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Improved Filtration Properties of Polystyrene Nanoparticle additives to Water Based Drilling Fluid

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Abstract. This work present polystyrene nanoparticle, a new nanoparticle that is non-conductive and less expensive. Polystyrene nanoparticle added to water based drilling fluid design and tested for filtration loss at Low Pressure Low Temperature (LPLT) condition (25ºC and 100 psi) and High Pressure High Temperature (HPHT) condition (150ºC and differential pressure of 500 psi). In comparison to based fluid design, polystyrene nanoparticle added drilling fluid reduced filtration loss by 29%. While in comparison to base fluid and polymer drilling fluid, the polystyrene nanoparticle added drilling fluid reduced filtration loss by 50.7% under LPLT condition. Under HPHT condition, polystyrene nanoparticle added drilling fluid reduced fluid loss by 44.4% in comparison to base fluid. While in comparison of base fluid, polymer and polystyrene nanoparticles reduced fluid loss by 61.1%. Polystyrene nanoparticle drilling fluid formed a thin non-erodible low permeability filter cake, this showed that polystyrene nanoparticles plugged the pores of the filter cake. Thus, it can be concluded that polystyrene nanoparticle improved filtration control of water based drilling fluid.

1. Introduction

Drilling operation involves making a conduit from the surface to subsurface reservoir target. Important to drilling operation success is drilling fluid used for the drilling. Mostly used drilling fluid is water based drilling fluid (WBDF) for reasons of low cost and environmental considerations. WBDF consist mainly of fresh water and other drilling fluid additives. Drilling through very permeable formation can cause loss of drilling fluid into formation pores and this can cause damage to the near wellbore region. Thus, it is important that the drilling fluid be designed to be able to resolve the problem of fluid loss into permeable zones.

To solve this problem of fluid loss, polymers has been integrated into drilling fluid to plug formation surfaces [1]. However, there are limitations when using polymers at high pressure high temperature, as the polymers tend to denature at extreme conditions [2]. Recently, nanotechnology research has shown that nanoparticles has application in the oil and gas industry. Integration of nanoparticles into drilling fluid design has been shown to affect the rheology and filtration properties of drilling fluid [3]. Table 1 shows review of research works where nanoparticles was integrated in drilling fluid design to achieve fluid loss control.

From the review, it is shown that metallic oxide nanoparticles are very efficient as filtration loss control additives. However, metallic oxide is expensive to manufacture and due to their magnetic and electrical properties they interfere with downhole sensor tools [9]. This work presents nano polystyrene, a non-metallic nanoparticle, electrically neutral and usually dumped at landfill as waste. Nano polystyrene was integrated into water based drilling fluid with environmentally friendly anionic surfactant to serve as fluid loss control in the water based drilling fluid.

Table 1. Review of nanoparticles application in drilling fluid filtration loss reduction

Nanoparticles/Nano-composites	Filtration control (30 mins)	Reference
TiO_2/Polyacrylamide nanocomposite	2-64% fluid loss reduction	[4]
Iron oxide (Fe_2O_3)	LPLT 19.3% filtration loss reduction HPHT 42.5% filtration loss reduction	[5]
Iron oxide (Fe_2O_3)/intercalated clay hybrid	LPLT 37% filtration loss reduction HPHT 47% filtration loss reduction	[6]
Multi-Walled Carbon Nanotube (MWCNT)/nanosilica	LPLT 0.01ppb MWCNT = 4.5 mL 0.01ppb nanosilica = 4.8 mL	[7]
Zinc oxide nanoparticles/acrylamide composite	LPLT 14% filtration loss reduction HPHT Minimal filtration loss reduction recorded	[8]

2. Materials and methods

Nano Polystyrene (NP) (25nm) with polystyrene density of 1.06 g/cm^3, Methyl Esther Sulphonate (MES) (Molecular Weight = 279.7 g/mol), NaOH, weighting material (Barite), Poly Anionic Cellulose (PAC).

2.1 Drilling fluid preparation

The experimental setup was formulated according to the American Petroleum Institute (API) standards, and it comprises of fresh water, bentonite, polymers, methyl ester surfactant (MES), barite and polystyrene. The polymer used in this experiment is Poly Anionic Cellulose (PAC), and nano polystyrene (NP) was used in this experiment. There were five different samples prepared and each with variation of the addition of materials into the water-based drilling fluid starting with the base fluid formulation which was fresh water and bentonite. The pH was maintained between 9 and 9.5 and this was done by the addition of sodium hydroxide solution into the samples.

