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A Robust, Field Friendly, Cement Spacer System

Marshall Bishop, Drilling Specialties Company; Larry Moran, ConocoPhillips Company, Mike Stephens, Drilling Specialties Company and Willie Reneau, Drilling Specialties Company

Abstract

Cement spacer fluids have traditionally been supplied by the cementing service companies. The specific performance properties of most spacer systems are not well defined. How a spacer is designed for a specific application has also not been well defined.

Cement spacers are required to be compatible with both the drilling fluid and the cement slurry. A cement spacer's basic function is to prevent non-compatible fluids from intermixing. The spacer must perform with a wide range of additives under varying conditions and still remain compatible with both the drilling fluid and cement slurry. The drilling fluid can range from simple aqueous to complex non-aqueous synthetic based systems. The cement slurry itself can also range from a very simple system with minimal additives to highly modified slurries designed for high densities, temperatures, and pressures. Spacer systems have traditionally been shrouded in secrecy and considered user unfriendly. This system has been successfully used in multiple wells drilled with both aqueous and non-aqueous based drilling fluids at temperatures up to 350°F (177°C). Information is provided to help demystify spacers and provide the operator with simple tools to adapt the spacer system to various drilling fluids and cement slurry formulations. This paper provides an overview of a new spacer system developed to be user and field friendly. Information is provided on performance properties as well as how to design a spacer system for specific applications.

Introduction

Cement and drilling fluid are normally not compatible. When combined, a viscous mixture is obtained which results in poor drilling fluid displacement and poor cement placement. The main reason that spacer fluids have been developed is to avoid mixing between the drilling fluid and cement. Spacer fluids have been developed for use with water based drilling fluids and for oil based drilling fluids. Spacers that are used to displace oil based drilling fluids should be compatible with the oil based drilling fluid and should leave formation and casing surfaces water wet.

Maintaining constant rheological properties of the spacer fluid during the course of the pumping operation makes modeling the mud displacement and the cement placement much easier. To maintain the rheological properties the amount of fluid in the spacer should not change, i.e. - the spacer should have good fluid loss control properties. To maintain the rheological properties during pumping, temperature should have a very limited effect on rheological properties.

Turbulent flow is the preferred flow regime for mud displacement and cement placement. In most cementing operations it is difficult to achieve turbulence. If turbulence is obtained it is normally achieved with a non-weighted fluid (water, base oil, chemical wash, etc.). These types of fluids have limited application due to their low density. The well may become under-balanced and start flowing if large volumes are pumped. If small volumes of non-weighted fluid are pumped, they become contaminated and fall out of turbulence. Therefore, in many situations, a weighted spacer is required. The weighted spacer will probably be pumped in laminar flow.

It is desirable to have the spacer density and rheological properties between those of the drilling fluid and the cement slurry in these situations. The spacer must be flexible in its design in order to obtain a density and rheological profile that is intermediate between the drilling fluid and the cement slurry. The spacer should not accelerate or excessively retard the cement set. A spacer should be quick and easy to mix on location. A spacer should not foam.

Once the job is finished the spacer may or may not have been circulated out of the well. If the spacer is still in the well it is desirable for the spacer to remain as a stable weighted fluid. It should not gel excessively and it should not settle. It should not develop free fluid.

A new adjustable spacer system has been developed that provides the characteristics described above. It is a modular or component system which allows the user to easily select the appropriate components, determine the addition level, check compatibility and mix the spacer fluid in equipment commonly available on site. The system's base component provides viscosity, carrying capacity, compatibility enhancers, and fluid loss control. The base component is specifically designed to maximize compatibility with cement slurries and water based drilling fluids. An antifoam, two surfactants, and a mutual solvent are additional components available to prevent foaming, enhance performance and impart compatibility and water-wetting capacity with non-aqueous based drilling fluids.

System Design

The spacer should be designed such that the density and rheological properties are between those of the drilling fluid that is being displaced and the cement system that will displace the spacer. The mud report (mud check sheet) provides basic information about the drilling fluid including density, rheological properties, and fluid type, i.e. aqueous or non-aqueous fluid. The cementing program provides the density of the cement slurry.

The density of the spacer should be approximately halfway between the density of the drilling fluid and the cement slurry or 60 kg/m^3 (0.5 lbm/gal) greater than the density of the drilling fluid, whichever is less. The rheological properties of the spacer should also be between those of the drilling fluid and cement. However, the rheology of the cement slurry is typically relatively high compared to the drilling fluid. It is preferable to design the spacer's rheological properties closer to those of the drilling fluid than to the cement slurry. This minimizes ECD and channeling and enhances efficient displacement of the drilling fluid by the spacer and spacer displacement by the cement slurry.

The drilling fluid mixes with the spacer at the interface and resulting transition zone between those fluids, especially in the annulus. The same mixing occurs in the transition zone between the spacer and cement, Figure I. The better the compatibility between the spacer and the drilling fluid and between the spacer and the cement slurry the lower the possibility of excessive increases in viscosity, coagulation, clabbering, and/or gel formation as the fluid in the annulus progresses from 100% drilling fluid to 100% spacer to 100% cement. Excessive viscosity, clabbering, etc. can lead to pockets of mud trapped in the annulus and reduce the quality of the cementing operation.

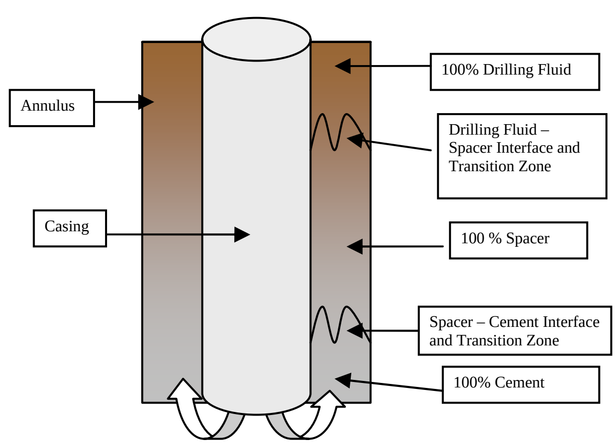

Figure I

Designing the spacer fluid for water based muds

The spacer fluid design is straight forward and field friendly. Four basic pieces of information are required to design the spacer fluid. Three pieces of information; mud density, rheology, and fluid type are obtained from the mud report. The fourth piece of information, cement slurry density, is obtained from the cementing program. Other information about the cement slurry may be beneficial for spacer design but is not normally required. This basic information and following the simple guidelines described above allows the user to easily determine the required spacer properties.

This new adjustable spacer system provides excellent rheology, fluid loss control, and carrying capacity for weighting agents such as barite. The system is effective over a wide range of downhole conditions and temperatures. A series of diagrams are provided enabling the user to compare the drilling fluid rheology with the spacer rheology. The user matches the properties of the drilling fluid to the reference rheology of the spacer at different densities. The guidelines provided earlier indicate the user should select a spacer system with slightly higher rheology and density than the drilling fluid. The cement schedule is consulted to determine the density difference between the drilling fluid and the cement slurry. The user then selects the appropriate formula to provide the required rheology. The spacer fluid is easily mixed in a batch truck, clean mud pit or slugging pit.

For ease of use, the spacer fluid is designated as low, medium, and high viscosity as shown in Figures II and III. The three categories do not require separate products but simply show how the rheology varies with different concentrations of base component at varying slurry densities.

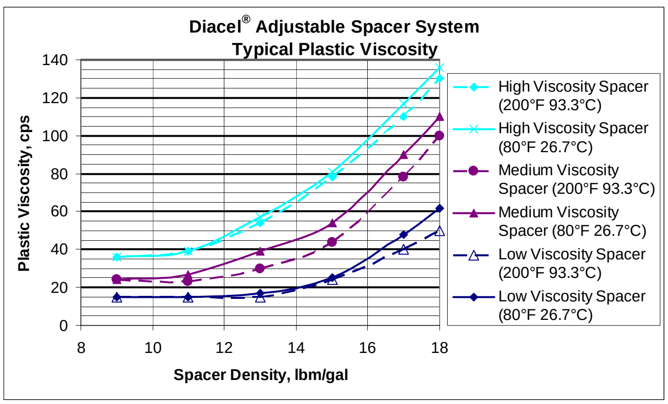

Figure II

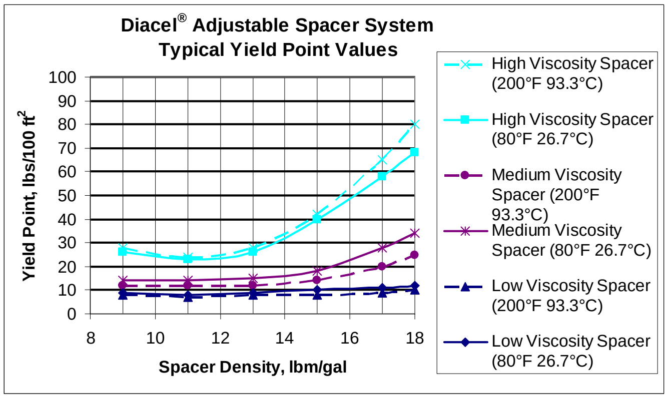

Figure III

For example, a field mud with a density of 1234 kg/m^3 (10.3 lbm/gal) had a PV = 23 and YP = 11 at 26.7°C (80°F). The proposed lead cement slurry had a density of 1558 kg/m^3 (13 lbm/gal). Referring to Figures II and III it is apparent the rheology of the mud is about the same as the medium viscosity spacer. Therefore a high viscosity spacer would provide the appropriate rheology, slightly higher than that of the mud. The density difference between the drilling fluid and cement slurry was greater than 120 kg/m^3 (1 lbm/gal). Following the guidelines the density of the spacer should be approximately 60 kg/m^3 (0.5lbm/gal) greater than the density of the drilling mud or 1294 kg/m^3 (10.8 lbm/gal).

Figure IV depicts the relationship between the concentration of the basic viscosifier additive and the rheology at various fluid densities. Increasing the viscosity at any given fluid density requires additional viscosifier. Reducing the concentration of basic viscosifier compensates for the increase in rheology that normally occurs as weighting agents are added to increase fluid density. Again referring to Figure IV, the user can determine that 48.5 kg/m^3 (17 lbm/bbl) of viscosifier is required for a high viscosity, 1294 kg/m^3 (10.8 lbm/gal) spacer fluid.

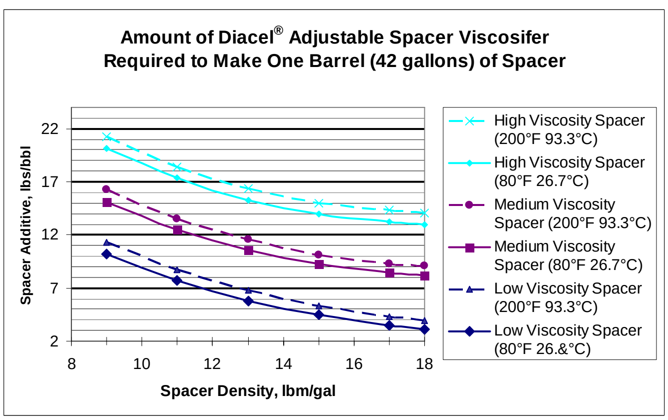

Figure IV

The spacer design is essentially complete for an aqueous based drilling fluid and ready for compatibility testing. Adding approximately 1 gallon surfactant per barrel of spacer will enhance water wetting of the formation and casing.

Compatibility testing can be easily accomplished by mixing various proportions of spacer and drilling fluid or spacer and cement slurry and measuring the rheology. As shown in Figure V, the system provides very smooth rheology as the drilling fluid concentration increases from 0% to 100%. Figure VI illustrates the compatibility of the spacer with a field cement slurry.

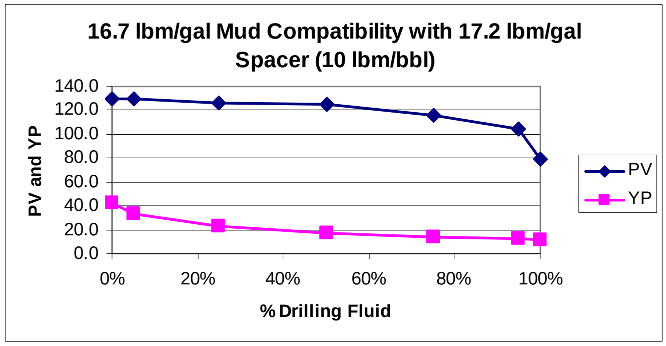

Figure V

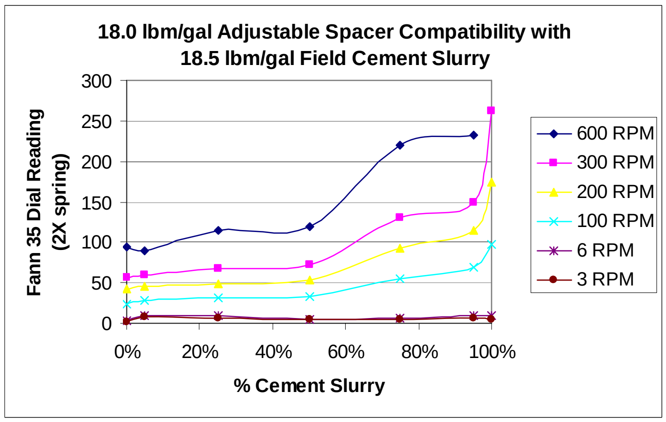

Figure VI

Designing the spacer fluid for non-aqueous based fluids

Non-aqueous based drilling fluids are fundamentally less compatible with the spacer and cement than aqueous based fluids. Non-aqueous based drilling fluids are stable water in oil emulsions containing various surfactants to ensure the aqueous phase remains as discrete droplets in the continuous non-aqueous (organic) phase during drilling operations. The fluid also contains numerous additional additives to provide the requisite fluid loss and rheological properties. The aqueous phase often contains relatively high concentrations of $CaCl_2$. The spacer must invert or flip the emulsion in the mixing and transition zone producing an aqueous continuous phase. It must leave the formation and casing water wet to facilitate bonding between the cement and those surfaces. As with aqueous based drilling fluids, the spacer must not gel, clabber, coagulate, or lead to exceedingly high viscosity mixtures in any combination with the mud or cement.

Field or laboratory pilot testing is required to determine the amount of surfactant required to invert the organic continuous emulsion and produce a compatible system. The recommended test procedure for testing water-wetting capacity of the spacer system is provided in API 10B-2[1].

A quick screening to provide a starting point for the surfactant concentration in the spacer fluid can be achieved by mixing additional water with the non-aqueous based drilling fluid to increase the water content to approximately 50%. This is followed by mixing incremental amounts of the spacer system's surfactant(s) and/or mutual solvent with the diluted drilling fluid. Transfer a few drops of the drilling fluid to a beaker or jar of water after each surfactant and/or mutual solvent addition. At some point, the drop of drilling fluid will spontaneously disperse in the water. Dispersion may be achieved with one surfactant or may require both surfactants and/or the mutual solvent. The amount of each product added provides an indication of the surfactant levels required in the spacer system to invert the drilling fluid.

The compatibility of the spacer system with a typical non-aqueous based drilling fluid is shown in Figure VII. Flat rheology is achieved. The system does not show evidence of gels, clabbering, or viscosity humps. The electrical stability is very good, returning to the instrument set point as the concentration of spacer approaches 100%.

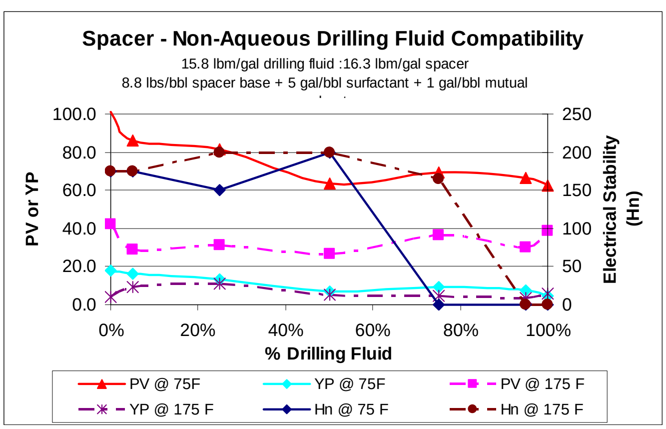

Figure VII

Standard HTHP tests demonstrate that the adjustable spacer provides very good fluid loss control in most cases. Higher fluid losses are noted in low density fluids and in higher density: low viscosity fluids, Figure VIII.

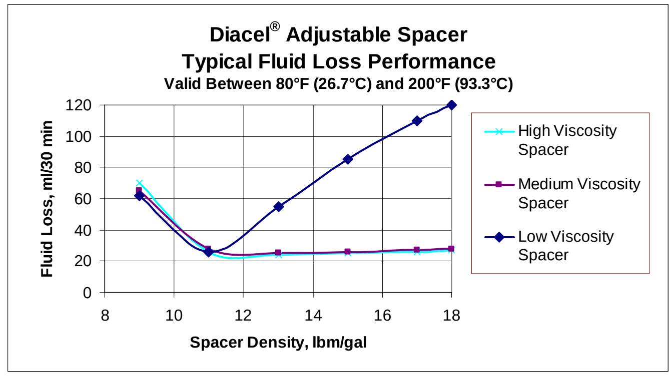

Figure VIII

The high fluid loss in the higher density low viscosity fluids is due to the fact that very little base spacer viscosifier, and thus very little fluid loss additive, is required to formulate this spacer. The use of the low viscosity spacer at higher densities should only be used when high fluid loss values are acceptable.

Multiple field jobs have been successfully completed using the new spacer. It has been successfully used with BHCT in excess of 177°C (350°F). A pumping job profile summary is provided in Figure IX. No unusual pressure events occurred indicating the spacer performed as designed.

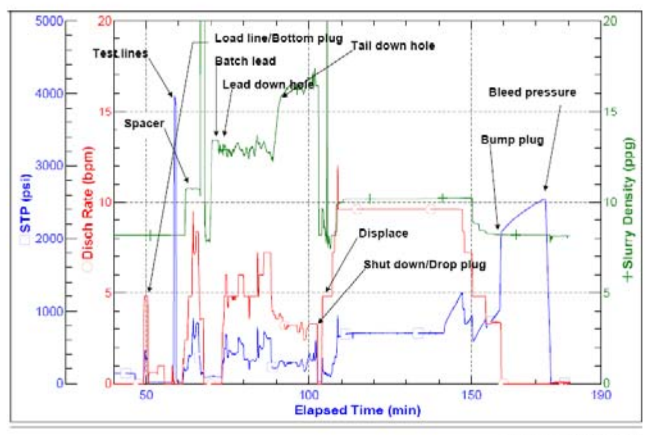

Figure IX

Conclusions

Spacers are not mysterious or complicated fluids. They have a specific role in drilling operations, to keep two incompatible fluids separated without compromising the function of either. They must be compatible with both such fluids in order to accomplish their role. The information presented in this paper provides the user with some basic guidelines for spacer design, performance information to enable the user to select the proper components, and a simple test to verify compatibility.

Acknowledgments

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Nomenclature

BHCT = bottom hole circulating temperature
HTHP = high temperature high pressure
kg/m^3 = kilograms per cubic meter
lbm/bbl = pounds per barrel
lbm/gal = pound mass per U.S. gallon
PV = plastic viscosity
YP = yield point
Hn = Hogans

Note

The spacer rheological properties of plastic viscosity and yield point were arrive at based on a linear least squares curve fitting procedure that uses multiple rotational viscometer readings (minimum; 300 rpm, 200, rpm, 100 rpm, 6 rpm, and 3 rpm). The drilling fluid rheological properties of plastic viscosity and yield point should also be arrived at using the same procedure.

References

1. Water-wetting capability testing, API Recommended Practice 10B-2 / ISO 10426-2