Characterizing Smart Spacer Fluid Modified with Iron Oxide Nanoparticles Using the Vipulanandan Rheological Model

A. R. Maddi and C. Vipulanandan, Ph.D., P.E.
Center for Innovative Grouting Material and Technology (CIGMAT)
Department of Civil and Environmental Engineering
University of Houston, Houston, Texas 77204-4003
E-mail: srmaddi@uh.edu, cvipulanandan@uh.edu Phone: (713) 743-4278

Abstract:

In this study, the effects of temperature and magnetic field strength on the electrical resistivity and rheological properties of a sensing smart spacer fluid modified with iron oxide nanoparticles (nanoFe_2O_3) were investigated. The temperature was varied from 25°C to 75°C. The magnetic field strength was varied from 0 T to 0.6 T. The nanoFe_2O_3 contents (particle size of 30 nm and surface area of 38 m^2/gm) in the spacer fluid were varied up to 1% by the weight of spacer fluid to enhance the sensing and rheological properties of the spacer fluid. The plastic viscosity, yield stress and maximum shear stress ($\tau_{max)}$ of smart spacer with 1% nanoiron decreased from 49 cP to 41.7 cP, 19.5 to 13 Pa and 65.5 to 53 Pa, a 19%, 33% and 19.2% decrease with increase in temperature from 25 to 75 °C. The plastic viscosity, yield stress and maximum shear stress ($\tau_{max)}$ of smart spacer with 1% nanoiron increased from 49 cP to 62 cP, 19.5 to 24.3 Pa and 65.5 to 84.7 Pa, a 26%, 24.6% and 29% increase with addition of 0.6 T magnetic field.

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 (Theron et al. 2002; Sarap et al. 2009). 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 Oil based drilling mud in drilling operations but there are concerns about potential contamination of the spacer and cement. Oil based drilling fluids can leave a thin layer of oil on the casing and the formation when displacing to completion brine. This layer of oil and leaking oil from the formations can contaminate spacer fluid and modify its performance. 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.

2. Objective: The objective of the study was to investigate the effects of magnetic field and temperature on the sensing and rheology property modifications..

3. Experiment

Materials:

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 ($Pb(NO_3)_2$). 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.

Methods:

The rheology tests for smart spacer fluid with different contents of nanoiron (nanoFe_2O_3) at temperature of 25°C to 75°C and magnetic fields of 0 to 0.6T 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.

Modeling:

Vipulanandan Model:

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

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

in which τ_0 is yield stress and k and n are experimentally fit parameters.

If we calculate the ultimate shear stress from this model we will have:

$$\lim_{\dot{\gamma}\to\infty} \tau = \tau_{0_2} + \frac{1}{D}$$

4. Results and Discussion

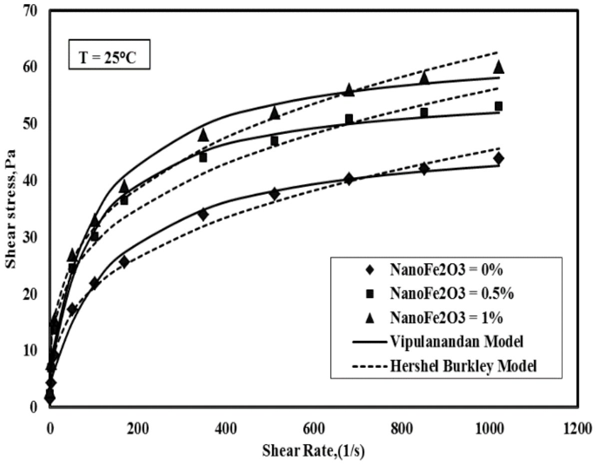

Figure 1:Shear Stress- Shear Strain rate Relationship for Spacer Fluid different nanoFe_2O_3 contents at 25°C.

