Sudan University of Science and Technology

College of Petroleum Engineering and Technology

Department of Petroleum Engineering

Project Title:

Expwerimental Study to Analyze the Effect of Calcium Carbonates (CaCO3) and Diesel on KCL/Silicate Mud to Prevent Differential Pipe Sticking (Case Study Dalieb-1)

دراسة معملية لتحليل تأثير كربونات الكالسيوم والديزل على سائل حفر من النوع (KCL/Silicate Mud) لمنع حدوث مشكلة الإستعصاء التفاضلي للأنابيب

(دراسة حالة لبئر Dalieb-1)

Graduation Project Submitted to College of Petroleum Engineering and Technology at Sudan University of Science and Technology

Partial Fulfillment of the Requirements of the Degree of B.Sc. in Petroleum Engineering

Prepared by:

1. **Abdullah Alsadig Abdullah Burma**
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Supervisor:

Lecturer Eng. Fatima Ahmed Eltigani

October 2015

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The project is approved by the college of petroleum engineering and technology to department of petroleum engineering.

Project Supervisor: Lecturer Eng. Fatima Ahmed Eltigani

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Head of petroleum engineering department: Lecturer Eng.: Fatima Ahmed Eltigani

Signature:

Dean of college: Dr. Eng.: Tagwa Ahmed Musa

Signature:

Date: / /2015

الإستهلال

قال الله عز وجل في محكم تنزيله:

بِسۡمِ ٱللَّهِ ٱلرَّحۡمَٰنِ ٱلرَّحِيمِ

﴿ فَأَمَّا الزَّبَدُ فَيَذْهَبُ جُفَاءً وَأَمَّا مَا يَنفَعُ النَّاسَ فَيَمْكُثُ فِي الأَرْضِ كَذَلِكَ يَضْرِبُ اللَّهُ الأَمْـثَـالَ ﴾

صــــــدق الله العظيـم

ســــورة الرعــــد ﴿17﴾

Dedication

To cheer up our hearts with their meeting

To gardens of love which grows the best flower

Our mothers…

To the symbols of Manhood and sacrifice in our life's

To who pushed us to science and we're proud by it

Our fathers…

To those closest to us more than our souls

To those join us mother's lap

Our brothers & sisters…

To those who accompanied us in our study and join our worries

Memorial and Tribute

Our friends…

To the scientific edifice and a beacon of science and knowledge

Sudan University of science and technology

Thank you, Lord, for always being there for us.

To all of you

We dedicate this research

Acknowledgment

First and foremost, we have to thank **our parents** for their love and support throughout my life. Thank you both for giving us strength to reach for the stars and chase our dreams.

We would like to sincerely thank **our supervisor**,

Lecturer Eng.: Fatima Ahmed Eltigani, for her guidance and support throughout this study, and especially for her confidence in us.

We would also like to thank **Eng. Mohammed Abd-Alkhalig** for serving as a member on our thesis committee. His comments and questions were very beneficial in our completion of the manuscript and especially at interview time.

Our thanks and gratitude to **everyone who helped us** from near or afar to complete this work and in overcoming the difficulties encountered, most notably **Eng. Mohammed Mustafa**, who spared us the guidance and advice of the value that was helpful for us to complete this research.

And don't forget to thank **Eng. Ghassan Mirghani**; because he gave and his tender sublimation the flags until thanks phrases lined up in front of the river flowing from the tender, thus we can only say "Our Lord reward you with all good".

And also deep thanks extended to this great edifice _ **Sudan University for science and technology**_ and to all colleges and special thanks to **college of petroleum engineering and technology**.

Abstract

Differential pipe sticking is one of most common problem faced during drilling of oil and gas well. It has a major impact on drilling efficiency and well costs.

In this research, the effect of additives on KCL/Silicate mud to prevent differential pipe sticking was identified using mud cake friction factor tester. Calcium Carbonate ($CaCO_3$) and diesel are used as drilling fluid additives. The experimental investigation furnishes that with the proper combination of these additives, the sticking tendency can be reduced significantly with suitable rheological properties and filtration of the drilling fluid required for optimum performance in oil and gas well drilling.

التجريد

إستعصاء الأنابيب التفاضلي يعتبر واحد من أكثر المشاكل التي تواجهنا عند حفر آبار النفط والغاز. والتي لها تأثير هام على كفاءة عملية الحفر كما أنها تؤثر أيضا على تكاليف البئر المحفورة.

في هذا البحث, تم إختبار تأثير بعض الإضافات على سائل حفر KCL/Silicate لمنع حدوث الاستعصاء التفاضلي للأنابيب باستخدام جهاز اختبار معامل احتكاك كعكة الطين. استخدمت كربونات الكالسيوم ($CaCO_3$) والديزل كإضافات. الإختبارات المعملية أوضحت أن استخدام كميات مناسبة من هذه الإضافات مجتمعة تؤدي إلى تقليل النزعة الاستعصائية بشكل كبير مع الحصول على الخواص التيارية المناسبة وراشح سائل الحفر المطلوب للأداء الأمثل في حفر آبار النفط والغاز.

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Nomenclature:

A	:	Contact area
AC	:	Alternating Current
API	:	American Petroleum Institute
CMC	:	Carboxy Methyl Cellulose
cp	:	centipoise
CO_2	:	Carbon Dioxide
D_B	:	Barite Density
D_W	:	Water Density
D_S	:	Silicate Density
DSF	:	Differential sticking force
HEC	:	Hydroxyethyl Cellulose
HS	:	Hole Size
H_S	:	hydrostatic pressure of mud
KCl	:	potassium chloride
kPa	:	Kilo pascal
MBE	:	Material Balance Equations
NaCl	:	Sodium chloride
NaOH	:	Sodium Hydroxide (Caustic Soda)
OD_P	:	Outside diameter of drill pipe or drill collar
PAC	:	Polyanionic Cellulose
ppg	:	pounds per gallon
psi	:	pounds per square inch

P_F	:	formation pressure
R_{600}	:	is the dial reading at 600 r/min
r/min	:	Rotation per minute
SG	:	Specific Gravity
SPIF	:	sulfonated phenol and formaldehyde
SUST Lab	:	Laboratory of Sudan University of Science and Technology
TC	:	Temperature Coefficient
t_{mc}	:	thickness of filter cake
USC units	:	United States customary *units*
V_B	:	Volume of Barite required
V_S	:	Volume of Silicate
V_w	:	Volume of Water required
WBM	:	water based mud drilling fluid
YP	:	Yield Point
g/ml	:	gram per mille liter
kg/m^3	:	Kilogram per cubic meter
lb/gal	:	pounds per gallon
lb/ft^3	:	pounds per cubic feet
$ml/30\ min$	:	mille liter per thirty minutes
°C	:	Degree Celsius
°F	:	Degree Fahrenheit
ρ	:	Mud weight
η_p or PV	:	plastic viscosity

Chapter 1: Introduction

Chapter 1

Introduction

1.1. Introduction:

Differential sticking is one of the most common and serious drilling problems that always increase drilling costs. The cost of stuck pipe to the industry is in excess of $250 million each year. It can range in severity from minor inconvenience to major complications, which can have significantly negative results, such as loss of the drillstring or complete loss of the well. If the drillstring becomes stuck, every effort should be made to free it as quickly as possible because the probability of freeing stuck pipe diminishes rapidly with time. Also, early identification of the cause of the sticking problem is crucial, since each cause must be remedied with different measures. An improper reaction to a sticking problem could easily make it worse. (Vikas Mahto, P. K. Chaudhary and V.P. Sharma 2012)

There are several approached of differential pipe sticking like use of special drilling tools such as square/spiral drill collars, use of oil muds, frequent movement of drill pipe, special treatment on water based drilling fluids etc. Out of these approaches, the most economical approach is special treatment on drilling fluids (selection and use of suitable fluid loss controlling agents and lubricant during the preparation of water based drilling fluids). Earlier, petroleum oils that are either refined or crude have been used for this purpose. But environmental regulations limit it use.

1.2. Problem Statement:

Dalieb-1 well has a differential pipe sticking when using KCL/Silicate mud as water based mud; because of the exceed hydrostatic pressure compared to formation pressure and high permeable formation (sand) at stuck point. That is require modification of the used mud by adding some additives in order to prevent or reduce mud sticking tendency. In this research, Calcium Carbonate ($CaCO_3$) and diesel are used as additives for that purpose.

1.3. Objective of the study:

The study objectives are to:

1. Identify the effect of calcium carbonate ($CaCO_3$) and diesel on the sticking tendency of water based mud.
2. Modify used mud in order to get a suitable mud with favorable rheological properties and filtration properties required for reducing pipe sticking tendency.

1.4. Methodology:

1. Prepare KCL/Silicate mud typical to that used when the problem occurred.
2. Identify the effect of Calcium Carbonates ($CaCo_3$) on the KCL/Silicate mud.
3. Identify the effect of lubricant (diesel) on the KCL/Silicate mud.
4. Identify the effect of combination between $CaCo_3$ and diesel on the KCL/Silicate mud.

