

Rheological Properties of Cement Spacer: Mixture Effects

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Abstract

Cement spacers serve various functions including eroding mud deposition and displacement of drilling fluids before cementing the well. The efficacy of a spacer system is largely dependent on the rheological properties of both the fluid being displaced and the spacer itself. A spacer fluid is commonly a mixture of (1) a solid compound (such as barite), (2) water, and (3) a rheological modification agent. The proportions of these components in a spacer system will control the rheological properties of the final mixture, and thus, performance of the spacer. Therefore, if the spacer system could be modified to yield the rheological properties needed, it would be extremely beneficial.

Such a “rheology modifying” spacer system has been developed. This system can be modified to yield the desired properties needed for the spacer to perform a particular function. The parameters needed to make this system work are based on findings from an extensive and systematic laboratory study in which component ratios were changed into numerous combinations and the results compared. This paper describes these tests and also how different flow regimes impact hole cleaning and fluid displacement. The paper then describes the spacer system that was successfully developed as well as its testing. The tests indicate that the rheology modification results in significant improvement in spacer performance.

Introduction

Well construction involves drilling a wellbore into the earth’s formation. While drilling, a drilling fluid (commonly referred to as drilling mud or mud) is circulated down the drillpipe and back up the annulus created between the formation and drillpipe. The mud serves two purposes:

1. Lubricate the bit.
2. Lift drill cuttings back to the surface where they may be separated from the mud.

The mud is then treated and circulated, and the process repeats continuously.

Once a target depth is reached, the drillpipe is removed and casing (or liner) is inserted into the newly formed wellbore. After the casing is placed to the new depth, the annulus between the formation and casing is sealed. The sealing of this annulus is commonly referred to as zonal isolation, and is accomplished through the placement of cement. Traditionally,

the cement is placed down the casing and back up the annulus. The cement serves three functions:

1. Support the casing.
2. Protect the casing from corrosion.
3. Isolate one formation zone from another, preventing communication.

For the cement to serve all three functions mentioned above, it must be properly placed. A successful zonal isolation requires that the drilling fluid that previously filled the annulus be completely removed and displaced. This is challenging, given that the mud may be gelled, large filter cakes may have developed during drilling, and the wellbore may be eccentric and may contain washouts. Over the years, several best practices have existed for successful zonal isolation:¹

- Conditioning of the drilling fluid.
- Use of spacers and flushes.
- Pipe/casing movement.
- Casing centralization.
- Displacing at maximum rate possible.
- Designing slurry for proper temperature.
- Testing cement composition.
- Use of proper cementing system.

As mentioned above, spacers play a critical role in proper zonal isolation by performing two important tasks:

- 1.) Helping to ensure complete displacement of the mud.
- 2.) Removal of filter cake developed along the formation wall.

In addition, the spacer should be compatible with the fluids on each side of it. Incompatible fluids can cause severe settling through loss of viscosity or gellation, resulting in a dramatic increase in viscosity. When spacers are used with oil-based muds or synthetic muds, the spacer should also water-wet the formation and pipe so that the trailing cement can sufficiently bond to those surfaces. However, this may not be accomplished if the mud is not properly displaced out of the annulus.

Spacer Design Fit for Application

A single spacer design (density and rheology) may not be used across the board. Spacer systems should be robust in

nature, such that they can be designed for a specific density, rheological profile, temperature, mud system, and cement system. If not designed correctly, each one of these parameters can lead to improper zonal isolation. Thus, it is necessary for the spacer system to be able to be modified accordingly.

In general, the final spacer fluid is comprised of three components:

1. Water.
2. Heavyweight additive.
3. Spacer blend package.

Density

Density is critical in wellbore applications because the density of the fluids in the wellbore can control the well dynamics. If the fluid density is high, the resulting hydrostatic pressure of the column of fluids can break the formation creating a lost circulation situation. Lost circulation is a time consuming and costly problem to encounter during well construction. On the other hand, if the density is too low, the hydrostatic pressure from the column of fluids is unable to control formation fluids (liquid or gas) from entering the wellbore. This can result in poor zonal isolation, migration of fluids to surface, loss of well control, or sustained casing pressure.

The density can be adjusted by varying the water and heavyweight additive concentrations. Light-weight designs can be achieved through the addition of extra water; conversely, high concentrations of heavyweight additives (such as barite or calcium carbonate) result in high-density spacer systems. Densities as low as 10 lb/gal and as high as 19 lb/gal can easily be achieved. Obviously, varying the concentration of water or heavyweight additives will have secondary effects on other key parameters such as desired rheology.

Rheology

Precisely predicting downhole rheologies is one of the key parameters in spacer design. For every density that may be required, the rheological profile of the spacer should be adjustable so that it matches each wellbore application. That is, the density and rheology should be able to be tailored independently.

As mentioned above, the spacer system is comprised of water, heavyweight agent, and a spacer blend package. This package typically involves rheological modifiers as well as other components. A balanced or systematic approach should be achieved to produce consistent results over a wide density, temperature, and rheology range. **Fig. 1** depicts how the blend package impacts rheology on the systematic approach. For example, if raising the rheology of the spacer is desired, then not only should the blend package be adjusted, but also the water or heavyweight agent, to maintain the same density. Maintaining the density by adjusting water or weighting agent can have a compound or adverse effect on the rheology modification. **Fig. 2** shows the relative contribution of each component to the rheology of the fluid.

Weighting agents can play a large role in the rheology of

the fluid. The particle-particle interaction contributes significantly to the viscosity of the fluid. In addition, the particles are able to contribute to a finite yield stress. However, a foundation of yield stress must exist, otherwise the heavyweight agent will settle. At lower densities, the blend package should contribute substantially to the rheology of the fluid. Similarly, the higher densities loaded with heavyweight agents should have enough base yield stress to suspend the heavy solids.

Temperature Stability

Wellbore operations are challenging in that the temperature the fluid encounters varies with depth and time. Temperature often plays a role in the rheology (viscosity and yield stress) of a fluid. It is very common for oilfield fluids to thermal-thin. That is, the fluid viscosity and yield stress reduce as the temperature increases. The variations as a function of temperature become harder to model, as time only permits a limited number of temperatures to be tested in the lab. In addition, unexpected and unaccounted for situations during the job can impact the performance.

It is preferable to have a fluid in which the rheology is stable with temperature. This can be achieved with the proper choice of components within the package blend. These components can either individually cover a wide range of temperature or have a synergistic effect that allows the rheology to remain constant. The system can be mixed at surface with a specific rheology. This rheology is maintained as the temperature increases down the wellbore and to the bottomhole temperature. This greatly increases accuracy of simulation and reliability in the field.

Fig. 3 shows the typical yield point values of the material being developed as a function of temperature. The experimental results were obtained by using a Fann-35 rheometer equipped with a new yield-stress adaptor.² The result demonstrates that the yield point (YP) of the sample is relatively constant over the range of temperature tested. This suggests the temperature-independent behavior of the material, which is a unique property of the material being developed.

In addition, the consistent rheology at surface and downhole allows for a greater operating range. The downhole rheology of thermal-thinning spacer systems is limited by the ability to mix high viscosities at the surface. If a thick fluid is required downhole, it may not be possible to mix at a sufficiently high viscosity at the surface to adjust for the thermal-thinning nature of the spacer. For temperature-stable systems, the downhole upper limit is the same as the surface.

Salt Tolerance

Many zonal isolation jobs require that a seawater or salt solution be used as the base fluid. This is often because of water-sensitive formations, such as shale. Shale formations are hygroscopic, meaning that they attract water molecules until the formation becomes weak and crumbles. Salt minimizes the amount of water pulled into the formation. Unfortunately, many rheological modifiers are negatively impacted by salts. Typically, salts reduce the yield (viscosification) of the

rheology modifiers.

Time or increased shear can sometimes reduce the salts' impact on viscosity. However, additional time may not be practical or may be very expensive, and equipment limitations may not allow additional shear to be added to the fluid. Systems capable of viscosifying in the presence of salts are advantageous. These systems can be used with any base water (fresh water, seawater, or brines). These systems save time and increase reliability.

Shear Sensitivity

As stated previously, the amount of shear available on location is predetermined by the equipment on location and may be impossible to change (increase or decrease). In addition, the range of shear varies from location to location. Offshore slugging pits may have minimal shear, batch blenders on land have medium shear, and continuous mixing heads impact the most shear. Typically, lab-prepared samples are mixed at a specific shear not dependent on the ultimate large-scale equipment used on location. Therefore, it is beneficial to develop a system that can produce consistent rheologies independent of shear.

Significant energy was focused on finding a chemical composition that produced consistent results independent of the shear provided. The result is a spacer system that may be designed in the lab and mixed in any equipment available at location with consistent results. **Table 1** shows how the rheology is independent of various laboratory mixing equipment and the resulting rheology is achieved in field equipment. In addition, **Table 2** compares laboratory design and results with rheologies from an offshore slugging pit.

Chemical Compatibility

Because the spacer system is designed so that it can work with all fluids (water-based muds, oil-based muds, synthetic muds, and cements), water-based muds and cements are less problematic. However, the fluids may contain chemicals that

can be detrimental to the rheological performance of the spacer. This is easily overcome through the use of surfactants. Surfactants may also be used to obtain compatibility with oil-based or synthetic muds. In general, surfactants lower the rheology of the spacer; thus, it should be accounted for during the design phase.

Conclusions

Successful zonal isolation relies on placing cement throughout the proper zones. To achieve this, the mud should be properly displaced. Spacers play a critical role in mud displacement. Further, the rheology of the spacer should be carefully chosen and implemented to completely displace the preceding mud. The following advancements in spacer technology allow for consistent rheological performance of the spacer system.

- Predictable rheological control, independent of density.
- Temperature-independent rheology.
- Minimal salt impact on rheology.
- Shear-independent rheology.
- Compatibility control.

Acknowledgments

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References

1. Crook, R., Bengel, G., Faul, R., Jones, R. 2001. Eight Steps Ensure Successful Cement Jobs. *Oil & Gas Journal*. July 2.
2. Gordon, C., Tonmukayakul, P., Morgan, R. 2007. A New Device Designed for Direct Yield Stress Measurements of Cement Spacers. Presented at the Canadian International Petroleum Conference, Calgary, 12-14 June.

**Table 1—Rheological Performance Independent of Mixing Shear
(Target = 32 lbf/100 ft²)**

Mixing Equipment	80°F	135°F	180°F
Atmospheric consistometer (30 min at ~150 rpm)	30	29	31
Waring® blender (5 min at 2,000 rpm)	31	31	30
Field batch blender (MMX)	28	30	30

**Table 2—Field Comparison,
Lab to Field Implementation of Design**

Location	Temperature, °F	PV, cp	YP, lbf/100ft ²
Lab (lab sample)	120	53	42
Rig (field batch)	80	55	42
Rig (field batch)	120	60	39

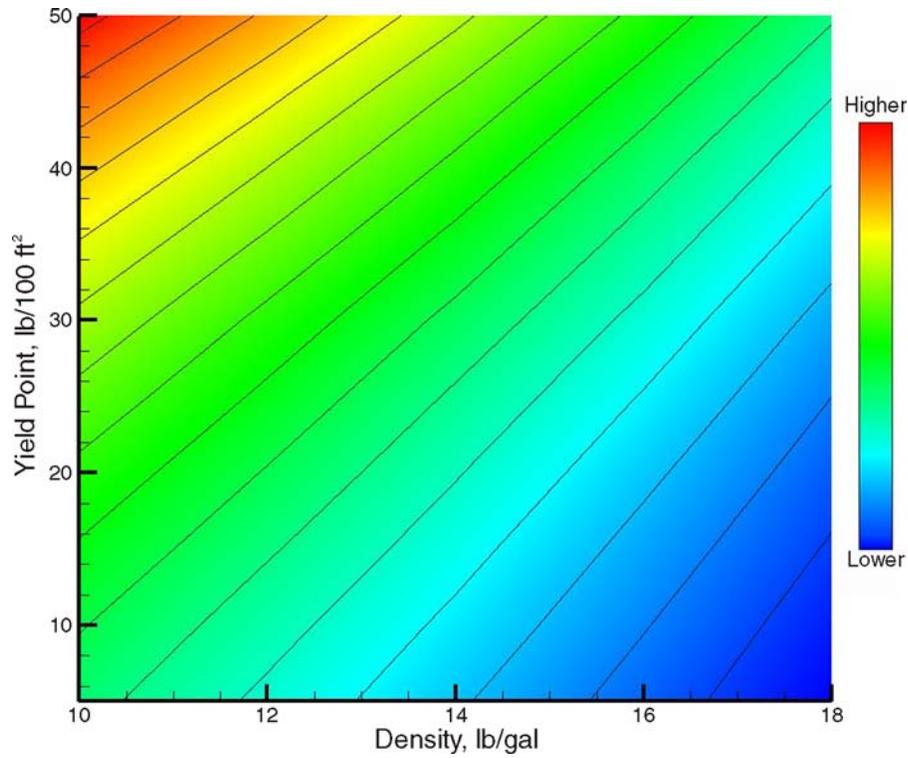


Fig. 1—Loading requirement of blend package as a function of density and desired yield point.

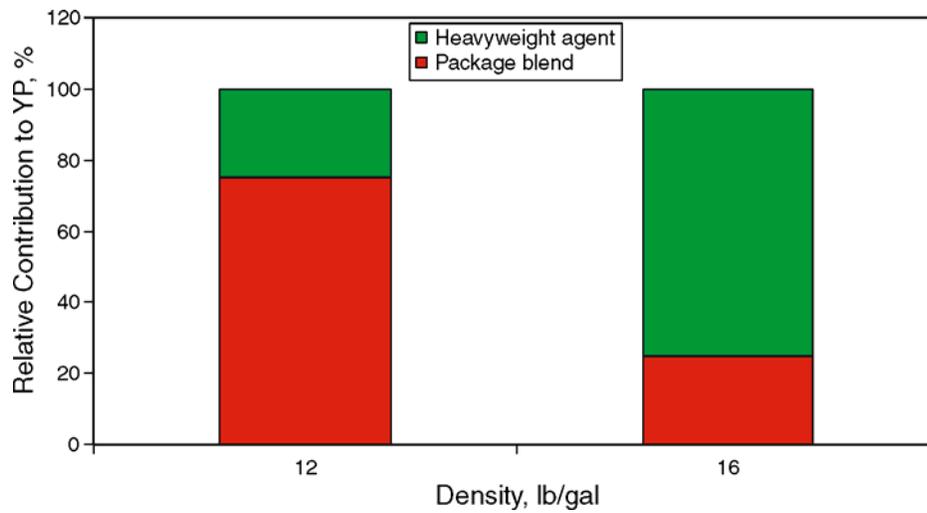


Fig. 2—Relative contribution of dry components to overall YP.

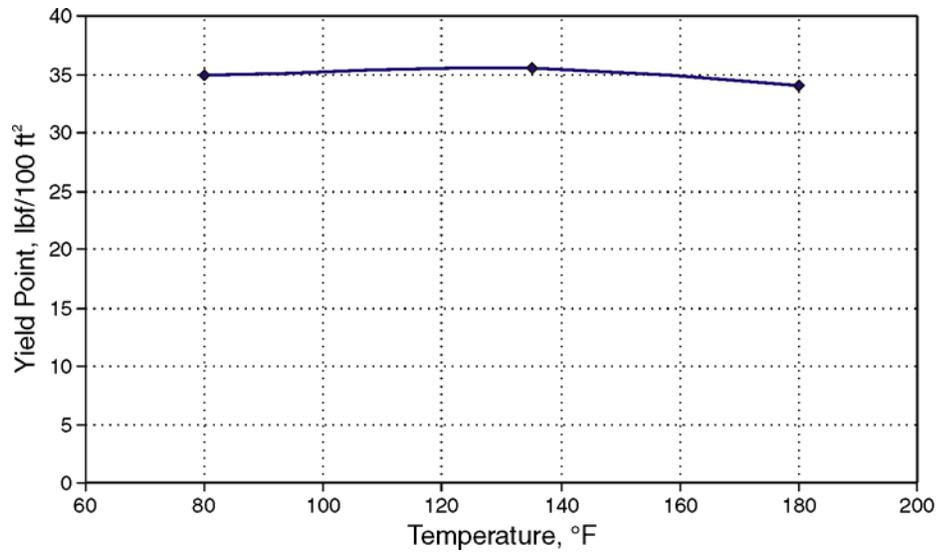


Fig. 3—Temperature stability; effects of temperature on yield point.