بسم الله الرحمن الرحيم

Sudan University of Science and Technology

College of Petroleum Engineering and Technology

Department of Exploration Engineering

Project title:

MECHANICAL STUCK PREVENTION CAUSED BY SHALE SWELLING USING LABORATORY EXPERIMENTS

Case study Ghadeer C-1

منع الاستعصاء الميكانيكي المسبب بواسطة انتفاخ الطين

باستخدام التجارب المعملية

دراسة حالة لبئر (Ghadeer C-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 Exploration Engineering

Prepared by:

1. **Abuhorira El Tahir Gumaa**
2. **Hassan Fath-Elrahman El-Hassan**
3. **Rammah El asaad El hassan**
4. **Mishaal Mairgani El hadi**
5. **Hosam Alden Ahmed Hamad**

Supervisor: **Dr. Yousif Bagadi**

October 2016

Mechanical Stuck prevention caused by shale swelling using laboratory experiments

(Case study Ghadeer C-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 Exploration Engineering

Prepared by:

Abuhorira El Tahir Gumaa

Hassan Fath-Elrahman Hassan

Rammah El asaad El Hassan

Mishaal Mairgani El hadi

Hosam Alden Ahmed Hamad

This project is accepted by college of petroleum engineering and technology to department of exploration engineering.

The graduation project supervisor: Dr Yousif Bagadi

Signature:……… .…………………………………………………………

Head of Department:…………………………………………… ……………….

Signature:…………………………………………………………… ………

Dean of college of petroleum engineering & Tech:………… ………………..

Signature:…………………………………………………………… ………

Date:………../………/2016

الإستهلال

قال الله عز وجل في محكم تنزيله:

بسم الله الرحمن الرحيم

اقْرَأْ بِاسْمِ رَبِّكَ الَّذِي خَلَقَ ﴿1﴾ خَلَقَ الْإِنْسَانَ مِنْ عَلَقٍ ﴿2﴾ اقْرَأْ وَرَبُّكَ الْأَكْرَمُ ﴿3﴾
الَّذِي عَلَّمَ بِالْقَلَمِ ﴿4﴾ عَلَّمَ الْإِنْسَانَ مَا لَمْ يَعْلَمْ﴿5﴾

صـــدق الله العظيـم

سـورة العلق﴿1﴾ الي ﴿5﴾

Dedication

We started over from the hand and we suffered more than the worry

We faced a lot of difficulties; today we thank Allah for this achievement. And we dedicate to teacher of the nation Holy Prophet Muhammad, peace be upon him.

And To

A fountain that does not get tired of giving to those who gave us happiness

Our mothers

To the sleepless nights in order to gain comfort that has given us everything For a push in the way of success

Our father

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

Acknowledgment

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

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

Dr. Yousif Bagadi for his cooperation and support throughout this study.

We would also like to thank **Eng. Ali Mamon** for his helping and assistance us in lab tests.

Our thanks and gratitude to **everyone who helped us** from near or a far to complete this work and in overcoming the difficulties encountered, most notably **Eng. MaaIdress Abd algalil** ,

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

Pipe Sticking is one of the serious problems that the drillers experience during drilling process of oil and gas wells. Pipe sticking can be divided into two categories: the differential stuck and mechanical stuck (shale swelling). In this research, we will focus on mechanical stuck and the effect of implementing additives on drilling mud to prevent mechanical pipe sticking. This project will investigate the shale swelling by using linear swell meter apparatus. Calcium Carbonate ($CaCo_{3}$), sodium silicate (Na_2Sio_3) and potassium chloride (KCL) are used as drilling fluid additives. The experimental investigation furnishes that with the proper combination of these additives, the sticking pipe can be precaution significantly with suitable properties of the drilling fluid required for optimum performance in oil and gas well drilling.

We conclude from our experiment results that the sodium silicate &potassium chloride succeed in mechanical sticking prevention where calcium carbonate ($CaCo_3$) is failed.

Keywords: Pipe sticking, Shale Swelling, Swell meter, potassium chloride (KCL), sodium silicate (Na_2Sio_3).

التجريد

تعتبر استعصاء الانابيب واحدة من اخطر المشاكل التي تواجه مهندسي الحفر اثناء حفر ابار النفط والغاز.يمكن تصنيف استعصاء الانابيب الى:الاستعصاء الميكانيكي والتفاضلي.

في هذا البحث سوف نركز على الاستعصاء الميكانيكي ودراسة تاثير بعض الاضافات على سائل الحفر لمنع مشكلة الاستعصاء الميكانيكي للانابيب وذلك باختبار انتفاخ الطين باستحدام جهاز(shale swell meter).

استخدمت كل من عينات كربونات الكالسيوم ($CaCo_3$) وكل من سيليكات الصوديوم (Na_2Soi_3)مع كلوريد البوتاسيوم (KCL).تم اختبار كل من هذه الاضافات باستخدام كميات مناسبة لمعرفة تأثيرها في تقليل انتفاخ الطين دون التأثير على بقية خواص سائل الحفر من الخواص التيارية والترشيح وغيرها.

وفي نهاية التجارب توصلنا الى ان سيلكات الصوديوم مع كلوريد البوتاسيوم نجحت في منع ظاهرة انتفاخ الطين بينما كربونات الكالسيوم لم تنجح.

ملخص البحث:استعصاء الانابيب - انتفاخ الطين - جهازقياس انتفاخ الطين - كلوريد البوتاسيوم - سيلكات الصوديوم.

Contents

List of figures:

List of Tables:

Nomenclature:

API**:** American Petroleum Institute

KCl**:** potassium chloride

$CaCo_3$**:** Calcium carbonate

Na_2Sio_3**:** sodium silicate

SUST Lab **:** Laboratory of Sudan University of Science and Technology

WBM: water based mud drilling fluid

YP**:** Yield Point

Ppg**:** pounds per gallon

gml**:** gram per mille liter

$kg/m3$**:** Kilogram per cubic meter

lb/gal**:** pounds per gallon

$lb/ft3$**:**pounds per cubic feet

$ml/30\ min$**:** mille liter per thirty minutes

cp**:** centipoise R_{600} **:** is the dial reading at 600 r/min

r/min**:** Rotation per minute

: Mud weight

η_p or PV: plastic viscosity

Chapter 1: Introduction

Chapter 1

Introduction

1.1.Introduction:

Stuck pipe is one of the most important drilling problems you will find in the oil-industry.

The stuck pipe cannot pull up – cannot go down – cannot rotate.

What is “stuck pipe”? [12]

Drilling a well requires a drill string (pipe & collars) to transmit the torque provided at the surface to rotate the bit, and to transmit the weight necessary to drill the formation.
The driller and the directional driller steer the well by adjusting the torque, pulling and rotating the drill string.

When the drill string is no longer free to move up, down, or rotate as the driller wants it to, the drill pipe is stuck. Sticking can occur while drilling, making a connection, logging, testing, or during any kind of operation which involves leaving the equipment in the hole.

The consequences of a stuck pipe are very costly. They include:[6]

□□ Increase the drilling time when trying to free the pipe.
□□ Time and cost of fishing: trying to pull out of the hole the possibility of broken part of the Bottom Hole Assembly (BHA).
□□ Abandon the tool in the hole because it is very difficult or too expensive to remove it. In that case the oil company pays for the replaced tool.

1.2.Problem Statement:

Ghadeer C-1 wild cat well has a mechanical sticking when using KCL/polymer mud as water based mud because the formation is commonly shale, clay stone and for this reason caused hole swelling and that lead to pipe stuck. This will require treatment to the mud by adding some additives in order to prevent formation from shale swelling. In this project, Calcium Carbonate ($CaCo_3$) or KCL/Sodium Silicate are used as additives for that purpose.

1.3.Objective of the study:

The study objectives are to:

1. Prevent shale swelling by study the effect of calcium carbonate ($CaCo_3$) and KCL/Silicate on the sticking pipe of water based mud.
2. Make treatment to the mud in order to get a suitable favorable rheological properties and filtration properties required for prevention pipe sticking tendency.

1.4. Methodology:

1. Prepare KCL/polymer mud typical to that used when the problem occurred.
2. Identify the effect of water on shale sample by using shale swell meter.
3. Identify the effect of used mud typical on shale sample by using shale swell meter.
4. Identify the effect of $CaCo_3$ on shale sample by using shale swell meter.
5. Identify the effect of both KCL /sodium silicate on shale sample by using shale swell meter.

1.5. Ghadeer C-1 Overview:

- Rig No: 4521(ZPEB)
- Well Name: Ghadeer C-1
- Well Type: Exploration well (wild cat)
- Plan Total Depth (m): 3000m
- Basin: Melut Basin
- Field/Block: PALOGUE/BLOCK 7E

- Position:16 km NW of Gumry field and
- 39 km to Adar base camp
- Offset well: Mishmish central-1 is located 5KM to East Ghadeer C-1

1.6. Geology of area:

There are two main basins in area these basins are all rift basins, owing their existence to the rifting activities of Western, Central and East African Rift Systems. Muglad, Melut, Blue Nile, Red Sea, Khartoum, and White Nile Basins. Fig (3), shows generalized stratigraphic columns for the Kaikang trough, which runs along the western flank of the Muglad basin and that of Unity in the Eastern flank, whereas, Fig (4) shows The stratigraphy of the Melut basin were sediments are inter-bedded sandstones, clay stones, siltstones, mudstones and shales. Intrusive rocks (Sills) were encountered in some wells such as in Garad-1, Sobat–1,Tabaldi-1, Ghadeer C-1…etc.

Abu Gabra Formation is the main source rock, consists of dark lacustrine shales containing a typically waxy kerogen and proved to be a reservoir in block # 6. Bentiu formation, Darfur group sandstone members, Amal and Tendi formations are the principal reservoirs. shale and claystones within Darfur Group as well as shales and clay stones within Abu Gabra Formation act as seal to underlying oil bearing horizons. None of the wells drilled in the Melut basin, has encountered the source rocks, however, based on the crude oil biomarker distributions and characteristics, it is believed that the source rock in Melut basin is equivalent to the Abu Gabra Formation found in the Muglad basin. Yabous Formation is the main reservoir in Meultbasin. Time of oil migration is uncertain, but it seems to be during mid to late Tertiary in the Muglad basin and during mid – Cretaceous to Late Cretaceous time in the melut basin.

The formation that causes shale swelling in our case study is **Lau formation (1795-1800 m)** in Melut basin. That contains shale and claystone.

