EXPERMENTAL INVESTIGATION OF THE EFFECT OF TEMPERATURE AND SALINITY ON DRILLING FLUIDS

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By
REBAZ SHARIF MAHMOOD

In Partial Fulfilment of the Requirements for the Degree of Master of Science in Petroleum and Natural Gas Engineering

NICOSIA, 2020

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Approval of Director of Graduate School of Applied Sciences

Prof. Dr. Nadire ÇAVUŞ

We certify that this thesis is satisfactory for the award of the degree of Masters of Science in Petroleum and Natural Gas Engineering

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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Date: 05-08-2020

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To my Mom…

ABSTRACT

Drilling fluid is one of the most significant fluids that used during drilling operation. Drilling fluid could be divided into different types including water and oil based mud as well as air drilling mud which each are used for different purposes. In addition, the most widely used drilling fluid is water based mud. A number of chemicals and materials mix with water such as: barite, bentonite, caustic soda, starch, and polymer. Each material or chemical is used for control two main factors such as, fluid lose control and weightings agent.

This research involves preparing mud sample in the laboratory to evaluate the effect of different temperature and salinity on drilling fluid performance and its viscosity through mixing, barite, xanthan gum, caustic soda, soda ash, starch and NaCl with specific concentration which is equal to one standard barrel of mud at the surface. Also through using laboratory equipment's such as, a mixer, mud balance and a viscometer for testing the rheological property of the mud at different temperatures for comparing the results and investigation their effects on the wellbore and drilling operation process.

The results show that mud rheology changes depending on different condition or different temperature for water base mud with different amount of NaCl and without it.in which plastic viscosity continuously increased with increasing amount of salt concentration in the mud system. Experiments showed that at 150 ^oF drilling mud plastic viscosity is 18 Ib/ft^2 while in the mud sample without salt is 9 lb/ft^2. However, when mud contamination happens viscosity becomes 34 lb/ft^2 in the same degree of temperature. Also the gel strength of water based mud increase when salt contamination is occurred and its will lead to form many serious problems. Based on the results, high level of gel strength will be very problematic situation due to requiring high pump pressure to break circulation and, becoming a factor to formation fracture and increasing fluid loss in the well.

Keywords: Drilling fluid; water based-mud; rheology; salinity; drilling fluid performance.

ÖZET

Sondaj sıvısı, sondaj işlemi sırasında kullanılan en önemli sıvılardan biridir. Üç farklı tipte sondaj çamuru vardır. (su bazlı çamurlar, petrol bazlı çamur ve her biri farklı amaçlar için kullanılan gazlı sondaj çamuru) En yaygın sondaj çamuru su bazlı çamurdur. Barit, bentonit, kostik soda, nişasta ve polimer gibi su ile karıştırılır. Her malzeme veya kimyasal, sıvı kaybı kontrolü, ağırlıklandırma maddesi, viskozite vb. reolojiyi kontrol etmek için kullanılır.

Bu araştırma, farklı sıcaklık ve tuzluluğun sondaj çamur performansı ve viskozitesi değerlendirmek için: barit, ksantan sakızı,kostik soda, soda külü, nişasta ve NaCl ile bire eşit konsantrasyonda değerlendirmek için laboratuvarda çamur numunesinin hazırlanmasını içerir. Bir varil standart çamur için, laboratuvar ekipmanlarını kullanarak sonuçları karşılaştırmak ve sondaj ve sondaj işlemi süreci üzerindeki etkilerini araştırmak, farklı sıcaklıklarda test etmek, çamur dengesi, çamurun reolojik özelliğini anlamak, viskozimetre gibi parametrelerle mümkündür.

Sonuçlar, çamur reolojisinin, farklı miktarda NaCl içeren ve NaCl siz su bazlı çamur için farklı koşullara veya farklı sıcaklığa bağlı olarak değiştiğini göstermektedir. İçinde plastik viskozite, çamur sisteminde artan tuz konsantrasyonu ile sürekli artmıştır. Deney, 150 ^{o}F sondaj çamurunda plastik viskozitenin 18 Ib / ft^2 olduğunu, tuzsuz çamur örneğinde 9 Ib / ft^2 olduğunu, ancak çamur kirlenmesi meydana geldiğinde aynı sıcaklıkta 34 Ib / ft^2 olduğunu gösterdi. Ayrıca tuz kontaminasyonu meydana geldiğinde su bazlı çamurun jel mukavemeti artar ve birçok ciddi soruna yol açacaktır. Sonuçlara dayanarak, yüksek jel gücü seviyesi, sirkülasyonu kırmak için yüksek pompa basıncına ihtiyaç duyulması ve kuyu oluşumunda bir faktör haline gelmesi ve kuyudaki sıvı kaybının artması nedeniyle çok sorunlu bir durum olacaktır.

Keywords: Sondaj sıvısı; su bazlı çamur; reoloji; tuzluluk; sondaj sıvısı performansı.

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LIST OF SYMBOLS AND ABBREVIATIONS

RPM: Round Per Minute

FWM: Fresh Water Based Mud

VG: Viscosity Gel Meter

SR: Shear Rate

SS: Shear Stress

PV: Plastic Viscosity

YP: Yield Point

Cp: Centipoise

CHAPTER 1
INTRODUCTION

1.1 Definition of Drilling Mud

Drilling fluid can be defined as a fluid that used during drilling process for many purposes, also it is straightly related to most of the drilling problems those may happen during this process (Caenn et al., 2001) . It can be said that with the help of drilling fluid many drilling problems could be solved and it is important in reducing difficulties and challenged conditions. Drilling mud during drilling process used for a number of purposes which are including: remove cutting from wellbore to outside of the hole, providing required pressure (hydrostatic pressure) to keep the well clean and prevent wellbore from entering formation fluid, hold the cuttings while stopping circulation process, lubrication and cooling bottom hole assembly.

Usually drilling mud pumped through a number of pumps at the surface to the wellbore and then coming back through the flow lines to the surface (Ruiz, 2015). Generally there are three different types of drilling mud including, water base mud, oil base mud and synthetic mud. Water base mud can be define as a mixture of water with a number of materials such as, solid, liquid and chemicals. In addition the types and specification of each of them that mix with drilling fluid depend on the well requirements and conditions (Ruiz , 2015). In drilling process all solids that mix with drilling fluid should not be active it means depending on the situations the active and inactive solids change (Asme Shale Shaker Committee, 2011).

Moreover, the preparation for drilling fluid goes through several actions. Fluid loss control, weighting agent, dispersants, and inorganic materials are those common additives that are used for different purposes during drilling operation. There are a number of different weighting additives like barite, calcium carbonate, and hematite, but the most common one is barite which has 4.20 g/cm^3 specific gravity. When the drill bit crush the rocks and separate it to the cuttings, all cuttings need to be carried out by drilling fluid, so the drilling mud must be capable to hold up all cutting to the surface and its depend on the rock cutting size, density of the drilling mud as well as its viscosity, because while transferring cutting from borehole to surface drilling mud viscosity is responsible for that issue, in another meaning if the mud viscosity is low all the cutting will settle at the bottom of the well and it will lead to stuck of the drill bit and will cause a number of other drilling problems (Asme Shale Shaker Committee, 2011).

1.2 Rhyological Properties of Drilling Mud

Drilling mud can be identified through a number of properties which are including: plastic viscosity, apparent viscosity, effective viscosity, yield point and the gel strength also there are several significant characteristics including density and filtrate control and so on. As mentioned before all characteristics and rheological properties are responsible for their functions which means it will be able to transfer and hold the cutting during drilling and circulation in a high yield stress (Alderman et al., 1988).

