Evaluation the performance of conventional water-based mud characteristics by applying Zinc Oxide and Silica Dioxide Nanoparticles materials for a selected well in The Kurdistan/ Iraq

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Evaluation the performance of conventional water-based mud characteristics by applying Zinc Oxide and Silica Dioxide Nanoparticles materials for a selected well in The Kurdistan/ Iraq

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Abstract

Nanomaterials have gained a wide interest in the oil and gas industry due to its immense applicability. Nanomaterial is being used for formulating a new generation of drilling mud which is known as Nano- mud. Where it has the ability to improve mud properties and eliminate bore hole problems. Using nanoparticles as an additive agent in conventional drilling mud can lead to a more efficient drilling process in troublesome formations. In this experimental study, several conventional water-based muds from a selected well drilled in the Kurdistan / Iraq oil field have been prepared. Then nano-drilling muds were formulated by dispersing SiO2 and ZnO nanoparticles in concentrations ranging from (0.25 to 1 wt.%) to conventional water-based mud (WBM).

The objective of this experimental study is evaluating and comparing the performance of conventional water-based muds after adding SiO2 and ZnO nanoparticles. This comparison was performed by carrying out a series of laboratory experiments to determine the rheological and mud filtrate properties. The results demonstrated that adding SiO2 and ZnO NPs to conventional water-based mud improved the rheological behavior and provided better filtration control compared to conventional drilling muds. However, there was little or no impact of nanomaterials on the mud density for all mud systems.

Keywords Nanoparticles. Nano-Muds. WBM. Rheological characteristics. Filtration loss

Introduction

Drilling fluid, or drilling mud, is an integral component of the drilling process. Generally, this mud is pumped from the surface to bottom of the well and it passes through drilling string (Drill pipe, Drill collar) and the bit. Then it returns back to the surface through the annular space between the drilling string and the borehole[1]. Primarily, drilling fluids are used for cooling down and lubricating the drilling bit and the drilling string, suspend the rock cutting when the circulation paused, carrying the rock cutting from borehole to the surface, maintaining the hydrostatic head pressure (Ph) greater than the pore pressure (Pf) to avoid any kind of unwanted formation fluids to flow to the well [2], [3]

Generally, drilling mud design is on the most essential aspects to consider during the well construction and completion stages. The proper selection of the drilling mud is one of the key factors for succussing any drilling operation, which is typically based on its performance, cost, and environmental influence. On the other hand, improper drilling mud design may cause several drilling problems such as pipe sticking, mud loss, kick, bit balling ,and bore hole collapse[3].

Water-based drilling muds (WBMs) and oil-based drilling muds (OBMs) are two main types of drilling muds which are widely used during drilling operations. For instance, in Kurdistan / Iraq fields, the WBMs are the most applied muds during drilling operations because it is cheap, eco-friendly, and easy to prepare in comparison with oil-based mud. However, drilling through a troublesome shale formation the WBM is not a good candidate and it should be changed to OBM since it has a better shale inhibition and more tolerability to high temperature and high-pressure formation. Nevertheless, the application of oil-based mud is restricted by its cost and environmental constraints and regulations[4],[5].

Recently, nanotechnology has gained a wide range of interest in the oil and gas industry due to its immense applicability and it is being used for formulating drilling muds which is known as nano-mud or smart mud. The combination of nanotechnology and drilling mud technology will take a major role to combat environmental and technical challenges. The nano sized particles ranging from (1 to 100 nm.) can significantly increase the resistance of drilling fluids to (Pollution, HPHT conditions) and control the fluid loss. Furthermore, adding NPs to drilling muds can improve cutting transportation efficiency and thermal conductivity[6], [7].

Several experimental studies were performed on the application of nano-sized particles as an additive agent in drilling fluid formulations. According to William, Jay Karen Maria, et al. (2014),adding small quantities of zinc oxide and copper oxide nano particles to the drilling mud enhanced the viscosity, thermal conductivity of the drilling mud[8]. In addition, a research performed by Mahmoud, Omar, et al (2017)showed that ferric oxide nanoparticles improved filtration and filter cake properties and make the mud cake less porous[9]. In 2016, Needaa, AL-Malki et al. found that the sepiolite nano sized particles would reduce the filtration volume and minimize the mud cake thickness under HPHT conditions [10].

A study by Geir Hareland, M. H. A. C., (2014) investigated the effect of various concentrations of Iron hydroxide ($Fe(OH)_3$) and calcium carbonate ($CaCO_3$) nano-sized particles on the rheological properties of oil-based mud (OBM). In their experimental study, they found that calcium carbonate NPs provided higher gel strength and plastic viscosity (PV) compared to the OBM sample without nano-particles. They also concluded that iron oxide reduced the yield point value, but there was no or minimum effect of iron oxide on the plastic viscosity and gel strength. In addition, both NPs reduced mud filtration loss and created a thick mud cake[11].

Jung, (2011) investigated the impact of two different sizes (3 and 30 nm) of the Fe_2O_3 nanoparticle on the rheological and filtration characteristics of bentonite-based drilling mud (BBDF) at high pressure and high temperature (HPHT) environments. The study showed that the smaller size of NPs increased the plastic viscosity (PV), Yield point (YP) more than the bigger size[12].

The objective of this experimental study is formulating and evaluating the performance of SiO_2 and ZnO water-based nano muds and comparing them with conventional water-based mud. This evaluation was carried out through a series of laboratory tests

Nano-Drilling Muds

Recently, nanoparticles are widely used in formulating WBM drilling fluids in order to improve the efficiently of the drilling mud in term of lubricity, wellbore stability, fluid loss and make the drilling mud more eco-friendly.

Drilling fluids which contain at least one or more nanosized participles in its composition are known as nano-drilling mud. The nano-drilling muds are classified into simple and advanced. The size of nano particles is ranging from 1-100nm and it has a high specific surface area to volume ratio. Due to high surface area, the NPs play a significant role in minimizing the torque and drag forces. They also work as lubricants by reducing the friction between the drill string and wellbore. NPs also help to reduce the pipe sticking and mud pump pressure [8]

In addition, the nano-sized particles have better thermal and electrical characteristics compared to macro-and micro-sized particles. The physical and chemical characteristics of these particles also differ from the bulk material. These properties allow the drilling fluids to overcome the problems associated with drilling operation. The small size of nanoparticles acts as a bridging agent; therefore, the small pores in the formation can efficiently seal and plug, which in turn prevent the loss of the fluid especially in the shale formation[12]. Figure 1. illustrates the high surface area to volume ratio for a tiny sized particle.

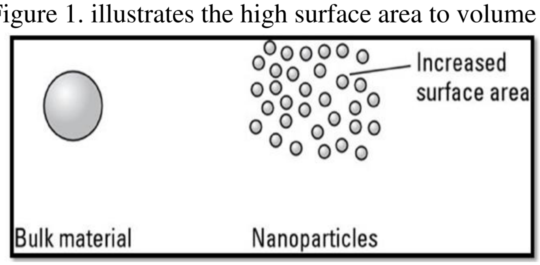

Fig.1 Surface area of NPs.

Furthermore, the nano-sized particles in the mud will enhance and stabilize the rheological properties of drilling mud, which eventually lead to improving the borehole cleaning and holding the drilling cutting. The nano-based drilling muds provide solution for a variety of borehole problems including pipe sticking, loss of drilling fluid, formation damage, low standard of mud cakes ...etc.[13]

However, a poor dispersion of NPs under bottomhole conditions with a change in base fluid PH, salinity, and temperature and can cause borehole instability and formation damage. Agglomeration is another problem as positive charged particles are exposed to acidic conditions and negative charged particles polluted with the base medium. The table below presents a summary of the main challenges that occurred during drilling operations and how the nano mud can solve it.

