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A Novel Spacer System to Prevent Lost Circulation in Cementing Applications

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Abstract

In between drilling and cementing, pre-flushes and spacers are commonly used to remove the mud and clean the wellbore. These fluids are essential in order to ensure excellent bonding of the cement to the casing and the formation. Biodegradable polymers have been widely used as gelling agents in spacer systems. Their application temperature, however, is limited up to around 300°F. In this study, a new spacer system is developed with a novel biopolymer to prevent lost circulation and improve zonal isolation. The new spacer is applicable in all types of wells and cementing operations, especially where high-permeable, fragile, unconsolidated, and low-fracture-gradient formations are present.

The performance of the novel spacer system is extensively evaluated in the laboratory. The results show that the spacer is stable at high temperature, compatible with various muds and cement slurries, and capable of preventing lost circulation. The rheological properties of spacers with densities from 12 to16 ppg were measured from room temperature up to 350°F. The spacer was stable up to 400°F with addition of a stabilizer. The compatibility tests were conducted between the spacer and various types of drilling muds and cement slurries. No significant viscosification, clabbering, or separation were observed between the fluids. In addition, the spacer effectively sealed a sand bed (approximately 200 darcy) under pressure. To date, the new spacer system has been successfully applied in several land operations.

Introduction

Successful cementing operations are critical to provide proper zonal isolation. Many factors and best practices contribute to obtaining a proper bond of the cement to both the casing and formation. Some of these include proper centralization to optimize eccentricity,[1] thorough circulation of the drilling fluid prior to cementing operations,[2] appropriate spacer selection and volume, and pipe rotation including reciprocation and rotation during cementing operations. Without proper implementation of these practices, the ability to achieve good zonal isolation could be at risk.

One of the most important aspects of the cementing operation is engineering an appropriate fluid train. Numerous elements must be taken into account when selecting the spacer system. When removing oil- or synthetic-based drilling fluids, the spacer must effectively clean and water-wet the casing and formation to ensure the cement can bond to these surfaces. Fluid train viscosities and densities should also be properly designed in order to obey the effective laminar flow, or ELF rules. Studies have shown that following the ELF rules improve the chances of attaining zonal isolation.[3] Compatibility of the spacer with both the drilling fluid and cement is also very important as incompatibility could lead to gel plugs, causing increased pressures, which might then lead to fractures in the formation. These fractures could cause mild to severe cases of lost circulation, which has plagued the industry for decades.

Lost circulation can lead to much lower top-of-cement than designed, or even complete loss of the well. Many techniques over the years have been applied to either prevent or relieve these issues. The ideal solution is to prevent lost circulation before it becomes a major concern. A method classified as wellbore strengthening has been used for this purpose. By strengthening the wellbore, the fracture gradient of the formation is increased, thereby increasing the tolerance to unexpected pressure spikes that could otherwise lead to formation fractures. Innovative spacer systems have been shown to strengthen the wellbore to mitigate lost circulation.[4-8] Such a system will be discussed in this paper. Also, improvements to such systems offer a more robust spacer with wider applications across the industry.

In this study, a novel cement spacer with biodegradable polymer has been developed to help control lost circulation during drilling and cementing. The new spacer system shows good rheological profile, high-temperature thermal stability, good compatibility with cement and drilling fluids, and effective sealing performance. Positive feedback has been received from field operations on US land.

Spacer Preparation

The spacer contains a viscosifier, barite, surfactant package, and defoamer. The viscosifier is used to control the viscosity of the spacer and suspend the weighting agent. The barite works as a weighting agent to vary the spacer density from 10 to 18 ppg. The surfactant package helps cleaning the mud and water-wetting the contact surface. A small amount of defoamer is used to minimize air entrainment. All spacer fluids are freshly made prior to testing following the procedures below:

- Add the defoamer to mix water and stir at 1000 to 1500 rpm.
- Add the viscosifier slowly and maintain agitation until

the viscosifier hydrates completely.

- Add the barite and stir for 5 min to obtain a uniform spacer fluid.
- Reduce agitation to a low vortex. Add surfactant depending on the spacer design and maintain a minimum agitation until fully dispersed.

Spacer Rheology

A Grace M3600 viscometer with R1-B1-F1 configuration is used to measure the rheology of the spacer system from room temperature up to 190°F. The viscosities in dial readings are recorded from 3 to 300 rpm according to API RP 10B-2.

