluid type and pH, solids shape, size and concentration, pressure and shear rates on filtration properties of the fluids. During drilling in ultra-deep waters severe fluid losses experienced have brought the attention to the need for non-invasive fluids to guarantee a successful operation (Lomba et al 2002). Significant permeability reduction and well productivity decrease are two of the main problems related to the presence of filtrate in productive oil and gas zones. The modeling of filtration process as to predict permeability changes and depth of damage penetration into the productive zone is essential to establish the stimulation technique that will better remove the existing damage (Schechter, 1992).

Khan et al (2001) said that formation damage depends on the permeability decrease as well as on the geometric extent of the damaged zone. Craft (1991) identified the skin parameter S as a key parameter in quantifying formation damage, Skin factor is defined as:

$$S = (k/k_d - 1)\ \ln(r_d/r_w)$$

Where k is the reservoir permeability, k_d the damaged zone permeability, r_d the damaged zone radius and r_w the well radius.

Lee (1982) said that the skin factor is directly used in the transient flow equations to estimate the oil production rate in wells that have been affected by formation damage.

2.2 Filter Cake Removal:

Ding et al (2004) stated that there are various techniques available for removing filter cakes, such as using acids or oxidative solutions. However the simplest and most common technique is the natural cleanup where pressure difference applied between the reservoir and the bottomhole. The external cake can be lifted off when this pressure difference is large enough, and a flow is initialized to remove particles in the zone occupied by the internal cake. Ding et al (2004) reported that two regions can be distinguished with regards to the oil return permeability variations, first is close to the wall of the well in which the regained permeability is caused by the combined effect of partial removal of solid particles and reduction of filtrate saturation, and second is far from the wall in which only the filtrate saturation reduction is considered, because particle deposits are assumed to be negligible.

2.3 Rheology Properties:

Rheology and hydraulics are interrelated studies of fluid behavior said Kassab et al. (2006). They defined Rheology as the study of how matter deforms and flows. It is primarily concerned with the relationship of shear stress and shear rate and the impact these have on flow characteristics inside tubular and annular spaces. Hydraulics describes how fluid flow creates and uses pressures. In drilling fluids, the flow behavior of the fluid must be described using rheological models and equations before the hydraulic equations can be applied. Kassab et al. (2006) stated that the physical properties of a drilling fluid, density and rheological properties contribute to several important aspects for successfully drilling a well, including:

i. Provide pressure control to prevent an influx of formation fluid.

ii. Provide energy at the bit to maximize Rate of Penetration (ROP).

iii. Provide wellbore stability through pressured or mechanically stressed zones.

iv. Suspend cuttings and weight material during static periods.

v. Permit separation of drilled solids and gas at surface.

vi. Remove cuttings from the well.

It is important to control these properties with respect to the requirements for a specific well and fluid being used because each well is unique. Kassab et al. (2006) claimed that the rheological properties of a fluid can affect one aspect negatively while providing a significant positive impact with respect to another aspect. In order to maximize hole cleaning, minimize pump pressures and avoid fluid or formation influxes, as well as prevent loss of circulation to formations being drilled, a balance between these properties must be attained.

Kassab et al. (2006) said that the properties of the drilling fluid such as viscosity, density, gel strength, fluid loss control, and sand content have effect on both the efficiency and rate of drilling wells. They claimed that the penetration rate of the drill bit may be increased, drill bit life may be increased, and unplanned borehole deviation may be decreased through the suitable designing and managing of drilling fluid properties. Improving productivity during drilling and reducing costly down-time are the economic benefits of these results. High solids or sand content increases the fluid density. High fluid density causes pressure in the formation of the borehole. This pressure drives the drilling fluid through the filter cake into the formation, leads to excessive drilling fluid loss to the formation, and extends well development time required to remove the mud from the formation. The pressure required to move the fluid up the borehole increases as the fluid density increases, leading to high mud pump pressure requirements. Due to high solids or sand content, significant abrasion in the drill tooling takes place as the fine particles are recirculating through the mud pump and drill string. Since drilling fluid density influences drilling rate and hole stability, it can be controlled by dilution with water or remove solids to decrease or add weighting agents to increase. The desirable limit is less than about 9.0 ppg, and sand content less than 2% by volume (M.I. LLC., 2006).

As a general rule, in order to provide the required hole-stability and water loss control. Thick mud is needed to remove coarse gravel from the hole viscosity should be maintained as low as possible, however thin mud does the best job of cleaning the bit and optimizing the drilling rate. Marsh funnel viscosity readings should be taken routinely and recorded on the boring log. The measure of the capability of a drilling fluid to hold particles in suspension after flow ceases is referred to as gel strength. Gel strength results from the electrical charges on the individual clay platelets. The capability of keeping cuttings in suspension prevents sand locking (sticking) the tools in the bore while drill rods are added to the string and minimizes sediment collecting in the bottom of the hole after reaming and before going back in the hole with a sampler. Since the viscosity influences the cuttings transport, cutting settlement, and circulation pressures, it can be controlled by adding water, phosphates, or lignites to thin and adding polymers or bentonite to thicken. The desirable viscosity limit is 34-40 sec/dm3 (Marsh funnel and measuring cup) according to (M.I. LLC., 2006).

The acidity or alkalinity (pH) of drilling fluid influences mud properties, filtration control, hole-stability, and corrosion of equipment. The pH can be increased with sodium carbonate and decreased with sodium bicarbonate. The pH desirable limit is from 8.5 to 9.5 (M.I. LLC., 2006).

The ability of the drilling fluid to limit fluid loss (filtrate) to the formation by deposition of mud solids on the walls of the hole is referred to as filtration, and the solid deposit is referred to as a filter cake. The ideal filter cake is thin with minimal intrusion into the formation. The thickness of the filter cake for a particular mud is generally a function of the permeability of the formation. The desirable limit of filter cake thickness is less than 0.2 cm, and can be controlled by controlling density and viscosity of mud.

Filtration rate is important because it influences the ease of moving tools in or out of the hole said Salathiel (1951). Filtration rate also affects the stability of the bore hole walls, which are subject to softening and degradation by aqueous filtrate. Difficulties in rotary drilling are often avoided by using low-filtration muds.

2.4 Effect of Particle Size:

Reactions take place at the surface of a chemical or material; reactivity of a material increases with increased surface area to volume ratio. The link to nanotechnology is that as particles get smaller; their surface area to volume ratio increases dramatically.

Abdo and Haneef (2012) claimed that nanoparticles due to their very fine nature and enormous area of interaction are expected to display novel behavior in drilling fluids in the form of allowing to tailor the properties in a handy way to suit particular drilling conditions, thus serving as a cause to reduce drilling operational problems which are often the main cause of bringing about huge additional costs due to nonproductive time.

CHAPTER 3:

METHODOLOGY

3.1 Research Methodology

An experimental procedure is followed to study effects of Bentonite particle size on the filtration and mud cake quality; the general work flow is as below:

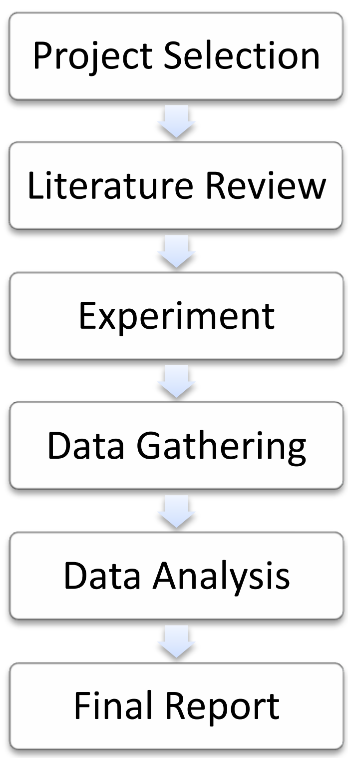


Figure 1: Project Workflow

3.1.1 Experimental Work:

Before preparing the two muds for testing, Bentonite has been milled using Ball Mill equipment (Fig) for 16 hours then 63μm mesh is used to sieve the milled Bentonite powder(Fig).

