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ALTINBAS UNIVERSITY

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EFFECTS OF SiO_2 AND Al_2O_3 NANOPARTICLES ON THE FILTRATION, RHEOLOGICAL AND PHYSICOCHEMICAL PROPERTIES OF DRILLING FLUID

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Master of Science

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by

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Hayder Khudhair Abbas

DEDICATION

I devote and pledge this research work to my supervisor who is salient for guiding me through whole research work as well as my family for always assisting me in my hard time.

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ABSTRACT

EFFECTS Of SiO_2 AND Al_2O_3 NANOPARTICLES ON THE FILTRATION, RHEOLOGICAL AND PHYSICOCHEMICAL PROPERTIES OF DRILLING FLUID

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There are many studies which reported the nanoparticles could develop the rheological behavior and the properties of filtration for water-based mud. Different types of nanoparticles were used in the experiment including silicon oxide and aluminum oxide, which were evaluated at three concentrations. In addition, the development and comparison of a new fluids utilizing a biopolymer (xanthan gum)/nanoparticle (Al_2O_3 and SiO_2) mix to optimize the properties of a water-based mud (WBM) formulation. In this research, the main objective is to compare the influence of changing the amount of Al_2O_3 and SiO_2 nanoparticle on the rheological properties and filtration rate of WBM at low-temperature 30 ^oC and low pressure 150 psi (LPLT). The nano drilling fluids showed higher yield point, plastic viscosity, and apparent viscosity. In addition, 10 seconds gel was decreased by aluminum oxide while, it was increased by silicon oxide. A viscometer (model 3500) was used to measure the rheological properties of drilling muds. Filtration process was conducted with Fan high-pressure high-temperature static filter press. In terms of hole cleaning and filtration rate, properly engineered nanofluids showed more effective performance than conventional water-based muds

Keywords: Water-based drilling, nanoparticles, chemical properties, rheological properties

ÖZET

SONDAJ SIVISININ FİLTRELEME, REOLOJİK VE FİZİKOKİMYASAL ÖZELLİKLERİNE SiO_2 ve Al_2O_3 NANOPARÇACIKLARININ ETKİLERİNİN İNCELENMESİ

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Su bazlı sondaj sıvılarının özelliklerini iyileştirmek için nanoparçacık katkılı pek çok formülasyon bulunmaktadır. Bu çalışmada biyopolimer (ksantan sakızı) ve nanoparçacık (Al_2O_3 ve SiO_2) katkılı su bazlı bir sondaj sıvısının özellikleri incelenmiş ve nanoparçacıklar karşılaştırılmıştır. Değişen nanoparçacık derişiminin düşük sıcaklık (30 ^oC) ve düşük basınç (150 psi) altında sondaj sıvısının reolojik özelliklerine etkisi araştırılmıştır. Sonuçlara göre katkılı sondaj sıvıları daha yüksek esneklik sınırı, plastik viskozite ve görünür viskoziteye sahiptir. Böylece delik temizleme uygulamaları için yararlı olacağı ve daha düşük süzüntü kaybı oluşturacağı sonucuna varılmaktadır. Nanoparçacık katkıları, sondaj sıvılarının performansını artırmaktadır.

Anahtar sözcükler: Su bazlı sondaj, nanoparçacıklar, kimyasal özellikler, reolojik özellikler

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LIST OF ABBREVIATIONS

NPs	:	Nanoparticles
OLEDs	:	Organic Light Emitting Diodes
EOR	:	Enhance Oil Recovery
CN	:	Carbon Nanotubes
SWCN	:	Single-Walled Carbon Nanotubes
DWCN	:	Double-Walled Carbon Nanotubes
TEM	:	Transmission Electron Microscopy
XRD	:	X-Ray Diffraction
YP	:	Yield Point
AV	:	Apparent Viscosity
PV	:	Plastic Viscosity
YPL	:	Yield-Power Law
SVM	:	Support Vector Machine
HPHT	:	High-Pressure Low Temperatures
LPLT	:	Low-Pressure Low Temperatures

1. INTRODUCTION

The drilling fluid is one of the main components in the wall process. It is designed to achieve in the best way probable under envisaged borehole conditions. Drilling mud can have different chemical and physical properties depending on the specific formulations. These properties must be enhanced or optimized to minimize the well problems and unforeseen costs. Consequently, the poorly designed mud leads to major problems in the well such as stuck pipes, bit balling, shale swelling, formation sloughing, torque and drag, reservoir damage, mud circulation loss, and inadequate hydraulics system. All these problems are conducted to filtration, rheological and hydraulic properties of the water-based mud (WBM). The using of nanoparticles has become popular as an additive to WBM. Nanomaterials can improve drilling mud rheology when included even in minimal quantities. This is due to their specified properties and large surface area to volume ratio. These properties are making nanoparticles the most promising materials in the drilling mud industry. Using silicon oxide and aluminum oxide as additives to drilling mud have been reported in several researches. Their effect on filtration and rheological properties were investigated at different conditions.

Drilling mud is a viscous liquid that results from mixing liquid or gas with suspended soil [1]. In the past, water was the sole fluid before the growth of drilling fluid technology. The use of water was followed by the use of water dispersion of plastic materials and plastic material as drilling fluid which successfully resulted in formation of a good wall around the hole. There are three basic categories of drilling fluids; water-based mud, oil-based mud, and gaseous-based fluids. The usages of drilling mud in oil industry cover several areas from cooling and lubricating the drill tool, cleaning by lifting the drilled cuttings to the surface and creating hydrostatic pressure to avoid formation fluid from the flowing in the borehole and create a mud cake around the wall, which reduces the borehole and causes fluid loss [2]. For improving the performance of WBM, different substances were added to these fluids to enhance the rheological properties.

The nanoparticles are small particles with sizes less than 100 nm [3], which been applied in oil and gas section, including enhanced oil recovery [4], shale stabilization [5], fluid loss reductions [6], wellbore strengthening and formation damage reduction [7]. On the other hand, biopolymers such as xanthan gum, are utilized to create rheological filtration properties

[8], drilling fluid invasion controllers [9], and fluid loss reducers [10]. To the best of our knowledge, most studies are managed to deal with a single property, such as rheological or filtration properties [11], however, the drilling fluid has multiple functions in the drilling process, such as cooling and lubrication. Secondly, the effect of nanoparticles may add one nanoparticle to one property, but not to the other [12]. Therefore, the main aim is to design formula of drilling properties that show acceptable capabilities both in static and dynamic conditions [13], which have not been taken into considerations in the last studies. The information needed to design a reliable predictive tool can be provided by comprehension the effects and mechanisms of nanoparticles. Lastly, the adding of nanoparticles can show a significant development of the physical and mechanical properties of polymers because of the high surface area/volume ratio resulting from nanoparticles. Generality of the polymers studied so far do not occur naturally. However, so far according to the knowledge in our hands, no systematic study has been accomplished on applying both silica and alumina nanoparticles along with a natural biopolymer to improve the properties of WBM and lowering the impact on the environment. The aim of this work is to compare and explore the impact of Al_2O_3 and SiO_2 nanoparticles on filtration performance and rheological properties of liquids to make the drilling operation smooth, and efficient. In order to accomplish the objective of the study, the important role played by WBM in the drilling operation was explained.

2. LITERATURE REVIEW

2.1 BENEFITS OF NANOTECHNOLOGY THAT SUPPORT SUSTAINABILITY [14-15]

2.1.1 Water

Nanotechnology can improve the water goodness for water sources, such as by filtration that allows water reuse, recycling, and desalination.

