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Potential of Nano-Fluid Application in Deep Well Drilling Operation Challenges

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Abstract. Nanotechnology have vast potentials for applications in oil & gas industry. Nanoparticles are ultra-fine in nature, usually larger than an atom cluster but smaller than ordinary micro particles and thus have very high specific surface area with enormous potential interactions with its surroundings. In fact, some nanoparticles exhibit high thermal conductivity ability and affinity to acid gases. These traits and features possessed by nanomaterials intrigues the industry players and makes them zoomed on its potential application in the industry. In this study, the potentials of nanomaterials application in formulating "smart" drilling fluids for deep well drilling operations are discussed. Major deep well drilling fluid related challenges such as narrow drilling tolerance window, HPHT environment, excessive fluid loss and extensive formation damage, wellbore stability issues, differential sticking and low rate of penetration could be addressed through the addition of specific functionally tailored nanoparticles in the fluid formulation. It has been proven at least experimentally in laboratories and some minor field applications that addition of nanomaterials to the formulation would bring positive impacts on the plastic viscosity, yield strength, gel strength, filtrate loss volume and the lubricating effects of drilling fluids, making them feasible to be used in addressing the challenges in deep well drilling operations as discussed in this project paper. Due to the rheological enhancements, nano-fluids application is deemed technically feasible, cost effective and more environmental friendly due to the low concentrations requirement, in formulating smart fluids that could help to combat and address the major and prominent challenges in deep well drilling operations.

1. Introduction

Hydrocarbons are finite resources and hence the surging demand made by the global community will need to be addressed via expansion of the reserves through continuous exploration activities and maximum recovery. The depleting amount of reserves in the low hanging fruits category has forced the oil and gas players to venture further into the sea; offshore exploration and even deep water and ultra-deep water exploration.

However, as the hydrocarbons exploration and extraction activities moves further deep down the Earth's crust, the challenges and risks involved prevails. Deep well drilling activities are commonly associated with complex drilling hazards usually not encountered in onshore and shallow drilling operations. In fact, the recent improvements in drilling techniques have imposed a new set of requirements on the drilling fluid; e.g. horizontal and extended reach drilling, multilateral drilling, mono-bore drilling, etc. Therefore, the formulation of a drilling fluid that is able to live up to the expectation from technical, commercial and environmental aspects, is paramount in the current drilling environment.

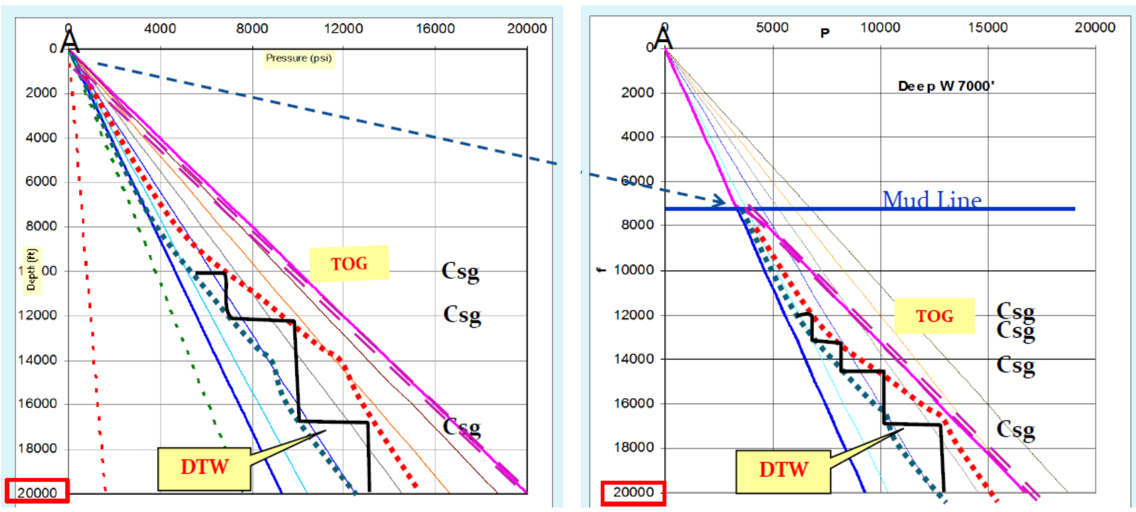
In the efforts to formulate such wholesome drilling fluid, the industry has called for the mapping of some of the technological breakthroughs in fields like nanotechnology, with the hope that they will help in curbing the challenges that exist in the deep water plays aforementioned. This paper will hence entail the analysis and the discussion of the potential and feasibility of nanomaterials in addressing the challenges in deep water drilling focusing on the fluid system.

