Improving wellbore stability by applying drilling mud with Fe_2O_3 nanoparticles

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Abstract: *Since 90% of all problems related to the wellbore instability occur during drilling through shales, which are mostly consisted of clay minerals, the filtrate from drilling mud penetrate into shale rocks and lead to their destabilization, so the industry is considering the possible application of new types of additives because conventional additives, due to their size, cannot enter in pores of shales, plug them and reduce further filtrate penetration. The oil industry in last few years turns to investigate possible application of nanoparticles because they can enter in small shale pores and plug them, thus increasing the wellbore stability. In this paper the influence of the size (50 nm and between 20 and 30 nm) and concentration (0.5, 1, 3 and 5 wt%) of Fe_2O_3 nanoparticles on density, rheology, API filtration, and swelling of laboratory prepared pellets in contact with mud without and with nanoparticles was determined. Due to the fact that the rheological properties are significantly increased at higher concentrations, and that smaller particles give better results with an emphasis on increasing the wellbore stability further tests should be carried out with nanoparticles Fe_2O_3 which size is between 20 and 30 nm in maximum concentration of 1 wt%.*

Keywords*: Fe_2O_3 NANOPARTICLES, DRILLING MUD, RHEOLOGY, API FILTRATION, PELLET SWELLING*

1. Introduction

Water-based mud has been used to flush wellbore since the early 1900s. From then until the present day, the industry has been working on the development of new additives that must meet the increasing technical, economic, and environmental requirements that are imposed during the wellbore drilling [1]. Changes are also taking place in the field of drilling fluids - muds, because the classic additives used in muds, which have relatively larger dimensions, are not always suitable for solving problems that arise during the wellbore drilling through different rocks. Analyzing the data from the literature, 90% of all problems related to the wellbore instability occur during drilling through shales, rocks that make up 75% of all rocks through which the wellbore is drilled [2]. Wellbore instability is defined as any unwanted change in the wellbore diameter (narrowing or expansion) in relation to the diameter of the drill bit used to make the individual section of the wellbore, and it represents one of the leading problems during drilling. During drilling, water from drilling mud penetrate into shale and lead to its destabilization because conventional additives cannot enter in shale pores, due to their size, plug them, reduce further penetration of the water and increase wellbore stability. Therefore, for the past ten years nanoparticles are considered as potential additive because its diameters range from 1 to 100 nanometers so they can enter in shale pores, plug them and increase the wellbore stability [3]. These mud additives are added to mud in order to adjust its properties, and they can be in liquid or solid state (powder material). Nanoparticles have begun to be tested in the laboratory, and examples of their successful application in the field can already be found, especially for solving problems related to the construction of well channels [4]. In this paper, the impact of adding Fe_2O_3 nanoparticles, as one of the most common types that has been tested in laboratory conditions so far, was examined because of their greatest distribution and ease of delivery. Table 1 shows an overview of previous tests on the impact of Fe_2O_3 nanoparticles on different mud properties, with an emphasis on mud properties related to wellbore stability (filtration) and the possibility of using such muds in practice (rheology). The size of Fe_2O_3 nanoparticles in all tests was less than 50 nm, and they were added in different concentrations (up to 2.5 wt% at most).

Within the framework of this paper, laboratory tests were carried out on the influence of the size and concentration of Fe_2O_3 nanoparticles (sizes 50 nm and between 20 and 30 nm) on the following mud properties: 1) density, 2) rheology, 3) API filtration, and 4) swelling of laboratory prepared pellets in contact with mud without and with nanoparticles. The tests were carried out by adding nanoparticles to a simple bentonite suspension, in 4 concentrations: 0.5, 1, 3 and 5 wt%. In a laboratory test, the influence of the size and concentration of Fe_2O_3 nanoparticles on the properties of a bentonite suspension was determined, based on the sizes and concentrations of nanoparticles that are able to increase the wellbore stability and which are considered to be able to be further tested with the aim of application in muds of more complex composition.

Table 1: *The influence of the Fe_2O_3 nanoparticles used in various laboratory studies on the filtration and rheological properties of drilling muds*

Literature	**Vryzas et al., 2015** [5]	**Mahmoud et al., 2016** [6]	**Mahmoud et al., 2018** [7]
Concentration (%wt)	0.5, 1.5 and 2.5	0.3, 0.5, 1.5 and 2.5	0.3, 0.5 and 1
Drilling mud formulation	Deionized water to which bentonite has been added in a concentration of 7 wt%		Deionized water to which bentonite has been added in a concentration of 7 wt%, PAC, Fe-Cr-lignosulfonat, NaOH, $CaCO_3$, Mn_3O_4
Type of filtration test and conditions	API filtration; HTHP filtration (Δp= 20.7 bar [300 psi], T=121 °C [250 °F])	HTHP filtration (Δp=13.8-34.5 bar [200-500 psi], T=79.4 °C -176.7 °C [175-350 °F])	HTHP filtration (Δp=20.7 bar [300 psi], T=121 °C [250 °F])
Rheology equipment and conditions	Grace M3600 viscometer	49 to 93 °C	60 °C
The influence of adding nanoparticles on filtration	Decrease	Decrease	Decrease/increase depending on the concentration
The influence of adding nanoparticles on rheology	Increase plastic viscosity and yield point values	Increase plastic viscosity and yield point values	Decrease plastic viscosity and slightly increase yield point values

