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Experimental study of temperature dependence of drilling fluids viscosity with nanoparticles

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Abstract. This research is focused on the dependence of viscosity of water-based drilling fluid modified by nanoparticles on temperature. Silicon oxide of 10 nm size was used as nanoparticles. The nanosuspensions were prepared for nanoparticle concentrations from 0.25 to 3 wt%. An aqueous solution of bentonite with a mass fraction of 5 % was used as a base drilling fluid. Rheological studies were conducted at varying temperatures (25, 40, 55 and 80 °C). The dependences of the effective viscosity of these suspensions on the concentration of nanoparticles and temperature have been obtained.

1. Introduction

Nanofluids show potential use in applications related to oil and gas industry to improve the processes performance as exploration, drilling and completion, production and enhanced oil recovery [1-3]. However, their applications to water-based drilling fluid need attention for efficient drilling in a High Pressure and High Temperature (HPHT) environment.

Solids in the drilling fluid cause resistance to flow in two ways - through the electrical forces of attraction and repulsion of particles and through a purely mechanical interaction between the particles and fluid. The electrical interaction of solids is largely responsible for viscosity at low shear rates, and mechanical interactions largely determine viscosity at high shear rates. It follows that effect of high temperature on the drilling fluid properties is different at low shear rates compared to high shear rates and should be considered separately. The study [4] presents the following conclusions about the high-temperature effect on the drilling fluid properties.

1. High temperature causes flocculation of bentonite clays, resulting in high yield point, high viscosity at low shear rates and high gel strength.

2. The high temperature causes the dispersion of bentonite clays resulting in a constant thickening of the drilling fluid.

Inorganic characteristics of nanoparticle additives are expected to stabilize drilling fluids even at high temperature and high pressure. In work [5] authors investigated high-temperature properties of bentonite fluids containing nanoparticles of iron oxide. The role of nanoparticle additives is explained by the fact that a large surface area of smaller particles overcomes the driving force for phase separation, such as gravity and packing entropy. In addition, the rheological properties of bentonite fluids were investigated as a function of temperature (20 ~ 200 ºC) and pressure (1 ~ 100 atm). The experimental results show that increase in the content of iron oxide particles in the bentonite suspension result in increasing viscosity, yield point and strength of particles interaction.

The work [6] studied the effect of temperature on the rheological properties of a water-based drilling fluid modified by iron oxide (Fe_2O_3) nanoparticles. The bentonite content in drilling fluids varied up to 6 wt.% and the temperature varied from 25 to 85 °C. The Fe_2O_3 content varied from 0 to 1% of weight of drilling fluid to modify of rheological properties. The results also showed that 1% Fe_2O_3 increased the rheological properties of the drilling fluid. The Fe_2O_3 modification increased yield point and plastic viscosity by 45-200 % and 20-105 %, respectively, depending on the bentonite content and drilling fluid temperature. Based on the Herschel Bulkley model, the maximum shear stress for 2%, 4% and 6% bentonite drilling fluids without nanoparticles at room temperature was 25 Pa, 35 Pa and 51 Pa, respectively. The maximum shear stress for for 2%, 4% and 6% bentonite drilling fluids modified by 1% Fe_2O_3 at 25 °C was 59 Pa, 84 Pa and 140 Pa respectively, hence the increase in the ultimate shear stress was 135-175 %.

In [7] the water-based drilling fluid was prepared using nanofluids CuO and ZnO (size ~ 50 nm) in a xanthan gum aqueous as the base fluid. The nanofluids are prepared for nanoparticle concentrations of 0.1, 0.3 and 0.5 wt% in base. Prepared nanofluids were added in an amount of 1% by volume to the drilling fluid. Drilling fluids based on CuO nanofluid were observed to show improved thermal properties and were more resistant to HPHT conditions than ZnO based suspensions. Rheological studies were carried out at different temperatures (25, 70, 90 and 110 °C) and pressures (0.1 MPa and 10 MPa). The effect of pressure on the rheology of drilling fluids modified by nanoparticles was more significant at higher temperatures and indicated better rheological stability in the case of nanoparticles added to the drilling fluid.

Based on the above, the study of the temperature dependence of drilling fluids modified by nanoparticles is very promising from a practical application and requires a systematic and comprehensive study. This paper studied the effect of silicon oxide nanoparticles to temperature dependence of drilling fluids. SiO2 is referred to the theory of "pure" substances that release active ingredients without the energy consumption. The nucleus of this particle is a three-dimensional polymer of SiO2 elements. The silicon – oxygen bond is characterized by high strength (reaches 372.5 J / mol), due to its polarity, so the covalent bond approaches the ionic bond. Also SiO2 has good sorption properties. Due to its properties and availability, silicon dioxide is of great interest for studying its effect on the properties of drilling fluids.

2. Materials and methods

The study is devoted to the dependence of drilling fluids viscosity with the addition of SiO2 nanoparticles on temperature. A base drilling fluid was water suspensions of various clay solutions.

2.1. Sample preparation

Clay suspension was prepared by the added clay powder (bentonite of Taganskiy deposit) to the distilled water and stirred intensively for 30 minutes with the use of high-speed 20000 rpm stirrer (OFITE 152-18– Prince Castle). After preparation the clay suspension was stabilized for two days for the final clay swelling. Colloidal stability of the suspensions was monitored using a TURBISCAN LAB analyzer.

Then, the necessary amount of nanosuspension with nanoparticles was added to clay suspension. A similar amount of distilled water was poured into the base clay suspension to ensure the same mass concentration of clay particles in all studied solutions. A standard two-step method was used for the preparation of nanosuspension. The required amount of powder is added to the fluid, after the resulting suspension is mixed mechanically. To destroy the nanoparticles conglomerates, the suspensions are treated by ultrasound.

The clay mass concentration of prepared suspension was 5 %. Silicon oxide particles were used as nanoparticles. The particle size was 10 nm. The mass concentration of nanoparticles in suspensions varied from 0.25 to 3 wt%.

2.2. Rotational viscosimeter OFITE1100

The rheological properties of suspensions were studied with an OFITE 1100 viscometer. This viscometer has a built-in thermostat that allows setting and maintaining a high temperature accuracy in the measurement process. The range of shear rates was 0.01–1022 s^{-1}. The error in the measurement of viscosity was not lower than 2%. All measurements were carried out at atmospheric pressure. Temperature was ranged from 25 to 80 °C.

3. Results

Measurements have resulted in the dependence of viscosity of drilling fluids modified by nanoparticles on shear rate and concentration of nanoparticles at different temperatures. The main patterns are shown in figures 1-2.

Analysis of temperature dependence has shown a significant increase of clay suspensions viscosity with increasing temperature, despite the dispersion medium viscosity (in this case, water) decreases. This is due to a decrease in the thickness of a solvate shell of hydrated bentonite particles with increasing temperature. This greatly facilitates their coagulation and flocculation, which lead to an increase in the effective viscosity. It has been found that the temperature rise from 25 to 80 degrees increases the effective viscosity of the clay suspension more than 10 times (see Fig. 1a).

Studies have also shown an increase in viscosity of clay suspensions modified by nanoparticles with increasing temperature. However, this increase was not as significant as that for the base clay suspension. Thus, for drilling fluid with 3 wt% nanoparticles at a temperature increase from 25 to 80 °C, the effective viscosity increases about 2.5 times. Fig.1 shows the dependence of the relative viscosity of the suspensions on the shear rate. Here the "relative" means the viscosity reduced to the suspension viscosity at room temperature. Analysis of the relative viscosity has shown weak dependence on the shear rate up to very high temperatures. This property is especially evident for drilling fluids modified by nanoparticles (see Fig. 1b). This means the rheology of drilling fluids with nanoparticles remains stable with the temperature changes. That is very important for their practical application.

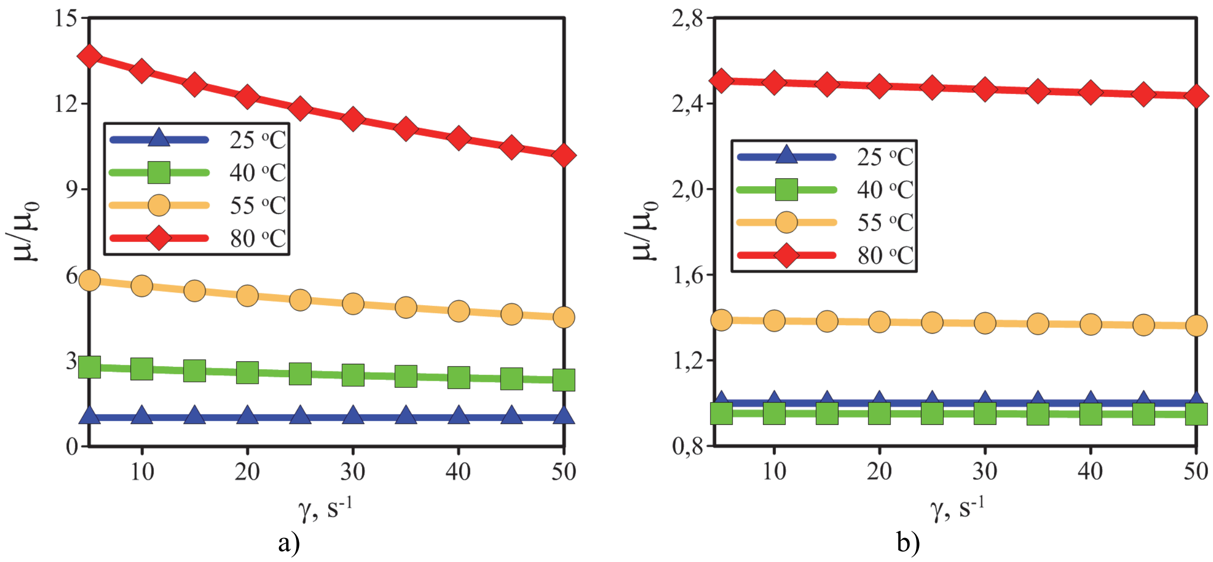

Figure 1. The dependence of relative viscosity of clay (5 wt %) drilling fluid on the shear rate at different temperatures a) without the nanoparticles addition and b) with addition of 3 wt % SiO_2 (10 nm) nanoparticles.

The viscosity rises for all temperatures with increasing nanoparticles concentration (Fig.2). Analysis of the relative viscosity (reduced to the base suspension viscosity) shows the effect of nanoparticle additives on the viscosity of drilling fluids decreasing with increasing temperature. So, at room temperature, adding 3 wt % nanoparticles increases the viscosity of the clay suspension about 8 times, at a temperature of 80 degrees, this increase is about 3 times. This is because most of the chemically active bentonite particles have flocculated at high temperatures, and the effect of nanoparticles on clay becomes weaker.

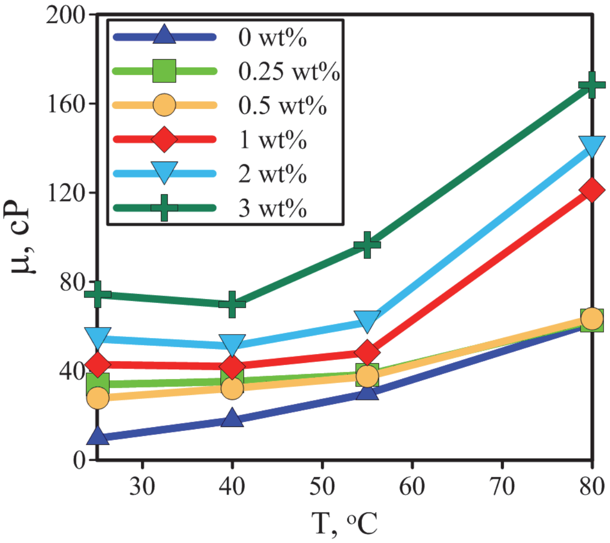

Figure 2. The effect of SiO_2 (10 nm) particle concentration on the effective viscosity of drilling fluid depending on the temperature at a shear rate of 170 s^{-1}.

Conclusion

Thus, a systematic experimental study has been carried out for the temperature dependence of the viscosity of drilling fluids modified by silicon oxide nanoparticles. It has been shown that the nanoparticles addition significantly affects the temperature dependence of the clay suspensions viscosity. The effect of nanoparticle additives on the drilling fluids viscosity was found to decrease with increasing temperature. So, at room temperature adding 3 wt % nanoparticles increases the viscosity of clay suspension about 8 times, and at a temperature of 80 degrees, this increase is about 3 times.

In addition, the addition of nanoparticles was found to make the viscosity of the drilling fluid less sensitive to temperature changes. So, with increasing temperature from 25 to 80 degrees, for the drilling fluid with 3 wt. % silicon oxide nanoparticles with a size of 10 nm the effective viscosity increases about 2.5 times, while for the base drilling fluid viscosity increase with a similar increase in temperature is about 10 times.

Acknowledgments

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