2. Deep Well Drilling Challenges for Conventional Fluid

As we explore farther and deeper into the Earth's crust for new hydrocarbon prospects, the drilling challenges gets tougher and intensified. The problems in many cases can be attributed to the performance of the fluids component used in drilling operations. Such problems may include well control issues, poor wellbore cleaning, loss circulation zones, fluid gelation, reservoir fluid invasions etc. Thus, the industry would need to figure out a robust solution to overcome these challenges [1]. Hence, the need to formulate a new comprehensive drilling fluid which is capable of good continuous performance under the adverse conditions presented by the deep water environment. Some of the prominent challenges in deep water drilling operations are discussed below.

2.1. Narrow Drilling Tolerance Window (DTW)

DTW is the range or difference between pore pressure and fracture gradient where the drilling operations can safely operate in without the risk of kicks or blowout. It is preferable to operate in big DTW as the range would provide a certain extent of safety and flexibility for the operators to formulate the drilling fluid to cater for different pressure zones. However, should the DTW becomes narrower, especially in deep well environment, the formulation of drilling fluid to cater for the different pressure zones becomes trickier. Figure 1 explains the DTW comparison between shallow well environment and deep well environment. DTW is indicated by the area between the blue dotted line (Pore Pressure Gradient) and the red dotted line (Fracture Pressure Gradient).



(a) (b)

Figure 1. (a) DTW in shallow water environment, (b) DTW in deep water environment [2].

The narrow DTW in deepest water environment has increased the complexity of the drilling activities in these areas; especially in maintaining the pressure balance inside the wellbore to prevent undesired events such as kicks or blowout. Hence, it is vital for the drilling fluid formulated to be able to function in such environment.

2.2. High Pressure - High Temperature (HPHT) Environment

Deep wells are mostly associated with HPHT environment. As the depth of drilling increased, more severe drilling conditions can be expected which may exceed temperature of 600°F (315°C) and pressure as high as 40,000 psi [3]. Drilling in a HPHT environment may affect the efficiency of the drilling operations when the drilling equipment, tools and materials ability to perform optimally is jeopardized due to the HPHT environment. More critically, the efficiency of the drilling fluid properties will be severely impacted due to the extreme temperature and pressure. The HPHT environment may change the rheological properties of the drilling fluid especially the polymer-based additives which will degrade under high temperature. When drilling fluids destabilize, it will cause various drilling, logging and completion issues which may eventually lead to kicks or even blowout.

With conventional invert emulsion fluids, the major challenges encountered under HPHT environment are related to the thermal degradation of emulsifiers and fluid-loss reducer that can lead to gelation and loss of rheological properties that can cause weighting material sagging, and other associated well control problems. An HTHP rheology plot of a conventional invert emulsion fluid is shown in Figure 2.

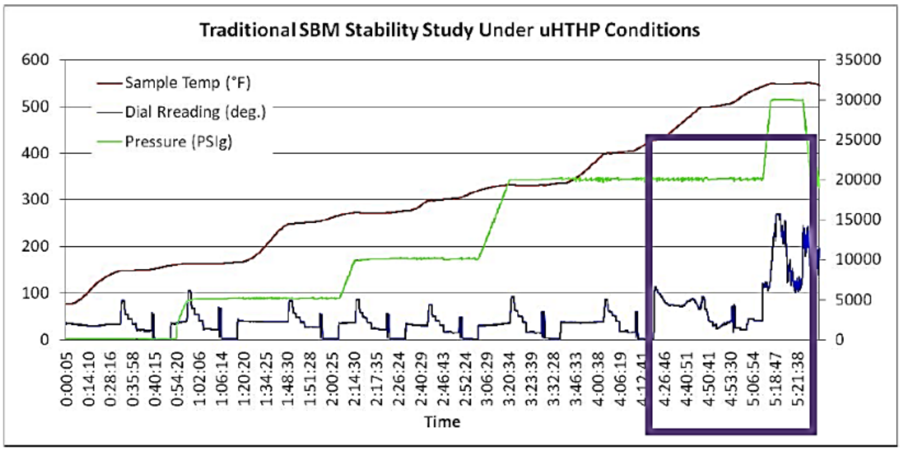


Figure 2. Effect of temperature and pressure on the rheology of a conventional invert fluid. The boxed area shows the impact on rheology after 60 minutes at temperatures above 400°F (204°C) [4]