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Table 1 Nano-Mud Technical solutions

Challenges	Nano-mud Solutions
Shale instability	Increase shale formation stability by: 1.Minimizing the interaction between shale formation and drilling fluid by its ultra-fine particles size. 2. Increasing the shale formation resistance to collapse and fracture.
Differential pipe sticking	Minimize the differential pipe sticking by: 1.Forming very fine filter cake 2.Creating non-sticking film on the borehole tools to avoid triggering of sticking. 3.It acts as a spotting fluid agent since it has the ability to enter between the mud cake and pip interface and release the stuck
Unconsolidated formation	Strengthen unconsolidated formation by: 1. Accessing to the pores of these formation, then entering the granular contact surface of this formation.
Thermal instability	Stable under HPHT environments.
Loss of circulation	Reduce the loss of circulation by creating a structural sealing which can prevent the fluid loss along the loss path
Bit Balling	It forms a hydrophobic film which acts as barrier to bit balling
Formation damage	Reduce formation damage by: 1.Reducing the spurt losses. 2.Protecttingthe porosity/permeability properties of the near-wellbore reservoir and increases productivity.

Characterization of conventional and nano muds

The successful rate of any drilling operation depends mainly on the rheological flow characteristics of the drilling muds under different flow conditions (i.e., plastic viscosity (PV), yield point (YP), filter loss, gel strength (GS)) and density (ρ).

Density (ρ)

One of the most essential characteristics of drilling muds is density or mud weight. The drilling muds must have a sufficient density to transport the rock cutting to the surface and provide better wellbore cleaning. The density can also contribute to the borehole stability by controlling the hydrostatic pressure and protect the borehole from the influx of unwanted formation fluids[14]

During drilling operations various formations are encountered and as the depth increases, the mud weight drilling fluid should be adjusted to appropriately balance the mud system during drilling. Therefore, weighting substances should be always added to drilling muds to increase mud weight and ensure borehole stability[5]. An example of a common weighting material is Barite ($BaSO_4$) which has a specific gravity between 4.2-4.4. The density of the mud is measured by using Bariod mud balance device.

Filtration (Mud filter loss)

An essential property when designing the drilling mud is mud filtration. Since it measures the ability of the solid contents in the drilling mud to build a thin, a well dispersed and tight filter cake on the wall of the well.

However, a thick mud cake effects on the well performance in different ways [15]

1. Tighten the bore hole (Enhanced torque and drag)
2. The pressure surge increases as a result of reducing hole diameter.
3. The contact between drill pipe and filter cake increase therefore resulting in (stuck pipe)
4. Formation evaluation problems (poor log quality)

Rheological Properties

It describes the performance or behavior of drilling fluid flow under different conditions. The mud viscosity is one of the rheological characteristics that should be measured and controlled; because the rock cutting suspensions relies on the drilling mud's viscosity. Therefore, when the mud circulation is ceased, the viscosity should be high enough to prevent cutting from settling in to the borehole[16].

Plastic Viscosity (PV): Is the internal resistance of the drilling mud to flow which is generated by mechanical friction. The sources of this friction are:

- ✓ The volume concentration of solid additives
- ✓ Size and shape of solids particles
- ✓ Viscosity of liquid phase

The plastic viscosity is influenced by several factors such as (mud density, borehole size, mud pump rate, drilling rate, ... etc.). The high PV leads to higher equivalent circulation density (ECD) which in turn results in an excessive risk of lost.

Yield Point (YP): It is the initial resistance of the drilling mud to flow, which is produced by electrostatic attraction forces between the solid particles of the drilling mud under flowing (dynamic) conditions. These attractive forces result from the existence of negative and positive charges on the solid surface particles.

The Yield point (YP) is used to measure the capacity of the drilling fluid to carry the cutting out of the annulus. The higher value of the drilling fluid yield point, the greater ability of the fluid to transport the cutting out of the annulus.

- ➢ The solid surface characteristics of the mud
- ➢ The volume of the solids
- ➢ The liquid ionic environment which is surrounding the solid particles [17]

Gel Strength (Thixotropic behavior): The ability of the drilling mud to suspend the rock cutting when the drilling fluid circulation is stopped is known as gel strength. This gel structure is formed by the interaction of drilling fluid components and it mainly depends on the size, concentration, and electrostatic charge of the solid particles like (clay and nanoparticles). This property should be carefully monitored to preserve solids without causing extreme recirculation pressure through the mud pumps start up [2]

Generally, the gel strengths are measured by a rotational viscometer after the mud has set gently for two different periods of time (ten seconds and ten minutes). The high gelation of drilling mud causes mud flocculation. There are three models which is used to describe the rheological properties of drilling muds. These models are: a) Bingham Plastic Model b) Power law model c) Herschel-Buckley Model (Modified Power law). In this study, the Bingham plastic model is used for mud characteristic calculations.

Bingham Plastic Model

This model describes the flow behavior of drilling muds. The Bingham plastic model is based on the assumption that the curve between the shear stress and shear rate is a straight line. The point of interception with the shear stress is known as the yield point and it is the minimum stress required to initiate flow. Yield point should be more than zero [9]. The Bingham plastic model equation is given by:

$$\boldsymbol{t} = \boldsymbol{YP} + (\boldsymbol{PV} * \boldsymbol{\gamma}) \qquad \textbf{(1)}$$

Where:

$\tau = shear\ stress\ \left(\frac{Ib}{100\ ft2}\right), \gamma = shear\ rate\ (sec^{-1}),$

$PV = Plastic\ Viscosity\ \ , Yp = Yield\ Point\ (\frac{Ib}{100ft2})$

The shear rate can be determined using the following equation.

$$\boldsymbol{\gamma = rpm \times 1.7034} \qquad \textbf{(2)}$$

$\gamma = Shear\ rate\ (sec - 1)$ *Rpm = Revaluation per minute (600, 300, 6, 3)*

The shear stress is related to the dial reading determined by.

$$\boldsymbol{\tau = D.R \times 1.067} \qquad \textbf{(3)}$$

τ = shear stress (Ib/100ft2) D.R. = dial reading.

Methodology

Conventional WBM formulation

In this experimental study, six different types of water-based drilling fluids were formulated, Spud mud, KCL-Polymer mud, and Salt KCL-Polymer mud. These muds have been used for drilling a well in Kurdistan / Iraq oil field. The well is located in Atroosh area, Duhok province. The Well-A has faced several problems such as stuck pipe sticking and loss of drilling fluid, ...etc. Table 2 shows the types of drilling muds used during drilling.

Table 2 Well-A Drilling muds design

Hole Size (inch)	Interval (m)	Mud type
26	57-297	Spud Mud
17 ½	297-1002	KCL Polymer
12 ¼	1002-2341	KCL/Polymer
8 ½	2341-3380	Salt / KCL /Polymer
8 ½	3145-4020	Salt/KCL / Polymer
6	4020-4525	Salt/KCL/Polymer

First of all, six conventional water-based drilling muds have been formulated following the concept of maintaining the same properties and components which used during drilling Well-A. The mud prepared by using EPU, oil and Gas technology lab and the used chemical additives were supplied from a local chemical supplier company located in Erbil.

The preparation procedure is based on API RP 13B-1 standard for WBM. Where 1 gram of solid material to 350 ml of liquid in the lab scale is equal to adding 1 Ib to 1 barrel of liquid at the field scale. The properties of the used conventional drilling muds while drilling well #A are shown in Table 3 (Appendix A)

The following sequences were used to prepare conventional WBM:

1.Adding Soda ash into the water for contamination treatment. The mixture was stirred by using Hamilton Beach mixer for about 2 minutes.

2. At the end of 2 minutes, caustic soda is added to increase the PH value of the mud.

3. Bentonite was added to the solution and stirred for 5 minutes to increase the viscosity.

7. After that, the right amount of barite was added to the solution to increase the drilling fluid density and the stirring were continued until 35 minutes. The amount of barite required to prepare the desired mud weight was determined by using the following equation.

$$\boldsymbol{Barite\ required\ = 1470 * [\rho 2 - \rho 1 / \ 35 - \rho 2\ ]} \qquad \textbf{(4)}$$

Where:

$\rho 1$ initial density in ppg $\rho 2$ desired mud weight in ppg

Formulation of Nano-WBM

To formulate the nano drilling muds, four various weight concentrations (0.25%, 0.5 %. 0.75% and 1 % wt%) of zinc oxide

(ZnO) and silica dioxide (SiO2) nano materials were added and stirred with conventional mud and mixed for 20 minutes to guarantee good dispersion of nano particles inside the drilling mud. The characteristics of ZnO and SiO2 nano particles materials are shown in Table 4 and Table 5 (Appendix B). The Figures 7 and 8 in the Appendix B show the TEM and SEM images of SiO2 and ZnO respectively.

