Loss Circulation Material in Drilling Fluid

By

Paarthiban a/l Gunnasegaran

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

September 2011

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Loss Circulation Material (LCM) in Drilling Fluid

By

Paarthiban a/l Gunnasegaran

A project dissertation submitted to the Mechanical Engineering Programme

Universiti Teknologi PETRONAS

In partial fulfillment of the requirement for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

SEPTEMBER 2011

Approved by,

____

(Dr. Azuraien Bt. Jaafar)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

SEPT 2011

CERTIFICATION OF ORIGINALITY

This is 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 the original work contained herein have not been undertaken or done by unspecified sources or person.

____

(PAARTHIBAN A/L GUNNASEGARAN)

ABSTRACT

This report concerns on investigation on lost circulation materials (LCM) derived from pineapple peel waste for drilling fluid formulation. The project mainly aims to study the effectiveness of using pineapple peel waste as LCM additives to prevent the lost circulation problem. The significant of using the pineapple peel waste is that it has the lost circulation material characteristics to prevent the mud losses, environmentally friendly and low cost. The work consists of developing a green LCM and optimizing using innovative test methods to ensure that it meets the field criteria for addressing loss circulation problems. Prior to that, equipments that have been identified to perform the testing are multimixer, mud balance, FANN (Model 35A) viscometer, API filter press, and Electrical Capacitance Tomography (ECT). Then the LCM will be prepared in a range of particle size of 212 micron which fall in coarse grades and its amount was variables used in the tests. Overall, the results shows that addition of pineapple peel waste of 5% increases the viscosity about 20% but decreases the yield point about 21%, the gel strength about 25% and the filtration rate about 6%. Moreover, the properties of pineapple peel waste as LCM degrade the drilling mud performance by about 20% after one month and it is identified that ECT sensor able to measure the permittivity distribution of mud with LCM.

ACKNOWLEDGEMENTS

Firstly, I would like to express a token of appreciation to UTP for providing laboratory equipments, facilities and funds for me to be able to conduct this project according to plan.

I would like to take this advantage to thank my supervisor, Dr, Azuraien bt. Jaafar for sharing her knowledge, experiences and guiding me all throughout this project. I also would like to express my gratitude to Pn. Mazlin Idress from the Geoscience and Petroleum Engineering Department for sharing her knowledge in drilling fluid formulations.

Special thanks to Geoscience and Petroleum Engineering technicians, including the other Mechanical Engineering technicians for assisting and guiding me during the whole lab sessions. Finally, I am indebted to so many people who have been helping me during to completing this project, where their presences are the essence in making this project successful. They are people of my respects who involve directly or indirectly throughout this project.

LIST OF TABLLES

LIST OF FIGURES

TABLE OF CONTENTS

CHAPTER 1 : INTRODUCTION

1.1 Background Study

In oil and gas industry, drilling fluid is a fluid that used to assist the drilling process. A fluid is a substance that flows. So, drilling fluid may be either a liquid or a gas. If it is in a liquid form, drilling fluid may be water or mixture of water and oil with additives which known as drilling mud. A gaseous drilling fluid may be either dry air or natural gas. A proper designed drilling fluid will enable an operator to achieve the desired geological objectives at the lowest overall cost.

Drilling fluids have a number of important functions which are lubricating the drilling tool, suspend the drilling cuttings in the event of a shutdown during the drilling process, removing the formation cuttings from the wellbore and providing enough hydrostatic pressure to prevent formation fluids from entering into wellbore (Gray and Darley, 1980).

For drilling fluids perform these functions and allow drilling to continue, the drilling fluids must be present in the borehole. Unfortunately, undesirable formation conditions are encountered causing drilling fluids lost to the formation (Clarence O. Walker, Richmond, 1985). Loss circulation is a term that used to define the condition where lack of mud returning to the surface after being pumped down into wellbore. Loss circulation occurs when applying more mud pressure on the formation than it is strong enough to withstand, thereby mud flows into fracture that have been created. In other words, hydrostatic pressure must be exceeded before the formations will accept the lost mud (J. M. Bugbee, 1953). This process is known as overbalanced drilling. Loss circulation probably is not restricted to any area and it can occur at any depth regardless of whether the drilling mud is weighted or not (H.CH Darley, 1988). Loss circulation causes million of dollars spent to overcome problems encountered in drilling a well such as lost rig time, stuck pipes, blow outs and reduction in production (Xiaolin Lai, 2010). Loss circulation material (LCM) is a substance that added to drilling fluids when drilling fluids is encountered loss into formation (Robert J.White, 1956). LCM can be divided into three groups which are fibrous, flakes and granular (George R. Gray, 1988). Based on the results of numerous laboratory and field investigations, minimum required characteristics for best lost circulation control materials have been revealed as follows (E.Fidan, T.Babadagli and E.Kuru. 2004):

- LCM should effectively seal both unconsolidated formations and fractures in hard formations.
- Form an effective seal under both low and high differential pressure conditions.
- Final plug shear strength should be sufficiently high to support fluid column pressure, but low enough to ensure removal by washing or jetting.
- The plugging seal has to withstand both swab and surge pressures applied during drilling, tripping and casing runs.
- It should have workable or controllable set time and compatible with oil, synthetic or water-based systems.

In this study, the author has selected the pineapple peel waste to be used as LCM and LCM is develop using current testing methods according to API 13B and Electrical Capacitance Tomography (ECT) technique to further study and evaluate the effectiveness of pineapple peel as LCM.

1.2 Problem Statement

Loss circulation is one of the most severe concerns of drilling contractor and costly problems encountered in drilling a well. Loss circulation occurs when the drilling fluid flows into one or more geological formation instead of coming back to surface.

1.2.1 Problem Identification

In most cases, a lost circulation material has been used as effective method to combat lost circulation during drilling of an oil well. There is a need of LCM that is low in cost and effective in preventing the fluid loss into formations. LCM added must be compatible with all the additives that added to the mud and the LCM preferably environmentally friendly. However, most of the commercial lost circulation materials have been tested with different levels of success and seen that it is essential to develop on the problem. Thus, it is crucial to rethink the different materials to better tackle the mud losses but at the same time reduce the drilling cost operation by using daily wastes. Moreover, new technique which is ECT sensor is chosen to develop study of the effectiveness of the LCM.

1.2.2 Significant of Project

A laboratory study will undertake on pineapple peel waste as a low-cost and effective lost circulation material, as well as compare the performance of industrial LCM with this new material.

1.3 Objectives

There are several objectives that need to be achieved when completing this project. The objectives are:

- ❖ Develop green LCM from pineapple peel waste
  - ➢ Formulate water based mud that is compatible with LCM chosen and testing with current testing method
  - ➢ Study and evaluate the effectiveness of LCM and develop the studies further with ECT sensor
  - ➢ Compare the performance of the new LCM with industrialized lost circulation material
  - ➢ Determine whether the properties of pineapple peel waste as LCM degrade with time or not

1.4 Scope of Study

The scope of work for this project is involving a laboratory study on the lost circulation material (LCM) derived from pineapple peel waste for the drilling fluid formulation. It consist of the literature review which involve lost circulation problems, drilling fluid properties and compositions, lost circulation material and the properties of formulated drilling fluids that are going to be measured. The laboratory experiments will formulate water based mud with the fluid loss additive and compare the properties with the selected industrial LCM that commonly used. Plus, the efficiency of the pineapple peel waste as an additive in mud system for the ability to control lost circulation problems will be examined. Moreover, further studies are conducted to determine the permittivity distribution of the mud with LCM using ECT sensor.

1.5 Relevancy and Feasibility of the Project

This project is relevant to the author's field of majoring since loss circulation is one of the focus areas in drilling process. Moreover, LCM study as the technology of using green fruit peel waste as LCM is not yet been used in the industry. The project also in phase with the recent technology used to prevent loss circulation. In this project, the author has applied fluid mechanics and drilling process theory to study the formulation of drilling fluids and find cost-effective LCM for loss circulation problem. As a mechanical engineer, the author has evaluated the current LCM to find the most cost-effective solution where the author has proposed pineapple peel waste as new LCM and develop ECT sensor to evaluate the effectiveness of LCM while still maintaining recognized engineering, governmental standards and environmental sustainability.

The project is feasible since it is within the scope and time frame. The author has planned to complete the research and literature review by the end of the first semester while preparing the material after the mid-semester break. Author plans to dedicate the first six weeks of final year project II (FYP II) to design LCM and evaluate effectiveness of LCM using current testing method whereas the next six weeks the author plans to conduct the experiment to evaluate the properties degradation of pineapple peel waste as LCM with time (1 month) and the permittivity distribution of the LCM in mud by using ECT sensor. Finally, all the results compared with the chosen industrial LCM which is nut plug.