2.1.2 Energy

Nanotechnology contribution to alternative energy technology, fuel cell, temperature control materials, increase efficiency of transmission lines, the manufacture of nanotubes through which gas passes through and turns in to electric current and the manufacture of vehicles because they are smaller in size and lighter in weight.

2.1.3 Materials

The fabrication of effective and efficient materials could also be obtained by using nanotechnology. For example, contribute to light-emitting organic diodes (OLEDs), improving the performance of catalytic converters by reducing the required platinum concentration ratio in the metals. One of the benefits of reduction is the increase in product life.

2.1.4 Fuel additives

It is used as fuel additives, for example it is added to diesel fuel and is used on rough roads to reduce emissions and will lead to environmental benefits and reduce fuel consumption by 5- 10 % .

2.2 DRILLING FLUIDS

2.2.1 Introduction of Drilling Fluids

The drilling fluids are an important part of the well drilling process. The drilling fluids have been developed to be suitable for drilling conditions at the present time and the development has made it more efficient and cost-effective and suitable for the excavation departments. The cost of drilling fluid is approximately 11% 0f the total well cost and the performance of drilling fluid greatly affective drilling means makes the well cost under control , maintaining the stability of the well drilling , reducing damage to formation and preserving environmental requirements [16].

Drilling fluids are classified into[17-18]:

- Pneumatic mud
- Oil Based mud (OBM)
- Water Based mud (WBM)

2.2.1.1 Pneumatic mud

Pneumatic fluids come into foam, mist, dry gas, and gasified mud. These fluids have been employed for drilling or formation for the exhausted zones, to encounter the abnormal low pressure. The increment of penetration rates is where the advantages of pneumatic fluid over liquid mud system can be noticed.

Formation and flowing of fluid from permeable zones to the wellbore takes place as a result of the high differential pressure. However, in zones with large volumes of formation fluids are happen, the Pneumatic fluids become ineffective. To maintain a high flow of formation fluids, it is required that the pneumatic fluid to be converted to liquid-based fluid. This may lead to increasing the losing circulation or causing damages to a productive zone. The well depth is another factor to be taken into the consideration when choosing pneumatic fluids as they are not applicable for less than 3000 meter depth due to volume of air to lifting cuttings from the bottom of the wellbore can be higher than the surface apparatus can transport.

2.2.1.2 Oil based mud (OBM)

Using of OBM in drilling fluid turbulent oil shale and enhancing the stability of the hole and it is also used in deflection fossil due to the high temperature of lubrication and the ability to moisturize the slurry. This type of clay is chosen in wells with high temperature and high pressure, reduce formation failure and resistance to pollutants.

The cost is a main reason for choosing clay and its type in excavation work. The use of this type of clay is very expensive because of the inability reuse of the clay again and there is a fear of using this clay in some countries due to environmental problems.

2.2.1.3 Water based mud

WBM is one of commend used for a number of reasons such as low cost, easy to prepare and a variety to overcome the problems of drilling, WBM is divided in to three sections:

- Inhibitive
- Non-inhibitive
- Polymer

2.2.2 Drilling Fluids Essential Functions

Drilling fluids functions could be classified into [19-20]:

2.2.2.1 Main purposes

Drilling fluids are formulated to achieve three key purposes:

- Control borehole pressure
- Moving out cuttings
- Stabilize the borehole

Control borehole pressure

The drilling fluids affect the well pressure and is controlled by hydrostatic pressure. Hydrostatic pressure is the pressure generated by the flowing drilling fluid and depends on the density of the clay and the depth of the well.

Transport cuttings

The fluid flowing from the mouth of the drilling tool penetrates to clean the drilling bit and clean the bottom of the borehole from cutting and lifting it to the surface because its stay on the drilling tool impedes effective penetration into uncut rock.

Support and Stabilize

The hydrostatic pressure of wellbore fluid works as confining force on the borehole and as this force substitute across filter cake, it supports the physical stabilization of the formation. Monitoring the loss of filtrate to permeable formations and controlling carefully the chemical structure of the drilling fluids are the ways for maintaining and improving Borehole stability. Small pore space openings could be found in permeable formations, the small volume of these openings not allowing the passage of the entire mud into formation, however, pore spaces receive filtrate from the drilling fluids. The value of the filter cake precipitated on the formation face and the pressure differential between the formation and the column of drilling fluid comprise the factors deciding the rate of filtration at which the filtrate enters the formation.

2.2.2.2 Minor purposes

Minor purposes of a drilling fluids consist:

Reinforce weight of tubular

Drilling mud floating force (buoyancy) reinforces portion of the weight of the drilling or casing string. The buoyancy influence is utilized to associate to the weight of the mud removed to the density of the substance in the tubes; thereafter, each increment in mud density rises in an increment in buoyancy.

Cooling and lubricating bit and drill string

Drill bit and the area between drilling string and wellbore are subjected to considerable amount of heat and friction during drilling operation. And during a rotation and drag during trip, high torque is created because of the touch between the drilling string and borehole. During the circulation of drilling mud is driven away from the frictional points, lowering the possibility of pipe damage and preterm bit failure. The other function of drilling mud it to lubricating the bit teeth and works as a lubricant fluid between the drilling string and wellbore which reduced drag and torque.

Transmit hydraulic horsepower to bit

Lowering volume and pressure drop throughout bit nozzles are factors responsible of generating horsepower to bit. Conversion of energy to mechanical energy removes cuttings from the downward and improves the penetration rate.

Provide medium for wire line logging

Drilling fluids are known for having differing physical characteristics and this how they affect selection of log. Selection of specific fluids can contribute on improving log pressure, thus eliminating the log use could be made possible by the use of given fluid. The estimation of drilling fluid is a significant factor for achieving the compatibility with the logging program.

Besides essential functions of drilling fluids, there are some other functions such as:

- Reduce Formation Impairment
- Decrease Corrosion
- Mitigate Lost Circulation
- Decrease Stuck Pipe
- Decrease Pressure Losses
- Enhance Penetration Rates
- Decrease Environmental Effect
- Develop Safety

2.3 NANOTECHNOLOGY AND THEIR USSING IN OIL AND GAS INDUSTRY

Many fields in the petroleum industry highly benefit from the growth of nanotechnology, these fields contain; processing and refinery, exploration, production, reservoir management, corrosion inhibition, logging operations methane release from gas hydrates, stimulation, cementing, and drilling [21, 22].

2.3.1 Exploration and Characterization of Reservoir

Hydrocarbon exploration is an essential and significant process in the petroleum industry, as the discovery of the hydrocarbon underneath the ground surface is the main objective of this process. Numerous of techniques are utilized to collecting sufficient information about hydrocarbons, one of which is seismic survey. Yet, the information been collected by this technique are not deemed sufficient concerning reservoir characterization. Nanotechnology is utilized to obtain accumulations and characterization of hydrocarbons through the application of many studies. Nano-sensors can be applied to collect data about the reservoir properties benefiting from its ability to migrate through the micropores of geological formations.

2.3.2 Drilling and Completion

Getting access to reservoir rocks is made possible by making use of drilling operation. To achieve an enhanced productivity, selecting efficient and proper elaboration of this process is of high importance. In general, filter cake generation, rheological, thermal stability and filtration properties are enhanced by adding different types of additive to drilling fluid. The effect of nanoparticles has been investigated in many studies and the results reveled that the drilling fluids having nanoparticles exhibit an ability to enhance rheological properties and high reduction in formation damage by creating thinner, impermeable and effective filter mud cake by sealing formation pores.