Laboratory Analysis (Experimental Measurements)

The following mud properties have been measured and calculated for both conventional (base) fluid and nano drilling muds:

1)The mud weight (Density) was measured by OFITE mud balance device.

2)The rheological properties (i.e., Plastic viscosity (PV), Yield point (YP) and Gel Strength (GS)) were determined based on API RP $13B-1\ 2003$ by using 6 speeds electrical rotational viscometer (Model RC35D) after applying the following mathematical equations

$$\boldsymbol{PV = \emptyset 600 - \emptyset 300} \qquad \textbf{(5)}$$

$\emptyset 600$ = dial reading at 600 rpm
$\emptyset 300$ = dial reading at 300 rpm

$$\boldsymbol{Yp = \emptyset 300 - PV} \qquad \textbf{(6)}$$

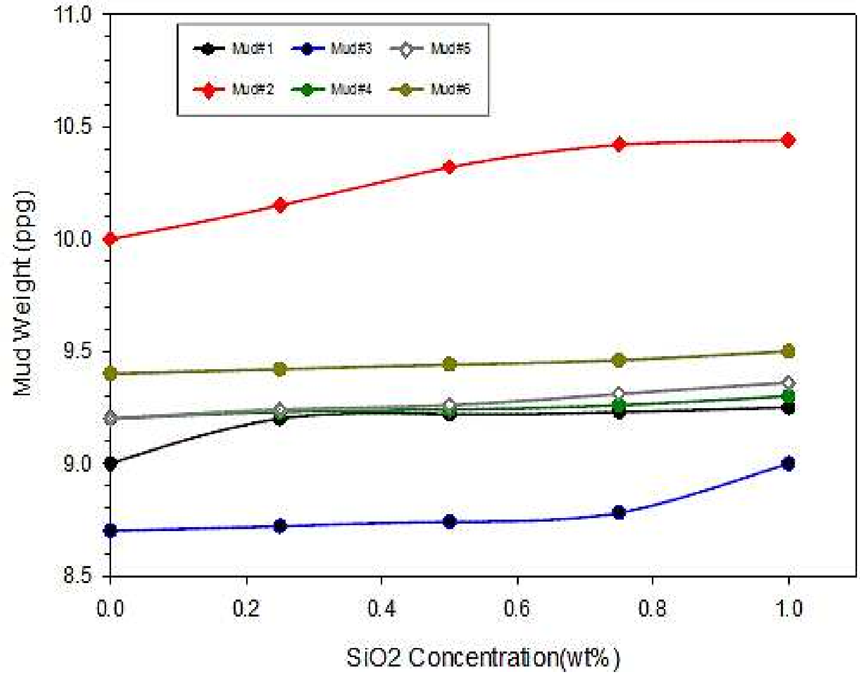
3) API fluid loss measurement: The standard API filter press device was used under 100 psi pressure. The experimental procedures are shown in the Figure 9 Appendix C The used equipment's for measuring all conventional and nano- drilling muds properties are shown in Figure 10, Appendix D

RESULTS AND DISCUSSIONS

In this experimental study, the rheological properties and API filtration of 5 different conventional drilling muds used during drilling well #A were examined with silica oxide and zinc oxide nanoparticles at different range of concentrations (0.25, 0.5,0.75 and 1 wt.%).

Mud Weight (Density)

The results shown in Figure 2 demonstrate that there is little or no impact of nanomaterials on mud weights. The addition of SiO2 and ZnO NPs does not greatly increase the mud density. This gives an advantage in selection NPs as a bridging agent and thus minimizing the rate of solid particles in the drilling muds particularly ,when drilling a high angle hole or horizontal and deviated wells.



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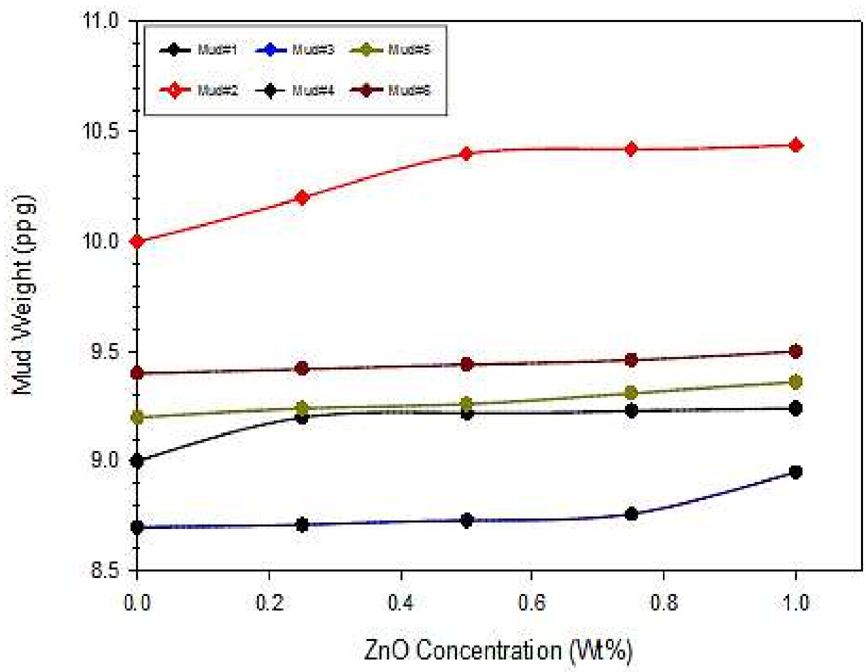


(b)

Fig. 2. Density of drilling muds (a) with and without SiO2 NPs (b) with and without ZnO NPs.

Rheological Characteristics

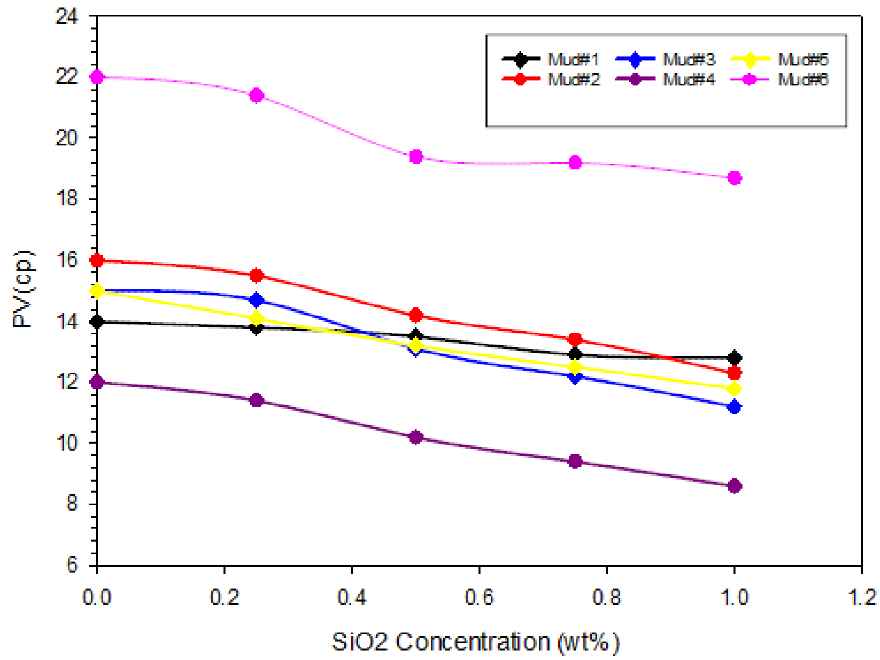
Plastic Viscosity (PV)

The results demonstrate a significant impact of SiO2 and ZnO NPs on the plastic viscosity where it decreases with increasing nano-sized particle concentrations from 0 to 1 wt.%.