The base fluid sample which is the sample 1 was prepared by adding 15g of bentonite into the mixing cup containing 350 ml deionised water. Then sample 2 and 4 were prepared in a similar method to sample 1, where the component was added after every 5 minutes to ensure even mixing. Sample 5 was prepared differently, 0.01wt% of nano polystyrene was mixed with 1g of MES in de-ionized water and then ultra-sonicated for 15 minutes. These is then mixed with base fluid sample 1 and PAC for 10 minutes. Lastly, weighting material barite was added to the mix and stirred continuously for another 10 minutes. Table 2 shows sample formulations of water based drilling fluid. Figure 1 shows dispersion of additives for sample 5.

2.2 LPLT and HPHT Filtration

The Low Pressure Low Temperature (LPLT) fluid loss filtration measurement was carried out according to the recommended API standard procedure using the filter press, at a differential operating pressure of 100 psi and at temperature of 25^{o}C. The filtrate volume was collected every 5 minutes for 30 minutes for each of the samples and the thickness of the filter cake was measured.

The High Pressure High Temperature (HPHT) fluid loss test was conducted using the HPHT filter press at the operating differential pressure of 500 psi and temperature of 150ºC. The filtrate volume was collected for 30 minutes at interval of 5 minutes for each of the samples and the thickness of the filter cake was measured. The filter cake deposit on the filter paper was then carefully rinsed and measured. Permeability of the filter cake was determined by the rate of filtration through the filter cake as described by the Darcy's Law with the following formula:

$$\frac{dV}{dt} = \frac{KA\Delta P}{\mu h} \quad (1)$$

Where dV/dt is the rate of filtration, A is the cross-sectional area (cm^2), K is the permeability (mD), ΔP is the differential pressure (psi), μ is the viscosity (cP) and h is the thickness of filter cake (inch). It was worth mentioning that the cross-sectional area of the filter cakes of the LPLT and HPHT were at 22.06 cm^2 and 46.6 cm^2 respectively.

Table 2. Formulation of water based drilling fluid

Sample	Formulation of water based drilling fluid
1	350 mL fresh water + 15g Bentonite
2	350 mL fresh water + 15g Bentonite + 0.1g MES
3	300 mL fresh water + 15g Bentonite + 50 mL of 0.01wt% NP
4	350 mL fresh water + 15g Bentonite +1g PAC
5	300 mL fresh water + 15g Bentonite + 1g PAC + 0.1g MES + 150g Barite + 50 mL of 0.01wt% NP

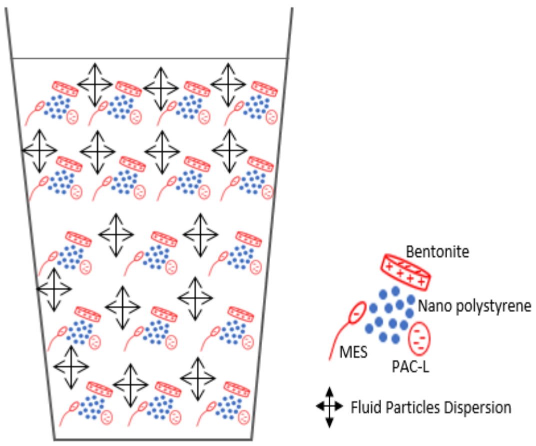

Figure 1. Dispersion of sample 5 drilling fluid additives.

