Investigation of temperature dependence of drilling mud viscosity with silica nanoparticles addition

M.I. Pryazhnikov[1,2], **E.I. Mikhienkova**[1], **A.V. Minakov**[1,2], **V.Ya. Rudyak**[1,3]

[1]Siberian Federal University, Kirensky street 26, Krasnoyarsk, Krasnoyarsky kray, 660074, Russia

[2]Institute of Thermophysics of the Siberian Branch of the Russian Academy of Sciences, Academician Lavrentyev Avenue 1, Novosibirsk-90, 630090, Russia

[3]Novosibirsk State University of Architecture and Civil Engineering, Leningradskaya st. 113, Novosibirsk, 630008, Russia

E-mail: arrivent@yandex.ru

Abstract. An experimental study on the effect of silica nanoparticles addition on the viscosity of water-based mud at different temperatures was carried out. The mass concentration of clay was 5%, and the nanoparticles concentration varied from 0.5wt% to 3wt%. The nanoparticle size was 10 nm. Viscosity coefficient measurements were carried out in a wide temperature range.

1. Introduction

Drilling deeper, longer and more challenging wells has been made possible by improvements in drilling technologies, including more efficient and effective the drilling fluids. Drilling fluids, also referred to as the drilling mud, are added to the wellbore to facilitate the drilling process by suspending cuttings, controlling pressure, stabilizing exposed rock, providing buoyancy, cooling and lubricating. Drilling fluids are essential to drilling success, both maximizing recovery and minimizing the amount of time it takes to achieve first oil.

The cost of the fluid system often represents one of the single greatest capital outlays in drilling an oil well. To minimize the cost of fluids and to ensure an efficient drilling program, the fluid properties must be maintained continuously during the drilling operation [1]. In addition, the high temperature and high pressure conditions faced in ultra-deep oil and gas drilling environments pose major challenges for fluids used in drilling operations. The degradation of drilling fluids in these environments reduces drilling efficiency by slowing the rates of penetration and creates severe problems that leads to leaving behind most of the oil unrecovered.

The constituents of drilling muds degrade with time at elevated temperatures: the higher the temperature the greater the rate of degradation. Both the temperature and the rate of degradation at the temperature must be taken into account then specifying the temperature stability of a mud or mud product. The critical temperature is that at which the coast of replacing the degraded material becomes uneconomical, which is generally established by experience, but may be calculated [2].

In this paper study of the effect of temperature on the viscosity of drilling fluids based on water and bentonite clay with SiO_2 nanoparticles addition were carried out in a wide temperature range.

Bentonite is employed by industry to perform a multitude of jobs [3]. Certain industrial applications become apparent from an understanding of the composition and structure of bentonite, and the properties they create. Bentonites disperse into colloidal particles and, accordingly, provide large surface areas per unit weight of clay. This large surface area is a major reason why bentonite functions so well in stabilizing emulsions, or as a medium to carry other chemicals.

Nanoparticles, a unique subset of the broad field of nanotechnology, include any type of particle with at least one dimension of less than 100 nanometers [4]. Research is being conducted to develop nanoparticle-amended drilling fluids with enhanced functionalities [5, 6]. Such enhancements include improved rheological, thermal, mechanical, magnetic and optical profiles [7].

Nanoparticles effect manifests itself at very low nanoparticles concentrations and depends on their size and chemical nature. This makes it possible to control the properties of drilling fluids. Therefore, the study of properties of drilling fluids containing nanoparticles is of great practical importance.

2. Sample preparation and experimental procedure

Drilling mud was prepared as follows. Clay powder (bentonite of Taganskiy deposit) was added to the distilled water and stirred intensively for 30 minutes with the use of high-speed 20000 rpm stirrer (OFITE 152-18–Prince Castle). The clay suspension was kept for two days after preparation for the final clay swelling. Then, the necessary amount of nanosuspension was added to clay suspension. A standard two-step method was used for the preparation of nanosuspension [8]. The clay mass concentration was 5%. Water nanosuspension was prepared with SiO_2 nanoparticles addition (JSC "Plasmoterm"). The average size of nanoparticles was 10 nm. The nanoparticles mass concentrations ranged from 0.5% to 3%.