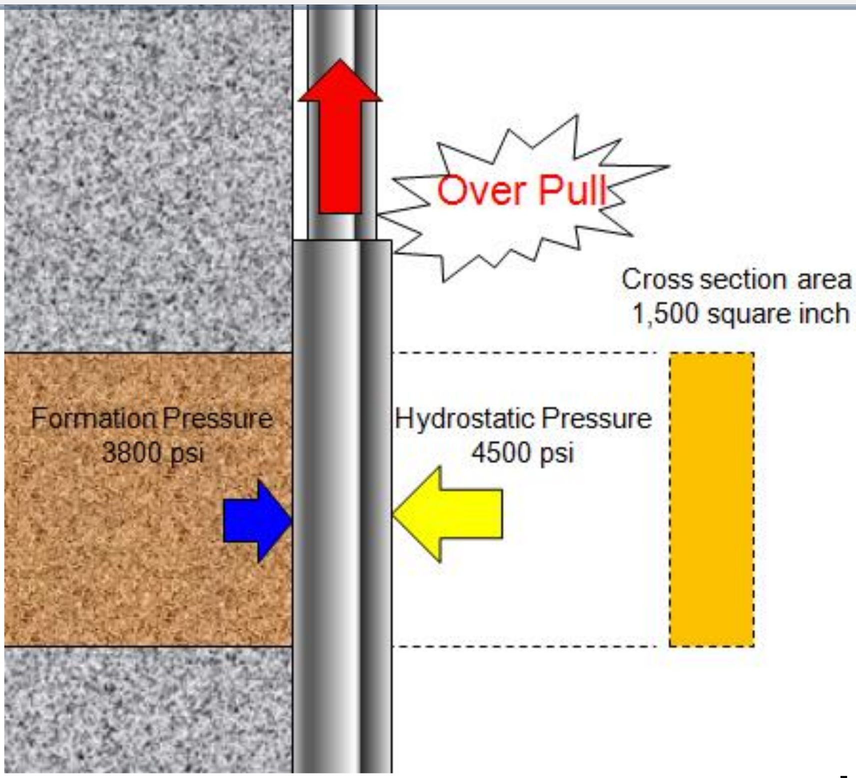
1.5. Dalieb Overview:

Dalieb-1 is a wildcat well of total depth 3000 meters which is located in western area of block-6 In South Kordofan state.

1.6. Thesis Outlines:

Chapter two of this thesis comprises literature review, drilling fluids background, water based mud background, drilling fluid additives in WBM, drilling fluid properties, and differential pipe sticking background, while chapter three consists of laboratory tests procedure, and chapter four consists of results and discussion, lastly, chapter five consists of conclusion and recommendation.

Chapter 2: Literature Review and Theoretical Background



Chapter 2

Literature Review and Theoretical Background

2.1. Literature Review:

W.R. Kelly, T. Fenton Ham and A.B. Dooley in 1946 conducted field and laboratory tests on many drilling fluids, all those muds agree on that their basis is water and is conducting tests to select the best drilling fluid from these different species. Choosing of the most appropriate drilling fluid is based on several factors, but the most important factors are: study the effect of drilling fluid on the mud cake formation and the other factor its importance lies in the effect of mud filtrate on permeable zones. From field evidence and laboratory data several conclusions have been drawn on the influence of mud on well performance. Information available at the present time is not complete enough for a quantitative understanding of mud practices in relation to well performance. Further study and accumulation data relative to the problem are necessary. (W.R. Kelly, T. Fenton Ham and A.B. Dooley 1946)

R.A. Salathiel in 1952 developed a new material to reduce filtration rate. The material is the soluble salt of a very high molecular weight condensation product of sulfonated phenol and formaldehyde (SPIF). Laboratory tests show that SPIF is effective in muds of all salinities varying from fresh water to saturated salt water, but SPIF effectiveness decrease when it is subjected to high pH and high temperature for a long time. (R.A. Salathiel 1952)

P.H. Monaghan and M.R. Annis in 1963 studied the effects of emulsifying several oils and oil plus special additive on the differential pressure sticking coefficient have been studied on the laboratory and verified in the field. The laboratory procedure used was to emulsify oil into the mud and then, at a pressure differential of 500 psi, measure the sticking coefficient between a steel plate and a mud filter cake deposited from the mud. Set time allowed to increase until the sticking coefficient became nearly constant. The results displayed that the oil additive has been added to the mud systems of three wells which were being drilled with kerosene oil emulsion mud. In all cases the sticking coefficient was reduced, and other mud properties were unchanged. (P.H. Monaghan and M.R. Annis 1963)

Katarina Simon et.al in 2005 was tested differential sticking tendency of two drilling fluids (Lignosulphonate mud and polymer mud) were determined in the laboratory using sticking tester as well as influence of lubricant and increase of solids content on fluids properties. (Katarina Simon et.al 2005)

Amorim et.al in 2011 had studied the behavior of lubricants and polymers on the differential sticking coefficient, rheological properties, its filtration and cake thickness by using different concentration from lubricants and polymers. The results showed that the polymer additives improved rheological properties and filtration properties. Also, the findings confirmed the idea that the presence of lubricant affects the differential sticking coefficient. (Amorim et.al 2011)

Vikas Mahto, P. K. Chaudhary and V.P. Sharma in 2012 were studied the effect of additives (Bentonite, polymers and lubricants) on the differential pipe sticking caused by water based drilling fluid using self fabricated stickance tester. Based on these studies a suitable water based drilling fluid with favorable rheological and filtration properties will be prepared using different concentrations from calcium carbonate and lubricant. The experimental investigation furnishes that with the proper combination of these additives, the sticking tendency can be reduced significantly without compromising rheological properties and the fluid loss control of the drilling fluids required for optimum performance in oil and gas well drilling. (Vikas Mahto, P. K. Chaudhary and V.P. Sharma 2012)

Based on these studies the effect of additives (calcium carbonate "$CaCo_3$" and lubricant "diesel") on KCL-silicate base studied and more suitable fluid could be selected.

2.2. Drilling Fluids Background:

Drilling fluid or also called drilling mud is a mixture of water, oil, clay and various chemicals. Within drilling it performs various functions and contributes with a large portion to the total well costs. In this way the mud system (or mud program) has to be carefully designed to ensure a successful drilling project.

The objective of a drilling operation is to drill, evaluate and complete a well that will produce oil and/or gas efficiently. Drilling fluids perform numerous functions that help make this possible. The responsibility for performing these functions is held jointly by the mud engineer and those who direct the drilling operation. The duty of those charged with drilling the hole including the oil company representative, drilling contractor and rig crew is to make sure correct drilling procedures are conducted. The chief duty of the mud engineer is to assure that mud properties are correct for the specific drilling environment. The mud engineer should also recommend drilling practice changes that will help reach the drilling objectives.

2.2.1. Drilling Fluid Functions:

Drilling fluid functions describe tasks which the drilling fluid is capable of performing, although some may not be essential on every well. Removing cuttings from the well and controlling formation pressures are of primary importance on every well. Though the order of importance is determined by well conditions and current operations, the most common drilling fluid functions are:

1. Remove cuttings from the well.
2. Control formation pressures.
3. Suspend and release cuttings.
4. Seal permeable formations.
5. Maintain wellbore stability.
6. Minimize reservoir damage.
7. Cool, lubricate, and support the bit and drilling assembly.
8. Transmit hydraulic energy to tools and bit.
9. Ensure adequate formation evaluation.
10. Control corrosion.
11. Facilitate cementing and completion.
12. Minimize impact on the environment.

2.2.2. Drilling Fluid Selection:

Many different types of water-base drilling fluid systems (muds) are used in drilling operations. Basic drilling fluid systems are usually converted to more complex systems as a well is deepened and the wellbore temperature and/or pressure increases. It is typical for several types of drilling fluid systems to be used in each well. Several key factors affect the selection of drilling fluid system(s) for a specific well.

The following requirements and criteria should be applied when considering the selection of drilling fluid or fluids for a particular well. It should be noted that it is common to utilize two or three different fluid types on one well.

1. Pore pressure/fracture gradient plots to establish the minimum/maximum mud weights to be used on the whole well.
2. Offset well data (drilling completion reports, mud recaps, mud logs etc.) from similar wells in the area to help establish successful mud systems, problematic formations, and potential hazards, estimated drilling time etc.
3. Geological plot of the prognosed lithology.
4. Casing design to give each casing point and the casing program. This will give a good indication of what the mud has to deal with per hole section i.e. formation type, hole size and length etc.
5. Basic mud properties required over each section.
6. Note any possible restriction that might be enforced i.e. Government Legislation in the area.

2.3. Water Based Mud Background:

The term water-base mud refers to any drilling fluid where the continuous phase, in which some materials are in suspension and others are dissolved, is water. The water may be fresh, brackish or seawater. Thus any water-base mud system consists of a water phase, inert solids, a reactive solids phase and chemical additives. Each of these parts contributes to the overall mud properties.