2.3. Well Formation Instability

The instability of the well formation is another major challenge need to be faced in deep well drilling operations. Formation instability such as caving, sloughing and collapsing are some of the examples frequently faced especially while drilling through shale formations. They happen mostly due to the hydration of the shale formations or by formation geo-mechanical failure due to the in-situ formation pressure anomalies.

In many deep well cases, both factors co-exist and effective simultaneously, hence, may cause the shale formation to swell and cause geo-mechanical failures. These may result in the slough of the shale formation which may lead to other drilling problems (stuck pipe and etc). The hydration of the formation caused by fluid invasion, can generally be minimized by the formulation of a proper fluid chemistry – adding appropriate additives (shale hydration inhibitors) such as bentonite into the drilling fluid. Hence, it is important to have a robust drilling fluid with the ability to prevent excessive fluid invasion into the formation while strengthening the mechanical strength of the formation.

2.4. Fluid Circulation Loss

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During a typical overbalanced drilling, drilling fluids are used to prevent influx of formation fluids into the wellbore. However, in doing so, the drilling fluids will in turn invade the formation to a particular extent especially in the highly porous and permeable zones and naturally fractured zones (Fig. 3).

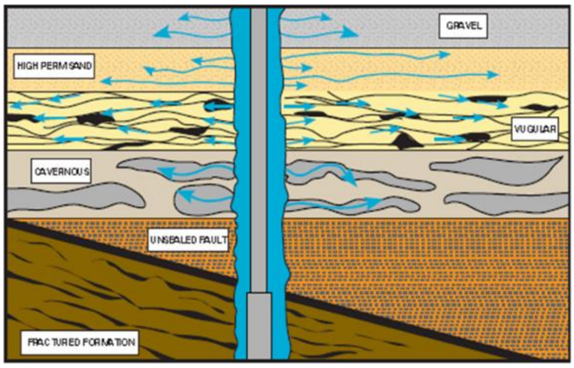

Figure 3. Example of naturally occurring loss zones [5]

Lost circulation may lead to well control issues and may even results in potential kicks and blowouts which will bring adverse impacts to the environment and personnel. Hence, in the effort to minimize the fluid loss through the invasion, drilling fluids are often added with plugging materials such as bentonite to aid in plugging the pores on the porous and permeable zones, forming mud cakes in doing so. Mud cakes presence is very critical as it defines the effectiveness of the plugging in avoiding fluid loss. The mud cakes however, could become too thick, it impedes the movement of the drill strings; making it stuck. This is often called differential sticking and this will be discussed in the following section.

2.5. *Differential Sticking*

Differential sticking occurs when the drill string is "sucked" up against the formation due to the pressure difference between the wellbore and the formation. This normally occurs at permeable zones where the mud cake is formed. Thick mud-cake may increase the likelihood of differential sticking during drilling operations. Hence, it is vital that the mud cake formed by the drilling fluid is kept at a minimum thickness while maintaining its effectiveness in preventing or minimizing fluid loss. This is another area that nanotechnology might come into the picture to aid.

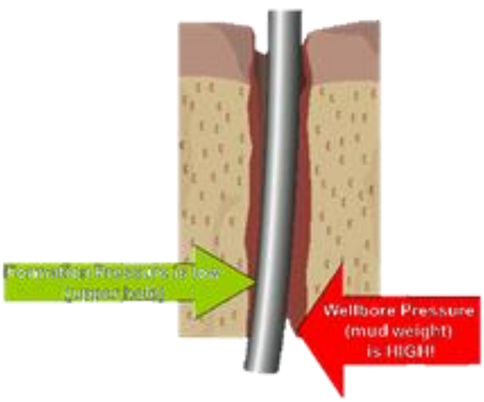

Figure 4. Differential sticking of drill string in wellbore [5]

3. Nanotechnology and Nanomaterials

"Nano" denotes a thousand millionths (10−9), hence, a nanometer is a millionth of a meter. That equals to the width of 10 hydrogen atoms. Indicatively, a human red blood cell is approximately 7,000 nanometers wide and a water molecule is 0.1 – 0.3 nanometers across. At nanoscale, the laws of classical dynamics begin to deteriorate and nanoparticles traveling at high velocities are subject to Einstein's law of relativistic-quantum mechanics. In other words, Quantum Mechanics becomes extremely important at this atomic scale [6]. Amazing phenomena begins to occur on the particles in this domain and this is what intrigues the industries to take a deep interest in nanotechnology.