2.3.3 Cementing

Wellbore failure and well instability due to unsuccessful cementing operation are considered as a major problem in the petroleum industry. Many cementing problems like casing centralization, bad cement-formation or cement-casing bond, formation damage because of cementing slurry, and cement slurry filter loss. Therefore, to ensure the success of cementing operation, the selection of cementing materials plays an effective role to obtain success in petroleum production. Recently, implementation of nanoparticles in cementing operations has obtained good attention. Several studies have illustrated the effect of Nano-sized materials as additives on cement and concrete such as improvement of durability, compressive strength, permeability resistance properties, and fracture toughness.

2.3.4 Stimulation and Production

Production from unconventional resources could be one of the greatest odds in petroleum production, such as extra-heavy oil and bitumen hydrocarbons. Nowadays, the evolution of nanotechnology has provided one of the powerful and efficient ways to collect petrol from unconventional resources. Nanocatalysts have been used widely in this domain. These nanoparticles are used in aquathermolysis method for the enhancement of heavy and additional heavy oil production. Aquathermolysis process is one of the most important processes which reduce the viscosity of huge heavy hydrocarbon chains and transform it into small chains as consequence of the degradation of large molecules like asphaltenes and resins. Moreover, nanomaterials have gained better attention in enhancing the oil recovery (EOR) domain. Nanoparticles have shown a better offer to improve and change rocks wettability due to their enormous small size (<100nm) which allows particles to flow through the perforated medium.

2.3.5 Refinery and Processing

The development in the fields of petrochemical industries and refineries is connected directly with the development of nanotechnology. The crystals that contains nanoparticles have been used widely in processing and refinery. The functions of nanocrystals are enhancing the efficiency of hydrocarbon conversion, providing better refining efficiency for extra-heavy oil and eliminating catalyst-poisoning issues. And for producing a fuel with environment- friend characteristics, nanocrystal have been used for its capability to obtain a cleaner fuel as a result of the lower sulfur and aromatic content. Nanocatalysts have been used in number of processes such as crude oil hydroprocessing for many reasons like high oxygen storage/release capacity, and good asphaltenes adsorption/oxidation

2.3.6 Corrosion Inhibition

Corrosion process conducive to the demolition of metallic structures for substance. This challenge is widely observed in the petroleum industry. Nanotechnology can be used to inhibit corrosion process. Formulation of Nano-magnetic fluid in a transporter fluid and that showed active in the reduction of corrosion of carbon steel in acidic medium.

2.3.7 Logging Operations

The logging process is gathering the information about lithology and formation rock properties through drilling operation or at other operations throughout the life of well. There is an innovative idea called Nano-logging, this idea represented by the utilization of Nano-robots for logging implementations. The inspiration emerged from using Nano-machines in the medical domain. However, the mobility of Nano-robots through the human bloodstream to prevent and destroy viruses and bacteria therefore the modification on this concept could be applicable in the petroleum industry.

2.3.8 Methane Discharge from Gas Hydrates

Natural gas hydrate is trapped within the crystalline frozen water. Gas hydrate is known as a source of a considerable amount of methane. An innovative approach uses the self-healing features of nickel ferrite ($NiFe_2O_4$) nanoparticles for the liberalization of methane from gas hydrate. These nanoparticles are known as environmentally friendly and non-toxic. The magnetic field performs the activation for nanoparticles and causes an increase in temperature of the hydrate formation. Therefore, the decomposition of water cage due to the temperature which leads to release the methane from gas hydrates formation.

2.4 DRILLING FLUID PROPERTIES

It is significant to measure drilling fluids properties to properly design and maintain the mud to perform a specific function and control its ability to accomplish its role. Consequently, various types of measurements are taking place on drilling fluids properties. Many researches invented different tests and correlated them with the function of drilling fluid [20-29].

2.4.1 Fluids Types

Solutions can be categorized into two types: Newtonian and non-Newtonian fluids. Newtonian liquids have constant viscosity at different share rates. Shear stress and the shear rate have a straight-line relationship in the Newtonian fluids, the share rate varies the viscosity of the fluid continues steady. In contrast, as the share rate change the viscosity of non-Newtonian fluids is changed. For non-Newtonian fluids, the connection between the shear stress and the shear rate is not constant. Drilling fluids and non-Newtonian fluid have a similarity in behavior as both of them does not present constant viscosity at various shear rates and this the reason that shear rate and shear stress have no direct proportionality. Non-Newtonian fluids are called dilatants when the apparent viscosity rises due to the growth in the shear rate. And Non-Newtonian are called pseudoplastic (shear thinning) as it becomes smaller. However, Non-Newtonian fluids are called thixotropic when apparent viscosity becomes smaller with time, while when if it rises with time then those liquids are rheopectic. Cement and drilling fluids commonly display pseudoplastic and thixotropic performance with reverence to shear rate and time correspondingly [30].

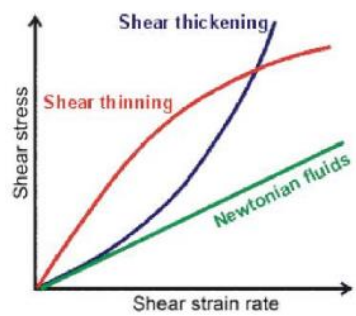

Figure 2.1: Fluids behavior

2.4.2 Drilling Fluid Rheology

Rheology is the science of the distortion and flow of material. Therefore, rheological properties of drilling fluid are the properties which characterize the flow features of drilling fluids under different conditions. By knowing the drilling fluid current behavior at different conditions in the circulation system, we can predict the consequence of this flow [31, 32].

2.4.2.1 Plastic iscosity (Cp centipoise)

The measure of friction between the fluids layers that maintain a method for calculating the thickness of the fluid is defined as plastic viscosity. Volume of objects in mud and the viscosity of the liquid phase can be obtained by plastic viscosity. Plastic viscosity should be kept as low as possible given that high plastic viscosity is not suitable for drilling fluids. Keeping the drilling fluids free of drilling solids is essential for maintaining low plastic viscosity.

The figure explains the behavior of plastic in water-based mud at different weight of mud. The lower curve shows muds with merely barite and specific quantity of bentonite used for assisting barite. The data provided by this curve are to gain good performance of mud by obtaining lower plastic viscosity. However, the upper curve shows the average for different field-tested muds. The test temperature for the curves is 120°F. The plastic viscosity decreases with increasing of temperature due to the thinning of water.

2.4.2.2 Yield point (yield stress Ib/100ft^2)

The attraction force between particles stem from the existence of negative and positive charge close or on the surface of these particles is called yield stress. Hole cleaning capability and the pressure control characteristic of a mud affect yield stress directly. High concentrations of colloidal solids and flocculation of clay solids are factors behind high yield points. Keeping yield points at high level is crucial for obtaining high circulating pressure drop in the annulus and high carrying capacity of drilling fluid.

2.4.2.3 Effective viscosity (Cp centipoise)

Actual viscosity is the viscosity of liquid under specific conditions such as pressure, temperature, and shear rate. Effective viscosity is also denoted to as apparent viscosity.