1.2.1 Plastic viscosity

Plastic viscosity is a resistance of fluid to flow and in another meaning the volume of solid and liquid phases in the drilling mud could be called plastic viscosity. Fluid plastic viscosity increase while mixing with resolvable materials. Plastic viscosity is important while drilling operation because the performance of the fluid that used for fluid loss control during drilling increase by increasing plastic viscosity (Annis and Smith, 1974).

1.2.2 Gel strength

Gel strength is another type of rheological property of drilling fluid which can be mentioned as the inner particle force or the forces between particles that are present on drilling fluid. Increase particle force mean increasing connection between each particle. So gel strength is responsible for holding up the cuttings and prevent cutting particle in the wellbore from setting in the hole. A rigid structure of particles is requiring having a good particle connection. In addition temperature, amount of chemicals or solids that used for having proper gel strength have influence on the gel strength and its ability. Also the ability of mud relate to the penetrated rock, because during drilling process the penetrated rock (soft rocks) will be dissolve with the mud and contaminate or change the rheological characteristic of the mud (Annis and Smith, 1974). So, salt contamination, bacteria, rock cutting or Ultra-fine solid, cement contamination, hydrate, lime, H_2S and other contamination lead to increase gel strength of the water based mud (Ryen et al., 2017).

1.2.3 Yield point

Yield point is another important parameter to evaluate drilling fluid condition, and physically it's belonging to the attractive energy between colloidal particles in the mud. In another meaning yield point measure the required stress of the fluid to flow. In the plot of Bingham plastic model it could be expresed through a x-y axis plot. where x-axis represents shear rate and y-axis represent shear stress. So in Bingham plastic model shear stress represent YP when shear rate is at zero. In the laboratory, Yp could be calculating through reading viscometer at 600 RPM and 300 RPM and then subtracting the result from plastic viscosity of the mud and it is reported as lb/100 ft^2. Basically, any drilling fluid ability to lift the rock particles in the well to the surface could be evaluated through its yield point, increasing and decreasing yield point will have a several effects on the well condition in which high YP means lifting cutting to the surface much better than other drilling fluid of lower YP (Drilling Formulas, 2016).

1.3 Problem Statement

Drilling fluid viscosity is a very significant issue during drilling process. Viscosity change will directly influence the performance of drilling fluid, cutting transformation, fluid lose as well as filter cake issue. In other meaning a number of problems are prevented through controlling drilling mud viscosity. Controlling the fluid viscosity will also affect and increase the wellbore cleaning from rock particles. The most common method for measuring viscosity is viscometer and rheometer device.

Increase and decrease of drilling mud viscosity will affect the well condition in different ways. Decreasing viscosity become a factor to having small filter cake or not proper mud cake, well problem and so on, on the other hand increasing viscosity more than required level increase the fluid loss issue, filter cake, pipe stuck problem and etc. it means proper drilling mud viscosity must be prepared through having a good plan for different types of formation, temperature and condition (M. Amani et al., 2012). Viscosity characterizes amount of material's resistance to a bending force (Balhoff et al., 2011). Therefore, drilling fluid viscosity requires to be sufficiently prepared and controlled.

Drilling mud must be able to hold up cuttings, this action happens because of shear stress of the fluid. Increase and decrease of shear stress highly affect drilling mud circulation process. When shear rate increase it will affect the retention of solids during this operation and reduce the tools performance that responsible to separate cutting from drilling fluid called shale shaker (Hall et al., 1950). On the other hand, shear rate reduction will affect the centrifuge tool at the surface and lead to several different problem inside the bore hole such as frictional pressure loss and etc (Hussaini and Azar, 1983).

1.4 Objectives of the Study

1- This research study is meant at analyzing the effect of different temperature and salinity on the drilling fluids

2- Evaluate the rheological property such as plastic viscosity, gel strength, yield point in order to know how drilling fluid rheology and viscosity change and how this change affect the drilling process as well as,

3- Evaluating the influence of temperature with its advantages and disadvantages during drilling process.

1.5 Scope of the Study

The research study plan/scope would be in three filds

• Provide an overview about the effect of temperature and salinity on the drilling fluid and drilling process operation.

• Provide a literature on drilling fluid performance and effect of changing viscosity on cuttings, formation and etc.

• Conduct experiment study in the laboratory to select the changes and their effect on the drilling operation.

1.6 Organization of Study

Chapter 1: This chapter provides an introduction to the topic in which it provides an overview of drilling fluid and its reyhological properties. Also providing and overview of the effect of temperature and salinity on oil based mud drilling fluid

Chapter 2: This chapter discusses and mentions studies and reviews litretures made on drilling fluid in different topics and sinario.

Chapter 3: Research methodology chapter contains all the information about the experiments and mthods which are used in this study by showing the procedure and recipy of prepared drilling fluid as well as methodology or the procedures that have been used to achieve the objective of this project.

Chapter 4: This chapter provides all the findings and results of the experment process, in which it describes and discuss the results through different plots and results.

Chapter 5: This chapter provides the conclusions of this project as it provides the key findings and provides recommendations. Also finalizing the effect of temperature and salinity on drilling fluids.

CHAPTER 2
LITERATURE REVIEW

2.1 Literature Review on Drilling Fluid Properties

Physical characteristic of fluid play a very important rule on its performance. Two important characteristics affecting mud quality are viscosity and surface tension. Both characteristics can be affected by temperature which affects the fluid inner state or, fluid particle connection (Rohde, 2018). As an example of viscosity between oil and water, water can move freely than oil due to having lower viscosity than oil. Also there is a relation between content structure and viscosity, which means fluid with having a complex molecular structure have a higher viscosity compared to the fluid with having normal molecular structure. Moreover, with increasing temperature fluid viscosity changes due to increasing the molecular energy, so this energy is able to overcome the strong connection or molecular relation between particles and it's called lowering viscosity (Rohde, 2018).

In another meaning, molecular attraction increases with rising temperature. Viscosity affects the gas phase more than liquid due to the molecular position and longer distances. Liquids having closer molecular distance the effect of temperature on viscosity is less ((Opentextbc, 2016). This issue is related to the kinetic energy between fluid and gas molecular. More specifically there are two processes during reducing temperature of liquid and gas which is called cohesion and molecular interchange. Cohesive force decreases by increasing temperature and it leads to increase of the level of molecular interchange between fluid and gas molecules (Ahmad, 2017). Such as temperature, viscosity could be affected by pressure, so with increasing pressure fluid and gas viscosity increase, it means viscosity and pressure are proportional to each other. But the effect of temperature is much higher compared to pressure on the same fluid because liquids are influenced very little by the applied pressure due to having low compressibility. If we compare between the effect of pressure and temperature of a specific liquid, increasing pressure from 0 to about 30 Mega pascal, viscosities different is almost the same when fluid temperature is increased by 1 ºC (Ahmad, 2017).

Bourgoyne state that high temperature condition directly affects the drilling fluid and lead to many problems and dangerous situations in the wellbore. So, the best drilling program requires for decrease of the drilling risk while drilling, reducing down time, decreasing the formation damage and so on. It's well-known that well temperature increases with increasing depth of the well due to unstable flow of the earth's core. It means because of increasing temperature and pressure the physical characteristics, (viscosity, plastic viscosity, etc.) change and it's directly affecting the drilling fluid performance. Drilling operation could be successful with proper water or oil base drilling fluid, because they have all required properties and they are the most common drilling fluids. So low penetration rate, bottom hole assembly failure, lost circulation, mud contamination and environmental problems are those happen due to unstable pressure and temperature which is called mud failure. Preparing drilling mud for very high temperature condition is very complex and challenging because it's responsible for having successful drilling operation (Bourgoyne et al., 1986).

