REDUCING BARITE SAGGING BY USING COPOLYMER IN HIGH PRESSURE HIGH TEMPERATURE WELLS

BY

SALEM ABDULLAH MUSALLAM BASFAR

A Thesis Presented to the
DEANSHIP OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

In

PETROLEUM ENGINEERING

April 2018

KING FAHD UNIVERSITY OF PETROLEUM and MINERALS

DHAHRAN- 31261, SAUDI ARABIA

DEANSHIP OF GRADUATE STUDIES

This thesis, written by **SALEM ABDULLAH MUSALLAM BASFAR** under the direction his thesis advisor and approved by his thesis committee, has been presented and accepted by the Dean of Graduate Studies, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN PETROLEUM ENGINEERING.**

Salaheldin Elkatatny

Dr. Salaheldin Elkatatny
(Advisor)

Mohamed Mahmoud

Dr. Mohamed A. Mahmoud.
(Member)

Dr. Muhammad Shahzad Kamal
(Member)

Dr. Dhafer Al-Shehri

Department Chairman

Dr. Salam A. Zummo
Dean of Graduate Studies

عمادة الدراسات العليا
DEANSHIP OF GRADUATE STUDIES

1/5/18

Date

I dedicate this work to my parents, my wife and my lovely daughters Retaj and Aisha

ACKNOWLEDGMENTS

Without my supervisor Dr. Salaheldin Mahmoud Elkatatny, associate professor at the college of petroleum and geoscience, this work would not have been possible to conduct. Professor Elkatatny was the main man flowed me to achieve this work and he has ever since been very helpful and patient in following up the work. I express my sincere gratitude to him for both spiritual support and supervision throughout these years.

I have also had the great pleasure of having Dr. Mohamed Mahmoud and Dr. Muhammad Shahzad Kamal, as committee members of my work. I truly admire them, and I would like to thank them for all their contributions for getting this work finalized. Moreover, I would like to thank Mr. Mobeen Murtaza for help me a lot at lab work. He has brought all chemicals. Furthermore, I appreciate Hadhramout Establishment for Human Development for support me with a scholarship. Finally, I would like to thank my family for their support and patience throughout these years. Without their support I would never have started nor finished this long work

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

API	American Petroleum Institute
ANOV	Analysis of Variance
IEFs	Invert Emulsion Fluids
OBM	Oil Base Mud
WBM	Water Base Mud
G'	Elastic or Storage Module
G''	Viscous or Loss Module
LVE	Linear Viscoelastic
ppg	Pound Per Gallon
HPHT	High Pressure High Temperature
SF	Sag Factor
VST	Viscometer Sag Test
VSST	Viscometer Sag Shoe Test
LSYP	Low Shear Yield Point
DHAST	Dynamic High Angle Sag Test
MRV	Modified Rotational Viscometer
PCF	Pound Per Cubic Feet

ABSTRACT

Full Name : Salem Abdullah Musallam Basfar

Thesis Title : Reducing Barite Sagging By Using Copolymer In High Pressure High Temperature Wells

Major Field : Petroleum Engineering

Date of Degree : April 2018

Weighting materials are an essential part of the drilling processes. One of the primary purposes of a drilling fluid is to suspend drilling cutting and weighting materials, in static and dynamic conditions. Low shear viscosity or poor gel strength resulted in settling of the weighting material down in the hole down in the drilling mud, known as barite sagging. Some drilling fluids exhibit elastic and viscous features at low shear rates. This means that the fluid has got solid-like and liquid-like qualities.

Completion of high-pressure high temperature well is one of the most challenging in the oil industry. Drilling fluids that are used in these situations required a lot of specific properties. This complexity in deep wells pushed the industry to develop a new formulation of drilling fluids to meet the requirements. Conventional drilling fluid weighted by barite material is one solution to those problems, but it exhibits some problems for instance barite settling.

This study evaluates the influence of add copolymer in oil-based drilling fluids to solve sag problems with the use of viscoelastic measurements. Oil based mud (OBM)with a density of 14.7 ppg is used in this study at temperature vary from 85 °F to 350 °F.

The conducted experiments included vertical and inclined (45° degree) sag measurements to simulate sag occurring in the vertical and deviated boreholes. Moreover, conventional rheological methodology and two different types of viscoelastic measurements conducted in this research for a subjective characterization. Furthermore, the effect of temperature investigated. Finally, a new formulation of barite oil base mud was designed.

The novelty of this work is the development of a new drilling fluid formulation that can be used in drilling high-pressure high temperature (HPHT) wells without any sag issue. This development will help the drilling engineers to safely drill deep wells and maintain the drilling fluid integrity during the drilling operation. In general, this will reduce the overall cost of the drilling operations by eliminating reduction the non-productive time in solving many issues such as well control, loss of circulation, or pipe sticking.

The results obtained showed that adding 1 lb_m /bbl of the new copolymer had no effect on drilling fluid density (14.7 ppg). The new copolymer slightly enhanced the electrical stability of the invert emulsion drilling fluid from 1470 volt in the base to 1482 volt in the new formulation. The new copolymer had a minor effect on the plastic viscosity, yield point, and it increases the gel strength to prevent sag. Adding 1 lb_m /bbl of the copolymer prevent barite sagging at 350°F, the sag factor was 0.504. The storage modulus (G') was increased by 40% after adding 1 lb_m /bbl of the new copolymer confirming the sag test results. There was no effect of adding the new copolymer in the filter cake thickness with a little improvement in filtration loss

ملخص الرسالة

الاسم الكامل: سالم عبدالله مسلم بصفر

عنوان الرسالة: التقليل من ترسب البارايت باستخدام البوليمرات في الابار ذات الضغط ودرجة الحراره العاليه

التخصص: هندسة بترولية

تاريخ الدرجة العلمية: ابريل، ٢٠١٨

تعتبر المواد المثقلة في طين الحفر جزء أساسي في عملية حفر الابار النفطية. واحد من اهم الوظائف لسوائل الحفر هي القدرة على تعليق القطع المحفورة بالإضافة الى تعليق المواد المثقلة في طين الحفر في كلا من حالة السكون ودوران طين الحفر اثنا الحفر. انخفاض لزوجة القص وضعف تركيب طسين الحفر يؤدي الى انفصال المواد ذات الكثافة العالية وترسيبها في قعر البئر وهو ما يعرف ب sag. بعض اطيان الحفر لديها مرونة ولزوجه عند تعرضها لمعدلات قص منخفضه، وهذا يعني ان هذه الموائع لديها خاصية المواد الصلبة والسائلة.

إن إكمال الابار ذات الضغط ودرجة الحرارة العالية يعتبر واحد من أصعب التحديات في الصناعة النفطية. لهذا فان طين الحفر المستخدم عند هذه الظروف يجب ان يحتوي على خصائص معينه بحيث تمكنه من مواجهة هذه الظروف. اطيان الحفر التقليدية ذات الأساس البارايتي هي واحده من هذه الحلول لكن البارايت يعتبر من المواد التي تترسب سريعا في قعر البئر. في هذا البحث سيتم تقييم إضافة نوع من أنواع البوليمر الى طين الحفر ذو الأساس النفطي لكي يحل مشكلة sag. طين الحفر المستخدم في هذه الدراسة لديه كثافه ١٤,٧ رطل لكل جالون في ظروف تبدأ من 85 °F الى 350 °F.

التجارب المستخدمة في هذه الدراسة تشمل على قياس sagفي الابار العمودية والابار المائلة بزاوية ٤٥°. بالإضافة اجراء التجارب التقليدية rheology، فان نوعين من فحص viscoelastic تستخدم للتشخيص الدقيق.

النتائج المحرزة أدت الى ان استخدام جرام واحد من البوليمر ليس لديه تأثير على كثافة طين الحفر وأيضا فان إضافة هذا البوليمر لديه تأثير خفيف على اللزوجة البلاستكية ونقطة المطاوعة. اضا عند إضافة جرام واحد من البوليمر أعطى sag حوالي ٠,٥٠٤ عند 350 °F وليس لديه تأثير على سماكة كعكعة طين الحفر بل انه قلل من راشح طين الحفر.

CHAPTER 1

INTRODUCTION

1.1 Background

weighting materials are used to increase the density of the drilling fluid in the drilling operations. The selection of the weighting agent to be used in drilling fluids is determined by many factors. One of the most important factors is to provide low rheology in high-density fluids and low sag (Zamora and Bell 2004). To increase the density of muds there are several weighting materials that are used in the oil industry such as barite, manganese tetroxide, ilmenite, and calcium carbonate. The most common weighting material is the barite because it has many properties such as it is very dense, economical, widely available and pure (Nguyen et al. 2011). However, these excellent properties, barite drilling fluids have a problem of settling known as barite sag. Also, barite is very hard to remove from the wellbore except by using expensive multistage chelating agents and barite converters to dissolve it and remove any formation damage (Ba Geri et al. 2017; Mahmoud and Elkatatny 2017)

1.2 High-Pressure High-Temperature Drilling Challenges

Oil or gas wells which have static reservoir pressure greater than 10000 psi and temperature above 300 °F are classified as high-pressure high-temperature wells HPHT **Figure 1.1** (Smithson 2016). Completion of high-pressure high-temperature wells is one of the most challenging in the oil industry. Drilling fluids that be used in such conditions must have specific properties. This complexity in HPHT well pushed the researchers to develop a formulation of drilling fluid to meet the requirements, barite weighting material was one of the solutions but, it has problem related to the settling of its particles.

There is a small window between pore pressure and fracture pressure gradient in HPHT wells, so if the mud has pressure much greater than fracture gradient of the formation, it will break down the formation and cause loss of circulation. On the other hand, if the mud pressure less the pore pressure of the formation, it allows the formation fluid to inter to the wellbore and causes kick followd by blow out.

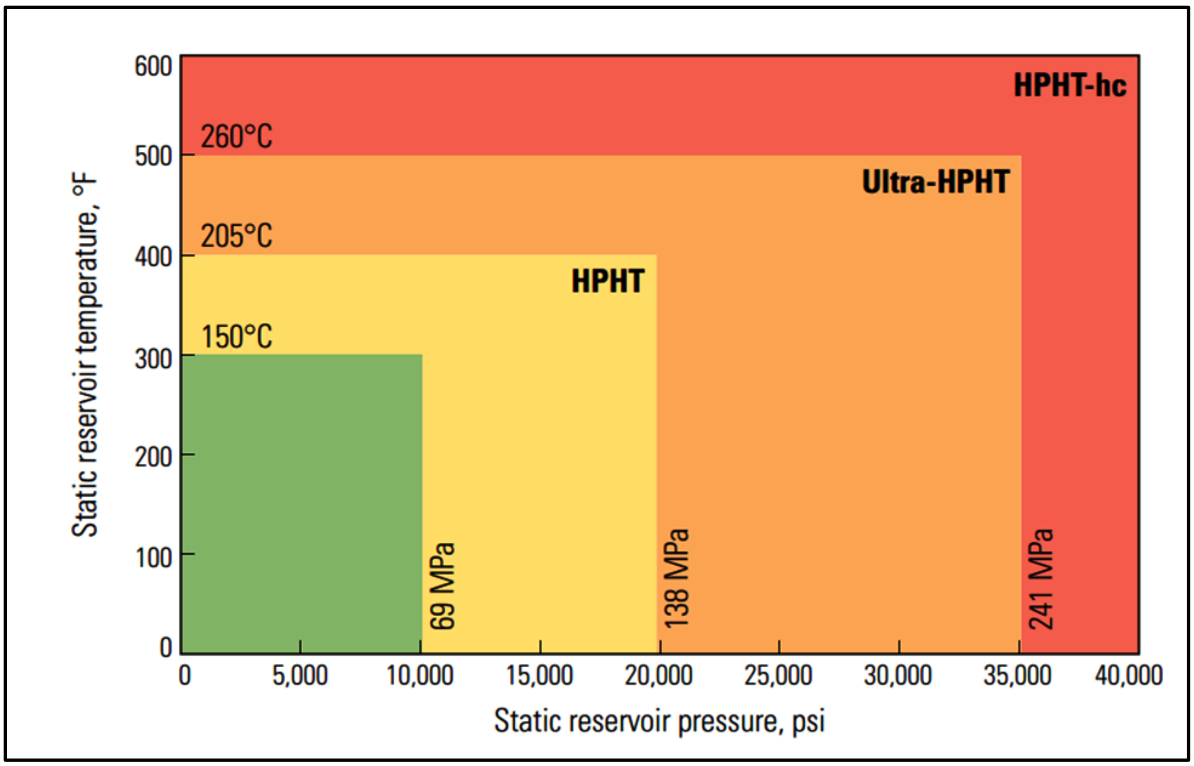

Figure 1.1: **HPHT Classification System** (Smithson 2016)

1.3 Oil Based Drilling Fluids

Drilling fluids or muds are fluids used in the drilling operations of oil and gas wells. These fluids should have some properties to allow it to drill wells safely and efficiency. Drilling fluid can be classified to three types (Simpson 1971) based on the continuous phase, **Figure 1.2.** The drilling fluid can be water-based mud (WBM) in both types fresh and salty base, oil or synthetic based mud (OBM) and air drilling fluid. All of the drilling fluids must have the ability to cool and lubricate drill bit during formation penetration and, at the same time suspend and move the drill cutting out of the borehole (Abraham 1933)

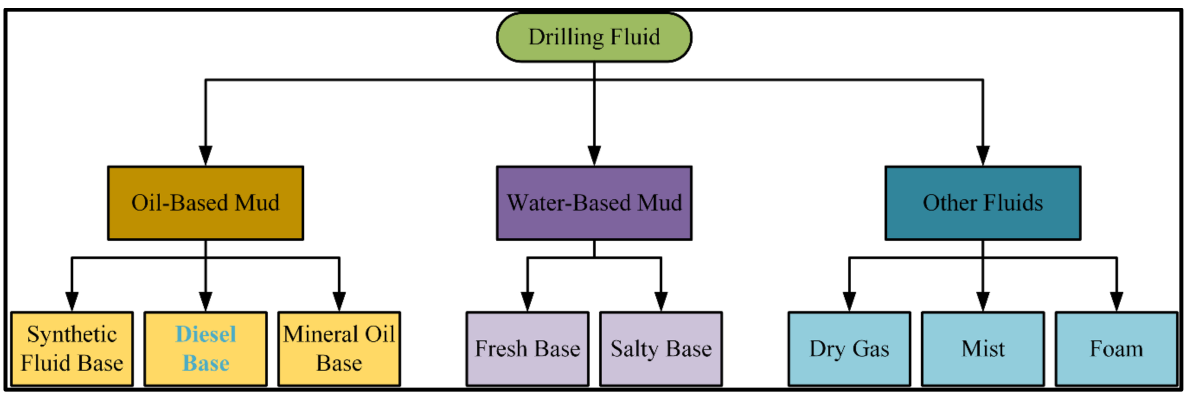

Figure 1.2: Drilling Fluid Classification

In the IEF, oil is the external or continuous phase and the water is the internal or discontinuous phase where droplets of oil are uniformly dispersed in continuous water base. There are some advantages of OBM (Abraham 1933; Miller 1951):

1. Shale stability.
2. Stable at high temperature.
3. less damage to the pay zone
4. Drilling salty, anhydrite and potash zones.