CHAPTER 2: THEORY & LITERATURE REVIEW

THEORY

2.1 Drilling Fluid

A drilling fluid or well known as mud, is a fluid that is used in a drilling operation in which that fluid is pumped from the surface (mud pit), down the drill pipe, through the bit, and back to the surface (mud screen) via the annulus. The drilling fluid must perform numerous essential functions that enhance penetration rates, reduce borehole problems and minimize formation damage. The primary functions of drilling fluid are to carry the drill cuttings loosened by the drill bit from the parent formation to the surface through the annulus and also to suspend the cuttings during a 'shutdown'. Other functions include cooling and cleaning the drill bit, reducing friction between the drill string and the borehole wall, maintaining stability for the uncased section of the borehole, preventing inflow of fluids from permeable rocks and forming a thin, low permeability filter cake which seals pores in formations penetrated by the drill bit (Gray and Darley, 1980). For different well, different drilling fluids have been developed and formulated in the oil industry to meet these functions and requirements.

Drilling fluids are discussed in detail in Gray and Darley (1980). They state that there are three types of drilling fluids which are:

- **Water Based Mud (WBM)** is drilling fluid that uses water as a continuous phase.
- **Oil Based Mud (OBM)** is a drilling fluid where the continuous phase is composed of liquid hydrocarbon.
- **Synthetic Based Mud** where the base fluid is synthetic oil. This is most often used on offshore rigs because it has the properties of an oil based mud, but the toxicity of the fluid fumes are much less than oil based fluid.

2.1.1 Drilling Fluid Physical Properties

Steve Devereux (1998) **s**tated that the drilling fluid properties are important to ensure the mud quality has not deteriorated and it should be treated properly if the mud quality is declined. Moreover, the mud quality must be regularly tested at the site by its specific recommended API 13B standard procedures. The properties are:

- **Density**

Mud density is widely known as mud weight in industry. This is important in maintaining well control. It is because the mud density will provide an adequate hydrostatic pressure to prevent the walls from caving in and formation fluids entering into the wellbore. In most cases, mud pressure should be higher than formation pressure to serve its function efficiently.

- **Sand Content**

There will be a presence of abrasive solid called sand in the mud and high sand content will increase wear on pumps, valves, and other equipments. However, all solids in the mud will contribute to mud abrasiveness. So, it is advisable to keep the solid content of the mud as low as possible.

- **Fluid Loss**

The fluid loss property is an indication of the mud ability to forms an effective seal against permeable formation. The formation of filter cake indicates the amount of water lost from the mud to the formation. High fluid loss mud will build up a thicker and stickier wall cake that is likely to lead to problems such as differential sticking. Ideally the mud cake should build up a thin, tough, and impermeable fairly.

2.1.2 Rheological Properties of Drilling Fluid

Rheology refers to the deformation and flow behavior of all forms of matter. The rheologic measurements made on fluids as discussed below helps to determine how this fluid will flow under a variety of different conditions. For drilling fluids, there are 3 parameters measured which are:

- **Plastic Viscosity**

Plastic viscosity is the part of flow resistance in a mud caused primarily by the friction between the suspended particles and by the viscosity of the continuous liquid phase (Principle of Drilling fluid Control). Plastic viscosity is usually regarded as a guide to solids control. PV increases when the volume percent of solids is increase or decrease when the size of particle decreases. It also represents the viscosity of mud. Low PV means mud capable drilling rapidly. High PV means the mud is too viscous which mean we have to dilute the mud so that the pump can pump the mud.

- **Yield Point**

Yield point is the measure of the electrochemical forces or attractive forces in the mud under flow conditions (Aminuddin 2006). These forces depend on surface properties of the mud solids, volume concentrations of the solids and electrical environment of the solids. This parameter helps evaluate the ability of mud to lift cuttings out of annulus.

- **Gel Strength**

Gel strength is a function of inter-particle forces. An initial 10 seconds gel and 10 minutes gel strength measurement give an indication of the amount of gellation that will occur after circulation ceased and the mud remains static. The more the mud gels during shutdown periods, the more pump pressure will be required to initiate circulation again.

2.1.3 Drilling Fluid Chemical Properties

Chemical properties can have a wide range of effects on drilling mud. Often chemicals are used to treat and adjust the mud so that control of other drilling fluid properties can be achieved. The chemical characteristics of the mud are mostly determined by wellbore stability considerations of the formations drilled through in a particular borehole section. One of the most important chemical properties that need to be considered is pH value. The control of pH value is needed to keep pH of mud high (between 9.5 – 10.5) to prevent corrosion.

2.2 Composition of Mud

Mud can be divided into 3 groups which are water based mud, oil based mud and synthetic mud. The main ingredients of mud are:

- Solids to give desired mud properties
- Inactive Solids that do not react within mud (e.g. barite, drill cuttings) to give required mud weight
- Active Solids like clays that react with chemicals (e.g. bentonite, attapulgite clays) that cause further viscosity and yield point.
- Additives that assist to control viscosity, yield point, gel strength, fluid loss, pH value, filtration behavior.

- **Mud Additives**

There are two main problems in controlling drilling fluid which are:

- Determining the drilling fluid properties such as weight, viscosity, gel strength, yield point, pH value and filtration
- Selecting the type of mud, materials and chemicals that will produce the desired mud properties at the lowest cost.

The properties of drilling mud can be adjusted to meet any reasonable set of conditions to overcome the lost circulation problem. Beside other additives in mud such as the corrosion inhibitors, emulsifiers, flocculants, shale control inhibitors and surfactants, there are four major additives that clearly needed to clarify which are:

- **Viscosity Control Additives**

It is used to control the viscosity of the mud and is being graded according to their yield points. Examples of viscosifiers are Bentonite and Polymers, while thinners are such as Phosphates and Lignites.

- **Fluid Loss Control Agents**

Fluid loss control agents are used to control the fluid loss to permeable zones to create an ideal filter cake. Bentonite is one example of effective fluid loss control agent while starch, polyacrylates and lignite are the other examples.

- **Weighting Agents**

These are agents to control the mud density and Barite is the primary weighting material used while others can be Hematite and even Calcium Carbonate.

- **pH control**

The value of pH control is needed to keep pH of mud high (between 9.5 – 10.5) to prevent corrosion and hydrogen embrittlement. Caustic soda is one of the major additives used.

2.3 Loss Circulation

Lost circulation refers to loss of the mud into a formation voids and the circulating mud fails to return to the surface (Kate Van Dyke, 2000). Lost circulation problems in drilling are not confined to any one area as they may occur at any depth where the total pressure exerted against the formation exceeds the formation breakdown pressure and there is a path that allows the mud to flow into the formation.

In general, four types of formations are responsible for lost circulation which are natural fractured formations, cavernous formations, highly permeable formations or unconsolidated formations and induced fracture formations (George C. Howard 1951).

Even with the best drilling practices, circulation losses can occurs in varying degrees and the severity of these losses is an indicator of the mud loss to the formation. Loss zones can be classified as:

Type of Loss Zones	Lost Severity (bbl/hr)
Seepage Loss	1-10
Partial Loss	10-500
Complete Loss	>500

Table 1: Loss Zone Classification (Ali A. Pilehvari 2002)

2.3.1 Loss Circulation Material

A wide variety of materials have been used to combat lost circulation over the years. The choice of lost circulation material to use in a given case is influenced to some degree by cost and availability in a given drilling area. Depending on the estimated width of the fractures, natural or induced, the LCMs are selected and mixed with drilling fluids in the form of a pill or run continuously with the fluid to treat the target zone.

2.3.1.1 Nut Plug as the industrialized Lost Circulation Material

Nut plug is a hard fibrous product made from ground walnut or pecan hulls. Nut Plug is an effective lost circulation treating material. It has a granular shape, and can be used in a blend of various sizes (fine, medium, and coarse) to prevent lost circulation or regain returns once losses begin. It is an inert additive which is compatible in all types and densities of fluids. Treating levels depend on the severity of the losses and type of formation where the losses occur. Typical treating levels for preventative measures are from 2 to 5 lb/bbl and for more severe losses use 5 to 25 lb/bbl (Mi Swaco product description).

The advantages of using nut plug as the LCM in drilling applications are:

- Inert additive, compatible in all types and densities of fluids
- Will not ferment
- Unaffected by pH or temperature
- Based on particle shape, size, and compressive strength, it is a superior lost circulation additive.

The limitations of using nut plug as the LCM are:

i. Larger-sized shale-shaker screens will be needed to retain the material in the system.
ii. When using large concentrations in non-water-base fluids, increased amounts of wetting agent may be needed.

2.3.1.2 Pineapple peel waste as a Lost Circulation Material

Pineapple (*Ananas comosus*) is the common name for a tropical plant and it is edible fruit, which is actually a multiple fruit consisting of coalesced berries. Pineapple peel waste is not only cheap but it is also environmental friendly. The peel are biodegradable over time thus it is not affect the bottom hole formation. The morphology of pineapple peel waste will be cut to be flaky type shape. The skin of pineapple also contains some fibre, thus it suitable to be as lost circulation material. From each pineapple fruit, only 52 % is used such as for canned product, jam and juice production. Remaining 48 % consists of fruit peel and leaves forming the waste. These wastes are rich in lignin and cellulose. Thus form a very good raw material for allied fibers and it is believed can be used as the loss circulation material in drilling fluids to seal the fractured formations according to its high fiber content.

