American Journal of Nano Research and Applications
2015; 3(3): 41-45
Published online April 13, 2015 (http://www.sciencepublishinggroup.com/j/nano)
doi: 10.11648/j.nano.20150303.12

How the Drilling Fluids Can be Made More Efficient by Using Nanomaterials

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To cite this article:
Mortatha Saadoon Al-Yasiri, Waleed Tareq Al-Sallami. How the Drilling Fluids Can be Made More Efficient by Using Nanomaterials. *American Journal of Nano Research and Applications.* Vol. 3, No. 3, 2015, pp. 41-45. doi: 10.11648/j.nano.20150303.12

Abstract: Drilling fluids serve many objectives in a drilling process, including the elimination of cuttings, lubricating and cooling the drill bits, supporting the stability of the hole and preventing the inflow-outflow of fluids between borehole and the formation. However, with increasing production from non-conventional reservoirs, the stability and effectiveness of traditional drilling fluids under high temperature and high pressure (HTHP) environment have become big concerns. Both water and oil based drilling fluids are likely to experience a number of deteriorations such as gelation, degradation of weighting materials and breakdown of polymeric additives under HTHP conditions. Recently, nanotechnology has shown a lot of promise in the oil and gas sectors, including nanoparticle-based drilling fluids. This paper aims to explore and assess the influence of various nanoparticles on the performance of drilling fluids to make the drilling operation smooth, cost effective and efficient. In order to achieve this aim, the article will begin by explaining the important role that drilling fluid plays during the drilling process with a historical review of drilling fluid industry development. Then, definitions, uses and types of drilling fluid will be demonstrated as well as, the additives that are appended in order to enhance drilling fluid performance. Moreover, the maturation of the oil production industry from unconventional wells will be discussed after which the limitations and degradation of the traditional drilling fluid will be cleared up. Finally, this essay will discuss the great potential of nanotechnology in solving drilling problems in addition to the technical and the economic benefits of using nanomaterials in drilling fluids before offering a brief conclusion.

Keywords: Drilling Fluids, Reservoir, Nanotechnology, HTHP Conditions, Nanoparticles, Nano-Fluid

1. Introduction

Every rotary drilling operation has three systems that work at the same time in boring hole: a rotating system which rotates the drill bit, a lifting system that raises and lowers the drill string into the hole, and a circulating system which performs the function of moving a fluid around from the drill stem, out of the drill bit and up again to the hole at the surface, this fluid is called drilling fluid (Van Dyke & Baker 1998). Drilling fluids are necessary for drilling success as they increase oil recovery and minimize the amount of time needed to achieve first oil (Nasser et al., 2013).

The drilling fluids in the drilling process can be considered the same as the blood in the human physical structure. The mud pump is the heart; the cuttings that are transferred from the borehole by drilling fluid represent the unwanted materials that are removed from the body by blood and the mud cleaning system works as the kidney and lungs.

Recent investigations have demonstrated that nano-fluids have engaging features for applications where heat transfer, gel formation, drag reduction, binding ability for sand consolidation, wettability alteration, and corrosive control is of interest.

Nano-fluids can be produced by adding nano-sized particles in low volumetric fractions to a fluid. The nanoparticles promote the fluid's rheological, mechanical, optical, and thermal characteristics. Fluids with nano-sized particles may provide the following supports:

(1) Nano-sized particles can have enhanced stability against sedimentation since surface forces easily balance the gravity force.

(2) Thermal, rheological, optical, electrical, mechanical and magnetic properties of nanoparticles, which depend significantly on size and shape, can be designed during manufacture and are often superior to the base material.

2. Historical Review of Drilling Fluid Development

It is useful to recognize the chronological succession of issues that contribute to the various developments in a drilling fluid industry before moving deeper into details. In the past, early drilling operations used water to remove the cuttings from the hole. This was reported in 1846 when Fauvelle drilled a well in France by using flushed water. Nevertheless, the role of water alone as a drilling fluid was only partly successful in removing cuttings and achieved limited drilling depth. Hence; the inability of water in this application promoted the researchers and oil companies to produce new fluids.

The real basis of drilling fluid science was started by the Chapman idea of using water and plastic material as drilling fluid which successfully formed a strong wall around the reservoir (Chapman, 1890). Moreover, the first development was produced in 1901, when a well was drilled by using a mixture of clay and water (Offshore technology report). As a result, in 1935, Harth (1935) introduced bentonite clay and this innovation takes the basis of current drilling fluids.