Figure (3a) shows that as the concentration of SiO2 NP increased from 0 to 1 wt. %, the plastic viscosity values decreased by 8%, 23%, 25%, 28% ,21% and 15%, for mud systems 1, 2 ,3, 4, 5, and 6 respectively. A similar trend was observed for

ZnO NPs Figure (3b); however, the rate of reduction was less. These decreases in PV values are caused by the NPs distribution in the drilling mud where they minimize the internal friction forces between particles, thereby minimizing the PV values. Reducing the PV value, minimize the pressure of the mud pump which required for mud circulation, particularly when high density mud is required for drilling deep formation.

Nevertheless, it is significant to emphasize that reducing the PV values are beneficial to the drilling processes, where it promotes the penetration rate (ROP), diminishes or saves the energy required for drilling fluid circulation finally, reduces the possibility of drilling fluid circulation loss to the formation fractures which resulted from the extreme (ECD) of the drilling fluid.



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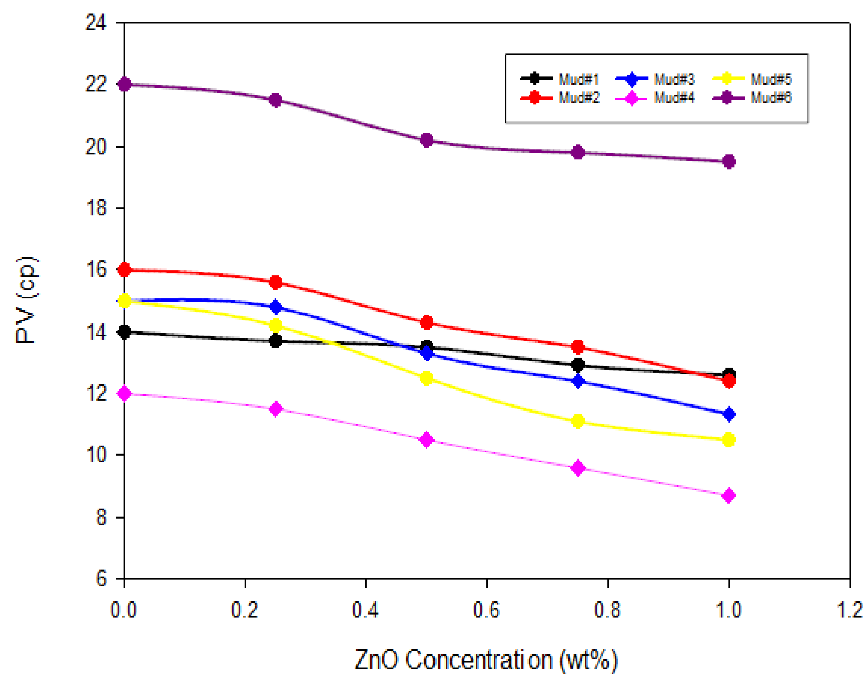


(b)

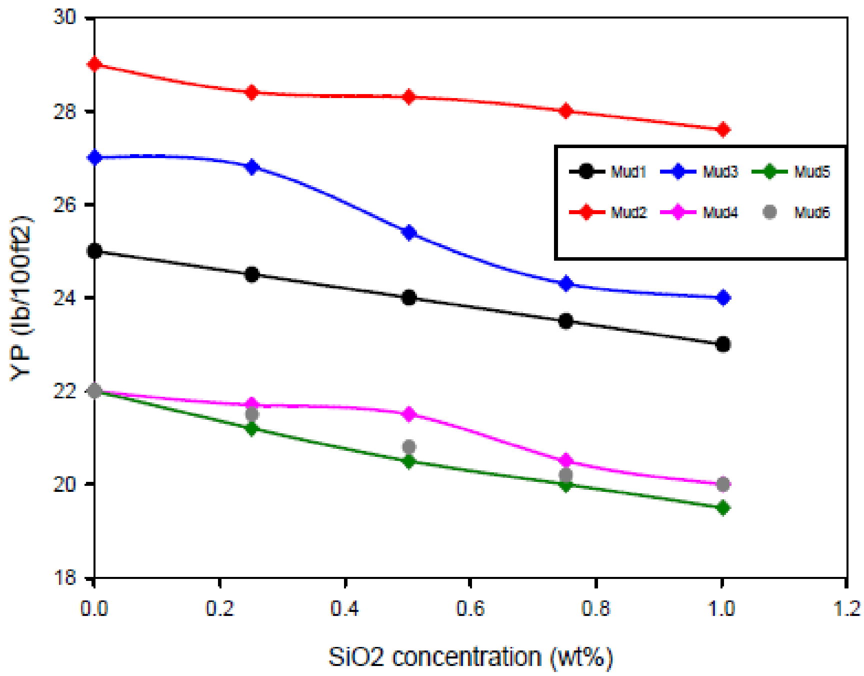
Fig. 3. Comparison of plastic viscosity values for the conventional WBM system before and after adding different concentrations of (a) SiO2 NPs and (b) ZnO NPs

Yield Point (YP)

As Figures 4 (a, b) demonstrate, the yield point (YP) values declined with increasing SiO2 and ZnO NPs concentrations. Furthermore, the results show that drilling fluids with high mud weight has higher reduction in the yield point values, compared with the other drilling fluids. Because as the mud weight increases, the resistance of the fluid to initiate flow increases.

For example, the rate of YP reduction for mud#2 with 10 ppg density is about 11% for SiO2 and 9.2 for ZnO, whereas mud#1 with 9ppg mud weight showed the lowest reduction in YP values by 4.8% and 4.5 % for SiO2 and ZnO respectively.

The reason behind this reduction is that the SiO2 and ZnO NPs increase the distance among the solid particles in the drilling muds.



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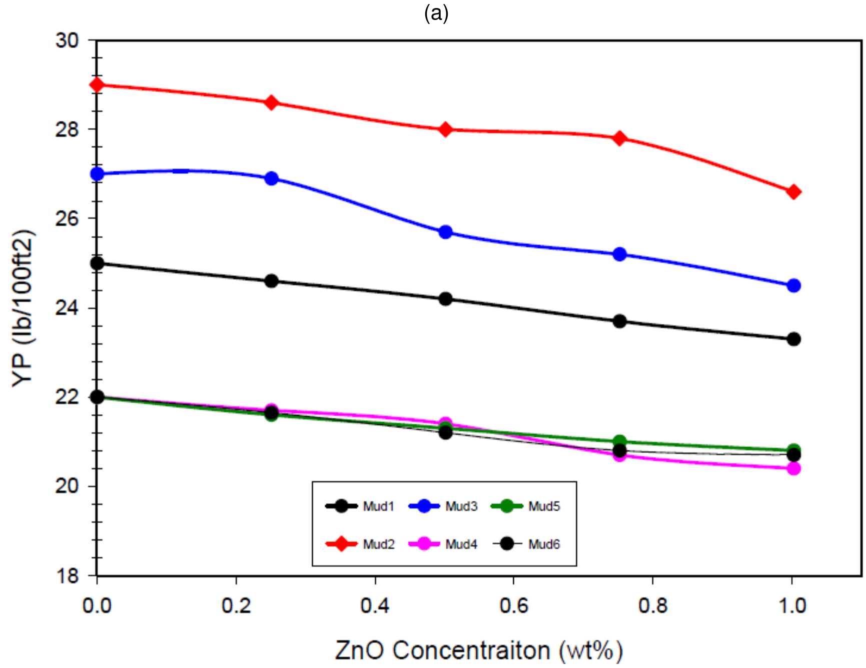


