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Review Article
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Nanotechnology: An Emerging Drilling Fluid Solution

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Abstract

Exploration of oil and gas involves drilling a continuous hole from the surface to a predetermined depth in the sub-surface which can be of several kilometres. One of the key factors to achieve a trouble free drilling task is the characteristic and design parameters of a drilling fluid. A drill bit is used as a primary tool, which has a long string of drill pipes attached to it. When a substantial amount of weight is applied, the bit tends to drill the area and releases little sections (cuttings). In order to carry out faster and effective drilling and to carry these cuttings to the surface a drilling fluid is used which flows from surface through the drill pipes to the drill bit and back to the surface and disposes off the cuttings. During a drilling operation there are mainly three components which operate simultaneously, namely, a rotatory system responsible for rotating the drill bit, a hoisting system for lowering and uplifting of the drill string and a circulatory system (like a human heart) which circulates the drilling fluid throughout the drill string to the drill bit and then back to the surface.

Keywords: Nanotechnology; Nanoparticles; Drilling Fluids; Reservoir; Oil and Gas

Introduction

Functions of drilling fluid

The drilling fluids should be properly synthesized to perform efficiently during the drilling operation and modifiable according to the formation to be drilled. The drilling fluid performs a number of functions (Table 1). However, the main motive of the drilling fluid is to clean the bottom of the wellbore, dispose of the cuttings, lubricate and cool the drill bit, maintain the wellbore stability by controlling formation pressure and to prevent fluid influx [1-3].

Types and selection of the drilling fluid

Drilling fluids may be classified as water-based drilling fluids and oil-based or engineered or synthetic drilling fluids. Water-based drilling fluids account for 80% of the total drilling operation carried out due to their environment friendly nature and they are highly cost-effective as compared to the synthetic or oil-based drilling fluids. The main factors upon which the choice of the drilling fluid depends are:

- The location and the type of formation which is to be drilled.
- The variation in the pressure and temperature of the wellbore.
- The nature of the formation fluids i.e. strength, porosity and permeability.
- Production factors, environmental factors and safety are the other important factors which are also considered while making the selection of the drilling fluids.

Since the drilling operations are carried out at higher costs so the selection of the drilling fluid should be made carefully considering all the above mentioned factors.

Limitations of the conventional drilling fluids

It is necessary for a drilling fluid to perform efficiently under high temperature and high pressure conditions. The key factors deciding the practical applications of the drilling fluids include the ability of the drilling fluids to be used over wide range of working conditions. However, the conventional drilling fluids fail to have the above-mentioned factors and hence there is a greater need of investigating such alternatives or additives which could enhance the rheological properties of the drilling fluids under certain specific conditions. The drilling fluids contribute to the losses in the drilling activities and can cost up to $ 800 million every year [4,5]. Furthermore, upon considering the leakage of drilling fluid in the formations and other expenses, the cost of the drilling operations might increase by 5% [6]. Drilling fluid leakage losses might vary from 1-10 bbl/hr to 500 bbl/hr depending on the type of formations. Various methods are adopted to reduce the drilling fluid losses and the most common practices include: the use of Lost Circulation Materials (LCM), strengthening the cement bond use of nanocomposite fluids forming a thick-film work [7-12].

Recent progress

Studies have been carried out to enhance the drilling fluid properties by means of polymers and clay hybrids. The polymer composites include Polyanionic Cellulose (PAC), CarboxyMethyl Cellulose (CMC) and Sodium Carboxy Methyl Cellulose (NaCMC) [13-16]. The clay hybrids comprise of palygorskite and hydrous clays. The use of such polymers and clays is limited to certain wellbore conditions and cannot be used to drill in adverse conditions. So, in order to overcome this issue, nanoparticles have been used as an additive in the water-based or oil-based drilling muds to increase the performance of these drilling fluids under HPHT (High Pressure High Temperature) conditions. These nano-enhanced drilling fluids exhibit higher gel-strength, lower drag and are anti-corrosive nature [17-23].