4. Addressing the Challenges in Deep Well Drilling Operation: Nanotech Way

Due to the enhanced physio-chemical, mechanical, electrical, thermal, hydrodynamic properties and interaction potential, nanomaterials are deemed to be the most promising option for smart fluid design in oil and gas field application [7]. Moreover, with the possibility of manufacturing tailored made nanomaterials with custom made functional behaviour, nanotechnology widened the door to the development of a new generation of drilling fluids.

These ultra-fine particles are usually larger than an atom but smaller than the micro particles. They have a high specific surface area to volume ratio, with enormous area for interactions with its surroundings. Hence, due to the nanoscale particle dimension, nanoparticles are thus expected to deliver superior fluid properties at a significantly reduced additive concentration [8]. In highlighting the potential of nanoparticles in addressing the technical challenges in deep water arena, the author has gathered and analyzed papers and reports that highlights the impacts of nanoparticles application in the field as well as those works in experimental stage in the laboratories.

4.1. HPHT Environment

The stability of additives in HPHT conditions is often the determinant for the drilling fluids to be able to fulfill the expected functional tasks as temperature above 200°C and downhole pressure of 20,000 psi and above are very common in deep water wells. In fact, when temperature exceeds 400°F (204°C), the stable additive options are almost nonexistent for both water based and non-aqueous based fluids [9]. The extremely high surface area to volume ratio of nanoparticles leads to a more effective interaction between the nanoparticles surfaces with external and internal rock surfaces and enhance the thermal conductivity of nano-fluids, which in turn enhances the efficiency of the cooling system. Hence, the nanoparticles, with their excellent thermal conductivity are deemed to be the most suitable materials of choice for application in such environment [8].

Experimental study on OBM with nanomaterials added as replacement of the conventional polymer-based additives and the fluid formulation was subjected to high temperature (175°C) aging for up to 96 hours. The rheological properties measured showed that the nano-fluid formulation maintained the desirable properties after aging and exposure to high temperature [10].

4.2. Loss Control & Formation Damage

Mud filtrates is believed to be the major factor contributing towards formation damage while drilling. Hence, formulation of fluids with no or negligible filtrate loss potential in downhole conditions is essential to avoid or minimize excessive filtrate loss and most of the mud induced formation damage. The prevention of circulation and filtrate loss by current drilling fluid with conventional lost circulation materials showed limited success in these environments. However, due to the extremely small size of the nanoparticles, they are able to provide effective sealing effect in the porous and permeable zones, fractured and cavernous formations. Due to the extremely small size, nanoparticles are able to access the smallest pores and pore throats in the matrix and act as sealing agents in all lithology types including even shales.

4.3. Wellbore Stability & Narrow Drilling Tolerance Window

One of the causes of wellbore instability in deep water environment is because the formations below the deep sea bed are weakly bonded with little cementation and inter-particle cohesion [11]. This is due to the presence of a big water column during the deposition instead of a long rock column as compared to onshore and shallow water formations of similar vertical depth. In other words, the formations in the deep environment are often unconsolidated and loose as compared to that of onshore and shallow environment.

Previous experience and drilling data reveals that various drilling problems arise while drilling unconsolidated formations using the conventional macro or even micro-material-based drilling fluid. These fluid formulations are often not able to prevent sanding, hole collapse, washout, fracturing problems due to their inability to generate effective inter-particle cohesion and cementation to strengthen near wellbore formation. Due to the ultra-fine size, nanomaterials are able to access the pores and the inter-granular contact surfaces of the unconsolidated sand particles. Hence, nanomaterials with gluing and cementing properties are expected to form bonded networks of particles within the formation matrix creating an integrated ring of rock mass around the wellbore wall [8].