LITERATURE REVIEW

For the study of LCM in drilling fluids, there are several research papers that were reviewed and studies in order to understand the scope of the topic. The research done was divided into to two categories which are the design of LCM and ECT sensor to measure the permittivity distribution of LCM in mud.

For the study of LCM, the paper entitled Laboratory Study of Lost Circulation Materials for Use in Oil-Based Drilling Mud published by T.M Nayberg and B.R Petty on 1986 was reviewed. The objective of this paper is to furnish the engineers with a simple means of estimating the appropriate LCM to be used in drilling fluid to prevent loss circulation. In this paper, it was said that LCM can be classified into 3 main categories which are fibers (exp.raw cotton, cedar wood fibers, nylon fibers, bagasse, flax shive, bark fiber, textile fiber, mineral fiber, leather, glass fiber, peat moss, feathers and beat pulp), flakes (exp. cellophane, mica, cork, corn cobs, cottonseed hulls, and vermiculite) and granules (exp. walnut shells, gilsonite, crushed coal, perlite, coarse bentonite, ground plastic, asphalt, wood, coke, and ground thermoset rubber). Moreover, it is also known that there are four basic factors affecting the performance of a LCM which are the concentration of LCM in mud, LCM particle size distribution, the size of largest particles in the material and the quantity of the largest particles.

Moreover, journal entitled High Fluid Loss, High Strength Loss Circulations Material by Mark W. Sanders, Jason T. Scorsone and James E. Friedheim published in 2010 was also reviewed. This paper is describes and discussing the development of high fluid loss, high strength pill system and its optimization using innovative testing methods to ensure that it meets field criteria to solve loss circulation problems. In this paper, it is found that the levels of complexity for evaluating LCM procedures vary. The test methods range from using simple, low pressure, API fluid loss test that use filter paper, to more sophisticated tests involving slots, ceramic discs or natural cores.

For the development of ECT technique, several books were reviewed. One of it is Drilling Fluids by Kate Van Dyke on 1951. Based on this book, it can be said that there are 5 basic properties that will be measured for the drilling fluid which are density, viscosity, rheology, fluid loss, and solids contents. The book also discussed about the current available methods to measure these properties which are mud balance, marsh funnel, pH meter, FANN (Model 35A) viscometer and High Pressure High Temperature filter press.

Besides that paper entitled Electrical capacitance tomography two-phase oil-gas pipe flow imaging by the linear back-projection algorithm by J. C. Gamio, C. Ortiz-Alemán and R. Martin which published in 2004 studied to get basic idea on ECT. It can be concluded that ECT sensor is a vessel that surrounded with a set of electrodes (metallic plates) which used to take capacitance measurements between each unique pair of electrodes. From these measurements, the permittivity distribution of the mixture which is related to the concentration the fluids can be deduced. ECT also offers some advantages over other tomography modalities, such as no radiation, rapid response, low-cost, being non-intrusive and non-invasive, and the ability to withstand high temperature and high pressure.

Paper entitled Electrical Capacitance Tomography – A Perspective by Q. Marashdeh, L.-S. Fan, B. Du, and W. Warsito published in 2008 was also studied. This paper describes the recent progress in research and development on electrical capacitance tomography (ECT). From the paper, it is known that ECT is a technique for measuring and displaying the concentration distribution of a mixture of two insulating (dielectric) fluids, such as oil, gas, plastic, glass and some minerals, located inside a vessel. Specifically, the article also highlights several aspects of ECT including the electrical capacitance volume tomography (ECVT) and the way the image constructed.

CHAPTER 3: METHODOLOGY

3.1 Project Work

The assessment on the efficiency of pineapple peel waste as LCM using current testing method and ECT sensor will be constructed based on several studies and experiment conducted on the properties of the LCM such as mud density, rheology of LCM, filtration and thickness of mud cake. There are 3 experiments planned to be conducted which are:

- **Experiment 1:** Study and determination of effectiveness of LCM using current testing method
- **Experiment 2:** Study the degradation of LCM performance in time
- **Experiment 3:** Develop ECT sensor and study the permittivity distribution of the mud with the LCM

The project activities flow is shown in Table 2.

<table>
<tr><th>Activities</th><th colspan="2">Description</th></tr>
<tr><td>Research and Review Literatures</td><td colspan="2">- Building the research base
- Extract relevant parameters and procedures</td></tr>
<tr><td>Preparation of LCM and mud formulation</td><td colspan="2">- Prepare pineapple peel in powder form prior to mix with mud
- Design mud formulation for water base mud system to analyze the LCM applicability and effectiveness
- Tools required (mortar grinder, sieve shaker and multimixer)</td></tr>
<tr><td>Testing mud plus industrial used LCM</td><td colspan="2">- Prepare water based mud plus with nut plug
- Measure all the properties of mud prior to comparison with pineapple peel later</td></tr>
<tr><td rowspan="3">Testing mud plus new LCM</td><td>Properties</td><td>Tools Required</td></tr>
<tr><td>Density</td><td>Mud Balance</td></tr>
<tr><td>- Plastic Viscosity
- Gel Strength
- Yield Point</td><td>FANN (Model 35A) Viscometer</td></tr>
</table>

	- Filtrate Volume - Mud cake thickness	Low Pressure Low Temperature Filter Press Vernier Caliper
Testing of new LCM after 1 month ☆	- Determine the degradation of LCM performance with time	
Testing with ECT sensor ☆	- Study the permittivity distribution of mud plus LCM	
Analyze the Results ☆	- Discuss the findings from the results obtained and make a conclusion out of the study	
Report Writing ☆	- Compilation of all works into a final report	

☆ Task completed

3.2 Preparation of Additives

The pineapple peel additive was prepared (refer Appendix B) by first collecting the pineapple peel from the fruit and let it dried naturally over the heat of the sun. After the drying process, it was typically being cut into smaller pieces, so it would be easier to grind and blend for further use. Next, the additive was put into the dehumidifying process for 16 hours at $80^{o}C$ in an oven. A Mortar Grinder is then being used to grind the additives into powder form. After that, the particle size will be determined by using a Sieve Shaker. The particle size of the pineapple peel waste chosen to be used for this project is 212 micron. The selected sizes were being chosen because it is the recommended particle sizes as mentioned in API 13B-1:

Particle Size (microns)	Particle Classification
>200	Coarse
200-250	Intermediate
250-74	Medium
74-44	Fine
44-2	Ultra Fine
2-0	Colloidal

Table 3: Particle Classification (Source: API Bul. 13C (June 1974), American Petroleum Institute, Dallas)

3.3 Mud Formulation

Due to laboratory equipments limitations, only water base mud with LCM additives can be done and any changes of the mud properties were observed carefully. The composition of the mud base samples and additives used in the experiment were:

Component	Base WBM Sample	Base WBM Sample + LCM
Water, (ml)	318.73	318.73
Soda Ash, (g)	0.5	0.5
Bentonite, (g)	12	12
Caustic Soda, (g)	0.25	0.25
Flowzan, (g)	0.3	0.3
API Barite, (g)	109.19	109.19
Nut Plug, (g)	-	5 & 10
Pineapple peel, (g)	-	5 & 10

Table 4: Mud formulation for 1 barrel of water base mud

The mud formulations were tested using standard procedures according to Drilling Engineering UTP laboratory manual (refer Appendix A).

3.4 ECT Sensor Setup

The permittivity tomogram displays a circular permittivity distribution for a circular sensor respectively. A colour-scale is used to display the variation in permittivity for ECT. The software utilises a linear back projection image reconstruction algorithm. This offers fast processing times in comparison to other algorithms; however, it does produce qualitative rather than quantitative images. When you move over an image with the mouse pointer, information about the pixel which is selected will be displayed on the status bar. This function is only available when the program is not busy with playback or data collection i.e. it only works when data collection is stopped and images are viewed one at a time.

The inverse problem is to determine the conductivity distributions (x,y) from a finite number of boundary voltage measurements. The linear back-projection algorithm back projects the capacitance measurements to permittivity values within the pixels for all possible injection and measurement combinations using the sensitivity map calculated. The image is therefore reconstructed via a matrix/vector multiplication which can be performed rapidly on modern personal computers.