The rheological properties of the suspensions were studied with an OFITE 1100 viscometer. The range of shear rates was 0.01–1022 s^{-1}. The error in the measurement of the viscosity was not lower 2%. All measurements were performed at the atmospheric pressure and a wide range temperature of 298 K to 353 K.

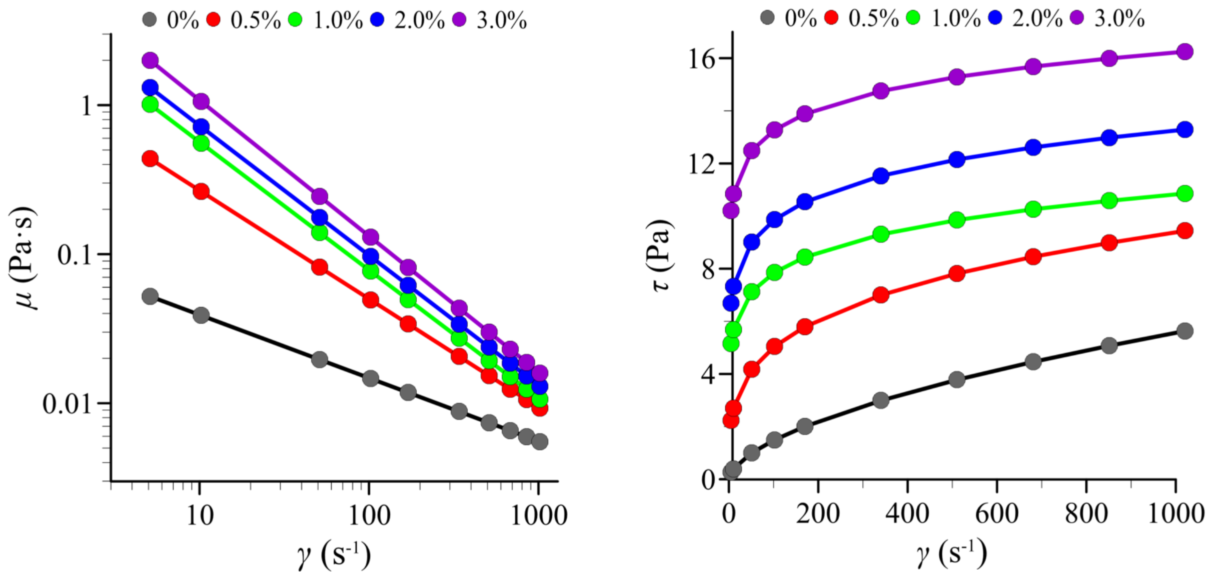
3. Results and discussion

Dependence of viscosity coefficient and shear stress on shear rate (see figure 1) at room temperature were obtained using a rotational viscometer. As the concentration of nanoparticles increased, the viscosity coefficient increased. A significant change in viscosity coefficient of drilling fluid is observed already at low nanoparticles concentrations. For example, adding 0.5wt% nanoparticles to the drilling fluid increased viscosity 1.7 times. Note that the presence of nanoparticles low concentrations has practically no effect on the density of drilling fluid.

The base drilling fluid is a non-Newtonian fluid. The analysis of the data obtained has shown that viscosity μ of the clay-based drilling fluids is adequately described by the following power-law model (coefficient of determination $R^2 = 0.997$):