Nano based drilling fluids

Drilling fluids which have at least one additive with a particle

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Metal Oxide Nanoparticles Used	Remarks
Iron Oxide (3-30 nm)	Increase in yield stress with 0.5 to 5 wt.% in bentonite base fluid at a temperature (20-200°C)
Zinc Oxide	Increase in yield stress and viscosity of the drilling mud by 4%-8%
Calcium Oxide and Iron Oxide	CaO minimized the formation damage with oil base mud until 120°C and exhibited higher fluid losses at higher concentrations. Iron oxide nanoparticles reduced the yield point and showed higher fluid losses at HTHP conditions.
Iron oxide and Silica Oxide (less than 50 nm)	At HTHP conditions, reduction in the filtration loss (42.5% compared to the WBM) obtained when 0.5% by wt iron oxide were added. At LTLP conditions, higher concentrations of iron oxide nanoparticles exhibited higher reduction in fluid losses. Less permeable filter cake formed by the iron oxide based drilling fluid which helped in the reduction of fluid loss.
Calcium Oxide (51 ± 11 nm)	0.5% by weight CaO nanoparticles reduced the fluid loss by 20%-30% with water base mud at HTHP conditions
Iron Oxide	At high pressure Fe_3O_4 nanoparticles with 5% Bentonite with ICH (Iron Oxide Clay Hybrid) improved yield stress. ASCH (Aluminosilicate Clay Hybrid) showed lower yield stress for lower shear rates. The filtration tests showed that at LTLP conditions, ICH and ASCH were able to reduce fluid loss by 37% and 47% respectively. At HTHP conditions, 0.5% by wt. of iron oxide nanoparticles of 3 nm and 30 nm were able to reduce the fluid loss up to 27.6% and 23.4% respectively. Both ICH and ASCH provided good dispersion and avoided flocculation and coagulation.
TiO_2 (21 nm), Al_2O_3 (50 nm) and SiO_2 (10-20 nm)	Increase in concentration of nanoparticles upto 0.25% by volume, increased the surface tension of the drilling fluids as compared to the addition of 0.20% by volume of the mentioned nanoparticles.
Iron Oxide (8 nm)	Na-Bentonite based drilling fluid at 250°F and concentration of 0.5% by wt of the nanoparticles showed increase in the yield stress and reduction in filtrate loss by 40%. Aging it at 350°F for 16 hours increased the thickness of the filter cake and 43% reduction of filtrate loss.
Iron Oxide and Silica	2.5% by wt concentration of iron nanoparticles with 7% Bentonite exhibited higher Yield Point and Plastic Viscosity at Higher Temperature (more than 200°F) but silica nanoparticles gave lower yield point at high temperatures. After aging at 350°F and for 16 hours showed that at a concentration of 0.5% by weight of iron oxide nanoparticles helped in reducing the filtrate loss by volume up to 42.7% and thickness of the filter cake increased by 17.32%
Copper Oxide and Zinc Oxide (<50 nm)	Nanofluid Enhanced Water-Based Drilling Mud (NWBM) with Xanthan Gum as a base fluid (0.4% by weight) increased the NWBM electrical and thermal properties by around 35% as compared to the Water-Based Drilling Mud (WBM).
TiO_2 (10-15 nm) and Polyacrylamide nanocomposite	Water-based drilling fluid with TiO_2 enhanced the plastic viscosity and yield strength. It also resulted in 64% reduction in fluid loss.
TiO_2 (21 nm), Al_2O_3 (13 nm and 50 nm) and SiO_2 (5~15 nm and 10~20 nm)	TiO_2-water based nanofluid exhibited higher surface tension as compared to Al_2O_3 and SiO_2 water based nanofluids. The surface tension of the nanofluids increased from 2.62% to 4.82% as compared to the base fluid.

Table 1: Effect of metal oxides nanoparticles on rheological properties [4,18,20,21,44-55].

size ranging between 1-100 nm are termed as Nano-based drilling fluids [24]. The main reason behind using nanoparticles as additives in drilling fluids is the much higher surface area to volume ratio of nanoparticles compared to the macro-sized or micro-sized materials [25]. This property changes the Van der Waal forces, molecular and atomic forces which consequently alters the fluid properties with the use of even less than 1% of the nanomaterial in the drilling fluid composition [26,27]. Carbon nanotubes and fullerenes play a vital role in enhancing the properties of drilling fluids [28,29]. The surface property of nanoparticles also enhances the thermal properties of the drilling fluid rendering it convenient to further cool the drill bit and find its applicability in HPHT conditions.

Effect of Nanoparticles on Properties of Drilling Fluid

With increasing demand of petroleum products, there is a need to explore more hydrocarbon reserves. This would require drilling of wells in unconventional formations and harsh conditions. It has been found that the drilling fluids account for 5%-15% of the total capital expenditure and often contribute to the failure of the drilling operations too [30]. Thus, it is essential to condition drilling fluid properties in accordance with the wellbore environment. Therefore, there is a need to develop highly efficient and economic drilling fluids. These next generation drilling fluids must possess enhanced rheological properties along with superior thermal and filtration control properties. Few difficulties that a drilling fluid might encounter include instability of additives, excessive fluid loss and disintegration of polymers, which eventually lead to sagging of weighing agents and rock cutting.