2.4.2.4 Gel strength

Initiation the stationary fluids flow requires measuring shear stress which is defined as Gel strength. Electrically charged particles that will be attached together to form solid structure can produce gel strength. The formed structure of gelation is a purpose of time, temperature, type and number of solids in suspension. Fann V G meter at low speed (3RPM) is used to measure Gel strength by reading the deflection peak. However, this denotes the magnitude of the shear stress needed to break gel structure and is taken in in Ibf/100ft^2. To measuring gel strength, the time should be set for 10 sec. and 10 min. (0 gel and 10 gel). and the result will be recorded after. The roughly selection of the times provides a comparison of gel building properties of muds. Besides, the difference in measurements is used to record the gelation rate. For getting barite suspended, weighted drilling fluid must have a gel strength of about 2-4 Ibf/100ft^2. However, the rice in gel strength is a sign of the beginning of flocculation

2.4.2.5 Filtration (fluid loss)

The process into which the fluids are allowed to pass through a permeable formation is called filtration in the case when the pressure of formation subjected to mud is higher the pressure of formation. The differential pressure is responsible of separating the drilling fluids liquid phase from the solid phase. However, filtrate passes through the rock and deposit the solids on the borehole walls Filtrate is liquid phase that penetrate the formation and its composition is made up of salts, soluble ion like calcium and soluble chemicals. Whereas mud cake is a term used to describe the solid phase that precipitate on the borehole walls. The ways by which filtration is controlled are providing permeable and strong mud cake on the wall of wellbore to prevent the formation of fluids that could penetrate into wellbore. The change in pressure between the wellbore and the formation drives the drilling fluids to break into permeable medium. The quantity of invasion is determined by number of points like formation porosity, formation permeability, solids content, the way of distribution of particle size in the drilling fluids. Moreover, viscosity of the fluid phase is the other factor influencing the filtration rate. Filtration falls into two types: Dynamic filtration and static filtration. The circulation of the fluid results in Dynamic filtration, whereas static filtration takes place when the fluid at break. Dynamic filtration could be distinguished from static filtration through mud flow, as it inclines to erode the mud cake deposited by filtration procedure. Fluid loss volume is calculated by this equation:

$$F30\ min = 2 * F7.5min \tag{2.1}$$

Where:

F30 min = Fluid loss collected volume for 30 minutes.

F7.5 min = Fluid loss collected volume for 7.5 minutes.

There are some impacts of the filtration of drilling mud on a drilling operation such as formation damage, differential sticking, torque, and drag while tripping operations. It's essential to control fluid loss properties even avoid these problems.

2.4.2.6 Density

Density is deemed as one of the greatest substantial properties of drilling fluid due its responsibility for controlling pressure. However, all the calculation of pressure control is dependent on the weight of mud column in the hole. The buoyancy effect will surge if the density of the cuttings that carrying capacity increases but this will lead to decrease the settling rate in the mud pit. Barite a commercial grade of barium sulfate acts as a weighting agent that is used for increasing the density of mud. Barite is a mineral in the form of soluble salts or evaporates has several characteristics that makes it favorite choice to use as a weighting agent, these characteristics include; its inertness, low cost, low abrasive tendencies, and high specific gravity. To maintain a formation pressure in a range that could prevent many problems. However, the densities of drilling fluid must be more than the required value. Yet, the higher the densities the higher differential pressure sticking, drilling fluid costs, possibility of lost circulation, and then rise total well price and high densities is responsible for lower penetration and settling rate in the mud pit.

2.4.3 Rheological Models

The models shown in the Fig (0.2) are used to explain how the viscosity of drilling fluids behaves. It includes an equation with the constants extracted by experiments into which different types of rheometer were used. By using shear rate values on x-axis and shear stress on the y-axis, flow curves will appear to be compared with flow curves of various rheological models so that the best model can be designated to define the fluid flow [33, 34].

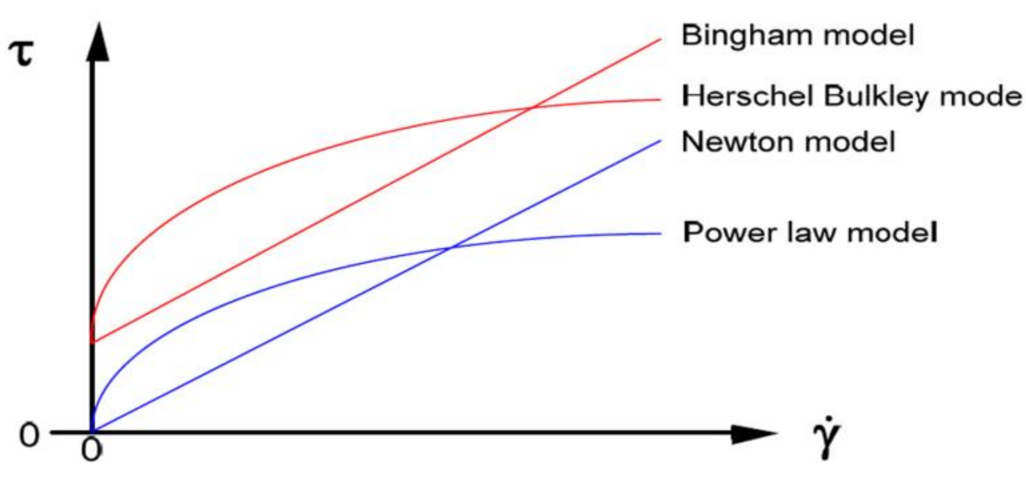

Figure 2.2: rheological models.

2.4.4 Newtonian Model

This model shows straight relationship between shear stress and shear rate. However, it denotes that the fluid move starts as soon as the shear stress is used to the fluid. Mathematically, the Newtonian model is declared as:

$$\tau = \mu\gamma \tag{2.2}$$

as

μ= viscosity of the fluid

τ= shear stress

γ= shear rate

2.4.5 Bingham Plastic Model

This model is used to define the performance of non-Newtonian fluids taking yield stress or yield point (YP) that definite as the minimum shear stress requests to be accomplished before the fluid start to flow. Then, the liquid will follow the performance of Newtonian fluid. Bingham plastic model is the standard viscosity model used throughout the industry. This model works well for the liquids having discrete solid. However, the Bingham plastic model has gained extensive acceptance in the drilling industry. Bingham model is specified by,

$$\tau = Yp + PV * \gamma \tag{2.3}$$

Where:

τ= represent the measured shear stress, lb/100 ft^2

Yp= represent the yield point, lb/100 ft^2

PV= represent the plastic viscosity, cP

γ= represent the shear rate, sec^{-1}

The values of PV, Yp, and AP (apparent viscosity) are computed by applying two different RPM readings (Φ600 and Φ300) on viscometer.

PV= Φ600- Φ300

Yp= Φ300- PV   AP= Φ600/2

2.4.6 Power Low Model

This model works better for polymer-based drilling fluids which don't show yield stress and to remove the imperfections of the Bingham model at a low shear rate. The connection between shear stress and shear rate is non-linear for power low model. The equation of this model is given by,

$$\tau = K * \gamma n \tag{2.4}$$

This equation can be linearized as

$$\log \tau = \log K + n \log \gamma \tag{2.5}$$

The value of the flow behavior index represents the nature of fluid such as (n=1) Newtonian fluid, (n<1) pseudo-plastic, and dilatant (n>1). The value of K and n is calculated by the RPM reading on viscometer.

$$n = \frac{\log(\frac{\tau 2}{\tau 1})}{\log(\frac{\gamma 2}{\gamma 1})} \tag{2.6}$$

$$K = \frac{\tau_2}{\gamma_2^n} \tag{2.7}$$

where

τ= calculated shear stress, lb/100 ft^2

τ_2= shear stress at a higher shear rate

τ_1= shear stress at a lower shear rate

γ= shear rate in sec^{-1}

γ_2= higher shear rate

γ_1= lower shear rate

K= consistency index (Ib/100ft^2.Sn)

n=Flow behavior index (dimensionless)

2.4.7 Herschel-Bulkley Model

This model is combined with the Bingham model and power law model. However, it could be named as a modified power law. This model describes the drilling muds rheological behavior very accurately more than other models because almost all drilling fluids show shear stress.

