INFLUENCE OF ADDING SIO_2 NANOPARTICLES ON RHEOLOGICAL AND FILTRATION PROPERTIES OF WATER-BASED MUDS

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Abstract: *Drilling mud is a working fluid which consists of a water and different added additives and is used during drilling of wells. By circulating through the wellbore, it ensures continuous cuttings removal, required pressure to stop the influx of reservoir fluid in wellbore, lubrication of drilling tools and maintaining wellbore stability while drilling through various types of formations. Since the well is often drilled through water-soluble rocks, which are mostly consisted of clay minerals, the penetration of the filtrate (water) into such rocks can lead to their destabilization, so the industry is considering the application of new types of additives because conventional additives, due to their size, can not enter in pores of rocks which has very low permeability, plug them and thus reduce further penetration of the filtrate. In recent years, scientists have paid great attention to the testing of nanoparticles (most tests are carried out with SiO_2 nanoparticles) for drilling through low permeability rocks. Nanoparticles are particles whose diameters range from 1 to 100 nanometers so they can enter into the pores and create a high-quality mud cake, thereby reducing the filtrate invasion and increasing the wellbore stability. This paper describes a laboratory test carried out with SiO_2 nanoparticles which average particle size was 20 and 60 nm added in concentrations of 1 and 3 wt% to water-based muds. Special emphasis was put on rheological and filtration properties. By optimizing the concentration and size of the used nanoparticles, the rheological and filtration properties of the used drilling muds were improved.*

Keywords: SIO_2 NANOPARTICLES, DRILLING MUD, RHEOLOGY, FILTRATION, PPT, WELLBORE STABILITY

1. Introduction

Nanoparticles are particles whose diameter range from 1 to 100 nanometers, where 1 nanometer equals 10^{-9} meters. Their significance along with the number of experiments conducted and field applications has been growing year by year. Additives and other materials which aren't usually used in the petroleum industry often get translated to the size of nanoparticles, and as such are added in the drilling mud, acquiring new properties or improving and speeding up their effects in the process. Fluids that contain nanoparticles are referred as nanofluids. Nanofluids are defined as suspensions of nanoparticles having an average particle diameter up to 100 nm [1].

Many previous experiments have been conducted on the topic of filtration properties of water-based muds using nanoparticles. For example, Vryzas et al. (2015) [2] discovered that iron oxide nanoparticles greatly reduce the filtration of bentonite suspensions. The largest filtration reduction of 42.5% in comparison to the base mud was observed in HTHP conditions using iron nanoparticles (0.5 wt.%) in a bentonite suspension. Using SiO_2 nanoparticles, all three concentrations (0.5 wt%, 1.5 wt% and 2.5 wt%) showed various reductions as well. On the other hand, Taraghikhah et al. (2015) [3] found that filtration properties remain the same using SiO_2 nanoparticles in concentrations below 1 wt%. Wahid et al. (2015) [4] used SiO_2 nanoparticles in a combination with synthetic mud at concentrations between 0.32 to 0.71 wt.%, showing a reduction in filtration and thickness of the mud cake, with stable and almost unaltered rheological properties. Salih et al. (2016) [5] found that the SiO_2 nanoparticles at low concentrations adjust rheological properties, such as yield point and gel strength, whereas if added to higher concentrations (more than 0.5 wt%) they have an adverse effect.

After searching the literature, a general conclusion can be drawn that the nanoparticles are used primarily to maintain filtration properties of the drilling mud because due to their large specific surface area they fill the fine pores in the mud cake formed on the borehole wall and reduce filtrate invasion in rocks, but in most cases they also have impact on rheological properties even their primarily function is not to maintain rheological properties.

All of these experiments, combined with many others, indicate that there is still a lot to be done in the field of research of the effect that nanoparticles have on filtration and rheological properties in drilling muds.

