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Enhancement of polymeric water-based drilling fluid properties using nanoparticles

Amirhossein Parizad, Khalil Shahbazi*, Abbas Ayatizadeh Tanha

Petroleum Engineering Department, Petroleum University of Technology, Ahwaz, Iran

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ABSTRACT

The maturity of shallow depth and conventional petroleum reserves together with growing demand for energy have forced the oil industry to drill harsh and deep reserves. Nanotechnology has the ability to improve drilling fluid performance for drilling deeper and harsher environments. In this study, a water-based drilling fluid containing polymers was set as the base fluid. TiO_2 nanoparticle was employed to improve rheology, electrical and thermal conductivities of the resultant drilling fluids. The test fluids were made by addition of different concentrations of TiO_2 nanoparticle and KCl salt to the base fluid. The resultant samples were examined at different temperatures and 19 different shear rates. Presence of TiO_2 particles enhanced not only the rheological behavior but also thermal and electrical conductivities of the drilling fluids up to 25% and 41%, respectively. Moreover, the addition of TiO_2 particles increased thermal resistance, shale recovery up to 97.2% and also decreased the filtration volume up to 27%. Moreover, the viscosities of aqueous TiO_2 dispersions at different temperatures and TiO_2 and KCl concentrations were measured. The TiO_2 nanoparticle has good soloubility in hot HCl and HF acids. It was found that the base aqueous fluid viscosity directly affects the resultant drilling fluid viscosity. In this regard, an analysis was performed and a model was proposed.

1. Introduction

1.1. Issue description

Nanoparticles are the materials that usually have a size smaller than 100 nm resulting in a very high specific surface area which causes special properties (William et al., 2014). Nanoparticles alter various properties of fluids such as rheological properties and electrical and thermal conductivities (Maghzi et al., 2013; William et al., 2014).

The drilling operation is nearly the most expensive stage of any oil and gas well construction and production. Nowadays, drilling of oil and gas wells is going to be deeper, more complicated, expensive, and problematic (Friedheim et al., 2012; William et al., 2014).

The drilling fluid is a crucial part of any drilling operation and its properties affect the efficiency of the drilling operation. Drilling fluids should handle the bottom hole high pressure high temperature (HPHT) conditions (Vryzas et al., 2016). Moreover, most of the drilling problems such as kick, blowout, drilling fluid loss, and stuck pipe, which would induce additional time delay and cost, are mainly related to the wrong selection and inadequate design of the drilling fluid (Bourgoyne et al., 1991; Caenn et al., 2011).

The drilling fluid must effectively remove the cuttings, clean the borehole and prevent deposition of drill cuttings when there is no circulation. In this regard, the rheology should be controlled. Rheology represents the resistance of the fluid against flowing. The rheology is a crucial property of any drilling fluid and must be carefully designed (Bourgoyne et al., 1991; Caenn et al., 2011).

One of the functions of any drilling fluid is cooling the bit during its penetration into the rock. The bit engages with the rock during drilling and due to friction, a high amount of heat is generated. If drilling fluid is not able to remove the heat, the bit performance will be decreased and, ultimately, it will be damaged and dulled (William et al., 2014).

One of the drilling fluid properties, which is important for the better evaluation of formations, is electrical conductivity. Due to drilling fluid invasion into formation, this property can affect the result of resistivity logs. Since nanoparticles alter this property, it is one of the properties of drilling fluids that should be measured and monitored (Standard-RP13B-l, 2009). Moreover, the drilling fluid lubricity is an important aspect of them and, therefore, should be investigated (Caenn and Chillingar, 1996).

The drilling fluid should have low filtration rate. The filtration rate of a drilling fluid is a crucial aspect, especially, encountering a high pressure high temperature (HPHT) condition. In high temperatures, the drilling fluid may fail and also drilling may encounter abnormal

* Corresponding author.
E-mail address: shahbazi@put.ac.ir (K. Shahbazi).

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filtration rate which is waste of resources and money. Therefore, the drilling engineer should design a drilling fluid at its optimum characteristics (Caenn et al., 2011; Cameron, 2001; Parizad et al., 2018).

As a result of cation exchange between shale and fresh water, shales will swell. Therefore, salts and other additives are employed in polymeric water-based drilling fluids to prevent cation exchange. The drilling fluid should prevent formations that contain shale from swelling and, also, shale contaminants in mud from disintegration. The most common salt in polymeric drilling fluids is KCl which is employed at different concentrations (Chenevert and Osisanya, 1989). Therefore, the effects of different KCl concentrations on drilling fluid performance were investigated in this study.

Drilling fluids usually are under high-temperature high-stress impacts. Being under such conditions for a while would alter properties of drilling fluid and drilling fluid would not have the same characteristic that initially had. Therefore, studying the alteration is usual in drilling fluid investigations. The dynamic aging and hot rolling at high temperatures will simulate this process in laboratory and allow researchers to find out what would happen (Ravi et al., 1992). Therefore, some tests were carried out after aging and hot rolling.

Nanoparticle dispersions, in fact, are colloidal dispersions. In the nanoparticle dispersions, sizes of solids are much smaller than those of solids in ordinary colloidal dispersions. In these dispersions, the addition of solid increases the viscosity of the mixture. Therefore, adding nanoparticles results in viscosity increment of that fluid (Chen et al., 2007; Maghzi et al., 2013). The nanoparticles in dispersions are surface charged and have interactive forces. The rheology of nanoparticle dispersions is governed by base fluid viscosity, size, and concentration of nanoparticles (specific surface area) (Chen and Ding, 2009; Hayat et al., 2017). Addition of nanoparticles enhances rheological properties of drilling fluid at high temperatures (Vryzas et al., 2016; Zakaria et al., 2012). Researchers have proposed models for viscosity prediction of micro and nanoparticle dispersions. These models predict the ratio of dispersion viscosity to its base fluid viscosity. Based on these models, the dispersion viscosity depends on base fluid viscosity, particles size, and concentration. These models were derived based on experiments in particular circumstances, for example in a limited concentration range or for a particular type of particles (Mishra et al., 2014).