The equation of Herschel-Bulkley is given by,

$$\tau = \tau^o + K * \gamma n \tag{2.8}$$

$$\tau - \tau^o = K * \gamma n \tag{2.9}$$

This equation can be linearized as

$$\log(\tau - \tau^o) = \log K + n \log \gamma \tag{2.10}$$

Where

τ= calculated shear stress, lb/100 ft^2

γ= shear rate in sec^{-1}

$\tau°$ = shear stress at zero shear rate

K= consistency index

n=Flow behavior index

2.5 A BRIEF SUMMARY OF PREVIOUS STUDIES

In drilling operations, the role of the drilling mud is important fluid. Any problem in drilling mud can significantly influence the functioning of the processes. Accordingly, it is essential to comprehend the performance of drilling mud in the borehole. Researchers are continuously looking at the use of nanoparticles in drilling fluid due to their specific properties. This section focuses on other studies that handled with the effect of nanoparticles on drilling fluid.

2.5.1 Al-saba et al. (2018)[35]

Discuss addition of many types of nanoparticles to see their effect (magnesium oxide, copper oxide, and aluminum oxide) on bentonite water-based mud rheological properties at HPHT and LPLT conditions. The results showed that plastic viscosity was reduced and both yield point and gel strength were increased. Whereas, the filtration was decreased up to 30% at LPLT and it was negatively affected at HPHT.

2.5.2 Amanullah and Al-Tahini (2009)[36]

Discussed comprehensively the advantages that will be gained from using nanoparticles based additives in oil well designing which is used in petroleum operations notably, the ways of drilling, completion, fracturing, stimulation. Nano drilling fluids minimize several problems that are appearing in drilling, completion, and production operations.

2.5.3 Mahmoud et al. (2017)[37]

Examined an advanced calcium bentonite-based mud containing nanoparticles (ferric oxide and nano-silica) to reduce formation damage during drilling in harsh circumstances. The results exhibited a decrease in filtration volume by 43% at adding 0.5 wt. % of ferric oxide. Whereas, nano-silica demonstrated a rise in fluid loss volume and mud cake thickness. It also showed at higher nanoparticle amount a third layer of nanoparticles was developed that negatively influenced the mud cake characteristics. Furthermore, at elevated temperatures, nano drilling muds had stable rheological properties.

2.5.4 Wong et al. (2010)[38]

Presented the implementations of Nanotechnology in heat transfer, electronic, Biomedical, and in industry. In the biomedical field, the colloids are considered as nanofluids used for a long time, and their uses will spread in the upcoming days. Nanofluid has been verified to practice as smart fluid. Using of Nanofluids have to be well characterized as taking in concern particle size, shape, size distribution, and clustering so the final results will be more applicable. As soon as the engineering of Nano-fluids is fully comprehended. Colloids will have an increase using in biomedical engineering and biosciences.

2.5.5 Parizad et al. (2018)[39]

Investigated in his study the effect of nano-silica and KCl on the filtration and thixotropic performance of polymeric water-based mud. Mostly, the addition of Nano silica enhanced drilling fluid performance. However, using Nano silica with higher concentrations was not so effective. The KCl has an influence on the performance of nano-silica in drilling fluid. At elevated temperatures, nano-silica and KCl have many properties. The high amount of KCl has an influence on the effectiveness of Nano silica infiltration enhancement.

2.5.6 Kong et al. (2010)[40]

Demonstrated the challenges that the petroleum industry is facing and nanotechnology can offer several solutions to solve these challenges. During exploration, Nanosensors can diffuse in the formation pore space which will provide more data and information about the reservoir characteristics, monitoring of fluid flow, and recognition of fluid type. While during drilling, Nanoparticles of silica or nano Fe_2O_3 had been responsible for increasing in flexural and compressive strength of Belite and Portland cement.

2.5.7 Ismail et al. (2016)[41]

Examined the influence of nanoparticles and glass beads on lubricity, filtration volume, and other rheological properties of water-based mud. The study included the effect of using many concentrations of nanoparticles and various sizes of glass beads on the rheological performance. Nanoparticles and glass beads provided a reduction in the friction coefficient. Multi-walled carbon nanotubes reduced the filtration volume better than Nano silica.

2.5.8 Kapusta et al. (2011)[42]

Presented certain applications of nanotechnology to exploration and production sectors. Lab testing showed that small concentrations (< 1%w/w) of nanoparticles can rise the viscosity of water-based mud without significantly affecting their weight, and could offer potential improvement in the efficiency of oil recovery.

2.5.9 Cai et al. (2012)[43]

showed the effect of commercial and modified silica nanoparticles on the permeability of Atoka shale formations. The formulated mud is water-based mud with low solids content. Nanoparticles addition is 10 wt. %, a large reduction in the permeability of Atoka shale after adding nanoparticles. The concentration of 10 wt. % and particle sizes varying 7-15 nm gave an effective reduction in shale permeability.

2.5.10 Mahmoud et al. (2017)[44]

Demonstrated the improvement of ferric oxide nanoparticles on characterization of mud cake as well as the fluid loss for calcium bentonite drilling mud. The conditions of the experiment are HPHT (P=500 psi, T= 350 ˚F) and Indiana limestone core disks were used as a filter medium. The results showed that ferric oxide enhances the filtration and the mud cake characterization of mud in the presence of polymer and certain additives. Using the concentration 0.3- 0.5 wt. % of ferric oxide is obtained good cake quality with the best characteristics.

2.5.11 Carpenter (2016)[45]

Focused on rheological properties of water-based mud at low pressure/ low temperature and high pressure/high-temperature situations with nano ferric oxide and nano-silica. The experiment results provide that nanoparticles addition improve mud cake characterization, filtration, and rheological properties.

2.5.12 Salih and Bilgesu (2017)[46]

Investigated anionic nanoparticles to develop water-based mud at low-pressure low-temperature conditions and high pH 11.5-12. Three different types of nanoparticles (Nano silica, nano aluminum, and nano titanium) at four various concentrations are tested. The rheological and hydraulic properties are improved by using 0.1 wt. % of nano-silica and 0.3 wt. % of nano titanium and nano aluminum. No more improvement is obtained for higher concentrations. Nano silica and nano titanium have the ability to decrease filtration volume and no filtration decrease constructed on nano aluminum.

2.5.13 Alshubbar et al. (2017)[47]

Illustrated the usefulness of nano-barite on the friction amount and rheology of water-based mud. The generation methods of barite nanoparticles are chemical and mechanical. The results provide friction reduction between particles due to nanoparticles can create a smooth film that coats the surfaces. The rheology of water drilling mud increases by provide extra specific particles for a certain amount.

2.5.14 Baghbanzadeh et al. (2012)[48]

Investigated a hybrid consist of silica-nanosphere and multiwall carbon nanotube. A hybrid can be defined as a matter where physical and chemical characteristics are a combination of various materials. Thus, it was noticed that the thermal conductivity of Nano muds starts increasing as the concentration of nanoparticles increasing. Moreover, the hybrid with the higher ratio of multiwall carbon nanotube exhibited further growth in the thermal conductivity effectiveness of the nanofluids, related to the supplementary hybrid.