5. Low corrosive fluid.

1.3 Barite Sagging

It is common when the driller waits for some time, they put the drill pipe under low rotation to avoid pipe stuck, this low in rotation causes break in drilling fluid so, it accelerates settling of barite which will give sever barite sag. Barite sag is generally defined as settling of weighting materials in drilling fluid. Sag is often seen when the driller circulating the mud out of the hole after the mud stayed for some time in the well, leading to the confidence that the static settling of mud is the main indicator to give barite sag. **Figure 1.3** showed the fluctuation in mud density of this case. Sag occurrences in vertical and deviated wells but, it potentially notable in deviated well, in particular, those with angle between 30° -75° (Amighi and Moghadam 2011; Amighi and Shahbazi 2010; Bern et al. 1996; Hanson et al. 1990) where the viscosity and annular velocity are low. Settling of barite in inclined pipes can be described as boycott settling.

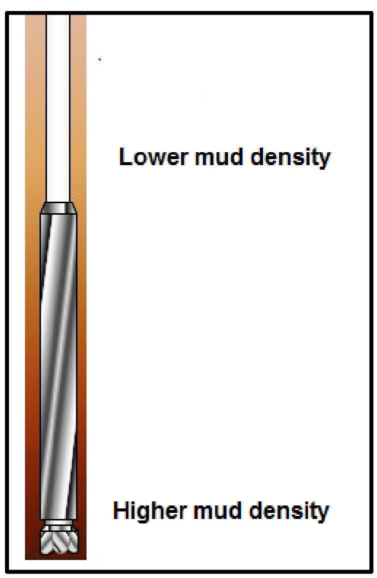

Figure 1.3: Density Variation Due to Sag

The appearance of barite sag is generally seen when the mud is circulating bottoms up and the resulting mud weight out of the wellbore is less than the original mud weight going to well. Although barite sag is associated with OBM more than WBM, it can also be seen in WBM (Leaper et al. 2006). As barite particles settle downward from suspension zone to the low side, the free fluid and lighter fluid will keep in the upper part of the cell. This will create a low-density thin layer on the top called free fluid and another just below free fluid. The particles will go down in the cell make sedimentation zone as shown in the **Figure 1.4.**

Most problems recognized in drilling and completion operations were referred to barite sag. These issues such as lost circulation, well-control issues, wellbore instability and stuck pipe (Massam et al. 2004; Tehrani et al. 2004).

Sag factor is defined as the bottom density divided by the summation of top and bottom density as the following equation:

$$SF = \frac{\rho_{bottom}}{\rho_{top} + \rho_{bottom}}$$

where SF is static sag factor, ρ_{bottom} and ρ_{top} are density of the mud from lower and upper part respectively.

The pressure difference over the fluid cross-sectional area will force the higher fluid to sediment downwards and the lighter fluid to go upwards (Albertsen et al. 2004; Omland et al. 2006). The effect of forcing high density fluid or particles downwards is called slumping. In the deviated well the flow stream moves along the high side, which will accelerate boycott settling even more (Boycott 1920; Sharman and Belayneh 2017). Settling of barite occurs more common during circulating than in static circumstances, hence barite sag is mostly a dynamic settling problem. When drilling under high pressure high temperature (HTHP) situations, the mud weight is commonly high, and temperatures are high. This causes the viscosity of the drilling fluid to decrease, which in turn can accelerate the potential for sag.

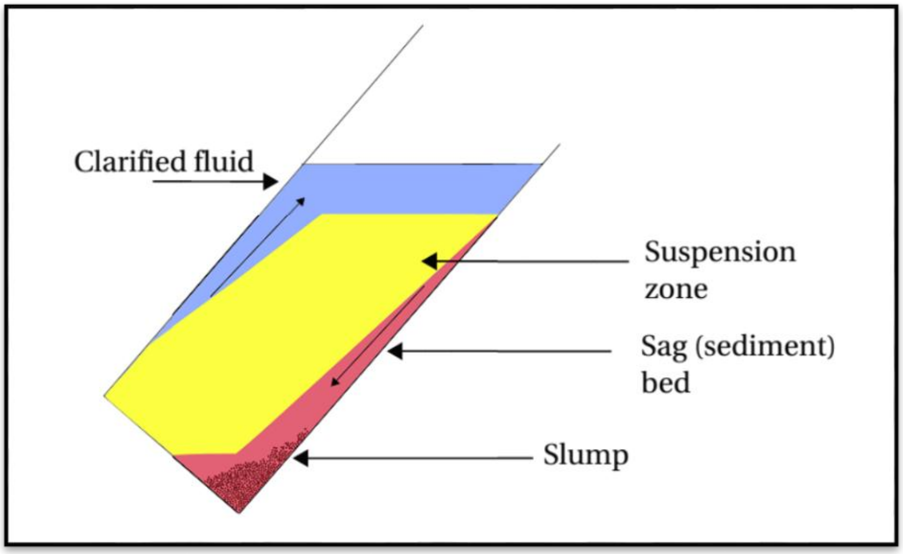

Figure 1.4: Particles Settling In Deviated Tubes (Sharman 2015)

CHAPTER 2

LITERATURE REVIEW

Bui et al. 2012; Saasen et al. 1995 focused on the linear viscoelastic properties and its applications on OBM. Also, the relation between static and dynamic sag was provided. They provided standard rheological tests to evaluate the viscoelastic properties drilling fluids by using sixteen different OBM sweep tests. They found that the range of viscoelastic region was less than 1% at 20 °C. Moreover, as temperature increase and frequency decrease, the gel strength, linear viscoelastic range and dynamic yield stress decrease. From frequency sweep data, the storage modulus(G') is greater than loss modulus (G") in the linear viscoelastic region. This means that the elastic behavior dominates over viscous behavior while the viscous property is dominated at low frequency in the linear viscoelastic range. Oscillation time sweeps have shown that the required time to build gel structure in the sample to achieve stability is often higher than the time recommended by API (30 minutes). Temperature has an effect on storage modulus, loss modulus, and complex viscosity, as the temperature increases the viscoelastic parameters decrease.

Albertsen 2004; Omland 2006 showed that, the ability of invert emulsion OBM to suspend barite has depended on the chemical composition of water base. Four base fluid (mineral oil, linear paraffin, linear alpha-olefin and Ester) and four different salts (Calcium Chloride ($CaCl_2$), Sodium formate (NaCOOH), potassium formate (KCOOH), and Ammonium calcium nitrate ($NH_4Ca(NO_3)$)) have been used in this study. Ammonium calcium nitrate salt $NH_4Ca(NO_3)$ with mineral oil base has given the lowest 0.505 sag factor at 16 Hrs.

compared to high sag factor achieved by linear paraffin and Potassium Format 0.54 **Figure 2.1**

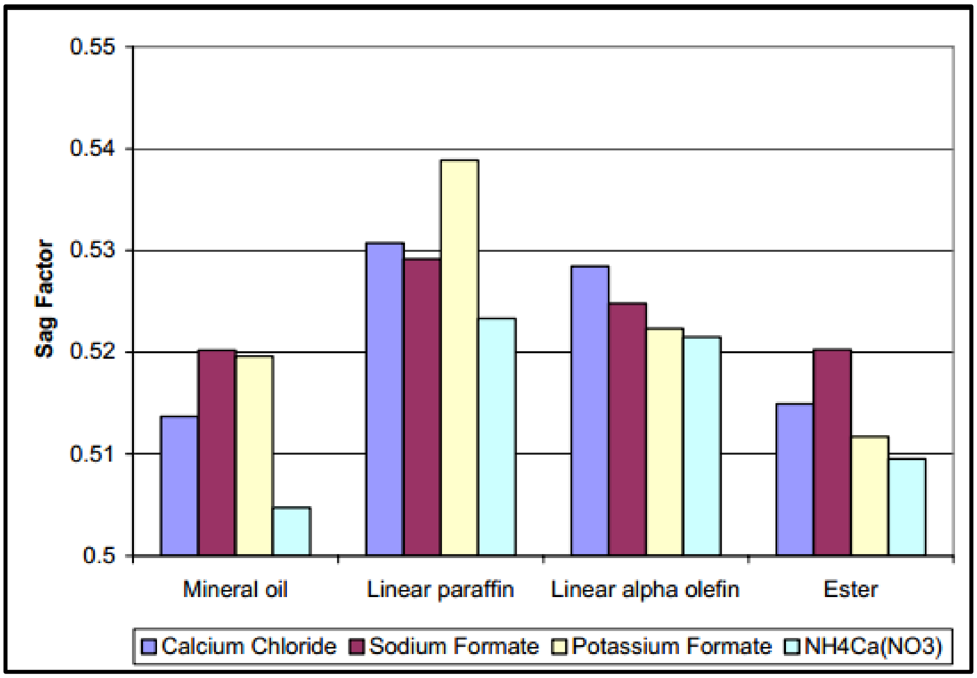

Figure 2.1: Sag Factor Calculated on Samples Aged Statically For 16 Hours
(Albertsen 2004)

Hanson et al. 1990 investigated the effective ways to minimize sagging in 70 tests high deviated wells by a flow loop experiments. **Figure 2.2** showed a plot of flowline mud weight versus circulation time after a trip on a Green Canyon directional well. The mud had an original density of 16 ppg. Samples from shaker under flow were measured in the binging and through mud out trip. The variance between original weight and flow mud with time can identify sag. The mud used in this study were OBM and WBM with a density about 12-20 ppg. They came up with the following: although sag can occur for existence the mud in the well for a long time, it may happen while the mud in circulating operation. They gave some recommendations to reduce sagging in deviated well. One recommendation was to not thin the mud before running the casing as this will helps fluid particles settling to the bottom of well-bore. Moreover, dynamic sagging is faster to happen in low fluid velocity which allows the fluid to slump faster at an angle of 40-50. They conclude that, dynamic sag is easier seen than static sag

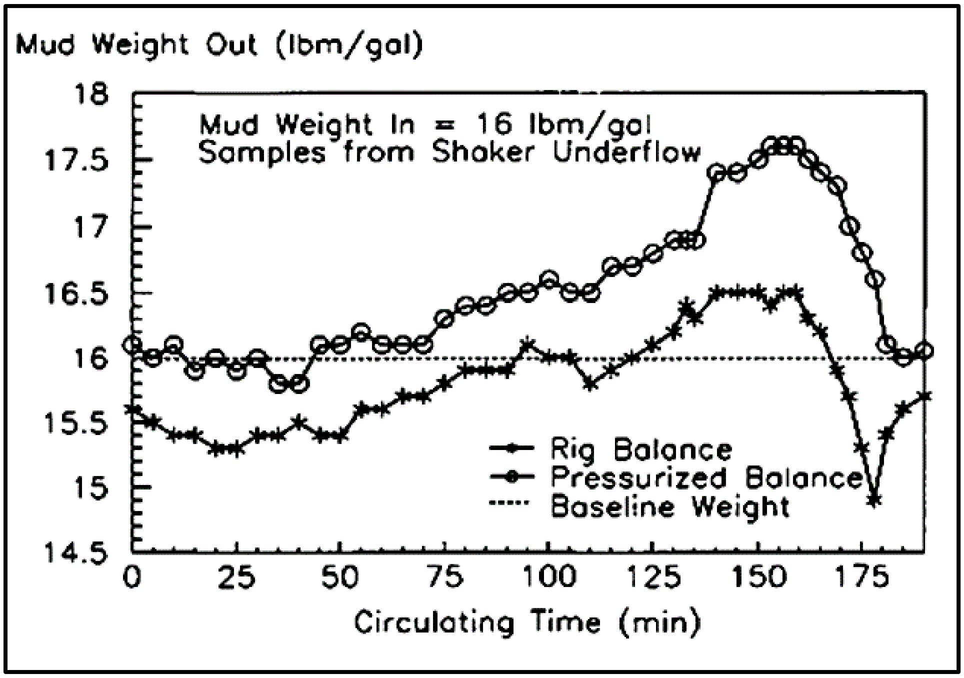

Figure 2.2: A Trip Report Showing Evidence of Sag in A Directional Well(Hanson 1990)

Saasen 2002 studied in details the mechanism of sag in especially oil based drilling fluids and how to deal with it. He did a comprehensive study of the weighting material behavior in invert emulsion OBM. This theory discussed that at ultra-low shear rate, the viscosity of these fluids is low, and the shear thickening happens at very low shear rate. The crystalline structure of water droplets creates low viscosity environment in invert emulsion fluids which lead to sag. By increasing shear rate, these water droplets are destroyed in non-continuous fashion, which reduces static sagging. Moreover, possible method to minimize sagging by reducing water oil ratio as this will reduce the free space for water droplet to move before they strike with neighboring water droplets. He also suggested reducing of free space water droplet but increase the mixing energy of water with no change in water fraction in invert emulsion fluids

Tehrani and Popplestone 2007 investigated the effect of the internal phase (brine viscofiers) of invert emulsion fluids (IEFs) on rheology and barite sag. They used viscometer sag test (VST) with sag shoe and Fan35 rotational viscometer to measure dynamic sag for fluid have the same chemical concentration except brine and organoclay viscofiers. The results showed that ionic polymer brine viscosifier additive increased the rigidity of water droplet and decrease barite sag by about 30% using dynamic sag test. But, the polymeric brine additive had some limitations, such as it was incompatible with a polyamide oil-phase viscosifier, lowering the rheology and increasing dynamic sag.