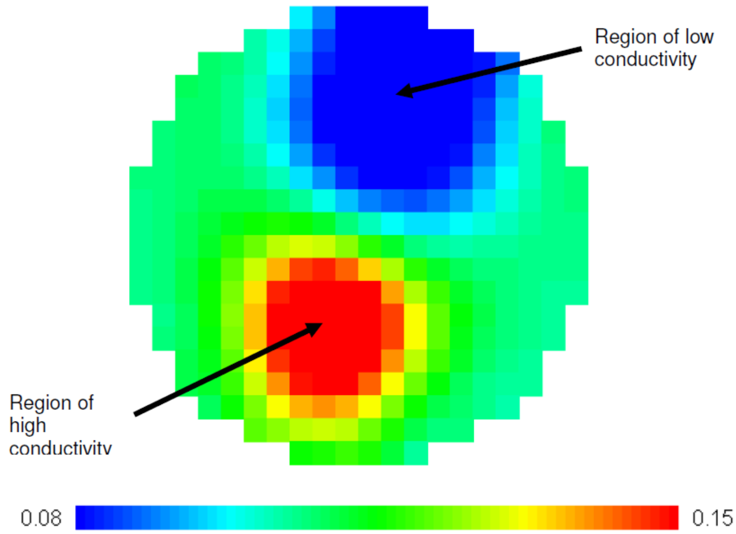


Figure 1 Tomogram showing region of high and low permittivity

Figure 1 show a typical tomography image obtained from the linear back-projection algorithm. The image contains a region of high conductivity indicated by the colour red and a region of low conductivity indicated by the colour blue. The scale below the image relates colour to conductivity. In this case the scale is between 0.08 and 0.15 mS/cm.

The measurements are taken by using Tomography Toolsuite software as shown below.

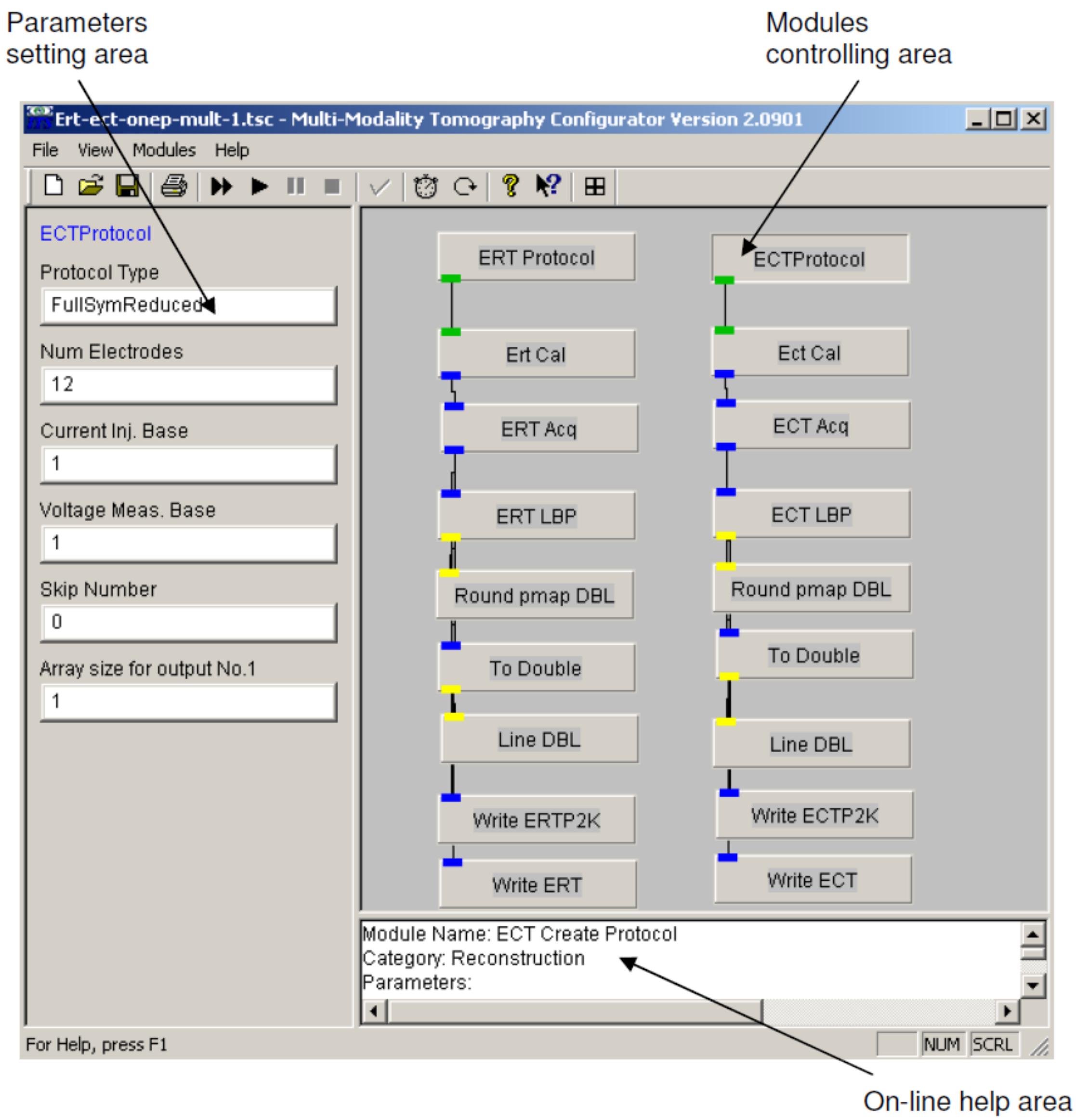


Figure 2 ITS m3000 software- Main GUI Configuration

Refer to figure above the measurements are taken by following procedures:

- Click the ‘*cal’ (eg. ErtCal or EctCal) box in the flow chart to set the calibrate reference in lowercase as ‘0’.
- Press start button to get the low reference measurement.
- Click the ‘*Cal’ box to set the calibrate reference in high case as ‘1’.
- Click the ‘write ECT/ERT TFC’ box to set the ‘multiple frames’ as ‘1’.
- Press the start button to get the high reference measurement.
- Click the ‘*Cal’ box to set the on-line measurement as ‘2’
- Operational - If you would like take block data measurements (in a fast process) online then you should click the ‘ERT/ECT Acq’ box to set the ‘bulk transfer’ for the number of frames to be acquired
- Click the start button for the system to commence taking data.
- Set the clock in the tool bar as any time (e.g. 100ms) – normally after low and high calibration, the system will do the continuous measurements until you press stop button.

3.2 Gantt Chart and Key Milestone

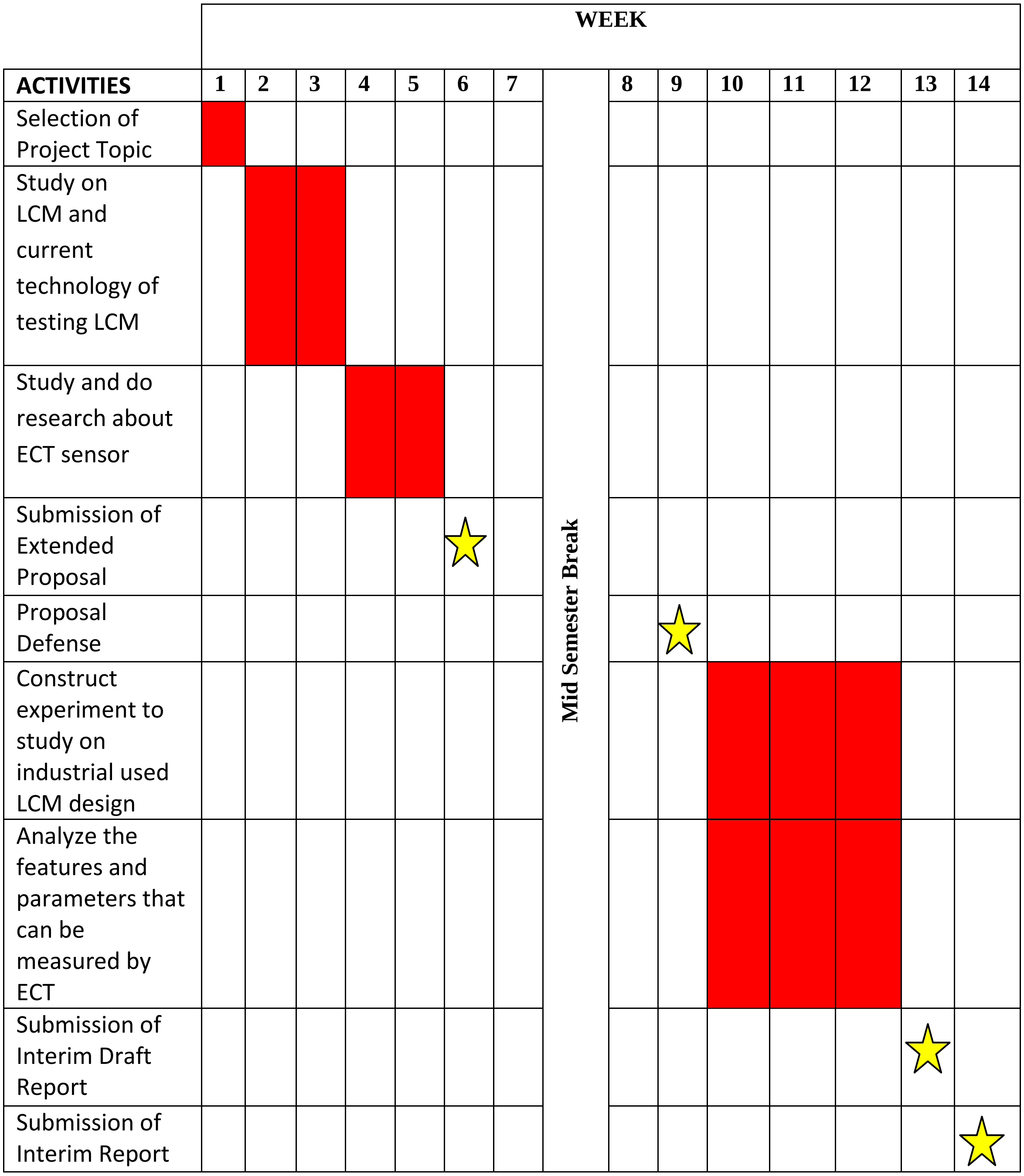
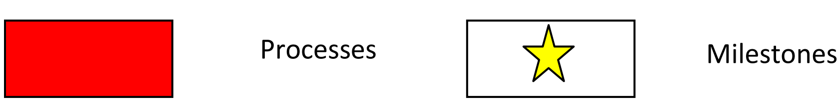


Figure 1: Gantt chart for the first semester project implementation



	WEEK															
ACTIVITIES	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
LCM preparation	■	■	■	■												
Construct experiment to study on new LCM (pineapple peel) design					■	■	■									
Submission of progress report									★							
Testing on the degradation of new LCM properties by constructing the experiment after kept the mixed mud for 1 month								**Mid Semester Break**	■	■						
Set up ECT sensor and do testing on the new LCM											■	■				
Compare and analyze the results													■			
Pre-EDX												★				
Submission of dissertation (soft bound)														★		
Submission of technical paper														★		
Oral presentation															★	
Submission of project dissertation (hard bound)																★

Figure 1: Gantt chart for the second semester project implementation

■ Processes ★ Milestones

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Result

The experiments were conducted according to the standard which has stipulated in American Petroleum Institute - API 13B-1; ‘’Recommended Practice Standard Procedure for Testing Water-Based Drilling Fluid’’. Sample 1 actually is the base (WBM without LCM) case for this experiment. Other drilling mud samples were prepared in order to measure the change in properties of the mud. Plus, the existing industrial lost circulation material, Nut Plug was tested and it will be used as comparison to the pineapple peel (new LCM) properties. Below are the formulations of the mud that have been tested.

	Base Sample (WBM)	**WBM + Nut Plug (NP)**		**WBM + Pineapple Peel Waste (PPW)**	
Products	**B1**	**NP-A**	**NP-B**	**PPW-A**	**PPW-B**
Water (ml)	318.73	318.73	318.73	318.73	318.73
Soda Ash (g)	0.50	0.50	0.50	0.50	0.50
Bentonite (g)	12.00	12.00	12.00	12.00	12.00
Flowzan (g)	0.30	0.30	0.30	0.30	0.30
Caustic Soda (g)	0.25	0.25	0.25	0.25	0.25
API barite (g)	109.19	109.19	109.19	109.19	109.19
Nut Plug (g)		5.00	10.00		
Pineapple Peel Waste (g)				5.00	10.00
Results					
Mud weight (ppg)	9.5	9.5	9.5	9.5	9.5
Rheology at	120F	120F	120F	120F	120F
600 rpm	44	49	50	44	43
300 rpm	31	36	35	34	31

200 rpm	24	29	25	28	25
100 rpm	20	23	20	20	18
6 rpm	8	11	8	15	16
3 rpm	7	10	7	9	11
PV (cP)	13	13	15	10	12
YP (lb/100ft²)	18	23	20	24	19
Gel 10 sec	8	10	10	14	12
Gel 10 min	14	17	12	20	15
Mud Cake Thickness (mm)	1.1	2.3	2.1	2.4	2.2
API , cc/30min	17.4	13.9	14.8	14.4	13.6
Spurt Loss	8.4	5.5	6	6.2	7

Table 5: Properties of mud tested for 212 microns of Nut Plug and Pineapple Peel Waste

4.2 Discussion

- **Mud Weight**

In this experiment, API Barite is added into the mud as weighting agent, as the amount of barite increased, the mud weight of the formulation is increased as well. Density is the most important mud property affecting penetration rate. For any given formation pressure, the higher the density, the greater will be the differential pressure. The mud maybe unnecessarily heavy and the additional weight may cause lost circulation (Aminuddin, 2006). So, the mud weight must be sufficient to confine the formation fluid but not great enough to break it down. In the experiment, the mud weight chosen to be set about 9.5 ppg since the recommended amount of mud weight in the field is around 8 to 11 ppg based on Scomi Oiltools manual handbook.

- **Plastic Viscosity**

Viscosity is the term that describes resistance to flow. So high force need to be applied for move the high viscosity liquids, whereas low viscosity fluids flow relatively required less force and easy to move. Plastic viscosity is a function of solids concentration and shape. It will be expected to increase with decreasing particle size with the same volume of solids. Moreover, it also can be increased by addition of more lost circulation material in the mud. This can be proven in the experiment as the amounts of LCM are increased, the value of PV also increased. In short, PV should be as low as possible in order to have low pumping rate for mud circulation.

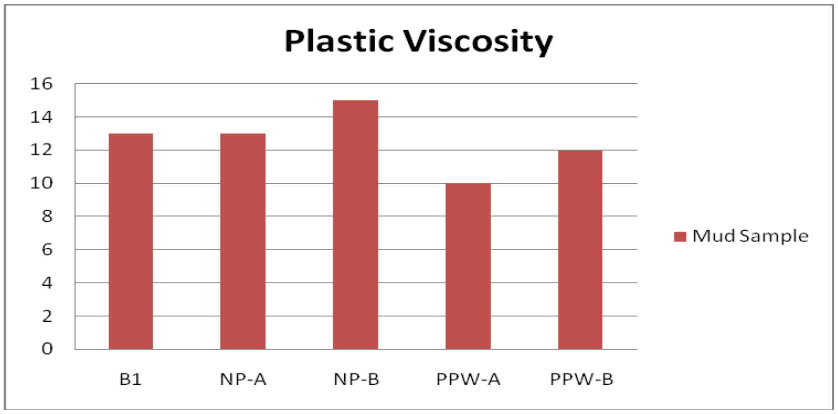


Figure 5: Plastic Viscosity of B1, NP-A, NP-B, PPW-A and PPW-B mud sample

- **Yield Point**

Yield point is the attractive force in the mud under flow conditions. The magnitude of these forces will depend on the type of their solid present, the ion concentration in the liquid phase (Growcock F, 2005). From the figure below which represents by the mud plus LCM concentration of 5 lb and 10 lb, the value of yield point for mud decreased as the concentration of LCM increased.

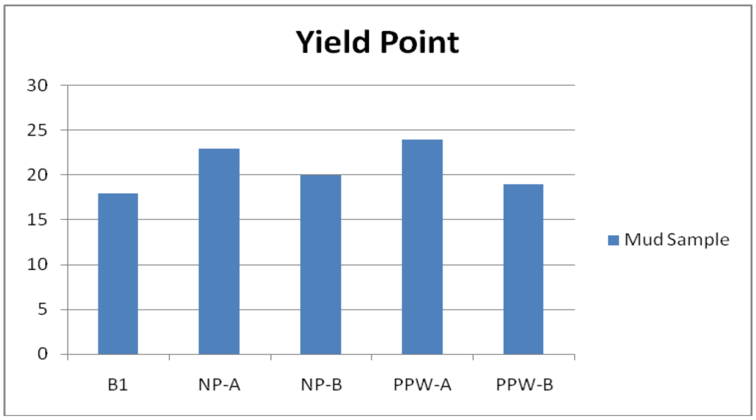


Figure 6: Yield Point of B1, NP-A, NP-B, PPW-A and PPW-B mud sample

Supposedly the value of yield point will increase as the amount of solid increased. It is different compared to the actual results obtained due to human error while conducting the experiment or due to the fact that pineapple peel LCM has certain effect that reduce the attraction force between solid particles.

- **Gel Strength**

Gel strength indicates the pressure required to initiate flow after the mud has been static for some time and the suspension properties of the mud. Shortly we can say that gel strength is the ability to suspend cuttings when the mud is stationary. For a drilling fluid, the fragile gel is more desirable. Gel strength, 10 seconds and 10 minutes indicate the strength of attractive forces (gelation) in drilling fluid under static condition. Excessive gelation is caused by high solids concentration leading to flocculation. The 10 minutes gel strength will cause the higher gel strength as the particles have more time to arrange themselves in a proper manner in which the repulsive and attractive forces best satisfied. As both the graph shown, they illustrate that the values obtained tend to decrease as the amount of LCM is increased. In general, high gel strengths are not desirable and can even be dangerous. Though, the desire gel strength can be achieved by controlling the LCM concentration.

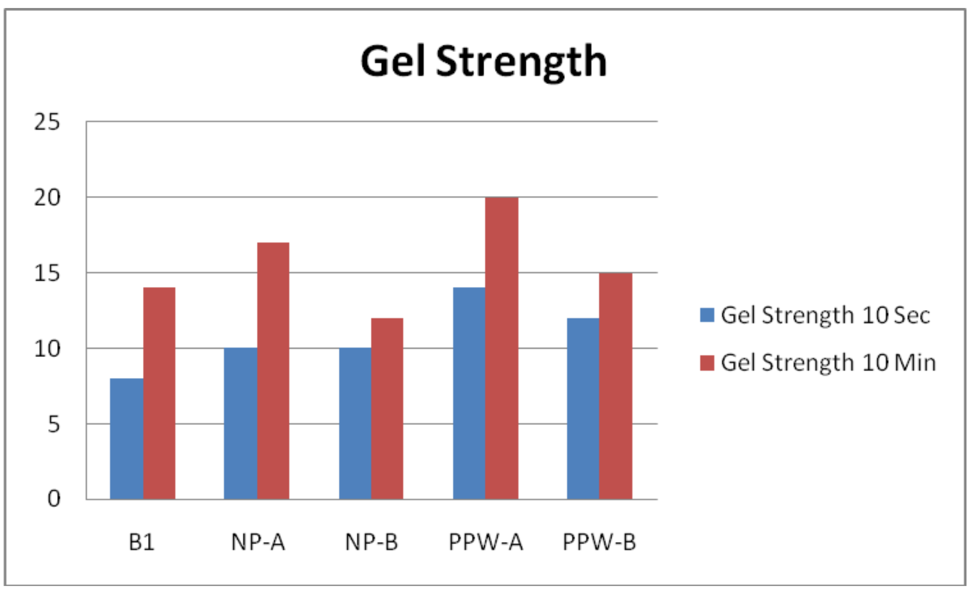


Figure 7: Gel Strength of B1, NP-A, NP-B, PPW-A and PPW-B mud sample

- **Mud Cake and Filtrate**

Based on the experiment, it is observed that the solid from the mud will form a layer of solid called "mud cake" against the formation face when pressurize the mud. Besides that, filtrate is an indication of amount of water lost from the mud to the formation where it simulates the quantity of fluid loss inside the wellbore. The preferable filter cake should be thin, impermeable, and have correct solids distribution to prevent fluid loss effectively. Thick filter cake reduces the effective borehole diameter and increases the chance of stuck pipe. The lower the filtrate volume the thinner the mud cakes, means that good fluid loss control in mud. When the LCM concentration is increased, the filtrate volume will be less. For the nut plug the results obtained for the amount filtrate is slightly increase when the concentration of LCM is increased due to some human error. As expected that pineapple peel gave lower filtrate volume when the LCM concentration is increased. This proves the fact that as the amount of additives is increasing, the viscosity increased too, causing the water to be less filtered. Hence, we can conclude that the higher the LCM concentration of the mud, the better the mud formulation is.

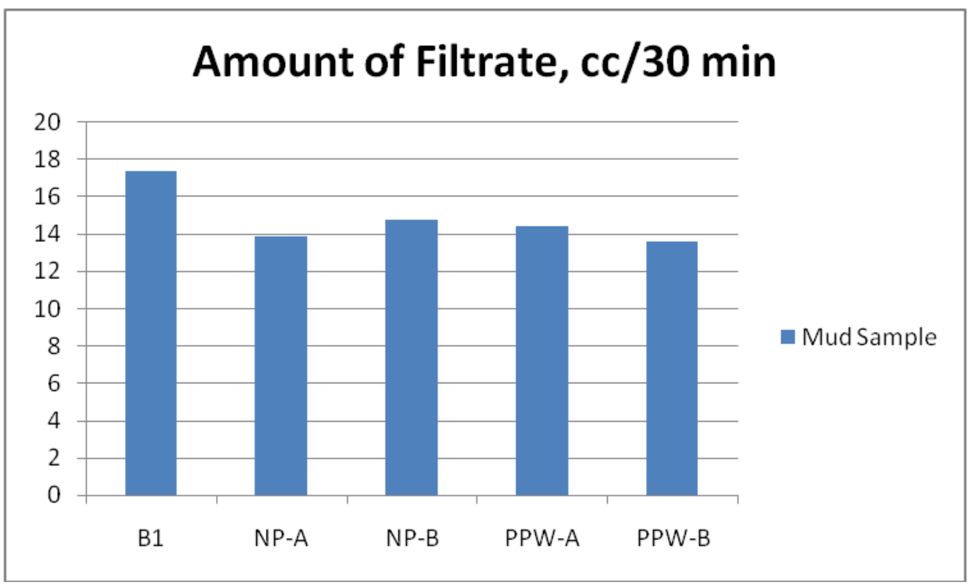


Figure 8: Amount of filtrate of B1, NP-A, NP-B, PPW-A and PPW-B mud sample

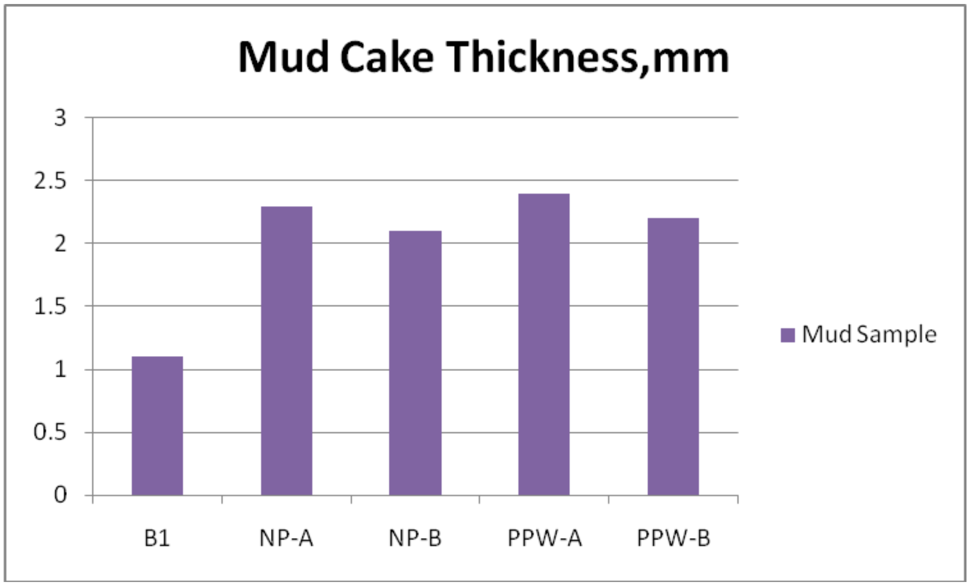


Figure 9: Mud Cake Thickness for B1, NP-A, NP-B, PPW-A and PPW-B mud sample

Based on the results and discussions above, the optimum concentration of pineapple peel waste is 10g. So, this concentration was chosen and tested after 1month from the day of mixing to evaluate the properties degradation of the pineapple peel waste as LCM. The results are shown below:

Products	**WBM + Pineapple Peel Waste (PPW)**	
	PPW-B	**PPW-C (After 1 month)**
Water (ml)	318.73	318.73
Soda Ash (g)	0.50	0.50
Bentonite (g)	12.00	12.00
Flowzan (g)	0.30	0.30
Caustic Soda (g)	0.25	0.25
API barite (g)	109.19	109.19
Nut Plug (g)		
Pineapple Peel Waste (g)	10.00	10.00
Results		
Mud weight (ppg)	9.5	9.5
Rheology at	120F	120F
600 rpm	43	50
300 rpm	31	36
200 rpm	25	31

100 rpm	18	24
6 rpm	16	18
3 rpm	11	13
PV (cP)	12	14
YP (lb/100ft²)	19	22
Gel 10 sec	12	14
Gel 10 min	15	19
Mud Cake Thickness (mm)	2.2	2.5
API , cc/30min	13.6	16.4
Spurt Loss	7	9

Table 6: Properties of mud tested for 10g of Pineapple Peel Waste after 1 month

Based on the results obtained, viscosity is increased about 16.7%, the yield point is increased about 16.8%, the gel strength is increased about 26.7%, the mud cake thickness is increased about 13.6% and the amount of filtrate is increased about 20.6%. In short, the properties of pineapple peel waste as LCM was degrade totally about 20% in time period of 1 month.

For ECT sensor testing, the choice of the electrode number is based on the data acquisition system available for experiments, which are 8 channels. The sensor design is equivalent to the rectangular sensor arrangement of eight-electrode sensors per plane. The length of the sensing domain is 10 cm. The volume images are reconstructed at 20 x 20 x 20 resolution. There are 66 combinations of independent capacitance measurements between electrode pairs.

In order to illustrate the permittivity distribution of LCM in mud, the synthetic response for a eight-electrode ECT sensor was computed. The capacitance values for all single-electrode combinations were calculated. It considered a two-component distribution with a lower permittivity material of 0 (water) and a higher permittivity material of 1 (mud). The flow pattern that used in this study is annular flow. The image reconstruction algorithm generates the permittivity map determined corresponding to the apparent permittivity of the mixed two phases of the system imaged. Results are shown below and quality of the reconstructed images is not quite good.

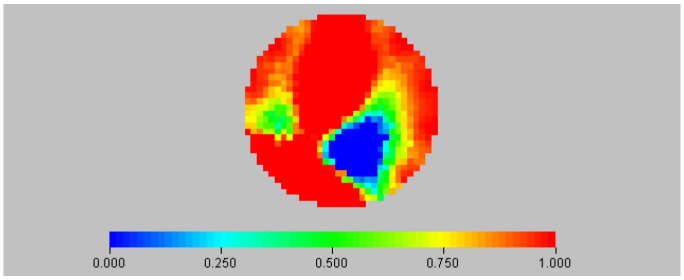


Figure 10: Image reconstruction of low permittivity material 0f 0 (water) during calibration test

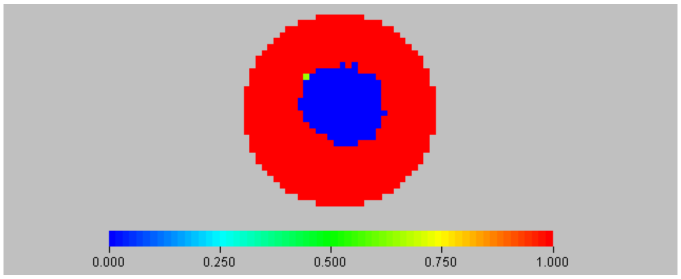


Figure 11: Image reconstruction of high permittivity material 0f 1 (mud) during calibration test

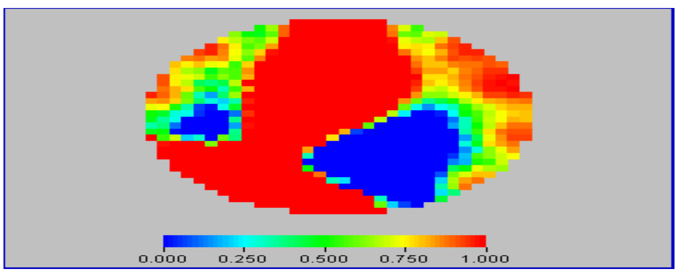


Figure 12: Image reconstruction of permittivity distribution of LCM in mud during online test

Visualizations of permittivity distribution of LCM in mud is limited because half of the image contours are not specifically interfaces; however they give a regular indication of the permittivity distribution of the LCM in mud. It is because there is exists a resolution trouble in the central zone of the sensor where some kind of phantom can be seen in some of the snapshots mainly caused by errors introduced at the normalization stage. The error calculated during the normalization stage is about 25% for high permittivity material calibration test and about 75% for low permittivity material calibration test as shown below:

Permittivity	Theoretical Value	Experimental value	Error (%)
Low	0	0.75	75
High	1	0.75	25

Table 7: ECT Sensor Calibration Test

CHAPTER 5: CONCLUSION & RECOMMENDATION

Lost circulation material is very important in preventing mud losses to the formation. Even with the best drilling practices lost circulation still occur. Thus it is essential to put lost circulation material to minimize mud losses to the formation and pineapple peel was chosen to be the lost circulation material in this project. The performance of a drilling fluid can be optimized by monitoring and controlling the density, viscosity, yield point, gel strength and filtration characteristics which can be achieved by modifying its components and additives.

As a result of the analysis of the study of pineapple peel waste as LCM, it can be concluded that it is justified that pineapple peel waste is appropriate and can be used as a new LCM. The results show that as the amount of additives is increased by 5%, the yield point about 21%, gel strength about 26.7%, filtration rate about 6% and the mud thickness will decreased as well. Meanwhile, the plastic viscosity shows a reverse relationship with the added amount and went increased about 20% as the amounts of additives were added progressively. Hence, the LCM concentration did affected and has a direct relationship with properties measured. Based on the analysis, the optimum value for the best concentration is obtained at the amount of LCM of 10g.

The properties of pineapple peel waste as LCM degrade the drilling mud performance by about 20% in time (after 1 month). It is identified that ECT sensor is able to measure the permittivity distribution of mud with LCM but certain modification and further calibration is required on the sensor for a more accurate result.

Overall, it is justified that pineapple peel waste is appropriate and can be used as a new LCM because of its availability, cost effective, environmentally friendly and effective in combating loss circulation problem. However, there are still a lot of things need to be done first before the product can be commercialized to the market as the experiments only covered the testing of the mud with coarse size pineapple peel waste only. Further testing with all different particle size (fine, medium and coarse) are still needed to confirm the effectiveness of using pineapple peel waste as lost circulation material n the industry.

More tests should be conducted to get an accurate result such as High Temperature High Pressure 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 such as pH, alkalinity, calcium content, salt content, and others that affect the performance of the drilling mud. These tests should be able to justify, identify and investigate further the properties of the fluid.

Then a proper study using complete water based mud system with the inclusion of pineapple peel as its additive can be tested under the chosen reservoir conditions for any particular field. This particular study will be very beneficial to the drilling fluids company out there. It will certainly enable them to operate with water based mud and pineapple peel as LCM system under extreme condition which is far cheaper and environmentally friendly.

REFERENCES

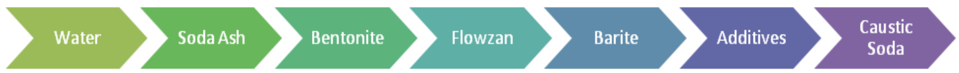
1. Van Dyke, Kate, 1951 - Drilling Fluids, 1st Edition, Rotary drilling series; unit II, lesson 2, ISBN 0-88698-189-1.
2. Van Dyke, Kate, 1951 - Drilling Fluids, mud pumps and conditioning equipment, 1st Edition , Rotary drilling series; unit I, lesson 7, ISBN 0-88698-181-6.
3. Electrical Capacitance Tomography, http://www.ect-instruments.com/ect.htm, 20 June 2011.
4. Q. Marashdeh, L.-S. Fan,* B. Du, and W. Warsito, 2008, Electrical Capacitance Tomography - A Perspective, Journal of Department of Chemical and Biomolecular Engineering, The Ohio State University, Columbus, Ohio 43210, 47, 3708-3719.
5. Mark W. Sanders, Jason T. Scorsone and James E. Friedheim, SPE,MI-SWACO 2010, High Fluid Loss, High Strength Loss Circulations Material, Journal of Society of Petroleum Engineers, SPE 135472.
6. T.M Nayberg and B.R Petty, 1986, Laboratory Study of Lost Circulation Materials for Use in Oil-Based Drilling Mud, Journal of Society of Petroleum Engineers, SPE 14995.
7. Clarence O. Walker, Richmond, 1985, Encapsulated Water Absorbent Polymers As Loss Circulation Additives for Aqueous Drilling Fluids, US Patent Number – 4664816.
8. H.C.H. Darley, and George R. Gray, (1988), Composition and Properties of Drilling and Completion Fluids, 5th ed. USA: Gulf Professional Publishing.
9. Kate Van Dyke, (2000), Drilling Fluids, 1st ed, USA: Petroleum Extension Service.
10. Devereux, Steve, (1999), Drilling Technology in Nontechnical Language, Pennwell Corporation.
11. Aminuddin, M, (2006), Performance of Ester-Internal Olefin Based Drilling Fluid. Universiti Teknologi Petronas.
12. Gray G.R and Darley H.C.H (1983), Compositional and Properties of Oil Well Drilling Fluid, 4th Edition, Gulf Publishing Company, Taxes.
13. Growcock F. (2005). Driilling Fluids. ASME Shale Shaker Committee, Elsivier, USA.

14. Recommended practice standard procedure for field testing oil-based drilling fluids. (1998). American Petroleum Institute.
15. J. M. Bugbee (1953), Lost Circulation – A Major Problem in Exploration and Development, SPE Paper , American Petroleum Institute.
16. Ali A. Pilehvari and Venkata R. Nyshadham (2002), Effect of Material Type and Size Distribution on Performance of Loss/Seepage Control Material, SPE Paper 73791, Texas A&M University-Kingsville.
17. Robert J. White, Baroid Div, 1956, "Lost-circulation Materials and their Evaluation", National Lead Co.
18. Xiaolin Lai, Jianhua Guo, and Yaxian Zhou, 2010, "A New Water-absorbent Resin for Lost Circulation Control", Zhongyuan Drilling Engineering Technology Institute of Sinopec, Society of Petroleum Engineers.
19. George C. Howard and P.P. Scott Jr. (1951), An Analysis and The Control of Lost Circulation, Stanolind Oil and Gas Co. Tulsa, Okla.
20. E. Fidan, T. Babadagli and E. Kuru, 2004, 'Use of Cement As Lost Circulation Material - Field Case Studies', Journal of Society of Petroleum Engineers, SPE 88005.
21. J. C. Gamio, C. Ortiz-Alemán and R. Martin, 2004, 'Electrical capacitance tomography two-phase oil-gas pipe flow imaging by the linear back-projection algorithm', Geofísica Internacional (2005), Vol. 44, No. 3, pp. 265-273.
22. Scomi Oiltools Manual Handbook.
23. UTP Department of Geosciences and Petroleum Engineering Laboratory Manual.
24. Zakuan, A (2006). The Investigation of Corn Cobs and Sugar Cane Waste as a Drilling Fluid Additive, Universiti Teknologi Petronas.
25. Ortiz-Aleman, C., R. Martin and J. Gamio, 2004.Reconstruction of permittivity images from capacitancetomography data by using very fast simulated annealing. Measur. Sci. Tech., 15, 1382-1390.
26. Isaksen, O., 1996. A review of reconstruction techniques for capacitance tomography. Measur. Sci. Tech., 7, 325-37.

APPENDIX A

Experiment procedure:

API RP 13B-1: Recommended Practice Standard Procedure for Field Testing Water-Based Drilling Fluids.



<u>MUD MIXING</u>

i. Add **0.5** ± 0.01 g of **soda ash** into **318.73** ± 5 cm^3 **deionized water** while stirring.

ii. After 2 ± 0.5 minutes, prepare a suspension of 75 µm bentonite powder by adding **12** ± 0.01 g of **bentonite** into the mixture while stirring.

iii. After stirring for 7 ± 0.5 minutes, add **0.3** ± 0.01 g of viscosifier or commercially known as **flowzan** into the mixture.

iv. From time to time, remove the container from the mixer and scrape its side with the spatula to dislodge any bentonite adhering to the container walls. All bentonite clinging to the spatula are being assured to incorporate into the suspension.

v. After stirring for 12 ± 0.5 minutes, add **109.19** ± 0.01 g of **barite** into the mixture.

vi. After 30 minutes, add the **additives** into the mixture carefully.

vii. Lastly, add **0.25** ± 0.5 g of **caustic soda** into the mixture.

viii. The container is then will be replaced and continued to stir. The container may need to be removed from the mixer and the sides scraped to dislodge any bentonite clinging to container walls after another 5 minutes therefore total stirring time is equal to 40 ± 1 minute.

MUD WEIGHT OR DENSITY TEST:

1. Remove the lid from the cup, and completely fill the cup with the mud to be tested.
2. Replace the lid and rotate until firmly seated, making sure some mud is expelled through the hole in the cup.
3. Wash or wipe the mud from the outside of the cup.
4. Place the balance arm on the base, with the knife-edge resting on the fulcrum.
5. Move the rider until the graduated arm is level, as indicated by the level vial on the beam.
6. At the left-hand edge of the rider, read the density on either side of the lever in all desired units without disturbing the rider.
7. Note down mud temperature corresponding to density.

MUD VISCOSITY:

1. With the funnel in an upright position, cover the orifice with a finger and pour the freshly collected mud sample through the screen into a clean, dry funnel until the fluid level reaches the bottom of the screen (1500 ml).
2. Immediately remove the finger from the outlet and measure the time required for the mud to fill the receiving vessel to the 1-quart (946 ml) level.
3. Report the result to the nearest second as Marsh Funnel Viscosity at the temperature of the measurement in degrees Fahrenheit or Centigrade.

VISCOSITY:

1. Place a recently agitated sample in the cup, tilt back the upper housing of the viscometer, locate the cup under the sleeve (the pins on the bottom of the cup fit into the holes in the base plate), and lower the upper housing to its normal position.
2. Turn the knurled knob between the rear support posts to raise or lower the rotor sleeve until it is immersed in the sample to the scribed line.
3. Stir the sample for about 5 seconds at 600 RPM, and then select the RPM desired for the best.
4. Wait for the dial reading to stabilize (the time depends on the sample's characteristics).
5. Record the dial reading and RPM.

RHEOLOGICAL CALCULATIONS

1. Plastic viscosity (in centipoise-up):

Plastic Viscosity = μ p = 600 RPM reading - 300 RPM Reading

2. Apparent Viscosity (in centipoise-cp):

$$\text{Apparent Viscosity} = \mu a = \frac{600 RPM\ reading}{2}$$

3. Yield Point (in lb/100 ft^2):

Yield Point = Y. P. = 300 RPM Reading - Plastic Viscosity

GEL STRENGTH:

1. Stir a sample at 600 RPM for about 15 seconds.
2. Turn the RPM knob to the STOP position.
3. Wait the desired rest time (normally 10 seconds or 10 minutes).
4. Switch the RPM knob to the GEL position.
5. Record the maximum deflection of the dial before the Gel breaks, as the Gel ($lb/100\ ft^2$ x 5.077 = Gel strength in $dynes/cm^2$).

YIELD POINT:

1. Obtain a recently agitated mud sample from each of mud tanks (1) and (2).
2. Using the FANN Viscometer, obtain dial readings at 3, 300 and 600 RPM.
3. By means of the viscometer calculations procedure, determine the Apparent and Plastic Viscosities, Yield Point and initial 10 sec. and final 10-minutes Gel Strength parameters.

FILTRATION:

1. Detach the mud cell from filter press frame.
2. Remove bottom of filter cell, place right size filter paper in the bottom of the cell.
3. Introduce mud to be tested into cup assembly, putting filter paper and screen 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. Place a graduated cylinder underneath to collect filtrate.
6. Open air pressure valve and start timing at the same time.
7. Report cc of filtrate collected for specified intervals up to 30 minutes.
8. Tabulate the results in an appropriate table.

APPENDIX B: Preparation of additives

Pineapple peel waste dried under hot sun

Pineapple peel waste cut into small pieces and dried further in oven for16 hours at 80^{o}

Then the fully dried pineapple peel is blendered using mortar grinder

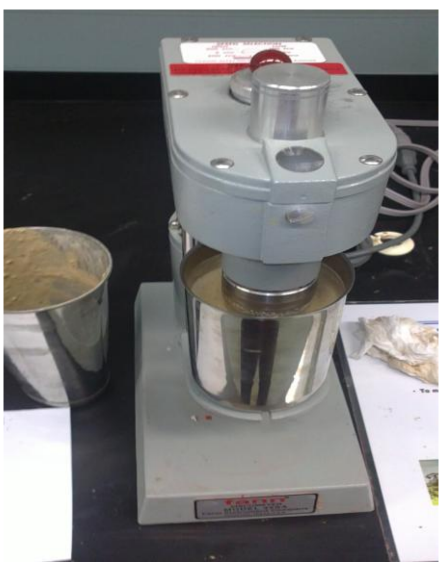
The blendered pineapple peel is sieved to get coarse size which is more than 212 micron

APPENDIX C: Mud plus LCM (pineapple peel) testing

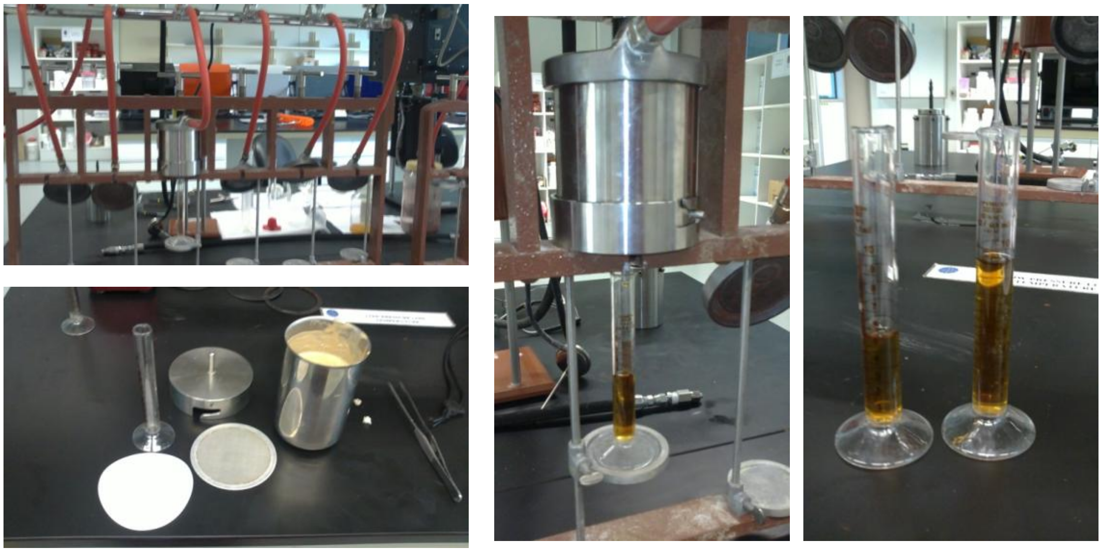
Components preparation

Mud mixing

Mud density test



Mud rheology test



Mud filtration test using Low Pressure Low Temperature (LPLT) filter press

Mud cake with thickness 2.4 mm for concentration of 5g of pineapple peel

Mud cake with thickness 2.2 mm for concentration of 10g of pineapple peel