2.5.15 Ogolo et al. (2012)[49]

Investigated enhanced oil recovery (EOR) by using nano-silica, aluminum oxide, zinc oxide, and magnesium oxide. The experiment results obtained that Nano silica and aluminum oxide are good agents to EOR. Aluminum oxide nanoparticle reduces oil viscosity and Nano silica changes the wettability of rock due to decrease of interfacial tension between oil and water.

3. EXPERIMENTAL WORK

3.1 SAMPLE PREPARATION

The drilling fluid samples were prepared by mixing 0.5-liter freshwater, 25 g bentonite clay, and 1g xanthan gum. The mixture was stirred at ~900 rpm for 15 min by constant speed mixer, then after 24 hours, xanthan gum was added in order to have a 0.2 wt % mixture. Thereafter, the mixture was retained for 24 hours for hydration. Then, two types of Nano-drilling muds were prepared by adding nanoparticles (SiO_2 and Al_2O_3) by (1, 2, or 3 g in 0.5 L) to blank mud at laboratory temperature (25˚C) and atmospheric pressure. Each type of Nano-drilling mud was blended for 30 minutes for each concentration. The Sample water-based, xanthan gum, and SiO_2 or Al_2O_3 were formulated as shown in Table 3.1 and Figure 3.1

Table 3.1: The Sample water-based, xanthan gum and SiO_2 or Al_2O_3.

Sample Name	Nanoparticle	Concentration (wt%)
A1	Al_2O_3	0.2
A2	Al_2O_3	0.4
A3	Al_2O_3	0.6
S1	SiO_2	0.2
S2	SiO_2	0.4
S3	SiO_2	0.6

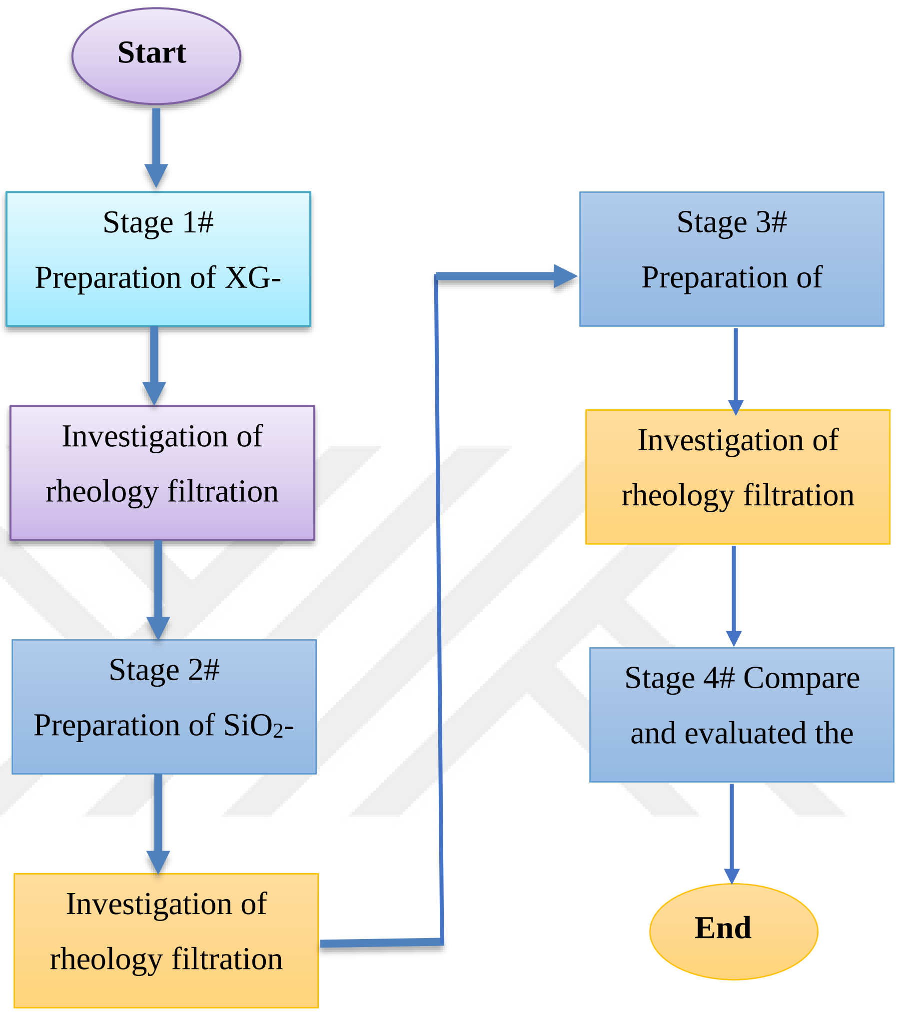

Figure 3.1: Experimental flow chart.

3.2 APPARATUS

3.2.1 Viscometer

This Viscometer, shown in Figure 3.2 is intended to estimate the rheological properties of WBM by estimating shear stress at defining shear rates. This device has been utilized in research lab, and field. The determination fluid is received within the annular space or shear gap between the rotor and bob. The rotor is rotated at remembered velocities (shear rates) and the viscous drag exerted by the test fluid forms a torque on the bob (shear stress). This torque is assigned to a precision torsion spring, and its deflection is estimated and associated with shear stress. This apparatus has 12 defined speeds 1, 2, 3, 6, 10, 20, 30, 60, 100, 200, 300, and 600 RPM.

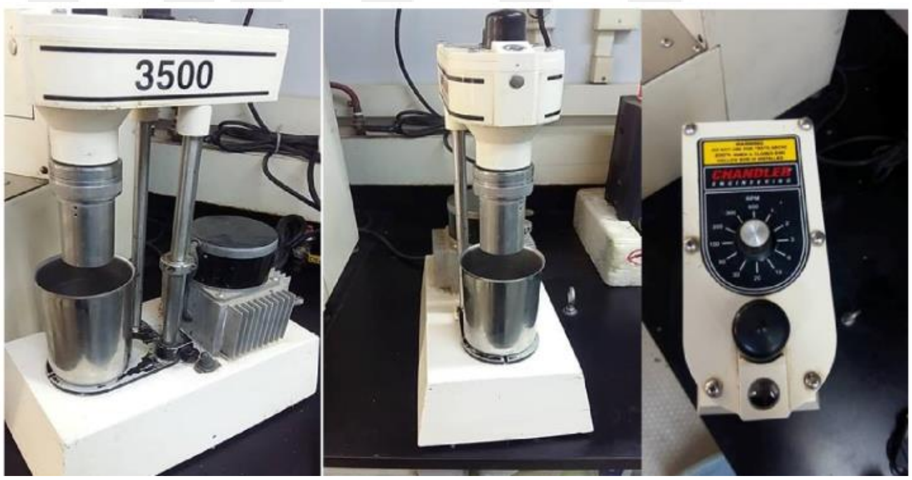

Figure 3.2: Viscometer model 3500

3.2.2 Fann High Pressure High Temperature Filter Press

This instrument is used to measure the cement slurries, fracturing fluids and filtration properties of drilling fluids. Filter press consists of stainless-steel cell, an aluminum heating jacket, filter medium, graduated cylinder to collect filtrate and pressurization equipment. This filter press imitates filtration against a permeable formation at high pressure high temperature condition. The cell of HPHT filter press is connected with positive pressure indicator that indicates the absence or presence of the pressure in the cell.