Ehrhorn and Saasen 1996 showed that fluids which loss gel strength, can't build bonding forces between its particles, so sagging cannot be avoided in these fluids. Also, they conclude that static and dynamic sag will be not prevented in oil based fluids. The only method to minimize static and dynamic sag by increase low shear rate viscosity.

Tehrani et al. 2004 evaluated the correlation between barite sag and rheological properties of oil and synthetic based mud at different quantity of organophilic clay and polymers in IEFs. From the experiment, the organoclay mud showed gel structure greater than polymeric mud. For the fluids correlated down shear rate of 10^{-2} s^{-1}, the organoclay based fluid showed a good correlated down to a shear rate of $10^{-4}s^{-1}$. Viscoelastic properties were also correlated with dynamic sag, organoclay fluids have given a good gel strength at very low shear rate. Experiments showed that dynamic barite sag decreased when viscoelastic parameters such as storage modulus (G') and complex viscosity η^* increased. Temperature relation showed that as temperature increases the elasticity of the mud decrease. Finally, dynamic sag was lower in the clay-based fluids tested than those formulated with polymeric additives.

Savari et al. 2013 searched for a correlation between dynamic sag and rheological behavior of oil base mud by performed laboratory test for five field samples. These tests were done by using dynamic high angle sag tester (DHAST) and Anton Paar rheometer. All drilling fluids in this study were compared at a low shear rate. Results presented in this paper showed that from shear rate shear stress curves, the fluids which exhibit high slop value, have low sag. Also, there is a good correlation between sweep curves and DHAST. Moreover, from frequency sweep, the fluid has high G' indicates that this fluid will resist sag. Finally, not all fluid samples have a consistent result, so in barite sag, there are several mechanisms should be involved.

Nguyen et al. 2011 evaluated dynamic sag in oil base mud by using modified rotation viscometer(MRV) with sag shoe and flow loop. They conducted a range of 0-100 RPM of rotation speed pipe. Moreover, they studied the effect of concentricity and eccentricity of rotating pipe. The flow loop results indicated that the concentric rotating pipe significantly decreased the barite sag. The authors noted that the MRV, which sag shoe, does not correlate flow loop sag tests that incorporate pipe rotation, pipe eccentricity, and annular velocity. They also recognized that under static condition, if the yield stress greater than 12 lb/100ft^2, barite did not settle down in the drilling fluid.

Nguyen et al. 2014 used Taguchi and Analysis of Variance (ANOVA) method to study the effect of four parameters on dynamic sag. These parameters include pipe rotation, angular velocity, inclination angle, and eccentricity. For each parameter, there are two conditions. The results showed that pipe rotation contributed to preventing dynamic sagging by 21% by increasing the drill pipe rotation from 16.34 ft/min to 65.37 ft/min. while the annular velocity has the major part in reducing sagging by 60% compared to another parameter so, this parameter should have the priority to avoid barite sagging. In additional, inclination angle different from 45° to 60° has minimum effect in reducing barite sag. Finally, the eccentricity has the lowest effect on reducing barite sag. If the solid barite bed was formed, drill pipe rotation and high drill pipe eccentricity together have a good impact to reduce sagging.

Maxey 2007 studied the effect of low shear rheological properties on the behavior of the drilling fluid as an indirect method to measure sag. He conducted low shear viscosity and oscillation sweep tests. From these methods, the potential of static sag in drilling fluid can be better understood. However, the best represents of static sag cannot sufficiently portray the potential for dynamic sag. The results showed in **Figure 2.3** and **Table 2.1** of four different static sag factors at similar mud density. Three of them were stable at 0.509 and 0.507 sag factor, while the fourth one had given sever sag factor of 0.565. He concluded that by using low shear viscosity and oscillatory frequency, the possibility of static sag of drilling fluids can be understood.

Table 2.1: Static Sag Factor For Different Drilling Fluids(Maxey 2007)

	Fluid#1	Fluid#2	Fluid#3	Fluid#4
$\rho_{top}(g/ml)$	1.68	1.674	1.549	1.693
$\rho_{tbottom}(g/ml)$	1.741	1.723	1.604	2.196
$sag\ factor$	0.509	0.507	0.509	0.565

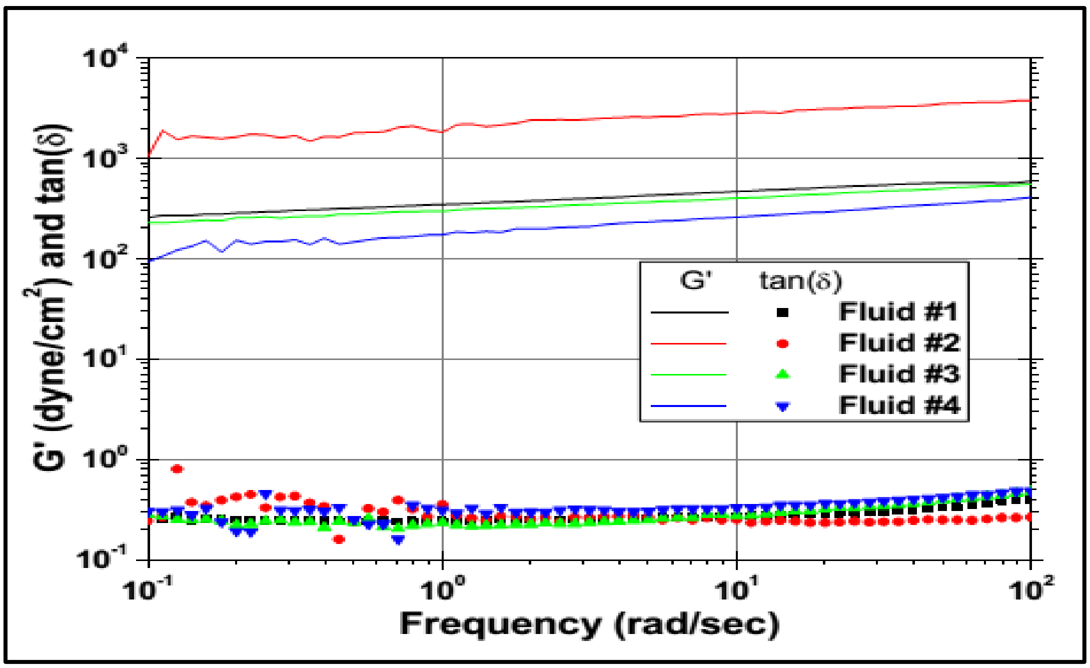

Figure 2.3: Strong Modulus From Oscillatory Frequency Sweeps of The Sample Fluids at 120°F (Maxey 2007)

Wagle et al. 2013, 2015 studied the effect of adding finely sized (nanoparticles) calcium carbonate, clay-type materials and novel suspension agent to organoclay free invert emulsion drilling fluid. They added these nanoparticles to three different muds density 9, 12 and 16 ppg in both vertical and inclined at 45°. The result showed that nanoparticles with rheological modifiers reduce sag factor of 9 ppg from 0.61 to 0.502 after 24 hrs. and 250°F. Also, for 12 ppg the sag factor has been minimized from 0.67 to 0.505 at the same condition of 9 ppg fluid. For the 16 ppg, the sag factor conducted at 250 °F and 300 °F have given sag factor 0.512 and 0.52 respectively. The 45 deviated results showed that after adding nanoparticles and rheological modifiers, the sag factor reduced to 0.509, 0.51 and 0.523 for 9, 12 and 16 ppg respectively. Finally, the three drilling fluids showed consistent in HPHT rheology after adding nanoparticles.

Amighi and Shahbazi 2010; Jefferson 1991 studied the most methods to predict barite sag in both conditions static and dynamic. Moreover, they presented some effective ways to avoid the appearance of barite sag in high-pressure high-temperature oil operations. From field case study they have given the following points:

- The most sever barite sag occurs at angles 60-75º.
- Eccentric of drill pipe and low annular velocity exacerbate barite sag.
- Dynamic sag can be tough even if the static sag is very small or no sag.
- VG viscometer cannot predict static sagging.
- Sagging can be reduced by using ilmenite weighting or manganese tetroxide material instead of barite.

Temple et al. 2005 invented a low molecular weight polyalkyl methacrylate under the to reduce barite sagging in invert emulsion fluids without significantly increasing the drilling fluid viscosity. The sag factor reduced from 0.55 to 0.50 by adding 0.5-3 ppb. Also, the additive that had been used did not alter or increase the fluid loss.

Al-Abdullatif et al. 2015; Al-Abdullatif et al. 2014 developed new kill fluids with minimum sagging for abnormal salty water formation in Jilh Saudi formation. This fluid has a density greater than 150 pcf and consists of 60/40 v/v% micronized barite/manganese tetroxide. The results showed that the sag factor of 100% barite in the vertical and deviated case was 0.52 and 0.53 respectively. For the 60/40 v/v% micronized barite/manganese, the sag factor was 0.51 in both cases.

Mohamed et al. 2017 used different barite particles size in water base drilling fluids and studied the effect of these particles size on solubility, stability HPHT filter press and sagging. They also studied the effect of temperature on barite settling. The results showed that as temperature increase from room temperature to 270°F the structure of mud breaks and the barite particles separated downwards. But, after barite particles have micronized the sagging was improved from 0.563 to 0.546 at 270 °F.

CHAPTER 3
RESEARCH OBJECTIVES AND EXPERIMENTAL STUDIES

3.1 The Need of This Research

Due to the complexity and difficulty of high-pressure high-temperature HPHT down hole conditions, adequate and sufficient knowledge properties of workover fluids must be accurately studied to understand the mechanism of these fluids. This thesis has studied a big issue in drilling fluids which is settling of barite particles in oil invert emulsion oil base mud by adding a copolymer to reduce the barite sagging. The effect of this polymer on rheology, filtration and sagging have investigated.

3.2 Research Objectives

The objectives of this thesis are to:

I. Study the effect of the temperature on barite settling.by using static aging cell
II. Perform vertical and deviated barite sag test.
III. Study the effect of add copolymer on rheology properties of OBM under HPHT conditions.
IV. Study the effect of add copolymer on filtration
V. Design a new formulation of drilling fluids that could minimize the barite sag.

3.3 Experiments Studies and Work Methodology

3.3.1 Materials and Chemicals

In this research, oil-based drilling fluids manually prepared by using Hamilton mixture as shown in **Figure 3.2**. The formula is taken from the field and the chemicals were provided by Halliburton company. The density was measured by mud balance **Figure** 3.1 at atmospheric pressure and 120 °F which is 14.7 ppg. In order to investigate the effect of adding copolymer on the oil-based drilling fluids, it was essential to keep the copolymer as low as we can to avoid any removal problems. The oil water ratio is 80:20 determined by Retort Kit **Figure 3.3.** The type of drilling fluid in this work is inverted emulsion oil base mud. The composition and propertied of drilling fluids are given in **Table 3.1** The oil phase is diesel oil with additives such as geltone is viscosifying clays type , Lime, primary and secondary emulsifiers are invermul and Ez-mul respectively, water and calcium chloride for activity control, HPHT filtration control agent is duratone, and weighting material is API barite. Falana et al. 2011 stated that primary emulsifiers are used to reduce interfacial tension between the liquid phases and therefore help the internal phase to disperse in the hole solution, while secondary emulsifiers consolidate stability of the dispersed phase or stability of the emulsion.

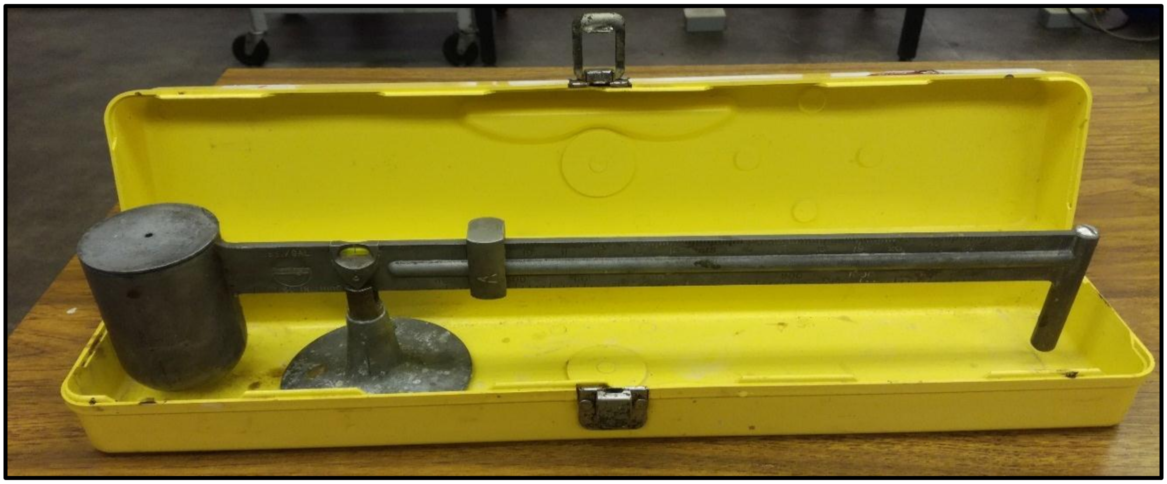

Figure 3.1: Mud Balance

Table 3.1: Recipe of 14.7 ppg invert emulsion drilling fluid

Additives	Unit	Quantity	Function
Diesel	bbl	0.491	Base oil
INVERMUL	ppb	11.0	Emulsifier
Lime	ppb	6.00	Contaminate remover
Duratone	ppb	7.00	Fluid loss control
Water	bbl	0.143	Activity control
CaCl2	ppb	32.0	
Geltone II	ppb	10.0	OBM Viscofier
EZ-Mul	ppb	4.00	Emulsifier
Copolymer	ppb	1.00	Prevent sagging
CaCO3	ppb	30.0	Bridging materil
Barite	ppb	300	Weighting material