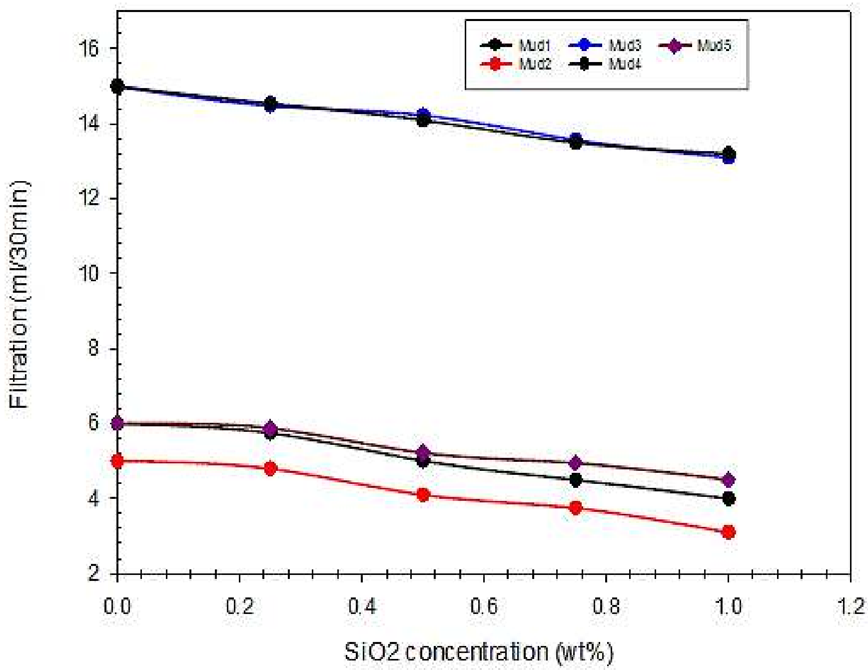
(b)

Fig. 4. Yield point values of 6 different mud systems (a) with and without silica NPs (b) with and without Zinc NPs at different concentration rate

Mud Filtration

The small size of NPs has the ability to physically plug the pore throats of the formation; therefore, they reduce the filtration volume loss to the formation. The results show that SiO2 and ZnO nanoparticles with different concentrations decrease the fluid loss over a period of 30 minutes.

It is observed from Figure 5 that the filtration volume declined slightly with time by increasing SiO2 and ZnO nano particle concentrations. Since the NPs have the ability to obstruct the pore space of formation, which prevents the drilling fluid to escape to the formation. For instance, adding 1wt.% of SiO2 NP to Mud 3 diminished the filtration volume by 12%, while adding the same amount of ZnO NP reduced the filtration loss by 10%. Furthermore, the Mud 2 showed the best fluid loss control where the mud filtration reduced by 38% for SiO2 and 32% for ZnO. Furthermore, mud filtration reduced by 30% for Mud1 and 31% for Mud 4, respectively.



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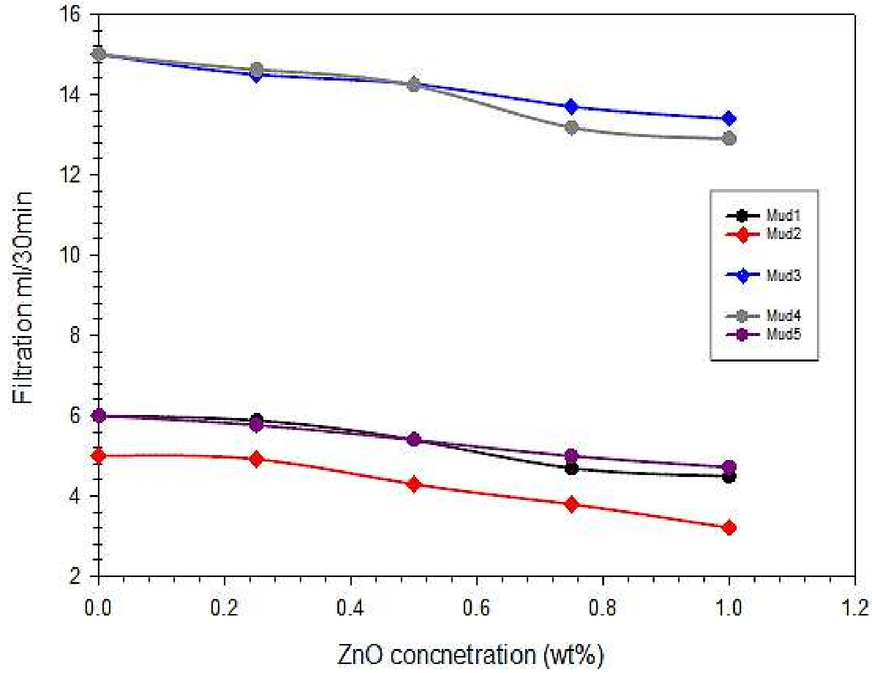


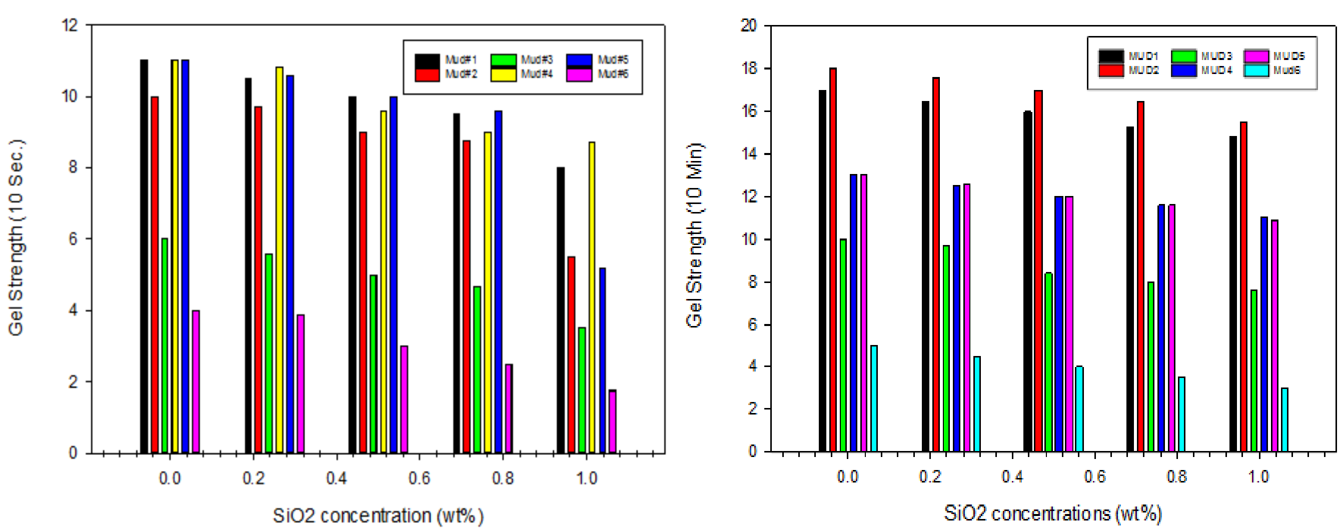
(b)

Fig. 5. Effect of different concentrations of SiO2 and ZnO NPs on mud filtration loss volume l (a) adding SiO2 NPs (a) adding ZnO NPs to the drilling muds

Gel Strength (GS) (10 sec. and 10 min)

Gel strength (SG) is the ability of drilling mud to enhance and sustain a gel structure whenever the drilling operation is paused. An appropriated fluid gel strength is usually required, as it would preserve the excessive circulation pressure to resume drilling activities. Figures 6 (a,b) demonstrate a comparison between 10 seconds and 10minutes gel strengths for each set of WBM samples before and after adding SiO2 and ZnO NPs.

It is clear that there is a gradual reduction in the gel strength as the SiO2 and ZnO concentrations increases as a result of the repulsive force happening between nano-particles and the water-based mud that causes the expansion between the nano-sized particle and the water molecule with the decrease in the mud gelation. We can say that the SiO2 and ZnO act as dispersion agents.



