Rheological Property and Bentonite Cleaning Efficiency of Smart Spacer Fluid quantified using Vipulanandan Rheological Model

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Abstract: In this study, the effect bentonite contamination on the electrical resistivity and rheological properties of a sensing smart spacer fluid modified with iron oxide nanoparticles (nanoFe2O3) were investigated. The amount of bentonite contamination was varied from 0 to 0.5% by weight of the spacer. The nanoFe2O3 contents (particle size of 30 nm and surface area of 38 m2/gm) in the spacer fluid were varied up to 1% by the weight of spacer fluid to enhance the rheological properties of the spacer fluid. The addition of nanoiron increased the maximum shear stress by 36% in bentonite contaminated spacer fluid. The cleaning efficiency of the spacer fluid was 82.3% without the addition of nanoFe2O3 for cleaning bentonite drilling mud. With the addition of nanoFe2O3 the cleaning efficiency increased from 82.3 to 98.5%, 16.2% increase in the efficiency.

1. Introduction: Spacer fluids have been primarily developed to separate the cement slurry from the drilling fluid because of contamination of the cement affecting the cementing operation and long-term stability of the cemented wells. Incompatibility in the fluids can cause significant increase in the viscosity, and thus hydraulic resistance inside the wellbore. Efficient displacement and effective removal of the drilling fluids and associated residues from the wellbore prior to the completion of a well is critical for optimized hydrocarbon recovery (Quintero, Christian et al, 2008). There are several benefits in using drilling mud in drilling operations but there are concerns about potential contamination of the spacer and cement (Vipulanandan and Amani, 2015). Also, cements are sensitive to drilling fluid contaminations and therefore even a thin layer of drilling fluid could prevent the cement from bonding to the formation and the casing. Effective displacement of the synthetic or oil based drilling mud is extremely important in order to minimize non-productive time (NPT), reduce waste volume, to prevent cement failures and to reduce the risk of completion tool complications (Quintero et al, 2012).

2. Objective: The overall objective was to experimentally determine and quantify the bentonite cleaning efficiency of nanoiron oxide based smart spacer fluid.

3. Experiment:

Raw Materials

UH Biosurfactant

The biosurfactant is produced from waste oil with acclimated bacteria in continuously stirred batch reactor (Harendra et al. 2008; Vipulanandan et al. 2000). The critical micelle concentration (CMC) for this biosurfactant is 0.5 g/L and the surface tension reduces to 30 dynes/cm. The biosurfactant is water soluble and based on Fourier Transform Infra Read (FTIR) spectroscopy analyses both carboxyl (COO-) and hydroxide (OH-) groups were identified in the biosurfactant.

Water Based Drilling Fluid

The water based drilling fluid is prepared by addition of 8% bentonite by weight of water. The density and resistivity of the drilling fluid was 8.2 ppg and 7 Ω-m.

Spacer Fluid Preparation

The spacer fluid was prepared by using water as the base fluid. Rheology modifiers such as Guargum upto 1% and UH bio-surfactant upto 0.4% were added. Also upto 3% KCL was added with the weighting agent lead nitrate (Pb(NO3)2). KCl was first mixed with water till it completely dissolves. Then rheology modifier Guargum was added followed with the UH Bio-surfactant and mixed until uniform solution is obtained. This uniform mixture is then mixed with the weighting agent to obtain the spacer fluid. Also, nanoiron was added to the spacer fluid to enhance the performance with pressure, temperature and magnetic field. Also the fluid was characterized with electrical resistivity and density measurements at each stage of mixing.

4. Methods

Rheological properties

The rheology tests for smart spacer fluid with different contents of nanoiron (nanoFe_2O_3) at temperature of 25°C and different bentonite contents were tested using a viscometer in the speed range of 0.3 to 600 rpm (shear strain rate of 0.5 s^{-1} to 1024 s^{-1}) and related shear stresses were recorded.

Cleaning efficiency test

The cleaning efficiency test was performed on the spacer fluid to quantify the ability of the spacer to clean the bentonite drilling fluid.