All the quantities above should be converted from field unit to lab unit by using following equations:

$$\boldsymbol{\frac{lb}{bbl} = \frac{453.6\ gm}{1\ lb} * \frac{1\ bbl}{5.615\ ft^3} * \frac{1\ ft^3}{30.48^3\ cm^3} = \frac{gm}{2.853E^{-3}\ cm^3}}$$

By assuming $1\ field\ bbl = 350\ cm^3$

$$so, \frac{lb}{bbl} = \frac{gm}{cm^3}$$

Figure 3.2: Hamilton Mud Mixture

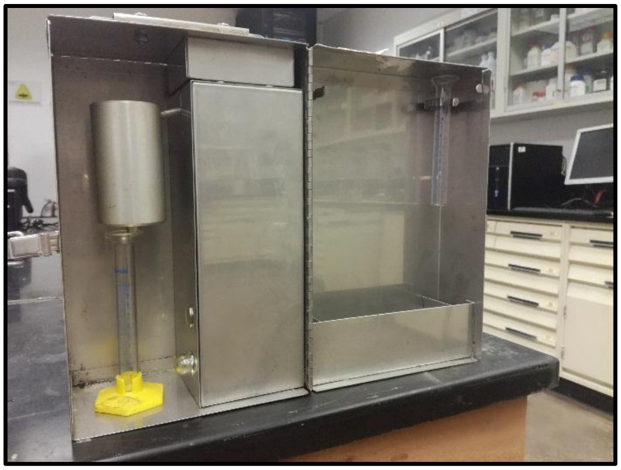

Figure 3.3: 10 ml Retort Kit

3.3.2 Static Sag

Barite or weight material sag is a problem of drilling fluid and it happens when weighting material (barite, manganese tetroxide, calcium carbonate, etc.) separate from the liquid phase and settle down. The method is based on continuously measuring fluid density during the first circulation after the fluid has been static for some time. Although, it can occur in a dynamic situation with low annular velocity. The barite sag can result in big variations in mud density in wellbore. The light density is on top and heavy density at the bottom

A static sag in drilling fluid was measured at the static environment to know either mud is stable or fluctuated in density. Sag factor is calculated by equation (1):

If the sag factor is higher than 0.53, the weighting material settles down from drilling fluid, (Maxey 2007). The procedure if the static sag is defined by the following steps:

- Drilling mud is mixed for 15 minutes by a mud mixture. **Figure 3.2.**
- Pour the fluid into the Teflon cell and put the Teflon cell inside aging cell **Figure 3.4**
- The aging sell is pressurized up to 500 psig by Nitrogen bottle supply

- Enter the aging cell inside the oven **Figure 3.6** and adjust the required temperature.
- After 24 hrs the cell is taken from the oven and called down to room temperature and release the pressure.
- Open the cell and remove the free oil from the fluid. Then, draw 10 ml from the top with a clean syringe and record the weight by 3-digit number mass balance **Figure** 3.7
- Determine the drawn fluid density and repeat the previous step but draw from the lower part of the fluid.
- Apply the following equation:

Sag factor can be determined by the following equation:

$$SF = \frac{\rho_{bottom}}{\rho_{bottom}+\rho_{top}} \dots\dots\dots\dots\dots\dots..(1)$$

where SF is static sag factor, ρ_{bottom} and ρ_{top} are density in ppg unit of the mud from lower and upper part, respectively.

Figure 3.4: Teflon And Aging Cell

Figure 3.5: Aging Sag Test Setup

Figure 3.6: Oven

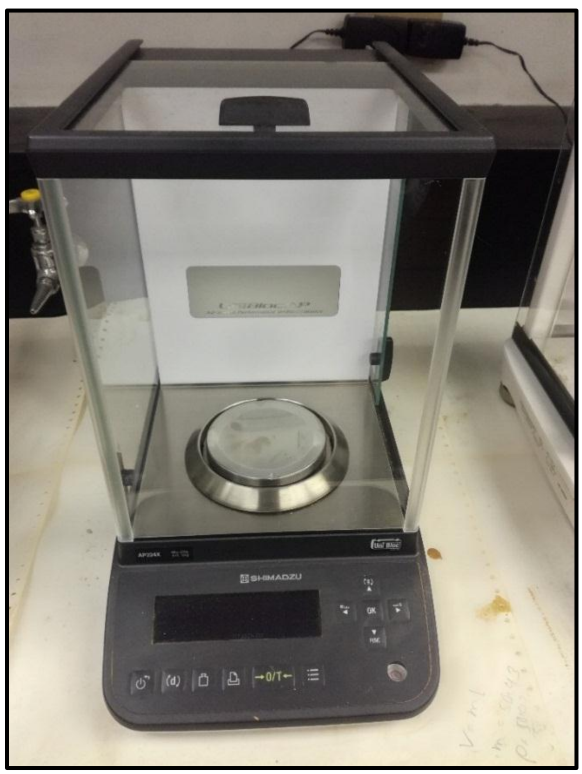

Figure 3.7: Digital Mass Balance

3.3.3 Viscometer Sag Test

The viscometer sag test (VST) introduced by (Jefferson 1991) as a practical well site test, has seen some success in the field and in the laboratory as a direct indicator of sag tendencies. Simplicity, low-cost, and equipment availability notwithstanding, the VST has not received sufficient industry support to become a de facto or API standard. Other field tests have been proposed; however, most have been variations on the VST procedure and have not achieved the same level of use as the VST.

3.3.4 Viscometer Sag Shoe Test

(Zamora and Bell 2004) used VST but they added sag shoe. This low-cost modification was developed to improve the consistency, sensitivity, and accuracy of the standard VST. The improved design also can characterize the sagging bed to help determine the best course of action to correct a sag problem in the field. Like the original VST, the recent version can also be used in the laboratory for evaluating the sag-tolerance of mud systems and products. The VSST shows in **Figure 3.8** was designed around the 6-speed rotational viscometer and thermocup used routinely to measure mud rheological properties. The viscometer provides the consistent (though somewhat complex) shear to simulate dynamic conditions; the thermocup serves as the mud container and heats the mud to 180°F maximum (although the test normally is run at 120 or 150°F) (Bern et al. 2010)

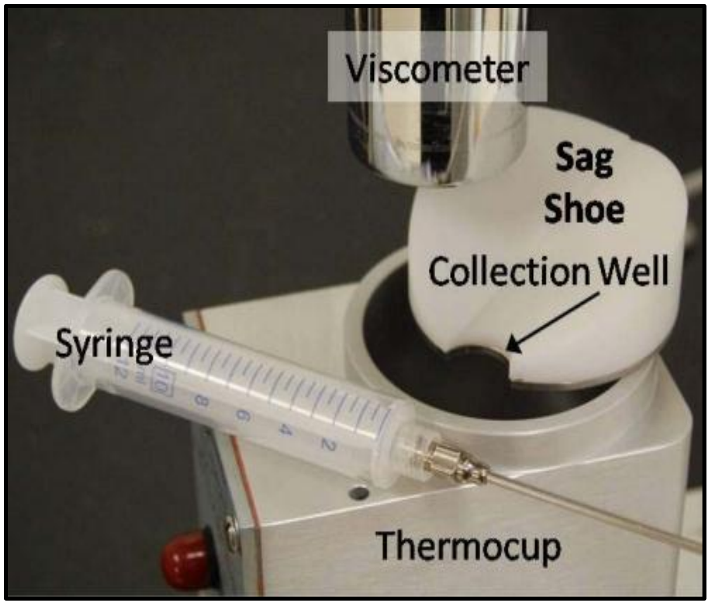

Figure 3.8: Basic Equipment for VSST (Bern 2010)

Dynamic sag test is a test required to measure the density difference of drilling fluids before and after shearing at 100 rpm. The test uses Fan 35 viscometer **Figure 3.9** equipped with sag shoe and thermocup components as shown in **Figure 3.10**.

The viscometer sag shoe test (VSST) is a wellsite and laboratory test to perform weight-material sag tendency of a field and lab-prepared drilling fluids under dynamic conditions (Zamora 2004). The idea is that the sloping surface of the thermoplastic shoe helps to accelerate settling and to concentrate the weighting material into a single collection well at the bottom of the thermos-cup.

(Zamora 2004) recommended the following procedure for the sag test:

- Sag shoe is inserted into thermocup and both are put on the plate of the viscometer.

- Poured the mud inside thermocup and rise it until the upper surface touches the lower part of viscometer sleeve. Then lower themocup around 7 mm.

- Heat the 140 ml mud with sag shoe to 120 °F ±2 °F error.
- Set the viscometer at 100 rpm and start 30 min timer
- Using the syringe with the cannula attached and clear of air to extract a 10 ml sample and record the weight of the mud-filled syringe, W1
- Stop the viscometer after 30 min and take another sample of 10 ml
- Record the weight of the mud-filled syringe (W2)
- Calculate the VSST using equation (2)

$VSST = 0.833 \times (W_2 - W_1)$ ………………………………. (2)

Where:

VSST = viscometer sag shoe test, ppg

W_1 = weight of the mud-filled syringe taken from the sample at the beginning, gm.

W_2 = weight of the mud-filled syringe taken from the sample after 30 minutes, gm.

It appears that a VSST value of 1.0 ppg or less would imply a drilling fluid with the minimal sagging tendency, (Aldea 2001). A VSST value above about 1.6 ppg would indicate the beginning of a possible sag problem (Bern et al. 2010)

Figure 3.9: Fan #35 Viscometer

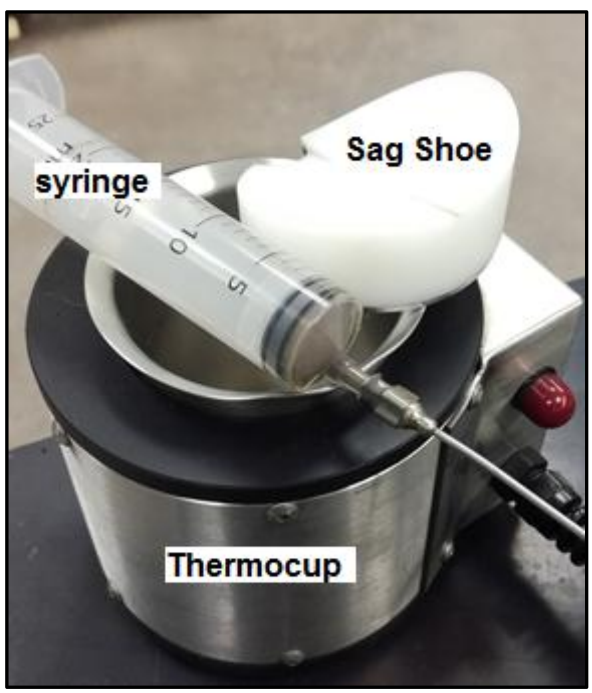

Figure 3.10: Basic Equipment for VSST Excluding the Viscometer

3.3.5 Flow Loop

Flow loop experiments can simulate field conditions such as hole angle, eccentricity, and annular flow, and serve as the guide for recognizing dynamic sag under laboratory conditions. The flow loop device has been used to study the relationship between shear rate and dynamic sag using invert emulsion mud systems in a deviated, eccentric annulus (Bern et al. 1996; Dye et al. 2001)

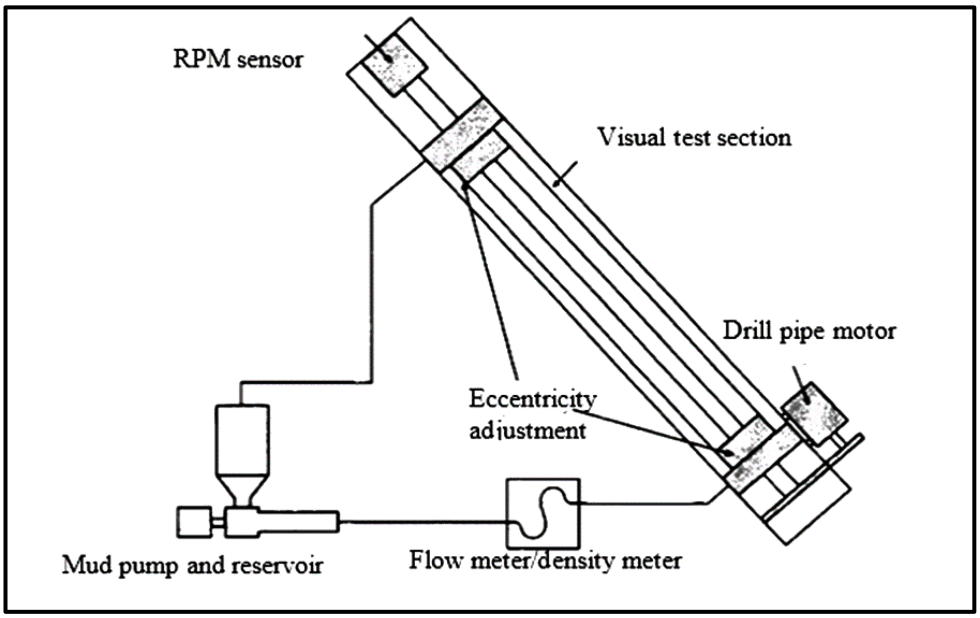

Figure 3.11: Dynamic sag flow loop set up (Bern 1996)

3.3.6 Rheology and Viscoelastic Tests

The rheological properties of IEFs were characterized in term of plastic viscosity (PV), yield point (YP), 10 sec gel strengths and 10 min gel strength. While the viscoelastic properties of IEFs are amplitude sweep and frequency sweep tests are determined by Anton Paar 302 Rheometer **Figure 3.12**

Viscoelasticity is the term used when the material has viscous and elastic characteristics at the same time when subjected to deformation. The internal force which resists fluid to flow is the viscosity and Newton's law is describing this situation, while the ability of materials to restore its original form after unloading is elasticity. Drilling fluids display viscoelastic performance and viscoelastic measurements can be involved to evaluate drilling fluids performance in drilling operations. Gel formation and gel structure can be evaluated by the viscoelastic property. To investigate and describe the structure of drilling fluid, dynamic tests are the normal rheological strategies have been used. These tests are essential to investigate low-shear rate properties, gel structure and clarify gelling time, dynamic yield point and structural stability of drilling fluids. However, viscoelastic properties of drilling fluids have not been expansively presented. The drilling industry even now needs a standard test method and experimental procedure to evaluate experimentally the viscoelastic properties of drilling fluids. In addition, the usage of viscoelastic statistics in field operations has not been extensively used. (Bui et al. 2012).