It's clear that increasing temperature change the rheological properties of mud and it is very complex issue for mud engineer. It means drilling fluid design correctly is very significant to meet economical and good operation process. Having a good drilling mud is not only requirement for designing good drilling mud but also related to managing and monitoring drilling fluid flow in and flow out during drilling operation. With increasing depth drilling engineer must monitor the properties of mud by and taking samples to make sure about the properties of the drilling fluid like gel strength (GS), yield point (YP), and plastic viscosity. If engineer detects any change he is responsible to fix the property by adding or droping the chemicals or other process to reduce formation damage and operation problems (Vasan and Gatlin, 1958).

A number of researches were done about drilling fluid to evaluate the performance of drilling mud and temperature effect on its performance. So one of the researches conducted at University of Tunisia, and evaluated the influence of temperature on the viscosity of drilling mud. Result of Vasan et al, (1958) showed that plastic and apparent viscosity greatly changed with rising temperature.

In another research viscosity of water base mud was evaluated against high pressure and temperature (Sinha, 1970). The result showed that viscosity of drilling fluid greatly changed under high temperature and pressure but the effect of temperature was greater than effect of pressure due to molecular reaction on drilling fluid. Also Annis stated that plastic viscosity of water base mud reduces by increasing temperature and laboratory experiment was done. Mud sample was prepared and tested under different temperature such as 300 ºF and 250 ºF and results demonstrated with increasing temperature decreases viscosity of water base mud (Annis, 1967).

Also Bartlett state that water base mud is not only affected by temperature but also affected by concentration and solid content on the fluid, plastic viscosity of drilling fluid increase with increasing the volume of solid concentration as well as change with mixing large particle or solid concentration size. Mixing large particle of solid content increase surface interaction and it leads to increase plastic viscosity of drilling mud (Bartlett , 1967)

2.2 Litreature Review on Salinity of Drilling Fluid

Naturally all ground waters contain dissolved salt, where the amount of dissolved salt assesses or determines whether the water is good quality and could be used for drinking or low quality (El-Swaify, 2000). Salt does not only exists in the water naturally, but also is existing in the soil. Water in soil is normal (contain a small amount of salt) or abnormal which called (saline and sodic). The salts that exist in water commonly include (Na^+, K^+, $Mg_2{}^+$, $Ca_2{}^+$ and Cl^-) and sometimes there are some percent of sulfate and carbonate as well. So, the way of dissolving NaCl in water start with attacking the NaCl crystals by water. This attack will lead to separate the both positive and negative part of the sodium chloride which is known as Na^+ and Cl^- ions. This process will be continuing until reaching fully saturated solution or until whole positive and negative part of NaCl breaks. And more specifically, due to the polarity of water NaCl will be break down, so the negative part or charge of water combine with positive part of sodium chloride (Na^+), while the water positive charge combine with negative charge of sodium chloride which is (Cl^-). This process mentioned as the ion-dipole force. (El-Swaify, 2000). So, the large content of salt in the drilling fluid will lead to increase Na+. Na+ will substitute or exchange some H+ ions and it will lead to reduce PH of the content. That is why when salt content increase in the drilling mud, process or dilution becomes necessary to reduce the concentration of chloride in the mud (Netwasgroup, 2019).

CHAPTER 3
MATERIALS AND METHODS

3.1 Laboratory Experiments

Chemical that require for laboratory experiments including xanthan gum, barite, soda ash, caustic soda were obtained.Through all required material and device, seven drilling fluid samples were prepared for evaluating the rheological properties under different temperature with different amount of NaCl and discover how rheology of mud change with adding NaCl.

3.2 Materials

The drilling mud which used in laboratory experiments was water based mud. Chemicals that used to mix with water include barite, X-gum, soda ash, starch, Caustic soda with NaCl. As its well-known, barite is the weighting material (or chemical). and starch is one of the chemical that used for drilling fluid loss control, X-gum is a polymer that used to provide a proper ability of drilling fluid to hold the cutting in the borehole and it is called additive, and Caustic soda is the chemical which used for PH control of the drilling fluid and finally NaCl was used for providing a different scenario about the salinity of the mud and how rheological property change with different temperature. The Table 3.1 to Table 3.7 show the percentages of each chemical used in seven experiments (Tests 3.1 to 3.7).

Table 3.1 : Drilling mud composition for Test 1

Additive	Quantity
Water	350 ml
Barite	50 g
X-gum	2.7 g
Soda Ash	0.5 g
Caustic Soda	0.5 g

Table 3.2: Drilling mud composition for Test 2

Additive	Quantity
Water	350 ml
NaCl	3.7 g
Barite	50 g
X-gum	2.7 g
Soda Ash	0.5 g
Caustic Soda	0.5 g

Table 3.3: Drilling mud composition for Test 3

Additive	Quantity
Water	350 ml
NaCl	18.1 g
Barite	50 g
X-gum	2.7 g
Soda Ash	0.5 g
Caustic Soda	0.5 g

Table 3.4: Drilling mud composition for Test 4

Additive	Quantity
Water	350 ml
NaCl	37.5 g
Barite	50 g
X-gum	2.7 g
Soda Ash	0.5 g
Caustic Soda	0.5 g

Table 3.5: Drilling mud composition for Test 5

Additive	Quantity
Water	350 ml
NaCl	58.2 g
Barite	50 g
X-gum	2.7 g
Soda Ash	0.5 g
Caustic Soda	0.5 g

Table 3.6: Drilling mud composition for Test 6

Additive	Quantity
Water	350 ml
NaCl	109.0 g
Barite	50 g
X-gum	2.7 g
Soda Ash	0.5 g
Caustic Soda	0.5 g

Table 3.7: Drilling mud composition for Test 7

Additive	Quantity
Water	350 ml
NaCl	5 g
Barite	50 g
X-gum	2.7 g
Soda Ash	0.5 g
Caustic Soda	0.5 g

3.3 Instruments used

The laboratory study conducted through using NANBEL viscometer which is able to read the rheological property like viscosity and gel strength of the mud. Mud samples were mixed through drilling mud Mixer device and then heated using a heater to reach the desirable temperature.

3.4 Temperature and Salinity Schedule:

For the study of temperature and salinity effects on drilling mud, seven compositions were determined (Table 3.8). One of the samples was only normal mud without adding NaCl, but the rest were mud sample with having different amount of NaCl.

Table 3.8: Salinity and Temperature schedule

Number of test	**Amount of NaCl**	**Temperature (^oF)**
Test 1	0	(120 ^oF, 130 ^oF, 140 ^oF, 150 ^oF)
Test 2	3.5	(120 ^oF, 130 ^oF, 140 ^oF, 150 ^oF)
Test 3	18.1	(120 ^oF, 130 ^oF, 140 ^oF, 150 ^oF)
Test 4	37.5	(120 ^oF, 130 ^oF, 140 ^oF, 150 ^oF)
Test 5	58.2	(120 ^oF, 130 ^oF, 140 ^oF, 150 ^oF)
Test 6	109	(120 ^oF, 130 ^oF, 140 ^oF, 150 ^oF)
Test 7	5	(120 ^oF, 130 ^oF, 140 ^oF, 150 ^oF)

CHAPTER 4

DATA ANALYSIS AND RESULTS

4.1 Result of the study

A number of results were obtained through laboratory experiments. Experiments include seven drilling fluid tests for understanding the effect of salinity and temperature on drilling fluid. The test procedure and its components are different, for example procedure for adding NaCl was not the same for all tests, in which one of the test perform without adding NaCl and another 5 tests were performed with dissolving NaCl in the water before adding any chemical and the last one performed with adding NaCl after adding all chemicals or after preparing mud sample. The Test 1 presented in Table 3.1 which is a drilling fluid sample without adding NaCl, and then reading shear stress and shear rate of the mud sample shown in Figure 4.1 to know how rhyology change with changing temperature and then comparing to other samples with NaCl content.