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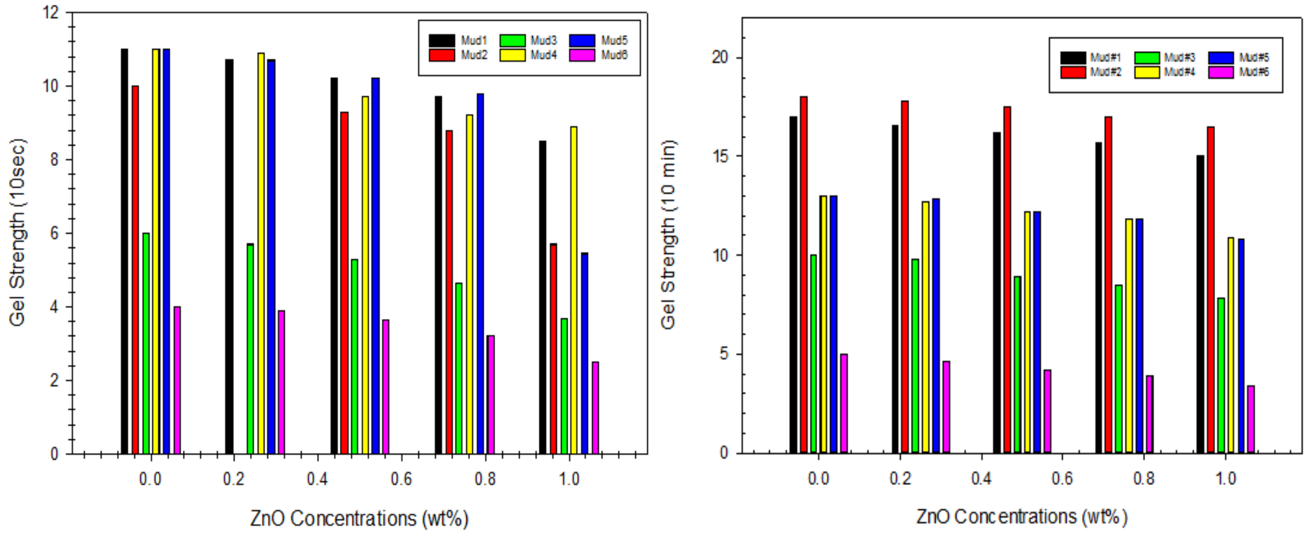

(b)

Fig. 6 Comparison of 10 min and 10 sec gel strengths of different WBM systems at different Wt % concentrations (a) adding SiO2 NPs (b) adding ZnO NPs.

Conclusions

This study presents the laboratory evaluation of adding different concentration of SiO2 and ZnO nanoparticles to six conventional water-based drilling muds. From the results obtained the following conclusions are presented:

1. Generally, NPs can be used to solve a number of issues related to drilling muds, such as improving thermal stability under HPHT environments, minimizing the thickness of mud cake, and adjusting the friction factor.
2. The water-based nano-muds can be used as an alternative to oil-based muds when drilling through the shale formation since they have the ability to penetrate the pore space of the shale and act as a bridging material and then strengthen the wellbore.
3. The results indicate that there is no or minimum effect of SiO2 and ZnO NPs on mud weight.
4. The SiO2 and ZnO nanoparticles can effectively enhance the rheological characteristics of conventional water-based muds, leading to better borehole cleaning and drilling cutting suspension. These nano -sized additives can replace the standard drilling additives and they can act as mud thinners showing a decrease in viscosity.
5. Both NPs provided a better fluid loss control agent in comparison with conventional drilling muds. Where the presence of SiO2 and ZnO NPs reduce the filtration volume through reducing the drilling fluid permeability.

Conflict of interest

The authors (Ahmed R. AlBajalan and Huner K.Haias) declare no competing financial interests

Acknowledgments

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Abbreviations

	Nano-particles
ZnO	Zinc Oxide
SiO2	Silica Di-oxide
WBM	Water based mud
OBM	Oil based mud

HPHT	High pressure high temperature
PV	Plastic Viscosity
YP	Yield point
ρ	Density
Mw	Mud weight
GS	Gel strength
API	American Petroleum Institute
ROP	Rate of penetration

Figures

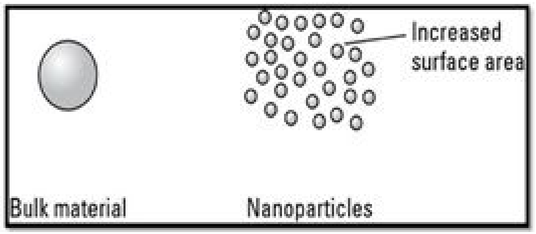
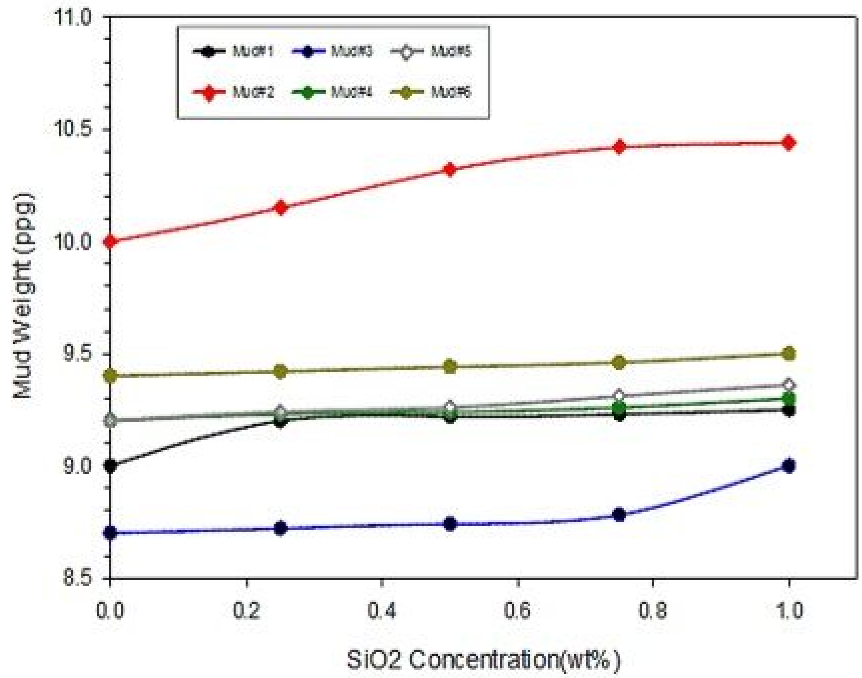


Figure 1

Surface area of NPs.



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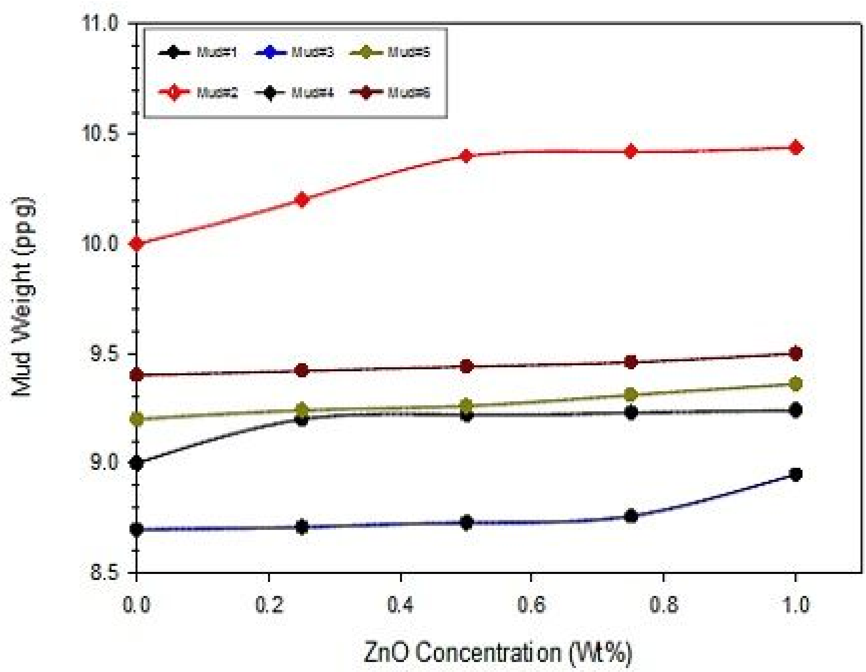
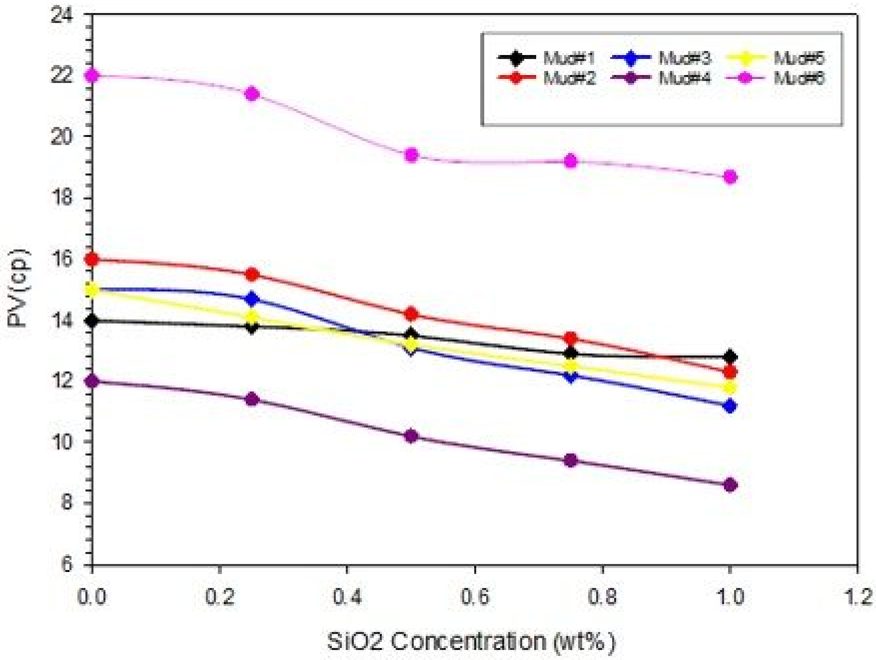