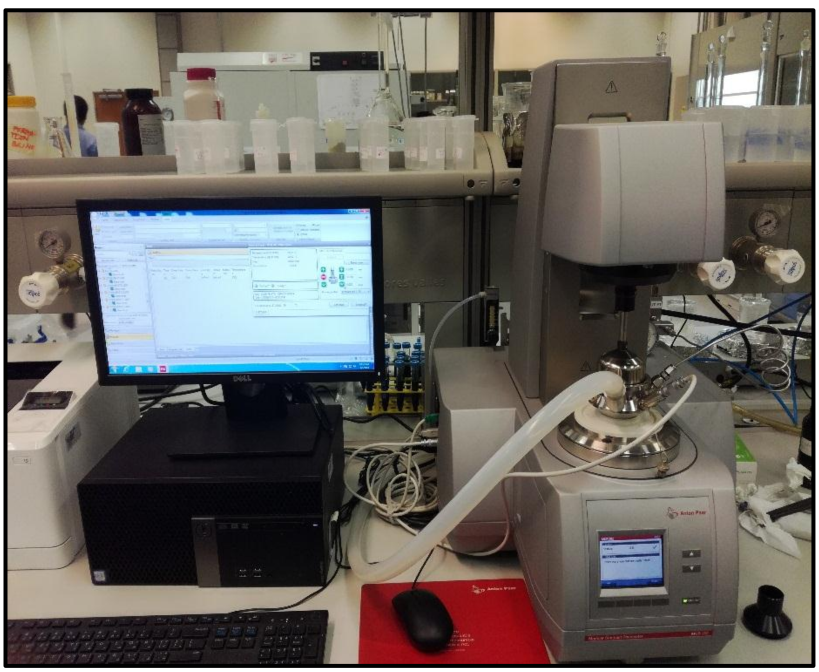

Figure 3.12: Anton Paar 302 Rheometer set up

The common oscillatory tests used to investigate the viscoelastic properties of materials are amplitude sweep, frequency sweep, oscillatory time sweep, and temperature sweep tests (Bui 2012). Oscillation amplitude test is firstly applied to determine linear viscoelastic (LVE) by keeping the frequency constant and free amplitude increase with time. LVE can be determined by plotted storage modulus (G') and loss modulus (G") against strain or stress on log-log paper. LVE region is defined when (G') and (G") does not change with increasing strain or stress. For the case when (G') is greater than (G") the elastic behavior domain over the viscous domain and the fluid exhibit gel structure. In contrast when (G') < (G") the viscous behavior domain over elastic behavior and the material exhibit characteristics of a liquid (Sharman 2015).

After LVE rang is determined, the oscillation frequency is applied by letting frequency free and constant amplitude. The objective of this test is to investigate time-dependent viscoelastic properties. This test can be applied on log-log paper by drowning Elastic modulus (G') and viscous modulus (G") on Y-axis and angular frequency (ω) on X-axis. The Information is extracted from amplitude sweep of highest strain to apply in frequency sweep test

3.3.7 HPHT Filtration Tests

Filtrate invasion is the mud filtrate that enters to the formation can cause formation damage. This filtration should be minimized by creating a thin impermeable filter cake.

Filtration test was performed to evaluate the effect of the copolymer on the invert emulsion drilling fluids by measuring fluid loss and filter cake thickness. A 50-micron porous ceramic disc, of 2.5-inch diameter and 0.25-inch thickness, is immersed in diesel and left for one day to completely saturated. The ceramic disc was weighted after saturation and then placed into the filtration cell then, 350 ml of completion fluid was poured into the cell. The cell was closed, and a pressure of 300 psi was applied using nitrogen cell and the filtration cell was heated gradually up to 250 °F. The experiment was run for 30 minutes to collect the filtration. Then, the valve was closed, and the cell was cooled down and the pressure was released. Finally, the disc was taken out and the filter cake was characterized by measuring the weight and the thickness. The setup of filtration test is shown in **Figure 3.13** and **Figure 3.14.**

Figure 3.13: Ofite HPHT Filter Press Set up

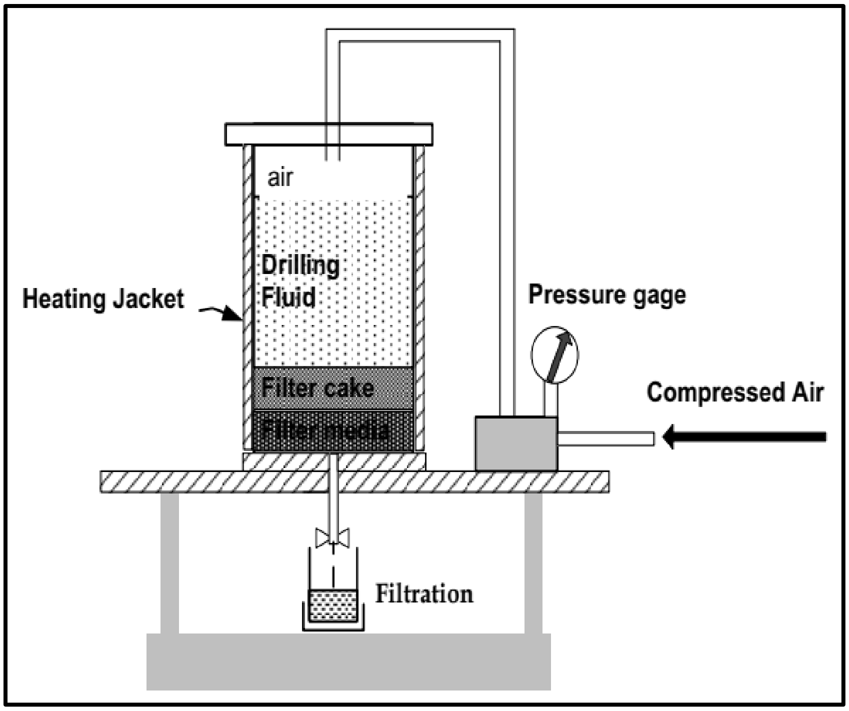

Figure 3.14: Diagram of HPHT Filter Press

3.3.8 Electrical Stability Test

Electrical stability is a test performed to measure the relative stability of water in oil emulsion. Invert-emulsion oil-based muds are water-in-oil emulsions that characteristically contain an organophilic clay and a weighting material (such as barite, calcium carbonate…. etc.). The water phase in this research is a solution of a $CaCl_2$. The water-in-oil emulsion itself is usually stabilized with a primary emulsifier (INVERMUL), while the weighting material and the drilled solids the drilling fluids acquires during drilling are made oil-wet and dispersed in the mud with a "secondary emulsifier" (EZ-MUL). This test is measured at 120 °F by Fann electrical stability meter **Figure 3.15**

Figure 3.15: Electrical Stability Meter

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Barite Sag Results

4.1.1 Static Sag

Sag test is a very important test to look at before circulating the fluid into the wellbore. Static sag test is the test performed to measure the density variation of drilling fluid. (i. e) barite settling out of drilling fluid. The effect of adding copolymer to barite settling is investigated by using sag test. Static sag test was measured for both of fluids at different temperature in vertical and 45° deviated conditions.

After preparing the fluid, it was kept in the aging cell at a specific temperature for 24 hrs. in the second day, the fluid was taken from the oven and cooling down. Then, the sag factor was measured by using this equation

$$SF = \frac{\rho_{bottom}}{\rho_{top} + \rho_{bottom}}$$

where SF is static sag factor, $\rho_{bottom}$and $\rho_{top}$are density of the mud from lower and upper part respectively.

It is known that as previous review the safe sag factor is between 0.5 to 0.53, above this limit, the barite settling is increased and cause drilling problems. **Figure 4.1** illustrates sag factor of three different temperature. The result shown that adding 1 lb_m/bbl of the copolymer to the mud enhanced the sag factor of vertical case from.0.55 at 250 °F to 0.501, 0.503 and 0.504 at 250 °F, 300 °F and 350 °F respectively. For the deviated of 45° **Figure 4.2,** the copolymer decrees the sag factor from 0.6 at 250 °F to 0.505, 0.507 and 0.51 at 250 °F, 300F and 350 °F.

These results confirmed previous studied that, adding polymer to the IEF will build a viscoelastic rheological structure which serves as prevention or reducing barite sag and enhance cutting transport (Temple 2005).

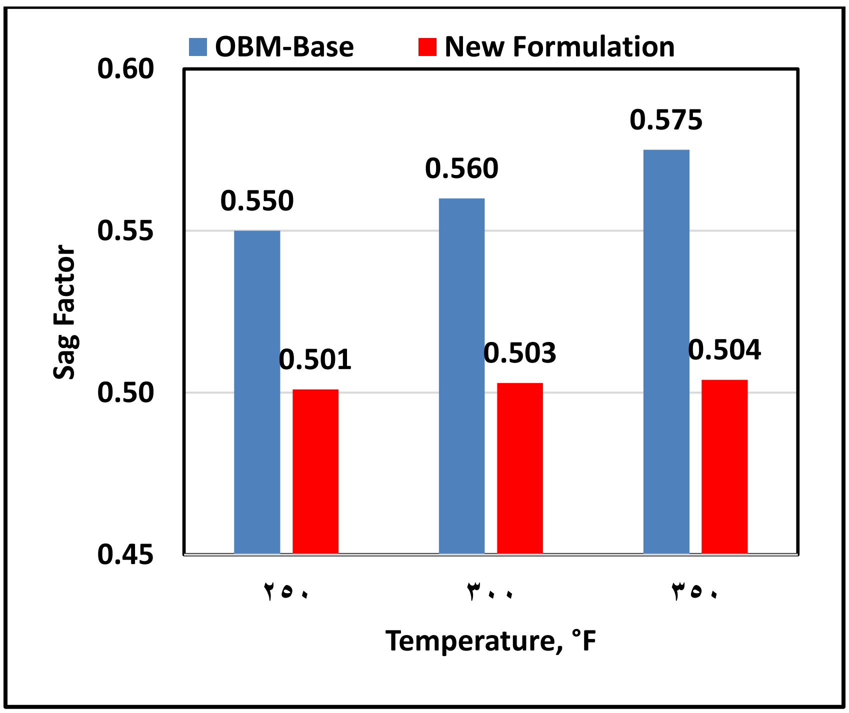

Figure 4.1: Vertical Sag Factor

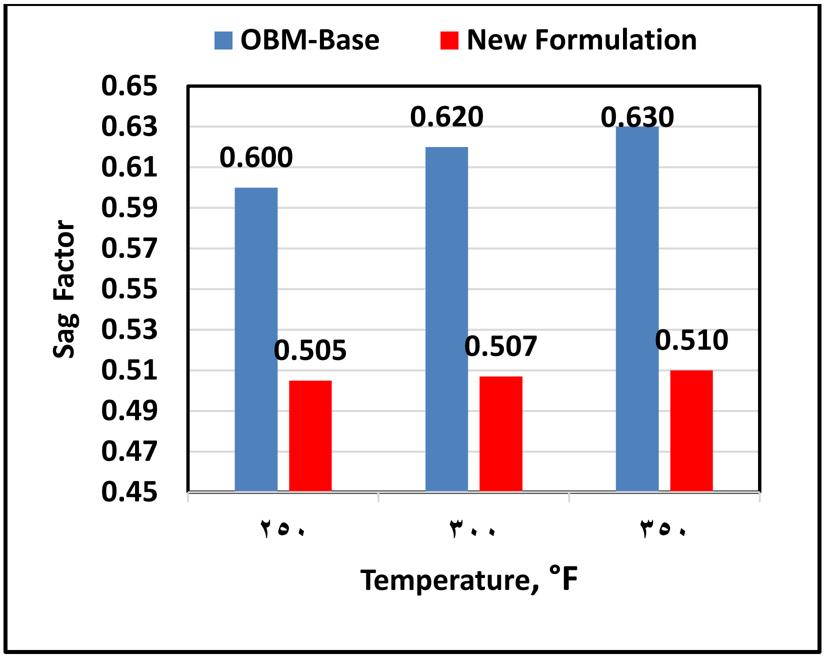

Figure 4.2: Deviated Sag Factor

Finally, all results of the mud are plotted together **Figure 4.3** to find sag factor at any temperature.

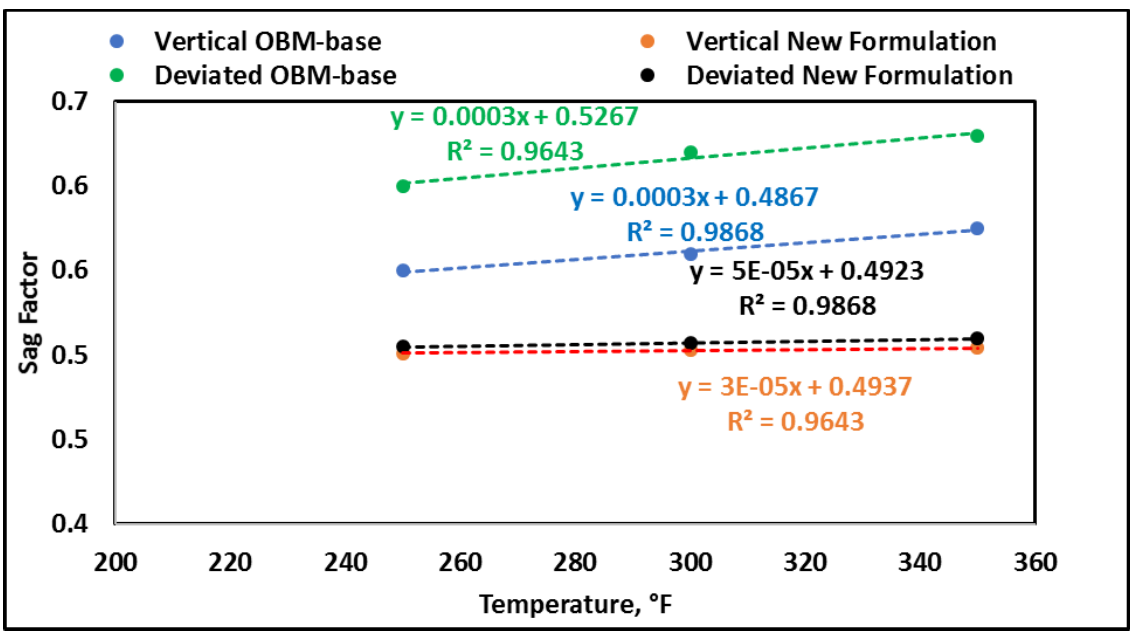

Figure 4.3: Predicting of Sag Factor at Different Time

4.1.2 Dynamic Sag

The viscometer sag shoe test was used to perform dynamic sag test. Density variation through 30 min was measured at 100 RPM rotating viscometer. The 100 RPM is selected because at this speed the maximum sag tendency will occur. Moreover, the 30 min is a practical consideration (Amighi 2010).