2. Laboratory testing

Laboratory testing was performed at the Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb, Croatia. Fe_2O_3 nanoparticles used were in the form of an aqueous suspension. In this research two types of Fe_2O_3 nanoparticles were used, nanoparticles which average particle size was 50 nm and between 20 and 30 nm. Nanoparticles used in this research were in the form of an aqueous suspension. Typical data for Fe_2O_3 nanoparticles used in laboratory research are shown in table 2.

Table 2: *Typical data for nanoparticles used in laboratory research*

Brand name	**SAT-02**	**SAT-01**
Manufacturer	SAT nano Technology Material CO., Ltd.	
Appearance	an aqueous suspension	
Nanoparticles content in aqueous suspension	20 wt%	25 wt%
Average particle size (D50)	50 nm	between 20 and 30 nm

As base drilling mud was chosen bentonite-based drilling mud (BM) which was prepared by adding 70 g of bentonite to 1 liter of water. Muds with nanoparticles were prepared in such a way that 70 g of bentonite and 5, 10, 30 and 50 g of Fe_2O_3 nanoparticles were added to 1 liter of water (water from aqueous suspension + added water). All muds were prepared according to American Petroleum Institute Standards, API Specifications 13A (1993) and API 13B-1 (1997) [8]. Drilling mud formulation used in this laboratory research is shown in table 3.

Table 3: *Drilling mud formulations*

Mud formulation	**Nanoparticles concentration added to drilling mud (wt%)**				
	0	**0.5**	**1**	**3**	**5**
Water (ml)*	1 000	1 000	1 000	1 000	1 000
Bentonite (g)	70	70	70	70	70
Nanoparticles (g)	0	5	10	30	50
* water from aqueous suspension + added water					

Within the framework of this paper, laboratory tests were carried out on the influence of the size and concentration of Fe_2O_3 nanoparticles (sizes 50 nm and between 20 and 30 nm) on the density, rheology, API filtration and swelling of laboratory prepared pellets. The equipment and measurement procedures are shown in table 4.

Table 4: *Laboratory test equipment and measurement procedures*

Test	**Equipment**	**Measurement procedures and conditions**
Density	Mud balance	The balance cup was filled with the drilling mud to the limit. Balance the assembly by moving the rider along the arm. Read the sample weight from the side of the rider nearest the balance cup.
Rheology	Fann viscometer	Shear stress data were obtained at six fixed shear rates of 5.1, 10.2, 170, 340, 510 and 1020 s^{-1}. According to equations shown in paper Mijić et al. (2021) [9] plastic viscosity (PV) and yield point (YP) values were calculated for all tested muds.
API filtration	API filter press	API filtration was carried out at a pressure of 7 bar (100 psi) and room temperature. 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 volume was recorded after 30 minutes.
Pellet swelling	Compactor and linear swellmeter	A mixture of 6 g of bentonite and 6 g of quartz was placed in a compactor, which was then exposed to the pressure of 41.36 MPa (6000 psi) that remained constant for the 30 minutes. After the compression time has elapsed, the swelling of prepared pellet was measured in linear swell meter.

3. Results and discussion

a) Effect of concentration and size of Fe_2O_3 nanoparticles on mud density

Table 5 shows the measured density values of drilling muds without and with Fe_2O_3 nanoparticles, both sizes.

Table 5: *Drilling mud density without and with nanoparticles Fe_2O_3-50 nm and Fe_2O_3-between 20 and 30 nm*

Fe_2O_3 nanoparticles (both tested sizes) concentration added to drilling mud (wt%)	**Drilling mud density (kg/m^3)**
0	1 030
0.5	1 040
1	1 050
3	1 060
5	1 080

By increasing the concentration of Fe_2O_3 nanoparticles in the drilling mud, the density of the drilling mud increases from 1 030 kg/m^3, which corresponds to the density of the drilling mud without nanoparticles up to 1 080 kg/m^3, as measured at a concentration of Fe_2O_3 nanoparticles (both sizes) of 5 wt%.

b) Effect of concentration and size of Fe_2O_3 nanoparticles on mud rheology

Figure 1 shows the results of the calculated values of the rheological parameters: plastic viscosity (PV) and yield point (YP).