Effect of metal oxides nanoparticles on rheological properties

It is generally observed that metal oxide nanoparticles tend to increase the yield point, viscosity and gel strength of the drilling fluid due to its ability to form ionic bonds. Use of metallic oxides nanoparticles is preferred due to their availability and economic viability, whereas, oxides of some transition metals can be toxic and harmful to the environment.

Effect of carbon nanotubes on the rheological properties of drilling fluids

Investigations were conducted to study the effect of Carbon Nanotubes on the rheological and filtration properties of drilling fluids. Studies showed that mixing 0.01 ppb Multi-Walled Carbon Nanotubes (MWCNTs) with oil-based drilling fluid tend to increase the yield strength, gel strength and emulsion stability of the drilling fluid [31]. A study was conducted on the significance of MWCNTs as an additive in water based drilling mud to increase the cutting carrying capacity of the mud which depends upon four forces: downward gravitational force, upward buoyant force, a parallel drag force and a lifting force perpendicular to the direction of mud flow. The cutting slip velocity was calculated and examined to be increasing with size of the cuttings. The cutting carrying capacity was determined as the percentage of cutting recovery from the bottom of hole to the surface. It was examined that addition of 0.005% of MWCNTs to the mud increased the cutting carrying capacity by 5%-15% and doubling the amount of MWCNTs to 0.01%, the cutting carrying capacity increases to 5%-21%. It was also reported that such multi-walled carbon nanotubes increased the viscosity of the mud suggested that carbon nanotubes can be used to enhance the rheological stability at high temperature and high pressure conditions of inverted emulsion drilling fluids but failed to contribute in control of fluid losses [32,33]. Another research was carried out to emphasize on nano based drilling fluids having CNTs as a functional additive. The results showed that the acid treatment of the hydrophobic CNTs had a significant increase in the thermal conductivity of the

CNT water based mud by 23.2% (using 1% by volume of CNTs) at 27°C. However, the thermal conductivity increased to 31.8% at a temperature of 50°C for CNT water based mud. An increase of 43.1% in the thermal conductivity was reported for oil-based muds for the same concentration of CNTs [33].

Halali investigated the effects of Carbon Nanotubes on engineered polymer based fluids. The results showed that combining Carbon Nanotubes with PMMA (Polymethacrylic Acid Methyl Ester) exhibited higher thermal conductivity at various temperature ranges. At 394 K, the HPHT filter loss was reduced by 82% and a significant increase in the gel strength was studied [34]. At 422 K, the fluid losses were reduced by 88% and the gel strength was enhanced. Further, at 450 K, the fluid losses were reduced by 90% and a slight improvement in the gel strength was examined. It was further investigated that the thermal conductivity of the sample increased with temperature. This concludes that CNTs play a vital role in increasing thermal properties of the mud and hence these muds can be operated at HPHT conditions.

Effect of silica nanoparticles on the rheological properties of drilling fluids

Various researches have been performed with silica nanoparticles as an additive to enhance the rheological properties of the drilling fluid due to its ease of availability. Initial researches involved the use of SiO_2 nanoparticles (40-130 nm) to develop an all-new drilling fluid which successfully reduced the formation damage by increasing the thickness of the mud cake by 34% [35]. Further researches have shown that using Nano clays and silica nanoparticles instead of the polymeric composites helped to stabilize the emulsion models of drilling muds at high temperature and high pressure. It was also found that the stability and flow properties were at their best when both nanoclays and silica nanoparticles were used simultaneously. Further aging the samples for 96 hours at 225°C, the yield stress decreased by 30% but the emulsion remained stable [36].

Mao used a hydrophobic polymer based silica nano-composite formed by inverse micro-emulsion and sol-gel method [37]. The results were quite drastic as 0.5% of the Nano-composite enhanced the rheological properties as well as provided better thermal stability and lubricity. It also helped in reducing the filtrate losses up to 69% under high temperature and pressure conditions. Other researches focused on mixing common materials like Bentonite (22.5 grams), Potassium Chloride (KCl) (0.25% by weight) and silica nanoparticles (0.20 g) to fresh water (350 mL) to design a water-based mud. The addition of these nanoparticles enhanced the rheological properties and reduced the filtrate losses [38]. The concept of Smart water-based muds using silica nanoparticles (0.1%-03% by weight) is gaining popularity as it can replace oil-based muds in a directional and horizontal well thereby, reducing the drilling and completion problems in the wellbore. Further, silica is quite sensitive to pH and hence it enhances the properties of the mud at high values of pH [39].