This method is performed to measure the density variation in the small container after shearing the fluid at 170 S^{-1}. It appears that a VSST value of 1.0 ppg or less would imply a drilling fluid with the minimal sagging tendency, (Aldea 2001). A VSST value above about 1.6 ppg would indicate the beginning of a possible sag problem (Bern et al. 2010).

The result shows that adding 1 lb_m/bbl of copolymer gas given the same density before and after 30 min. **Figure 4.4** shows the new formulation reducing the sag factor by 60%

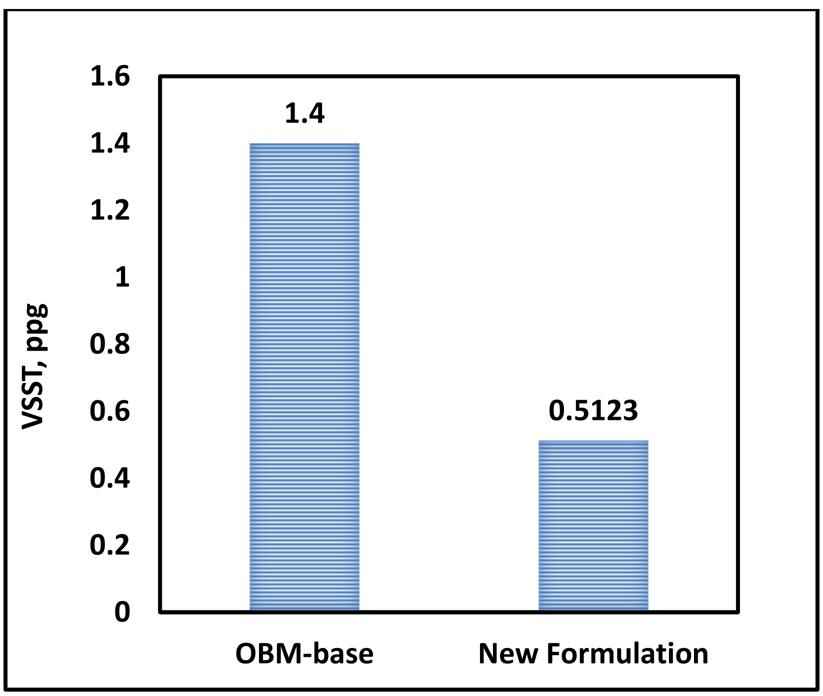

Figure 4.4: VSST at 120 ºF

4.2 Rheology and Viscoelastic Measurements

4.2.1 The Effect of the Copolymer on Rheological Properties

The rheology properties are studied at different temperature started from room temperature to 300 °F. the flow curves are converted from lab unit to oilfield unit as a common representation in the oil industry. The X-axis considers as shear rate in revolution per minute, while the Y-axis is shear stress in lb/100ft^2. The comprehensive study of all rheological properties including 10 sec. and 10 min. gel strength.

copolymer. From these tables, gel strengths increased by 20% from OBM-base to the new formula for both 10 sec. and 10min. this increasing keep the mud stable at high temperature to prevent barite settling.

The rheological measurements of OBM without copolymer and New formulation are shown in **Figure 4.5** and **Figure 4.6** which gives an overview how temperature effect on rheological properties. Form both figures, the temperature has a great effect on rheology at lower temperature variation. On the other hand, as temperature goes beyond 250 °F, the effect of temperature is less influencing.

4.2.2 Analysis of Gel Strength Test

Gel strength is another set of tests done were the gel strength tests and structural failure analysis. The response of the sample to flow initiation in gel strength tests after rest periods of 10-second and 10-minutes are presented in **Figure 4.7** and **Figure 4.8** Represent the formation structure of OBM-base and new formulation respectively. The result shows that in the temperature has the main effect to reduce the gel strength in the low-temperature part. After 250 °F, only small decrees in the 10 sec. and 10 min. gel structure. Another important factor was seen from the result, the gel strength of new formulation increased by 20 % compared with OBM-base at 300 °F. This means that the structure force of the new formulation was built stronger than OBM-base, so this increasing prevents barite form settling down in the fluid.

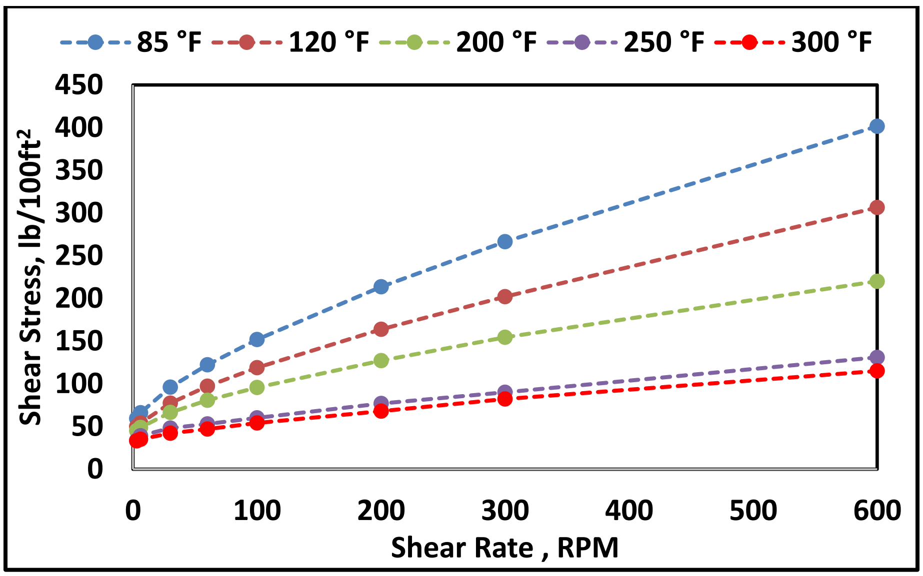

Figure 4.5: Rheometer Reading Versus Rotational Speed of OBM-Base

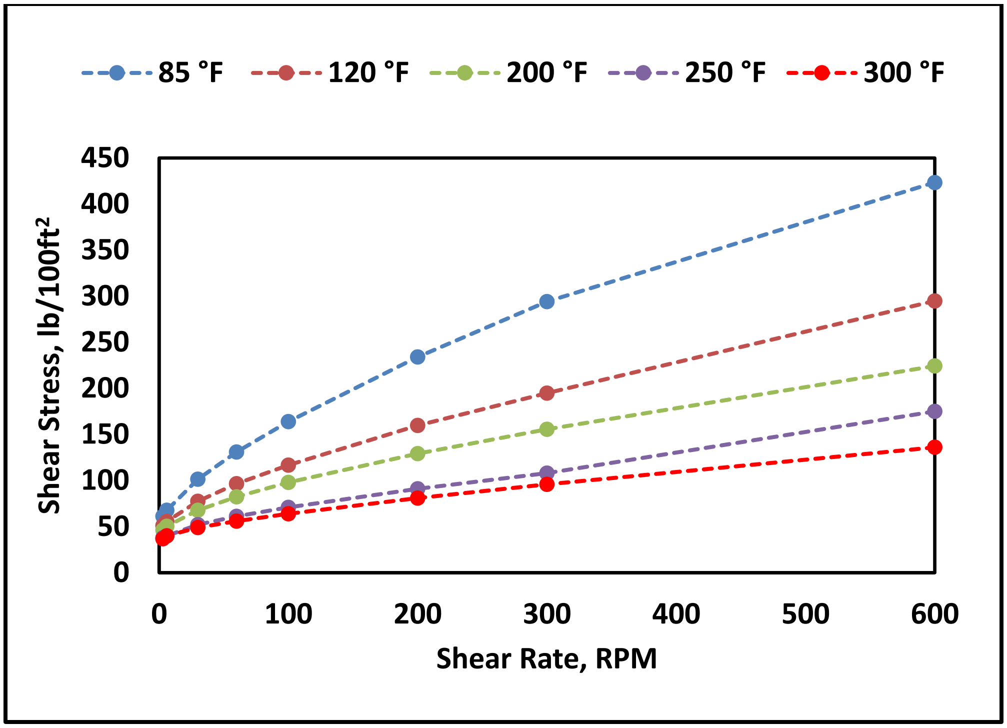

Figure 4.6: Rheometer reading versus rotational speed of New Formulation

Table 4.1: Rheology of 14.7 ppg OBM-base

Temperature, °F	85 °F	120 °F	200 °F	250 °F	300 °F
R600	402	306	220	131	115
R300	267	202	154	90	82
R200	214	164	127	77	68
R100	152	119	96	60	54
R60	122	97	81	53	47
R30	96	77	67	48	42
R6	66	54	49	39	35
R3	59	50	45	34	33
PV, cp	135	105	66	41	33
YP, lb/100ft2	132	97	89	49	49
Gel 10 sec.	68	49	45	31	29
Gel 10 min.	73	52	48	31	30

Table 4.2: Rheological properties of New Formulation

Temperature, °F	85 °F	120 °F	200 °F	250 °F	300 °F
R600	423	295	224	175	136
R300	294	195	156	108	96
R200	234	160	129	91	81
R100	164	117	98	71	64
R60	131	96	82	61	56
R30	101	77	68	52	49
R6	68	56	50	40	40
R3	61	51	46	38	37
PV, cp	129	100	69	67	40
YP, lb/100ft2	165	95	87	41	56
Gel 10 sec.	80	69	60	40	35
Gel 10 min.	82	75	65	41	38

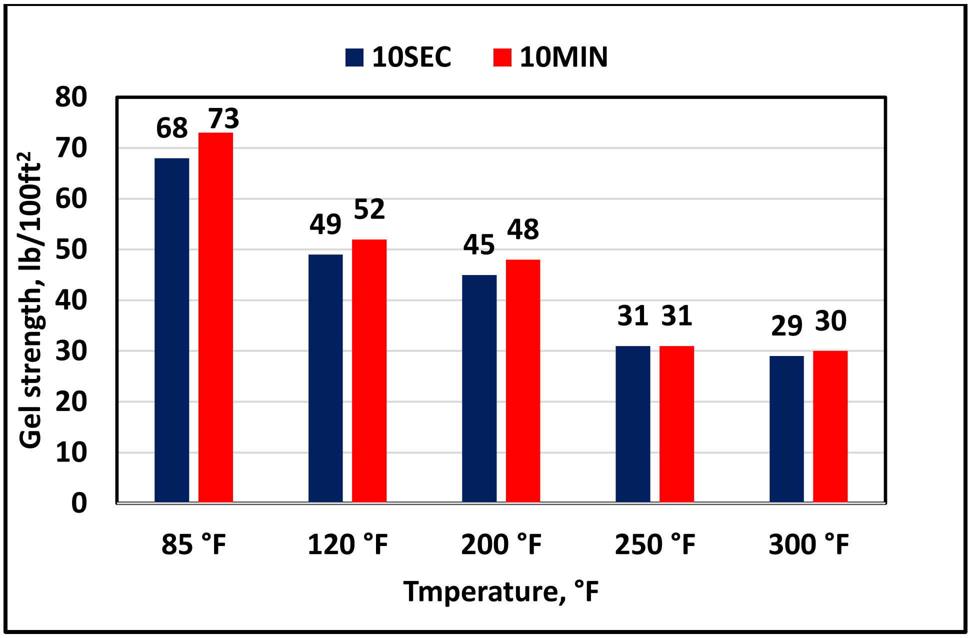

Figure 4.7: Gel strength test for the OBM-base at different temperature

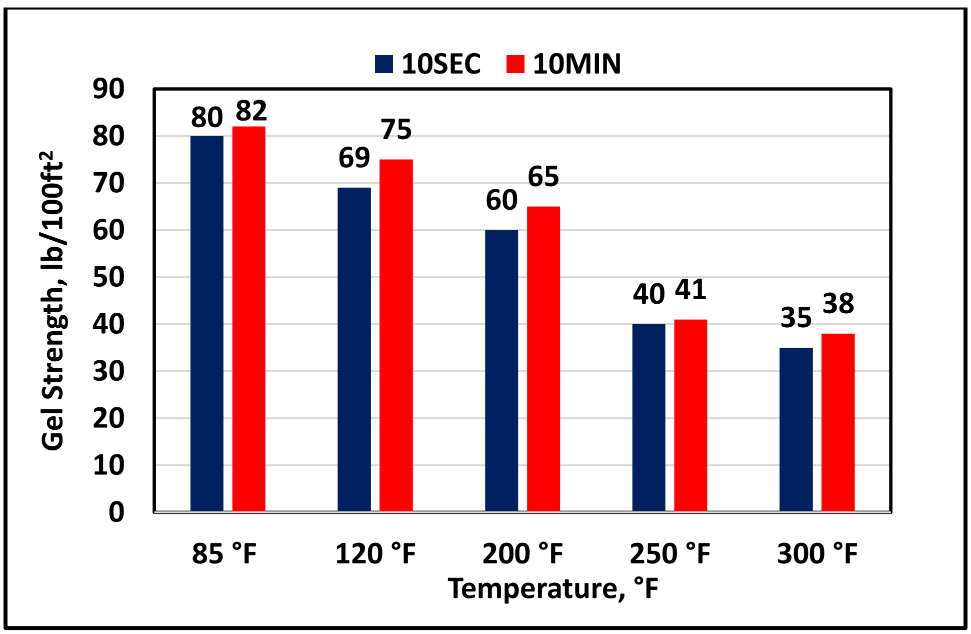

Figure 4.8: Gel strength test for New Formulation at different temperature

4.2.3 The Effect of the Copolymer on Amplitude Sweep

The first test performed to define the linear viscoelastic region and recognize the structural properties of the liquid is amplitude test. This test was performed with a constant angular frequency of 10 rad/sec. with 0.01% to 100%, ramp logarithmic strain and a number of data points are 31 points to get more accuracy. The results from the amplitude sweep test are shown in **Figure 4.9** where the new formulation clearly exhibits the highest value of G' over the entire test region while exhibiting the best sag behavior in sag testing. **Figure 4.10** shows that the storage module is greater than loss module for both fluids. This means that the elastic behavior domain over the viscous domain. LEV for both the fluids is same but in the range between elastic and viscous (i. e) transition zone, the new formulation showed wide area. This means that new formulation has long area before converted from elastic behavior to viscous behavior.

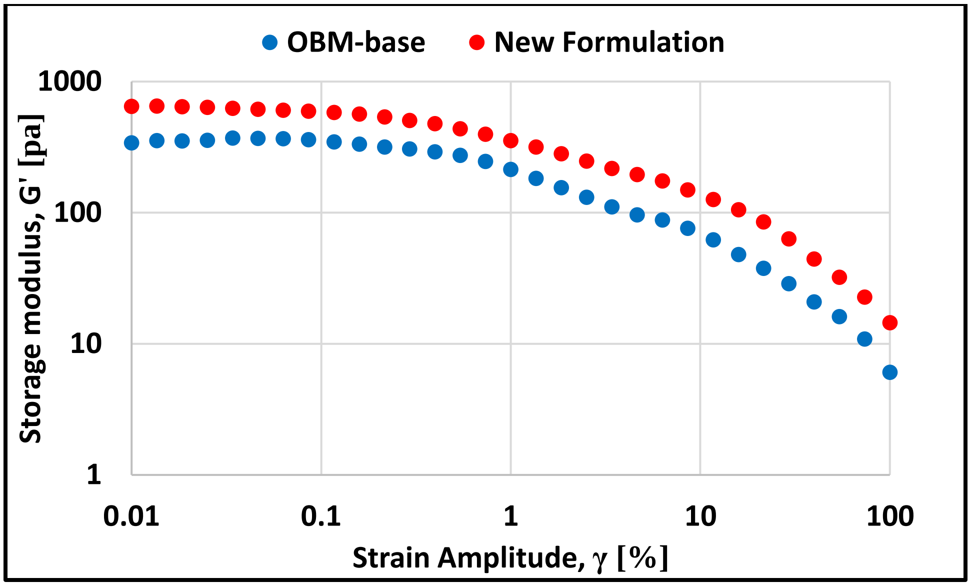

Figure 4.9: The Storage Modulus, G', From Oscillatory Strain Amplitude Testing At 120°F.

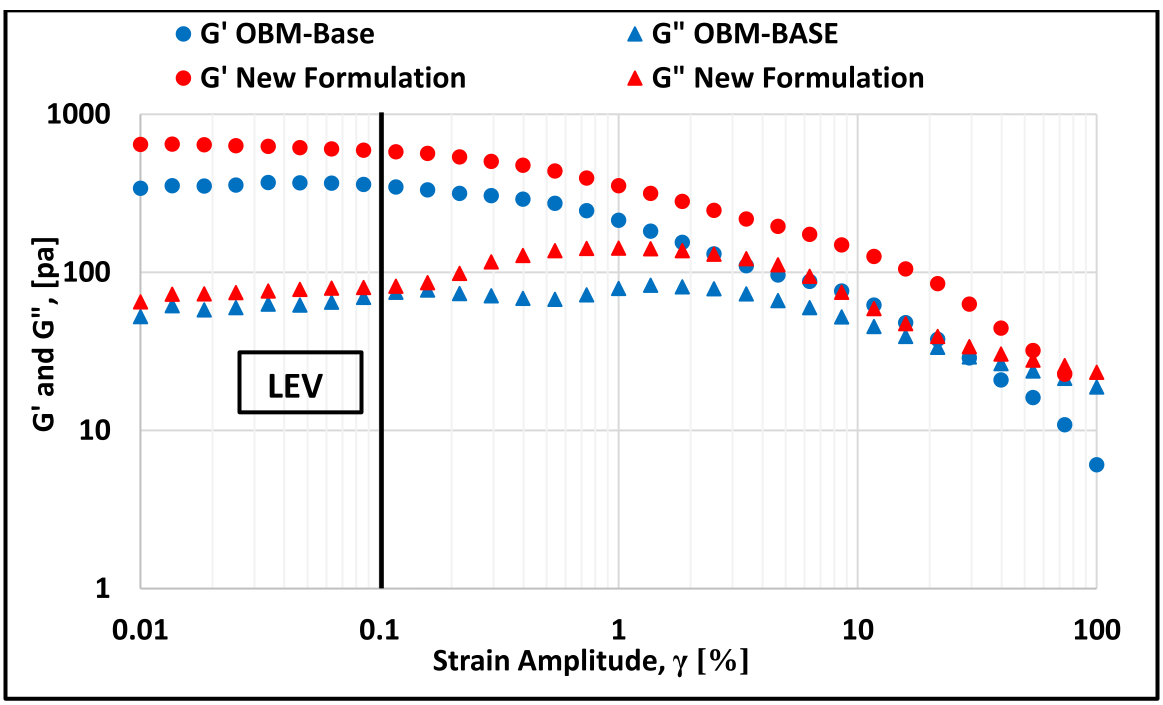

Figure 4.10: Amplitude Sweep Test for Both Fluids At 120 °F

4.2.4 The Effect of the Copolymer on the Frequency Sweep

Another test can help to investigate the sag behavior in IEF is frequency sweep test. The objective of this test is to study time-dependent viscoelastic properties. It is generally referred to when relating rheological properties to sag behavior is the value of the damping function, tan(δ), which is the ratio of G" to G' and indicative of the degree of elastic or viscous behavior in a fluid. When tan(δ) is less than unity, the material behavior is dominated by elastic contributions. On the other hand, a value greater than unity indicates viscous dominance in the system.

This test was performed at with constant strain taken from amplitude with 0.01% to 100 rad/sec. ramps logarithmic angular frequency and a number of data points are 31 points to get more accuracy. The results in **Figure 4.11** showed that G' for the new formulation is higher than OBM-base. This confirmed the sag test result. y indicates viscous dominance in the system. The fluid should have elastic behavior to provide support of solids in suspension both drilled cuttings and barite. Comparisons of OBM-base and the new formulation is illustrated by frequency sweep test in **Figure 4.12**. Results, in general, had the same trend at different temperature in the same fluid, with tan(δ) of the OBM- base significantly higher than new formulation. This compares well to the results from sag tests, which indicated that the Fluid OBM-base sample was most likely to experience sag tendency.

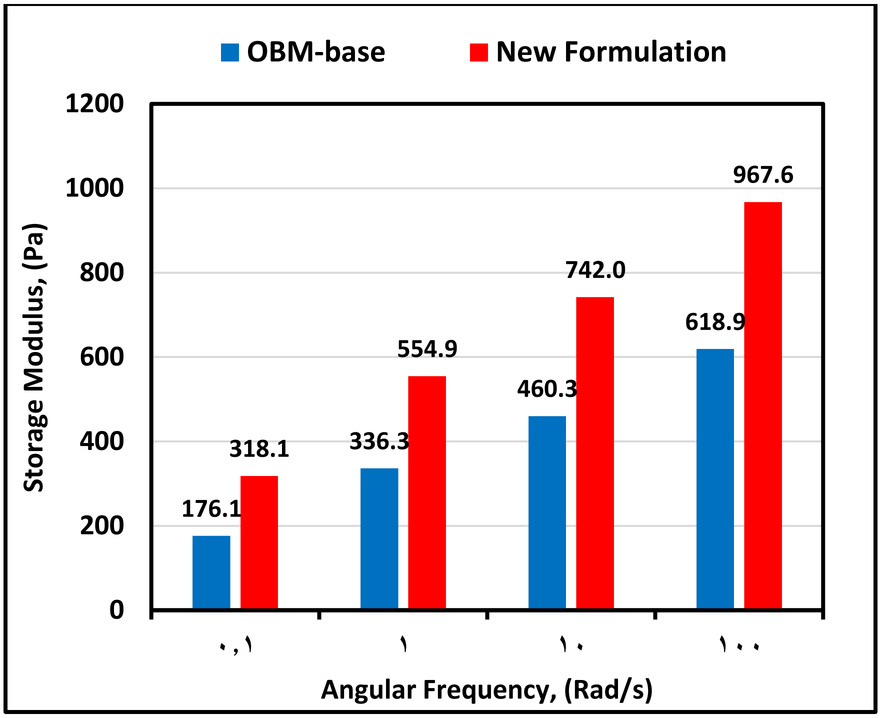

Figure 4.11: Storage Modulus, G' Of IEF at 120°F

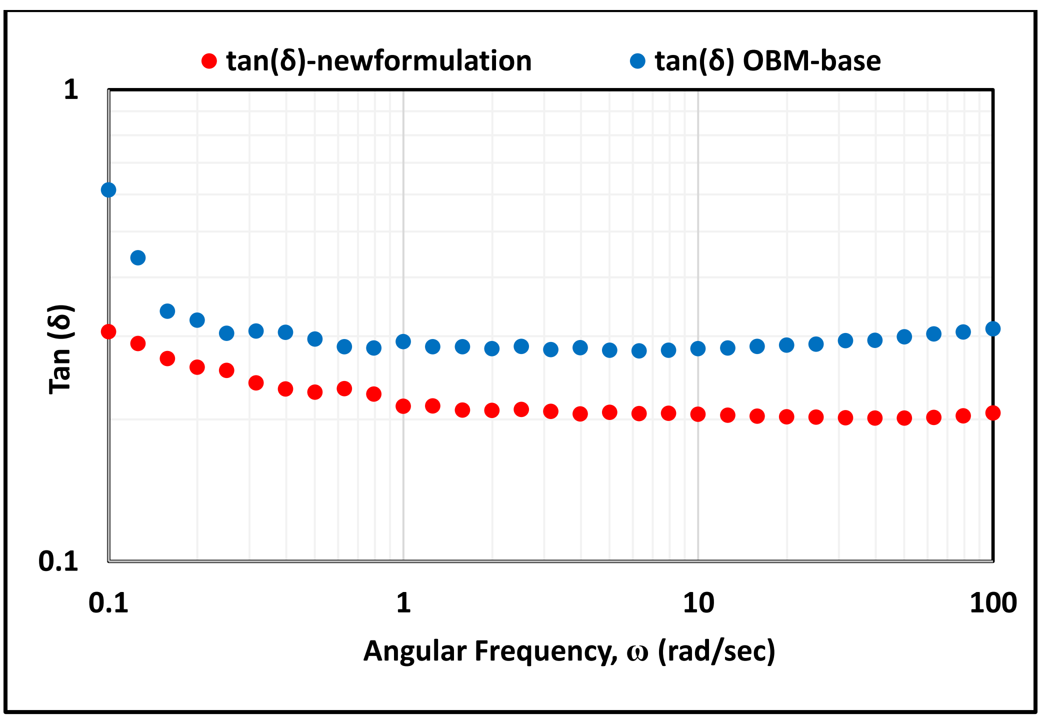

Figure 4.12: Damping Function, Tan(δ), From Oscillatory Frequency Sweep Testing At 120°F

4.3 The Effect of the Copolymer on the Filtration

A filtration test was performed using an HPHT filter press under static conditions. The drilling fluid was put in the cell, the cell was placed in the heating jacket, and the temperature was adjusted to 250 °F and 300 psi differential pressure. High permeability Indiana limestone cores with a thickness of 1 in. and a diameter of 2.5 in. where used in this experiment.

Filtration test is conducted to evaluate the effect of adding copolymer on fluid filtration of invert emulsion mud. Filtration test is performed under static conditions at 250 °F and 300 psi. **Figure 4.14** shows the result of HPHT filtration performance of OBM-base and new formulation. The results show that copolymer reduces the filtration by 20%. While the affection on cake thickness is very small **Figure 4.13.**

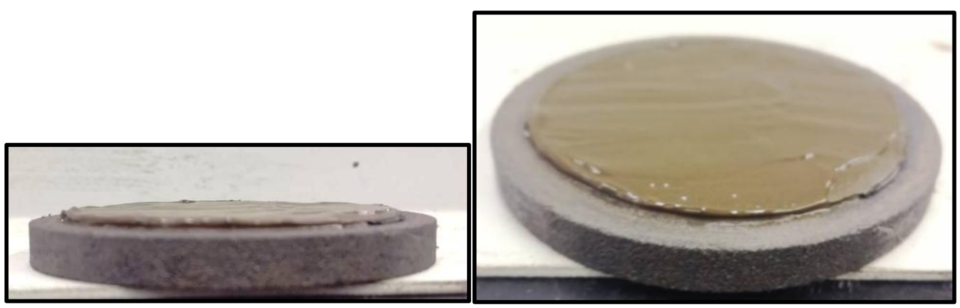

Figure 4.13 Filter Cake Thickness

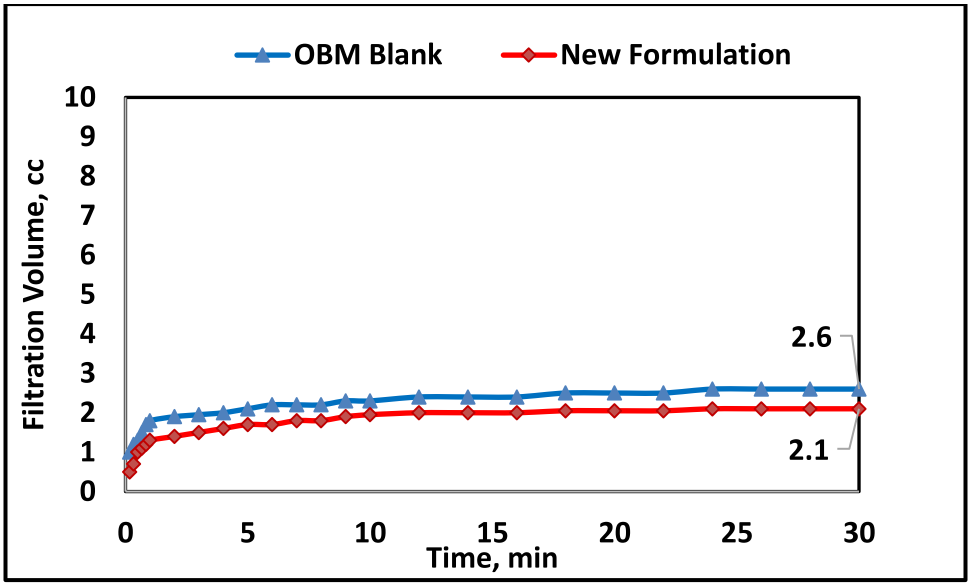

Figure 4.14: Filtration Performance Of OBM-Base and A New Formulation

Table 4.3: HPHT Filtration Test Data

Parameter	OBM-base	New Formulation
Filtration, cm^3/30min	2.6	2.1
Filter cake thickness, mm	1.45	1.42
Filter cake weight, gm	5.8	5.75