2. Laboratory testing

Laboratory testing was performed at the Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb, Croatia. In order to better understand the impact of the addition of SiO_2 nanoparticles on the rheological and filtration properties of the drilling mud, two water-based drilling muds were chosen as base drilling muds. It was bentonite-based drilling mud (BM) and polymer-based drilling mud (PM). Preparation of base mud was carried out following American Petroleum Institute Standards, API Specifications 13A (1993) and API 13B-1 (1997) [6]. Bentonite-based drilling mud (BM) and polymer-based drilling mud (PM) formulations are shown in table 1 and 2.

Table 1. *Bentonite-based drilling mud formulation (BM)*

Base mud formulation	Quantity	Purpose
Water	-	base fluid
Bentonite	70 g/l	rheological and filtration properties
NaOH	2 g/l	alkalinity
PAC LV	2 g/l	filtration

Table 2. *Polymer-based drilling mud formulation (PM)*

Base mud formulation	Quantity	Purpose
Water	-	base fluid
XC polymer	3 g/l	rheological properties
CMC	6 g/l	rheological and filtration properties
$CaCO_3$	50 g/l	weighthening material
KOH	1 g/l	alkalinity
KCl	20 g/l	weighthening material, swelling inhibitor

SiO_2 nanoparticles used in this research were in the form of an aqueous suspension, and were added to both based muds until nanoparticles concentration reach 1 wt% and 3 wt%. This type of nanoparticles were chosen because of their greatest distribution and ease of delivery. Two types of SiO_2 nanoparticles were used, nanoparticles which average particle size was 20 nm and 60 nm. Data on SiO_2 nanoparticles used for laboratory research are shown in table 3.

Table 3. *Typical data for nanoparticles used in laboratory research*

Brand name	JN-30	JN-4060
Manufacturer	JinWei Group	JinWei Group
Appearance	an aqueous suspension	an aqueous suspension
Nanoparticles content in aqueous suspension	30 wt%	40 wt%
Density of aqueous suspension @20° (kg/m^3)	1 209	1 301
Average particle size (D50)	20 nm	60 nm
pH	9.6	9.8

Ten types of drilling muds were prepared and subjected to laboratory testing: two base drilling muds which formulation is shown in tables 1 and 2 and eight drilling muds contain SiO_2 nanoparticles, both types (20 and 60 nm) added in two concentrations, 1 and 3 wt%. In order to minimize the agglomeration of nanoparticles they were added slowly to base drilling muds and mixed for 30 more minutes.

After preparation of drilling muds, rheological and filtration properties were measured. The equipment and conditions are shown in table 4.

Table 4. Laboratory test equipment and conditions

Test	Equipment	Conditions
Rheology	OFITE Viscometer 900 	Atmospheric pressure, temperature 25, 50 and 75 °C
API filtration	API filter press 	Pressure 700 kPa, room temperature

Table 4. *Laboratory test equipment and conditions (continue)*

Test	Equipment	Conditions
PPT filtration	Permeability plugging tester (PPT) 	Diferential pressure 48.27 bar (700 psi), temperature 90 °C

3. Results and discussion

3.1. Rheological properties

Rheological properties were tested at 25, 50 and 75 °C using OFITE Viscometer 900. The following two figures show the relation of shear stress measured at shear rate of 5.1, 10.2, 170, 340, 510 and 1020 s^{-1} according to American Petroleum Institute Standards, API Specification API 13B-1 (1997) [6]. Figure 1 refers to bentonite-based mud (BM), while figure 2 refers to polymer-based mud (PM).

