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Wellbore Shielding Spacer Improves Cement Bond While Preventing Cement Losses

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Abstract

Cement bond integrity and zonal isolation can be compromised when severe losses are encountered during cementing operations. When casing mechanically weak and/or depleted reservoirs, resultant narrow fracture gradient windows and higher cementing equivalent circulating densities (ECDs) can break down the formation. The combination of existing and induced losses invariably requires costly remedial cementing.

Generally, cement spacers are used to create full placement of uncontaminated cement and deliver effective cement bond. However, in loss-prone reservoirs conventional spacers optimized for hole cleaning are not normally capable of controlling losses. The losses-while-cementing issue has recently been addressed with the development of a spacer suitable for temperatures up to 350 deg F (177 deg C) with loss-prevention capabilities, incorporating proprietary Wellbore Shielding (WBS) technology.

Discussion of the role of spacer fluid technology in cleaning the hole of immobile drilling fluid to then creating efficient cement bonds while improving the overall cement job quality will be covered. A sampling of recent field results demonstrating the efficacy of the WBS spacer in delivering high-quality cement jobs in troublesome environments will be shared. Finally, it will be demonstrated in both the laboratory and field, how the new spacer technology supports a high-pressure differential, allowing cementing operations at increased ECD that otherwise would exceed the formation's fracture gradient. The capacity to safely operate above the fracture gradient under downhole conditions minimizes the cement density limitations posed by low fracture gradients. In addition, by reducing post-placement slurry fallback, the spacer eliminates induced losses and resulting top jobs or liner top squeezes.

Introduction

While often considered just an unavoidable task, primary cementing plays a critical role in the useful longevity of a wellbore. The effectiveness of the annular seal provided by cement jobs are one of the most important aspects of the wells long-term health. This annular cement sheath is necessary to: 1) Provide support for the pipe, 2) Provide protection to the pipe from corrosive down-hole fluids, 3) Prevent cross-flows which may lead to loss of precious hydrocarbon and 4) Prevent flow back to the surface on the outside of the pipe, which could also lead to loss of production and potentially even worse, environmental contamination.[1]

To further complicate matters, these four simple tasks must be accomplished over a wide variety of down-hole conditions. On conductor jobs in deepwater, temperatures can be near the freezing point and/or in geothermal applications, where temperatures can exceed 400 deg F. Regardless of well conditions, to achieve an effective and lasting seal, the drilling-fluid must be completely or nearly completely removed from the annular space.[2] At times, the drilling fluid is water-like and can be easily removed. In other cases, such as PHPA systems, high gel strengths during the static period can occur between reaching total depth (TD) and getting the casing to TD, making displacement difficult (see Figure 1). Oil-based muds (OBM) and synthetic-based muds (SBM) provide an additional issue, associated with the external phase being oil wet. Cement does not like to bond to oily substances, thus to achieve this effective annular seal, the pipe and formation must be flipped to a water wet condition prior to cement placement.

Numerous papers have been written discussing how to provide effective mud displacement.[3,4,5,6] Primarily they focus on: 1) Modifying the properties of the mud to make it more displacement friendly (thinning it down and/or decreasing the gel strength), 2) Centralization of the casing or liner (standoff - minimum 70%), 3) Pipe movement, either rotation or reciprocation (neither need to be too fast, 10-30 rpm/1-3 minutes per up or down stroke), 4) Displacement rate, pump as fast as safely possible, 5) Spacer volume and viscosity volume must be sufficiently large to allow for the existence of pure spacer, at the end of the job, to account for the intermixing[7,8] that will occur with the cement and the mud at both the trailing and leading edges (see Fig 2.). Spacer viscosity must be thin enough to ensure effective mixing and generate minimal friction pressures during displacement, but thick enough to push the drilling fluid up and out of the annular space. If all of these tasks are done properly, achieving a good cement job can be accomplished, if a stable, in-gauge wellbore is drilled. What happens if all of these steps are not taken or the wellbore itself has integrity issues? Zonal isolation can be compromised resulting in the potential for unexpected operational costs. Pipe movement and/or extra spacer volume of the optimal viscosity can make up for less-than-ideal focus on the other characteristics.

Spacer Optimization

If hole cleaning is an essential job for the spacer system, the spacer must be designed so Yield Point (YP) of the spacer system exceeds that of the drilling fluid. While a handful of spacer systems are a ones-size fits all solution, other spacer systems are multiple component systems where concentrations are interdependent, making adjustments complex. Ideally, the spacer system will provide a fairly linear relationship between concentration and wall shear stress. In other words, adding a little more or less of the spacer system means the spacer becomes a little thicker or a little thinner. This is exactly how this paper's subject Wellbore Shielding (WBS) spacer system performs (see Fig 3.). This simple linear relationship allowed for the development of a very easy to use software application that guides the user towards optimum spacer design. In Figure 4, the initial input screen is displayed. The YP range displayed in the drop-down list is density dependent. Lightweight systems do not need to be extremely thick and heavyweight systems cannot be overly thin. In Figure 5, a sample calculated lab recipe is displayed. With this information a lab technician can then weigh, blend, condition, measure the rheology, and then calculate the YP of the spacer. Ideally this calculated value will be in the requested range. If it is too thick or thin, simply return to the input screen (Fig 4) and enter a new spacer loading, slightly higher or lower than what was used in the previous lab test. After clicking the Formulate button, a new recipe will be displayed. Repeat the lab test with the new recipe until the YP is in the correct range. With an optimized spacer viscosity, displacement efficiency will be maximized.

Standard spacer volume rules-of-thumb call for 10-15 minutes of contact time or 1000-1500 feet of fill. Contact-time is simply the volume of spacer divided by pump rate. When calculating contact-time, use the pump rate that will be utilized when the spacer is entering the annulus not the spacer mixing rate. Rules-of-thumbs are fine for use as a starting point but cannot be taken as the ideal answer for every question. In some cases, greater spacer volumes will be required to provide optimal displacement efficiency. With longer hole-sections more spacer will be required. Figure 2 illustrates the reason for this. With every additional foot, the intermixing increases. At some ratio of spacer volume to open-hole length the leading and trailing intermixing zones will consume the entire spacer volume. At this point mud and cement will come in contact. One of the primary reasons to pump spacer is to separate the mud and the cement. If the spacer volume is not sufficiently large and the contaminated ends connect, this task will not be accomplished. Lost circulation is a second reason to consider using more spacer. If only slight losses are present, include 25% extra spacer. If the loss rate is higher, use 50% excess spacer. With severe losses, double spacer volume could be required.

Wellbore Shielding Spacer

In wells where only, effective separation of mud from cement and mud removal is required any non-WBS spacer will do. If, however, pre-job losses are encountered or the Equivalent Circulating Density (ECD) is expected to be near or even exceeding the frac gradient, the likelihood of achieving the pre-determined cement job KPI's will be greatly enhanced, through the use of this paper's subject WBS spacer.[9] The Equivalent Circulating Density (ECD) is the measure of the combined effect of the hydrostatic pressure of the fluid in a well-bore plus the created friction while the fluid is being circulated.

Prevention

The WBS technology has been designed to deposit a non-damaging shield on the inside of the wellbore face. This shield inhibits fracture propagation. If new fractures do not propagate, the ECD can be near or slightly above the frac gradient, and the full column of cement will be circulated. In one example, two-stage cementing was previously required as any circulating pressure above 10.98 lb/gal caused fracture initiation and cement was lost. After the addition of the WBS spacer to the job procedure, cement was circulated in a single stage, even though the ECD reached 12.02 ppg.[10]

Use of a WBS spacer, by itself, cannot cure annular gas migration problems following cementing as the pressure shield traps pressure in the annulus and is only held in place by differential pressure. However, if WBS spacer technology is utilized, the initial overbalance pressure can be safely increased. If the overbalance-pressure is increased to an amount that is greater that what will be lost during the transition time, gas migration issues are eliminate or at least drastically reduced.

Without a WBS spacer, should the pre-job ECD simulation indicate fracturing possible, the first step is usually a reduction in displacement rate. If this is not enough to decrease ECD sufficiently, density reduction is a common second step. While better than fracing the well while cementing, neither of these options are beneficial for the enhancing the cement job quality. With a WBS spacer pumped as the primary cementing spacer, the displacement rate has shown to be safely maintained at the higher rate and cement density reduction can also be avoided without inducing losses.

Curative

Service companies are often asked to cement wells that do not have full circulation with just mud in the wellbore, let alone after heavier cement has been pumped. Without full returns prior to cementing, unless the goal is just to tack the shoe, results will probably be less than desired. In an ideal world, the losses will be cured prior to cementing. If enough effort was not devoted to curing the losses during drilling, additional time and resources may not be applied to accomplish this task prior to cementing. This is the second scenario that separates this paper's subject spacer system.

A specially optimized lost circulation package has been designed specifically to work with the WBS spacer system, when just preventing problems is not enough and losses are already present prior to increasing the ECD from the process of trying to lift cement. In Figure 6, a correlation has been made between loss rate and concentration of lost circulation material (LCM) required in the spacer. If the loss rate is not too large, the combined system should be able to cure these losses. At higher loss rates (up to and including total losses) while the WBS spacer system may not work every time, it will provide the best chance for success.

In one particularly problematic geothermal region, on the surface casing, an average of eleven top jobs were needed to get cement back to the surface requiring an additional 1047 bbl of remedial cement. While the WBS spacer system with the LCM package did not completely cure the losses, only two top jobs with only 138 bbl of cement was required to get cement to surface. On the intermediate string, the average of eight top jobs were again reduced down to two, resulting in a savings of $329,500/ well.[3] In another example, well conditions were poor and it took over three weeks to drill one hole section because losses were occurring the entire time. Once TD was reached, the losses were total. The operator's cement specialist requested the WBS spacer, plus the LCM package, believing it would give them the best chance for success. In this case, cement was circulated on top of the liner, on the first try.

Case Histories – Permian Basin

Loving County:

In a Loving County well, 15,408-ft. of 5.5-in. casing was to be cemented back to the surface. Returns to the surface are not often achieved in this region, even with light-weight beaded slurries. With the WBS spacer system, not only was cement circulated to the surface, but it was done with a less costly 10 lb/gal lead slurry instead of the costlier 9.5 lb/gal recipe that is standard in that area. The 100 bbls of the 9.7 lb/gal WBS spacer system was pumped ahead the cement. The spacer was designed with 20-lb of spacer concentrate/bbl and an additional 10 lb/bbl of the synergistic LCM package. Along with the physical observation of cement returns to the surface, proof of spacer effectiveness can be gathered from Figure 7 by careful examination of the smooth and steadily increasing pressure curve during the displacement period immediately prior to the pressure spike created when the plug landed and seated at 5000 psi. Further proof of the complete circulation achieved with the WBS spacer system can be drawn from Figure 8. In this chart, the pre-job simulated displacement pressure (that which is required to lift the cement; 245 minutes to 290 minutes) is compared to the actual displacement pressure measured during the job. Losses are not taken into account during pre-job simulation. If losses were occurring during the job the lift pressure would decrease and there would be a divergence between the two pressure curves. In Figure 8 both pressure curves remain remarkably parallel, until the plug lands.

Midland County Example:

In Midland County, on a 5 well pad the effectiveness of the WBS spacer in helping to achieve cement returns, on intermediate casing strings, was tested by comparing the results with and without the WBS spacer. In both wells utilizing the WBS spacer cement returns were observed. In one of the 3 jobs without the WBS spacer system, some spacer was observed and the other two jobs cement was not circulated.

Summary

• To achieve effective zonal isolation, best practices must be observed

• Sufficient spacer volume and proper spacer viscosity are key pieces of the required best practices

• Use of a WBS spacer can help to maintain full circulation when attempting to lift heavy cement

• With the addition of specialized LCM to the WBS spacer system not only can losses be prevented, but existing losses can be cured as well.

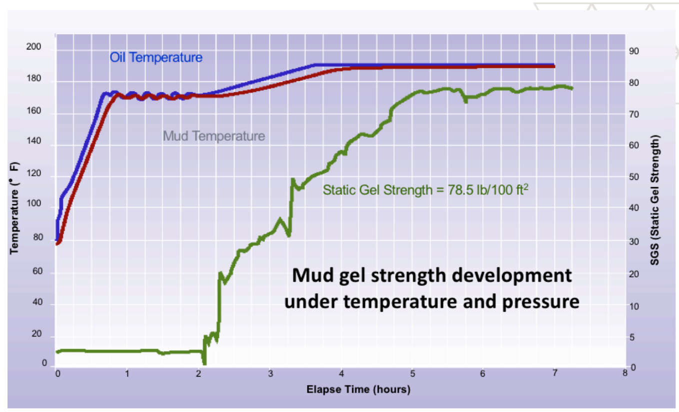

Figure 1 – Excessive gel strength displayed by a conventional drilling fluid

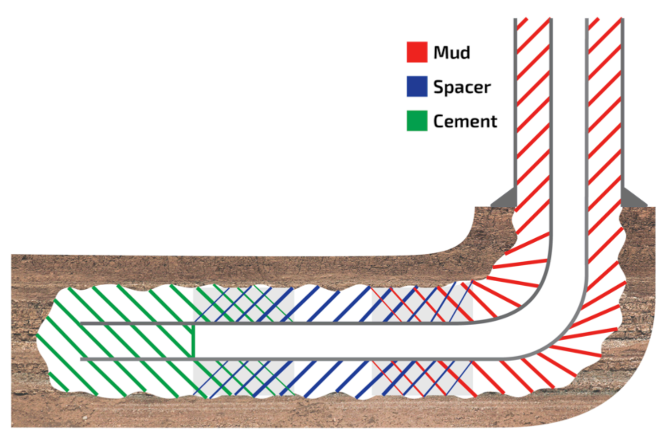

Figure 2 – Schematic of spacer intermixing intervals

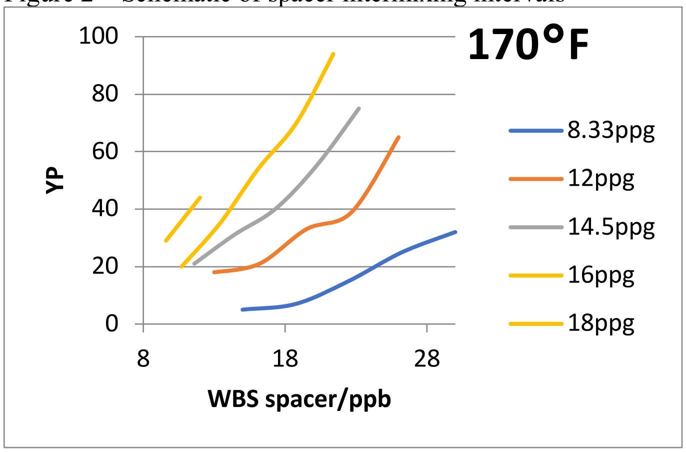

Figure 3 – YP linearity at 170 deg F

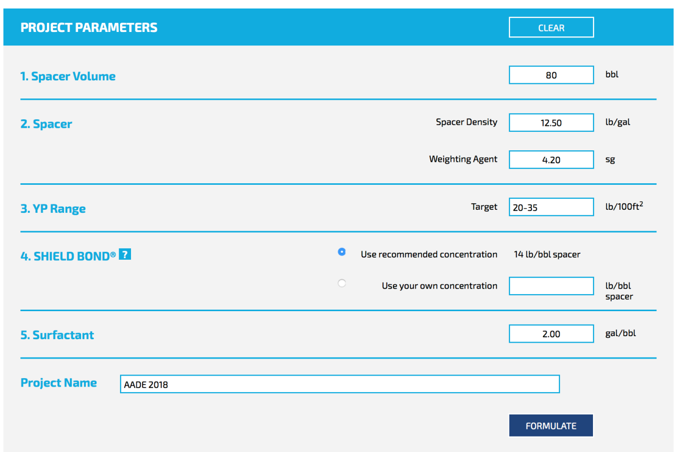

Figure 4 – Input screen for WBS design application

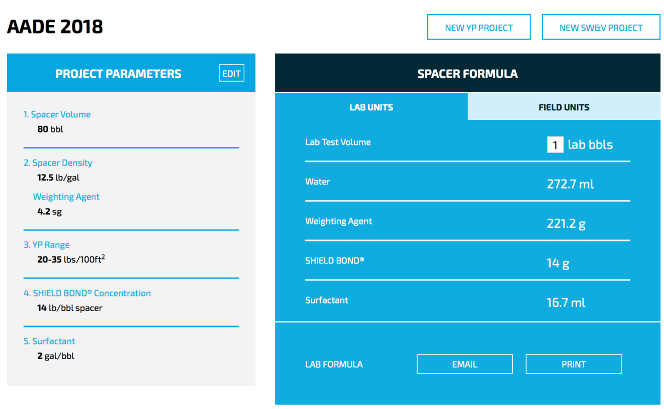

Figure 5 – Lab design output screen for WBS design application

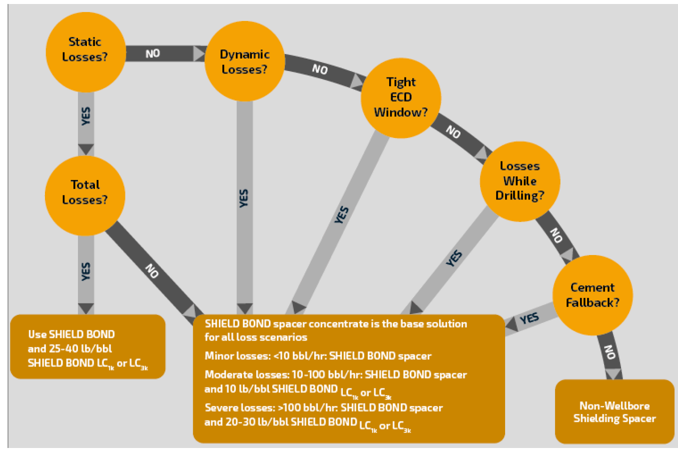

Figure 6 – Decision tree for WBS spacer system

Figure 7 – Job log with WBS spacer system

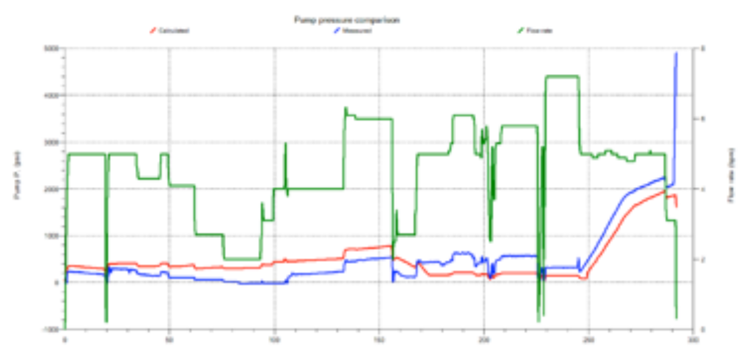

Figure 8 – Comparison of predicted and actual pressure for cement job with WBS spacer system

Nomenclature

TD = Total Depth
ECD =Equivalent Circulating Density
WBS =Wellbore Shielding Spacer
LCM =Lost Circulation Material
YP =Yield Point

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