The following designations are normally used to define the classifications of water based drilling fluids:

i. **Inhibitive water-base Mud – Calcium Muds:**

When swelling and hydration of clays and shales are expected, inhibitive water-base muds can be applied. Calcium muds are best suited to penetrate horizons that contain gypsum and hydrite. A subclassification of inhibitive water-base muds distinguishes seawater muds, saturated saltwater muds, lime muds and gypsum muds.

ii. **Dispersed Muds – Lignosulphonate Muds:**

Dispersed muds are used when the mud has to have following characteristics: relative high mud weight (larger than 14 [ppg]), used at moderately high formation temperatures, low filtration loss required and high tolerance for contamination by drilling solids.

Some of the disadvantages when using dispersed muds are: heaving of shales and causing formation damage due to dispersant of formation clays in the presence of lignosulphonate.

Dispersed mud systems consist of: fresh or salty water, bentonite, lignosulphonate, caustic soda and colloidal polymers (carboxy methyl cellulose 'CMC' or stabilized starch). In general, these mud systems exhibit better control of viscosity, a higher solids tolerance and a better control of filtration than nondispersed muds.

iii. **Nondispersed Muds – KCL/Polymer Muds:**

To drill water sensitive and sloughing shales such as productive sands which are prone to formation damage, fresh water nondispersed muds are applied. Commonly, nondispersed muds are associated with low mud weights and low solid concentrations.

Nondispersed mud systems consist of: fresh water or brine, potassium chloride (KCl), inhibiting polymer, viscosifier, stabilized starch or carboxy methyl cellulose, caustic soda and lubricants.

iv. **Flocculated Muds:**

Flocculated muds posses generally a dynamic increase in filtration, viscosity and gel strength. Flocculation refers to a thickening of the mud due to edge-to-edge and edge-to-face association of clay particles. The flocculation is commonly caused by high active solids concentration, high electrolyte concentration and high temperature. To reduce the flocculating tendency of the mud, chemical additives, also called deflocculants or thinners are used. Thinners like phosphates, tannins, lignins and lignosulphonate are applied to lower the yield point and gel strength. When deflocculants are added, the pH-value is controlled by NaOH.

v. Salt-saturated Muds:

Salt-saturated muds are used to drill through salt domes and salt sections. These mud systems are saturated with sodium chloride (NaCl) that prevents severe hole enlargements due to washouts of the salt formations. Swelling of bentonite shales is controlled by adding of polymer.

2.4. Drilling Fluid Additives in WBM:

There are many drilling fluid additives which are used to either change the mud weight (density) or change its chemical properties.

The variety of fluid additives the complexity of mud systems currently in use. The complexity is also increasing daily as more difficult and challenging drilling conditions are encountered. Indeed, it would be easy to write several volumes on mud types and mud additives. We shall limit ourselves to the most common types of additives used in water-based mud.

2.4.1. Weighting materials or densifiers:

Are solid materials which when dissolved or suspended in water; will increase the mud weight. Some examples of weighting materials are barite, hematite, calcium carbonate and galena.

2.4.2. Viscosifiers:

Are materials used to increase the viscosity of drilling mud to make it able to suspend drill cuttings and weighting materials. Without viscosity, all the weighting material and drill cuttings would settle to the bottom of the hole as soon as circulation is stopped.

They are several types of clays available that are used as viscosifiers. But the most widely used clay in oil industry is bentonite.

Bentonite is added to fresh water or fresh-water muds for one or more of the following purposes; (1) to increase hole cleaning capability; (2) to reduce water seepage or filtration into permeable formation; (3) to form a thin, low permeability filter cake; (4) to promote hole stability in poorly cemented formation, and (5) to avoid or overcome loss of circulation.

Attapulgite is another quietly different family of clay mineral which can be used as viscosifiers in water based muds. Attapulgite-based muds have excellent viscosity and yield strength and retain these properties when mixed with salt water. However, they have the disadvantage of suffering high water loss thereby giving poor sealing properties across porous and permeable formations.

Polymers are used as viscosifiers and also used for filtration control, flocculation and shale stabilization. Clays may be entirely replaced by polymers when drilling water sensitive shales or water producing zone. Some examples of polymers used as additives in drilling mud make up are: Starches, Guar Gum, Xanthan Gum (Microbial Polysaccharides), Carboxymethylcellulose (CMC), Polyanionic Cellulose (PAC)and Hydroxyethyl Cellulose (HEC).

2.4.3. Filtration control materials:

Are compounds which reduce the amount of fluid that will be lost from the drilling fluid into a subsurface formation caused by the differential pressure between the hydrostatic pressure of the fluid and the formation pressure.

Bentonite, polymers and thinners or deflocculants all function as filtration control agents.

2.4.4. Lubricating materials:

Are used mainly to reduce friction between the wellbore and the drillstring. Lubricating materials include: oil (diesel, mineral, animal, or vegetable oils), surfactants, graphite, asphalt, gilsonite, polymer and glass beads.

2.5. Drilling Fluid Properties:

The properties of a drilling fluid can be analyzed by its physical and chemical attributes. The major properties of the fluid should be established in the mud program.

Each mud property contributes to the character of the fluid and must be monitored regularly to show trends, which can be used to ascertain what is happening to the mud whilst drilling and show any problems the fluid is experiencing. Addition of treating chemicals are added in concentrations, i.e. pound per barrel(ppb). Many chemicals have primary and secondary effects on the mud system. The most important drilling fluid properties are listed below:

2.5.1. Density: pounds/gallon (lb/gal)

The density (commonly referred to as mud weight) is measured with a mud balance of sufficient accuracy. For all practical purposes, density means weight per unit volume and is measured by weighing the mud. The weight of mud may be expressed as a hydrostatic pressure gradient in $lb/in^2 per$ 1,000 ft of vertical depth ($psi/1{,}000\ ft$), as a density inlb/gal, lb/ft^3 or Specific Gravity (SG).

2.5.2. Plastic Viscosity: centipoise (cps)

The plastic viscosity (η_p) is calculated by measuring the shear rate and stress of the fluid. These values are derived by using a Fann viscometer.

2.5.3. Yield Point: $lbs/100ft^2$

This parameter is also obtained from the viscometer. The yield point (YP) is a measure of the electro-chemical attractive forces within the mud under flowing conditions. The yield point is the shear stress at zero shear rate.

2.5.4. Gel Strength: $lbs/100ft^2(10sec/10min)$

This is a measurement that denotes the thixotropic properties of the mud and is a measurement of the attractive forces of the mud while at rest or under static conditions. Gel strength is measured with the viscometer.

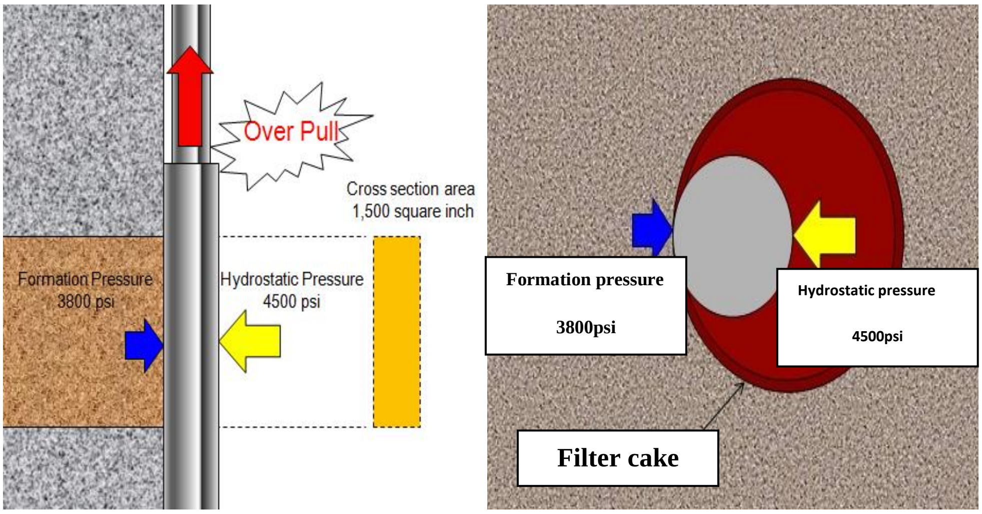
2.5.5. Filtrate/Water Loss: $ml/30min$

And Filter Cake Thickness: $1/32inch$

These two properties shall be dealt with together, as it is the filtration of mud that causes the buildup of filter cake. Loss of fluid (usually water and soluble chemicals) from the mud to the formation occurs when the permeability is such that it allows fluid to pass through the pore spaces. As fluid is lost, a buildup of mud solids occurs on the face of the wellbore. This is the filter cake.

2.6. Differential Pipe Sticking Background:

The differential sticking is the sticking of the drillstring against a permeable formation containing less pore fluid pressure than hydrostatic pressure exerted by the drilling fluid column (as shown in fig 2.1), and usually occurs when the drill string remains motionless for a period of time during a connection or when taking a survey. These are caused in wells where higher mud densities are used in those formations where pressures are greatly depleted. The high differential pressure pushes the pipe deep into the mud cake causing the stuck pipe, and is indicated by full circulation and no up/down mobility or rotary freedom, other than pipe stretch and torque.