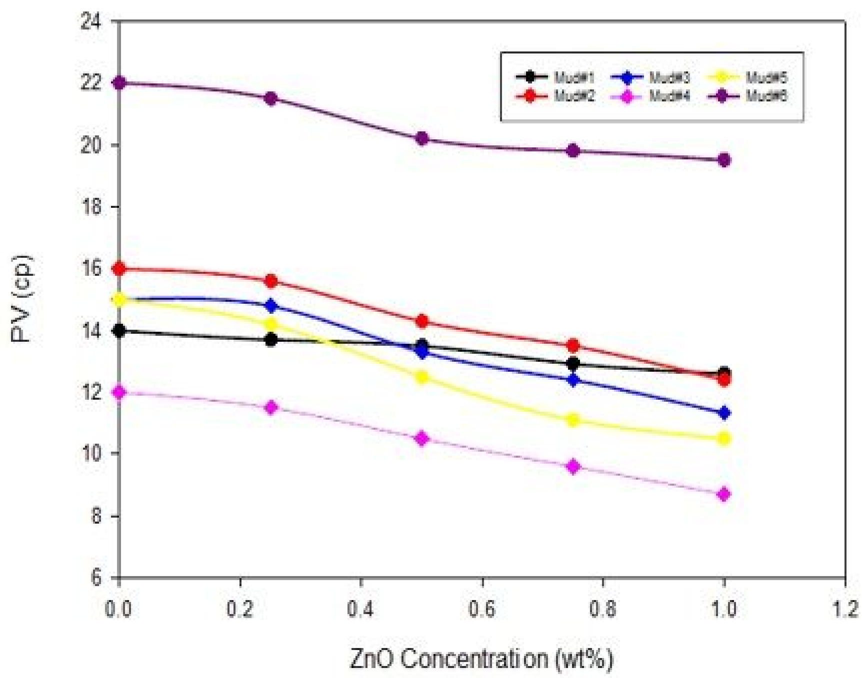
(b)

Figure 2

Density of drilling muds (a) with and without SiO2 NPs (b) with and without ZnO NPs.



(a)



(b)

Figure 3

Comparison of plastic viscosity values for the conventional WBM system before and after adding different concentrations of (a) SiO2 NPs and (b) ZnO NPs

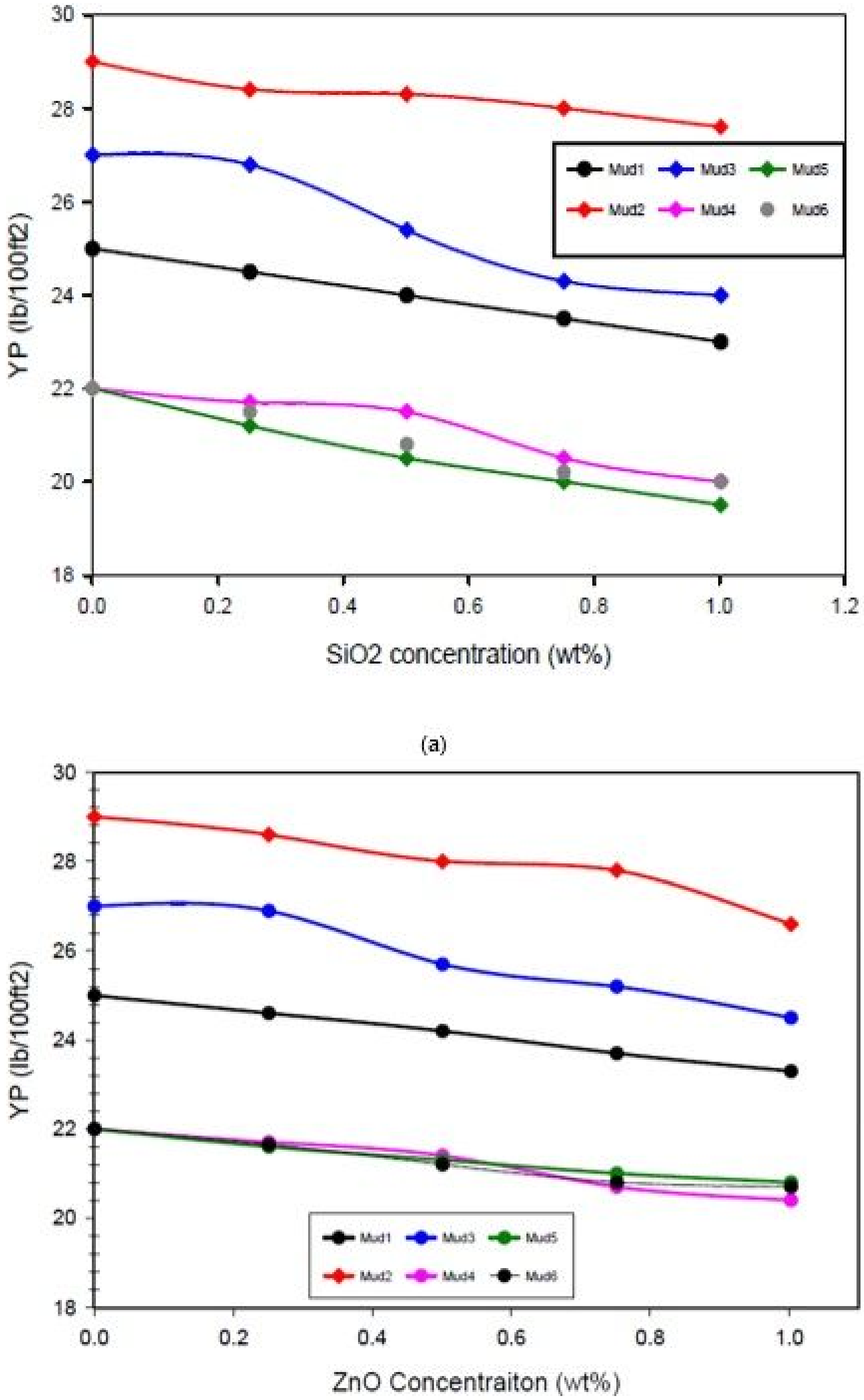
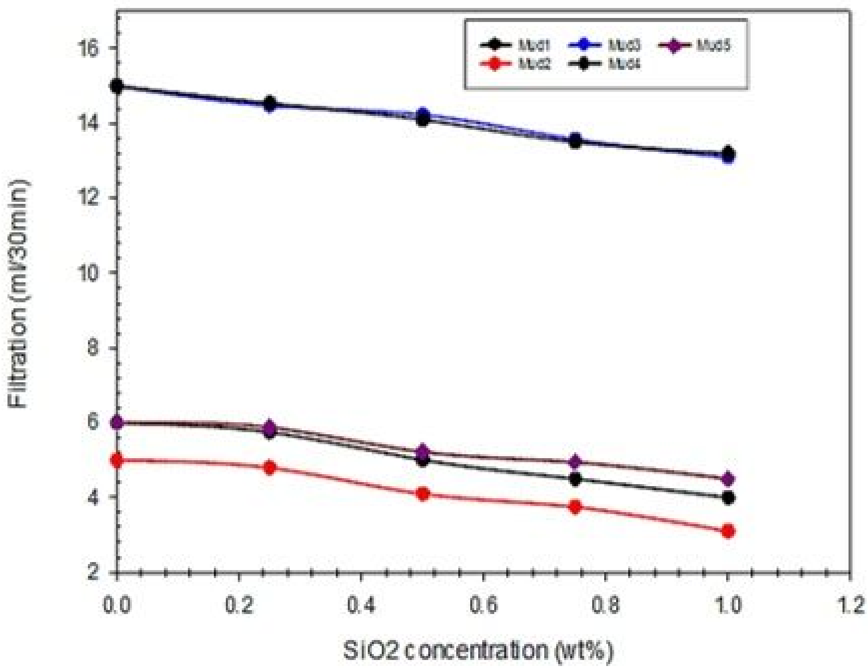
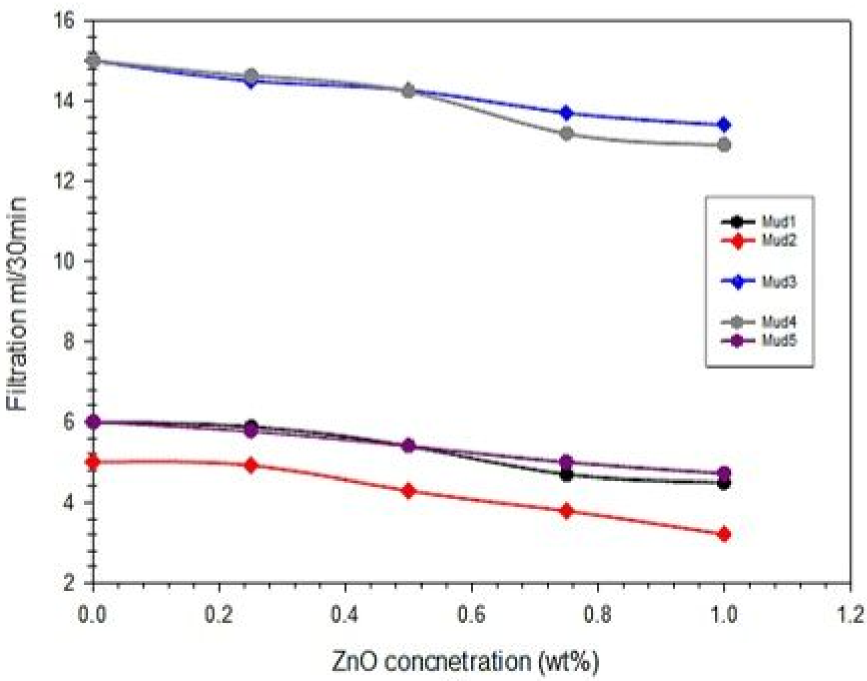