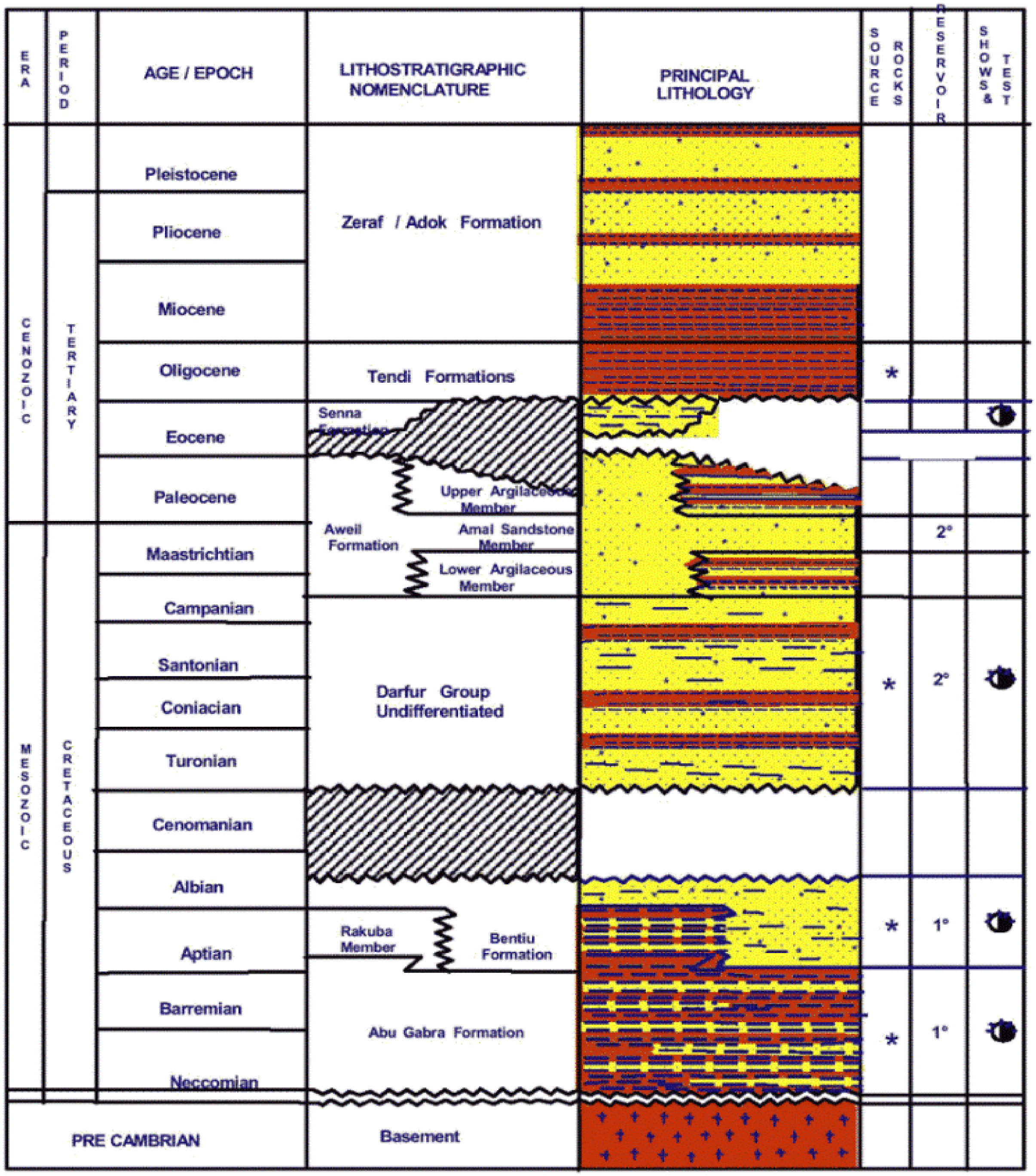


Fig (1-1) Stratigraphic summary of Muglad basin

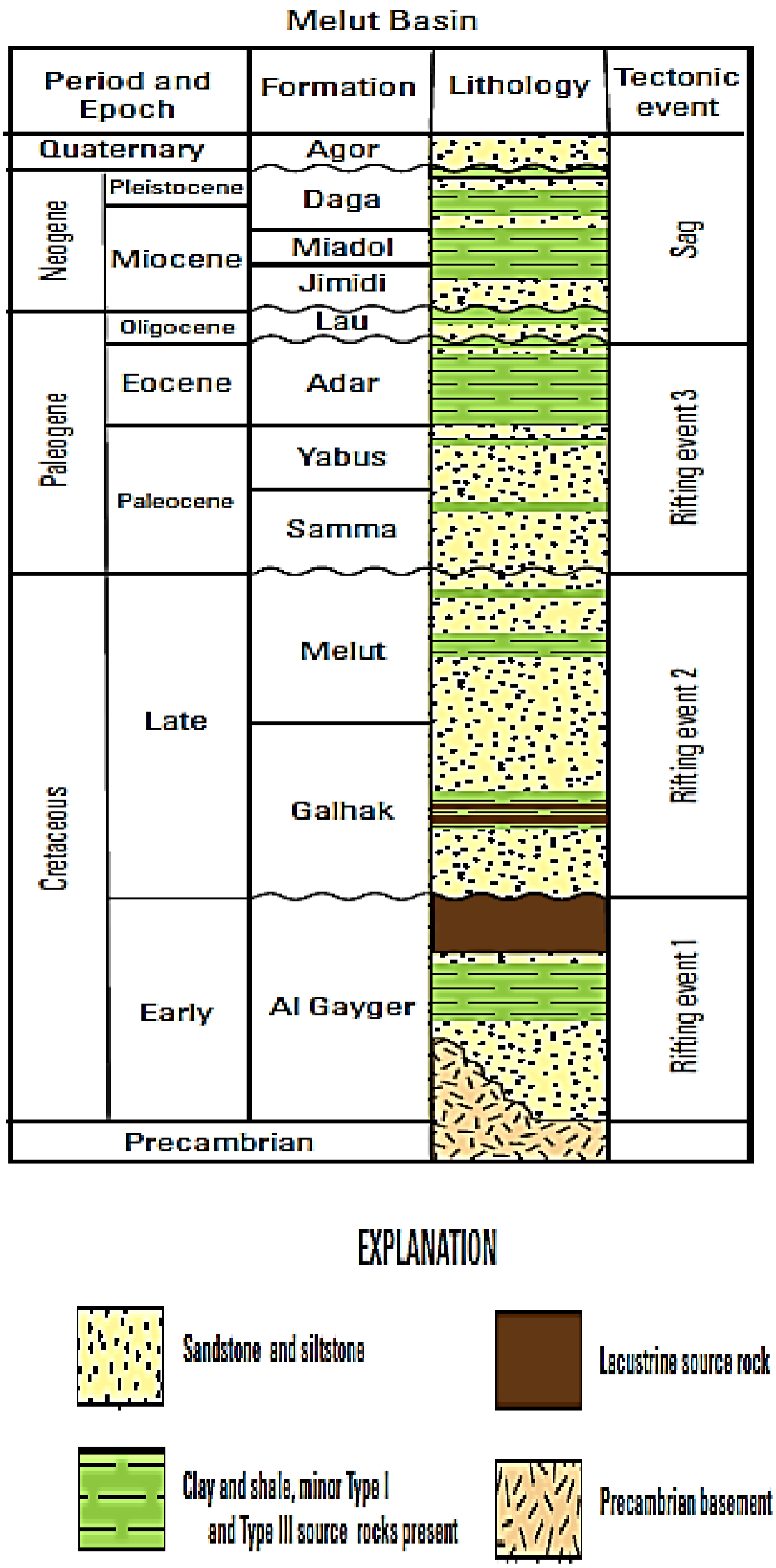
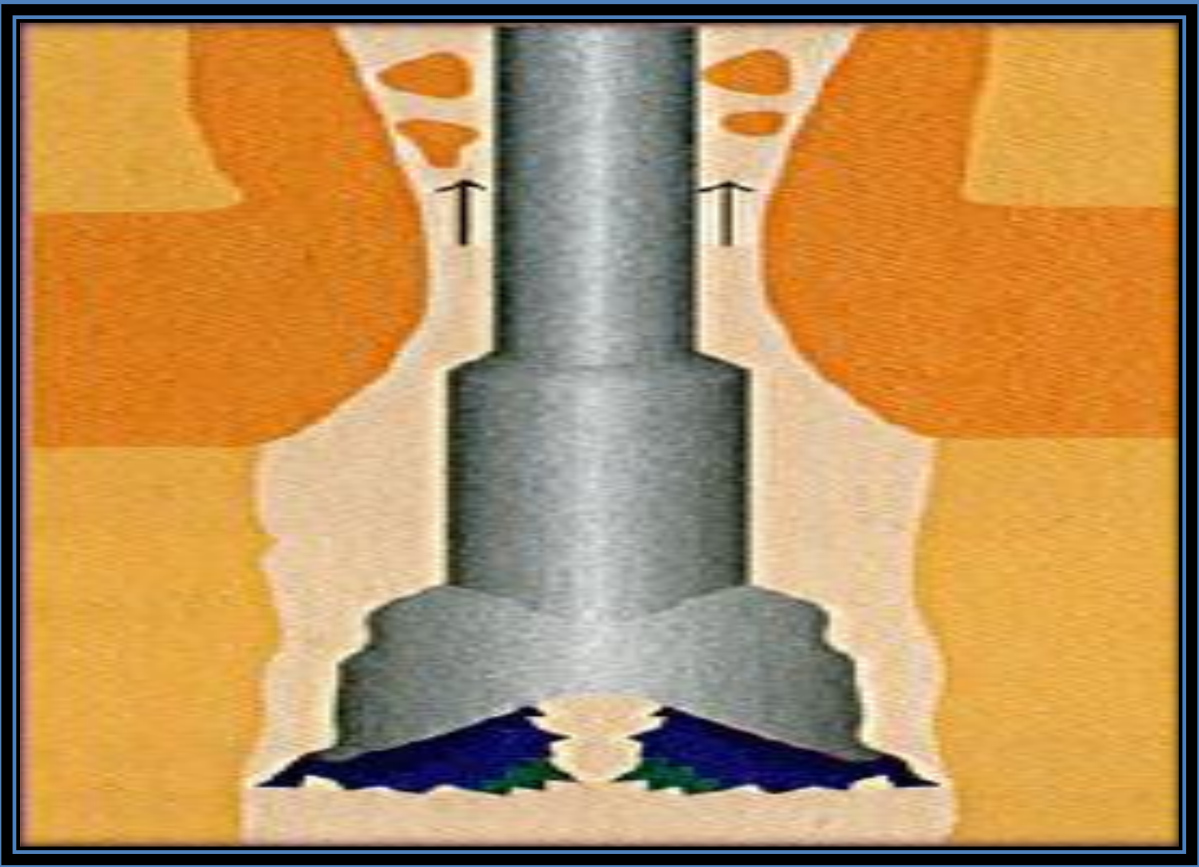


Fig (1-2) Stratigraphic summary of Melut basin

Fig(1-3) Central African rift basins: Muglad rift basin and muglad basin.

Chapter 2: Literature Review and Theoretical Background



Chapter 2

Literature Review and Theoretical Background

2.1. Literature Review:

Dennis, Brien and Martin, in September 1973 using Laboratory and field studies have demonstrated that potassium cations at sufficient concentrations in water-based drilling fluids can effectively reduce the swelling and dispersive tendencies of clay-containing shale's. Here is a unified classification method for relating the amount of water-sensitive clay in a shale to the occurrence and severity of wellbore problems.

Simpson,Van et al., 1994 explain that potassium salts have been used for a long time as swelling inhibitors in WBM. The inhibition is explained by the possible penetration of small non-hydrated ions into the porosity of the shale. And explain the reduction of the filtrate flow into shale by an increase of the viscosity leading to a reduction of shale permeability and a flow of mud filtrate into the shale driven by osmotic pressure.

Friedheim, Patel, et a in 2002 For laboratory tests, a typical mud contains several additives at concentrations commonly used, including a viscosifier (xanthan gumwith or without bentonite), a fluid loss reducer (polyanionic cellulose:

PAC), and different polymeric swelling inhibitors such as partially

hydrolysed polyacrylamide (PHPA), and polyalkyleneglycols (PAG or "glycol") to improve shale stability.

2.2. Drilling Fluids Background:[6]&[8]

Drilling a small hole into underground formation that may or may not be well consolidated introduces the possibility of some type of hole problem. The potential of having hole problems may be shown by geology used in well planning or by past experience which shows a specific hole problem may occur. The well plan should be designed to attack the potential hole problem. Drilling programs based on caution and containment generally results in expensive wells and very often wells that fail to reach the desired objective.

In one sense drilling operations are unique in that an operator is almost sure to encounter some type of hole problem in any area. Many hole problems are unexplained. Drilling practices may be standard and yet the hole sloughs, where in several years of previous work no similar problems have existed. One obvious answer is that the underground formations are not homogenous and new problems may occur at any time in carefully planned wells. Unfortunately many times hole problems in one or two wells will dictate practices for an area where no such problems have existed previously. As a result drilling wells times are extended, the hole problems continue cost increase and the good old days are forgotten. Major hole problems that include pipe sticking, and lost circulation and blowout etc…

2.2.1 Drilling Fluid Functions:

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 The properties of a drilling fluid:

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 is 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.