Sectional view **Horizontal view**

Fig.(2-1) Differential sticking

www.drillingformulas.com

2.6.1. Causes of Differential Pipe Sticking:

When the pipe becomes differentially stuck, the following conditions exist:

1. The hydrostatic pressure of the mud exceeds the adjacent formation pressure.
2. The formation is permeable (usually sandstone) at the point where the pipe is stuck.

This combination of differential pressure and a permeable formation results in fluid loss to the formation and the deposition of a filter cake.

A mathematical equation showed that the differential sticking force depends on the magnitude of the overbalance, the area of contact between the drillpipe and the porous zone and the friction factor between the drillstring (steel) and the filter cake.

$$\text{Differential sticking force}(DSF) = (H_S - P_F) \times \text{effective contact area} \times \text{friction factor} \qquad (2.1)$$

Where:

$H_S =$ hydrostatic pressure of mud

$P_F =$ formation pressure

Another equation for estimating the contact area is given by:

$$A = 2h\sqrt{\left[\frac{HS}{2} - t_{mc}\right]^2 - \left[\frac{HS}{2} - t_{mc}\left(\frac{HS - t_{mc}}{HS - OD_P}\right)\right]^2} \qquad (2.2)$$

Where:

$h =$ thickness of permeable zone

$t_{mc} =$ thickness of filter cake

$HS = Holesize$

$OD_P =$ Out side diameter of drillpipe or drillcollars

When a filter cake builds up on the formation, it increases the contact area between the wellbore and the drill pipe. Excessive drill solids and high fluid loss increase filter-cake thickness and the coefficient of friction, making it more difficult to pull or jar the drill pipe free.

2.6.2. Differential Pipe Sticking Prevention or Reduction:

All of the conditions associated with differentially stuck pipe cannot be eliminated; however, the possibility of differential sticking can be reduced by following good drilling practices. These include the following:

1. Reduce the overbalance pressure by keeping the mud weight as low as good drilling practices allow.
2. Reduce the area of contact between the wellbore and the pipe by using the minimum length of drill collars needed for the required bit weight.
3. Reduce filter-cake thickness. Filter-cake thickness can be reduced by lowering the filtration rate and drill solids content.
4. Maintain a low filtration rate. Filtration rates should be monitored on a regular basis at downhole temperatures and differential pressures. Mud treatment should be based on the results of these tests relative to desired properties.
5. Control excessive ROP to limit the concentration of drill solids and an increase of mud weight in the annulus.
6. Minimize the mud’s coefficient of friction by keeping a good quality filter cake with low drill solids and by using the proper lubricants in sufficient quantities.
7. Keep the pipe moving when possible and use good drilling practices to minimize differential sticking.
8. Run drilling jars when possible.
9. Watch for depleted pressure zones, where differential sticking occurs frequently.

Chapter 3: Laboratory tests and procedures

Chapter 3

Laboratory tests and procedures

3.1. Introduction:

This chapter contains a detailed description of the chemicals used in experiments (name and function of each material).

As well as this chapter contains a detailed description of the experiments which measure and estimate Rheological properties of drilling fluid, and that description contains (clarify measurement principle, devices used, the tests are carried out on each drilling fluid is prepared and how the testing process achieved).

3.2. Description of Materials:

1. Barite:

Barite is the most commonly used weighting material in the drilling industry. The chemical formula of barium sulphate is $BaSO_4$ and in pure form it contains 65.7% BaO and 34.3% SO_3. Barium sulphate has specific gravity in the range of 4.2 – 4.6.

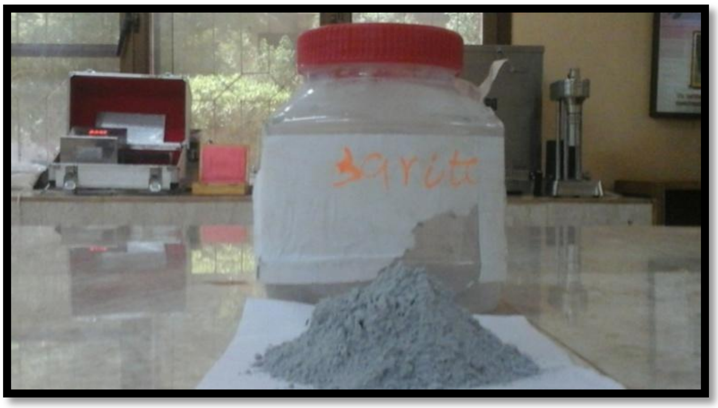


Fig.(3-1) Illustrate a sample of Barite

SUST Lab

2. Doul Vis:

Doul Vis is a high-molecular-weight xanthan gum polysaccharide with an enhanced dispersibility feature. Doul Vis is an effective viscosifier in most water regardless of salinity or hardness.

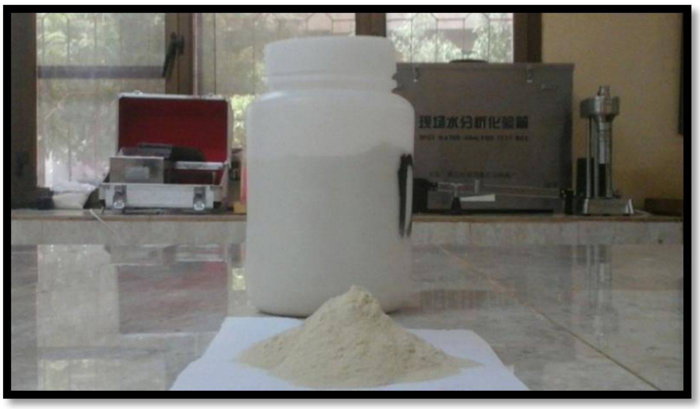


Fig.(3-2) Illustrate a sample of Doul Vis

SUST Lab

3. PAC LV:

PAC LV is a modified cellulosic viscosity and filtration control additive for water-based drilling fluids. PAC LV benefits include: an excellent fluid loss control, borehole stability, creates thin slick filter cakes, provides viscosity and increase hole cleaning.

Fig.(3-3) Illustrate a sample of PAC LV

SUST LAb

4. Starch:

Starch work well as fluid-loss agents in the presence of low soluble calcium or sodium ions, starch suitable for salt-water or gypsum mud's, An increase in viscosity is observed when it is used, A bactericide must be used to prevent degradation and fermentation and It degrades at temperatures over 200°F.

Fig.(3-4) Illustrate a sample of starch

SUST Lab

5. Soda Ash:

Soda Ash is sodium carbonate (Na_2CO_3) for hardness control.

Fig.(3-5) Illustrate a sample of Soda Ash

SUST Lab

6. Caustic soda:

Caustic soda is sodium hydroxide (NaOH) for pH control.

Fig.(3-6) Illustrate a sample of Caustic soda

SUST Lab

7. Potassium Chloride:

Potassium Chloride (KCL) used primarily to formulate solids.

Fig.(3-7) Illustrate a sample of Potassium Chloride (KCL)

SUST Lab

8. Sodium Silicate:

Soluble sodium silicate has been used in industry for a wide variety of application. From detergent to adhesives, and deflocculants aids to corrosion inhibitor.

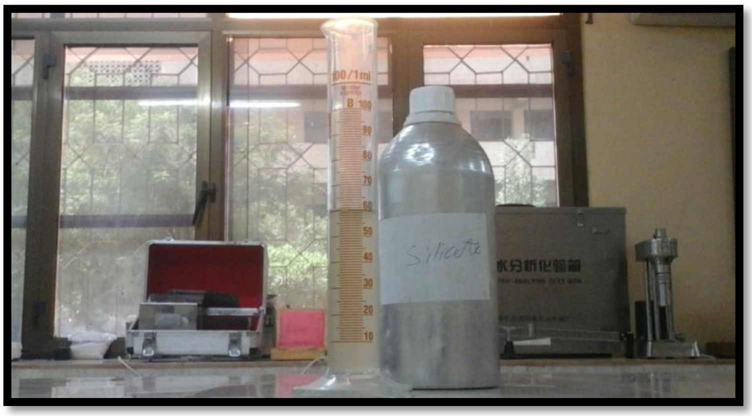


Fig.(3-8) Illustrate a sample of sodium silicate

SUST Lab

9. Calcium Carbonate:

Calcium Carbonate ($CaCO_3$) is used as a bridging agent and/or weighting material in oil base and water base drilling fluids. Calcium Carbonate comes in a wide variety of particle size ranging from 325 meshes (35 µ) to 30 meshes (550 µ).

In a water based system the pH of drilling fluid needs to be above 7.0 since the Calcium Carbonate is acid soluble.