Investigations were carried out to study the effect of silica nanoparticles on the polymers like High Viscosity CarboxyMethyl Cellulose (HV-CMC), Low Viscosity CarboxyMethyl Cellulose (LV-CMC), xanthan gum and Potassium Chloride or Sodium Chloride treated Bentonite drilling fluids. It was observed that by mixing 0.2 g of LV-CMC and 0.3 g of xanthan gum to 25 g/500 g of Bentonite and 2.5 g KCl, also adding 0.25 g of silica nanoparticles results to a maximum yield stress of 10 Pa. API filtration tests showed that 4.5% reduction in filtrate loss. However, adding 0.2 g and 0.3 g of silica nanoparticles resulted in an increase of fluid loss by 8.7% and 13% [40].

Effect of Graphene on the rheological properties of drilling fluids

Use of Graphene with drilling fluids is an emerging concept where its addition is able to enhance the drilling fluid rheological properties. In an investigation by graphite nanoparticles (Nano graphite) of particle size 40 nm were used [41]. The study revealed that adding 0.1% by weight of nano graphite helped in increasing the density of the mud by 50% (from 1.4 g/cc to 2.2 g/cc). It was found that at normal drilling temperature (90°C) and pressure (100 psi), viscosity was enhanced with lesser filtrate losses compared to convention drilling fluid. In another research by Methylated Graphene Oxide were prepared and used as an additive in the water-based drilling mud [42]. The results proved that Graphene Oxide could be used for fluid-loss control when added to water-based muds. Further, methylated graphene oxide helped in increasing the stability of the mud in saline environments. The filtration properties were enhanced by using a mixture of large flake graphene oxide and powdered graphene oxide in a ratio of 3:1 with water-based mud, which resulted in the formation of a filter cake of 20 µm. Thus, it can be concluded that using graphite materials significantly helped in fluid loss control.

Effect of clay nanoparticles on the rheological properties of drilling fluids

In a research, synthesis of palygorskite, hydrous clay, was carried out to form a needle shaped structure with 10-20 nm in diameter. The prime objective of this research was to study its stability and applicability at HPHT conditions. Comparing the results of palygorskite and montmorillonite showed that using montmorillonite alone did not enhance the rheological properties to much extent but, using palygorskite nanoparticles in small concentrations along with montmorillonite helped to enhance the rheology [43-49].

Summary

Nanotechnology has shown a lot of potential in its application to improve the performance of drilling fluids. This paper provides a summary of work carried out to address challenges and limitations of conventional fluids used in the industry. It is concluded that the use of nanotechnology has not been fully utilized for critical situations such as HPHT, drilling of unconventionals or deep offshore wells. The main purpose of this review is to present the effect of the nanoparticles on the rheological properties of the drilling fluids based on the types of nanoparticle used. Although, various reseaches were carried out in this field but it is still a challenge to make the Nano-enhanced drilling fluids homogeneous in composition, cost-effective, periodically stable and environment friendly without compromising with the improvements in the rheological and filtration properties [50,51]. This review presents a gist upon the effect of nanoparticles on the rheological and filtration properties of the drilling fluids. The following conclusions can be drawn on the basis of this review:

1. The concentration and average size of the nanoparticles effect the properties and performance of the drilling fluids.

2. Studies have revealed that these nanoparticles provide greater surface area to volume ratio and help in enhancing the rheological properties of the drilling mud at HTHP conditions.

3. Studies have revealed that the nanoparticles are effective under low concentration and could be used under LPLT conditions but there is less room for the lower concentrations of these nanoparticles to be used at HPHT conditions.

4. It has also been concluded that the nanoparticles enhance the cutting carrying capacity of the drilling fluids by increasing the gel strength of the drilling fluids.
5. Studies have revealed that the nanoparticles played a vital role to reduce the permeability of the shale formations by occupying the pores of the formation.
6. Studies have also revealed that the nanoparticles provided stability to the wellbore due to their capacity to increase the fracture pressure and hence reducing the chances of kick.
7. The efficiency and stability of the drilling fluids is overall enhanced with the help of nanoparticles.

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