3. Drilling Fluid Definitions, Functions and Types

There is a wide range of drilling fluid definitions, depending on function, composition and complexity. The American Petroleum Institute (API) defines the drilling fluid as a circulating fluid employed to save any or all of the various responsibilities involved in drilling operations in rotary drilling (Fink 2011). The drilling fluid can also be defined as all compositions that used to remove the cuttings from a borehole (Apaleke et al., 2012). In addition, it can be defined as a complex fluid that consists of a multitude of additives (Shah et al., 2010). The form and the quantity of additives are based on the drilling technique and the formations of a reservoir (Ibid).

In drilling operations, drilling fluids are utilized to remove cuttings from a borehole and transport it to the surface, to stabilize and support wellbore, and to cool and lubricate the drill bit. In addition, drilling fluids play a role in suspending cuttings when not circulating and controlling formation pressure. Furthermore; drilling fluids protect the environment by preventing inflow-outflow of fluids between a borehole and the reservoir formation (Nabhani & Emami, 2012; Abdo & Haneef, 2012).

The challenges during drilling operations in the petroleum industry have contributed to the formulation of different types of drilling fluids. All the same, the primary ingredients of these fluids are water, oil and gas in addition to chemical additives (Apaleke et al., 2012). More often than not, the drilling fluids are classified as water-based mud, oil-based mud and gas-based mud. According to Shah et al. (2010) the most popular drilling mud used in drilling is water-based mud (WBM) while, oil-based mud (OBM) is usually used in swelling shale formation. In WBM, particles are suspended in water or brine (Caenn et al., 2011). OBM is used in swelling shale formation because with WBM, the shale will absorb the water, as a consequence of this it expands and this expansion may cause stuck pipe (Shah et al., 2010). However, there are drilling special conditions under which a liquid drilling fluid is not a suitable circulating medium. Therefore; foam, air and gases may be employed in drilling some wells when these conditions exist (Ibid). In this situation, the drilling fluid type is called gas based mud (GBM).

4. Chemical Additives

Chemical additives are added to drilling fluids in order to enhance its performance by changing the properties and composition, particularly when circumstances need mud with special capabilities to optimize the oil production process. Several mud additives exist some performing more than one function (Awele, 2014).

The most common additives are: pH control to control the acidity and alkalinity of the fluids, bactericides to reduce the bacterial count and corrosion inhibitors to prevent corrosion and the formation of scale in drilling fluids. In addition, defoamers are used to reduce foaming action, emulsifier to make a mixture of two liquids and a filtrate loss to reduce water loss to the formation. Also, flocculants are used to settle out the solids, lubricants to reduce the friction coefficient, and lost circulation materials to plug the zone in the formation (Skalle 2010; Hawker 2001).

5. Limitations of Drilling Fluids and Challenges

There are still limitations during use these traditional drilling fluids in spite of the chemicals added to improve the drilling fluid performance. The main limitations of water based drilling fluids are: the ability of WBM to dissolve salts which may result in an unwanted jump in density. Moreover, the WBM is capable of interfering with the flow of gas and oil through porous media. Other limitations are the ability of WBM to promote the disintegration and dispersion of clays and the inability of WBM to drill through water sensitive shale. As well as the ability of WBM to corrode iron such as drill pipes, drill collars and drill bits (Mellot, 2008).

Just like water based mud, oil-based drilling fluids have limitations such as the fluids are very expensive from several aspects, as the constituents of this type of mud are very expensive and the high cost of treatment cuttings and disposal of it (Oakley et al., 1991). On the other hand, this type is not favourable to the surroundings because their disposal may result in the pollution of water bearing aquifers, pollution of lands, and the decimation of the coral reefs. Furthermore; this type of fluids is unsuitable for use in dry gas reservoirs (Apaleke et al., 2012).

Not only do WBM and OBM have limitations, but GBM is also likely to experience a number of limitations. The most common one is a high risk of explosion due a high pressure that may be generated because the phase of SBM is gas or foam. Besides, this type causes drilling string corrosion. As well the SBM cannot be used through water bearing formations because the cuttings will aggregate together in these formations, therefore it is impossible to carry out by air or gas (Apaleke et al., 2012).