2.2.2.1 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 in lb/gal, lb/ft^3 or Specific Gravity (SG).

2.2.2.2 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.

2.2.2.3 Yield Point: $\boldsymbol{lbs/100\ ft^2}$

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 rates.

2.2.2.4 Gel Strength: $\boldsymbol{lbs/100\ ft^2(10\ sec/10min)}$

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.

2.2.2.5 Filtrate/Water Loss: $\boldsymbol{ml/30\ min}$

And Filter Cake Thickness: $\boldsymbol{1/32\ inch}$

These two properties shall be dealt 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.

2.3. Stuck pipe Background: [12]

Drilling a well requires a drill string (pipe & collars) to transmit the torque provided at the surface to rotate the bit, and to transmit the weight necessary to drill the formation.
The driller and the directional driller steer the well by adjusting the torque, pulling and rotating the drill string.

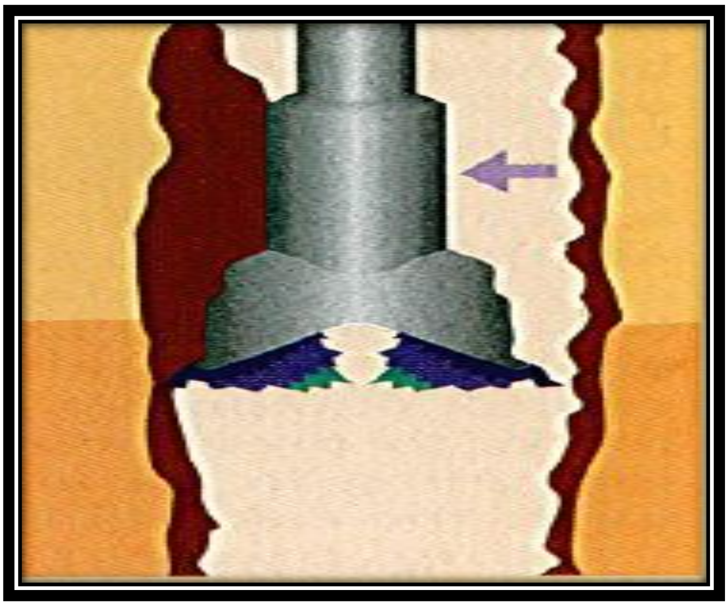
When the drill string is no longer free to move up, down, or rotate as the driller wants it to, the drill pipe is stuck. Sticking can occur while drilling, making a connection, logging, testing, or during any kind of operation which involves leaving the equipment in the hole.

In other words, the drill string is stuck when the static force necessary to make it move exceeds the capabilities of the rig or the tensile strength of the drill pipe.
Stuck pipe can result in breaking a part of the drill string in the hole, thus losing tools in the hole.

Hole pack-off and bridges settled cuttings. If cuttings are not removed from the borehole, they accumulate in the well, eventually causing the hole to pack-off, often around the Bottom-Hole Assembly (BHA) and sticking the drill string.

2.3.1. Types of stuck pipes:

2.3.1.1 Differential sticking: It is one of the most common causes of pipe sticking. It is due to a higher pressure in the mud than in the formation fluid. Differential sticking happens when the drill collar rests against the borehole wall, sinking into the mud cake. The area of the drill collar that is embedded into the mud cake has a pressure equal to the formation pressure acting on it. The area of the drill collar that is not embedded has a pressure acting on it that is equal to the hydrostatic pressure in the drilling mud.

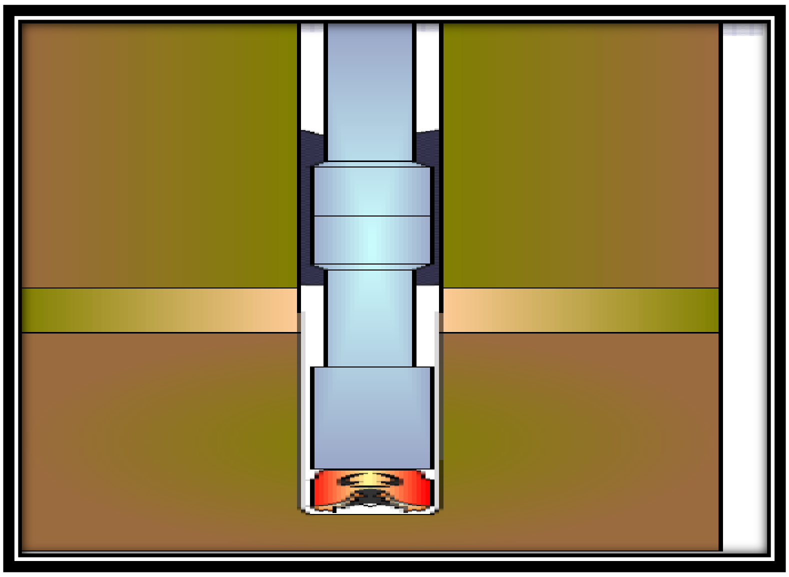


Fig(2-1) Differential sticking

2.3.2.2 Mechanical sticking:

It is one of causes of pipe sticking, in this project, we will show the mechanical pipe sticking parameters and reason why this happen on our drilling well. Mechanical sticking can be caused by junk in the hole, wellbore geometry anomalies, cement, or a buildup of cuttings in the annulus.

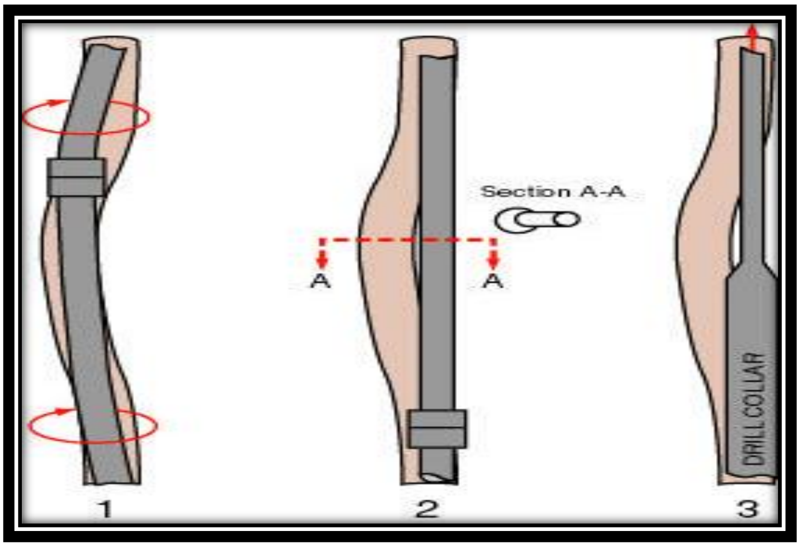
Hole pack-off and bridges settled cuttings. If cuttings are not removed from the borehole, they accumulate in the well, eventually causing the hole to pack-off, often around the Bottom-Hole Assembly (BHA) and sticking the drill string



Fig(2-2) mechanical sticking

2.3.2.3 A key seat:

It is caused by the drill string rubbing against the formation in doglegs. The body and tool joints of drill pipe wear a groove in the rock about the same diameter as the tool joints. During a trip out of the hole, the BHA may be pulled into one of these grooves, which may be too small for it to pass though. This type of sticking is likely to happen in a soft formation while dropping angle

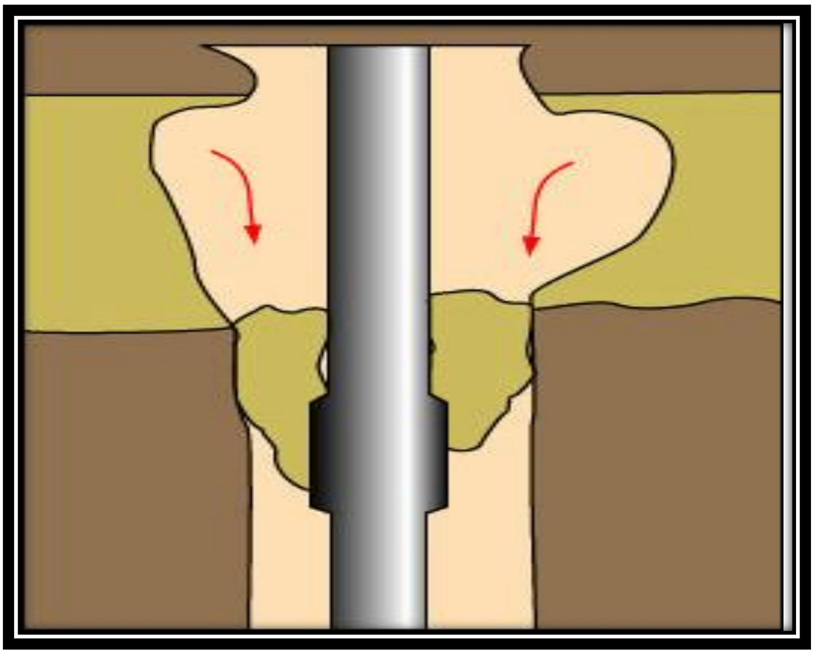


Fig(2-3) A key seat

2.3.2 Pipe sticking the most common causes and Preventative methods:

2.3.2.1. Unconsolidated Formations:

Unconsolidated motions such as loosely compacted sand and gravels can collapse into the wellbore forming a bridge around the drill string.



Fig(2-4) Unconsolidated Formations

Preventative method

- These formations need an adequate filter cake to help stabilize the formation.
- Seepage loss can be minimized with fine lost circulation material.
- If possible avoid excessive circulating time with the BHA opposite unconsolidated formations to reduce hydraulic erosion.

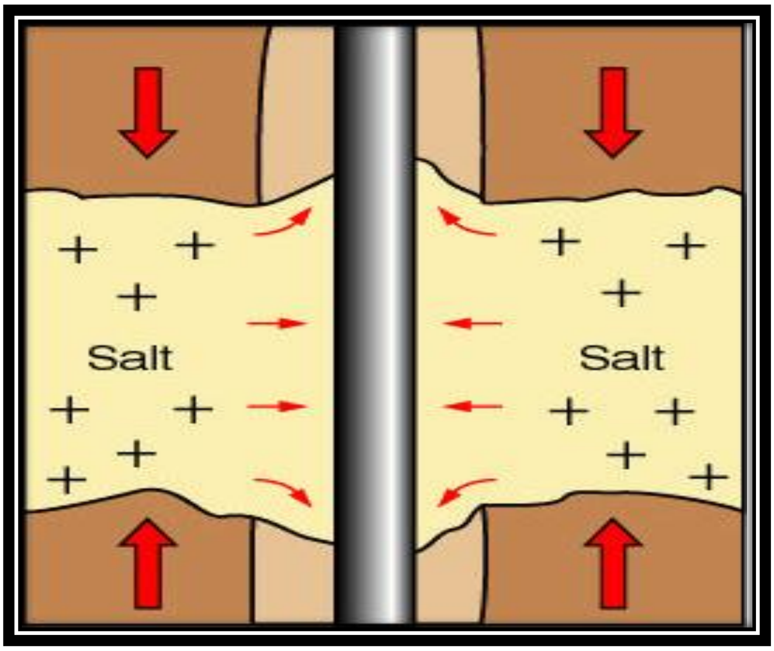
- Slow down tripping speed when the BHA is opposite unconsolidated formations to avoid mechanical damage.

Start and stop the pumps slowly to avoid pressure surges being applied to unconsolidated formations.

- Use sweeps to help keep the hole clean.
- Be prepared for shaker, desilter and desander overloading.

2.3.2.2. Mobile Formations:

Formation like salt and plastic shale's literally flow into the wellbore when restraining stresses is removed jamming the drill string.