Maxwell proposed a model for prediction of thermal conductivity of suspensions. Based on his model, with increasing specific surface area and concentration of nanoparticles, the thermal conductivity will be increased (Chen and Ding, 2009; Singh et al., 2014). Metals have high thermal conductivities and their presence in a fluid causes an increase of thermal conductivity of that fluid (Chen and Ding, 2009; Singh et al., 2014). Due to a very high specific surface area, the thermal conductivity increment is much higher than prediction (Chen and Ding, 2009). It should be mentioned that the electrical conductivity of metallic nanoparticle dispersions is important as much as thermal conductivity of these mixtures (Dirmyer et al., 2009; Parizad and Shahbazi, 2016).

Nanoparticle size and degree of agglomeration which dictates hydrodynamic size in a fluid, are important aspects of nanoparticle dispersions. After dispersing of nanoparticles in a fluid, groups of particles will be held by a weak van der Waals force. Therefore, the real diameter of particles in the fluid is larger than individual particles size and this size is called the hydrodynamic size of particles (Jiang et al., 2009). Salt addition will increase the size of nanoparticles and decrease the specific surface area. Therefore, the presence of salt affects the properties of nanofluids (Jiang et al., 2009; Metin et al., 2011). This phenomenon is severe in salts with divalent ions like $CaCl_2$. In salts such as KCl, this phenomenon is less severe than divalent ions. Nanoparticle dispersions, in fact, are a colloidal dispersion of surface charged particles. The salts destabilize this dispersion by assailing to their surface charge and, consequently, destabilizing the particles. The salts with divalent ions are much more capable in this regard than single ion salts (Badawy et al., 2010; Metin et al., 2011). The nanoparticles concentration increment decreases the specific surface area of nanoparticles. Therefore, higher nanoparticle concentration can lead to less efficiency (Jiang et al., 2009; Metin et al., 2011).

The TiO_2 nanoparticle is not much soluble in acid however, it is considerably in hot acid solute. Moreover, the lower size of particles would result in higher solubility of them (Avramescu et al., 2017; Baba et al., 2009; Bright and Readey, 1987).

Sedaghatzadeh and Khodadadi (2012) studied the effect of multi-walled carbon nanotube (MWCNT) on thermal and rheological properties of bentonite and freshwater solutions. They concluded that the addition of MWCNT increases the rheology and thermal conductivity of drilling fluid. However, they did not investigate the high-pressure high temperature (HPHT) condition and the base drilling fluid was not a drilling fluid that nowadays is utilized in drilling systems. The water and bentonite utilization are limited to surface drilling where drilling is very fast and non-problematic (Sedaghatzadeh and Khodadadi, 2012).

William et al. (2014) investigated the effect of CuO and ZnO nanoparticles on the polymeric water-based drilling fluids. They studied the effect of three different concentrations of each nanoparticle on rheology, thermal, and electrical conductivities. They concluded that these nanoparticles increase the viscosity of fluids. Furthermore, the nanoparticle presence enhances the electrical and thermal conductivities of the drilling fluid. They observed that the CuO has a higher impact on drilling fluid than ZnO. They investigated the effect of two different nanoparticles on water-based drilling fluids. However, the study was carried out in a limited number of nanoparticle concentrations and the effect of salt on the nanofluid rheology was not considered (William et al., 2014).

Zakaria et al. (2012) investigated the effect of a commercial nanoparticle on LPLT rheology and filtration of oil-based drilling fluids. They concluded that the nanoparticle addition increases the viscosity of the resultant fluid. Moreover, nanoparticles form a thin filter cake and improve filtration property of drilling fluids. However, the particles concentrations were limited and the measurements just carried out in LPLT condition (Zakaria et al., 2012).

Ismail et al. (2016) investigated the effect of multi-walled carbon nanotubes (MWCNT), nanosilica, and glass beads on a polymeric water-based drilling fluid. They studied the effect of low concentrations of the nanoparticle on LPLT rheology, 10sec and 10min gel strengths, LPLT filtration volume, and lubricity of the drilling fluid. They concluded that the addition of these particles improves rheological, filtration, and gel strength behavior of the drilling fluid. However, the glass beads were less effective than MWCNT and nanosilica (Ismail et al., 2016).

The drilling fluid is one of the main parts of the drilling system. Augmentation of its performance efficiency would greatly improve the function of the whole drilling system and reduce costs considerably. In this study, it is discussed how the TiO_2 nanoparticle can increase the drilling and drilling fluid efficiency and also in what way can contribute to the drilling industry. The effect of the TiO_2 nanoparticle on popular KCl polymer mud in different aspect is investigated. In this study, it is tried to find optimum concentration for the TiO_2 and investigate its cost effectiveness. The experiments were performed in wide range of TiO_2 and KCl concentrations. used TiO_2 nanoparticle in this study has a very high specific surface area. The properties of polymeric water-based drilling fluid at different temperatures, KCl, and TiO_2 nanoparticle concentrations are studied. Rheological properties are studied meticulously and it is tried to extract the relation between the drilling fluid viscosity and the base fluid viscosity containing TiO_2 and salt. Moreover, a comprehensive study on other properties like filtration, shale inhibition, aging effect, and thermal and electrical conductivities are performed.