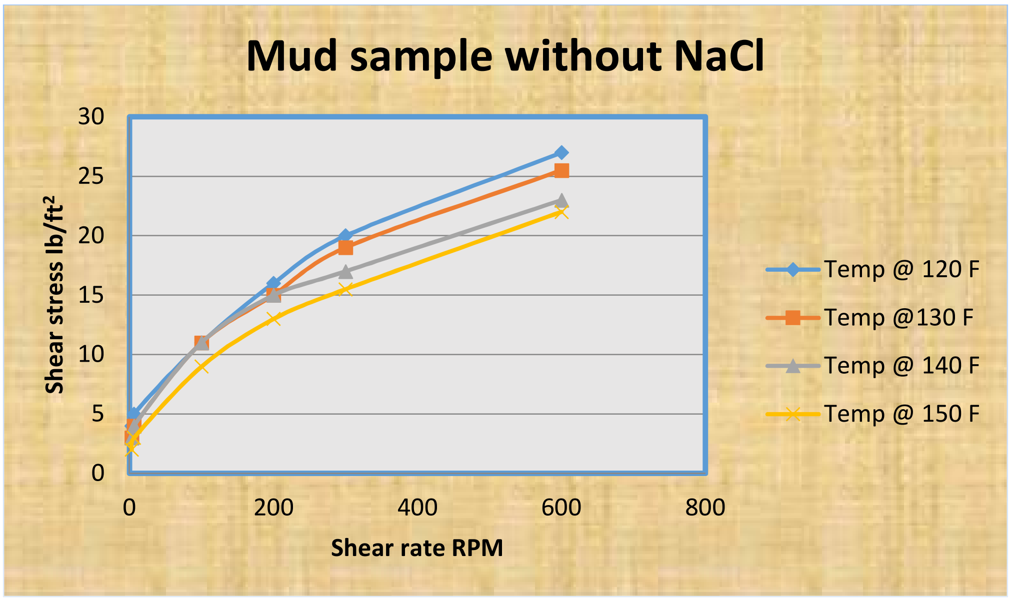

Figure 4.1: Shear stress and shear rate of the first mud sample prepared in Test 1 without adding NaCl

Figure 4.1 shows that, the shear stress of the mud sample is decrease with increasing temperature. So, with adding 3.7 g of NaCl the rheology of the mud sample increase due to the effect of the salinity on the mud sample which is shown in Figure 4.2

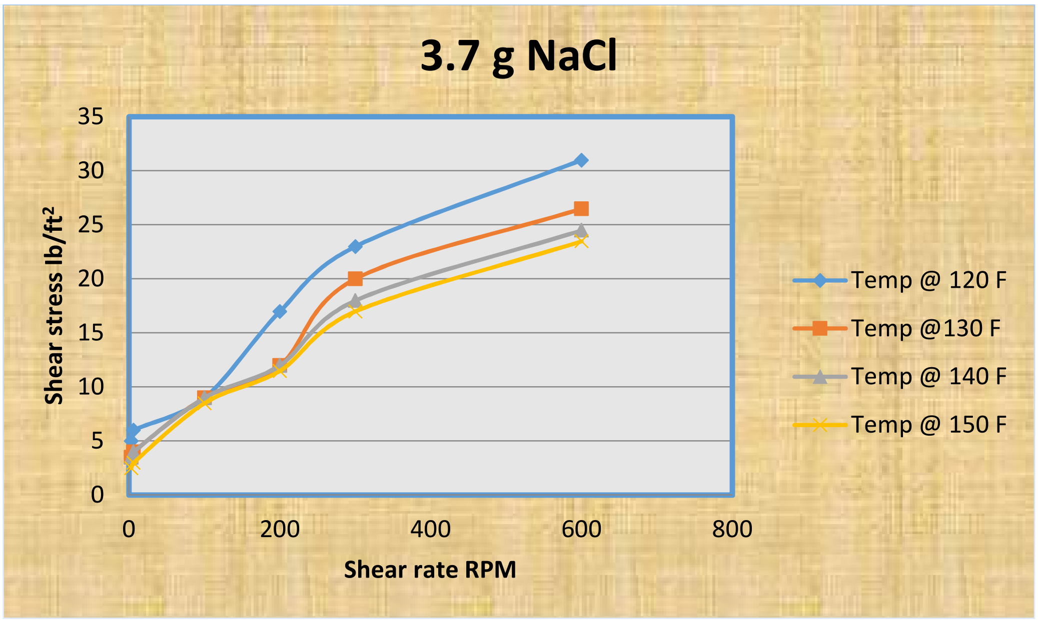

Figure 4.2: Shear stress and shear rate of secound mud sample in Test 2 with adding 3.7 g NaCl

As we can see in the Figure, shear stress of the mud sample at 150 F is about 24 Ib/ft^2, but at the same temperature in the Test 1 (mud sample without NaCl) shear stress is about 22 Ib/ft^2. Also the salinity effect will increase with increasing NaCl concentration on the mud sample such as below Figure 4.3 which refers to the Test 3 with increasing the NaCl amount to 18.1 g.

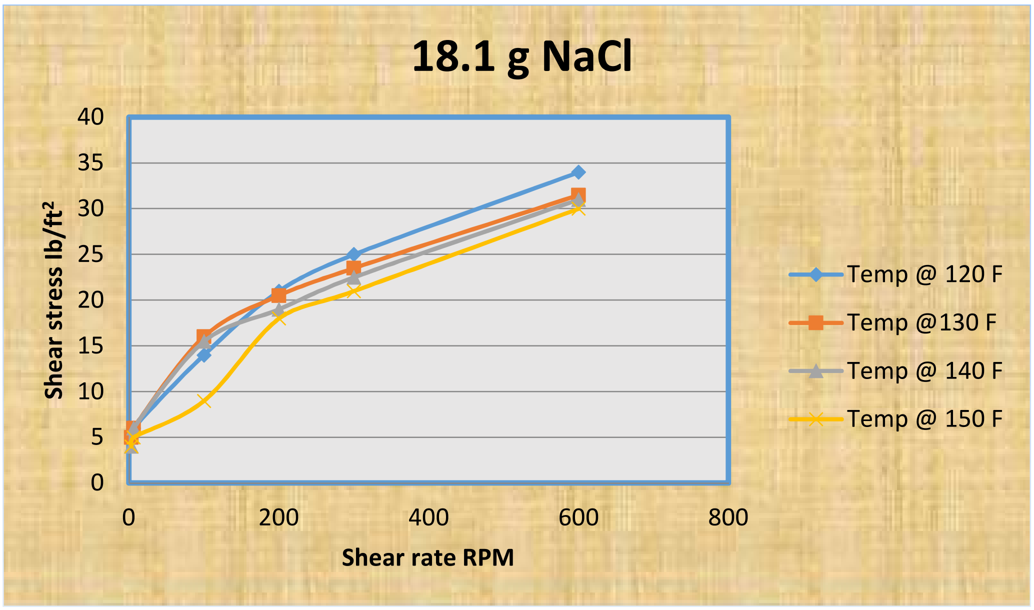

Figure 4.3: Shear stress and shear rate of third mud sample in Test 3 with adding 18.1 g NaCl

It can be said that, the result of shear stress and shear rate is slowly changing with increasing the concentration of NaCl in to the mud. Figure 4.4 refers to the mud sample shear stress and shear rate with increasing the NaCl to 37.5 g.