Figure 2: Ball mill equipment

Figure 3: Electric sieve vibrator

Bentonite and milled Bentonite are used to make two muds by adding 350ml of water to 22.5g of each separately in the mud mixer .Mud balance equipment is used to measure density of each mud, and funnel viscosity is measured before using viscometer to test rheology properties. LPLT filtration test has been conducted to asses performance of milled Bentonite mud comparing to normal Bentonite. Schematic diagram of the experimental work is shown in the figure below:

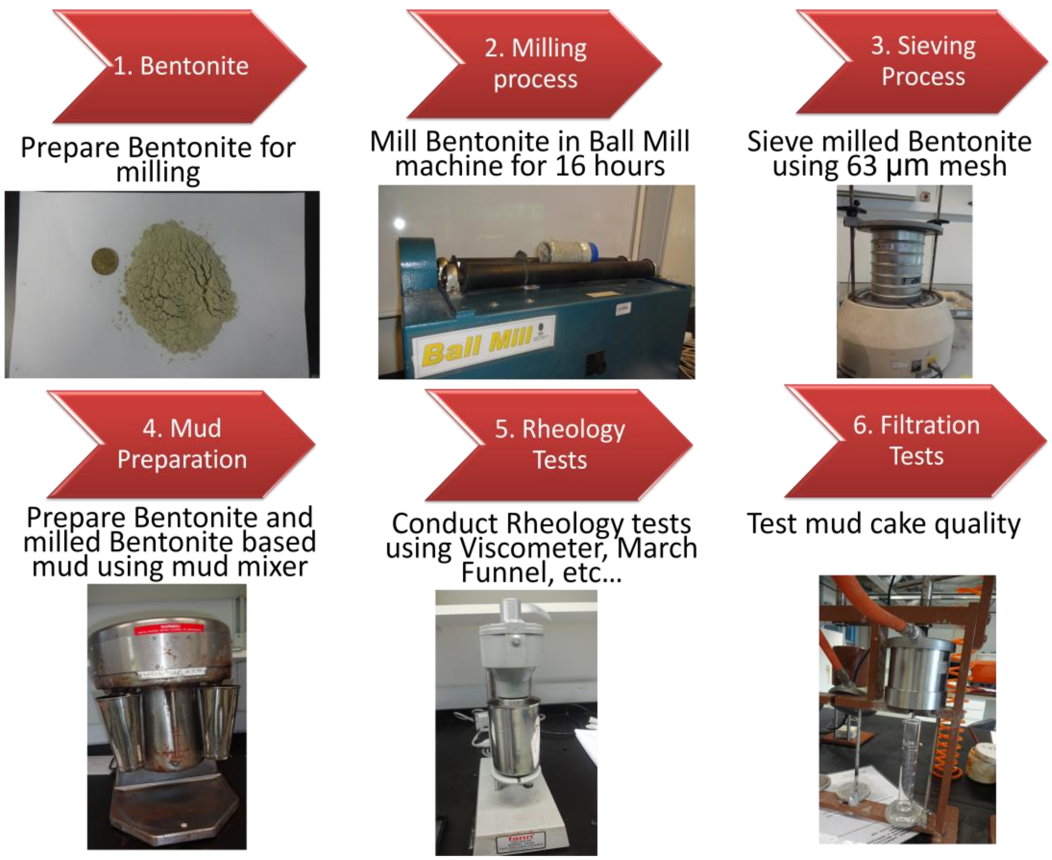


Figure 4: Schematic diagram of experimental work

I. Rheology Tests:

Rheology refers to the deformation and flow behavior of all forms of matter. Certain rheological measurements made on fluids, such as viscosity and gel strength help determine how this fluid will flow under a variety of different conditions. To run rheology tests, the recently agitated sample is first placed in the cup, the upper housing of the viscometer is tilted back, the cup is located under the sleeve, and upper housing is lowered to its normal position. The knurled knob between the rear supports is turned posts to adjust the rotor sleeve until it is immersed in the sample to the scribed line. The sample is stirred 600 and 300 RPM. To measure gel strength of the sample, it is stirred at 600 RPM for about 15 seconds, the motor is then stopped (0 RPM) for the desired rest time which is 10 seconds and 10 minutes, the RPM knob was switched to the GEL position (6 RPM), the maximum deflection of the dial was recorded before the Gel breaks, as the Gel strength in lb/100 ft2.

II. Filtration Test:

Filtration is defined as the loss of the liquid phase of a drilling fluid into permeable formations. The process occurs in a well being drilled with higher wellbore pressure than formation pressure. When the permeability is such that it allows fluid to pass through the pore spaces, Loss of fluid from the mud to the formation occurs. As fluid is lost, a buildup of mud solids occurs on the face of the wellbore. This is what called mud cake which controls the loss of liquid from a mud due to filtration. The test in the laboratory consists of measuring the volume of liquid forced through the mud cake into the formation drilled in a 30 minute period under given pressure and temperature using a standard size cell. The two commonly determined filtration rates are the low-pressure, low temperature and the high-pressure high-temperature.

1) LPLT Filtration test:

The low pressure test is made using standard cell under the API conditions for 30 minutes at room temperature. Filter press used for filtration tests consists of four independent filter cells mounted on a common frame.

Running procedure of LPLT filtration test starts with detaching the mud cell from the filter press frame, the bottom of filter cell is then removed, and right size filter paper is placed in the bottom of the cell. Mud is introduced into cup assembly to be tested, filter paper and screen is put on top of mud tighten screw clamp. A graduated cylinder is placed underneath to collect filtrate. Air pressure valve is opened and start timing at the same time.

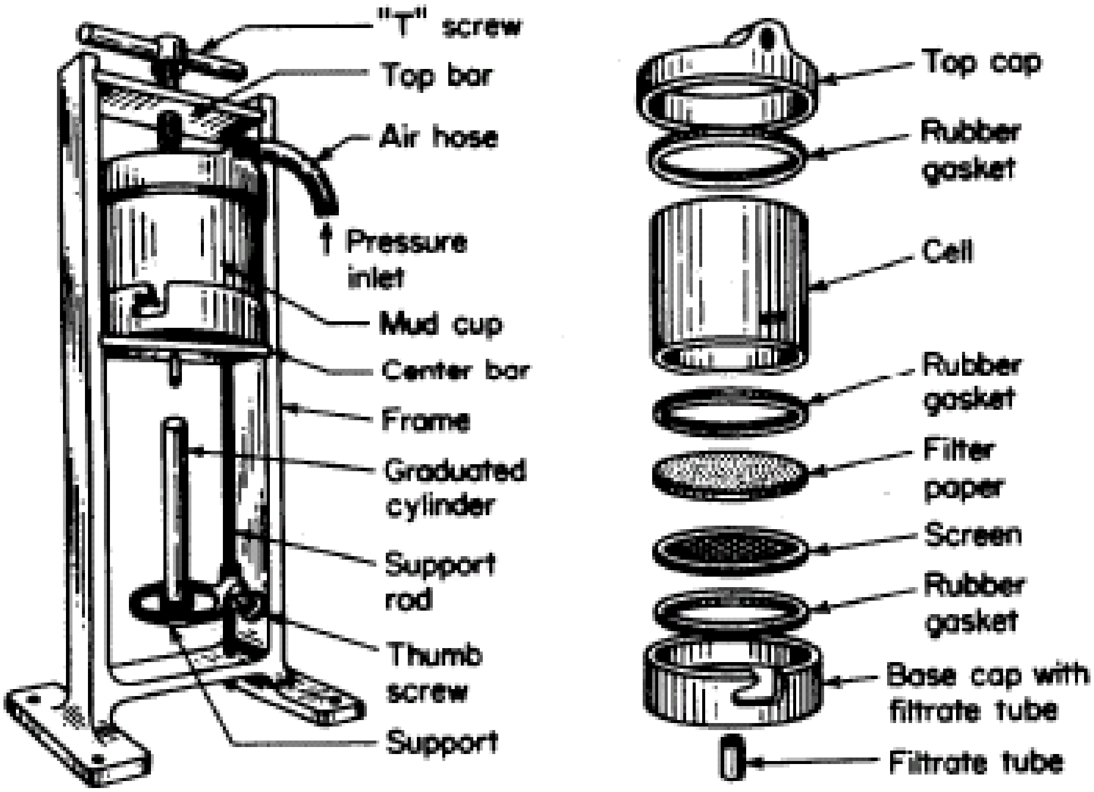


Figure 5: Standard API filter press

Test procedure for LPLT filtration rate:

1. The mud cell is detached from filter press frame.
2. The bottom of filter cell is removed; right size filter paper is placed in the bottom of the cell.
3. Introduce mud to be tested into cup assembly, filter paper and screen is put on top of mud tighten screw clamp.
4. With the air pressure valve closed, clamp the mud cup assembly to the frame while holding the filtrate outlet end finger tight.
5. A graduated cylinder is placed underneath to collect filtrate.
6. Air pressure valve is opened and start timing at the same time.
7. Report cc of filtrate collected for specified intervals up to 30 minutes.
8. The results are tabulated in an appropriate table.

2) HPHT Filtration Test:

High Pressure-High Temperature (HPHT) Filter Press is an efficient mean of evaluating the filtration properties of drilling muds at high temperatures and pressures. The cell has a filtering area of 3.5 in2 and is operated at pressure of 150 psi. Before starting the test, all parts of the cell have been lubricated to ease the process of assembly; the cell was filled with the mud, filter paper placed on top of the cell then reversed and closed and put in its right place in the heating jacket. 150 psi pressure is allowed into the cell and temperature is raised up to 200˚F. Lower valve of the cell is half turn opened when the specified temperature attained. Filtrate volume readings are noted in a 5 minutes interval for 30 minutes.

III. Formation Damage Tests:

Different types of laboratory tests could be carried to achieve aforementioned objectives and they could be divided into two main types that are destructive and non-destructive tests. Destructive tests include Core waterflooding and non-destructive tests include Leak-off Experiment and Ultrasonic Experiment.

A. Leak-off Experiment

Menouar et al 2002 explained that the leak-off experimental set-up is designed to simulate the drilling fluid circulation process in the well bore at the sand face level under bottom hole conditions. A Hassler type core holder is used for this purpose. It is a stainless steel core holder that can accommodate up to 30.48-cm and 5.08-cm diameter cores. The core itself is mounted inside a rubber sleeve and subjected to a confining pressure (overburden pressure). One end piece of the core holder, the injection end, has two ports to circulate the drilling fluid across the face and also to saturate the core with oil or brine. The other end piece, the production end, is used to collect the filtrate/oil/brine, pumped from the injection end.