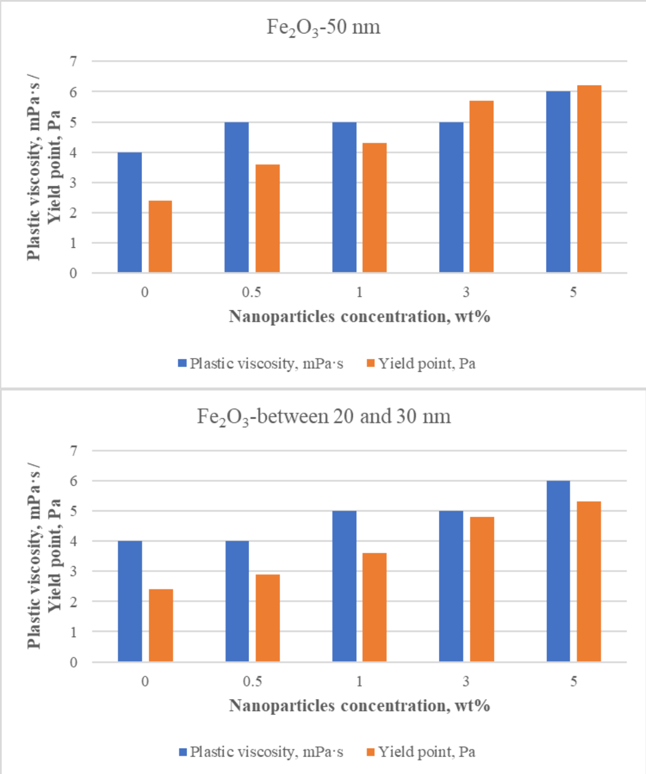

***Fig 1.** PV and YP of all tested drilling muds*

The plastic viscosity (PV) values increase with an increase in the concentration of Fe_2O_3-50 nm nanoparticles above 0.5 wt%, while for Fe_2O_3-between 20 and 30 nm nanoparticles it increases above 1 wt%. The values of the yield point (YP) increase with an increase in the concentration of Fe_2O_3 nanoparticles for both tested sizes, but the measured values were higher for muds containing Fe_2O_3-50 nm nanoparticles.

c) Effect of concentration and size of Fe_2O_3 nanoparticles on API filtration

Figure 2 shows measured data for API filtration of drilling muds without and with Fe_2O_3 nanoparticles (both sizes).

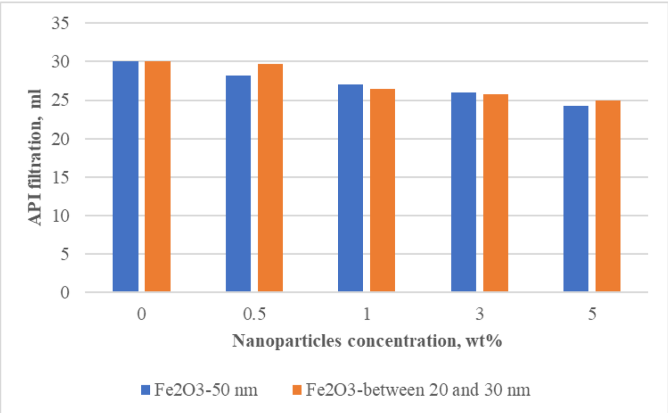

***Fig 2.** API filtration of drilling muds without and with Fe_2O_3 nanoparticles (both sizes)*

In Figure 2 can be seen that by increasing the concentration of nanoparticles the API filtration value decreases for both tested sizes. Comparing both tested sizes, it can be seen that for a certain concentration the API filtration values are slightly different. Table 6 shows the decrease/increase (%) of API filtration of drilling mud with Fe_2O_3 nanoparticles compared to API filtration of drilling mud without nanoparticles (30 ml). Those sizes and concentrations of Fe_2O_3 nanoparticles which reduce API filtration are highlighted in green. Based on the data presented in Table 6, the positive impact of adding Fe_2O_3 nanoparticles to the drilling mud on the reduction of API filtration can be observed at small concentration of 0.5 wt%, but a more significant decrease in API filtration value was recorded at a concentration of 1 wt% for both tested muds (over 10 %). The best results were achieved by adding 5 wt% Fe_2O_3 nanoparticles which size was 50 nm (reduction of API filtration by 16.67 %) and between 20 and 30 nm (reduction of API filtration by 19.17 %).

***Table 6:** Decrease/increase (%) of API filtration of drilling mud with Fe_2O_3 nanoparticles compared to API filtration of drilling mud without nanoparticles*

Decrease/increase (%) of API filtration		
Fe_2O_3 nanoparticles concentration in drilling mud (wt%)	Nanoparticles size	
	50 nm	between 20 and 30 nm
0.5	-0.83	-5.83
1	-11.67	-10.00
3	-14.17	-13.33
5	-16.67	-19.17

Figure 3 shows the swelling of pellets in mud without and with Fe_2O_3 nanoparticles, both tested sizes. The swelling is expressed in percentages after the pellet has been in contact with the mud for 24 hours.