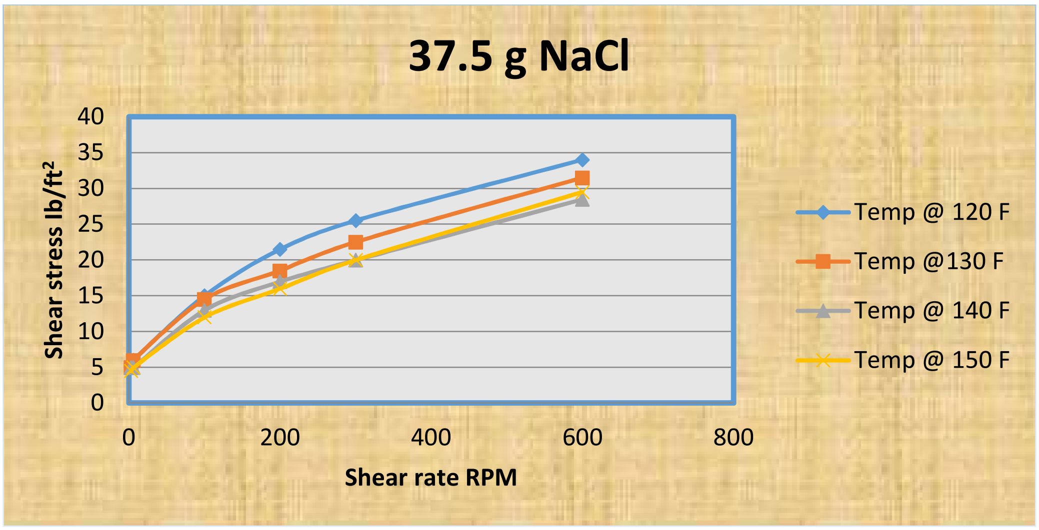

Figure 4.4: Shear stress and shear rate of fourth mud sample in Test 4 with adding 37.5 g NaCl

For Test 5 NaCl concentration increased to 58.2 which is equal to around 50 % of the total additives in the mud sample and the result of shear stress and shear rate increased, but its decreased with increasing temperature as well which is shown in Figure 4.5.

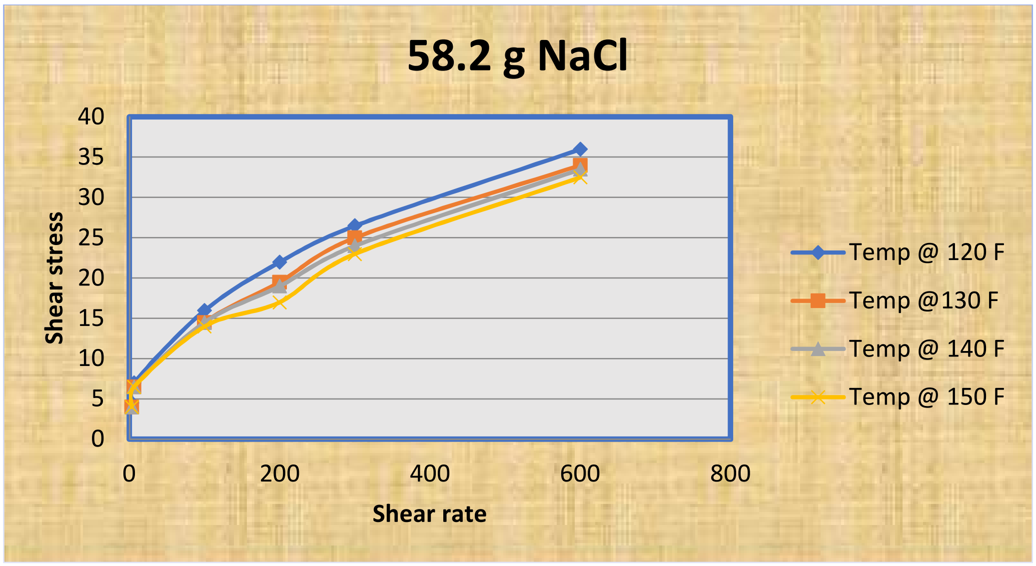

Figure 4.5: Shear stress and shear rate of fifth mud sample in Test 5 with adding 58.2 g NaCl

Test 6 was the fully saturated mud with NaCl concentration. In this test 109.1 g of NaCl is added to the water and then using a mixer to dissolve the NaCl properly in water. Then depending on the engineering recipe for preparing mud sample all other chemicals were added to the brine. As a result of the investigation, fully saturated mud sample with NaCl lead to increase the rheological property of the mud sample. The result of the Test is shown in Figure 4.6.

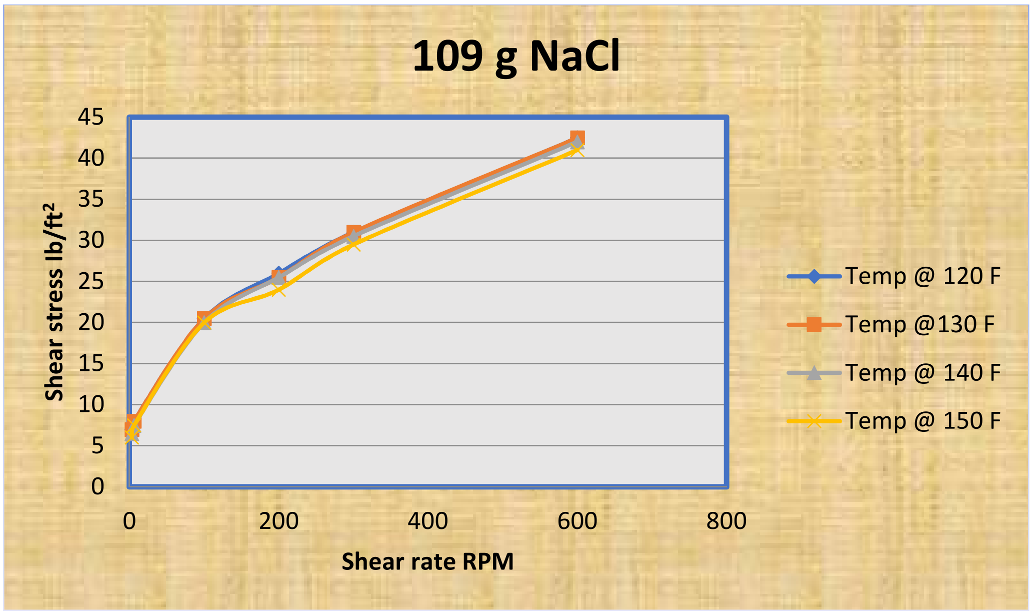

Figure 4.6: Shear stress and shear rate of sixth mud sample in Test 6 with adding 109 g NaCl

For the previous tested sample with different NaCl concentration, mud samples rhyology were decreased with increasing temperature, but the last sample with fully saturated NaCl several things are differ. In general the reading for shear rate at 600 RPM and 300 RPM is increased compared to the previous samples. But with increasing temperature all cases are close to each other which is related to increasing solid content in the mud sample.

Test 7 belongs to the mud sample with adding 5 g NaCl after mixing all chemicals in the mud. The result show that, adding NaCl after preparing mud will lead to reverse the reading of rheology of the mud due to containing high amount of solid in the mud which is called salt contamination. As we can see in Figure 4.7 with increasing temperature shear stress won't be decrease, contraily it will increase gradually.