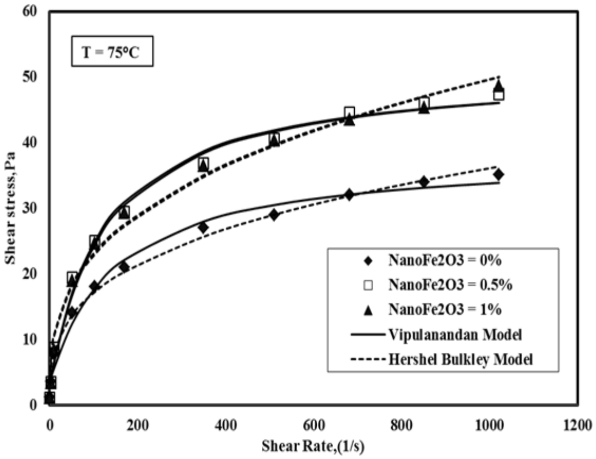

Figure 2:Shear Stress- Shear Strain rate Relationship for Spacer Fluid different nanoFe_2O_3 contents at 75°C.

Table 1: Bingham Plastic, Herchel-Bulkley and Hyperbolic Rheological model parameters for smart spacer fluids with different nanoFe_2O_3 contents.

	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%	37	12.34	0.33	4.58	0	1.34	3.43	0.022	3.94	49.4	1.39
NanoFe = 0.5%	44	17.93	0.29	7.61	0	2.3	1.95	0.019	5.43	58.1	1.7
NanoFe = 1%	49	19.52	0.29	8.14	0	2.03	1.99	0.017	6.63	65.5	2.13

Table 2:Bingham Plastic, Herchel-Bulkley and Hyperbolic Rheological model parameters for Spacer Fluid with different nanoFe_2O_3 contents at temperature of 75°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%	29.8	10.06	0.33	3.82	0	0.99	4.17	0.028	3.31	39.0	1.27
NanoFe = 0.5%	41	13.3	0.33	4.99	0	1.99	2.56	0.021	2.98	50.6	1.42
NanoFe = 1%	41.7	13.04	0.34	4.77	0	1.85	2.67	0.02	2.94	52.9	1.49

Effect of Temperature

Bingham model (1919)

The spacer fluid with and without nanoFe_2O_3 showed decrease in rheological properties with the increase in temperature from 25 to 75°C. The Plastics viscosity of spacer fluid without nanoFe_2O_3 reduced from 37 to 30 cP, 19 % decrease and yield stress from 12.34 Pa to 10.06 Pa, 18.5% decrease as in figure 4. The Plastic Viscosity of the spacer fluid with 0.5% and 1% nanoFe_2O_3 were 41 and 41.7 cP. The yield stress for the spacer fluid with 0.5% and 1% nanoFe_2O_3 were 13.3 and 13 Pa.

Herschel-Bulkley model (1926)

The model parameter k for the spacer fluid with and without nanoFe_2O_3 at 75°C varied from 3.82 to 4.99 $Pa.s^n$ as summarized in table 2. The model parameter n was in range of 0.32 to 0.34.

Vipulanandan model (2014)

The shear thinning behavior of spacer fluids without and with nanoFe_2O_3 were tested and modeled using the Vipulanandan model up to a shear strain rate of 1024 s^{-1} (600 rpm). The average yield stress decreased from 3.31 to 2.94 with the addition of 1% nanoFe_2O_3 at 75°C. The Maximum shear stress (τmax) for the spacer fluid increased from 39 Pa to 52.9 Pa, 36% increase with the increase in nanoFe_2O_3 at temperature of 75°C. (Table 4)