Figure 4

Yield point values of 6 different mud systems (a) with and without silica NPs (b) with and without Zinc NPs at different concentration rate



(a)



(b)

Figure 5

Effect of different concentrations of SiO2 and ZnO NPs on mud filtration loss volume l (a) adding SiO2 NPs (a) adding ZnO NPs to the drilling muds

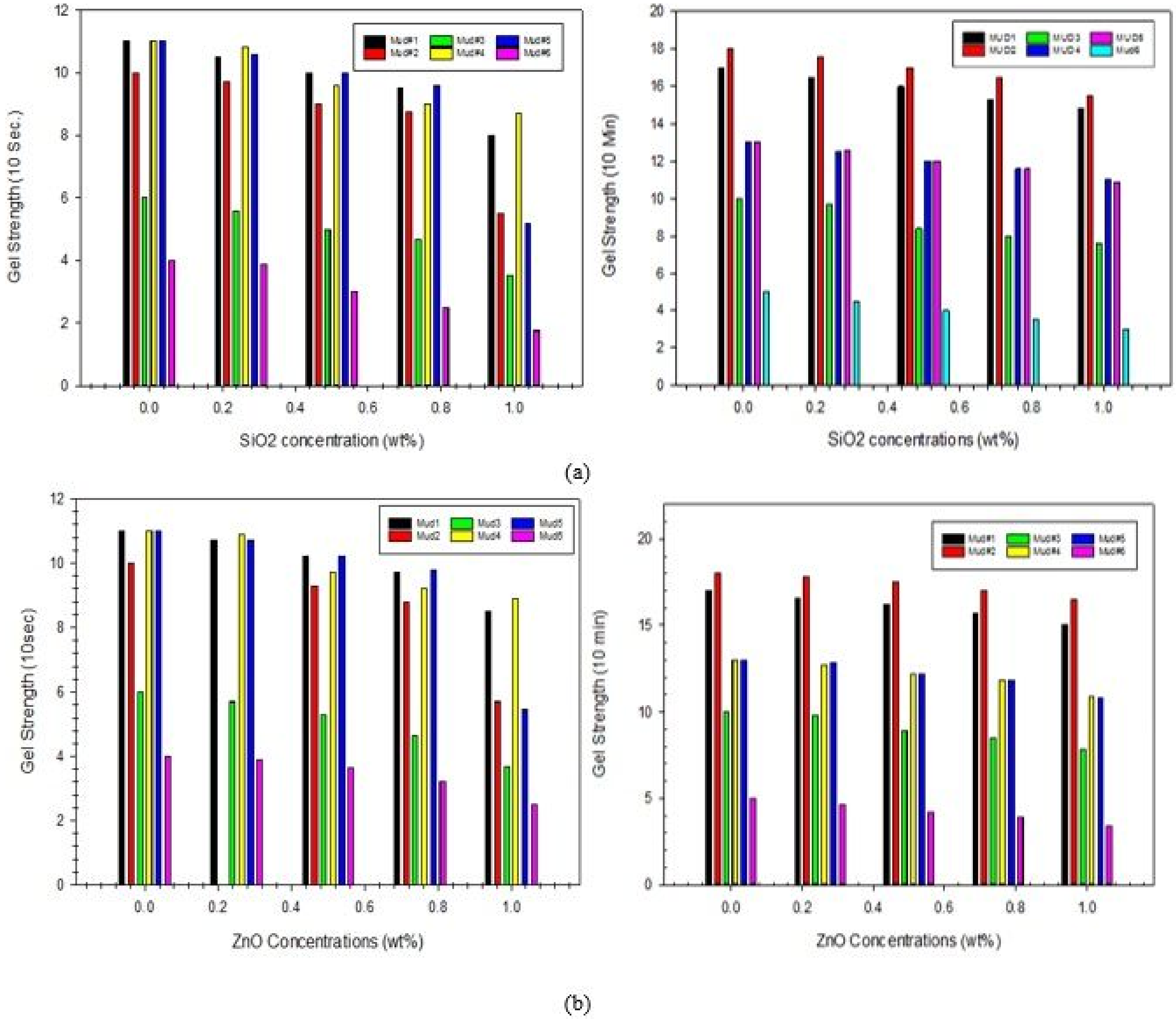


Figure 6

Comparison of 10 min and 10 sec gel strengths of different WBM systems at different Wt % concentrations (a) adding SiO2 NPs (b) adding ZnO NPs.