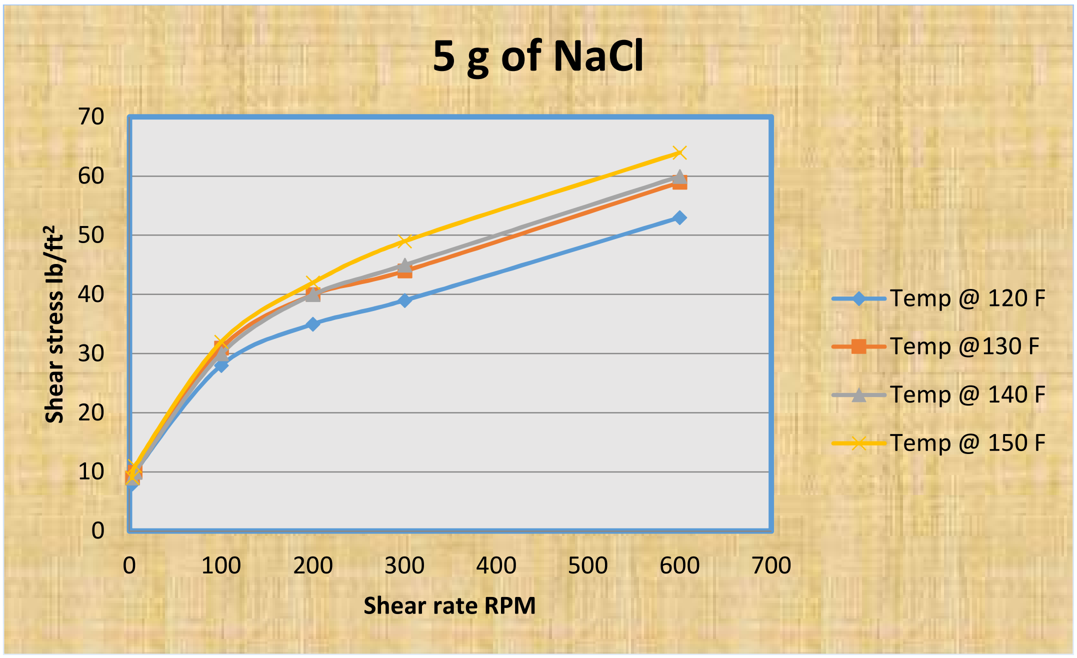

Figure 4.7: Shear stress and shear rate of seventh mud sample in Test 7 with adding 5 g NaCl

Through using both 600 RPM and 300 RPM both plastic viscosity and yield point of each sample were calculated, as its well-known Plastic viscosity and Yield point are to different unit measurement of the drilling mud which very important during reporting the drilling fluid properties. So Plastic viscosity could be reported by (CPS) which is stand for centipoise and YP could be reported by (lb/ft2) which stands for pound per feet squared. Both of the measurements are calculate through rotating viscosity meter by different speed. In addition the rotational steps are 600, 300, 200, 100, 6 and 3 RPM. But only 600 RPM and 300 RPM are used to measure the plastic viscosity and yield point in which plastic viscosity could be calculate by subtracting the 300 RPM reading from the 600 RPM reading. While yield point could be calculate through subtracting PV from 300 RPM. Tables 4.1 to 4.8 represent different PV and YP of all our laboratory investigations.

Table 4.1: Test 1 result with 0 g NaCl concentration

Temperature (°F)	600 RPM	300 RPM	200 RPM	100 RPM	6 RPM	3 RPM	Plastic viscosity	Yeild Point
120	27	20	16	11	5	4	7	13
130	25.5	19	15	11	4	3	6.5	12.5
140	23	17	15	11	4	3	6	11
150	22	15.5	13	9	3	2	6.5	9

Table 4.2: Test 2 result with 3.7 g NaCl concentration

Temperature (°F)	600 RPM	300 RPM	200 RPM	100 RPM	6 RPM	3 RPM	Plastic Viscosity	Yeild Point
120	31	23	17	9	6	5	23	13
130	26.5	20	12	9	4	3.5	20	12.5
140	24.5	18	12	9	4	3.5	18	11
150	23.5	17	11.5	8.5	3	2.5	17	9

Table 4.3: Test 3 result with 18.1 g NaCl concentration.

Temperature (^oF)	**600 RPM**	**300 RPM**	**200 RPM**	**100 RPM**	**6 RPM**	**3 RPM**	**Plastic Viscosity**	**Yeild Point**
120	34	25	21	14	6	5	9	16
130	31.5	23.5	20.5	16	6	5	8	15.5
140	31	22.5	19	15.5	6	4	8.5	14
150	30	21	18	9	5	4	9	12

Table 4.4: Test 4 result with 37.5 g NaCl concentration.

Temperature (^oF)	**600 RPM**	**300 RPM**	**200 RPM**	**100 RPM**	**6 RPM**	**3 RPM**	**Plastic Viscosity**	**Yeild Point**
120	34	25.5	21.5	15	6	5	8.5	17
130	31.5	22.5	18.5	14.5	6	5	9	13.5
140	28.5	20	17	13	5	5	8.5	11.5
150	29.5	20	16	12	5	4.5	9.5	10.5

Table 4.5: Test 5 result with 58.2 g NaCl concentration

Temperature (^oF)	**600 RPM**	**300 RPM**	**200 RPM**	**100 RPM**	**6 RPM**	**3 RPM**	**Plastic Viscosity**	**Yeild Point**
120	36	26.5	22	16	7	4.5	9.5	17
130	34	25	19.5	14.5	6.5	4	9	16
140	33.5	24	19	14.5	6.5	4	9.5	14.5
150	32.5	23	17	14	6.5	4	9.5	13.5

Table 4.6: Test 6 result with 109.1 g NaCl concentration

Temperature (^oF)	**600 RPM**	**300 RPM**	**200 RPM**	**100 RPM**	**6 RPM**	**3 RPM**	**Plastic Viscosity**	**Yeild Point**
120	42.5	31	25.5	20.5	8	7	11.5	19.5
130	42	30.5	25.5	20	7.5	6.5	11.5	19
140	41	29.5	24	20	7.5	6	11.5	18
150	44	31	24	20	7.5	6	13	18

Table 4.7: Test 7 result with 5 g NaCl concentration after mixing mud chemicals

Temperature (°F)	600 RPM	300 RPM	200 RPM	100 RPM	6 RPM	3 RPM	Plastic Viscosity	Yeild Point
120	53	39	35	28	10	8	14	25
130	59	44	40	31	10	9	15	29
140	60	45	40	31	10	9	15	30
150	64	49	42	32	11	9	15	34

Table 4.8: Result of 10 sec Gel strength for all mud samples

Temperature (°F)	120 °F	130 °F	140 °F	150 °F
10 Sec Gel strength lb/ft^2 with 0 g NaCl	4	3.5	3	3
10 Sec Gel strength lb/ft^2 with 3.7 g NaCl	4	3.5	3	2.5
10 Sec Gel strength lb/ft^2 with 18.1 g NaCl	4.5	4	3.5	3.5
10 Sec Gel strength lb/ft^2 with 37.5 g NaCl	6	5.5	5	4.5
10 Sec Gel strength lb/ft^2 with 58.2 g NaCl	6.5	6	5.5	5
10 Sec Gel strength lb/ft^2 with 109.1 g NaCl	8	7	7	7.5
10 Sec Gel strength lb/ft^2 with 5g NaCl	9	9	9	9

4.2 Discussion

Drilling fluid performance relies on the types of chemicals, their concentration and mixing mud recipe or drilling order. Drilling engineer is responsible for preparing mud sample based on the requirement that needed for drilling process, because if it does not meet the requirement it will not be a proper mud with having less performance for doing the drilling mud functions. So, there are some important parameters which show the mud performance, such as plastic viscosity, gel strength, yield point and so on. For example, plastic viscosity is a straight sign of the size and nature of the particles on the drilling mud. Yield point is a parameter showing the ability of the drilling fluid to hold and suspend the rock cutting in the borehole during drilling process (Samsuri, 2018).

Using salty drilling mud or saltwater drilling mud is the only choice for high salty formations in order to avoid the salt contamination in the mud. While increasing the rheology of the drilling fluid, the salty drilling mud will not form the huge problem compared to the salt contamination or other contamination in the fresh mud during drilling process. Increasing the chloride and rheology of the drilling fluid is a quick indication for salt contamination in the drilling fluid. And also it will lead to increase the fluid lose during drilling process (Netwasgroup, 2019).