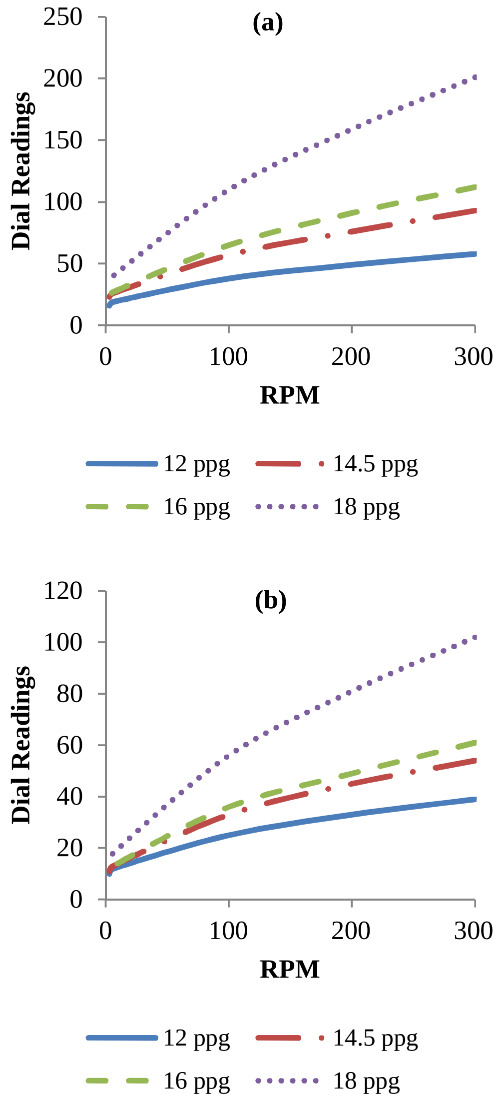

Figure 1. Rheology of the spacer system at various densities tested at (a) 80°F and (b) 170°F using a Grace M3600 viscometer.

Figure 1 shows the testing results of the spacer system from 12 to 16 ppg at (a) 80°F and (b) 170°F. The viscosities of spacer systems increase with density, which is caused by adding barite, and reduce with temperature, which is due to thermal thinning of the viscosifier. The 18 ppg spacer is much more viscous than the 16 ppg spacer at both testing temperatures. The dramatic increase in viscosity indicates that the viscosifier is more effective in suspending barite at higher densities. The result also suggests that the loadings of the viscosifier can be reduced to meet rheological requirements, especially at higher densities, and therefore to reduce the cost of the spacer system.

The HPHT rheology of the spacer system is performed on a Chandler Model 7600 HPHT viscometer with R1-B1-F1 configuration. The Chandler 7600 has an operating temperature range from 40°F to 600°F and a maximum operating pressure of 40,000 psi. The spacer system is heated to testing temperature (300 to 400°F) at 4°F/min and conditioned for 30 min. The applied pressure is 3000 psi during testing. The rotor speed keeps constant at 150 rpm during ramping and conditioning. The viscosity of the spacer is recorded in dial readings following a downward ramp program at 300, 200, 100, 60, 30, 6, and 3 rpm with 1-min intervals at each rotational speed. The viscosity profiles of a 16 ppg spacer at various temperatures are presented in Figure 2. The results show that the spacer system displays lower viscosities at higher temperatures due to thermal thinning effect of the viscosifier. The YP is calculated as 35 and 20 $lb_f/100ft^2$ at 300°F and 350°F, respectively. The recommended operational temperature for the spacer system is up to 350°F.

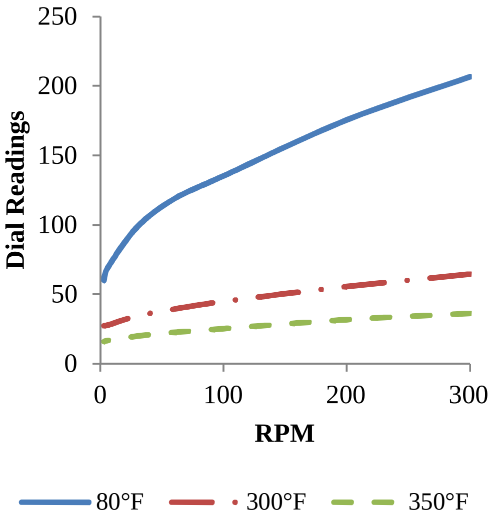

Figure 2. Rheology of the spacer system (16 ppg) tested at 80°F, 300°F and 350°F on Chandler 7600.

A gel stabilizer is incorporated to improve the thermal stability of the new spacer system. Figure 3 compares the rheological profiles of a 15 ppg spacer with/without the stabilizer at 80°F and 400°F. The results at 80°F show that adding the gel stabilizer into the spacer system slightly increases the surface viscosity of the spacer. The spacer still remains as a shear-thinning fluid at 400°F. We expect the spacer without stabilizer loses most of its viscosity and is unable to suspend barite in the system above 350°F. The results confirm that adding the stabilizer improves the thermal stability of the viscosifier and extends the spacer application to a much higher temperature.

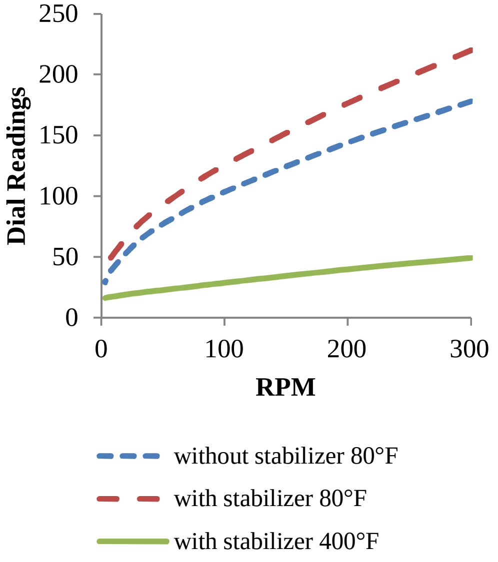

Figure 3. Rheology of the spacer system with and without gel stabilizer at 15 ppg tested at 80°F, 400°F using Chandler 7600.

Spacer Compatibility with Cement Slurry and Mud

The compatibility test between the spacer and the mud or cement slurry is conducted according to API RP 10B-2. Spacer and mud or cement slurry were mixed at 95/5, 75/25, 50/50, 25/75, 5/95 ratio based on volume. Fresh fluids are prepared prior mixing. Rheology sweeps of the mixtures were recorded at 80°F.

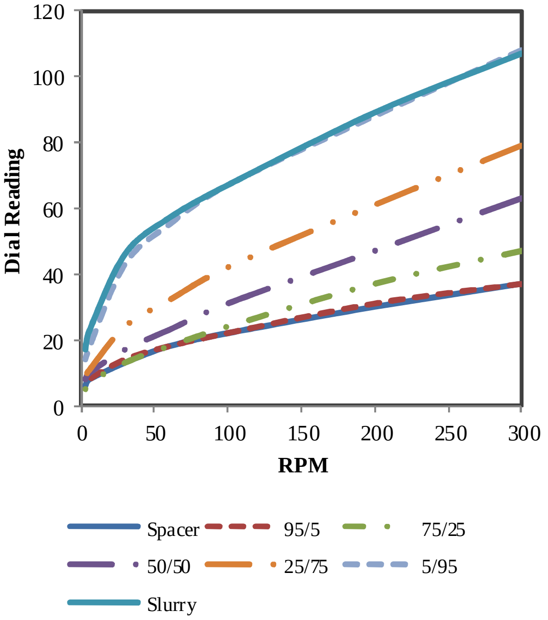

Figure 4. Rheology of the spacer mixed with cement slurry at 80°F.

Figure 4 shows the viscosities of spacer/slurry mixtures at various RPM. The viscosities of spacers and the cement slurry are presented as the solid lines for reference. The spacer was prepared at 12 ppg with viscosifier (13 ppb), barite and defoamer. The cement slurry was mixed at 16.4 ppg with class H cement and defoamer. No viscosification was observed during and after the mixing. The viscosities of the mixtures at all mixing ratios are in between the viscosities of the spacer and cement slurry. The results illustrate the spacer is compatible with the cement slurry.

The compatibility test between the spacer and a 9.8 ppg diesel-based mud (A) was tested and the rheology result is plotted in Figure 5. The viscosities of the spacer and the mud A are also presented for reference. The spacer was prepared at 11.5 ppg with 12 ppb viscosifier, 4 gpb surfactant, barite, and defoamer. No gelling was observed during and after mixing. The viscosities of the 75/25 spacer/mud mixture are slightly higher than the spacer viscosities at higher RPM. The viscosities of the mixtures at other mixing ratios are in between the viscosities of the spacer and mud. The spacer is still considered compatible with the diesel-based mud.

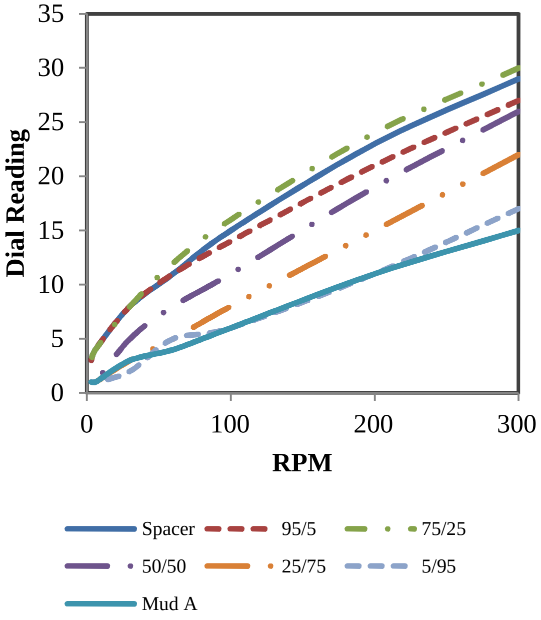

Figure 5. Rheology of the spacer mixed with mud A at 80°F.

The result of the compatibility test between the spacer and a 13.7 ppg synthetic-based mud (B) is presented in Figure 6. The spacer was prepared at 15 ppg with 16 ppb viscosifier, 2 gpb surfactant, barite, and defoamer. No viscosification was observed during and after the mixing. The viscosities of the mixtures at different mixing ratios fall in between the viscosities of the spacer and mud. Therefore, the spacer is compatible with the synthetic-based mud.

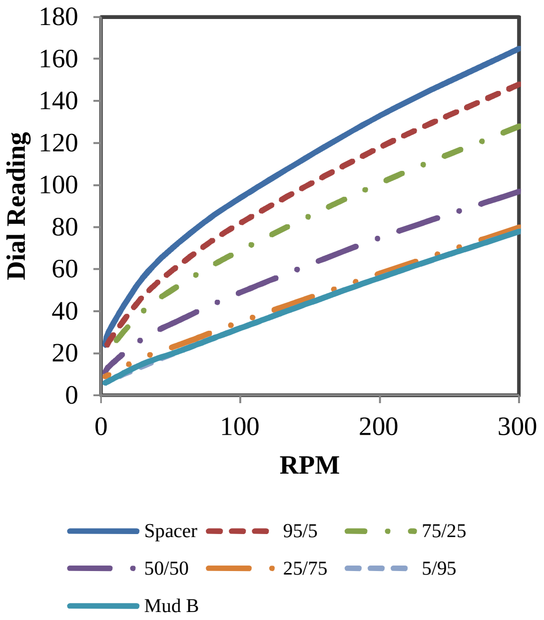

Figure 6. Rheology of the spacer mixed with mud B at 80°F.

Lost Circulation Control

The sealing performance is tested in a 5-in. fluid loss cell with a 325-mesh screen on a 60-mesh screen. The cell is half-filled with ~75 ml of 20/40 proppant with water permeability of 200 Darcy to simulate the lost circulation zone. The testing fluid is poured on top of the sand bed and 100 psi differential pressure is applied during testing. The filtrate is collected in 30 min and the collected volume is considered an indication of the sealing or lost circulation control performance. During the test, the spacer successfully blocked the sand bed without blowing out. The collected filtrate is 14 ml, suggesting that the spacer is capable of sealing a lost circulation zone.

Field Application

The new spacer system was introduced commercially in late 2015; so far more than 100 operations have used it, with the main application on land. One operator in the Permian basin has used the spacer system for more than 10 operations, including intermediate and production casings, with good results on mitigating losses while cementing and good compatibilities between fluids.

In one example in the Permian basin, a 5-in. production casing was cemented at 18,850 ft MD (11,680 ft on a 6.75-in. open hole) with a BHCT of 192°F. The objective of the cementing job was to cover the production zones and bring the top of cement 660 ft inside the previous casing at 3,432 ft. During the design phase of this job, due to the low fracture gradient at the bottom of the formation, the in-house hydraulic simulator predicted losses during the displacement of the cement. In order to mitigate the losses, several simulations were run considering different spacer and slurry densities and different displacement rates.

After analyzing multiple scenarios, engineers recommended using 40 bbl of the new spacer system at 12.0 ppg, 35 bbl of conventional lead slurry at 13.5 ppg, and 167 bbl of gas-tight tail slurry at 16.4 ppg. Considering these fluids densities and a displacement rate of 4 bpm, the in-house simulator calculated losses during the last 25 bbl of the displacement from a total of 315 bbl. With the experience of the spacer system’s effectiveness in reducing and preventing cement losses without damaging the permeability of the production zone, the client agreed to use the proposed new spacer system.