Fig(2-5) Mobile Formations

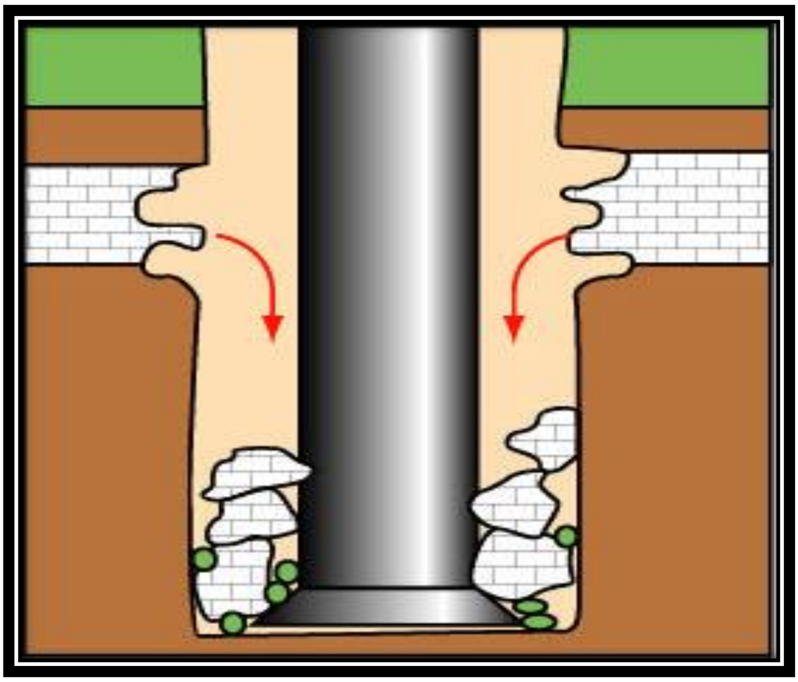
Preventative method

- Maintain sufficient mud weight.
- Select an appropriate mud system that will not aggravate the mobile formation.
- Consider bi-center PDC bits.
- Slow trip speed before BHA enters the suspected area.
- With mobile salts consider using a slightly under-saturated mud system to allow a controlled washout.

2.3.2.3. Fractured/Faulted Formation:

Formation that is naturally fissured or near a fault zone may break off in pieces into the bore hole and jam the drill string.

Pieces can vary from small up to boulder size. Formations that commonly fracture are carbonates and shale's.



Fig(2-6) Fractured/Faulted Formation

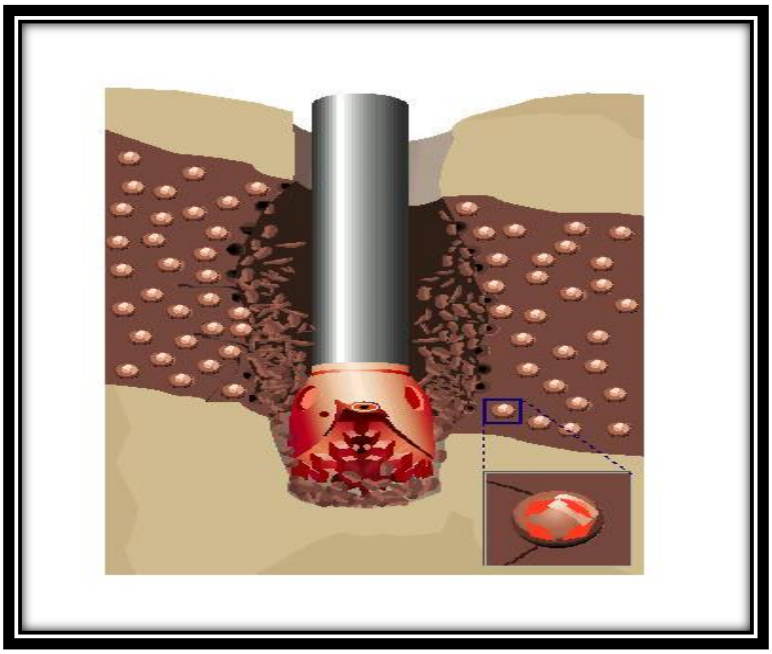
Preventative method

- Minimized drill string vibration.
- Choose an alternative RPM or change the BHA configuration if high shock vibrations are observed**.**
- Slow the trip speed before the BHA enters a suspected fractured/faulted area.
- Circulate the hole clean before drilling ahead. Start / stop the drill string slowly to avoid pressure surges to the well bore.

2.3.2.4. Overpressure formation:

A naturally over-pressured shale is one with a natural pore pressure greater than the normal hydrostatic pressure gradient.

Naturally over-pressured shale are most commonly caused by geological phenomena such as under-compaction, naturally removed overburden (*i.e. Weathering)* and uplift. Using insufficient mud weight in these formations will cause the hole to become unstable and collapse.



Fig(2-7) Overpressure formation

Preventative method

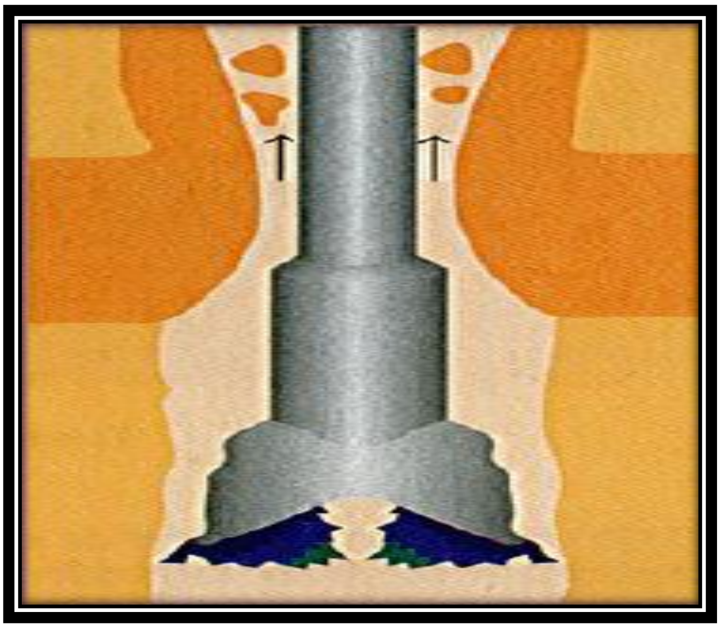
- Ensure planned mud weight is adequate.
- Use any information to predict pore pressure trends.
- It may also be the case that the mud weight will need to be raised with an increase in inclination.

2.3.2.5. Reactive or swelling shale formation:

Certain montmorillonite and bentonitic shale's hydrate and swell on contact with water base mud filling the borehole and creating clay balls that can block the wellbore and constrict the drill string.

Treating the mud with KCL and polymer can arrest hydration.

Oil base mud inhibits the process completely.



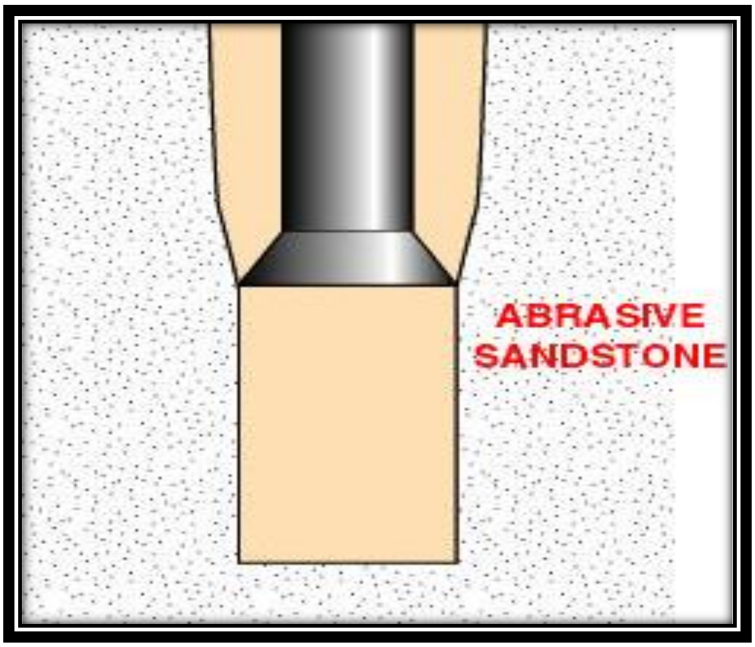
Fig(2-8) Reactive or swelling shale formation

Preventative method

- Use an inhibited mud system.
- Maintain the mud properties as planned.
- The addition of various salts (*potassium, sodium, calcium, etc.*) will reduce the chemical attraction of the water to the shale.
- Monitoring mud properties is the key to detection of this problem.
- Ensure hole cleaning is adequate to clean excess formation i.e. clay balls, low gravity solids etc.

2.3.2.6. Under gauge Hole:

Under gauge hole occurs when the gauge protection on the bit has become ineffective through drilling long sections of abrasive formations. If care is not taken when tripping in the new bit, it can become jammed in the under gauge hole.



Fig(2-9) Under gauge Hole

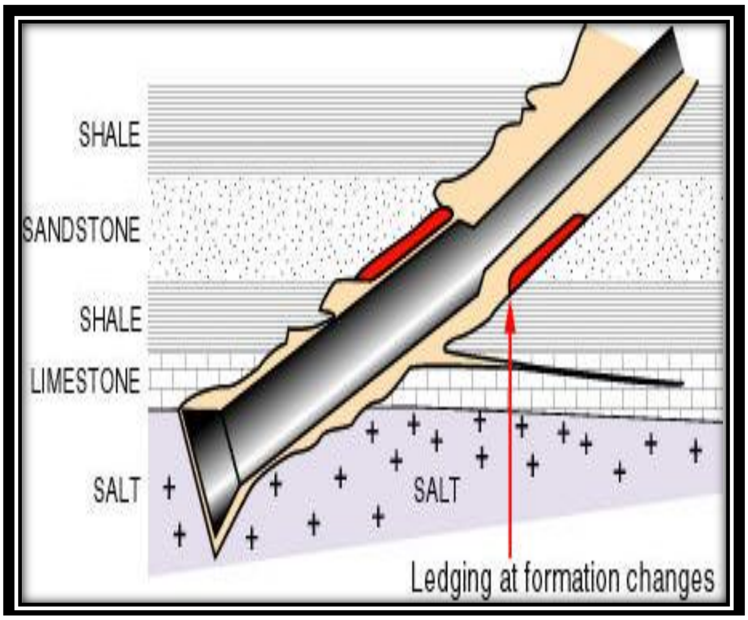
Preventative method

- Use suitably gauge-protected bits and stabilizers.
- Always gauge all BHA components both when running in and pulling out of the hole.
- Slow the trip speed down before the BHA enters an under gauge zone.

2.3.2.7. Wellbore geometry:

Doglegs and ledges between hard and soft formation can stick the drill string particularly when tripping out.

The drill string is under less tension tripping in more flexible and able to circumvent obstacles



Fig(2-10) Wellbore geometry

2.3.2.8.Poor cealing:

Poor hole cleaning results in overloading the annulus with cuttings, potentially sticking the drill string. This is most likely in washouts where annular velocity decreases and cuttings from beds on the low side of the hole and can migrate up hole like shifting sand dunes

Fig(2-11) Poor cealing

Preventative method

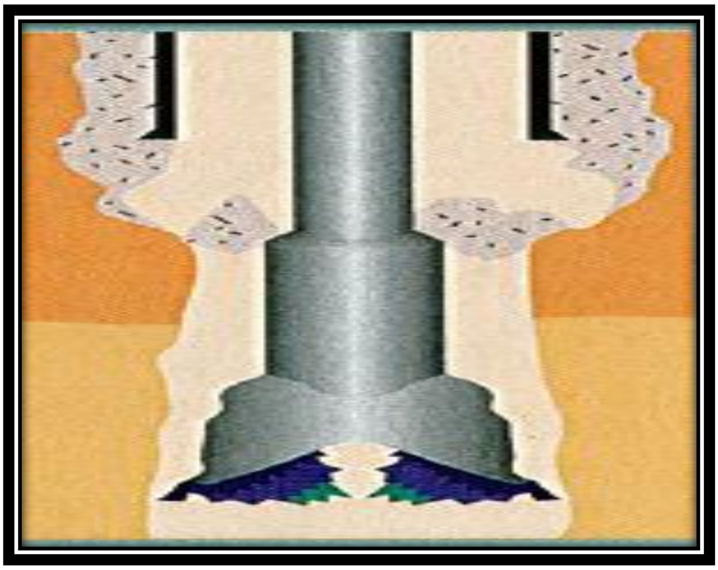
- Maximize the annular velocity.
- Ensure circulation times are adequate.