4.4. Differential Sticking

Since the presence of thick mud cake may increase the likelihood of differential sticking during drilling operations, it is important to produce a thin and low sticking mud cake on the wellbore wall in preventing pipe sticking problems [8]. As established in the previous sections of this paper, nano-fluids has proven to possess the ability to produce thin, non-erodible, impermeable mud cake that are effective in preventing fluid loss. In addition, nano-fluids would be able to reduce the adhesive tendency of mud cake by forming another thin non-adhesive nano-film on the drill pipe surface. This would help to decrease the likelihood of stuck pipe to occur.

Due to the extremely small particle size, the nanoparticles added into the formulation of nano-fluids can easily enter the pipe-mud cake interface to form an effective lubricating film, isolate the mud cakes or even destroy the mud cake for an effective de-bonding of the pipe from the mud cake surface. This demonstrates the potential of nanomaterials application in the formulation of both drilling and spotting fluids to address the pipe sticking problems. Therefore, in curbing the stuck pipe problems, the researchers have decided to use nanoparticles (carbon black particles) in their drilling fluid formulation in their experimental study [12]. The specific gravity of carbon black is typically in the range of 1.9 – 2.1 and its thermal stability is up to 3,000ºF (1,649°C). The estimated initial diameter of carbon black particles is about 30 nanometers in which after aggregation this value will be about 150 to 500 nanometers.

4.5. Rate of Penetration and Bits Balling

Solid contents of in the drilling fluid is one of the factors that reduces the ROP. Hence, it is important to keep the amount of solid contents in the fluid at a minimum required level [7]. It has been established in the previous section that nanomaterials application in the drilling fluid would be able to form a continuous layer of a very thin film on the surface of wellbore surfaces, mud cake and even on the surface of the drill pipes. This characteristic of nano-fluids would be able to provide sufficient lubricating features, minimize the frictional resistance between the drill pipes and the wellbore surfaces, minimize the torque and drag problems and hence improve the overall ROP.

Apart from that, the progressive sticking and accumulation of this gumbo shale on the bit tooth gaps and the tooth surfaces can turn the drill bit into a ball-like structure which would drastically reduce the ROP and the drilling efficiencies [8]. This could lead to a significant increase in the total drilling cost should the operations need to be stopped to clean or change the drill bit. Hence, nano-fluid formulation containing a combination of inhibitive and hydrophobic film forming nanomaterials can eliminate and minimize the bit balling problems and could potentially lead to cost saving measures. In conclusion, the enhanced lubricating effect provided by nano-fluids application would bring positive impacts on the overall drilling performance, increases the ROP, minimizes tools and equipment break down related problems and hence, brings in a significant potential cost saving and value creation for the drilling operation.

5. Health, Safety and Environment

Technically, from environmental compliance point of view, the application of nanoparticles in drilling fluid may be deemed a more environmental friendly measures as the concentration requirement is low (typically less than 1% concentration) in the fluid formulation. Hence, nano-fluids could be the fluid of choice in conducting drilling operations in sensitive environments [7].

However, at the moment, the eco-toxicological and toxicological data library of nanomaterials applications in oilfield environments is barely minimum and thus insufficient to make any broad statements regarding the health and ecological effects of these nanoparticles. Hence, it is highly recommending for the related government and non-governmental bodies to establish specific local work instructions and enforce mandatory use of appropriate personnel protective equipment (PPE) to minimize or prevent any unwanted health and environmental risks and exposure [9].

6. Conclusions

The reviewed literature suggests that the current drilling operation is facing many fluid and materials based challenges, some of which may be able to be addressed through application of nanomaterials. Nanotechnology offers many potential solutions to drilling fluid related problems especially in deep well environment that cannot be effectively solved with the current conventional fluid formulation.

The laboratory tests and a few field application results reviewed here shows that although most of the nano-fluids and solutions are still in the laboratory testing stage, they could be extensively applied in the field once the economic challenges have been resolved. The tremendous improvement it brought unto the rheological properties of the drilling fluid has made it the suitable option (if not the only option), to be used in technically challenging environment of deep well drilling operations.

Hence, through the discussion made, it is concluded that though there has been limited application of nanomaterials in the drilling fluid formulation to date, the numerous benefits of its application in addressing some of the major problems and issues in drilling operations especially deep well drilling operations cannot be ignored.

Acknowledgments

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