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Evaluation of a New Spacer System Mixed On-The-Fly

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Abstract

A good cement bond between the casing and the formation is critical for zonal isolation and life of the well. The application of pre-flushes and spacers with surfactant package facilitates mud removal and leaves a clean water-wet surface on the wellbore for cementing. Traditionally, spacer fluids are pre-mixed in a batch mixer before pumping downhole. This process requires additional waiting time, personnel, and equipment footprint. In this study, a new spacer system consisting of all dry materials is developed to provide on-the-fly (OTF) mixing capabilities, which utilize the cement unit to mix and pump simultaneously. One specific requirement is the viscosifier in the spacer design; it needs to hydrate sufficiently during OTF mixing providing enough viscosity. The spacer was systematically investigated at various compositions and densities in the laboratory. The field mixing was then conducted using the same spacer formulations on a cement unit. The rheological performance and densities of the spacers were measured on site during mixing and pumping. Comparing the field and the laboratory mixing results, a laboratory mixing procedure for OTF mixing in the field was established accordingly. OTF mixing for spacers improves the speed and reduces the cost of drilling and cementing operations. This study also correlates the OTF mixing in the field with laboratory data, which is very limited in the literature.

Introduction

Spacers are pumped between drilling fluids and cement slurries in order to clean the pipe and wellbore efficiently to improve cement bonding. The spacer system should be effective in displacing mud and leaving a clean, water-wet surface for subsequent cementing. When designing the spacer system several criteria need to be fulfilled:

- Density hierarchy: the density of the spacer is usually 10% to 15% lower than the cement slurry and higher than the displaced mud.
- Rheology hierarchy: the spacer should be thinner than the cement slurry and thicker than the displaced mud. In some studies, the YP of the spacer is used to represent the viscosity.[1,2]
- Friction pressure gradient hierarchy: 20% higher in friction pressure gradient is needed for the fluids to achieve a good displacement.[3]
- Thermal stability: the spacer system especially the viscosifier should be stable at the downhole temperature and pressure.
- Compatibility: The spacer system should also be compatible with both the displaced mud and cement slurry.[4-6] Ideally, the spacer should not significantly alter the cement/slurry properties such as thickening time and compressive strength development.

Traditionally, spacer fluids are pre-mixed in a batch mixer before pumping downhole. The components are added individually. The operation time can last for hours depending on the hydration of the viscosifier, and the inter-mixing of all the components to achieve a uniform fluid. Also, the spacer volume is usually limited by the capacity of the batch mixer. The proposed On-The-Fly (OTF) mixing uses the cement unit to mix and pump simultaneously in order to engineer the spacer volume and reduce waiting time, personnel, and equipment footprint. However, a spacer mixed OTF faces several challenges. First, the viscosifier must hydrate sufficiently during OTF mixing to provide adequate surface and downhole viscosity. Inadequate hydration may result in unevenly distribution of the components, especially the barite and the surfactant. The barite settling or insufficient local surfactant concentration lower the mud removal efficiency and are detrimental to the subsequent cementing operation. Second, all of the materials including the viscosifier, the weighting agent, the surfactant and the defoamer should be solid and blended uniformly prior mixing and pumping. The commonly used surfactant and defoamer are liquids. Additional screening and investigation are needed to develop solid surfactants and defoamers that are economic and effective in downhole applications. Additional blending before operation is also necessary to make sure the dry blend is uniform and well dispersed. Another concern is excessive foaming when mixing the solid surfactant in the spacer system. Normally the liquid surfactant is dispersed into the spacer at low shear rate to prevent further foaming. OTF mixing on the cement unit has much higher mixing energy than traditional batch mixing; therefore, a solid surfactant with less foaming tendencies is preferred.

In this study, a new spacer system consisting of all dry materials is developed for OTF mixing. The hydration rate of viscosifier and the spacer system were investigated and compared in laboratory and on field equipment. The lab mixing procedure for OTF mixing in the field was established after the field trial.

Hydration of Polymer

As discussed above, the polymer selection is of vital importance for mixing/pumping a spacer OTF, not only to keep all the ingredients in place and evenly distributed, but also to give the fluid the desired properties such as density, friction, and stability.

Five biopolymers were tested over time for hydration at different concentrations and different shear rates for 15 min to select the best suitable for OTF applications. Figures 1 and 2 present the hydration profiles for Polymer A to E with their respective low and high concentrations.

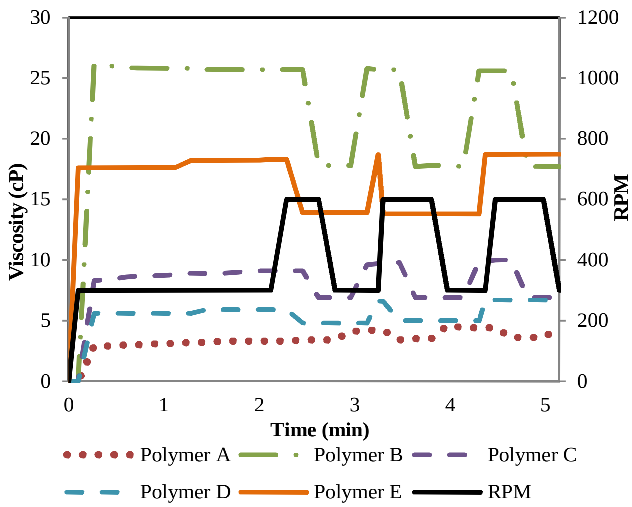

Figure 1. Hydration test profile for different biopolymers with low concentration at 300 and 600 rpm.

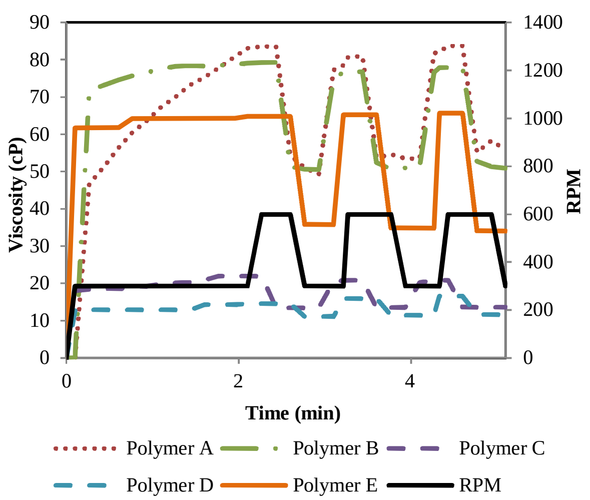

Figure 2. Hydration test profile for different biopolymers with high concentration at 300 and 600 rpm.

From the two analyses, it was concluded that Polymer B and Polymer E were the most effective because of their rapid hydration characteristics and higher viscosity. However, because of its higher thermal stability and better compatibility with cement and mud overall, Polymer E was chosen as the best fit for initial testing.

Also with Polymer E, additional hydration tests were conducted; hydration tests in water with varying pH and temperature showed extraordinary consistency compared to other results, with negligible undesirable effects.

Laboratory Testing of the Spacer System

The rheology variations of the spacer system on the mixing procedures were investigated in the lab. A Waring blender is used to mimic the field mixing on a cement unit, instead of the stand mixer which has been used to resemble the batch mixing. The rheology of the spacer is measured on a Grace M3600 immediately after mixing. The rheology data provide the hydration degree of the polymeric viscosifier with various mixing procedures.

Figure 3 shows the rheology of 11.5 ppg spacer prepared by three different mixing schedules. The Mix 1 and Mix 2 spacers were mixed at low shear rate (4,000 rpm) for 15 s and 50 s, respectively. The Mix 3 spacer used the API standard mixing schedule for cement, which is mixed at low shear (4,000 rpm) for 15 s and high shear rate (12,000 rpm) for 35 s. The result shows that the viscosity of Mix 3 is the highest and Mix 1 is the lowest. Higher shear rate (12,000 rpm) and longer mixing time speed the hydration of the polymeric viscosifier.

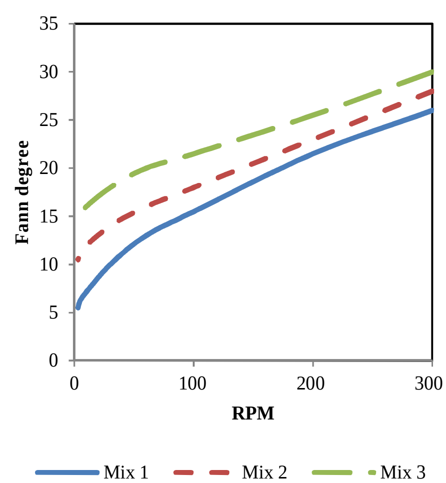

Figure 3. Rheology curves of the spacer using different mixing procedures. The designed density of the spacer is 11.5 ppg.

Figure 4 shows the rheology of 15 ppg spacer prepared by five different mixing schedules. The Mix 1 and Mix 2 spacer were mixed at low shear rate (4,000 rpm) for 15 s and 2 min, respectively. The Mix 3 and Mix 4 spacer were mixed at low shear (4,000 rpm) for 15 s and high shear rate (12,000 rpm) for 35s and 90s, respectively. Mix 5 spacer was mixed at 1000 rpm for 20 min using the stand mixer, which is the common lab mixing procedure to represent batch mixing. The result shows that the viscosity of Mix 3 is the highest and Mix 1 is the lowest. The viscosity readings at 300 rpm show no dramatic difference when varying the mixing procedures. More significant variation is observed at lower (3 to 100) rpm. Similar to the previous results (Figure 3), higher shear rate (12,000 rpm) and longer mixing time speed the hydration of the polymeric viscosifier. Low-shear mixing for a longer time (Mix 2) is most likely to represent batch mixing (Mix 5) which is mixed at 1000 rpm for 20 min.

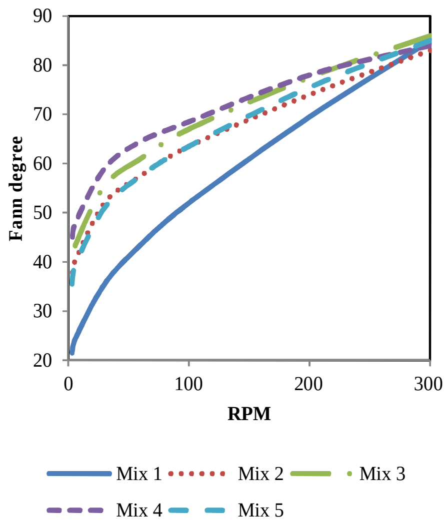

Figure 4. Rheology curves of the spacer using different mixing procedures. The designed density of the spacer is 15 ppg.

Field Mixing of the Spacer System

Field mixing of the spacer was conducted on a cement unit to check mixability and foaming effect. The spacer contains the viscosifier, barite, and water. Two spacer designs are selected from the lab mixing test: a low-density design of 11.5 ppg with 1 ppb viscosifier, and a high-density design of 15 ppg with 1.5 ppb viscosifier. The viscosifier and barite are pre-blended at the bulk plant. The dry blends are then transported to location, mixed with local fresh water and pumped with a cement unit. The spacer volume is 30 bbl for each design. The pump rate is 5 to 6 bbl/min. Samples were collected on the sample collection spot on the cement unit and at the discharge. The rheology and densities of the collected samples were tested onsite using a Grace M3600 and pressurized mud balance. After field mixing, the dry blend and local fresh water were used for rheology and density testing in the lab.

Low-density Spacer

The low-density spacer is designed at 11.5 ppg with 1 ppb viscosifier. The pumping lasted for approximately 5 min. Four samples were collected on the unit and one sample at the discharge. The rheology tests were conducted immediately after sample collection on a Grace M3600. The dial readings in Fann degrees were recorded at different rpm and plotted in Figure 5. The viscosities of all samples are close to each other, which indicates the low-density spacer is uniform throughout mixing and pumping. The average measured density is 11.0 ppg for the unit samples and 11.4 ppg for the discharge sample. This may suggest air entrainment in the spacer during mixing was reduced when the spacer reached the discharge.

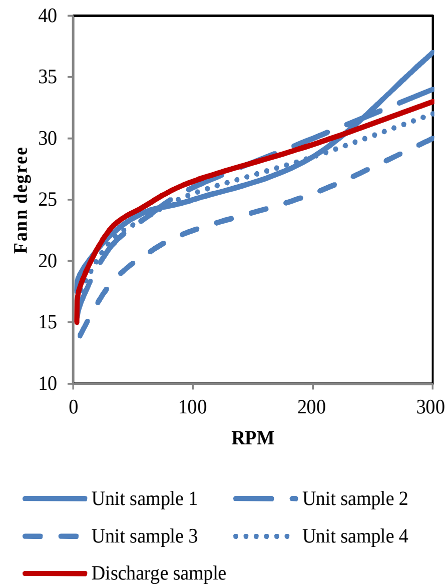

Figure 5. Rheology curves of the unit and discharge samples mixed OTF. The designed density of the spacer is 11.5 ppg.

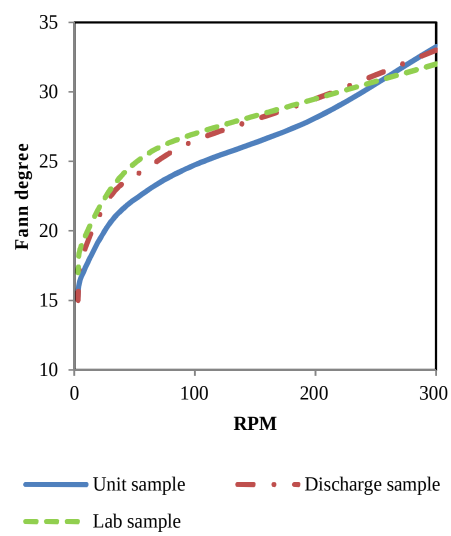

Figure 6. Rheology curves of the unit and discharge samples mixed OTF and the lab sample mixed using cement API method. The designed density of the spacer is 11.5 ppg.

Figure 6 compares the rheological curves of the unit and discharge samples with the lab testing result. The rheology of the unit sample is based on the average of four unit samples. The lab testing is carried out in the Waring blender and mixed by the API cement method, which is 15 s at 4,000 rpm and 35 s at 12,000 rpm. The lab testing result is similar to the rheology of the discharge sample and close to the rheology of the average of the unit samples. Also, the measured density of the lab testing is 11.2 ppg which is between the unit and discharge results. The comparison shows that we can use the API cement mixing method to represent the OTF mixing.

High-density Spacer

The high-density spacer is designed at 15 ppg with 1.5 ppb viscosifier. The pumping lasted for approximately 5 min. Four samples were collected on the unit and at the discharge, respectively. The rheology tests were conducted immediately after sample collection. Figures 7 and 8 show the rheology curves of the individual samples on the unit and at the discharge, respectively. All the samples show similar rheology curves, except the first sample, which is not used for calculating the average rheology. The unusual result may be due to the adjustment of the feeding rate of the blend and mixing water at the beginning of pumping. Once the spacer becomes stable, the rheology data are repeatable at different sampling periods. The average measured density is 14.5 ppg for the unit samples and 15.1 ppg for the discharge samples. The density results indicate that less air entrainment occurred in the high-density spacer than in the lower-density test, and most air bubbles tend to break when the spacer reaches the discharge.

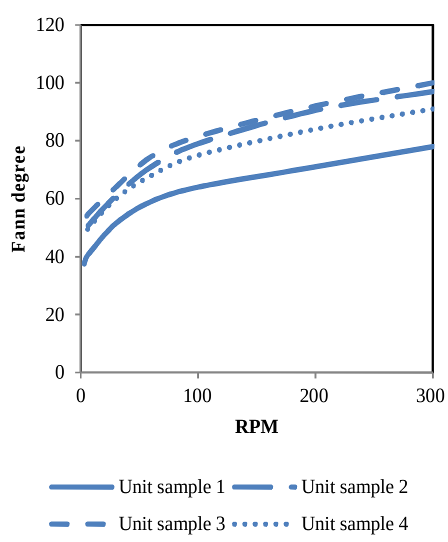

Figure 7. Rheology curves of the unit samples mixed OTF. The designed density of the spacer is 15 ppg.

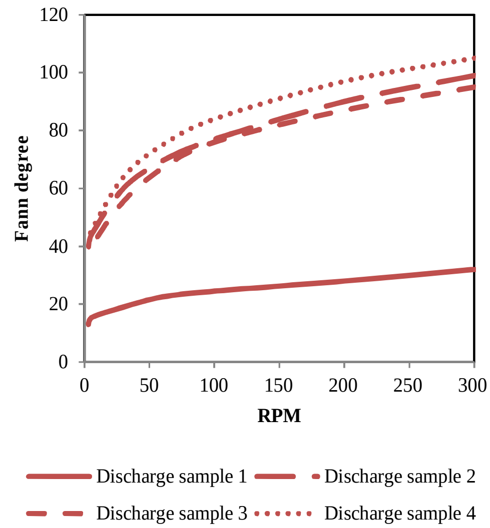

Figure 8. Rheology curves of the discharge samples mixed OTF. The designed density of the spacer is 15 ppg.

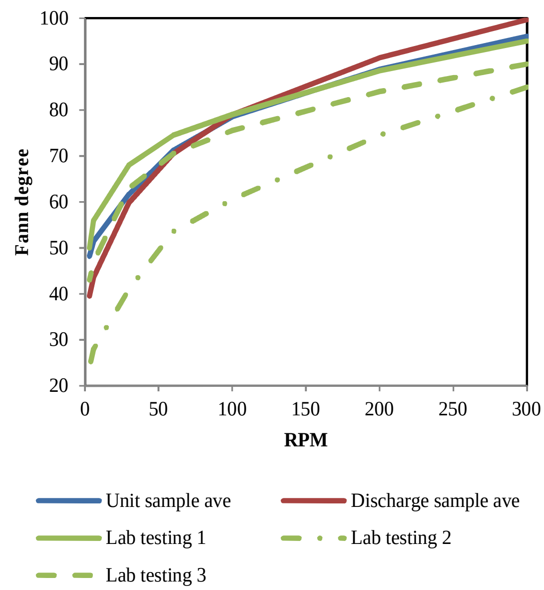

Figure 9. Rheology curves of the unit, discharge mixed OTF and lab samples. The designed density of the spacer is 15 ppg.

Figure 9 compares the average rheological curves for the unit and discharge samples with the lab testing result. The rheology data of the unit and discharge sample are based on their average values without the first samples. The lab testing is carried out in the Waring blender and mixed by three different schedules: lab testing 1 is the API cement method, which is 15 s at 4,000 rpm and 35s at 12,000 rpm; lab testing 2 is 15 s at 4,000 rpm; and lab testing 3 is 3 min at 4000 rpm. The API method combining low- and high-shear energy resembles the field OTF mixing on a cement unit. The lab testing 2 method gives the lowest rheology, meaning that mixing at 4000 rpm for 15s is not enough to hydrate the viscosifier. Increase the duration time of the low shear helps increase the viscosity of the spacer, as shown in lab testing 3. The measured spacer density is 14.8 ppg using the API cement mixing method, which also suggests less foaming in the high-density spacer than the low-density one.

The lab testing results illustrate the cement API mixing method matches the field mixing the best for both the low-density and high-density spacer systems. Therefore, the lab mixing procedure for OTF mixing in the field is established for future study.

Conclusions

An all-solid-component spacer blend comprising a polymeric viscosifier and barite is developed especially for OTF mixing using a cement unit. The hydration rates of five viscosifiers were investigated and compared at various mixing procedures in the lab. After choosing one viscosifier for its lab performance, OTF mixing was conducted using spacers at low and high densities on a cement unit. Rheological properties and densities of the spacer fluids were measured on site during mixing and pumping and were compared with laboratory testing results. The API cement standard mixing schedule is determined to be the most accurate and representative lab testing procedure for field mixing. This spacer system allows for engineered designs with variable volumes that can be adjusted at the location, and significantly improves operation efficiency by reducing operation time, personnel and equipment.

Acknowledgments

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Nomenclature

API = *American Petroleum Institute*
bbl = *barrel*
cP = *centipoise*
min = *minute*
OTF = *on the fly*
ppg = *pound per gallon*
ppb = *pound per barrel*
rpm = *revolutions per minute*
s = *second*
YP = *yield point*

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