- Maximize mechanical agitation of cuttings beds.

2.3.2.9. Cement related:

Cement related Sticking occurs when blocks of cement fall into the wellbore from casing rat holes or cement plugs.

Jamming drill string becomes planted in soft or “green” that flash sets when pressure is applied



Fig(2-12) Cement related Sticking

Preventative method

- Slow the trip speed down before the BHA enters the casing shoe or the plug depth
- Allow sufficient curing time for cement before attempting to kick off or drill out.
- Ream casing shoe and open hole plugs thoroughly before drilling ahead.

2.4. About shale swelling: [5]

The swelling potential presupposes in most cases wet conditions and the material undergoes both shrinkage and swelling as a result of drying and wetting cycles from water content changes. An important factor is the dissimilar behavior the various clay minerals have according to the water content changes, and will thus be a source of different volume changes which in turn might affect the stability.

When the conditions for a swelling potential are present a mobilization of this potential will initiate the swelling process. For most expandable clay minerals the swelling process first takes place as a hydration where water molecules are attached to the negatively charged clay surfaces. A transition of highly bonded water molecules on the clay surface to freely pore water is gradually taking place and major swelling might occur. The hydration stadium is followed by an osmotic swelling where water will flow in the direction of highest ion concentration due to differences in the ion concentration between the unit layers and in the pore water (Nilsen and Broch, 2009). Water molecules will be flowing towards the interlayers of the clay minerals and the swelling degree depends on a number of factors like the interlayer spacing, ion concentration and valence and water availability

Fig(2-13) Photo of prepared discs for swelling testing.

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:

3.2.1. 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.

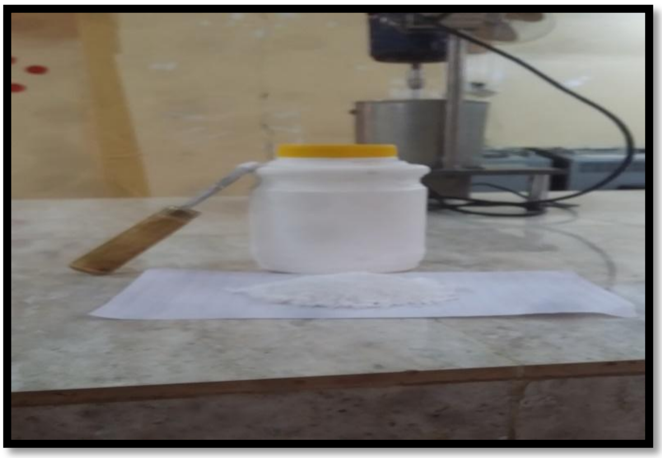


Fig.(3-1) a sample of Barite
SUST Lab

3.2.2. PAC- LV:

PAC- LV is a modified cellulosic viscosity and filtration control an 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.(3-2) a sample of PAC LV
SUST LAb

3.2.3. Starch:-

Starch work well as fluid-loss agents in the presence of low soluble calcium or sodium ions, starch suitable for salt-water or gyp 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.(3-3) a sample of starch
SUST Lab

3.2.4. Caustic soda:

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

Fig.(3-4) a sample of Caustic soda
SUST Lab

3.2.5.Potassium Chlorite:

Potassium Chloride (KCL) used primarily to formulate solids.

Fig.(3-5) a sample of . Potassium Chlorite
SUST Lab

3.2.6. Flowzan:

Flowzan Biopolymer is a high-purity, high-viscosity xanthan gum featuring patented dispersion tech. for optimal hydration. It delivers exceptional rheological properties to

fresh and salt water-based muds.

Fig.(3-6) a sample of Flowzan
SUST Lab

3.2.7.Sodium Silicate:

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

Fig.(3-7) a sample of Sodium Silicate
SUST Lab

3.2.8.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.

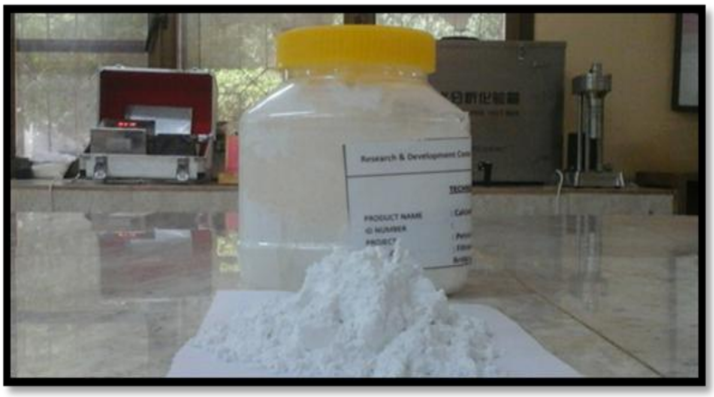


Fig.(3-8) a sample of Calcium Carbonate
SUST Lab

3.3. Description of Equipment:

3.3.1. Digital Balance:

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

Fig.(3-9) 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. (3-10) the mud mixer consist mainly from crank connected to an electric motor and fan to stir the component.

Fig.(3-10) 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.(3-11) mud balance from Sust lab

3.3.4.Six speed viscometer:

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.(3-12) six speed viscometer

www.atlanticsupply.com

3.3.5.API Filter Press:

As shown in fig. (3-13), 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).

Fig.(3-13) API-filter-press from luheng.en.alibaba.com

3.3.6. Linear Swell Meter :

Drilling problems such as stuck pipe, tight hole, washout, and sloughing can be related to shale stability.

The Fann Linear Swell Meter (LSM) helps determine shale hydration or dehydration by measuring the increase or decrease in length over time of reconstituted or intact shale core.

Fig.(3-14) Linear swell meter from luheng.en.alibaba.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: [6]

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 $600\ r/min$ at, 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 $(10 - second\ gel) in\ pounds\ per\ 100ft^2$.
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:

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 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 1 The plastic viscosity is commonly known in the industry by the abbreviation PV.
- NOTE 2 $1\ cp = 1\ mpa.s.$

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 abbreviation Y_P.

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

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

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

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

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

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 $cm\ to$ 1,5cm (0.4 $in\ to$ 0.6 in) of the top (to minimize CO_2 contamination 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. Shale swelling Test Procedure:

1. Prepare shale samples according to the required specifications of device linear swell meter.
2. Make sure the holes of cylinder lids do not close by any previous sediment.
3. Put shale sample in cylinder and Superimpose Compressor.
4. Put cylinder and sensitive measure in device and make sure that the measure does not shed any pressure from the compressor.
5. Fill the cup with fluid, and then place the device inside the cup and Record reads per minute or two minutes.
6. Zero the device by using zeroing button and then repeat the previous steps with the other fluid or other experiment.

Chapter 4: Results and Discussion

Chapter 4

Results and Discussion

4.1.Results:

KCL-polymer base fluid was prepared in the laboratory, and then two additives were tested in the laboratory:

(1) calcium carbonate "$CaCo_3$"
(2) sodium –silicateNa_2sio_3 and KCL

To study the effect of additives on the mud properties, especially on mechanical sticking; amount of additives in the base fluid were varied.

Mud Weight, Rheological properties, filtration and shale swelling of tested fluids were determined according to API recommended practice standard procedure for testing drilling fluids, API. As shown in table (4-2).

Table(4-1) Marital of tested muds

Components	Drilling Fluids	
	Amount in lab	Amount in field
Water	600 (ml)	0.00377 (barrel)
Barite	174.6 (gm)	0.38493(pound)
Caustic Soda	1.0 (gm)	0.0022(pound)
PAC LV	1.0 (gm)	0.0022(pound)
Starch	24.3 (gm)	0.05357(pound)
KCL	2 (gm)	0.0441(pound)
Flowzan	1.0 (gm)	0.0022(pound)
Na_2Sio_3	74 (ml)	0.00465 (barrel)

Table (4-2) properties of tested muds

Properties	Units	Drilling Fluids			
		A	B	C	Average
Mud weight	Ppg	10.2	10.2	10.3	10.23
θ_{600}	Rpm	54	52	53	53
θ_{300}	Rpm	36	34	35	35
Apparent Viscosity (AV)	CP	26	26	26	26
Plastic Viscosity (PV)	CP	18	18	18	18
Yield Point (YP)	$lb/100ft^2$	18	18	18	18
pH	-	12	12	12	12
Mud cake	mm	0.4	0.4	0.4	0.4
Filtration	ml	4.5	4.4	4.4	4.4

A= Experiment No(1)

B= Experiment No(2)

C= Experiment No(3)

Table (4-3) shale swelling tested values by using water

Shale swelling value by using water	
Values (mm)	**Time (min)**
00.4	**1**
0.6	**2**
0.7	**3**
0.9	**4**
1	**5**
1.15	**6**
1.23	**7**
1.3	**8**
1.39	**9**
1.48	**10**
1.51	**11**
1.6	**12**
1.63	**13**
1.7	**14**
1.78	**15**
1.8	**16**
1.84	**17**
1.89	**18**
1.9	**19**
1.98	**20**
2	**21**
2.02	**22**

2.06	**23**
2.1	**24**
2.15	**25**
2.2	**26**
2.23	**27**
2.25	**28**
2.29	**29**
2.32	**30**

Table (4-4) shale swelling tested values by using drilling fluid

Shale swelling value by using drilling fluid	
Value (mm)	**Time (min)**
0.04	**1**
0.12	**2**
0.39	**3**
0.51	**4**
0.61	**5**
0.71	**6**
0.81	**7**
0.92	**8**
0.99	**9**
1.05	**10**
1.13	**11**
1.2	**12**
1.29	**13**

1.32	**14**
1.4	**15**
1.45	**16**
1.5	**17**
1.55	**18**
1.6	**19**
1.62	**20**
1.67	**21**
1.7	**22**
1.75	**23**
1.8	**24**
1.85	**25**
1.9	**26**
1.92	**27**
1.94	**28**
2	**29**
2.11	**30**

Table (4-5) shale swelling tested values by using deferent quantity of $CaCo_3$:

Shale swelling value by using $CaCo_3$					
Time (min)	$CaCo_3$				
	1 (gm)	2 (gm)	5 (gm)	7 (gm)	17 (gm)
	Shale swelling Values (mm)				
1	0.1	0.08	0.05	0.11	0.1
2	0.21	0.1	0.15	0.15	0.28
3	0.3	0.16	0.21	0.2	0.41
4	0.42	0.21	0.25	0.25	0.5
5	0.5	0.35	0.3	0.3	0.6
6	0.7	0.42	0.35	0.31	0.69
7	0.81	0.51	0.37	0.35	0.74
8	0.92	0.58	0.42	0.39	0.81
9	1.04	0.61	0.45	0.41	0.85
10	1.13	0.69	0.46	0.43	0.9
11	1.39	0.72	0.51	0.49	0.95
12	1.48	0.78	0.55	0.52	0.99
13	1.55	0.81	0.58	0.58	1.08
14	1.64	0.86	0.64	0.63	1.12
15	1.74	0.93	0.65	0.67	1.25
16	1.79	0.99	0.67	0.7	1.29
17	1.84	1.02	0.73	0.74	1.35
18	1.88	1.06	0.75	0.76	1.39
19	1.91	1.09	0.76	0.79	1.43
20	1.95	1.12	0.8	0.81	1.49
21	1.99	1.19	0.82	0.83	1.55
22	2.01	1.22	0.87	0.88	1.61
23	2.05	1.25	0.9	0.91	1.69
24	2.14	1.28	0.93	0.96	1.74
25	2.19	1.3	0.94	0.99	1.82
26	2.22	1.31	0.95	1.02	1.89