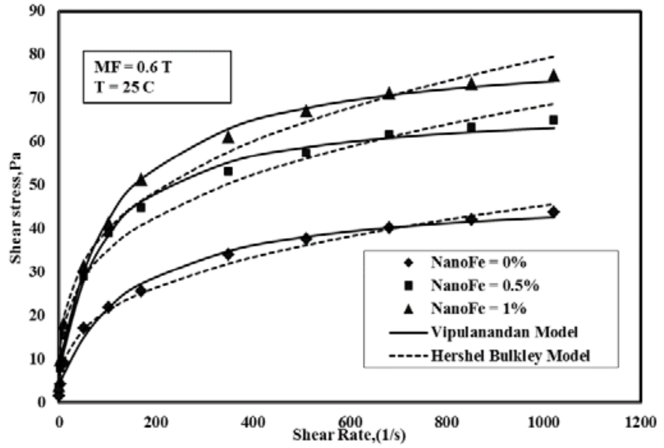

Table 3: Shear Stress- Shear Strain rate Relationship for Spacer Fluid with different nanoFe2O3 contents at temperature of 25°C under Magnetic Field Strength of 0.6 T.

Table 3:Bingham Plastic, Herchel-Bulkley and Hyperbolic Rheological model parameters for Spacer Fluid with different nanoFe_2O_3 contents at temperature of 25°C under Magnetic Field Strength of 0.6 T.

	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%	37	12.34	0.33	4.6	0	1.34	3.44	0.022	3.94	49.4	1.39
NanoFe = 0.5%	53.2	21.7	0.29	9.2	0	3.01	1.49	0.016	5.95	68.5	1.74
NanoFe = 1%	62	24.3	0.3	10	0	3	1.58	0.013	7.80	84.7	2.01

Magnetic field = 0.6 T

Bingham model (1919)

The spacer fluid with nanoFe_2O_3 showed increase in rheological properties in the presence of magnetic field of 0.6 T (Figure 6). The Plastic viscosity increased from 37 to 62 cP, a 67% increase and yield stress from 12.3 Pa to 24.3 Pa, a 97% increase with addition of 1% nanoFe_2O_3 at 25°C. (Figure 6 and Table 4).

Herschel-Bulkley model (1926)

The model parameter k for the spacer fluid at 25°C varied from 4.58 to 9.96 $Pa.s^n$ as summarized in table 4. The model parameter n was in range of 0.29 to 0.33 for Spacer Fluid with different nanoFe_2O_3 contents at temperatures of 25°C under Magnetic Field Strength of 0.6 T. (Table 4)

Vipulanandan model (2014)

Increasing the magnetic field strength from 0 T to 0.6 T, increased the yield stress from 3.94 to 7.8 Pa and τmax from 49.4 to 84.7 Pa for spacer fluid with different nanoFe_2O_3 contents at temperatures of 25°C. The maximum shear stress increased by 71% for increasing the magnetic field from 0 to 0.6 T as in figure 6. (Table 4)

5. Conclusion

The plastic viscosity, yield stress and maximum shear stress (τmax) of smart spacer with 1% nanoiron decreased from 49 cP to 41.7 cP, 19.5 to 13 Pa and 65.5 to 53 Pa, a 19%, 33% and 19.2% decrease with increase in temperature from 25 to 75 °C. The plastic viscosity, yield stress and maximum shear stress (τmax) of smart spacer with 1% nanoiron increased from 49 cP to 62 cP, 19.5 to 24.3 Pa and 65.5 to 84.7 Pa, a 26%, 24.6% and 29% increase with addition of 0.6 T magnetic field.

6. Acknowledgements

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7. References

1. Theron BE, Bodin D, Fleming J. (2002). “Optimization of spacer rheology using neural network technology. SPE-74498-MS, IADC/SPE Drilling Conference, Dallas, Texas.
2. Quintero, L., Christian, C., et al., (2008). “New Spacer Technology for Cleaning and Water Wetting of Casing and Riser”, AADE Fluids Conference and Exhibition.
3. Sarap G.D. et al. (2009). “The use of high-performance spacers for zonal isolation in high-temperature high-pressure wells,” SPE-124275-MS, Middle East Drilling Technology Conference & Exhibition, Manama, Bahrain, 26-28.