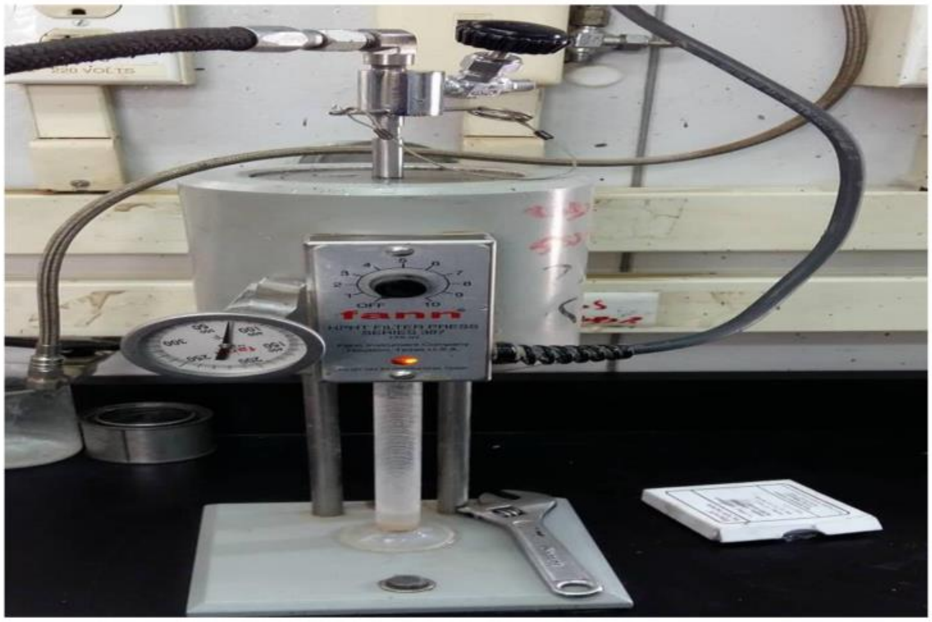

Figure 3.3: HPHT filter press

3.2.3 Constant Speed Mixer

This apparatus is provided for mixing cement slurries and drilling fluids according to the API specifications. The mixer has a digital tachometer, motor speed control electronics, and a timer. Mixing speeds are defined 4000 and 12000 RPM for use with one liter of stainless-steel container. The mixing speeds could be adjusted using a variable potentiometer from 1000 to 18000 RPM.

Figure 3.4: Constant speed mixer

3.2.4 Pressurized Fluid Density Balance

The mud weight balance involves a graduated scaled beam. This beam has a slipping density (rider) that passes along the graduated scale on the beam and a bubble level that shows when it is stabilized. The indention on the beam rests securely on the knife-edge of the support. The plunger works similar to a syringe. It is utilized to pressurize the specimen cup for precisely measuring mud weight.

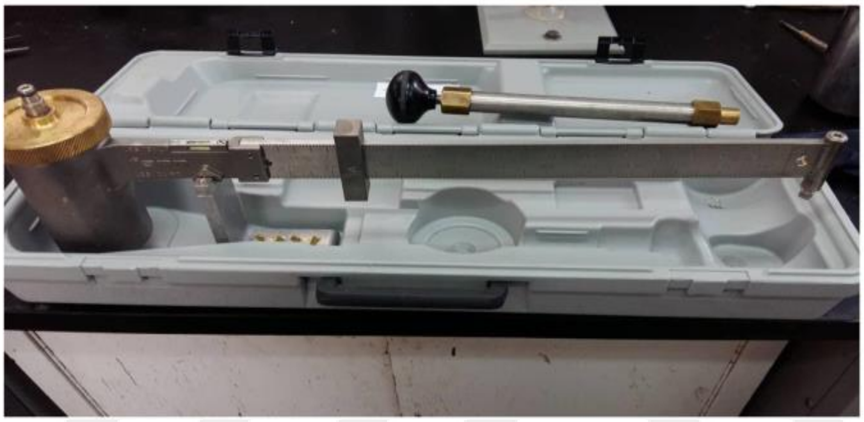

Figure 3.5: Pressurized mud balance

3.2.5 Electronic Precision Balance

This balance is a high-resolution balance. It is specially manufactured for the precise purpose of material mass in the fluid paste, powder, or solid formula. It covers a weighting range from 0.01 milligram to 6200 grams.

Figure 3.6: Electronic balance

3.2.6 pH meter

In this study, we used pH meter to calculate pH value of drilling fluid. It is consisting a conductor whose sensor occupied by the drilling mud through measurement.

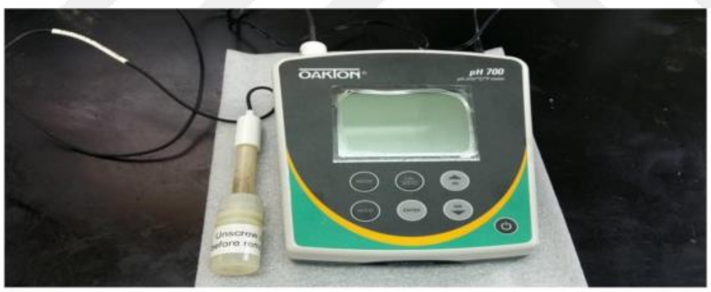

Figure 3.7: pH meter

3.3 EXPERIMENTAL MATERIALS

3.3.1 Distilled Water

Distilled water is used in the lab to prepare the water-based mud because it is free of pollutants such as magnesium and calcium which can affect the mud properties. Water is the continuous phase of water-based mud which is linked with the viscosity.

3.3.2 Bentonite

Bentonite is one of the most widely used materials in WBM. The main component of this material is the montmorillonite, the component of this material is expressed by following formulation: (Na, Ca)(Al, Mg)$_6$(Si$_4$O10)$_3$(OH)$_6$nH$_2$O. Bentonite must be milled down into small particles to use it in drilling fluid. The size of bentonite particles should be below 1 mm. For the high-density muds, bentonite is required to suspend the particles of weighting materials. Commercially bentonite is sold as a powder in different colors and tints such as off white, pale brown, or grey depending on the cations that exist during the natural deposit. Bentonite is insoluble in water, alcohol, dilute acids, and alkalis. The main function of bentonite is increasing viscosity and filter agent. Therefore, there are 2 types of bentonite; Sodium bentonite and Calcium bentonite [50].

3.3.3 Xanthan Gum

A heteropolysaccharide is resulting from the evaporation of sugars by the Xanthomonas campestris bacterium with below good features:

1-Dissolve easily in both hot and cold water.

2-Compatible with a variety of products.

3-Highly efficient thickener.

4-Good pseudoplastic (shear thinning).

Controls viscosity across a large-scale of temperatures and pH variations.

3.3.4 Measurements

Rheological properties of drilling mud were measured as follows:

1- Preparing drilling mud as described in the preparation section.
2- Setting the drilling mud sample into the viscometer cell (350ml).
3- Measuring shear stress at different shear rates at laboratory temperature for FWB muds.

4- Shear stress readings are taken at 20, 30, 60, 100, 200, 300, and 600 RPM. At each reading, viscometer stays 15 sec for stabilization.

5- Measuring initial and final gel strength, as follow:

* Drilling mud sample was submitted at 600 RPM for one minute.

* The rotor was stopped for 10 seconds.

* Rotor speed control was adjusted at 3 RPM.

* Rotor was operated and the maximum torque value was recorded to measure the initial gel.

* Rotor was ceased for 10 minutes at 3 RPM.

* Rotor was started and the maximum torque value was recorded to measure the final gel.