Usually the PV and YP and gel are the most important parameters to detect the drilling mud performance, increasing temperature will lead to decrease YP due to temperature, also the shear stress of the drilling mud fall by increasing temperature from 120 ^{o}F to 150 ^{o}F as shown in Figure 4.8 and Figure 4.9 below

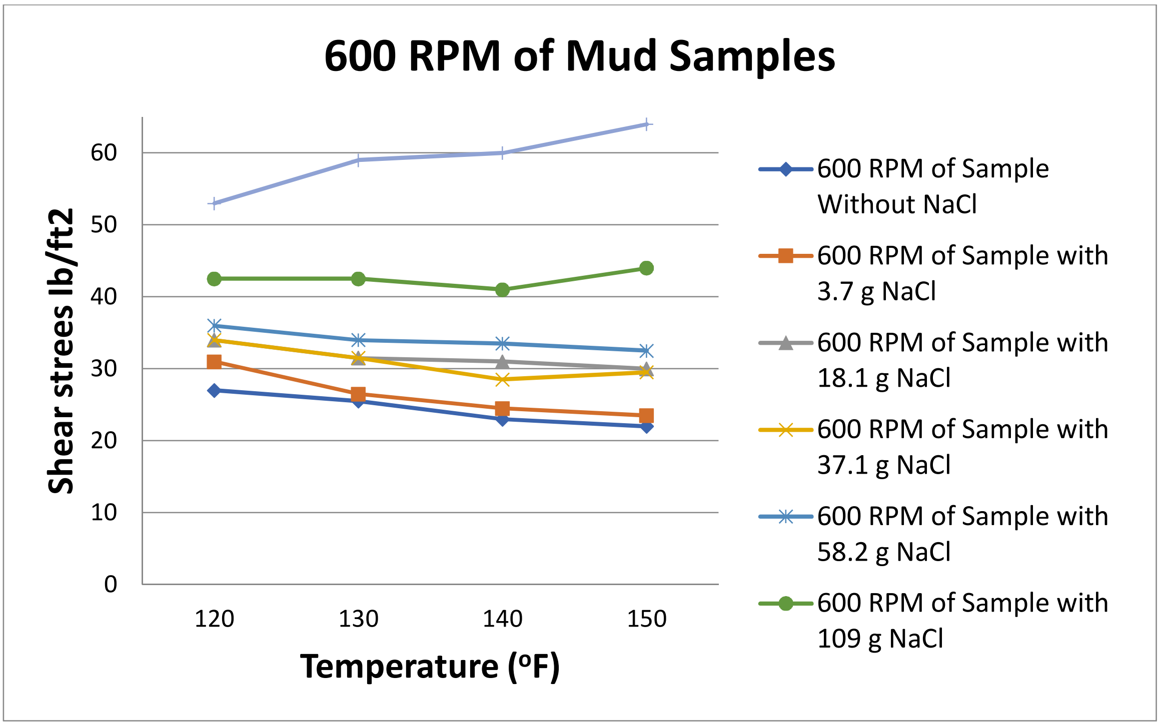

Figure 4.8: Shear stress at 600 RPM versus temperature plots of all mud samples

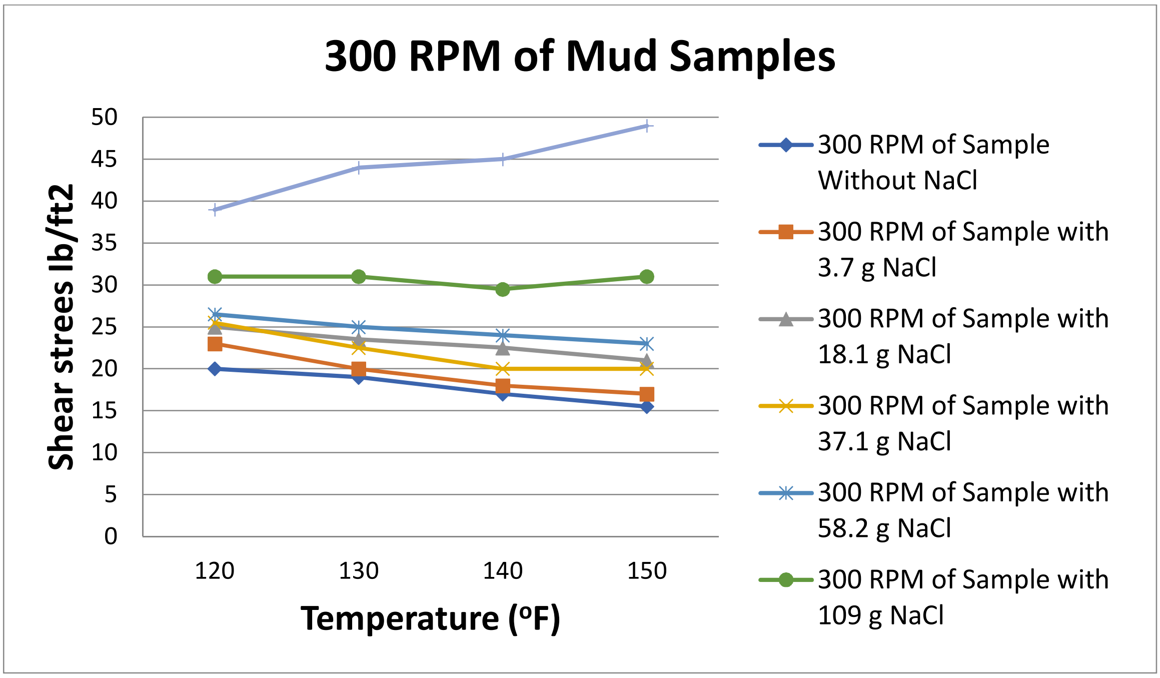

Figure 4.9: Shear stress at 300 RPM versus temperature plots of all mud samples

As explaned in the above different amount of NaCl has been used for different mud samples. The results show that, YP, PV and gel strength of all samples that contain dissolved NaCl before adding chemical decrease with increasing temperature, but with increasing the salt concentration in the samples the rheology of the drilling fluid increase gradually. For example in a mud sample with fully saturated NaCl shear stress at 150 F is above 40 Ib/ft^2 while at the same temperature shear stress of the mud sample with containing 3.7 g NaCl is 23.5 Ib/ft^2 . But there is a very big difference between adding salt before mixing chemicals and adding it after mixing chemicals in the mud sample. Also increasing drilling fluid temperature lead to increase rheology of drilling mud due to salt contamination problem. As mentioned before, yield point is one of the parameter to show the ability of the drilling mud and deliver cutting from the wellbore to the surface during dynamic condition of the well, also there is a strong relation between yield point and frictional pressure loss, It means with increasing YP of the drilling fluid the frictional pressure loss increase and it will lead to having less performance of the drilling mud (Shifeng et al., 2009).