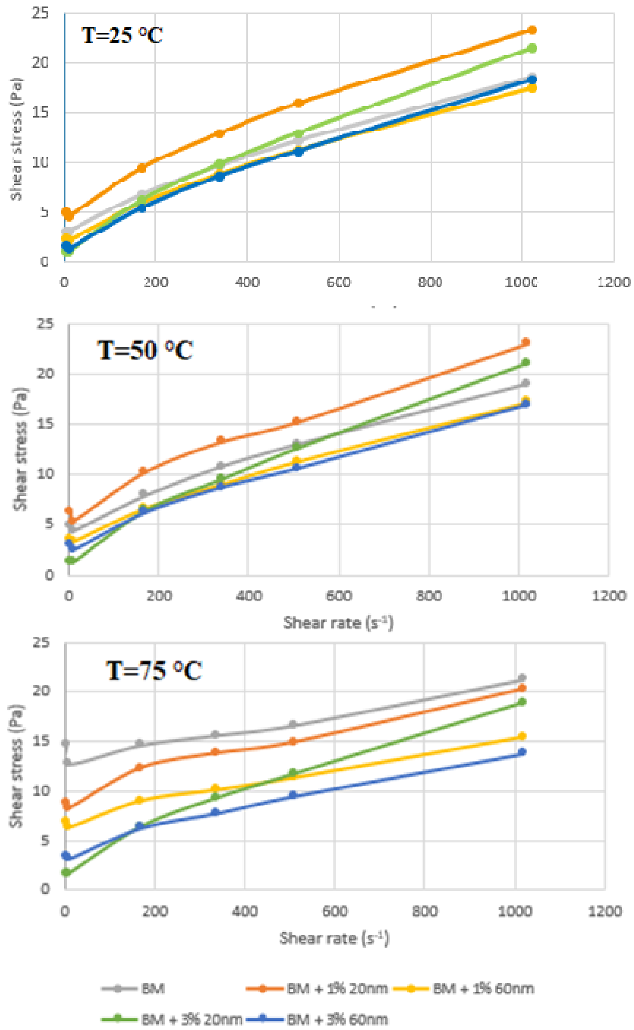

Fig 1. *Shear rate vs shear stress of BM at 25, 50 and 75 °C [according to 7]*

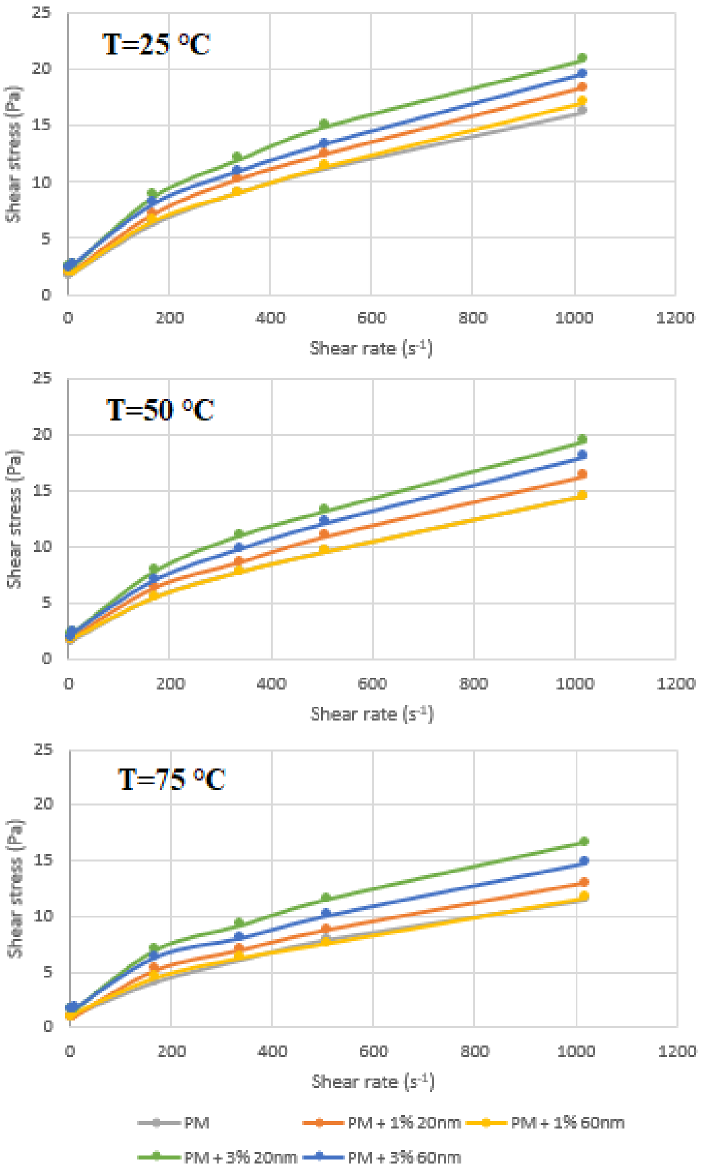

Fig 2. *Shear rate vs shear stress of PM at 25, 50 and 75 °C [according to 7]*

In bentonite-based muds, the lowest shear stresses measured at shear rates were obtained in mud which contain SiO_2 nanoparticles which has average particle size 60 nm added in both concentrations (blue and yellow line). In polymer-based muds the lowest shear stresses measured at shear rates were obtained in base mud without nanoparticles, while the highest shear stresses were measured in mud which contain SiO_2 nanoparticles which average particle diameter was 20 nm added in concentration of 3 wt%.

Also, as it was expected, by increasing temperature shear stresses values decreases for all tested muds.

3.2. API filtration

API filtration was carried out at standard API conditions at a pressure of 7 bar (100 psi) and room temperature according to American Petroleum Institute Standards, API 13B-1 (1997) [6]. Filter media was Whatman filter paper No. 50 and filtration area was 45,8 cm^2. Test was carried out for 30 minutes, while filtrate volumes were recorded after 1, 5, 7.5, 10, 15, 20, 25 and finally 30 minutes. Table 5 shows the results of API filtration for bentonite-based muds (BM) and table 6 shows the results of API filtration for polymer-based muds (PM).