27	2.24	1.35	0.96	1.05	1.93
28	2.31	1.38	0.96	1.09	1.97
29	2.36	1.42	0.96	1.12	2.01
30	2.39	1.46	0.97	1.16	2.09

Table (4-7) shale swelling tested values by using deferent quantity of Na_2SIO_3 and KCL:

Shale swelling value by using Na_2SIO_3 and KCL					
Time (min)	Na_2SIO_3 (mml) and KCL (gm)				
	20 (mml) 2 (gm)	54 (mml) 2 (gm)	74 (mml) 2(gm)	74 (mml) 7 (gm)	74 (mml) 17 (gm)
	Shale swelling Values (mm)				
1	0.2	0.1	0.14	0.1	0.08
2	0.36	0.18	0.17	0.16	0.09
3	0.45	0.2	0.26	0.23	0.1
4	0.5	0.21	0.33	0.25	0.1
5	0.59	0.25	0.35	0.26	0.1
6	0.61	0.28	0.39	0.28	0.1
7	0.69	0.29	0.43	0.33	0.1
8	0.71	0.31	0.45	0.34	0.12
9	0.78	0.32	0.45	0.35	0.12
10	0.81	0.34	0.5	0.36	0.12
11	0.85	0.36	0.53	0.38	0.12
12	0.86	0.39	0.54	0.4	0.12
13	0.9	0.4	0.55	0.42	0.12
14	0.91	0.4	0.56	0.44	0.12
15	0.93	0.41	0.56	0.45	0.12
16	0.99	0.41	0.57	0.46	0.12

17	1	0.42	0.58	0.46	0.12
18	1.03	0.43	0.58	0.46	0.12
19	1.07	0.43	0.58	0.47	0.12
20	1.1	0.44	0.59	0.47	0.12
21	1.12	0.46	0.59	0.48	0.12
22	1.13	0.48	0.59	0.5	0.13
23	1.15	0.49	0.6	0.52	0.13
24	1.18	0.49	0.6	0.53	0.13
25	1.2	0.5	0.6	0.55	0.13
26	1.21	0.5	0.61	0.56	0.14
27	1.24	0.5	0.64	0.56	0.14
28	1.28	0.5	0.65	0.56	0.14
29	1.3	0.5	0.66	0.56	0.14
30	1.32	0.50	0.67	0.56	0.14

4.2.Discussion:

The effect of additives was investigated and the results obtained clarify whether we succeed or failed in reducing shale swelling value.

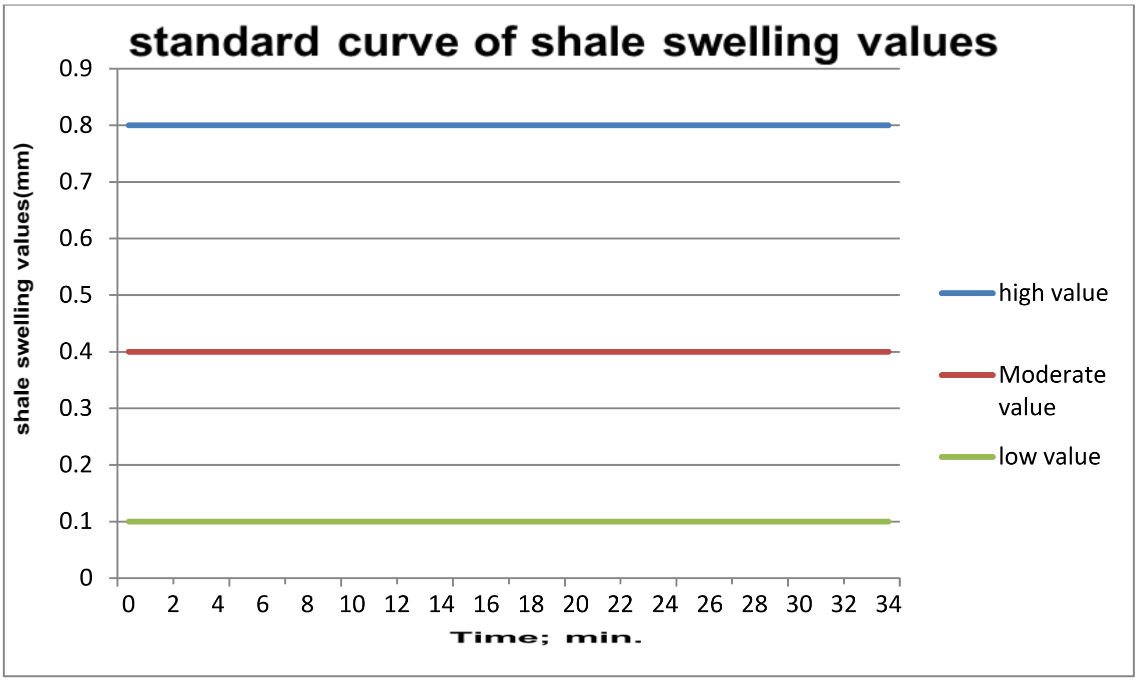


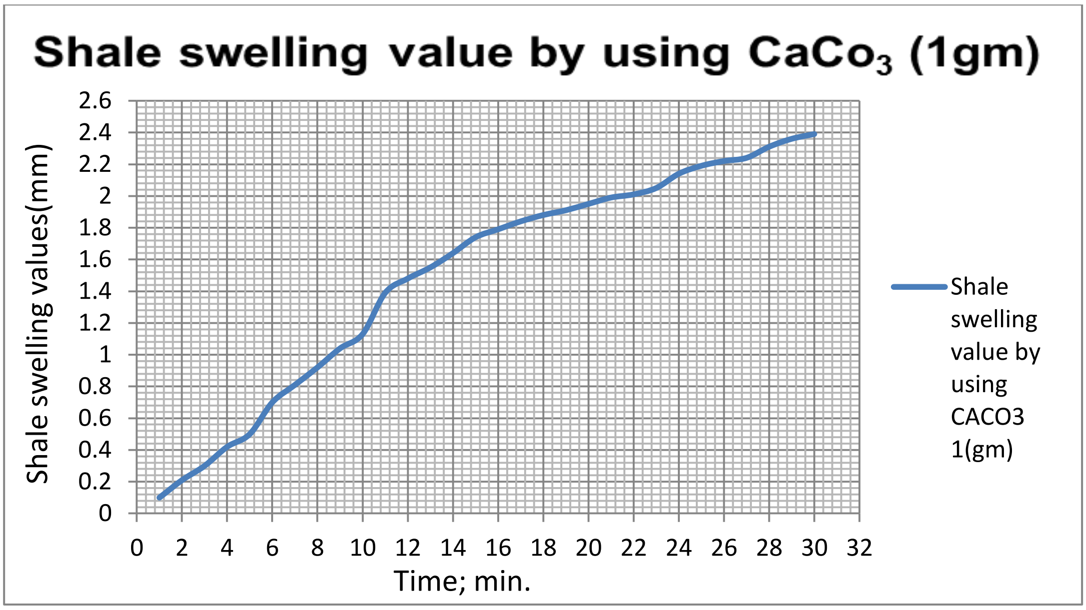
Fig (4-1)standard curve of shale swelling values

4.2.1. Calcium carbonate ($CaCo_3$)

The effect of different quantities of ($CaCo_3$) on the shale sample:

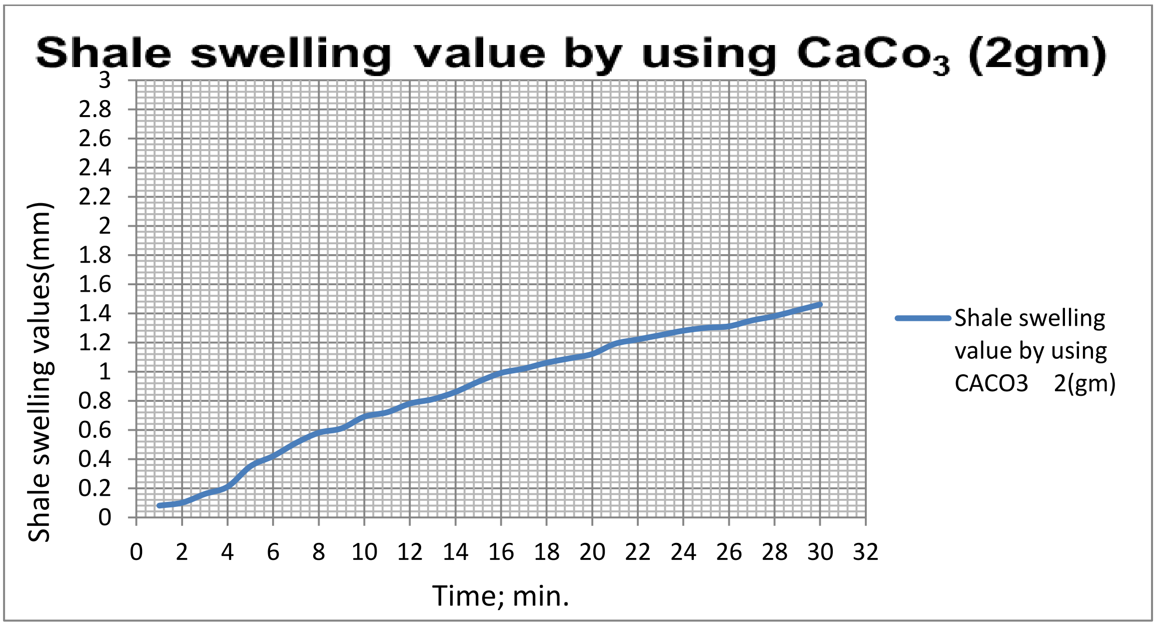
Our reference in this material based on civil engineering ,is used for soil swelling prevention by mixing this material in powder form with soil mud.

(1) when we added small weight of $CaCo_3$ (1gm), the results shows a very high values of swelling as shown in fig(4-2) which mean that this quantity added is not succeed in preventing swell propagation.



Fig(4-2) explain change of shale swelling values with time effected by $CaCo_3$ (1 gm).

(2) When we added more of $CaCo_3$ (2gm),it reduced the values of swelling comparing with above concentration (1gm) as shown in fig(4-3)but the results is not succeed in preventing swelling value .



Fig(4-3) explain change of shale swelling values with time effected by $CaCo_3$(2 gm).

(3) Then we continue added weight of $CaCo_3$ (5gm), the values of swelling continues reducing , as shown in fig(4-4) , best result is obtained here as we can notice no more shale swelling after 24 min. anyhow it's not gave optimum value.

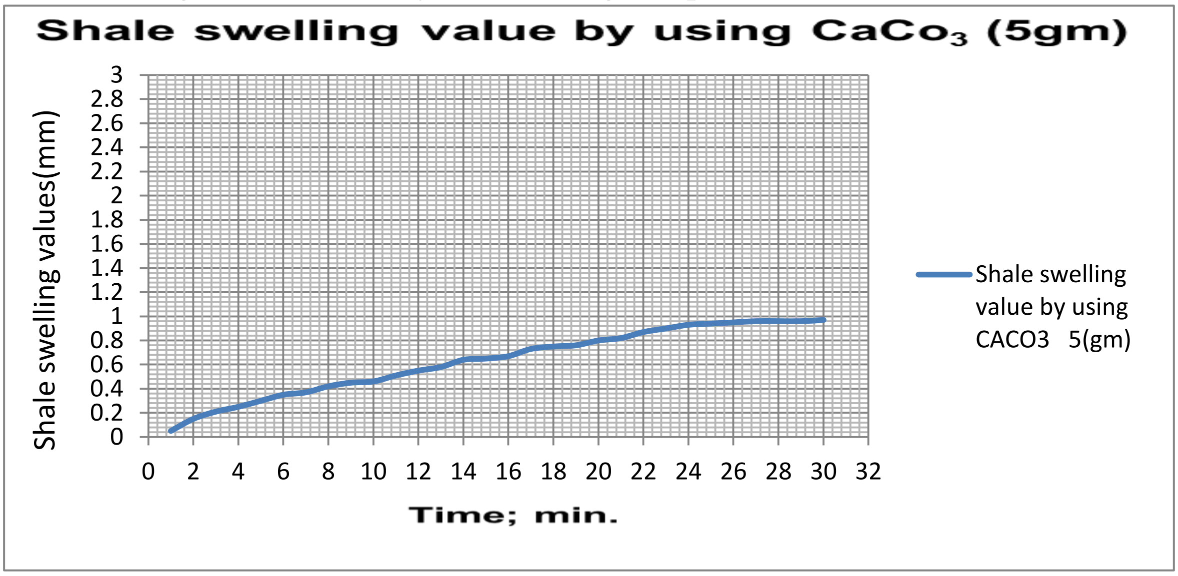


Fig (4-4) explain change of shale swelling values with time effected by CaCo3

(5 gm).