B. Ultrasonic Experiment

Menouar et al 2002 reported that the experimental set-up for the ultrasonic investigation of the damaged zone consists of a Panametric pulser-receiver model 5072 and two Panametric transducers model V403, one to launch the ultrasonic pulses from one side and the other to receive them from the other side. A Panametric pre-amplifier is used to amplify the transmitted signals and a 500 MHz digital oscilloscope HP 54615B is used to record the results, which are subsequently transmitted to a PC for further processing and analysis.

3.2 Project activities.

The main activity of this project is to perform experiments to compare and recommend either normal or milled Bentonite based mud in terms of filtration losses and filter cake quality.

3.3 Key Milestone

Table 1: Key milestone

No	*Activities*	*Date*
1	*Submission of Proposal Defense Report (Prelim)*	*2 July 2012 (Wk7)*
2	*Proposal Defense (Oral Presentation)*	*9 July– 20 Jul 2012 (Wk8-9)*
3	*Submission of Interim Draft Report*	*9 Aug 2012 (Wk12)*
4	*Submission of Progress Report*	*7 Nov 2012 (Wk7)*
5	*Pre-SEDEX*	*26 Nov 2012 (Wk10)*
6	*Submission of Draft Report*	*30 Dec 2012 (Wk11)*
7	*Submission of Technical Paper*	*30 Dec 2012 (Wk11)*
8	*Submission of Dissertation (soft bound)*	*5 Dec 2012 (Wk12)*
9	*Oral Presentation*	*Dec 2012 (Wk13)*
10	*Submission of Project Dissertation (Hard Bound)*	*Dec 2012 (Wk15)*

3.4 Gantt chart

Table 2: Gantt chart

No	*Detail/Week*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*
1	*Project Work Continues*														
2	*Submission of Progress Report*							●							
3	*Project Work Continues*														
4	*Pre-SEDEX*										●				
5	*Submission of Draft Report*											●			
6	*Submission of Technical Paper*											●			
7	*Submission of Dissertation (soft bound)*												●		
8	*Oral Presentation*													●	
9	*Submission of Project Dissertation (Hard Bound)*														●

3.5 Tools

Different laboratory tools have been used to execute required laboratory tests such as LPLT and HPHT filtration tests and. It was also planned to use Formation Damage System (FDS) however the equipment malfunctioned before running the test.

3.5.1 Formation Damage System:

The TEMCO FDS-800-10000 HTHP Formation Damage Test System is designed for formation damage testing of core samples, at in-situ conditions of pressure and temperature. Tests that can be performed with the system include initial oil saturation, secondary water flooding, formation damage testing with leak-off through the core, and before-and-after permeability measurement, in both forward and reverse (backflow for damage clean up) directions. Brine, oil, drilling mud, gels, or other fluids can be injected into and through the core sample.

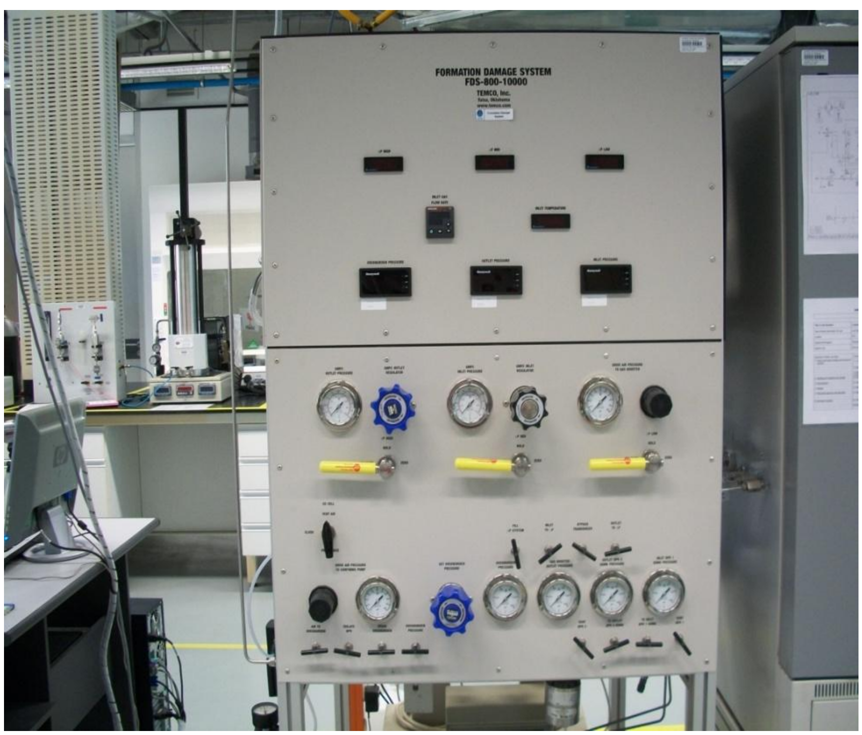


Figure 6: Formation Damage System Apparatus

3.5.2 Mud Mixer:

Is a mixing system used to mix dry powder materials with a base liquid, such as cement slurry or drilling muds.

Figure 7: Mud mixer

3.5.3 Mud Balance Equipment:

Mud balance is a device to measure density (weight) of mud, cement or other liquid or slurry. A mud balance consists of a fixed-volume mud cup with a lid on one end of a graduated beam and a counterweight on the other end. A slider-weight can be moved along the beam, there is also a bubble indicates when the beam is level. Density is read at the point where the slider-weight sits on the beam at level which is indicated by the bubble. Accuracy of mud weight should be within +/- 0.1 ppg (+/- 0.01 g/cm3) (glossary.oilfield.slb.com)

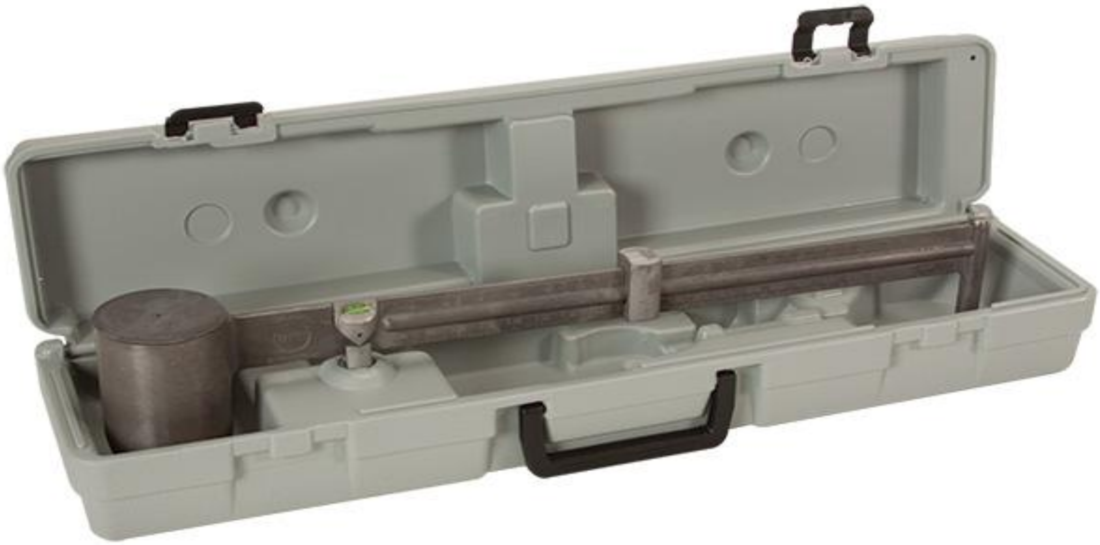


Figure 8: Mud balance

3.5.4 Marsh Funnel:

Marsh funnel is a funnel in a conical shape, mud flows under a gravity head through a small-bore tube on the bottom end. A screen over the top removes large particles that might plug the tube. In the test standardized by API for evaluating oil-base and water-base muds, the funnel viscosity measurement is the time (in seconds) required for one quart of mud to flow out of a Marsh funnel into a mud cup. Funnel viscosity is reported in seconds per a quart.

Figure 9: Marsh Funnel

3.5.5 Fann Viscometer :

Fann viscometer is also known as direct-indicating viscometer or V-G meter, it is an instrument used to measure viscosity and gel strength of drilling mud. The Fann viscometer is a rotational cylinder and bob instrument. Six speeds of rotation, 3, 6, 100, 200, 300 and 600 rpm, are available in the instrument. It is called "direct-indicating" because at a given speed, the dial reading is a true centipoise viscosity.

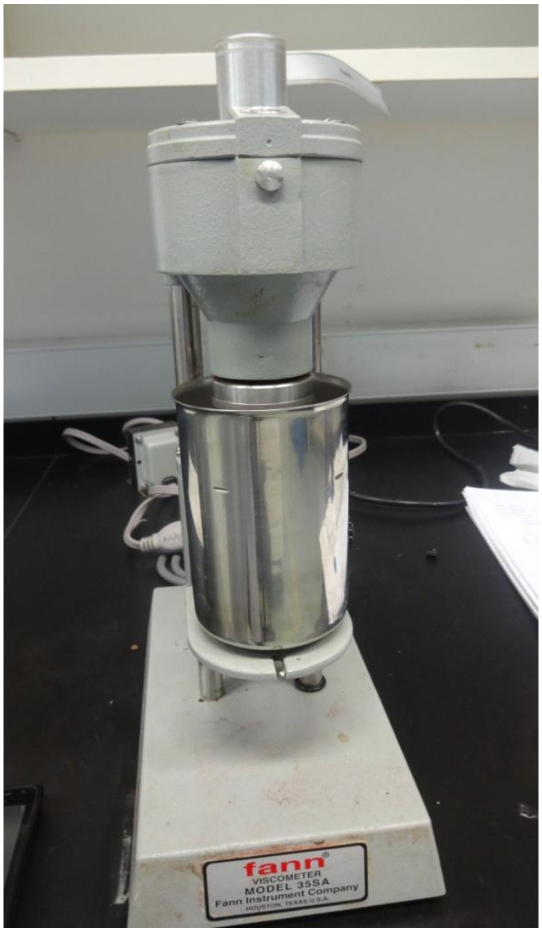


Figure 10: Fann Viscometer

3.5.6 Filter Press

Filter press is a pressurized cell, fitted with a filter paper, used for evaluating filtration characteristics of a drilling fluid while it is either static or stirred (to simulate circulation) in the test cell. Generally, either low-pressure, low-temperature or high-pressure, high-temperature devices are used.

Figure 11: LPLT Filter press

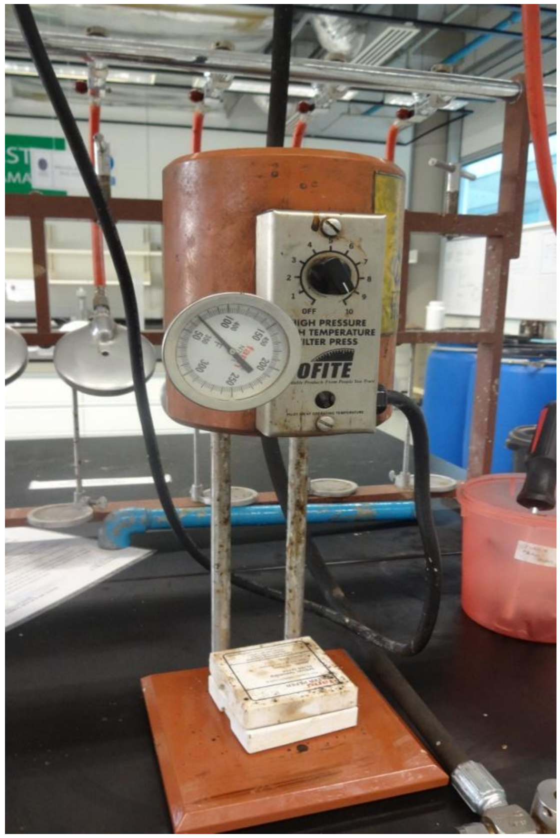


Figure 12: HPHT Filter press

3.5.7 Vernier Caliper

Is a device used to measure the distance between two opposite sides of an object. It has extremely precise measuring; the reading error is 1/20 mm = 0.05 mm.

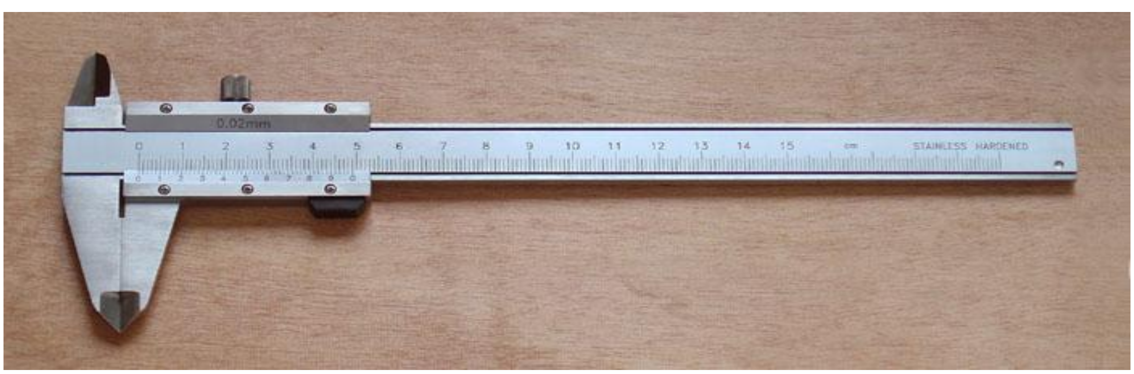


Figure 13: Vernier caliper

CHAPTER 4:

Results and Discussions

Different laboratory tests have been conducted to examine differences between Bentonite and milled Bentonite; results showed that milled Bentonite mud has significant differences with normal Bentonite.

4.1 Rheology Tests:

Bentonite mud resulted in better rheological properties compared to milled Bentonite, however mud additives such as Barite and Calcium Carbonate can overcome this disadvantage. Results of the rheology tests are tabulated in Table 1.

Table 3: Rheology properties of the two mud types

Property	**Bentonite**	**Milled Bentonite**
Mud Weight (ppg)	8.7	8.68
Funnel Viscosity (sec)	42	32
pH	8.7	8.56
Plastic Viscosity	10	9
Apparent Viscosity	17	12.5
Yield Point (Ib/100ft2)	14	7
Gel Strength (10 Sec) (Ib/100ft2)	5	2.5
Gel Strength (10 Min) (Ib/100ft2)	15	10

4.2 LPLT Filtration Test:

Static LPLT filtration test was conducted and resulted in different filtration rate of milled Bentonite based mud and normal Bentonite mud. In the first 5 minutes of the test both muds showed the same rate of filtration which indicate absence or delaying in the formation of filter cake in both muds. However filtration rates start to differ as the time passes giving total filtration of 12.5 ml for normal Bentonite based mud and 11.0 ml for milled Bentonite mud. This show a reduction in water filtrate of about 12% in milled Bentonite comparing to normal Bentonite which means better quality and performance of milled Bentonite mud cake. Based on the experiment, the fluid loss increase proportionally with time. Therefore, the theory is accepted as it states that volume of fluid lost is roughly proportional to the square root of the time for filtration.

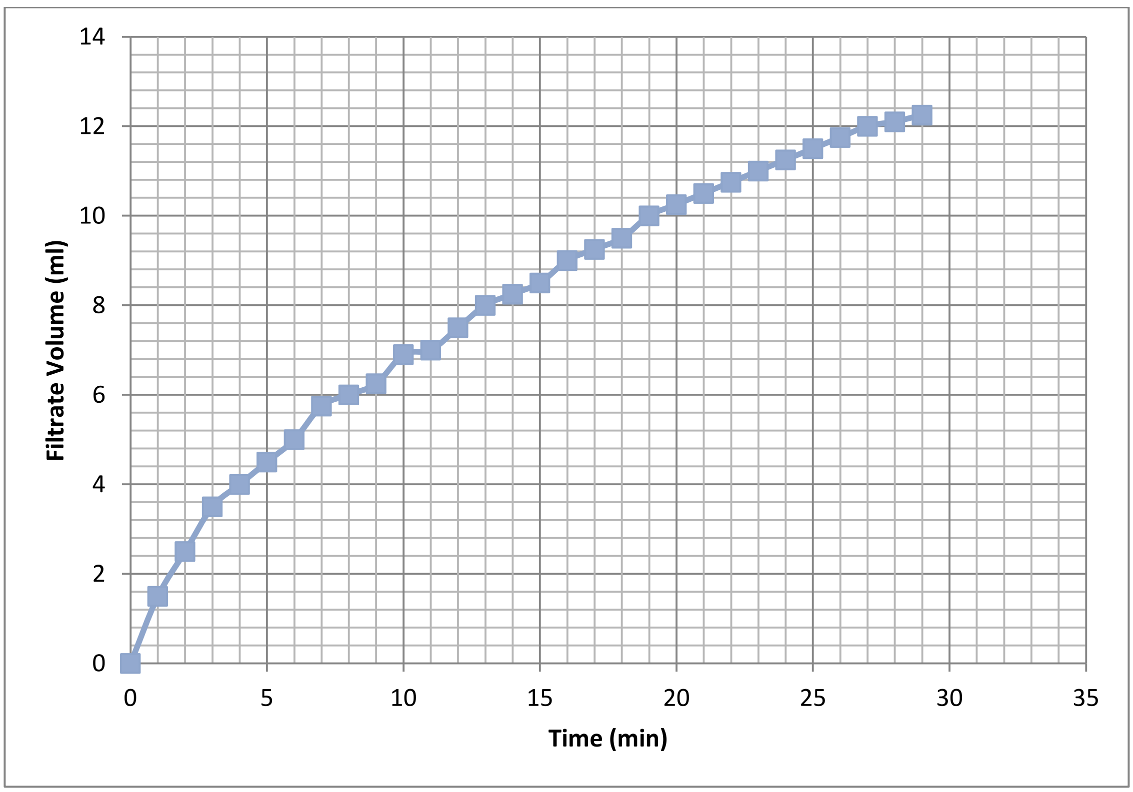


Figure 14: Normal Bentonite filtration rate

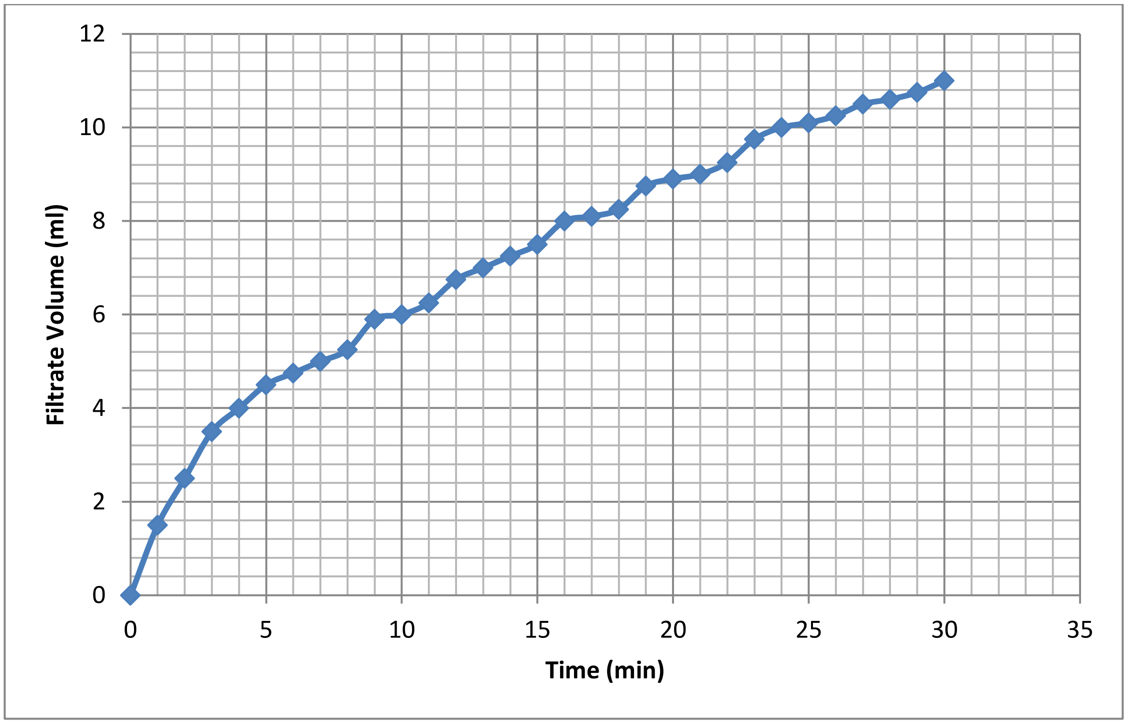


Figure 15: Milled Bentonite filtration rate

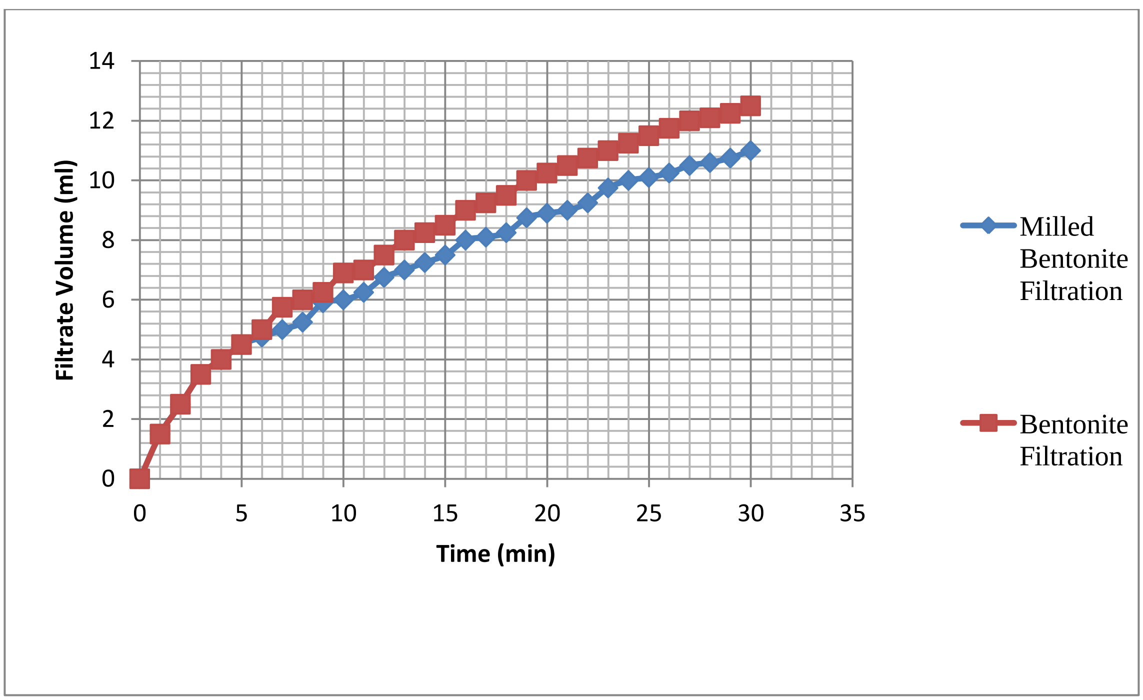


Figure 16: Comparing filtration rate of normal and milled Bentonite

4.3 HPHT Filtration Test:

Static HPHT filtration test was performed using a standard HPHT Fann filter press cell. Drilling fluid samples showed totally different filtration rate and total volume of filtration. Normal Bentonite lost around 5.5 ml of water during the first 5 minutes of the test and total volume of 15.5 ml of water, on the other hand milled Bentonite lost only 2 ml of water in the first 5 minutes and total filtration of only 5.25 ml. These results indicate that milled Bentonite based mud is way much better than the normal Bentonite mud in HPHT conditions.

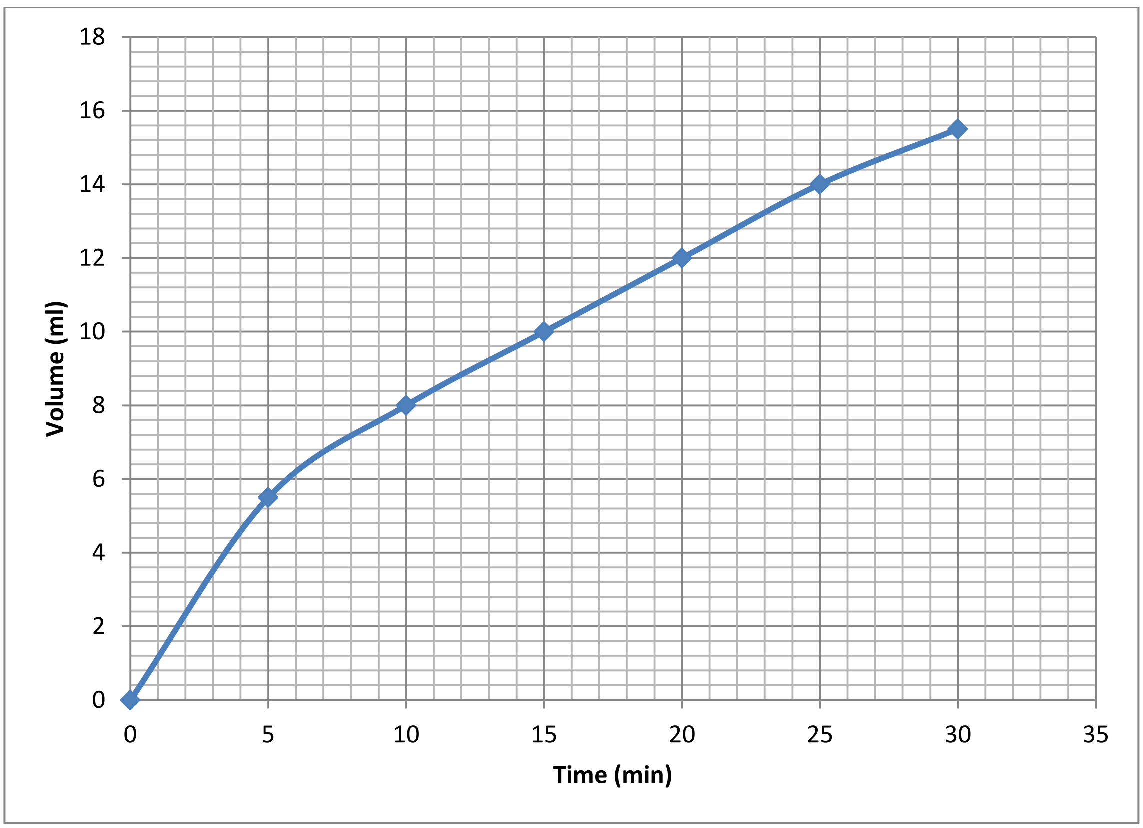


Figure 17: Filtration rate of Normal Bentonite under HPHT

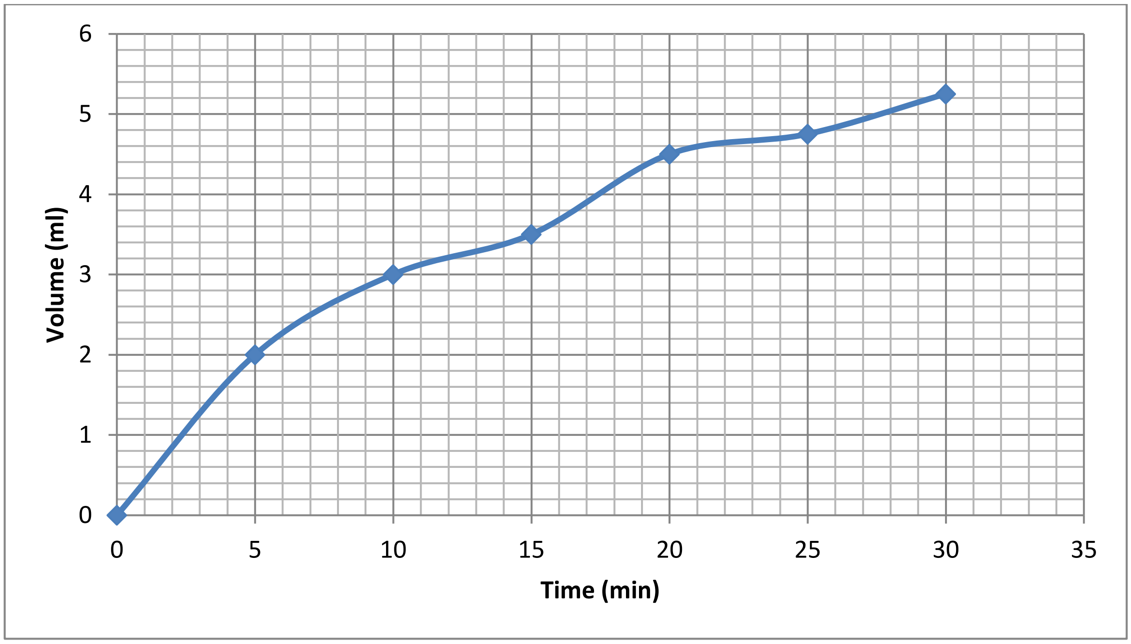


Figure 18: Filtration rate of milled Bentonite under HPHT

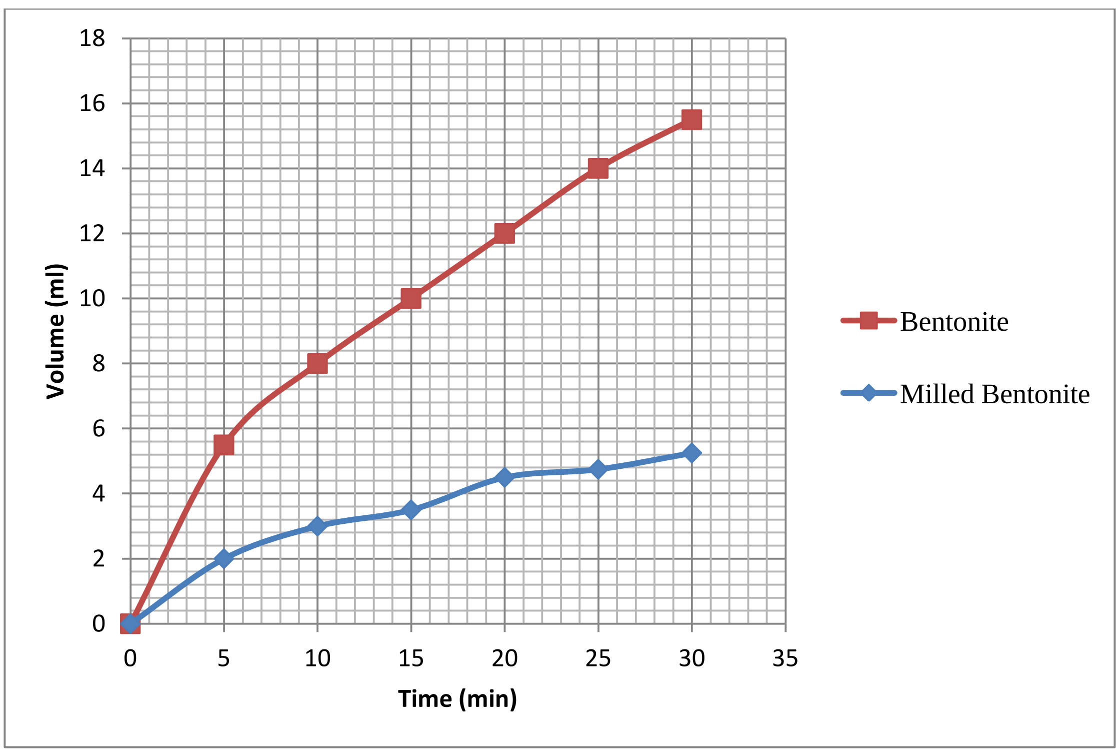


Figure 19: Comparing filtration rate of normal and milled Bentonite under HPHT

Production rate is highly affected by filtrate invasion (degree of formation damage or skin factor value) that alters oil relative permeability by reducing it and consequently reducing the production rate. Filtrate invasion length is also critical as least flow rate or production rate is obtained from high internal cake or length longer invasion depth that increases the skin factor value (Ding et al 2004).

4.4 Mud Cake Thickness:

The LPLT filtration test showed a reduction in filter cake thickness of 60% in the milled Bentonite mud with 1.3 mm compared to 2 mm thickness in the normal Bentonite mud. This indicate slowness in the development of milled Bentonite mud cake at the low pressure low temperature conditions, however the opposite takes place at the high pressure high temperature conditions where by mud cake thickness of milled Bentonite is more than that of the normal Bentonite. Milled Bentonite mud cake thickness in the HPHT conditions is 6mm where by mud cake thickness of normal Bentonite mud under the same conditions is 5 mm. It could be concluded that milled Bentonite mud performance in the HPHT conditions is much better than its performance in the LPLT conditions and is also better than the performance of normal Bentonite under both conditions.

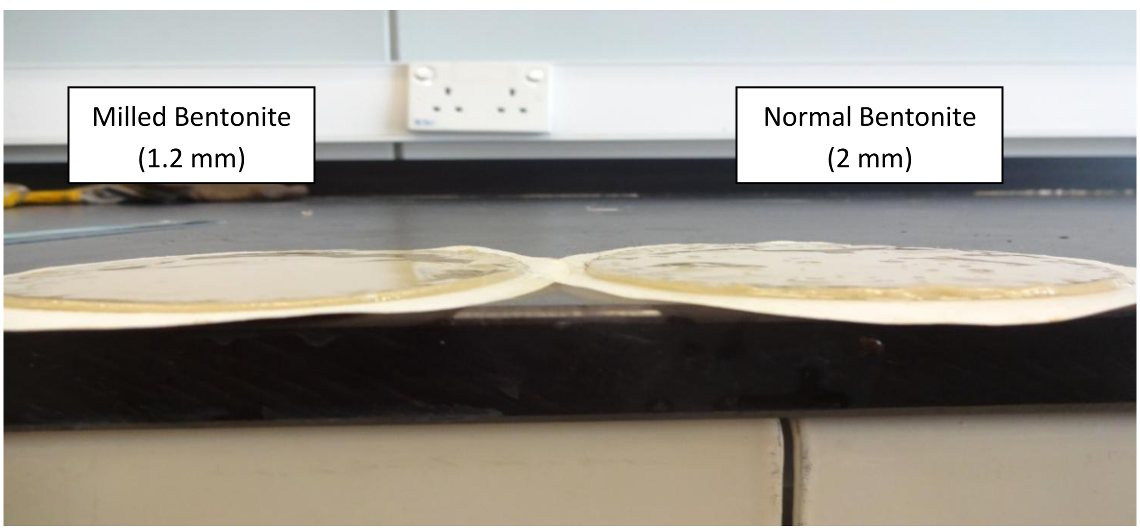


Figure 20: LPLT Mud cake thickness of Bentonite and milled Bentonite

Figure 21: HPHT Mud cake thickness of milled Bentonite (6mm)

4.5 Surface area to volume ratio:

According to Smalley and Yakobsonb (1998) the high surface area to volume ration of nano and micro material compared to macro material of the same mother source provides them dramatically increased interaction potentials with reactive shale to eliminate shale drilling mud interactions and associated borehole problems. Amanullah et al. stated that the huge surface area to volume ratio of nano and micro material is expected to improve their thermal conductivity and hence provide efficient cooling of drill bit leading to significant increase in operating life cycle of a drill bit. The high heat transfer coefficient of these fluids also plays a positive role in cooling the drilling mud quickly at the surface.

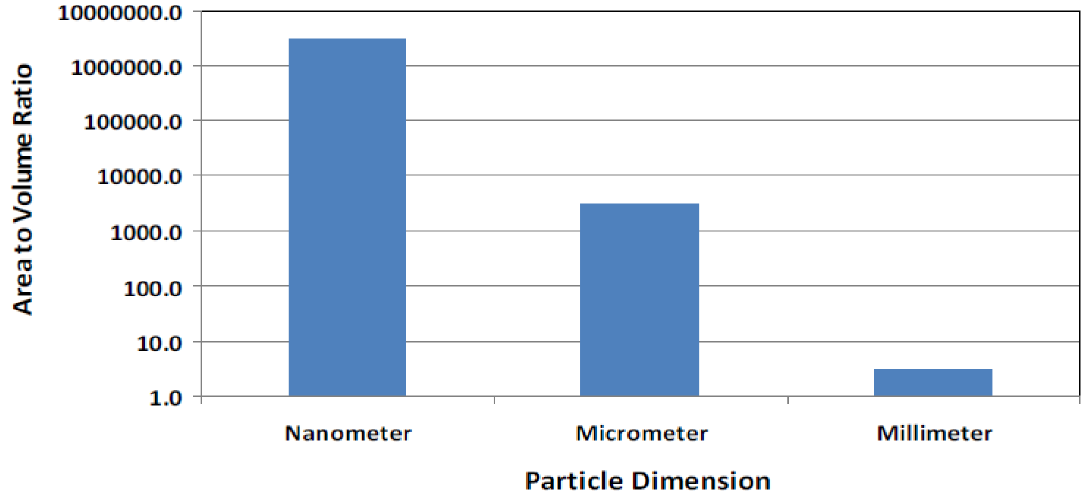


Figure 22: Surface area to volume ratio of same volume of materials

(Amanullah and Al-Tahini, 2009)

CHAPTER 5:

CONCLUSION AND RECOMMENDATIONS

This project aimed at studying the effect of different drilling fluids on reservoir skin factor, skin factor value depends on the degree of formation damage caused by the drilling fluid, and hence selecting a drilling fluid that induces the less damage to the reservoir could give better production rates.