Table 5. *Results of API filtration for bentonite-based muds [according to 7]*

Time, min	BM	BM + 1% NP 20nm	BM + 1% NP 60nm	BM + 3% NP 20nm	BM + 3% NP 60nm
	Filtrate volume, ml				
1	1.5	2.5	2.5	1.5	2
5	4.75	4.5	5.5	4.5	4.5
7,5	5.5	5.75	6.5	5.5	5.5
10	6.5	6.5	7.25	6.5	6.5
15	7.75	7.75	9	8	7.75
20	9	9	10.25	9	8.75
25	10	10	11.5	10.5	9.75
30	11	11	12.5	11.5	10.5

Table 6. *Results of API filtration for polymer-based muds [according to 7]*

Time, min	PM	PM + 1% NP 20nm	PM + 1% NP 60nm	PM + 3% NP 20nm	PM + 3% NP 60nm
	Filtrate volume, ml				
1	1.5	1.5	1	1.5	1.5
5	4	4	4	4.75	4.5
7,5	5.5	5	5	6.25	6
10	6.5	6.5	6	7.5	7
15	8	8.25	7.25	9.75	8.75
20	9.5	9.75	8.5	11.5	10.5
25	10.5	11.25	9.75	13.25	11.5
30	12	12.5	11	14.75	12.5

For bentonite-based muds, as shown in Table 5, the only drilling mud with nanoparticles that reduced the filtrate volume in comparison to the base bentonite-mud (11 ml) was the mud that contained 3% NPs 60 nm, by a slight margin of 0.5 mL, while the worst results were achieved by the combination of 1% NPs 60nm (12.5 ml).

The only polymer-based mud with NPs that showed improvement was the one containing 1% NP 60 nm (11 ml), reducing the amount of final filtrate by 1 mL. The rest of combinations of added NPs aggravated the volume of filtrate in comparison to the base polymer mud (12 ml), while worst was those with 3 wt% 20 nm (14.75 ml).