(4) Then we added more of $CaCo_3$ (7gm), but unfortunately the values of swelling increased , as shown in fig(4-5)and also this value not accepted to prevention from shale swelling.

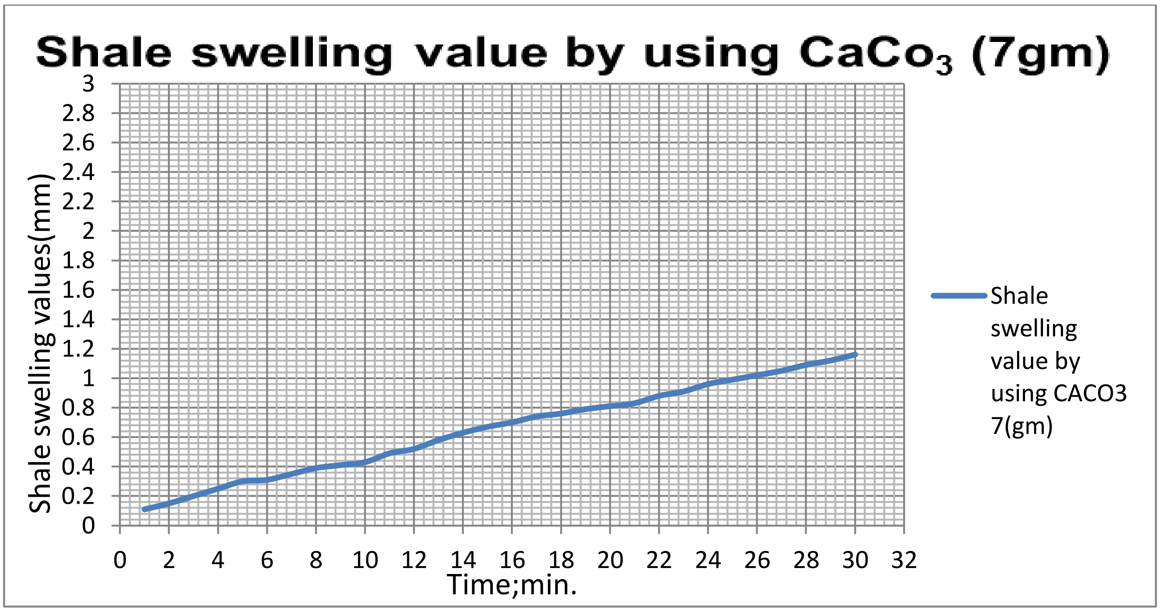


Fig (4-5) explain change of shale swelling values with time effected by $CaCo_3$(7 gm).

(5)) By adding more of $CaCo_3$ (17gm) , the values of swelling increased more, as shown in fig(4-6)this indicate continue adding concentration of $CaCo_3$ is not succeed in preventing swell propagation.

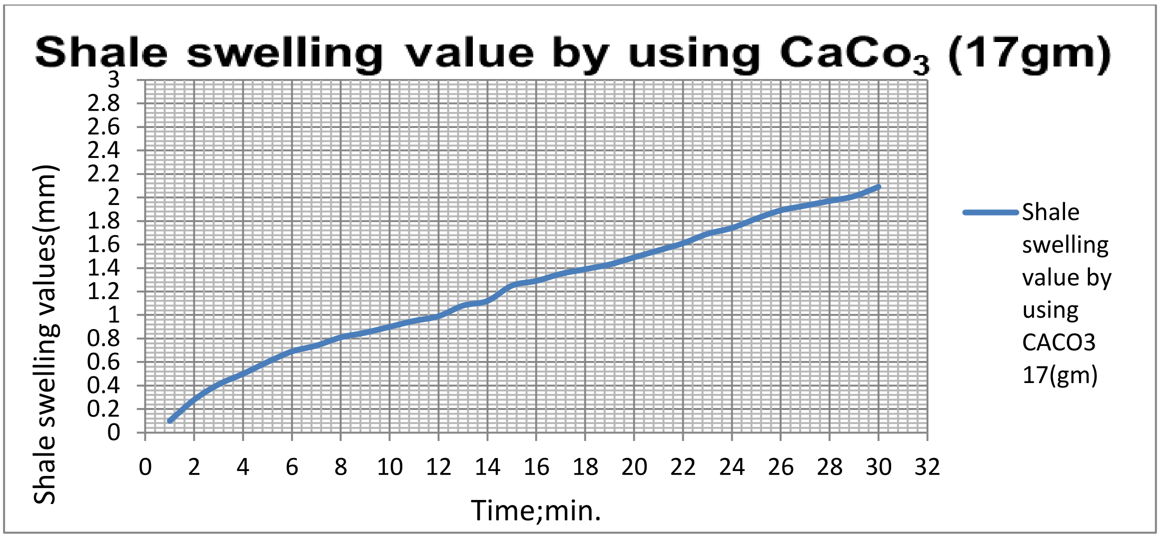


Fig (4-6) explain change of shale swelling values with time effected by CaCo3 (17 gm).

4.2.2. Sodium silicate (Na_2Sio_3) and KCL

The effect of different quantities of (Na_2Sio_3) and (KCL) on the shale sample:

The swelling formation content sodium cation (Na+) when we add KCL additives to drilling fluid the sodium cation replace potassium cation and

Produce sodium chloride (NaCl) and potassium cation (k+).

And also sodium silicate when it find alkaline medium it converge to classes material and isolate formation from drilling mud. And hence prevent from swelling.

(6) when we added (20 ml) of Na_2SIO_3 and(2 gm) of kcl ,gave high values of swelling as shown in fig(4-7) is not succeed in preventing shale swelling values .

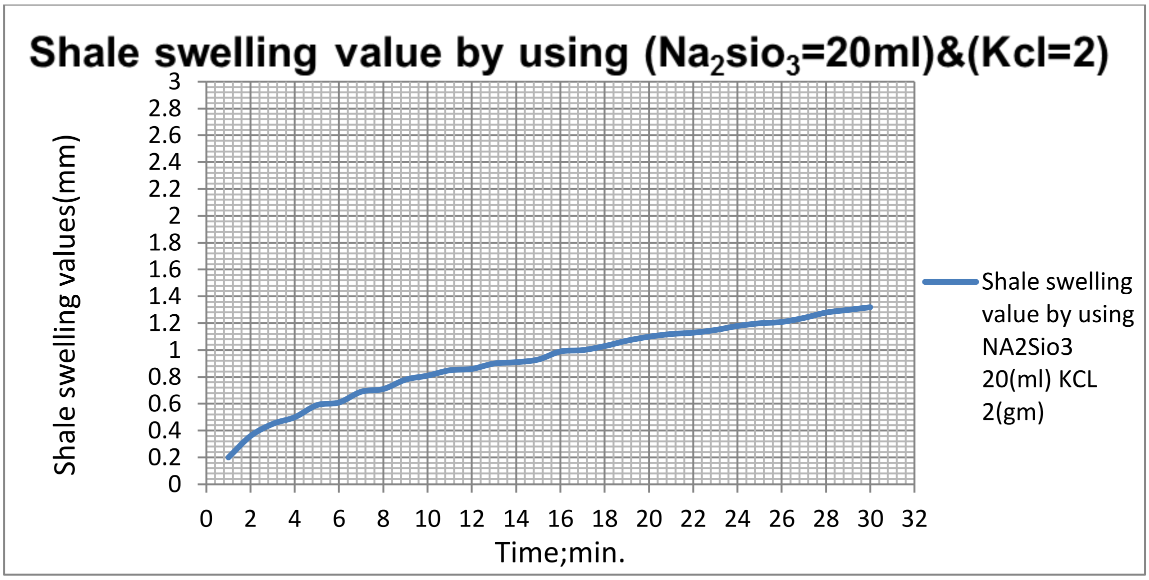


Fig (4-7) explain change of shale swelling values with time effected by (20 ml) of Na_2SIO_3 and(2 gm) of KCL.

(7) when we added (54 ml) of Na_2SIO_3 and(2 gm) of kcl , it reduced the values of swelling comparing with above quantities as shown in fig(4-8), a good results is noticed here because a small shale swelling value and after 22 min. no more shale swelling.

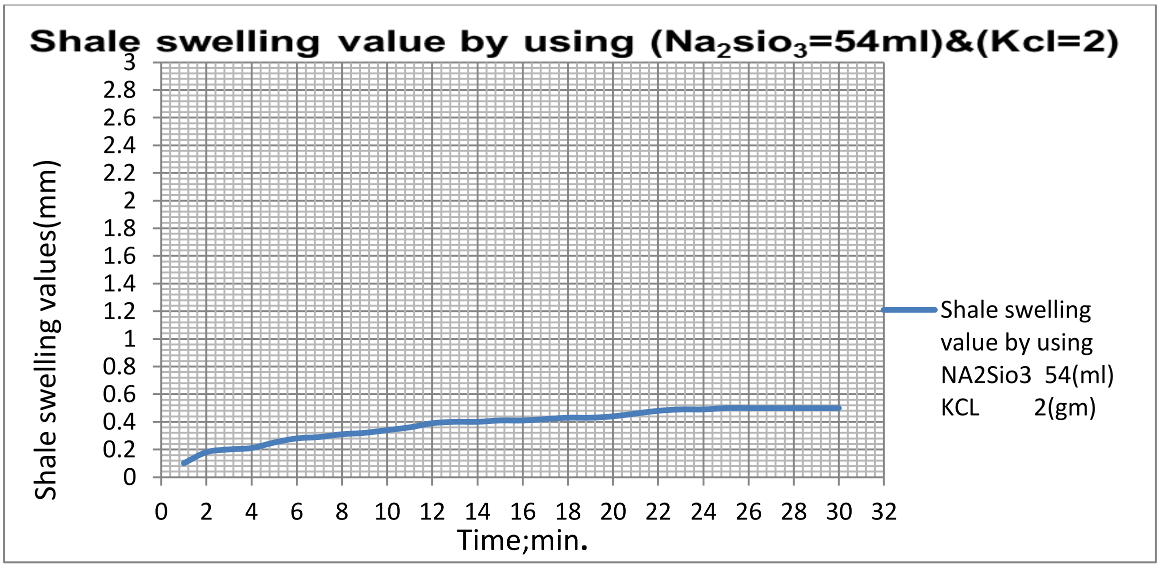


Fig (4-8) explain change of shale swelling values with time effected by (54 ml) of Na_2SIO_3 and (2gm) of KCL.

(8) when we added (74 ml) of Na_2SIO_3 and(2 gm) of KCL , gave little increase values of swelling as shown in fig(4-9), also consider to be a good results since there is no change in swelling value after 12 min .

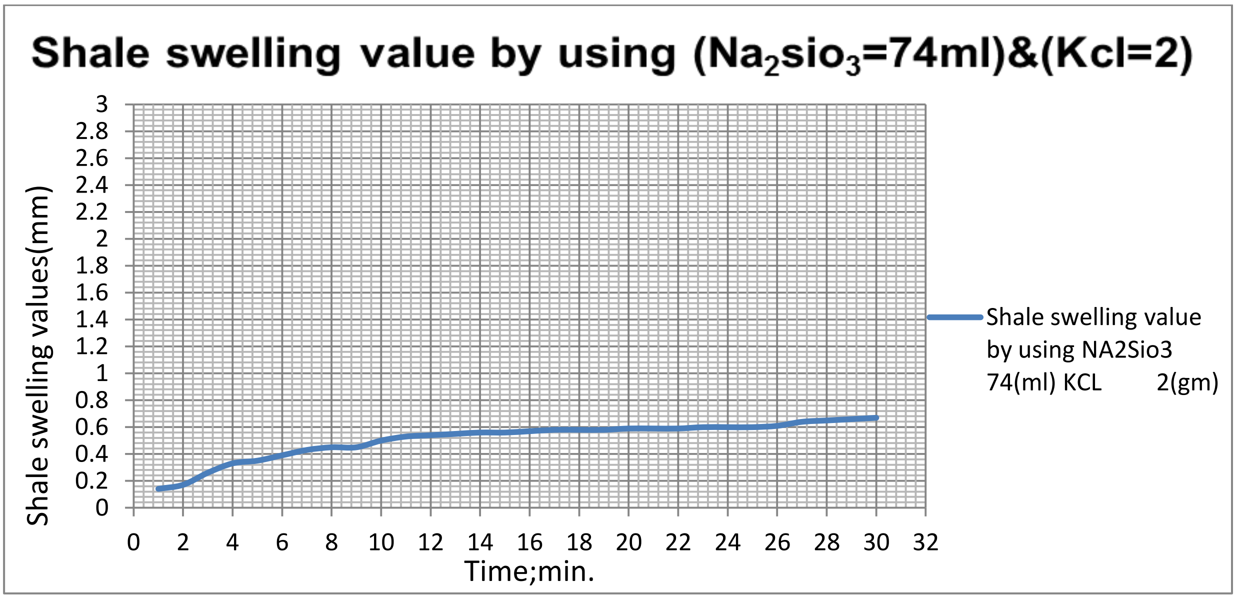


Fig (4-9) explain change of shale swelling values with time effected by (74 ml) of Na_2SIO_3 and (2 gm) of KCL.

(9) when we added (74 ml) of Na_2SIO_3 and(7 gm) of KCL ,the value of shale swelling start reducing again as shown in fig(4-10),), also a good results since there is no change in swelling value after 12 min .

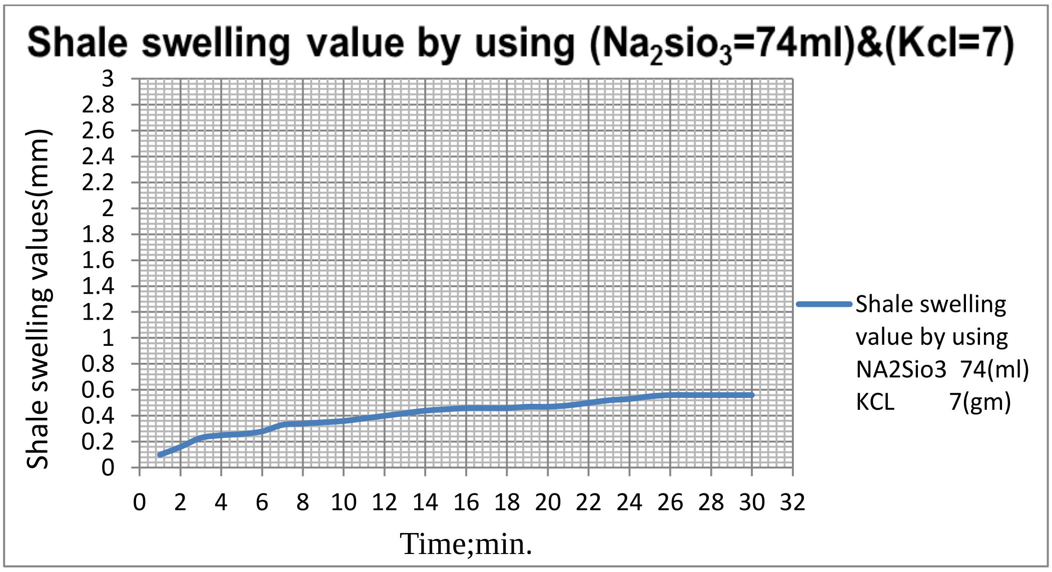


Fig (4-10) explain change of shale swelling values with time effected by (74 ml) of Na_2SIO_3 and (7gm) of KCL.

(10) when we added (74 ml) of Na_2SIO_3 and(17 gm) of KCL ,the value of shale gave optimum value of shale swelling as shown in fig(4-11), this results shows entirely prevention of shale swelling.

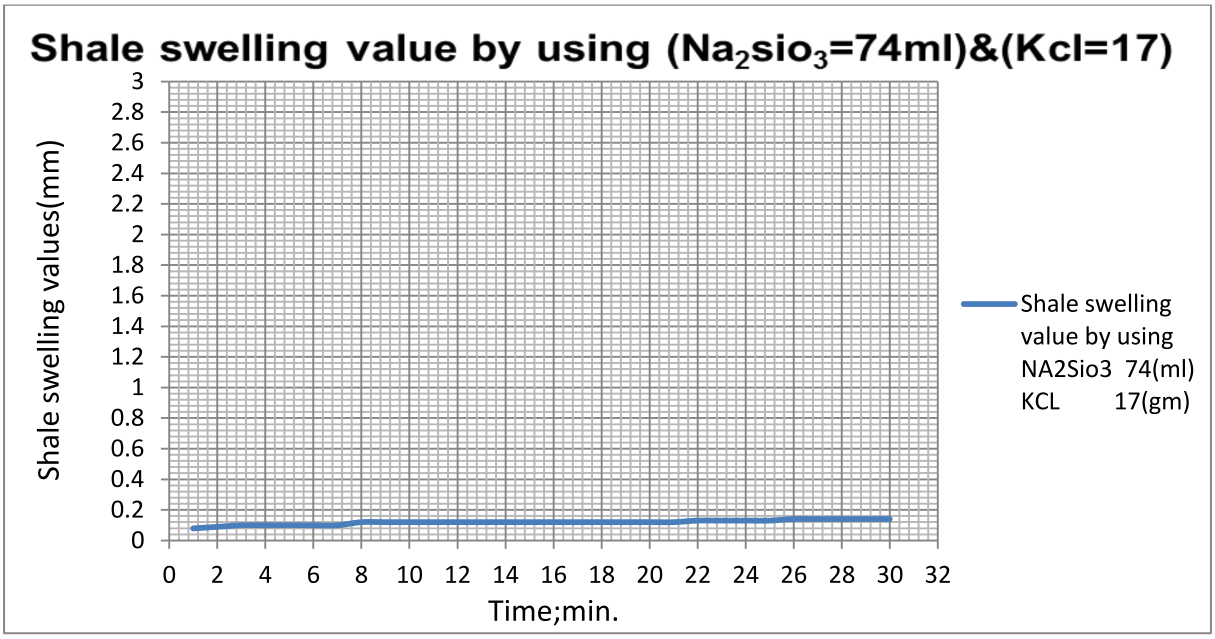


Fig (4-11) explain change of shale swelling values with time effected by (74 ml) of Na_2SIO_3 and (17gm) of KCL.

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-polymer base fluid when mixed by (**74ml**) sodium silicate Na_2SIO_3 and (**17gm**) from potassium chloride KCL. is the most suitable drilling fluid that is reduce the value of shale swelling (0.14 ml) and hence prevent the mechanical sticking

Chapter 5: Conclusion and Recommendations

Chapter 5
Conclusion and Recommendations

5.1. Conclusion:

From the experimental performed tests the following conclusions can be made:

1. concentration of $CaCo_3$ less than (5 gm) show a high value of swelling thus is not succeed in preventing swell propagation, Fig (4-2),fig (4-3).
2. Add 5 gm of $CaCo_3$ show low values of reducing swelling. But also not succeed in preventing shale swelling, fig(4-4).
3. Add Concentration of $CaCo_3$ above (5 gm) show a high value of swelling thus is failed in preventing shale swelling values, Fig (4-5),fig (4-6).
4. Faintly that calcium carbonate failed in reducing shale swelling value as we nested above.
5. Add (20 ml) of Na_2SIO_3 and(2 gm) of kcl ,results high values of swelling as shown in fig(4-7) is not succeed in preventing shale swelling values .

.

6. Add (54 ml &74 ml) of Na_2SIO_3 and(2 gm,5 gm) of kcl ,the result shows a good values of swelling, succeed in preventing shale swelling values but is not optimum values.

.

7. The proper combination of Sodium silicate Na_2soi_3 (74 ml) and potassium chloride KCL (17gm) can reduce the shale swelling value. Thus that is essential for the development of optimum drilling fluid systems to prevent the mechanical pipe sticking problems. Fig (4-11).

5.2. Recommendations:

1. It is recommended to conduct the laboratory tests under high pressure and high temperature.
2. Effect of other additives can be identified such as (polymer, potassium saults, and Quaternary ammonium compounds).

3. Other instruments can be used in shale swelling measurement(digital shale swelling).

It is recommended to add quantities 12% of ($Na2SIO_{3)}$ and 2.8% of (KCL) of drilling mud if we faced formation caused shale swelling to prevent mechanical sticking.

5.3.References:

1. **Alford, S.E. (**1991), North Sea field application of an environmentally responsible water-base hale stabilizing system. In: Proceedings Volume, SPE/IADC Drilling Conf.(Amsterdam, the Neth, 3/11–14/91), pp. 341–355.

2. Aadnoy, B.S., Chenevert, M.E.(1987), Stability of highly inclined boreholes. SPEDE, 364– 374

3. AMERICIAN PETROLEUM INSTITUTE (API). (2003),*Recommended Practice on the Rheology and Hydraulics of Oil-well Drilling Fluids 13D,* 4th ed. New York: American Petroleum Institute (API).

4. Ballard, T.J., Beare, S.P., Lawless, T.A. (1992),Fundamentals of shale stabilization.water transport through shales: Paper SPE 24974 presented at the SPE European Petroleum Conference, Cannes.

4. Ballard, T.J., Beare, S.P., Lawless, T.A. (1992),Fundamentals of shale stabilization.water transport through shales: Paper SPE 24974 presented at the SPE European Petroleum Conference, Cannes.

5. Bonar MARBUN, Arif SOMAWIJAYA, Arnold R.(2016), **Study of Prevention and Mitigation of Stuck Pipe in Geothermal Drilling.** Stanford University, Stanford, California

6. Clapper, D.K.,Watson, S.K., (1996) Shale stabilising drilling fluid employing saccharide derivatives. EP Patent 702 073:assigned to Baker Hughes Inc

7. Cliffe, S., Dolan, B., Reid, P.I., (1995). Mechanism of shale inhibition by polyols in waterbased drilling fluids. SPE Paper 28960:SPE International Symposium on Oilfield Chemistry. San Antonio, TX, 14–17 February.

8. Krishna Kanta Panthi, IGB, (2014) Study on the Swelling Potential of some Selected Rocks. Norwegian University of Science &Technology :Department of Geology and Mineral Resources Engineering
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. W.R. KELLY, T. FENTON HAM and A.B. DOOLEY, (1946). *Review Of Special Water-Base Mud Developments*. New York: American Petroleum Institute (API).
12. *Zurich, Stefano-Franscini* (2015) Existing methods for swelling tests – a critical review. European Geosciences Union: Division Energy, Resources & Environment, ER
13. *Zurich, Stefano-Franscini* (2015) Existing methods for swelling tests – a critical review. European Geosciences Union: Division Energy, Resources & Environment, ERE