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Drilling fluid properties were measured for an invert emulsion drilling fluid, which confirmed the presence of sag issue (barite settling). A new copolymer was added with a concentration of 1 lb_m/bbl to the invert emulsion drilling fluid. The properties were measured again. A series of experiments were performed to evaluate the effect of adding copolymer to oil-based mud. These experiments including sag test to evaluate the barite settling in the mud at different temperature in both cases vertical and 45° deviated. Also, rheological properties and viscoelastic characterization were conducted at different temperature to study the effect of copolymer on plastic viscosity, yield point and gel strength. Moreover, high-pressure high-temperature filtration test was performed, and the following conclusions can be drawn:

- Adding 1 lb_m/bbl l of the new copolymer had no effect on drilling fluid density (14.7 ppg).
- The new copolymer enhanced the electrical stability of the invert emulsion drilling fluid.
- The new copolymer had a minor effect on the plastic viscosity, yield point, and increase gel strength.to prevent sag
- Adding 1 lbm/bbl of the copolymer prevent barite sagging at 350°F, where the sag factor was 0. 504 in the vertical case and 0.51 in the deviated case.

- The storage modulus (G') was increased by 40% after adding 1 lb_m/bbl of the new copolymer confirming the sag test results. There was little decrease in the filtration volume after copolymer was

5.2 Recommendation

1. Study the effect of the copolymer on the dynamic sag at high temperature by flow loop method.
2. Study the effect of the copolymer on the other viscoelastic properties such as: dynamic time sweep and dynamic temperature sweep.
3. Study the effect of adding ilmenite to barite as a weighting material in the OBM on enhancing fluid stability.
4. Study the effect of copolymer on removal efficiency.

References

Abraham, W. 1933, 'The Functions of mud fluid used in rotary drilling', 1st World Petroleum Congress, pp. 396–400.

Al-abdullatif, Z., Al-yami, A., Wagle, V., Bubshait, A. & Al-Safran, A. 2015, 'Development of New Kill Fluids with Minimum Sagging Problems for High-Pressure Jilh Formation in Saudi Arabia', SAUDI ARAMCO JOURNAL OF TECHNOLOGY.

Alabdullatif, Z., Al-yami, A., Wagle, V., Bubshait, A. & Al-safran, A. 2014, Development of New Kill Fluids with Minimum Sagging Problems for High Pressure Jilh Formation in Saudi Arabia, paper SPE-171683-MS, presented at the Abu Dhabi International Petroleum Exhibition and Conference, 10–13 November, Abu Dhabi.

Albertsen, T., Omland, T.H., Asa, S., Taugbol, K. & As, M.N. 2004, The Effect Of The Synthetic- And Oil Based Drilling Fluid's Internal Water Phase Composition On Barite Sag. paper IADC/SPE 87135. presented at the IADC/SPE Drilling Conference, 2–4 March, Dallas.

Amighi, M.R. & Shahbazi, K. 2010, Effective Ways to Avoid Barite Sag and Technologies to Predict Sag in HPHT and Deviated Wells, paper SPE132015, presented at the SPE Deep Gas Conference and Exhibition, 24–26 January, Manama, Kingdom of Bahrain.

Bern, P.A., Zamora, M., Hemphill, A.T., Marshall, D., Omland, T.H. & Morton, E. 2010, Field Monitoring of Weight-Material Sag. AADE paper presented at the 2010 AADE Fluids Conference and Exhibition, 6-7 April, Texas,.

Bern, P.A., Zamora, M., Slater, K.S. & Hearn, P.J. 1996, The Influence of Drilling Variables on Barite Sag. SPE 36670 paper presented at the SPE Annual Technical Conference and Exhibition, 6–9 October, Colorado.

Boycott, A.E. 1920, 'Sedimentation of Blood Corpuscles', Nature, vol. 104, no. 2621, pp. 532–532, URLviewed 31 March 2018, <http://www.nature.com/articles/104532b0>.

Bui, B., Saasen, A., Maxey, J., Ozbayoglu, M.E., Miska, S.Z., Yu, M. & Takach, N.E. 2012, 'Viscoelastic Properties of Oil-Based Drilling fluids', Annual Transactions of the Nordic Rheology Society, vol. 20, pp. 33–47.

Dye, W., Hemphill, T., Gusler, W. & Mullen, G. 2001, Correlation of Ultralow-Shear-Rate Viscosity and Dynamic Barite Sag paper. SPE-70128. presented at the SPE Annual Technical Conference and Exhibition, SPE, Houston, Texas.

Ehrhorn, C. & Saasen, A. 1996, 'Barite sag in drilling fulids', Ann. Trans. Nordic Rheology Soc, 4, 66, vol. 4, pp. 66–8.

Falana, O., Arthur, G. & Edward, M. 2011, SECONDARY EMULSIFIERS FOR INVERTED EMULSION FLUIDS AND METHODS FOR MAKING AND USING SAME. US ptent no: 20110021385.

Hanson, P.M., Trigg, T.K., Rachal, G. & Zamora, M. 1990, Investigation of Barite ‘Sag’ in Weighted Drilling Fluids in Highly Deviated Wells. Paper SPE 20423 presentet at the 65th Annual Technical Conferance and Exhibition, September 23-26, New Orleans.

Jefferson, D.T. 1991, 'New procedure helps monitor sag in the field, ASME paper, presented at Energy Sources Technology Conference', Petroleum Science and Technology, 20-24 Jan., New Orleans.

Maxey, J. 2007, Rheological Analysis of Static and Dynamic Sag in Drilling Fluids, vol. 15.

Miller, G. 1951, Oil Base Drilling Fluids, URLviewed 31 March 2018, <https://www.onepetro.org/conference-paper/WPC-4123>.

Mohamed, A.K., Elkatatny, S.A., Mahmoud, M.A., Shawabkeh, R.A. & Al-Majed, A.A. 2017, The Evaluation of Micronized Barite As a Weighting Material for Completing HPHT Wells, Manama, Kingdom of Bahrain.

Nguyen, T., Miska, S., Yu, M., Takach, N., Ahmed, R., Saasen, A., Henry, T. & Maxey, J. 2011, 'Engineering Experimental study of dynamic barite sag in oil-based drilling fl uids using a modi fi ed rotational viscometer and a fl ow loop', Journal of Petroleum Science and Engineering, vol. 78, no. 1, pp. 160–5.

Nguyen, T., Miska, S., Yu, M., Takach, N., Ahmed, R., Saasen, A., Omland, T. & Maxey, J. 2011, 'Experimental study of dynamic barite sag in oil-based drilling fluids using a modified rotational viscometer and a flow loop', Journal of Petroleum Science and Engineering - J PET SCI ENGINEERING, vol. 78, pp. 160–5.

Nguyen, T.C., Miska, S., Saasen, A. & Maxey, J. 2014, 'Using Taguchi and ANOVA methods to study the combined effects of drilling parameters on dynamic barite sag', Journal of Petroleum Science and Engineering, vol. 121, pp. 126–33.

Omland, T.H., Albertsen, T., Taugbol, K., Saasen, A., Svanes, K., Asa, S. & Amundsen, P.A. 2006, 'The Effect of the Synthetic- and Oil-Based Drilling Fluid ’ s Internal Water-Phase Composition on Barite Sag', SPE Drilling and copmletion, vol. 21 (02), pp. 91–8.

Saasen, A. 2002, Sag of Weight Materials in Oil Based Drilling Fluids, paper IADC / SPE 77190 presented at the IADC/SPE Asia Pacific Drilling Technology, 9–11 September, Jakarta.

Saasen, A., Liu, D., Marken, C.D. & Halsey, G.W. 1995, Prediction of Barite Sag Potential of Drilling Fluids from Rheological Measurements. SPE/lADC 29410 paper presented at SPE/IADC Conference, Feb.28-March 2, Amsterdam.

Savari, S., Kulkarni, S., Maxey, J. & Kushabhau, T. 2013, A Comprehensive Approach to Barite Sag Analysis on Field Muds, paper AADE-13-FTCE-30, presented at the 2013 AADE National Technical Conference, February 26-27, Oklahoma.

Sharman, T. 2015, Characterization and Performance Study of OBM at Various Oil-Water Ratios, Master thesis.

Sharman, T. & Belayneh, M. 2017, 'Dynamic Viscoelasticity And Dynamic Sagging Correlation Of Four Oil Based Drilling Fluids (OBM)', International Journal of Fluids Engineering, vol. 9, pp. 9–19.

Simpson, J.P. 1971, 'Drilling Fluids-Today and Tomorrow', Journal of Petroleum Technology, vol. 23, no. 11, pp. 1294–8.

Smithson, T. 2016, The Defining Series HPHT Wells, Schlumberger.

Tehrani, A. & Popplestone, A. 2007, Can You Improve Rheology and Mitigate Barite Sag in Invert Emulsion Fluids through Brine Phase Treatment, paper AADE-07-NTCE-02, presented at the AADE National Technical Conference and Exhibition, April 10-12, Houston.

Tehrani, A., Zamora, M. & Power, D. 2004, Role of Rheology in Barite Sag in SBM and OBM, paper AADE-04-DF-HO-22, presented at the AADE 2004 Drilling Fluids Conference, April 6-7, Texas.

Temple, C., Aterson, A.F. & Leith, C.D. 2005, Method for reducing sag in drilling, completion and workover fluids. US patent no: US 6,861,393 B2, Mar. 1, 2005, Washington, DC.

Wagle, V., Al-yami, A.S. & Alabdullatif, Z. 2015, Using Nanoparticles to Formulate Sag-Resistant Invert Emulsion Drilling, paper SPE/IADC-173004-MS, presented at the SPE/IADC Drilling Conference and Exhibition, 17–19 March, London.

Wagle, V., Maghrabi, S. & Kulkarni, D. 2013, Formulating Sag-Resistant , Low-Gravity Solids-Free Invert Emulsion fluids, paper SPE 164200, presented at the SPE Middle East Oil and Gas Show and Conference, 10–13 March, Manama.

Zamora, M. & Bell, R. 2004, Improved Wellsite Test for Monitoring Barite Sag. paper AADE-04DF-HO-19. Presented at the AADE 2004 Drilling Fluids Conference, April 6-7, Houston, Texas.

Vitae

PERSONAL DETAILS

Name:	Salem Abdullah Basfar
Residential Address:	KFUPM campus Dhahran KSA
Mobile:	+966500964392 / +967712702556
Date of Birth:	1 February 1988
Nationality:	Yemeni
Status:	Married
E-mail:	salimbasfar@gmail.com

CAREER OBJECTIVE

Petroleum Engineer interested in joining drilling projects that may represent a challenge but also an apprenticeship regarding my career. Traveling availability.

EDUCATION HISTORY

July 2015 – Current Dhahran KSA	**King Fahd University of Petroleum and Minerals**, *Master's in petroleum engineering* Expected graduation: April 2018
May 2007 – Oct 2012	**Hadhramout University**, Hadhramout Yemen, Bachelor of petroleum engineering honour degree (87.83%)
May 2003 – Feb 2006	**AL-Masmom High School**, Hadhramout Yemen, Secondary School Scientific section

WORK EXPERIENCE

Nov 2013– Dec 2014	Academic teacher (Hadhramout University) Responsibilities and achievements: • Explain tutorial problems • Explain Laboratory experiments
May 2012- Nov2014	Petro Masila Petroleum Exploration and Production Company Al-Masila Block (14) Hadhramout Yemen(training 4 weeks)
March 2010-Aug 2011	Math. Teacher

OTHER SKILLS AND CERTIFICATES

Computer Skills:

- **TECHLOG** formation evaluation program at (KFUPM)
- **CMG** simulation program at (KFUPM)
- Diploma in Computer Application Programming (windows, word, excel, power point, typing, internet and outlook)
- (MAT LAB) Course

- "First Aid" Course

Language Skills:

- Arabic (Native Tongue)
- English (reading, writing, speaking skills)

PERSONAL COMPETENCIES

- Ability to work in a fast-paced environment to set deadlines
- Fast learning
- Enthusiastic self-starter who contributes well to the team

INTERESTS AND ACTIVITIES

- Football, Tennis and swimming
- Reading

Publications

- A conference paper: “Prevention of Barite Sagging while Drilling High-Pressure High-Temperature (HPHT) Wells”, Accepted for presentation at 2018 SPE-KSA ATS&E.
- A conference paper: New Hydrogen Sulfide Scavenger for Drilling Sour Horizontal and Multilateral Reservoirs Accepted for presentation at 2018 SPE-KSA ATS&E.
- A conference paper: Using Artificial Intelligence to Predict IPR for Vertical Oil Well in Solution Gas Derive reservoirs: A New Approach Accepted for presentation at 2018 SPE-KSA ATS&E.
- Journal paper “Prevention of Barite Settling while Drilling High-Pressure High-Temperature (HPHT) Wells” submitted to Journal of Molecular Liquids

Note: all documents are available upon request.