3. Result and discussion

Filtration characteristics of the water-based drilling fluid is dependent on the nature of the quantity of colloidal materials included in the drilling fluid. Thus, an effective fluid loss additive that controls and limits the filtration loss is achieved by adding optimum amount of certain colloidal materials [10][11]. In Figure 2 (a) and (b), sample 1 is the reference base fluid, which is representative of bentonite-water based drilling fluid. Sample 2 which only consist of the surfactant alone do not improve the drilling fluid formulation in the filtration loss control. This is because the surfactant reduces the interfacial tension between the bentonite particles which allows the water to flow out from the drilling fluid and leads to substantial fluid loss comparable to base fluid loss. Sample 3 LPLT filtration loss measurement shows similar trend as sample 1 and 2, this due to improper dispersion as a result of absence of MES. Thus, leading to the agglomeration of the nano polystyrene in the drilling fluid. In contrast, sample 3 showed improvement of filtration loss control at HPHT condition this is because at higher temperature the bentonite particles surface area decreases [12]. This allows nano polystyrene with large surface area to occupy available pores as a result control fluid loss. Sample 4 shows improvement because of the addition of polymer (PAC) is added into the mixture of sample 1. This improvement was observed in both LPLT and HPHT filtration loss. The polymer forms cross-linker between the bentonite particles to have a higher water retention in the drilling fluid [13]. Sample 5 shows the best drilling fluid formulation that had the least amount of filtration loss at LPLT and HPHT conditions. This is due the fact that the addition of the surfactant reduces the interfacial tension between the bentonite particles, allowing a better dispersion of the polymers to plug macro scale of the pore spaces whilst the nano-polystyrene plugs the nanoscale pore spaces.

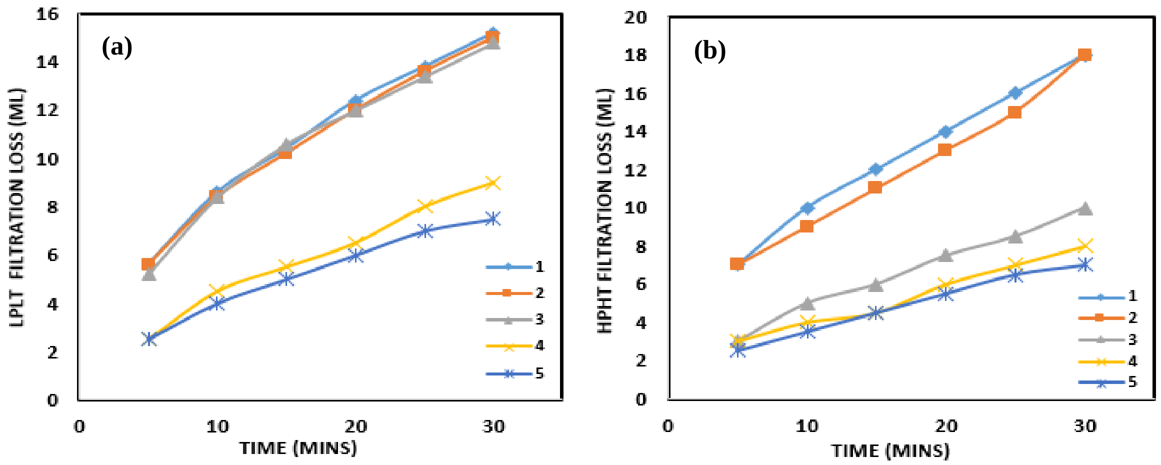

Figure 2. Filtration loss plot of five drilling fluid samples (a) LPLT filtration loss (b) HPHT filtration loss

Table 3 presents percentage of filtrate volume reduction with respect to reference base fluid, filter cake thickness and permeability of filter cake for LPLT filtration. Samples 2, 3 and 4 showed reduction in fluid loss when compared to base fluid sample 1. Sample 5 showed improved filtration with 50.7% fluid loss reduction when compared to the base fluid, its filter cake thickness is 1 inch less than the base fluid with very low permeability. The low permeability value supports the fact that nano polystyrene present in sample 5 was able to plug pore spaces thereby preventing excessive fluid loss. Table 4 present percentage of filtrate volume reduction, filter cake thickness and permeability of filter cake for HPHT filtration. Sample 2 fluid loss was low as compared to base fluid because sample 2 active additive is MES which is a surfactant. MES functions as a dispersant and only affect the rheology of the drilling fluid. Samples 3 and 4 showed good fluid loss control while sample 5 showed the best result of 61.1% fluid loss control when compared to base fluid. The filter cake thickness of sample 5 is 1.5 inch less than the base fluid. The permeability of sample 5 is the lowest when compared to all the fives samples. This is an indication that the filter cake is non-erodible with very tight permeability, which supports the high filtrate volume reduction. Figure 3 shows the illustration of sample 5 filter cake, the schematic clearly illustrates how the dispersed additives of MES, PAC and nano polystyrene particles plug and occupy pore spaces in the filter cake. This mechanism further supports the result of low permeability of the filter cake and reduction of fluid loss.