Modeling

Vipulanandan Rheological relationship between shear stress and shear strain rate for the smart spacer fluids was investigated (Vipulanandan and Mohammed 2014).

$$\tau = \tau_{0_2} + \frac{\dot{\gamma}}{C + D\dot{\gamma}},$$

where τ: shear stress (Pa); C $(Pa.\ s)^{-1}$ and D $(Pa)^{-1}$: are model parameters;

5. Results and Discussion

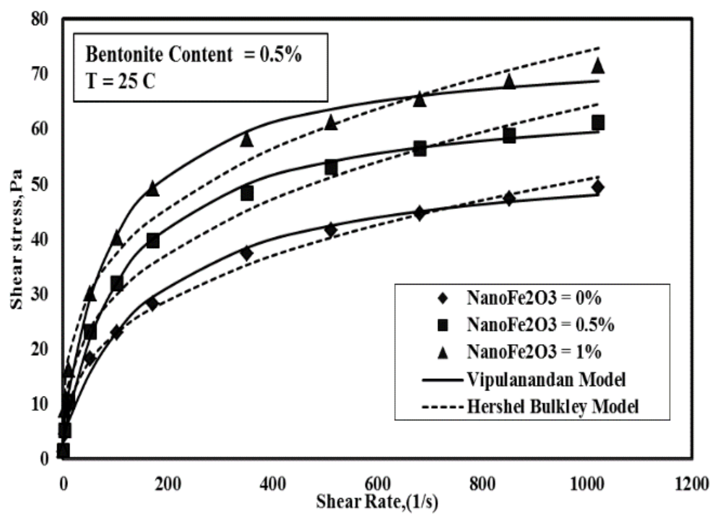

Fig.1: Shear Stress- Shear Strain rate Relationship for Spacer Fluid with different nanoFe_2O_3 contents and 0.5% bentonite contamination at temperature of 25°C.

Table 1: Bingham Plastic, Herchel-Bulkley and Hyperbolic Rheological model parameters for Spacer Fluid with different nanoFe_2O_3 contents and 0.5% bentonite contamination at temperature of 25°C.

	Bingham Plastic Model		Hershel Bulkley Model				Vipulanandan Model				
Model Parameters	PV(cP)	Yield Stress (τ), Pa	n	k	τ (yield)	RMSE	C(Pa. s)$^{-1}$	D (Pa)$^{-1}$	τ (yield)(Pa)	τ (max)(Pa)	RMSE
NanoFe = 0%	43.2	13.02	0.35	4.57	0	1.34	3.41	0.019	4.18	56.8	1.52
NanoFe = 0.5%	53.3	17.26	0.33	6.42	0	2.83	1.96	0.015	3.61	70.3	1.23
NanoFe = 1%	58.9	22.74	0.3	9.36	0	3.33	1.44	0.014	5.89	77.3	2.16

Bentonite Contamination = 0.5%:

Bingham model (1919)

The Plastics viscosity increased from 43.2 to 58.9 cP, 36 % increase and yield stress from 13 Pa to 22.7 Pa, 75% increase (Fig. 1).

Herschel-Bulkley model (1926)

The model parameter k for the spacer fluid at 25^{o}C varied from 4.57 to 9.36 Pa.s^n. The model parameter n was in range of 0.3 to 0.35 (Table 1).

Vipulanandan model (2014)

The yield stress for the spacer fluid without nanoFe_2O_3 was 4.18 Pa which increased with the increase in the addition of nanoFe_2O_3, showing 41 % increase. The τmax for the spacer fluid increased from 56.8 Pa to 77.3 Pa, 36% increase with the increase in the addition of nanoFe_2O_3 at temperature of 25 ^{o}C. (Table 1)

<u>Cleaning Efficiency Test</u>

The cleaning efficiency test of the smart spacer fluid to effectively clean the bentonite drilling mud was performed (Fig. 3). The cleaning efficiency of the spacer fluid was 82.3% without the addition of nanoFe2O3. With the addition of nanoFe_2O_3 the cleaning efficiency increased from 82.3 to 98.5%, 16.2% increase in the efficiency (Fig. 2).

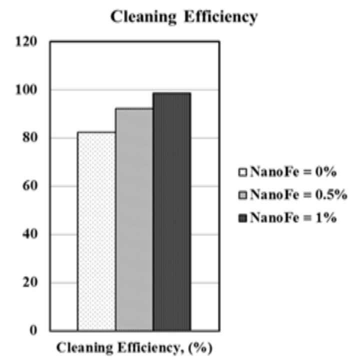

Figure 2: Cleaning efficiency of Spacer fluid different nanoFe2O3 contents.

Figure 3: Cleaning efficiency test of Bentonite Drilling muds using Viscometer.

6. Conclusion

Spacer fluid with 0.5% Bentonite contamination showed 36% increase in the plastic viscosity and 75% increase in the yield point with addition of 1% nanoiron. The Vipulanandan rheology model had the best fit which showed a 36% increase in maximum shear stress in 0.5% bentonite contaminated spacer fluid. The addition of nanoiron increased the cleaning efficiency by 16.2% due to increased shear produced by the nanoiron particles.

7. Acknowledgements

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8. References

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