In order to ensure long-term zonal isolation, it was necessary to test compatibility between the oil-based mud of 11.0 ppg used in the well and the new spacer system. The laboratory tests results are shown on Table 1. These results in conjunction with the fluid friction pressure hierarchy chart (Figure 7) obtained from the in-house hydraulic simulator confirmed an adequate engineering design.

After running the casing to TD, the well was circulated for 4 hours with no losses. The cementing operation was conducted as designed. While pumping the spacer, slurries, and displacement full returns were observed at surface. The plug was bumped with 3,200 psi, and the floats were checked with 2 bbl returning to the displacement tanks.

No losses occurred during the operation. The operator was pleased with the results and requested to continue using the spacer system for any job were computer simulation indicates that losses are expected or where losses are known to have occurred during drilling.

Table 1: Rheological profiles of spacer (12.0 ppg) mixed with OBM (11.0 ppg) at various spacer-to-mud ratios in volume at 190°F.

	300	***200***	***100***	***6***	***3***
100% Spacer	78	64	51	18	12
95/5	62	54	32	12	9
75/25	33	24	21	8	6
50/50	26	21	15	7	5
25/75	49	36	24	14	10
5/95	47	34	22	10	6
100% OBM	46	31	21	6	4

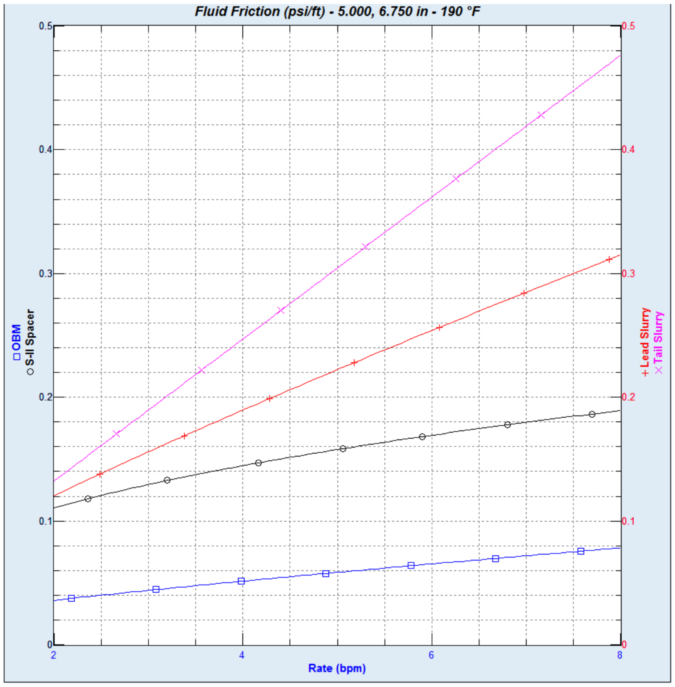

Fig. 7. Fluid friction pressure hierarchy chart obtained from the in-house hydraulic simulator confirms appropriate hierarchy between the fluids at the designed densities and displacement rate.

Conclusions

A novel cement spacer with biodegradable polymer has been developed and introduced to help control lost circulation during drilling and cementing. The new spacer system has a good rheological profile and is effective in viscosifying aqueous solutions. The new spacer system also is thermally stabile: The gelling agent used in the new spacer system is stable above 300°F, and up to 400°F with a gel stabilizer. The new spacer system is compatible with various muds and cement systems. In addition, the new spacer system is effective in sealing a 200-D sand bed under 100 psi differential pressure.

The new spacer system has been pumped in numerous cementing operations with good results in minimizing or preventing cement losses. The field testing for one operation shows the new spacer system was compatible with the cements and muds used in the well.

Acknowledgments

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Nomenclature

API = *American Petroleum Institute*
bbl = *barrel*
BHCT = *bottom hole circulating temperature*
ft = *feet*
gpb = *gallon per barrel*
HPHT = *high pressure and high temperature*
in. = *inches*
lb_f = *pound*
MD = *mud depth*
min = *minute*
ml = *milliliter*
OBM = *oil-based mud*
ppb = *pound per barrel*
ppg = *pound per gallon*
psi = *pounds per square inches*
RPM = *revolutions per minute*
RT = *room temperature*
TD = *total depth*
YP = *yield point*
°F = *temperature in Fahrenheit*

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