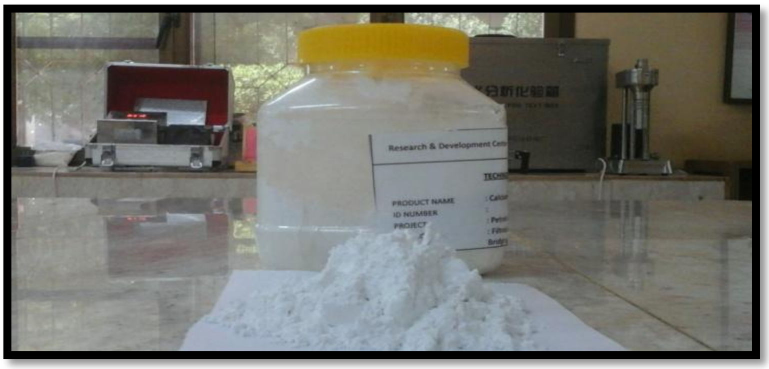


Fig.(3-9) Illustrate a sample of Calcium Carbonate

SUST Lab

10. Diesel:

Diesel is a lubricant material used to reduce torque and drag between drill string and formation.

Fig.(3-10) Illustrate a sample of Diesel

SUST Lab

3.3. Description of Equipments:

3.3.1. Digital Balance:

The digital balance is the instrument used for weighing solid materials. As illustrated in figure below.

Fig.(3-11) Digital balance

www.atlanticsupply.com

3.3.2. Mud Mixer:

The mud mixer is the instrument used for mixing the mud components. As shown in fig. (3-12) the mud mixer consist mainly from crank connected to an electric motor and fan to stir the component.

Fig.(3-12) Mud mixer

www.rigchina-com.sell.curiousexpeditions.org

3.3.3. Mud Balance:

The mud balance is the instrument generally used for drilling-fluid density determinations. Fig. (3-13) illustrate that the mud balance is designed such that the drilling-fluid holding cup, at one end of the beam, is balanced by a fixed counter weight at the other end, with a sliding-weight rider free to move along a graduated scale. A level-bubble is mounted on the beam to allow for accurate balancing. Attachments for extending the range of the balance may be used when necessary.

The instrument should be calibrated frequently with fresh water. Fresh water should give a reading of 1.00 g/ml or 1000 kg/m^3 (8.33 lb/gal or 62.3lb/ft^3) at 21 °C (70 °F). If it does not, adjust the balancing screw or the amount of lead shot in the well at the end of the graduated arm as required.

Fig.(3-13) Mud balance

www.testapparatus.com

3.3.4. Six speed viscometer:

This type of viscometer is a rotational instrument powered by an electric motor or a hand crank. Drilling fluid is contained in the annular space between two concentric cylinders. The outer cylinder or rotor sleeve is driven at a constant rotational velocity. The rotation of the rotor sleeve in the fluid produces a torque on the inner cylinder or bob. A torsion spring restrains the movement of the bob, and a dial attached to the bob indicates displacement of the bob. Instrument constants have been adjusted so that plastic viscosity and yield point are obtained by using readings from rotor sleeve speeds of 300 r/min and 600 r/min.

Fig.(3-14) Six Speed Viscometer

www.alibaba.com

3.3.5. API Filter Press:

As shown in fig. (3-15), API filter press consisting mainly of a cylindrical drilling-fluid cell having an inside diameter of 76.2 mm (3 in) and a height of at least 64.0 mm (2.5 in).This cell is made of materials resistant to strongly alkaline solutions and is so fitted that a pressure medium can be conveniently admitted into, and bled from, the top. It shall also be fitted such that a sheet of 90 mm (3.54 in) diameter filter paper can be placed in the bottom of the cell just above a suitable support. The filtration area is (45.8 ± 0.6) cm^2 [(7.1 ± 0.1) in^2]. Below the support is a drain tube for discharging the filtrate into a graduated cylinder. Sealing is accomplished with gaskets and the entire assembly supported by a stand. Pressure can be applied with any non-hazardous fluid medium. Pressures are equipped with pressure regulators and can be obtained with portable pressure cylinders, midget pressure cartridges or means for utilizing hydraulic pressure. To obtain correlative results, one thickness of the proper 90 mm diameter filter paper shall be used.

Fig.(3-15) API-filter-press

www.ofite.com

3.3.6. Mud Cake Friction factor Tester:

The friction factor apparatus is the instrument generally used for friction factor determination. Mainly consists of a horizontal slab as shown in fig. (3-16) which you place the filtration paper that is out of the API-Filtration press, adjust and control it through three screws works to make it balanced in the horizontal position. A level-bubble is mounted on the slab indicates that the device is set horizontally when it is located in the Middle.

To control the device it has three buttons:

i- Play button: is used to turn on the device after you connect it to AC power source.

ii- Rotation button is used to rotate the slab after it placed the filtration paper and model "drillpipe or drill collar" and then start recycling, with increasing slope inclination angle is read by a digital display device exists (greater inclination Guide to increase the friction coefficient).

iii- Zeroing button is used when you reset the device).

Fig.(3-16) Mud cake friction factor tester

www.diytrade.com

3.4. Preparation of Mud:

To prepare any drilling fluid; you must follow the following steps

1. Fill the cup by the specified quantity of water.
2. Then, weight of the solids to be added.
3. Turn on the mud mixer to stir the water inside.
4. Add solids gradually according to quantities measured previously.
5. Waiting period (3-5) minutes until mixture becomes homogeneous.

3.5. Tests Procedures:

It is necessary to perform certain tests to determine if the mud is in proper condition to perform the functions previously discussed. The frequency of these tests will vary in particular areas depending upon conditions.

Tests procedures performed according to **API** recommendation.

3.5.1. Mud Density Test Procedure:

1. Set the instrument base on a flat, level surface.
2. Fill the clean, dry cup with drilling fluid to be tested; put the cap on the filled drilling-fluid holding cup and rotate the cap until it is firmly seated. Ensure that some of the drilling fluid is expelled through the hole in the cap in order to free any trapped air or gas.
3. Holding the cap firmly on the drilling-fluid holding cup (with cap hole covered), wash or wipe the outside of the cup clean and dry.
4. Place the beam on the base support and balance it by moving the rider along the graduated scale. Balance is achieved when the bubble is under the centerline.
5. Read the drilling fluid density from one of the four calibrated scales on the arrow side of the sliding weight. The density can be read directly in units of g/ml, lb/gal, and lb/ft^3, or as a drilling fluid gradient in $psi/1000ft$.

3.5.2. Rheological Properties Test Procedure:

1. Place the sample in a container and immerse the rotor sleeve exactly to the scribed line. Measurements in the field should be made with minimum delay (within 5 min, if possible).
2. With the sleeve rotating at $600\ r/min$, wait for viscometer dial reading to reach a steady value (the time required is dependent on the drilling-fluid characteristics). Record the dial reading for $600\ r/min$.
3. Reduce the rotor speed to 300 r/min and wait for the viscometer dial reading to reach a steady value. Record the dial reading for $300\ r/min$.
4. Stir drilling fluid sample for $10\ s\ at\ 600\ r/min$. Stop the rotor.
5. Allow drilling fluid sample to stand undisturbed for 10 s. Slowly and steadily turn the hand-wheel in the appropriate direction to produce a positive dial reading. The maximum reading is the initial gel strength. For instruments having a speed of $3\ r/min$, the maximum reading attained after starting rotation at $3\ r/min$ is the initial gel strength.
6. Record the initial gel strength (10-seconds gel) in $per\ 100ft^2$.
7. Re-stir the drilling fluid sample at $600\frac{r}{\min} for\ 10s$, stop the rotor and allow the drilling fluid to stand undisturbed for 10 min. Repeat the measurements as in 3.5. and report the maximum reading as the $10 - minute\ gel\ in\ pounds\ per\ 100\ ft^2$.
8. Calculate the Apparent Viscosity (AV), Plastic Viscosity (PV), Yield Point (η_p), Power Low Index (N) and Consistency Index (K) by using the following equations.

The calculation for the plastic viscosity, η_p , expressed in millipascal seconds (centipoise), is given in Equation (3.1):

$$\eta_p = R_{600} - R_{300} \qquad (3.1)$$

Where:

R_{600} is the dial reading at 600 r/min;

R_{300} is the dial reading at 300 r/min.

NOTE: The plastic viscosity is commonly known in the industry by the abbreviation PV.

NOTE: $1\ cp = 1\ mpa.s.$

The calculation for the yield point$Y_{P,A}$ expressed in pascals, is given in Equation (3.2):

$$Y_{P,A} = 0.48 \times R_{300} - \eta_p \qquad (3.2)$$

When calculating values in USC units, the yield point (expressed in pounds per one hundred square feet) is calculated as follows:

$$Y_{P,A} = R_{300} - \eta_p \qquad (3.3)$$

NOTE: The yield point, expressed in pounds per one hundred square feet, is commonly known in the industry by the abbreviationY_P.

Both Plastic Viscosity (PV) and Yield Point (η_p) are mathematical values which can be used for calculating the pressure loss in the circulating system as When plastic viscosity rises, this is usually an indication that the solids control equipment are running inefficiently. Ideally, the yield point η_p should be just high enough to suspend the cuttings as they are circulated up the annulus.

The other rheological properties can be calculated from the following equations:

$$\text{Apparent Viscosity } (AV) = R_{600}/2 \qquad (3.4)$$

$$\text{Gel strength} = R_{3@10sec}/R_{3@10min} \qquad (3.5)$$

$$\text{Non-Newtonian (power law) Index } (n) = 3.32 \times log\left(\frac{R_{600}}{R_{300}}\right) \qquad (3.6)$$

$$\text{Consistency Index } K = R_{300}/511^n \qquad (3.7)$$

3.5.3. Filtration Test Procedure:

1. Be sure each part of the cell, particularly the screen, is clean and dry and that the gaskets are not distorted or worn. Pour the drilling fluid sample into the cell to within 1 $cmto$ 1,5cm (0.4 $into$ 0.6 in) of the top (to minimize CO_2contamination of filtrate), and complete the assembly with the filter paper in place.

2. Place a dry graduated cylinder under the drain tube to collect the filtrate. Close the relief valve and adjust the regulator so that a pressure of $690\ kPa \pm\ 35\ kPa$ ($100\ psi \pm\ 5\ psi$) is applied within 30 s or less. The test period begins at the time of pressure application.
3. At the end of 30 min, measure the volume of filtrate collected. Shut off the flow through the pressure regulator and open the relief valve carefully. The time interval, if other than 30 min, shall be reported.
4. Report the volume of filtrate in milliliters (to the nearest 0.1 ml)
5. Remove the cell from the frame, first making certain that all pressure has been relieved. Carefully save the filter paper with a minimum of disturbance to the cake, disassemble the cell and discard the drilling fluid.

3.5.4. Friction factor Test Procedure:

1. Place the filter cake on a horizontal plate in the devise
2. Make sure that the Filter cake parallel to the horizon by screws weight and stability of bubble in Centre.
3. Put one of models (drillpipe or drill collar) on the filter cake, and press the Rotation button.
4. Record angle that the model is slid by it and read the friction coefficient from the attached guide (friction factor chart).
5. Zero the device by using zeroing button and then repeat the previous steps with the other model or other experiment.

Chapter 4: Results and Discussion

Chapter 4

Results and Discussion

4.1. Material Balance Equation and experiments results:

As stated earlier, the main cause of differential sticking is the difference between hydrostatic and formation pressure. However, there are direct or indirect influences of other factors such as mud formulation, mud properties, characteristics of the filter cake, type of lubricant …etc. Their relationship, as well as pipe sticking probability and appropriate way of prevention, can be evaluated through continuous laboratory research.

KCL-silicate base fluid (mud B) was prepared in the laboratory, and then three additives were tested in the laboratory:

1. KCL-silicate base fluid with calcium carbonate "$CaCo_3$" (mud F).
2. KCL-silicate base fluid with lubricant (mud P), and
3. KCL-silicate base fluid mixed by calcium carbonate "$CaCo_3$" and lubricant (mud M).

To study the effect of additives on the mud properties, especially on differential sticking tendency; amount of additives in the base fluid were varied. The number included in the mud sign implies additive concentration, i.e.

i. The number included in the (mud F) implies $CaCo_3$ concentration in pounds per barrel of mud.
ii. The number included in the (mud P) implies lubricant "diesel" concentration in barrels per barrel of mud.
iii. Whereas in (mud M) the number implies $CaCo_3$ concentration in pounds, when the diesel concentration is constant at 3% vol.

Formulations of tested muds could be estimated according to relationship called **the material balance** and can be expressed as follows:

$$V_1 D_1 + V_2 D_2 + V_3 D_3 = (V_1 + V_2 + V_3)\, D \qquad (4.1)$$

Where:

V_1=Volume of the first substance;

V_2=Volume of the second substance;

V_3=Volume of the third substance;

D_1=Density of the first substance;

D_2=Density of the second substance;

D_3=Density of the third substance;

D =Density of the resulting mixture.

Preparing the required drilling fluid with Density=10.58 ppg, and Volume=**1bbl,** and with materials such as water, silicate and barite can be related in a similar manner.

$$V_W D_W + V_S D_S + V_B D_B = (V_W + V_S + V_B)\, D$$

Where:

V_w = Volume of Water required,

V_S = Volume of Silicate (taken as 0.09 bbl/bbl),

V_B = Volume of Barite required,

D_W = Water Density, (8.33 ppg),

D_S = Silicate Density, (12.71 ppg),

D_B = Barite Density, (35 ppg).

$$V_W \times 8.33 + 0.09 \times 12.71 + V_B \times 35 = 1 \times 10.58$$

$$V_W \times 8.33 + 0.09 \times 12.71 + (1 - 0.09 - V_W) \times 35 = 1 \times 10.58$$

Find out that:

$V_W = 0.84$ bbl/bbl

$V_B = 0.07$ bbl/bbl

Then a (0.07) bbl/bbl of Barite weight = (0.07) (35) (42) = 102.9 lb/bbl.

The drilling fluid was prepared using a sample of Soda Ash, Caustic Soda, PAC LV, Starch, Doul Vis, KCL, Barite, Fresh water and Silicate, According to **Baker Hughe** recommendation.

Formulations of tested muds are shown in table (4-1).

Table (4-1) Formulations of tested muds

Components	Units	Drilling Fluids							
		B	5F	10F	0.01P	0.03P	5M	7.5M	10M
Water	bbl/bbl	0.84	0.84	0.84	0.83	0.81	0.81	0.81	0.81
Soda Ash	lb/bbl	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Caustic Soda	lb/bbl	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Pac Lv	lb/bbl	5	5	5	5	5	5	5	5
Starch	lb/bbl	1	1	1	1	1	1	1	1
Doul Vis	lb/bbl	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
KCL	lb/bbl	22	22	22	22	22	22	22	22
$CaCO_3$	lb/bbl	_	5	10	_	_	5	7.5	10
Barite	lb/bbl	74.2	69.2	64.2	74.2	74.2	69.2	66.7	64.2
Diesel	bbl/bbl	_	_	_	0.01	0.03	0.03	0.03	0.03
Silicate	bbl/bbl	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09

Where:

(Mud F) = KCL-silicate base fluid with calcium carbonate ($CaCo_3$)

(Mud P) = KCL-silicate base fluid with lubricant, and

(Mud M) = KCL-silicate base fluid mixed by calcium carbonate ($CaCo_3$) and lubricant.

Rheological properties, filtration and friction factor of tested fluids were determined according to API recommended practice standard procedure for testing drilling fluids, API RB 13B-1. As shown in table (4-2).

Table (4-2) Effect of calcium carbonate and diesel on the properties of tested muds

Properties	Units	Drilling Fluids							
		B	5F	10F	0.01P	0.03P	5M	7.5M	10M
Mud weight	g/cm^3	1.26	1.25	1.24	1.254	1.244	1.24	1.236	1.234
θ_{600}	rpm	88	88	88	92	100	105	100	97
θ_{300}	rpm	60	60	60	62	66	70	65	62
Apparent Viscosity (AV)	CP	44	44	44	46	50	52.5	50	48.5
Plastic Viscosity (PV)	CP	28	28	28	30	34	35	35	35
Yield Point (YP)	$lb/100ft^2$	32	32	32	32	32	35	30	27
Gel strength	$lb/100ft^2$	7/8	7/8	8/9	4/5	5/6	7/8	5/6	4/5
Non-Newtonian Index (n)	-	0.552	0.552	0.552	0.5690	0.599	0.585	0.621	0.6453
Consistency Index (K)	-	1.919	1.919	1.919	1.7836	1.575	1.823	1.352	1.1083
pH	-	12	12	12	12	12	12	12	12
Fluid loss volume/30min	ml	7.4	7.2	7	5.8	5.4	5	5	5
Friction coefficient	-	0.0787	0.0963	0.1139	0.0787	0.0699	0.0787	0.0787	0.0787

4.2. Discussion:

First and foremost, 1st experiment in all graphs indicates that the effect of KCL-silicate base fluid (mud B) on mud properties.

Whereas, the 2nd experiment indicates to:

- The effect of 5 **lb/bbl** of $CaCo_3$ mixed with KCL-silicate base fluid (mud F).
- The effect of 1**%** diesel mixed with KCL-silicate base fluid (mud P).
- The effect of (5 **lb/bbl** of $CaCo_3$ and 3**%** diesel) mixed with KCL-silicate base fluid (mud M).

And the 3rd experiment indicates to:

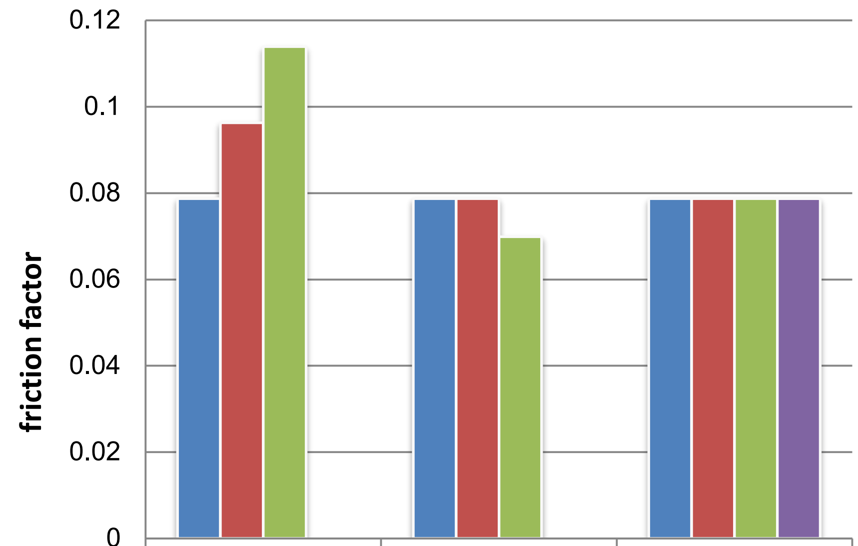
- The effect of 10 **lb/bbl** of $CaCo_3$ mixed with KCL-silicate base fluid (mud F).
- The effect of 3**%** diesel mixed with KCL-silicate base fluid (mud P).
- The effect of (7.5 **lb/bbl** of $CaCo_3$ and 3**%** diesel) mixed with KCL-silicate base fluid (mud M).

Finally, the 4th experiment in all graphs indicates that the effect of (10 **lb/bbl** of $CaCo_3$ and 3**%** diesel) mixed with KCL-silicate base fluid (mud M) on mud properties.

The effect of calcium carbonate ($CaCo_3$) and lubricant (Diesel) on the sticking tendency of the KCL-silicate mud was studied and it is shown in fig (4-1). With the increase in concentration of calcium carbonate ($CaCo_3$) the friction factor of drill collar in this study with filter cake increases.

Then, the results illustrated in the same figure show that the effect of lubricant (diesel) it is not clear when adding it in small quantities, but when increasing the concentration of diesel, the friction factor of drill collar with the filter cake decreases, (i.e. the torque required to free the drill collar decreases).

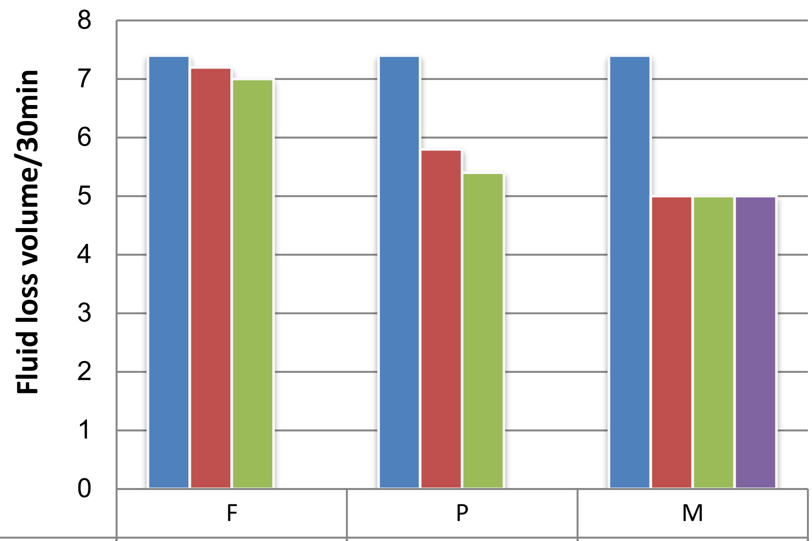
Further, a drilling fluid was prepared by mixing calcium carbonate ($CaCo_3$) and lubricant (diesel) together in KCL-silicate base fluid (diesel was added in 3% volume, and $CaCo_3$ was added in varying proportions). The developed drilling fluid shows that in the presence of 3% vol of diesel, the effect of $CaCo_3$ on the friction factor is negligible; because there is no change in the friction factor when varying $CaCo_3$ proportions, i.e. (the lubricant (diesel) is considered the main factor which affected on the friction factor).



	F	P	M
1st experiment	0.0787	0.0787	0.0787
2nd experiment	0.0963	0.0787	0.0787
3rd experiment	0.1139	0.0699	0.0787
4th experiment			0.0787

Fig.(4-1) Comparison of friction coefficients of muds (F,P and M)

Also, the effect of calcium carbonates ($CaCo_3$) and lubricant (Diesel) on the filtration volume was depicted in the fig (4-2) below, with the increasing concentration of calcium carbonate ($CaCo_3$) the filtration volume decreases. Hence, the torque required to free the drill collar was also decreases, which indicating that the calcium carbonates ($CaCo_3$) work as a loss filtration material.

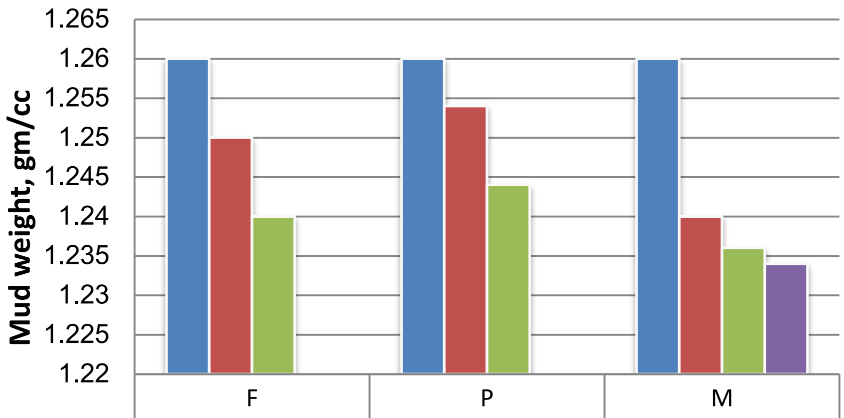


	F	P	M
1st experiment	7.4	7.4	7.4
2nd experiment	7.2	5.8	5
3rd experiment	7	5.4	5
4th experiment			5

Fig.(4-2) Effect of calcium carbonate and lubricant on the fluid loss volume

As stated previously, with the increasing concentration of calcium carbonates ($CaCo_3$) the filtration volume decreases, but that decreasing is much more noticeable when diesel is added, and to make sure; carefully consider the figure (4-2) above.

As you can notice from the same figure that the value of fluid loss volume less significantly when adding **(5 lb/bbl** of $CaCo_3$ with **3% volume** of diesel), and then we note that the value of fluid loss volume stabilize with the increasing of calcium carbonate concentrations, demonstrating that the main controller in the filtration volume is diesel (not $CaCo_3$).

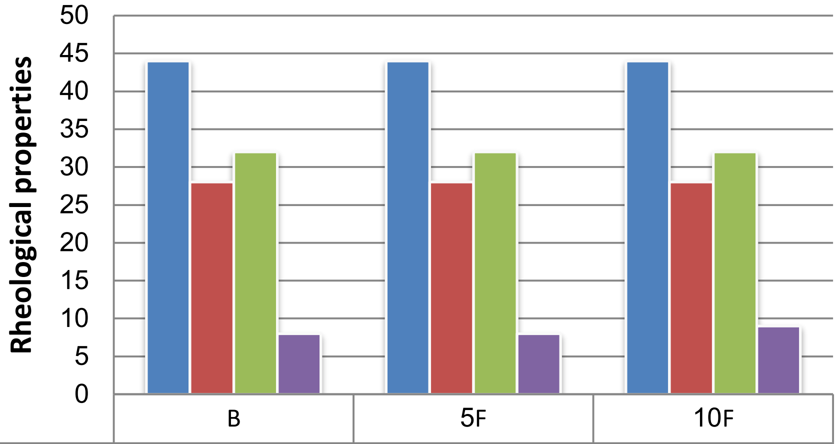


	F	P	M
st experiment1	1.26	1.26	1.26
nd experiment2	1.25	1.254	1.24
rd experiment3	1.24	1.244	1.236
th experiment4			1.234

Fig.(4-3) Effect of calcium carbonate and lubricant on the mud weight

It can be seen from figure (4-3) that the effect of calcium carbonate ($CaCo_3$) in the mud weight is very small compared to the effect of barite. In other words, the mud weight decreases while increasing concentrations of both ($CaCo_3$ and diesel).

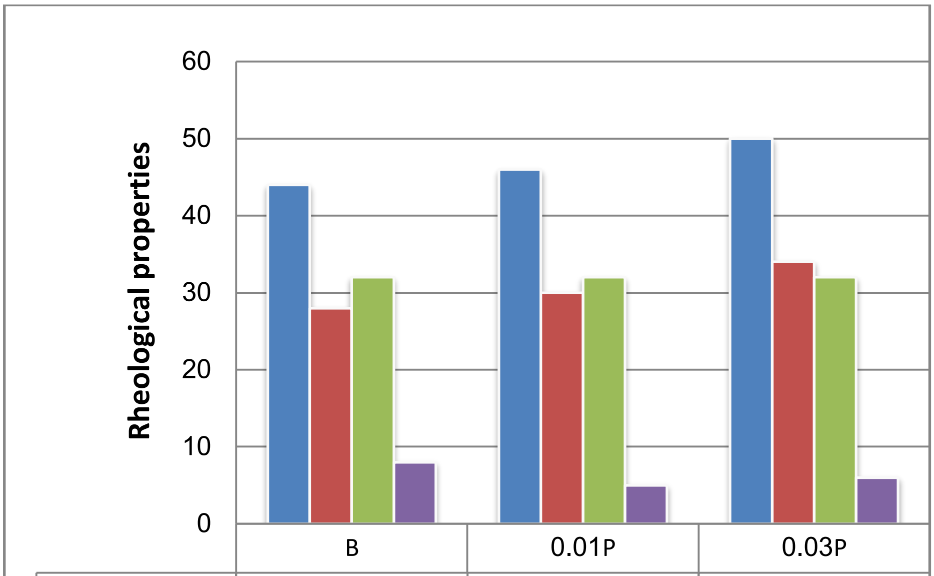
However, if we go back to see the effect of $CaCo_3$ in the rheological properties as illustrated in fig (4-4), we don't observe any change in the rheological properties when changing $CaCo_3$ concentrations.