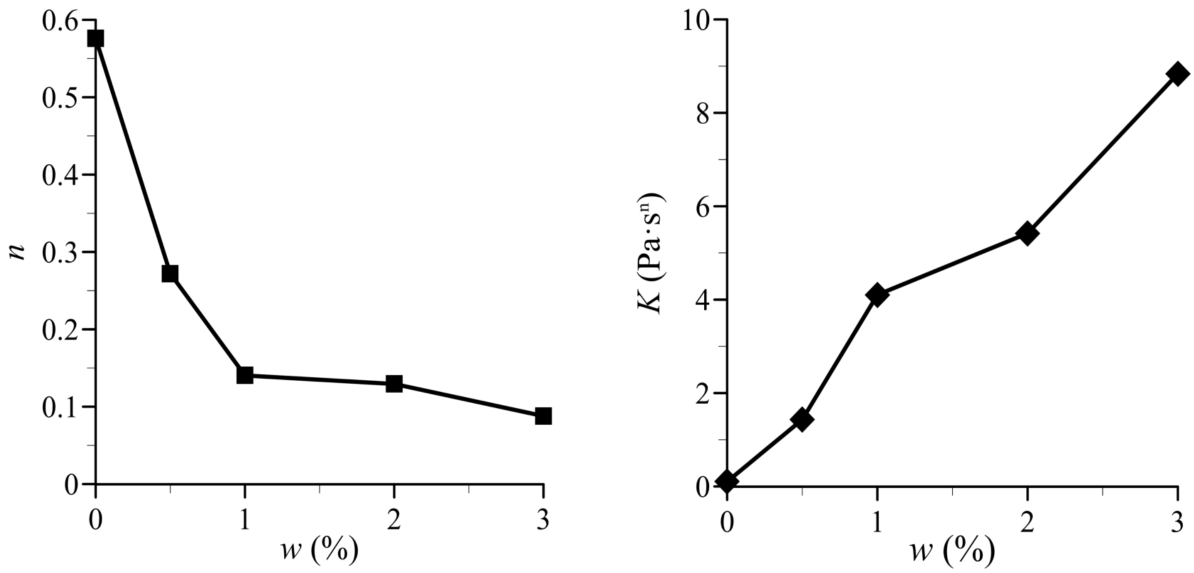
$$\mu = K\dot{\gamma}^{n-1} \quad (1)$$

where $K = 0.104$ is the consistency factor (Pa s^n), $\dot{\gamma}$ is the shear rate (s^{-1}), and $n = 0.576$ is the flow index. The dependence of rheological parameters drilling fluid on silica nanoparticle concentration is shown in figure 2. It is seen that nanoparticles addition significantly affects rheology of drilling mud. As nanoparticles concentration increases, flow index significantly decreases, while the consistency factor increases. Effect of low nanoparticles concentration on



(a) (b)

Figure 1. Viscosity coefficient (a) and shear stress (b) versus shear rate for drilling fluids at different concentrations of SiO_2 nanoparticles.



(a) (b)

Figure 2. Flow index (a) and consistency factor (b) versus nanoparticles concentration at room temperature.

the effective viscosity of drilling fluid is an important feature of nanoparticle additives. For example, addition of 1wt% SiO_2 nanoparticles increased consistency factor of drilling mud by 4 times.

Figure 3 shows that as the temperature increases, viscosity of drilling fluid increases. The

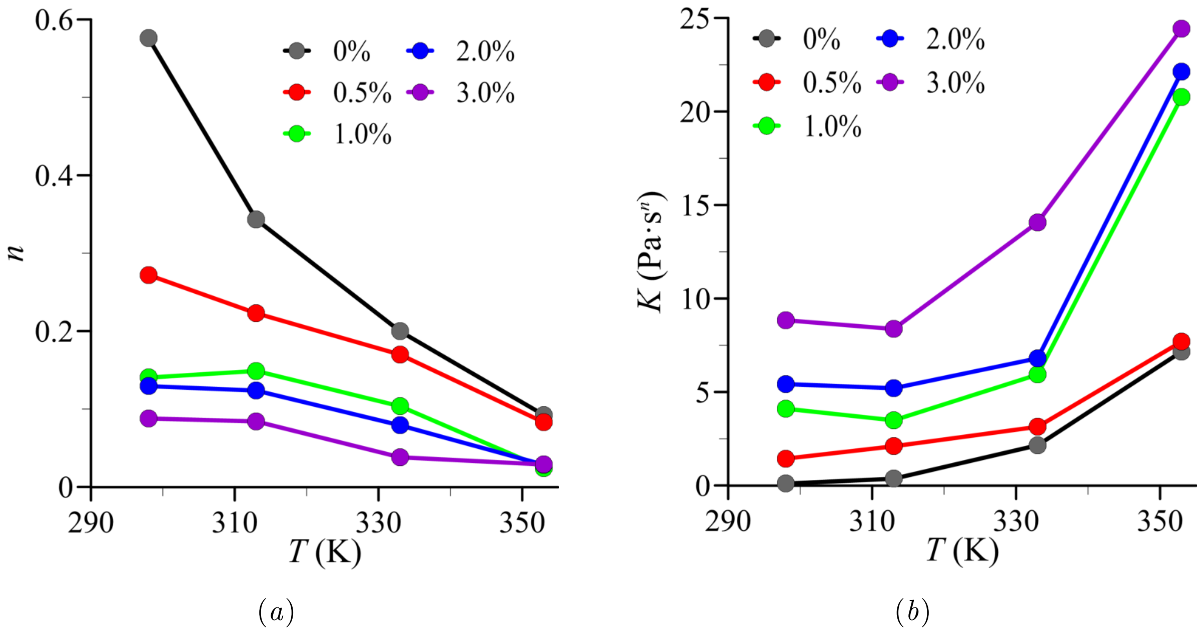


Figure 3. Dependence of flow index (a) and consistency factor (b) of drilling fluids on temperature.

addition of nanoparticles leads to an even greater increase in viscosity and can reach an increase of up to 5 times at high concentrations of nanoparticles and high temperatures. This can contribute to a more cutting transport performance [9].

4. Conclusion

The temperature dependence of viscosity of water-based clay drilling fluids with nanoparticles addition was investigated. It was shown a significant increase in viscosity of drilling fluid at low SiO_2 nanoparticles concentrations. It is also shown that the viscosity increment of drilling fluids with the addition of nanoparticles decreases with increasing temperature. Nanoparticles may, for sure, be selected in a manner such that their use will yield better results, because the rheological parameters of nanoparticles containing clay-based suspensions (in contrast to the suspensions with a macro- and microscopic particle size) depend on the size and material of the particles. It holds great promise for using nanoparticles to control drilling mud characteristics.

Acknowledgments

The work was supported by the Russian Science Foundation (project No. 17-79-20218).

References

[1] Nasser J, Jesil A, Mohiuddin T, Ruqeshi M A, Devi G and Mohataram S 2013 *World J.Nano Sci. Eng.* **3** 57–61
[2] Caenn R, Darley H and Gray G R 2011 *Composition and properties of drilling and completion fluids* (Houston, TX: Gulf Professional Publishing)
[3] Clem A G and Doehler R W Industrial application of bentonite *Proceedings of the Tenth National Conference on Clays and Clay minerals* ed Ingerson E (Austin, TX: Macmillan Co)
[4] Scalf J and West P 2006 *Pacific Nanotechnol.* **16** 1–8
[5] Minakov A V, Mikhienkova E I, Neverov A L and Buryukin F A 2018 *Tech. Phys. Lett.* **44** 367–70
[6] Minakov A V, Mikhienkova E I, Zhigarev V A, Neverov A L and Rudyak V Ya 2018 *Colloid J.* **80** 418–426
[7] Barry M M, Jung Y, Lee J K, Phuoc T X and Chyu M K 2015 *J. Pet. Sci. Technol.* **127** 338–46

[8] Rudyak V Ya, Minakov A V and Pryazhnikov M I 2017 *Tech. Phys. Lett.* **43** 23–6
[9] Minakov A V, Zhigarev V A, Mikhienkova E I, Neverov A L, Buryukin F A and Guzei D V 2018 *J. Pet. Sci. Technol.* **171** 1149–58