Salt contamination could be mention as one of the serious problem which may occur during drilling process and there is no any specific way to remove the salt in the mud by chemical, This could be solved or treatd only through mixing water which is called dilution process. Salt contamination will lead to decrease the drilling fluid performance due to increasing ionic concentration of the mud, and also it will form the flocculation problem which lead to increase rheology and lost circulation problem. Moreover, having extra amount of salt contamination will lead to dry out the sensitive chemicals in the mud and it will increase fluid loss problem and affecting viscosity as well. Dilution process depend on the amount of salt contamination in the mud, because having small amount of contamination or deflocculated mud can be accept when it is equal to 10000 mg/L, because having contamination more than mentioned amount lead to uncontrolled rheological property and lost circulation problem. Controlling rheological property is a specific issue and if there is a plan for drilling a huge amount of salt formation, the drilling mud rheology should be either controled or changed to saturated salt system. Because in this way it will lead to avoid disolving formation salt and deliver salt cutting to the surface (Netwasgroup, 2019). Also saturated salt mud provide a better situation to avoid well enlargement because if fresh water based mud used for salty formation, formation salt will get dissolved in the mud and drilling process face a number of problem like, well enlargement, rheology change and missing formation cuttings (Glossary.oilfield.slb, 2012)

Related to the gel strength, increasing the amount of NaCl in the mud will lead to rise the gel strength of the mud but with increasing temperature gel strength decrease except the mud sample with adding NaCl after mixing chemicals. It means salt contamination also effect the gel strength of the mud. So high level of gel strength leads serious problems in the wellbore during static condition in the drilling process, it will need high pump pressure to break circulation. Moreover drilling mud with high gel strength may become a factor to formation fracture and increasing fluid loss in the well due to requiring high pump pressure. On the other hand, low gel strength mud is another kind of drilling mud problem which is related to the ability of the mud to hold the cuttings in the well. It means with having low gel strength mud it is hard to suspend cuttings due to this issue. Formation cuttings will settle down in the wellbore and become a factor to pipe stuck and many other problems (Ryen et al., 2017).

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study of temperature and salinity effect on drilling mud performance was carried out using the laboratory experiments. The results showed how the drilling fluid rhyology changes with changing salt concentration and temperature as well. In conclusion the following points could be highlited:

1- Depending on different temperature mud rhyology changes in prepared laboratory samples with different amount of NaCl concentration and without NaCl.

2- The plastic viscosity continuously increased with increasing amount of NaCl concentration in the mud samples. At 150 ^{o}F mud sample plastic viscosity was 9 lb/ft^2 and its changed to 18 lb/ft^2 with fully saturated NaCl as well as its increase to 34 lb/ft^2 when salt contamination occur.

3- The shear stress of the mud samples gradually rise with rising NaCl content in the laboratory samples.

4- With rising NaCl content in the samples gel strength of 10 second increase, but it is reduce by increasing temperature, also in salt contamnination condition it does not change with changing temperature.

5- Volume of the fluid loss and pressure loss increase when mud contamination happen in the fluid .

5.2. Recommendations

1. To avoid salt contamination issue and protect the wells more researches on salinity and salt contamination is require, because with out proper mud drilling process will not be successful.
2. More experiments about salinity at very high temperature and very high pressure situation is require to evaluate mud rhylogy on such different conditions.

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APPENDICES

APPENDIX 1

EQUIPMENTS USED

Devices	Names	Usage
	Mixer	Used to mix the materials properly.
	NABEL viscometer	Used to find RPM.
	Balance	To measure material amounts. .

APPENDIX 2

SHEAR STRESS (LB/FT²) DATA AT DIFFERENT TEMPERATURE AND SALINITY

Mud Composition	RPM	120 ºF	130 ºF	140 ºF	150 ºF
	600	27	25.5	23	22
	300	20	19	17	15.5
0 g NaCl	200	16	15	15	13
	100	11	11	11	9
	6	5	4	4	3
	3	4	3	3	2
Mud Composition	**RPM**	**120 ºF**	**130 ºF**	**140 ºF**	**150 ºF**
	600	31	26.5	24.5	23.5
	300	23	20	18	17
3.7 g NaCl	200	17	12	12	11.5
	100	9	9	9	8.5
	6	6	4	4	3
	3	5	3.5	3.5	2.5
Mud Composition	**RPM**	**120 ºF**	**130 ºF**	**140 ºF**	**150 ºF**
	600	34	31.5	31	30
	300	25	23.5	22.5	21
18.1 g NaCl	200	21	20.5	19	18
	100	14	16	15.5	9
	6	6	6	6	5
	3	5	5	4	4
Mud Composition	**RPM**	**120 ºF**	**130 ºF**	**140 ºF**	**150 ºF**
	600	34	31.5	28.5	29.5
	300	25.5	22.5	20	20
37.5 g NaCl	200	21.5	18.5	17	16
	100	15	14.5	13	12
	6	6	6	5	5
	3	5	5	5	4.5

Mud Composition	RPM	120 °F	130 °F	140 °F	150 °F
	600	36	34	33.5	32.5
	300	26.5	25	24	23
58.2 g NaCl	200	22	19.5	19	17
	100	16	14.5	14.5	14
	6	7	6.5	6.5	6.5
	3	4.5	4	4	4
Mud Composition	**RPM**	**120 °F**	**130 °F**	**140 °F**	**150 °F**
	600	42.5	42.5	41	44
	300	31	31	29.5	31
109 g NaCl	200	26	25.5	24	24
	100	20.5	20.5	20	20
	6	8	8	7.5	7.5
	3	7	7	6	6
Mud Composition	**RPM**	**120 °F**	**130 °F**	**140 °F**	**150 °F**
	600	53	59	60	64
	300	39	44	45	49
5 g NaCl	200	35	40	40	42
	100	28	31	30	32
	6	10	10	10	11
	3	8	9	9	9

APPENDIX 3

SHEAR STRESS (LB/FT^2) DATA AT DIFFERENT TEMPERATURE AND SALINITY

Temperature (F)	120 ^oF	130 ^oF	140 ^oF	150 ^oF
10 sec Gel strength lb/ft2 with 0 g NaCl	4	3.5	3	3
10 sec Gel strength lb/ft2 with 3.7 g NaCl	4	3.5	3	2.5
10 sec Gel strength lb/ft2 with 18.1 g NaCl	4.5	4	3.5	3.5
10 sec Gel strength lb/ft2 with 37.5 g NaCl	6	5.5	5	4.5
10 sec Gel strength lb/ft2 with 58.2 g NaCl	6.5	6	5.5	5
10 sec Gel strength lb/ft2 with 109.1 g NaCl	8	7	7	7.5
10 sec Gel strength lb/ft2 with 5 g NaCl	9	9	9	9

APPENDIX 4

TURNITIN SIMILARITY REPORT

AUTHOR	TITLE	SIMILARITY	GRADE	RESPONSE	FILE	PAPER ID	DATE
Rebaz Sherif	ABSTRACT	0%	--	--		1360841434	22-Jul-2020
Rebaz Sherif	CONCLUSION	0%	--	--		1360843081	22-Jul-2020
Rebaz Sherif	CHAPTER 1	1%	--	--		1360841793	22-Jul-2020
Rebaz Sherif	CHAPTER 2	1%	--	--		1360841939	22-Jul-2020
Rebaz Sherif	THESIS	5%	--	--		1360841267	22-Jul-2020
Rebaz Sherif	CHAPTER 4	6%	--	--		1360842650	22-Jul-2020
Rebaz Sherif	CHAPTER 3	11%	--	--		1360842401	22-Jul-2020

Prof. Dr. Salih SANER
Thesis Supervisor
12.08.2020

APPENDIX 5

ETHICAL APPROVAL DOCUMENT

YAKIN DOĞU ÜNİVERSİTESİ

ETHICAL APROVAL DOCUMENT

Date: 07/08 /2020

To the **Graduate School of Applied Sciences**

The research project titled "**EXPERIMENTAL INVESTIGATION OF THE EFFECT OF TEMPERATURE AND SALINITY ON DRILLING FULIDS**'' has been evaluated. Since the researcher will not collect primary data from humans, animals, plants or earth, this project does not need through the ethics committee.

Title:

Name Surname: Prof. Dr. Salih SANER

Signature:

Role in the Research Project: Supervisor

Title:

Name Surname:

Signature:

Role in the Research Project: