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Using Large Cellulose Particles to Improve High-Temperature Cement Slurry Stability

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Abstract

Cellulose derivatives are widely used in cementing applications as rheology modifiers, free fluid control agents, and fluid loss prevention additives. Typically these types of additives are not advantageous in slurry designs for high-temperature applications due to severe thermal thinning effects and degradation of the polymer chains. In long, horizontal well cementing, the cement slurry is exposed to high temperatures over long periods. Therefore, cement slurry stability is especially difficult to achieve. This work describes a process to improve the usability of such materials in higher temperature ranges. Moreover it can help simplify complex cement slurry designs, which are needed to meet all operational requirements.

The different size ranges of the polymer particles and their effects on cement slurry properties such as stability (both dynamic and static settling), free fluid, rheology, and fluid loss control were evaluated in the laboratory. By using larger particles rather than the typical powdered form of cellulose-derived polymers, the hydration of the polymer within the cement slurry can be delayed. Because of the delay, more of the material can be incorporated in the cement slurry while maintaining suitable surface rheology values. In particular, the material helps eliminate the need for excessive viscosifying agents in combination with large quantities of dispersant in order to maintain slurry stability at higher temperatures. This particle-sizing approach, applied to conventional oilfield chemistry, is proven within this paper to add significant value to cementing operations.

Introduction

Cement slurry stability is one of the most critical factors when cementing long horizontal wells. Even the slightest amount of free fluid along the horizontal section can lead to communication between zones, thus limiting isolation.[1-3] Suspension of the cement slurry to prevent solids settling or separation is another important requirement for these types of wells.[4] Although the industry has laboratory standards for measuring cement stability in a static state, these results do not necessarily mimic what is seen under dynamic conditions.[5,6]

To help combat free fluid/solids settling, the industry uses a number of different types of cement additives, including cellulosic-type polymers,[7-9] biopolymers,[10] and synthetic polymers.[11] These types of polymers are effective; however, at high temperatures polymer degradation or severe thermal thinning can occur, reducing their effectiveness. The biopolymers typically cannot survive at temperatures higher than approximately 275°F for any sustained period. The cellulosic-type polymers provide a lot of surface viscosity, thus limiting the amount that can be added to a cement slurry while maintaining the ability to place the cement in the annulus. Synthetic polymers exhibit severe thermal thinning. This can lead to false positive lab testing results while testing for free fluid. Even when the cement slurry is conditioned at BHCT, the temperature must be lowered to 190°F to perform the actual test. As the temperature is decreased, the polymer's viscosity will rebound, indicating higher rheology and more cement slurry stability.

Some technologies have been developed to help overcome high surface rheology and downhole cement slurry stability. Lu *et al*. developed a temperature-insensitive viscosifier.[12] By combining a synthetic polymer with cationic, anionic, and hydrophobic moieties and a layered inorganic mineral, synergistic interactions lead to network structures that provide viscosity stability. Funkhouser *et al.* introduced a synthetic crosslinked polymer system that is activated at elevated temperatures due to degradation of the crosslink bonds. While these synthetic polymer solutions have proven to be effective, these types of additives can be somewhat costly. This paper describes a more cost-effective solution for providing cement stability at elevated temperatures while maintaining low slurry viscosity at surface.

Recommended Test for Cement Slurry Stability

To evaluate the stability of a cement slurry, two tests model different stages of the cementing process – static and dynamic settling tests. The static settling test is designed to quantify the slurry's stability in the annulus after it has been placed. According to API RP 10B-2, both the free fluid and sedimentation tests are required in order to understand the static stability of cement slurry under downhole conditions.

Passing the static test indicates that the density and strength of the cement at the top of a certain zone is comparable to the cement at the bottom. A dynamic settling test's objective is to observe the stability that contributes to slurry's ability to be placed effectively. This test was developed based on industry experience to indicate of how solids settling occur while the fluid system is in motion at low speed. The laboratory testing procedure is essentially a modification of the thickening time test procedure, using a bladeless paddle that has a base for collecting the solid particles as they settle at low rotation speed (**Figure 1**).

Figure 1: Slurry cup and bladeless paddle for dynamic settling test

Test evaluation guidelines for dynamic settling test

A syringe and a weight scale are used to take density readings for the top, middle and bottom of the slurry. The density differential from top to bottom of the cup normally should not be more than 1 ppg.

After the paddle is removed from the cup, the presence of a cone of settled solids on the plate is observed, and the height and condition of the solid cone are recorded. The maximum cone height should be about ½ in., and the condition of settling solids should be non-compacted.

Testing procedure

Determination of rheological properties

The rheological properties of cement slurries were determined according to API RP 10B-2 by using a rotational viscometer M 3600 from Grace Instruments at ambient and desired temperature. The cement slurry rheology data was measured in FANN degrees at standard speeds 3, 6, 100, 200, 300 and 600 rpm.

Fluid loss test

According to API RP 10B-2, the fluid loss rate of slurry was measured at desired temperature for 30 minutes at 1,000 psi (±50 psi) differential pressure in a HPHT stir fluid loss cell against a 325/60 mesh screen. Cement filtrate was collected and measured in a graduated cylinder.

Dynamic settling test

The cement slurry was prepared according to API RP 10B-2 and then poured into a slurry cup with a dynamic settling paddle. The slurry cup was placed in a HPHT consistomer and brought to circulating temperature and downhole pressure at a rotation speed of 150 rpm. After reaching bottom hole conditions and allowing 10 minutes to equilibrate, the rotation speed was reduced to 25 rpm and continued for 30 minutes. The consistometer was cooled as quickly as possible until reaching a safe temperature to remove the cup from the consistometer. Then the cup was removed carefully without inverting it and the top of the cup disassembled. Density differential from top to bottom of the slurry cup was measured and the height and condition of settling solid cone recorded after the paddle was removed from the cup.

Result and discussion

Because the new cement stabilizer has a large particle size, the hydration time of polymer during mixing in cement slurries is delayed. This delayed hydration facilitates slurry mixing, requires less mixing energy, reduces slurry mixing time and results in a lower initial slurry rheology compared to other viscosifying agents.

Slurries were prepared by mixing class H cement, 35% bwoc silica sand, 1.5% bwoc lignosulfonate, and a viscosifying agent to achieve a slurry density of 16.4 ppg. The rheology tests were conducted according to API RP 10B-2 at room temperature after the slurries were mixed. The results demonstrate that replacing conventional viscosifying agents with the new cement stabilizer lowered the surface rheology values. With 0.9% bwoc regular size of HEC, the viscosity of cement slurry was above 900 Fann degrees at 300 rpm. With 0.5% bwoc welan gum or 1% bwoc synthetic polymer, the viscosity of cement slurry was about 350 Fann degrees at 300 rpm. Compared to those rheology data, **Figure 2** shows the cement slurry with 0.9% bwoc new cement stabilizer had lower viscosity. This will allow higher loading of new cement stabilizer added to cement slurry as needed.

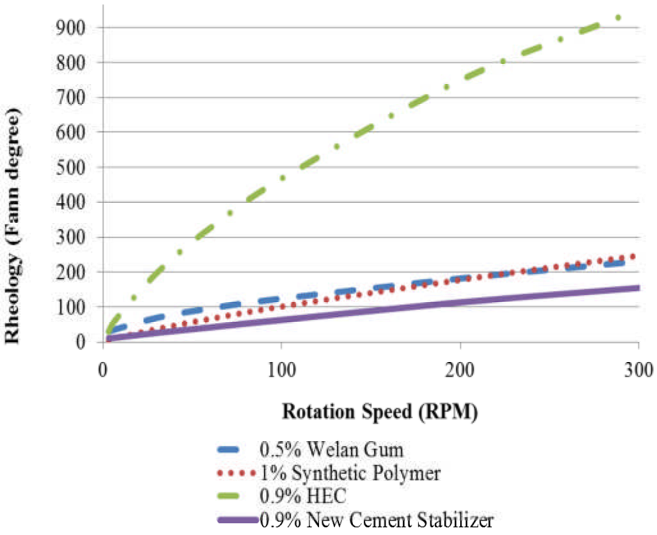

Figure 2: Comparison of rheology properties of cement slurries contained current and new cement stabilizer at 80°F

To evaluate the cement slurry stability, dynamic settling tests were run for slurries with the same concentration of viscosifying agents used in the rheology tests. **Table 1** shows the new cement stabilizer ensured the stability of cement slurry at high temperature. The welan gum and synthetic polymer cement slurries did not pass the requirements of the dynamic settling test: Their differential densities were 4.30 and 1.48 ppg, respectively, and their cone heights 2.0 and 0.5 in., respectively. The conventional HEC slurry passed the criteria of this test, but the above surface rheology values were too high for use in the field. Only the slurry with the new cement stabilizer passed both tests.

Table 1: Dynamic settling test results of current and new cement stabilizers at 300°F

Cement Stabilizer	Concentration (% bwoc)	Δ Density (ppg)	Cone Height (in.)
Welan Gum	0.5	4.30	2.0
Synthetic Polymer	1.0	1.48	0.5
HEC	0.9	0.34	0.3
New Cement Stabilizer	0.9	0.75	0.5

In the laboratory, the new cement stabilizer was mixed in slurries at different concentrations and at different temperatures. Class H cement, 17.5% bwoc silica flour, 17.5% bwoc silica sand, 10% bwoc silica fume, lignosulfonate and the new cement stabilizer were mixed to achieve a slurry with density of 16.4 ppg. **Table 2** shows the resulting slurries' dynamic settling test results from 245 to 400°F. With the higher temperature, the loading of the new cement stabilizer was increased to maintain solids suspension throughout the cement slurry. For temperatures at or below 300°F, 0.8% bwoc of the new stabilizer was added to the cement slurries to yield a differential density or 0.58 ppg at 245°F and 0.41 ppg at 300°F. For temperatures above 300°F, the stabilizer loadings were increased to ensure the cement slurries would pass the criteria of the dynamic settling test. The differential densities were 0.47 ppg at 350°F and 0.49 ppg at 400°F. The cone heights for were all less than or equal to 0.5 ppg at temperatures from 245 to 400°F.

Table 2: Dynamic settling test results of new cement stabilizer at elevated temperature

Cement Stabilizer (% bwoc)	Temperature (°F)	Δ Density (ppg)	Cone Height (in.)
0.8	245	0.58	0.3
0.8	300	0.41	0.4
1.1	350	0.47	0.5
1.2	400	0.49	0.5

Fluid loss properties of the same cement slurries were tested from 245 to 400°F according to API RP 10B-2. The experimental results are summarized in **Table 3**. Adding the new cement stabilizer to cement slurries helped to control API fluid loss value across the full temperature range. This will help to reduce operational costs by decreasing the concentration of fluid loss additive in the cement system.

Table 3: Fluid loss test results of new cement stabilizer at elevated temperature

Cement Stabilizer (% bwoc)	Temperature (°F)	Calculated API Fluid Loss in 30 min. (cc)
0.8	245	44
0.8	300	44
1.1	350	60
1.2	400	176

Case Study

The first job using the new cement stabilizer was performed for a 5 ½-in. casing in a horizontal well with the TVD of 10,075 ft and MD of 17,635 ft in South Texas. The BHST is 285°F and BHCT is 275°F. The objective of the job was to confirm the pump truck could mix the slurry with the new cement additive in the mixing tub without issues and maintain the density throughout the mixing and pumping operation.

First, several tests were performed to ensure that the slurry properties and settling patterns met customer expectations. All testing was confirmed and approved by the customer prior to loading the job. **Table 4** shows with the new additive, the cement slurry had good rheology at 300 rpm for surface temperature. The 300 rpm dial reading gives a good indication of how the slurry will be pumped in the field during the cementing operation. In this job, 240 Fann degrees was acceptable. In addition to helping the surface viscosity, the new cement stabilizer also helps to prevent fluid loss of cement slurry to the formation. The API calculated fluid loss of the slurry design was 22 cc in 30 minutes.

Table 4: Rheology property of the tail slurry with new cement stabilizer at 80°F

	Rotation Speed (RPM)				
	3	6	100	200	300
Fann degree	9	15	114	180	240

In addition, this cement slurry stability was evaluated by the dynamic settling test at BHCT. From **Table 5**, the differential density from the top to the bottom of the slurry cup was 0.66 ppg, and the cone height was 0.25 in. Both factors were within the test criteria, so the cement slurry passed the dynamic settling test.

Table 5: Dynamic settling test result of the tail slurry with new cement stabilizer at 275°F

Top Density (ppg)	Middle Density (ppg)	Bottom Density (ppg)	Δ Density (ppg)	Criteria (ppg)	Cone Appearance
15.76	16.06	16.42	0.66	< 1	¼ in.

The spacer system was pumped as gelling agent, 1.2 ppb viscosifying agent, 2 gpb mutual solvent, 2 gpb surfactant agent and weighting agent at a density of 11.8 ppg to remove 10.5 ppg oil-based mud. The lead cement slurry was mixed from class H cement and fly ash (35:65 ratio), blended with 20% bwoc silica flour, 8% bwoc cement extender, 0.3% bwoc sodium metasilicate, 0.25% bwoc suspending agent, 0.25%

bwoc dispersant agent and 0.8% bwoc retarder at a density of 13.0 ppg. Then the tail cement slurry with class H cement, 20% bwoc silica flour, 15% bwoc silica sand, 0.7% bwoc of the new cement stabilizer, 0.25% bwoc dispersant, 0.3% bwoc fluid loss agent, and 0.6% bwoc retarder at 16.4 ppg was pumped until the job was finished.

Figure 3 shows the data collected during the job. During the cementing operations, the tail slurry containing the improved additive had no issues while mixing and pumping downhole. The density of the tail slurry was maintained steady at 16.4 ppg and displayed excellent fluid stability. This job in South Texas illustrates the successful application of the new cement stabilizer in a horizontal well.

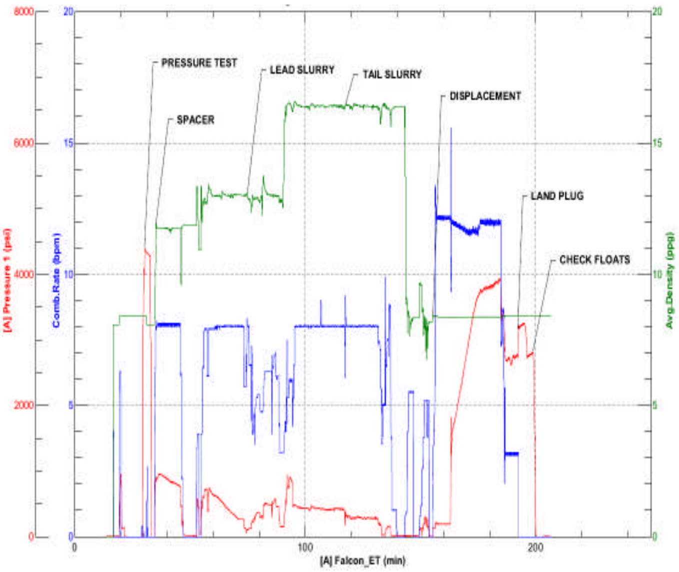

Figure 3: Operation chart for the case study

Conclusions

The new cement stabilizer was developed by adjusting the particle size of polymer to delay its hydration. It not only helps to reduce the initial slurry rheology compared to other viscosifying agents, but also ensures the cement stability at high temperature. The cement system with the new cement stabilizer eliminates the need for anti-settling agents and reduces requirements for fluid loss agents but still meets all operational requirements.

Especially with long horizontal wells, cement slurry stability is one of the most critical factors. So by providing slurry stability, this new cement stabilizer will prevent some undesirable consequences which can result in remediation implication or communication between zones. These results can cost the operation company in millions of dollars in additional completion costs and lost production.

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Nomenclature

API RP = *American Petroleum Institute Recommended Practice*
BHCT = *bottom hole circulating temperature*
BHST = *bottom hole static temperature*
Bwoc = *by weight of cement*
cc = *cubic centimeter*
ft = *feet*
gpb = *gallon per barrel*
HEC = *hydroxyethyl cellulose*
HPHT = *high pressure and high temperature*
in. = *inches*
MD = *measured depth*
ppb = *pound per barrel*
ppg = *pound per gallon*
psi = *pounds per square inches*
RPM = *revolutions per minute*
TVD = *true vertical depth*
°F = *temperature in Fahrenheit*

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