Rheological properties were measured with the Model-350 Viscometer. Apparent, plastic and effective viscosities, yield point, and gel strength parameters were measured. Fan high pressure high temperature filter press was utilized to measure the filtration properties at 150 psi and 30c^o.

The result was crumpled from the measurements because the filtration area of API standard being 7.1 in^2 [51]. The following equations are used [52]:

$$\mu_a = \frac{\phi_{600}}{2} \tag{3.1}$$

$$\mu_p = \phi_{600} - \phi_{300} \tag{3.2}$$

$$\mu_e = \frac{300\phi}{w} \tag{3.3}$$

$$Y_p = \phi_{300} - \mu_p \tag{3.4}$$

$$Shear\ Stress\ (\tau) = 1.065\phi \tag{3.5}$$

$$Shear\ Rate\ (\gamma) = 1.7023 * w \tag{3.6}$$

As ϕ is dial reading (lb/100 ft^2) and w is speed of the rotor (rpm).

3.3.5 Results and Discussion

The first step taken was holding a comparison and discussion for rheological properties of conventional drilling mud with nano-drilling mud. Shear stress, shear rate and results of PV, AV, YP, and gel strength as nanoparticle concentrations change at LPLT conditions (low-pressure low temperatures) were also listed in tables. The filtrations loss possessions of the sample at 150 psi and 27 ^oC were discussed as well as the pH effect.

Rheology tests were accomplished at low temperatures to determine the potential utilization of the drilling mud at low-temperature circumstances. Shear stress shear rate at 30 ^oC is listed in Tables 3.2 and 3.3, for Al_2O_3 and SiO_2 doped drilling fluids, respectively. Results indicate that the viscosity of mud somewhat rises with 1 g nano-SiO_2 addition and significantly rise with 2 g and 3 g of SiO_2 additions. On the other hand, Al_2O_3 with drilling fluid showed a growth in their shear stress values as meditation increase. All shear rate is at 30 ^oC, as shown in Table 3.2.

The rheological properties for WBM analysis by calculated PV, AV, YP, Gel strength values for 10 min 10 s for the samples are as shown in Tables 2 and 3. Overall, for SiO_2 and Al_2O_3 nanoparticles, the other properties (PV, YP, and AV) increase with different concentrations [53].

The 10s gel strength for WBM was 15 pa, and it's decreased with 1 g, 2 g, 3 g of Al_2O_3 nanoparticles to 14 pa, 14pa, and 12 pa, respectively. Furthermore, it is increased with 1 g, 2 g, and 3 g of SiO_2 nanoparticles to 16 pa, 17pa, and 19pa. The 10 min gel strength for WBM was 30 pa, and it is increasing with different concentrations of Al_2O_3 and SiO_2.

Table 3.2: Plastic viscosity, apparent viscosity, yield point and YP/PV ratio values of the samples

Sample Name	Apparent Viscosity (cp)	Plastic Viscosity (cp)	Yield Point (lbf/100ft2)	YP/PV Ratio
FW	30.5 ± 0.3	15 ± 0.1	31	2.07
A1	33.0 ± 0.3	17 ± 0.2	32	1.88
A2	34.0 ± 0.3	16 ± 0.2	36	2.25
A3	33.0 ± 0.3	16 ± 0.2	34	2.13
S1	31.0 ± 0.3	17 ± 0.2	32	1.88
S2	35.0 ± 0.4	17 ± 0.2	36	2.12
S3	38.0 ± 0.4	18 ± 0.2	40	2.22

Table 3.3: Gel strength values of the samples

Sample Name	Gel Strength for 10 min	Gel Strength for 10 sec
FW	30	15
A1	41	14
A2	32	14
A3	33	12
S1	37	16
S2	39	17
S3	33	19

In this study, Fan HPHT filter press was used and the experiment of filtration loss on Al_2O_3 and SiO_2 nanoparticles doped drilling fluid carried out at laboratory temperature (25˚C) and pressure of 120 Psi and under static condition. Filtration is the process of allowing the fluids to pass through a permeable formation, whenever the formation exposed to mud at HP and HT. The differential pressure causes to separate the drilling fluids liquid phase from the solid phase.

The obtained results also showed that as the concentrations for nanoparticles are decreased, the thickness is increased since at higher concentrations more particles will be present in the fluids and thus thicker filter cake. Stable suspended materials (bentonite particles) form dense and compact sediments, whereas flocculated suspended materials form more voluminous sediments and particles linked in the form of open networks or poor fabrics. Moreover, the water able to pass easily through the soft mud cake then increases the filtration loss [54, 55]. Also, this is because of small size of nanoparticles that reduces porosity of filter cake [56].

Table 3.4: Filtration properties of the samples

Sample Name	Filtration Volume (ML)	Mud Cake Thickness (mm)
FW	9.6	1
A1	9.2	1.5
A2	9.0	1.5
A3	9.1	1.5
S1	8.8	1.25
S2	8.6	1.25
S3	8.4	1.25

As for the pH, it can be observed that both Al_2O_3 and SiO_2 had no significant influence on the pH as revealed in Table 3.5, all formulations had pH values around 9.0.

Table 3.5: pH values of the samples

Sample Name	pH
FW	9.3 ± 0.1
A1	9.2 ± 0.1
A2	9.1 ± 0.1
A3	9.0 ± 0.1
S1	9.1 ± 0.1
S2	9.0 ± 0.1
S3	8.9 ± 0.1

4. CONCLUSION AND RECOMMENDATIONS

4.1 CONCLUSIONS

Nanotechnology has potential applications in many sections, including the health domain, transportation, oil and gas industry, food, and products. Nanotechnology demonstrates the ability to enhance the environment via direct and indirect applications. This study includes the examination of the properties of two types of water-based drilling muds with various concentrations of NPs. In this study, we formulate and evaluate the specimens of WBM that included xanthan gum with Al_2O_3 or SiO_2 nanoparticles for the comparison and assessment of the drilling water fluid properties, also to investigate the impact of nanoparticles on the rheological properties of nanoparticles. Based on the experimental results, the following conclusions were made: The adding of NPs to drilling fluids influences the viscosity. The shear stress of FWB increases by adding both kinds of NPs. The viscosity of mud increases with Nanosized SiO_2 addition. Overall, for both nanoparticles, the other properties (PV, YP, and AV) increase with different concentrations. The 10 s gel strength decreased with different concentrations, while the 10 min gel strength increased with different concentrations. Filtrate loss volume was reduced for both nanoparticles and the thickness of filtrate cake is increased as expected. Incorporation of nanoparticles into such drilling fluid formulations may result in positive results. Further studies can extend this work and compare more nanoparticles on the effects on drilling fluid. Interestingly, the addition of NPs does not change the density as the concentration is kept at a lower level.

4.2 RECOMMENDATIONS

Different characters of nanofluid can be examined. Hence, some instructions are inscribed that can be applied to figure out other advantages of nanofluid over traditional muds.

1-Investigating the effect of adding NPs to other kinds of drilling fluids such as oil-based fluid, salt-saturated fluid, and polymers fluid.

2- Using core disks as a filter medium instead of filter paper.

3- Rheological tests should be administered at high pressure, consequently, the results become extra realistic.

4- Tests should be conducted to examine thermal conductivity and specific heat of nanofluid.

5-Stability of nanoparticles must be considered with the assistant of certain chemicals additives.

6- Investigating the effect of NPs dispersion within the drilling mud on filtration.

7-Using other NPs with drilling mud such as graphene nanoplatelets, aluminum oxide nanoparticles, and ferric oxide nanoparticles.

8- Choosing other sizes of NPs.

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