Oil well drilling technology has evolved from vertical, horizontal to sub-sea and deep-sea wells. These specific drilling techniques require specialized drilling fluids to fulfil the objectives (Shah et al. 2010). The traditional drilling fluids are suitable for low and medium temperature and pressure conditions. Although oil based drilling fluids were used in high temperature and pressure because of their stability, but these fluids are likely to experience a number of deteriorations such as gelation, degradation of weighting materials and breakdown of polymeric additives under HTHP conditions (Oakley et al., 2000).

This debasement of the fluids in these conditions decreases drilling performance by deceleration of the rates of penetration and this creates intractable problems that lead to leaving behind most of the oil unrecovered (Nasser et al., 2013).

6. Drilling Fluids for HTHP Conditions

Drilling fluid should have appropriate high temperature transfer and flow properties. Besides, it must be friendly to the environment in order to perform the functions in an effective responsible (Gupta & Walker, 2007). Recently, these specifications have been achieved, with some limitations as mentioned before, by water-based and oil-based muds. Both have bentonite clay and some of the chemical additives (Shah et al., 2010).

These additives may improve density, decrease corrosion rate, change viscosity, and stop bacterial growth (Hawker, 2001). However, for deep-well drilling the temperatures and pressures can be very high and the heat transfer requirements on the drilling fluid impossible to meet (Oakley et al., 2000). In this situation, to design a drilling fluid has capability to work successfully, it is required to significantly enhance the fluid's thermal properties.

Nanotechnology offers light, strong and corrosion-resistant materials which is what the drilling fluid industry needs (Ragab & Noah, 2014). The application of nanoparticles in drilling fluids will enable the drilling engineers to adjust the drilling fluid rheology by modifying the composition, type, or size distribution of nanoparticles in drilling fluid to accommodate any special situation (Abdo & Haneef, 2012). Materials manufactured from nanoparticles are not like those prepared using their larger equivalents. Nanomaterials are stronger and more reactive than other materials. They also conduct heat efficiently (Singh & Ahmed, 2010). The reason behind that is the increased surface interaction. As, for given quantities of material, there are a higher number of particles as a result of their size reduction as well as there is more surface area to bear the heat (Shah et al., 2010).

7. Nanomaterials Based Drilling Fluid

The beginning of nanotechnology has revolutionized the science and engineering sectors due to its vast range of applications. The oil production industry like every other industry can take out massive benefits from nanotechnology (Abdo & Haneef, 2012). One of the most encouraging prospects is the use of nanoparticles in drilling muds so as to have a clear operational performance, stability, and suitability. These features make drilling fluids adopt well with a wide range of operating conditions by minor changes in composition and sizes (Ibid).

Amanullah and Al-Tahini (2009) define nanomaterials based drilling fluids as mud containing additives with particle sizes between 1 to 100 nanometres; also they classified the nano-fluids into simple and advanced nano-fluids based on the concentration of the nanoparticles in drilling fluids. Nanoparticles in drilling fluids can play a major role in fixing the most common problems during drilling like wellbore instability, lost circulation, pipe sticking, toxic gases, high torque and drag.

8. Prospective Performances

1. Wellbore Instability

It is known, each year, millions of dollars are spent due to wellbore instability problems which are happening from exposure of shale to drilling fluid (Nabhani & Emami, 2012). The drilling fluids that contain nanoparticles have the power to depreciate wellbore instability (Singh & Ahmed, 2010). The nanoparticles size is less than the pore throat sizes of rocks that lead to plug the pore throats (Ibid). According to Suri and Sharma (2004), the particle size should not be higher than one-third of the pore throat to build a bridge and plug the pores.

2. Lost Circulation

One of the most popular drilling problems is loss circulation (Nabhani & Emami, 2012). It is a partial or complete loss of the drilling fluid to the formation. This situation occurs due to naturally fractured, crevices and channels (Abdo & Haneef, 2012). The loss of circulation leads to increase the cost and time required for drilling to reach the target depth (Nabhani & Emami, 2012). The loss of circulation also causes loss of pressure control and increasing safety concerns (Ibid).

Therefore; a lot of time and effort has been spent to control the loss circulation through produced additives materials or muds. The use of micro and macro particles have shown limited success (Mostafavi et al., 2011). The utilization of nanoparticles led to reduce loss circulation by raising carrying capacity sufficiently to carry the cuttings efficiently and to maintain drilling fluid density and pressure over a wide range of operational conditions (Bicerano, 2009).