	B	5F	10F
AV, CP	44	44	44
PV, CP	28	28	28
sqft100 YP, Ib/	32	32	32
min gel10	8	8	9

Fig.(4-4) Effect of calcium carbonate on the Rheological properties

To determine the effect of lubricant (diesel) on mud weight; the figure (4-3) illustrate that the addition of lubricant (diesel) reduced mud weight, on the other hand and from fig (4-5) it can be seen that the value of rheological properties (Apparent viscosity AV, plastic viscosity PV and 10 min gel) were slightly increased with the increasing diesel concentrations, whereas yield point remaining constant.



	B	0.01P	0.03P
AV, CP	44	46	50
PV, CP	28	30	34
YP, Ib/100 sqft	32	32	32
10min gel	8	5	6

Fig.(4-5) Effect of lubricant (diesel) on the Rheological properties

Finally, the effect of calcium carbonates when mixing calcium carbonate ($CaCo_3$) with **3% volume** lubricant "diesel" together in KCL-silicate base fluid on the mud weight as shown in figure (4-3), we note that with the increasing $CaCo_3$ concentration, the mud weight decreased.

Whereas the effect of $CaCo_3$ in the mixture when changing its concentration on the rheological properties, we oversee that their values fluctuate between increase and decrease, as shown in figure (4-6) later on.

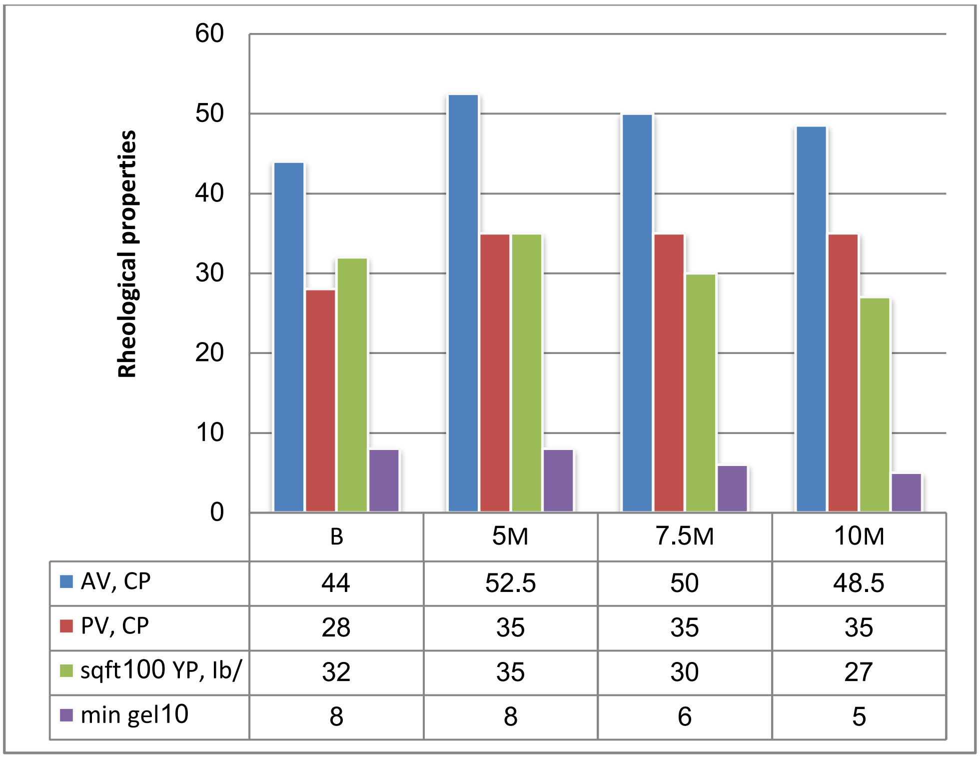


Fig.(4-6) Effect of calcium carbonates when mixed with 3% diesel on the rheological properties

In conclusion, after observation and audit in the results of laboratory experiments and figures those have been drawn from laboratory tests, we can choose the most appropriate drilling fluid. And conclude that the KCL-silicate base fluid when mixed by **10 lb/bbl** calcium carbonate "$CaCo_3$" and 3% volume lubricant (**mud-10M**) is the most suitable drilling fluid for the following reasons.

1. The developed drilling fluid shows the favorable rheological properties and filtration properties required for the optimum performance in the oil well drilling.
2. It also shows that less friction factor of drill collar with filter cake, and hence reduce the torque required to free the drill collar.

Chapter 5: Conclusion and Recommendations

Chapter 5

Conclusion and Recommendations

5.1. Conclusion:

From performed tests the following conclusions can be made:

1. Increasing the level of calcium carbonate ($CaCo_3$) additive in water base mud lowers the sticking tendency.
2. Lubricant (Diesel) can reduce the sticking tendency of filter cakes in water base muds.
3. The proper combination of calcium carbonate ($CaCo_3$) and lubricant (Diesel) are essential for the development of optimum drilling fluid systems to prevent the differential pipe sticking problems.

Thus, each beginning has the end, and the good work which has a good end, and the best speech which is brevity and has a meaning.

After this humble effort, we wish to be successful in the explaining of the contents of this research narrative which is not boredom or shortening.

5.2. Recommendations:

It is recommended to:

1. Conduct the laboratory tests under high pressure and high temperature.
2. Identify the effect of other additives.
3. Identify the effect of other ranges of $CaCO_3$ and diesel.
4. Implement pilot test to achieve high verification.

References:

1. AMERICIAN PETROLEUM INSTITUTE (API), 2009. *Recommended Practice for Field Testing Water-based Drilling Fluids 13B-1,* 4^{th} ed. New York: American Petroleum Institute (API).
2. AMORIM et.al, 2011. *Evaluation of the behavior of biodegradable lubricants in the differential sticking coefficient of water based drilling fluids*. Brazil: Brazilian journal of petroleum and gas.
3. ATLANTIC DRILLING SUPPLY, INC., 2015. *Service supply*. [online]. United States: North Atlantic Basin. www.atlanticsupply.com. Available from: [Accessed 10 September 2015].
4. HUGHES TOOL COMPANY, 1995. *Drilling Engineering Workbook,* Section B. United States of America: Houston.
5. KATARINA SIMON et.al, 2005.*Drilling fluids differential sticking tendency determination.* Croatia: University of Zagreb, faculty of mining geology and petroleum engineering.
6. KINGSBAG INTERNATIONAL COMPANY LIMITED, 2006. *Analysis Instrument.* [online]. Available from: http://www.diytrade.com/china/manufacturer/1750795/main/Kingsbag_International_Company_Limited.html. [Accessed 16 October 2015].
7. OFI TESTING EQUIPMENT (OFITE), 2008. *Scales and Balances - General Lab Supplies.* [online]. Texas: Houston. www.ofite.com. Available from: [Accessed 10 September 2015].
8. P.H. MONAGHAN, M.R. ANNIS, 1963. *Differential-pressure Sticking-The Effect of Oil and a Special Additive on Sticking Coefficients*. New York: American Petroleum Institute (API).
9. RABIA H., 2002. *Well Engineering and Constructions.* Entrac Consulting.
10. R.A. SALATHIEL, 1952. *A New Additive for Control of Drilling Mud Filtration.* Texas: Society of Petroleum Engineers (SPE).
11. SHANGHAI LUHENG INSTRUMENT Co.,Ltd, 2014. *Products.* [online]. Available from: http://www.testapparatus.com/ProductShow_381.html. [Accessed 10 September 2015].

12. VIKAS MAHTO, P. K. CHAUDHARY and V.P. SHARMA, 2012. *International Conference on Oil, Gas and Petrochemical Issues (ICOGPI'2012). Study the Effect of Additives on the Differential Pipe Sticking Caused by Water Based Drilling Fluid.* Thailand: 11-12 August 2012. Thailand: Phuket.
13. W.R. KELLY, T. FENTON HAM and A.B. DOOLEY, 1946.*Review Of Special Water-Base Mud Developments*. New York: American Petroleum Institute (API).
14. Y.M. BUSHNELL-WATSON, S.S. PANESAR, 1991. *Differential Sticking Laboratory Tests Can Improve Mud Design*. Texas: Society of Petroleum Engineers (SPE).