Objectives of the project have been met by executing number of experimental tests using two different Bentonite based muds that differs in their particle sizes. Milled Bentonite used has a particle size less than 63 µm the other normal Bentonite is used in the second mud.

Micro and nano materials have significantly different properties compared to the parent materials. Macro material has the lowest surface to volume ratio compared to micro and nano materials. The high surface area to volume ratio of nano and micro material improves their thermal conductivity and provide efficient cooling of drill bit leading to significant increase in operating life cycle of a drill bit.

Rheology and filtration tests have been successfully conducted to asses Bentonite and milled Bentonite based mud differences. Milled Bentonite based mud gives relatively better filtration results (12% less) in the LPLT filtration test with thinner mud cake thickness (1.2 mm) compared to normal Bentonite (2mm). In the HPHT filtration test, milled Bentonite mud resulted in low filtration rate of 5.35 ml compared to 15.5 ml filtration in case of normal Bentonite mud (66 % less). As the Milled Bentonite mud has less filtration rate, it is expected to result in lower skin factor compared to normal Bentonite and specially in HPHT conditions.

In the future, it is recommended to perform a formation damage test using the two mud types to compare mud cake permeability, thickness and formation permeability impairment caused by the two mud types. It is also recommended to further investigate application of nano and micro Bentonite on drilling fluids in way that helps reducing costs and enhancing productivity.

REFERENCES

- Abdo, J., and Haneef, M.D., "Nano-Enhanced Drilling Fluids: Pioneering Approach to Overcome Uncompromising Drilling Problems", Journal of Energy Resources Technology, n.134, 2012.

- Alfenore, J., Longeron, D., and Saintpère, S., "What Really Matters in Our Quest of Minimizing Formation Damage In Openhole Horizontal Wells", paper SPE 54731 presented at the SPE European Formation Damage Conference, The Hague, 31 May–1 June. 1999.

- Al-Homadhi, E.S., "Improving Local Bentonite Performance for Drilling Fluids Applications", paper SPE 110951 presented at the SPE Saudi Arabia Technical Symposium, Dhahran, Saudi Arabia, 7-8 May 2007.

- Al-Yami, A. S., Nasr-El-Din, H. A., Bataweel, M. A., Al-Majed, A. A., Menouar, H., "Formation Damage Induced by Various Water-Based Fluids Used To Drill HP/HT Wells", paper SPE 112421 presented at the SPE International Symposium and Exhibition on Formation Damage Control, Lafayette, Louisiana, U.S.A., 13–15 Feb. 2008.

- Amanullah, M.D., and Al-Tahiti, A.M., "Nano-Technology – It's Significance in Smart Fluid Development for Oil and Gas Field Applicatio" SPEKSA-J4, SPE Saudi Arabian Section Technical Symposium and Exhibition, Al-Khobar, Saudi Arabia, 9-11 May 2009.

- Argillier, J. F., Audibert, A., and Longeron, D., "Performance Evaluation and Formation Damage Potential of New Water-Based Drilling Formulas", SPEDC 266, Dec. 1999.

- Audibert, A. et al., "Role of Polymers on Formation Damage", paper SPE 54767 presented at the SPE European Formation Damage Conference, La Haye, France, 31 May–1 June. 1999.

- Bennion, D.B, Thomas, F.B., and Bietz, R.F., "Formation Damage and Horizontal Wells—A Productivity Killer?", paper SPE 37138 presented at the SPE International Conference on Horizontal Well Technology, Calgary, Canada, 18–20 Nov. 1996.

- Bennion, D.B. et al., "Reductions in the productivity of oil & gas reservoirs due to aqueous phase trapping", paper CIM 1993-24 presented at the Petroleum Society's Canadian International Petroleum Conference, Calgary, Canada, 9–12 May. 1993.

- Craft, B.C., Hawkins, M.F., "Applied Petroleum Reservoir Engineering" Second ed., pp.210, Printice Hall Inc., Englewood Cliffs, New Jersey, U.S.A., 1991.

- Datong, S., Baoyan, l., Michail, G., Rajani, S., Randi, E., "Comparison of Skin Factors for Perforated Completions Calculated with Computational Fluid Dynamics Software and a Semi-Analytical Model", paper SPE 143663 presented at the SPE European Formation Damage Conference, Noordwijk, Netherlands, 2011.

- Dearing, H. L., and Ali, S. A., "Drill-in Fluid Selection Crucial To Well Productivity", Petroleum Engineer International, Jan. 1996.

- Ding, Y., Longeron, D., Renard, G., and Audibert, A., "Modeling of Both Near-Wellbore Damage and Natural Cleanup of Horizontal Wells", SPE 88807, pp. 252-264, Sep. 2004.

- EM., "Engineering Manual", EM 1110-1-1804, USA, 2001.

- http://www.glossary.oilfield.slb.com, Retrieved 31 Oct 2012.

- Jilani, S. Z., Menouar, H., Al-Majed, A.A., Khan, M.A., "Effect of overbalance pressure on formation damage", Journal of Petroleum Science and Engineering, n. 36, pp. 97– 109, 2002.

- Khan, M.A., Jilani, S. Z., Menouar, H., Al-Majed, A.A., "A non-destructive method for mapping formation damage", Elsevier Science, Ultrasonics n. 39 pp. 321– 328, 2001.

- Lee, J., "Well Testing", SPE Text Book Series., pp.50,1982

- Lomba, R. F. T., Martins, A. L., Soares, C. M., Brandao, E. M., Magalhaes, J. V. M., Ferreira, M. V D., "Drill-In Fluids: Identifying Invasion Mechanisms", paper SPE 73714 presented at the SPE International Symposium and Exhibition on Formation Damage Control, Lafayette, Louisiana, U.S.A., 20-21 Feb. 2002.

- M.I. LLC., "Drilling Fluid Engineering Manual", M.I. LLC., USA, 2006.

- Md. Amanullah. Alarfaj, M.K., and Alabdullatif, Z., "Preliminary Test Results of Nano-based Drilling Fluids for Oil and Gas Field Application", paper SPE/IADC 139534 presented at SPE/IADC Conference and Exhibition , Amsterdam, The Netherlands, 1-3 March 2011.

- Menouar, H., A. Al-Majed, and S. H. Sajid, "Effect of Formation Damage, Length and Reservoir thickness on the Inflow Performance of Horizontal Wells", SPE 59356, Presented at the 2000 SPE/DOE Improved Oil Recovery Symposium held in Tulsa, Oklahoma, U.S.A., 3-5 April 2000.

- Menouar, H., Aman, H. M., Al-Majed, A. A., Khan, M. A., and Jilani, S.Z., "Use Of a Non-Destructive Method To Estimate Drilling Fluid Invasion Depth In Cores, Application To Formation Damage", SCA2002-19,2002.

- Peng, S. J., and Peden, J. M., "Prediction of Filtration under Dynamic Conditions", paper SPE 23824 presented at the SPE International Symposium and on Formation Damage Control, 1992.

- Salathiel, R.A., "A New Additive for Control of Drilling Mud Filtration", Petroleum Transactions, AIME paper presented at the Petroleum Branch Fall Meeting in Oklahoma City, USA, 3-5 Oct 1951.

- Schechter, R. S., “Oil Well Stimulation”, Prentice Hall, Englewood Cliffs, New Jersey, U.S.A., 1992.

- Shaw J.C. and Chee, T., “Laboratory Evaluation of Drilling Mud Systems for Formation Damage Prevention in Horizontal Wells,” paper SPE 37121 presented at the SPE International Conference on Horizontal Well Technology, Calgary, Canada,18–20 Nov. 1996.

- Smalley, R.E. and Yakobsonb, B.I., “The Future of the Fullerenes”, Solid State Communications, n. 107(11), pp. 597-606, 1998.

- Smith, P. S., Browne, S. V., Heinz, T. J., and Wise, W. V., “Drilling Fluid Design to Prevent Formation Damage in High Permeability Quartz Arenite Sandstones”, paper SPE 36430 presented at the SPE Annual Technical Conference, Colorado, USA, 1996.

- Zhou, W., Heiney, P.A., Fan, H., Smalley, R.E. and Fischer, J.E., “Single-Walled Carbon Nanotube- Templated Crystallization of H2SO4: Direct Evidence for Protonation”, Journal of the American Chemical Society, n. 127, pp. 1640-1641, 2005.