3. Pipe sticking

Sometimes the drill pipe stuck to the wall of the borehole due to cutting accumulation when drilling fluid circulation stops or because the filtrate loss in the wall of the wellbore

(Palaman &Bander, 2008). Pipe sticking has a significant impact on the drilling performance and well costs. Many parameters are affected on the pipe sticking which are dependent on drilling fluid rheology (Nabhani &Emami, 2012). Any change in any rheology property can cause pipe sticking (Ibid).

The nano-fluids can play a role in recovering the stuck pipe. Nanomaterials based drilling mud have the potential to decrease the sticking tendency of mud cakes by making a thin film covering the drill pipe that lead to cutting down the pipe sticking problem (Amanullah & Ashraf, 2009). Also, nano-fluids have excellent carrying capacity, thus reducing the pipe sticking by cleaning the wellbore from cuttings (Nabhani &Emami, 2012).

4. Reduction Torque and Drag

There is a noteworthy boost in torque and drag difficulties due to the clash between the drill string and the borehole. Micro and macro materials based drilling muds have limited power to overcome torque and drag problems (Wasan & Nikolove, 2003). On the other hand, the application of nanoparticles leads to a significant reduction of the friction between the pipe and the borehole (Donald & Frank, 2007). Nano-fluids have the potential to form slightly lubricating film in the wall pipe interface (Ibid).

5. Toxic Gases

Nanoparticles can be employed in drilling fluids to rid of toxic and corrosive gases, like hydrogen sulphide. This gas should take away from the drilling fluids in order to cut environmental contamination as well as to protect the health of drilling staff and to prevent corrosion of drilling equipment's (Singh & Ahmed, 2010). Sayyadnejad et al. (2008) have found that the addition of 14 to 25nm zinc oxide particles into drilling muds removes hydrogen sulphide completely while bulk zinc oxide remove only 2.5% and take more time.

9. Technical and Economic Benefits from Using Nanomaterials in Drilling Fluid

In addition to the enhance drilling fluid performance, the most engaging features of nanomaterial are their low cost (Abdo & Haneef, 2012). This is imputable to the amount of nanomaterials required for any utilization is, much less which results from the fact that nanoparticles have a very huge surface area to mass ratio that enhances the reactivity of nanomaterials (Shah et al., 2010).

Also, the using of nanoparticles in drilling fluids has technical and economic benefits (Abdo & Haneef, 2012). Technically, nanofluids are suitable to use in new oil production techniques and to overcome severe drilling operations (Nasser et al., 2013). Economically, the use of nanoparticles can affect through three aspects. The first one is the use of nanoparticles instead of expensive additives reduces the drilling fluids cost (Nabhani &Emami, 2012). Also, the use of nanofluids as drilling fluids was enhanced oil recovery by reaching deep challenge formations (Abdo & Haneef, 2013). As well as, the non-productive time was shortened due to an elimination of troubles, thus saving huge costs (Abdo & Haneef, 2012).

10. Conclusion

To sum up, drilling fluids have been used to serve many purposes in the drilling process and it as blood in human bodies. However, there are problems with wellbore instability, lost circulation, pipe sticking, toxic gases and high torque; with continued using of these fluids with unconventional reservoirs. During the last decades, scientists and researchers discovered nanotechnology and nowadays there are attempts to apply this technology in the drilling process.

This paper has explained the drilling fluid functions, types and the purpose of adding additives. In addition, it has clarified the degradation of drilling fluids during high-temperature and high-pressure conditions.

From this article, it can be inferred that nanoparticles can enhance drilling fluids due to their stability of the rheological properties at high pressure and high temperature conditions. The nano drilling fluid can cause a revolution in oil and gas drilling industry because it can fulfil the specific needs of new drilling technologies and it can hit the target depth in less time.

One of the main limitations in this paper is that has ignored a mention of the sizes and the concentrations of nanoparticles that used in drilling fluid because the article's purpose is review of important role that nanoparticles did in drilling fluids rather than research. Likewise, each circumstance or problem would need to use nanomaterials with specific sizes and concentrations.

Future work could be borne out in the field of property measurements to establish a better comparison study. The cost feasibility of using nanoparticles in drilling fluids can also be research.

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