Table 3. Filtration volume, filter cake thickness and permeability for LPLT filtration

Sample	Filtrate volume reduction (%)	Filter Cake Thickness (/32 in.)	Filter Cake Permeability $x10^{-2}$ (mD)
1	0.00	3.00	8.50
2	1.30	3.00	7.10
3	29.00	2.00	5.20
4	40.80	2.00	6.90
5	50.70	2.00	1.10

Table 4. Filtration volume, filter cake thickness and permeability for HPHT filtration

Sample	Filtrate volume reduction (%)	Filter Cake Thickness (/32 in.)	Filter Cake Permeability $x10^{-2}$ (mD)
1	0.00	3.50	3.20
2	0.00	3.50	3.87
3	44.40	3.00	2.74
4	55.60	2.00	3.11
5	61.10	2.00	2.18

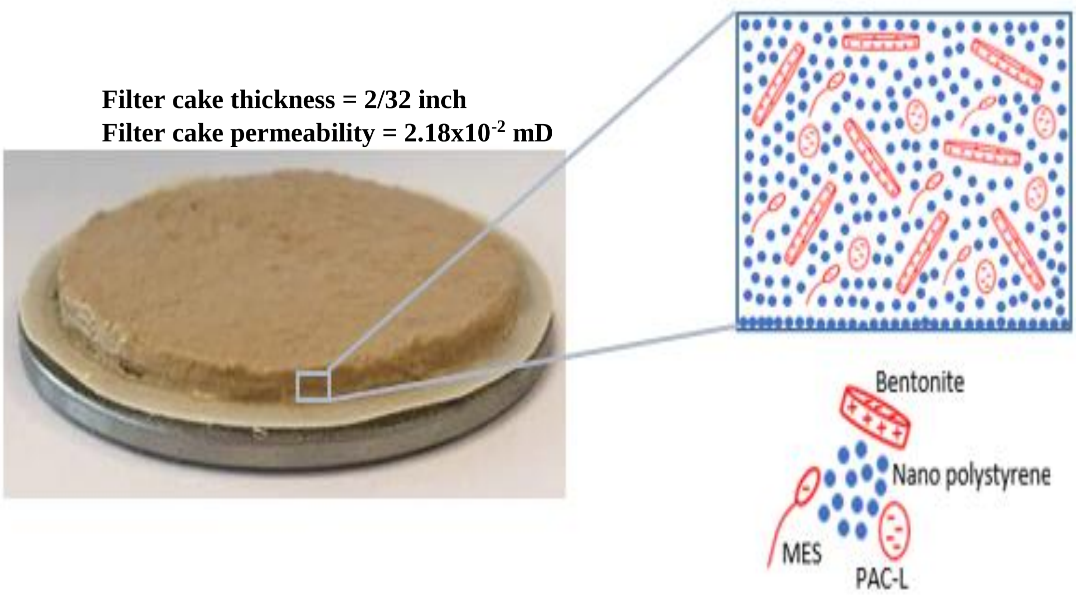

Figure 3. Illustration of filtration loss reduction mechanism for sample 5 filter cake.

4. Conclusion

In this study, an experimental investigation was conducted to improve the filtration properties of water based drilling fluid by the addition of methyl ester sulphonate (MES) surfactant and nano-polystyrene. Fluid loss control experiments was performed under LPLT and HPHT conditions. From the result, it was found that sample 5 which contains active additives such as methyl ester sulphonate (MES), poly anionic cellulose (PAC) and nano polystyrene showed the best reduction in filtrate volume reduction, non-erodible filter cake and very low permeability. Particularly, nano polystyrene had made an improvement in terms of filtration control due to its plugging properties in between the nano pore spaces of the filter cake. The negatively charged ions of the methyl ester sulphonate (MES) surfactant allows a well dispersion of the poly anionic cellulose (PAC) and the nano-polystyrene which contributes to the optimised result in sample 5. It can be concluded, that the synergy of methyl ester sulphonate surfactant and nano polystyrene improved filtrate loss control of water based drilling fluid.

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