Appendices

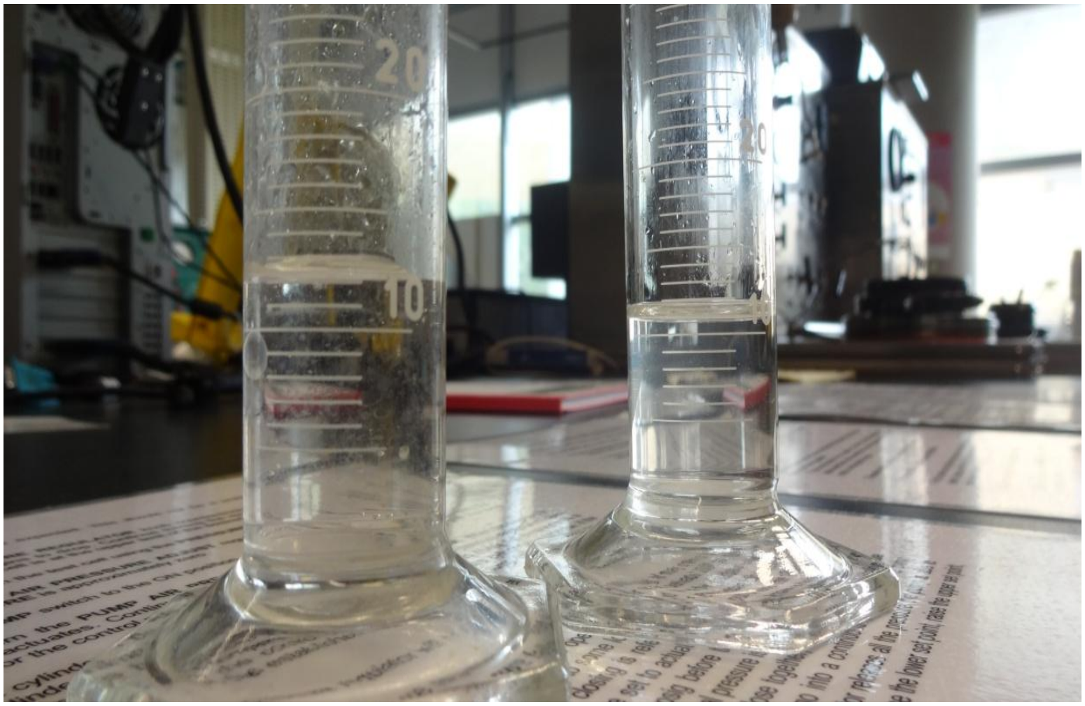
Appendix 1

Appendix 1: Milling Balls

Appendix 2

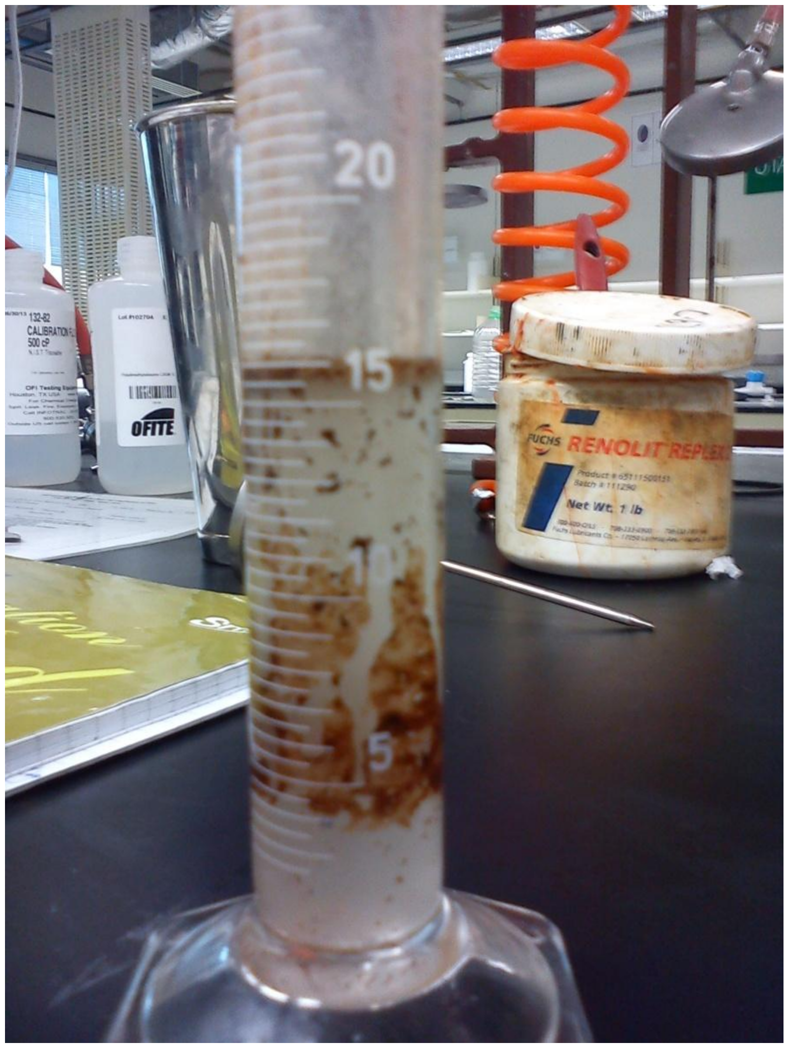
Appendix 2: Bentonite categories after milling and sieving

Appendix 3



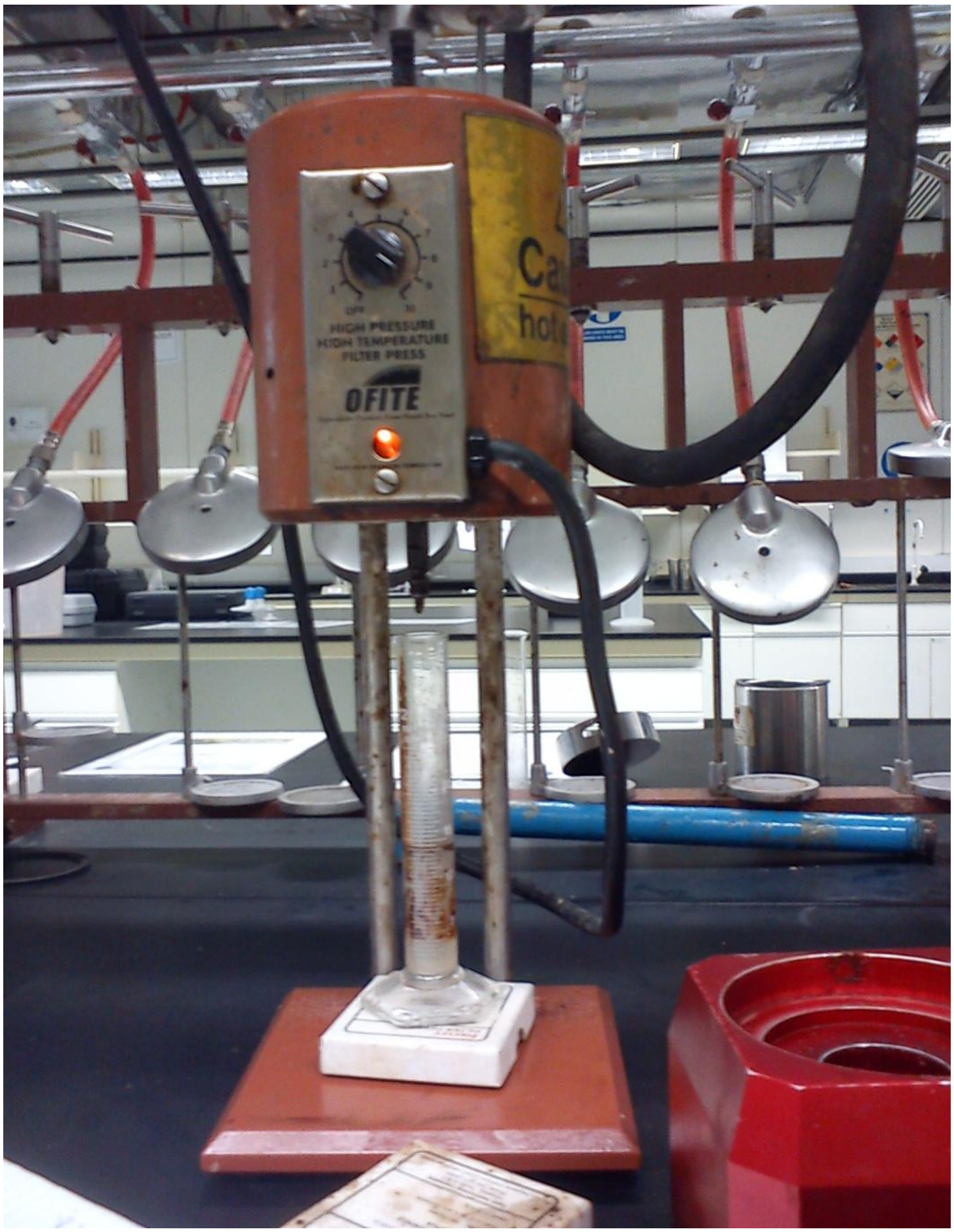
Appendix 3: LPLT Filtrate volumes of normal Bentonite (Right) and milled Bentonite (Left)

Appendix 4



Appendix 4: Normal Bentonite HPHT Filtrate

Appendix 5



Appendix 5: HPHT Filtrate press cell