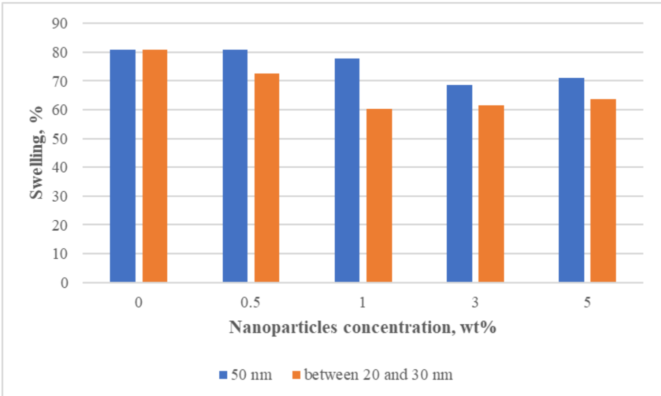

***Fig 3.** Swelling of pellets in mud without and with Fe_2O_3 nanoparticles expressed in percentages after the pellet has been in contact with the mud for 24 hours*

It is evident from Figure 3 that muds with added Fe_2O_3-50 nm nanoparticles in concentrations of up to 1 wt% have no significant influence on the swelling of the prepared pellets and the measured values are similar to the one measured in the drilling mud without nanoparticles (80.9%). By increasing the concentration of nanoparticles up to 3 wt% and more, a significant reduction in swelling is achieved. The addition of Fe_2O_3-between 20 and 30 nm nanoparticles in any concentration reduced the swelling of the prepared pellets, but a more significant decrease was recorded at a concentration of 1wt%. Table 7 shows the decrease/increase (%) of pellet swelling in drilling muds with Fe_2O_3 nanoparticles after 24 hours compared to their swelling in drilling mud without Fe_2O_3 nanoparticles (80.9%). Those sizes and concentrations of Fe_2O_3 nanoparticles which reduce pellet swelling are highlighted in green.

***Table 7:** Decrease/increase (%) of pellet swelling in drilling muds with Fe_2O_3 nanoparticles after 24 hours compared to their swelling in drilling mud without Fe_2O_3 nanoparticles*

Decrease/increase (%) of pellet swelling		
Fe_2O_3 nanoparticles concentration in drilling	Nanoparticles size	
	50 nm	between 20 and 30 nm

mud (wt%)		
0.5	0.12	-10.38
1	-3.71	-25.34
3	-15.08	-23.98
5	-11.96	-21.31

Based on the data presented in Table 7, the positive impact of adding Fe_2O_3 nanoparticles on the reduction of pellet swelling in contact with drilling mud can be observed. After 24 hours, the swelling of the pellets in the drilling containing from 0.5 to 5 wt% of nanoparticles Fe_2O_3-20 to 30 nm was reduced regardless of their size. The best result was obtained by addition of 1 wt% nanoparticles Fe_2O_3 which size was between 20 and 30 nm (25.34%). The addition of Fe_2O_3-50 nm nanoparticles also reduced the swelling of the prepared pellets, but the results were slightly worse compared to Fe_2O_3-between 20 and 30 nm.

4. Conclusion

Based on the conducted laboratory tests, the following can be concluded:

- The values of the PV increase slightly with increasing concentration up to 5 wt% for both tested sizes, but YP values were higher for muds containing Fe_2O_3-50 nm nanoparticles at the same concentration.
- API filtration value decreases by increasing the concentration of Fe_2O_3 nanoparticles for both tested sizes. Also, particle size has a negligible effect on API filtration.
- Analyzing the swelling of the prepared pellets, the positive influence of Fe_2O_3 nanoparticles can be seen. Comparing both types of tested nanoparticles, nanoparticles with a size between 20 and 30 nm performed better, and the swelling of the prepared pellets after 24 hours was significantly reduced at a concentration of 1 wt%. It was significantly less than the swelling measured at any concentration with Fe_2O_3-50 nm.

Based on the analysis of the application of Fe_2O_3 nanoparticles in a simple drilling mud (bentonite suspension), it can be concluded that positive results are obtained, but due to the fact that the rheological properties are significantly increased at higher concentrations, tests with smaller concentrations (up to 1 wt%) are recommended.

When comparing the results obtained by adding nanoparticles Fe_2O_3-50 nm and Fe_2O_3-between 20 and 30 nm, it is evident that smaller particles give better results with an emphasis on increasing the wellbore stability, so further tests should be carried out with nanoparticles Fe_2O_3 which size is between 20 and 30 nm in maximum concentration of 1 wt%.

5. References

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