3.3. PPT filtration

PPT filtration was carried out using a Permeability Plugging Tester (PPT) at 90 °C. The experiment was performed with a differential pressure of 48.27 bar (700 psi), where the constant inlet pressure equaled 68.95 bar (1000 psi), while the outlet pressure amounted to 20.7 bar (300 psi). Filtration was performed through the ceramic disc which has a permeability of 0.75 μm^2 (750 mD). Tables 7 and 8 show the amount of measured filtration after 7.5 and 30 minutes and calculated amounts of Standard Filtrate Volume (VPPT) and Spurt Loss (V_1) of bentonite and polymer-based muds respectively. The PPT device has a filtration area of 22.9 cm^2, half the area of a API filter press so the total volume should multiply by 2 [8]. Also, Spurt Loss is the amount of filtrate collected before the mud cake has formed, expressed in ml.

Standard Filtrate Volume (VPPT) and Spurt Loss (V_1) can be calculated using the following equations [8]:

$$V_{PPT} = 2 \times V_{30} \tag{1}$$

$$V_1 = 4 \times V_{7,5} - 2 \times V_{30} \tag{2}$$

Where:

$V_{7,5}$ – Filtrate volume collected after 7.5 minutes

V_{30} – Filtrate volume collected after 30 minutes

V_{PPT} – Standard Filtrate Volume, ml

V_1 – Spurt Loss

Table 7. *PPT filtration after 7.5 and 30 minutes and calculated Standard Filtrate Volume and Spurt Loss of bentonite-based muds [according to 7]*

	BM	**BM + 1% NP 20nm**	**BM + 1% NP 60nm**	**BM + 3% NP 20nm**	**BM + 3% NP 60nm**
$V_{7,5}$	15	13	13	16.5	13.5
V_{30}	21.5	20.5	20.5	25	21.5
V_{PPT}, ml	43	41	41	50	43
V_1, ml	17	11	11	16	11

Table 8. PPT filtration after 7.5 and 30 minutes and calculated Standard Filtrate Volume and Spurt Loss of polymer-based muds [according to 7]

	PM	**PM + 1% NP 20nm**	**PM + 1% NP 60nm**	**PM + 3% NP 20nm**	**PM + 3% NP 60nm**
$V_{7,5}$	18	14	11.5	15.5	12
V_{30}	26.5	23	18.5	27	22
V_{PPT}, ml	53	46	37	54	44
V_1, ml	19	10	9	8	4

The values of Spurt Loss and filtration after 7.5 minutes were reduced in every mud with nanoparticles in comparison with their respective base muds, except for the BM + 3% NP 20nm. Filtration after 30 minutes, as well as the total filtration, was reduced in all muds with nanoparticles except for the BM and PM with 3% NP 20nm.

4. Conclusion

The examination of the impact of adding nanoparticles to drilling muds has been growing year by year. However, it is mostly referred to many laboratory tests with few field applications. In this paper were used SiO_2 nanoparticles which has different particle size and was added in different concentrations. The best result of the reduction of the final filtration volume during the measurement of PPT filtration was achieved by polymer-based drilling mud with nanoparticles which average particle diameter was 20 nm added in concentration of 1 wt%, while the smallest value of the Spurt Loss was achieved by polymer-based drilling mud with nanoparticles which average particle diameter was 60 nm added in concentration of 3 wt%. The lowest value of API filtration was measured in bentonite-based drilling mud with nanoparticles which average particle diameter was 60 nm added in concentration of 3 wt%.

However, in these conducted tests, few combinations of different nanoparticles added in different concentrations proved to be more successful, while some other combinations were more unfavorable during the same experiments. Therefore, based on these tests, it is not possible to extract one or more drilling muds that are generally shown to be the best, but it is necessary to continue testing on this subject with new nanoparticles added in different concentrations.

5. References

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ACKNOWLEDGMENTS

Dissemination process is supported by the Development Fund of the Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb.