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Novel Fluid Technology Used to Overcome Induced Losses While Cementing in the Permian Basin

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Abstract

Lost circulation while cementing is defined by two key variables: the fracture pressure of the formation and the placement pressures of the cementing job. Losses while cementing occur if the equivalent circulating density (ECD) surpasses the frac gradient. When the wellbore encounters elevated ECDs, isolating the formation can mitigate the risk of induced loss. Field data will illustrate the effectiveness of an innovative cement spacer technology in isolating potential weak zones, thereby facilitating complete cement placement.

Ensuring wellbore stability and zonal isolation are pivotal throughout a well's lifecycle. To achieve an optimal top of cement (TOC), preventing lost circulation is imperative during the primary cementing operation. The deployment of this novel spacer technology has enabled superior cementing jobs, even in challenging formations. This not only helps operators in minimizing downtime, but also enhances their environmental stewardship by avoiding remedial work and the use of additional cement.

Before the introduction of the new spacer, cementing engineers predominantly centered their efforts on ECD management, using strategies such as washes, unweighted spacers, or lightweight cements. The novel spacer technology has been key in allowing cementing companies to avoid losses, while ensuring thorough mud removal and securing cement coverage across the entirety of the casing. Two case studies are presented within this paper that detail the success in healing lost circulation and achieving desired top of cement placement in both surface casing and production casing applications in the Permian Basin.

Introduction

In modern US land shale development, economics are key to any drilling and completion operation. Lost circulation is a costly problem for drillers – causing non-productive time, wasted material, additional trips, unplanned casing strings, and can even cause additional problems later in the life of the well if proper zonal isolation is not achieved. The cementing operation, while a small portion of an operator's overall drilling budget, is a key component of ensuring a well is constructed with the necessary annular barriers.

The Permian Basin, stretching from West Texas into Southeast New Mexico, has a long history of lost circulation. Traditional methods of solving lost circulation have been used with limited success. As lost circulation occurs when the force applied to a formation exceeds its fracture gradient, primary methods of preventing lost circulation have centered around reducing the hydrostatic pressure of the column of fluid in the annulus by pumping lightweight spacers and cements, and minimizing the frictional forces and surge pressures applied to the formation by limiting mixing and displacement rates while pumping. Reducing the cement density can have drastic effects on cement properties, depending on the method used. For conventionally extended lightweight slurries, slurry stability can be compromised or the final set cement density is often weaker. Foamed cement slurries will have higher strength and better stability than conventionally extended slurries, but these foamed cement slurries will often have much higher rheological properties and the risk of ECD exceeding the fracture gradient is higher than with conventionally extended cements (Dusterhoft, 2003). High performance lightweight slurries can overcome these issues, but the cost is significantly higher than either other cement option and is often not an economical choice.

Once lost circulation occurs, this means a fracture has been induced and must be sealed to regain circulation to surface. Historically this has been done using lost circulation materials such as polyester or cellophane flakes, ground laminate flakes, ground coal or Gilsonite® resin[1], fibrous materials, or a combination thereof. The success of these materials typically relies on a cement or drilling engineer's experience in an area. An LCM loading or combination that works in one part of the basin may not work as effectively in another part of the basin, so much of the industry's experience with LCM application is trial and error. A solution is needed that is more widely and easily applicable across various formations and basins.

The novel spacer technology discussed in this paper offers a solution to these problems. Traditionally, spacers have two

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[1] Gilsonite is a registered trademark of American Gilsonite Company.

primary functions in cementing operations. The first is to separate the mud from the cement by one more spacers. Drilling fluids and cement slurries are typically not compatible and by placing a fluid in between them, the risk of fluid mixing is reduced. The second function of a spacer pumped ahead of cement is to aid in the mud removal process. A properly designed spacer will have rheological properties optimized such that the spacer is more viscous than the drilling fluid it is displacing, but less viscous than the cement that will in turn displace it. The density of the cement spacer will ideally also be between those of the drilling fluid and cement slurries (Nelson and Guillot, 2006). This novel spacer technology also helps to both prevent losses before they begin, and with the addition of a new lost circulation material, can heal severe losses after they have started.

Novel Spacer Technology

The novel spacer technology is a cellulosic formulation engineered to form a non-damaging filtercake on the inside face of the formation that can withstand the differential pressure encountered while cementing (Shine et al., 2023). When this material is placed at the tip of a pore throat, it can hinder fracture initiation and propagation, allowing the formation to support higher forces than it normally could. The new spacer is able to seal equivalent slot widths of up to 350 µm, which allows the cement operation to be performed without reducing slurry densities or pump rates during the job.

A novel LCM has also been designed to work with the new spacer technology. The LCM enhances the capacity to seal equivalent slot widths from 350 to 3,000 µm. The paired LCM was engineered for particle size and sealing capabilities across a broad variety of densities and equivalent slot widths. Before the deployment of the novel spacer technology and its paired LCM, a comprehensive series of lab tests were conducted to validate its sealing performance.

Slot Testing – Loss-Preventative Spacer

The primary method of evaluation for the lost circulation spacer is to study the fluid's capacity to seal a specific slot width based on the expected downhole conditions. These tests were performed on the spacer with and without the use of LCM.

The tests were performed using a modified particle plugging apparatus (PPA) with a variety of differential pressures and slot widths (Fig. 1). The fluid is loaded into the cell above the slot, and pressure is applied from the top. The valve at the bottom is opened to atmospheric pressure creating a pressure differential across the slot. The volume of fluid that escapes from the slot is measured and compared between the formulations – the less fluid that is pushed through the slot, the more effective the seal. Larger slots correspond to larger fracture widths; the larger a slot which a spacer formulation can seal, the more severe losses that the spacer could prevent.

Figure 1 – Photo of the PPA (left) and slot disks (right).

To perform this test, a 600-mL spacer sample is prepared and loaded into the cell above the slotted disk. Pressure of 100 psi is applied to the top of the cell and the valve at the bottom is opened, creating a pressure differential across the slot. This differential is maintained for 15 minutes, then pressure is increased to 500 psi for 15 minutes, and finally pressure is increased to 1,000 psi for 15 minutes. The fluid collected through the valve is measured in milliliters at the initial spurt, and at the end of every different pressure interval. The leak off is calculated as percentage of the original volume loaded in the cell. The lower the leakoff value, the more effective the spacer is at sealing the slot at that differential pressure.

Table 1 shows the results of the loss-preventative spacer without LCM at two different densities, 8.7 lb/gal with a concentration of 20 lb/bbl of spacer polymer and 11.5 lb/gal with a concentration of 17.5 lb/bbl of spacer polymer. Upon completion of the test, slot disks are removed and analyzed to visually confirm effectiveness of the shield (Fig. 2 and Fig. 3).

Table 1 – Slot Width Performance of Preventative Spacer without LCM

Density (lb/gal)	Slot size (µm)	Spurt (%)	100 psi (%)	500 psi (%)	1,000 psi (%)
8.7	200	0	0	0	0
	350	1	1	2	1
11.5	200	0	0	0	0
	350	1	0	0	0

Figure 2 – 8.7-lb/gal spacer tested on 200-µm slot disk (left) and 350-µm slot disk (right).

Figure 3 – 11.5-lb/gal spacer tested on 200-µm slot disk (left) and 350-µm slot disk (right).

Slot Testing – Loss-Preventative Spacer Paired with LCM

The use of the paired LCM that offers a greater range of sealing or plugging capabilities for solving predicted fractures when downhole circumstances make it necessary to support the principal function of the lost circulation spacer. The testing analyzes the incremental improvement in sealing performance using the loss circulation spacer and its LCM. The testing follows the same method as the previous section. The 8.7-lb/gal fluid was loaded with 20-lb/bbl spacer polymer and 40-lb/bbl LCM; the 11.5-lb/gal fluid was loaded with 17.5-lb/bbl spacer polymer and 40-lb/bbl LCM. The results are displayed in Table 2. Figure 4 and Figure 5 show the effectiveness of the shield across the 1,000, 2,000, and 3,000-µm slots.

Table 2 – Slot Width Performance of Preventative Spacer with LCM

Density (lb/gal)	Slot size (µm)	Spurt (%),	100 psi (%)	500 psi (%)	1,000 psi (%)
8.7	1,000	0	0	0	0
	2,000	1	0	3	2
	3,000	7	0	4	2
11.5	1,000	0	0	0	1
	2,000	2	0	0	0
	3,000	14	0	0	0

Figure 4 – 8.7-lb/gal spacer with LCM. Left to right: 1-mm, 2-mm, and 3-mm slot apertures.

Figure 5 – 11.5-lb/gal Spacer with LCM. Left to right: 1-mm, 2-mm, 3-mm slot apertures.

Rheology Testing

It is important to understand the rheological behavior of a spacer system. A good spacer system has rheological properties optimized such that the fluid is more viscous than the one it is displacing, but less viscous than the next fluid in the displacement train (Nelson and Guillot, 2006). The loss-preventative spacer system provides a linear relationship between concentration and yield point, which means that the rheological properties are easily modified by simply adjusting the loading of the spacer. (Fig. 6)

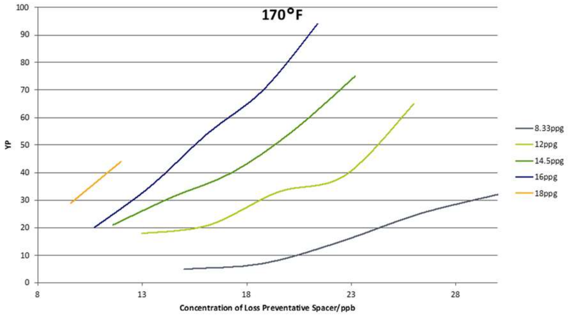

Figure 6 – Loss-preventative spacer designed to allow optimized hole cleaning with easily adjusted YP.

Stability Testing

In a cementing job, the spacer faces both dynamic and static conditions during placement, and it is critical to the success of the cementing job that the spacer remains stable in both conditions. The LCM that is added to the loss-preventative spacer provides added solids to the fluid and therefore the cement spacer with the LCM requires testing to measure and evaluate the risk of instability due to solids settling.

For the dynamic stability test, the loss-preventative spacer fluid paired with the LCM is placed in a high-pressure, high-temperature (HPHT) consistometer for a thickening time testing which follows the same procedure as with the cement. The dynamic stability test includes a static period of 45 minutes after 2 hours stirring at 150 rpm. After the static time, rotation is resumed and the consistency is observed for a spike, which would indicate solids settling. The dynamic stability results are shown in Figure 7. Two different spacer densities (8.7 lb/gal and 11.5 lb/gal) each with 40 lb/bbl of LCM were tested.

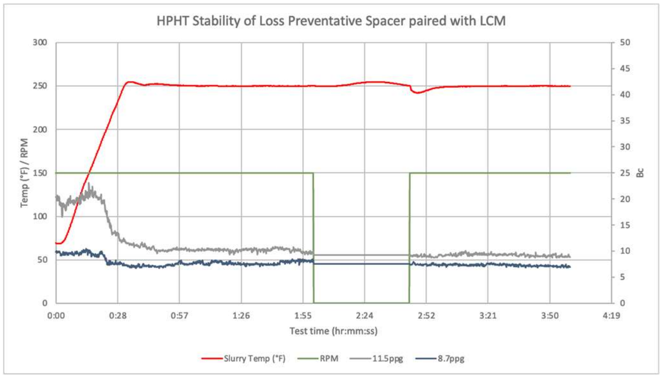

Figure 7 – Dynamic testing of the loss-preventative spacer with LCM using HPHT consistometer.

To further analyze the dynamic stability results, at the end of the test, it is necessary to observe the paddle and the bottom cap of the fluid cell (Fig. 8) to confirm the ability of the spacer fluid to remain uniform and with no sedimentation.

Figure 8 – Visual observation after dynamic testing. Unweighted, 8.7 lb/gal (top) and 11.5 lb/gal (bottom) slurries.

The dynamic stability test is followed by the static stability test which follows the same method used to measure the free water of the cement slurry. The spacer is decanted into a 250-mL graduated cylinder and left to rest for two hours to monitor for separation or settling (Fig. 9). To confirm the ability of the spacer system to remain stable, after the two hours, the density of the fluid is measured at different sections of the cylinder. Because the fluid contains LCM, plastic pipettes are modified by cutting the end back to a section with a 5-mm diameter, then samples are collected from the top, middle, and bottom of the cylinder. Table 3 shows the densities of the fluids upon completion of the static stability test.

Table 3 – Static Stability Density Verification

Density (lb/gal)	Top (lb/gal)	Middle (lb/gal)	Bottom (lb/gal)
8.7	8.6	8.7	8.7
11.5	11.5	11.5	11.6

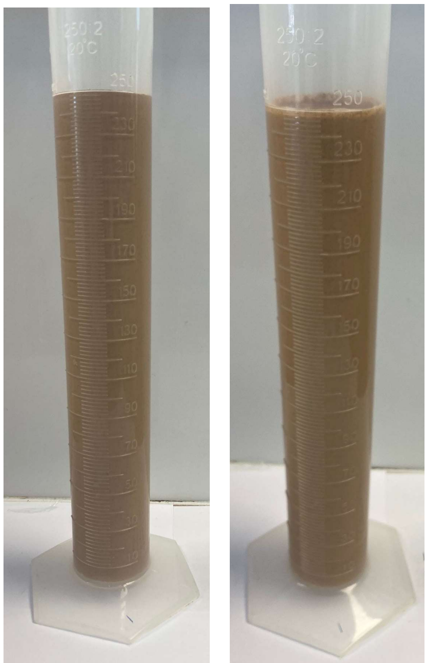

Figure 9 – Static testing of 11.5-lb/gal loss-preventative spacer with 40-lb/bbl LCM. Before (left) and after two hours (right).

Mixability and Pourability Testing

The Mixability and Pourability Test is a further examination to corroborate the capacity of the loss-preventative spacer paired with its LCM to freely travel between surface equipment and through a variety of downhole constraints.

The mixability test uses a table top paddle to simulate the equipment that is used in the field when mixing the spacer. The loss-preventative spacer and LCM are mixed using the paddle and the vortex behavior is observed. The pourability test analyzes the fluidity of the mixed spacer with LCM to transfer freely between beakers. Results showed good fluid mobility without clumping (Fig. 10).

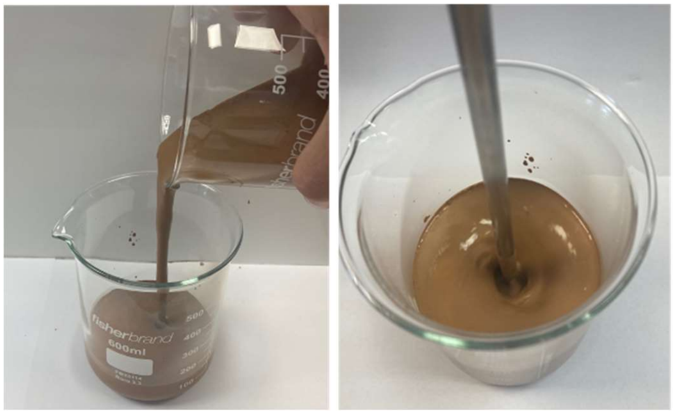

Figure 10 – Mixability and pourability of 11.5-lb/gal spacer loaded with 40-lb/bbl LCM.

Case Study 1

In Loving County, Texas, part of the Permian Basin, an operator planned to drill a four-well pad. In this part of the basin, circulating cement to surface while cementing the surface casing can be difficult and top out jobs are sometimes required.

On the first well, the shoe was set at 1,702 ft and the job was pumped without the loss circulation spacer; the cement was not circulated to surface.

On the second well, the shoe was set at 1,686 ft. The service company proposed to use the loss circulation spacer and LCM discussed previously. Although cement was not circulated to surface, the TOC was higher when compared to the first job.

Since some progress had been made, on the third job the shoe was set at 1,721 ft and it was decided to run the loss circulation spacer and LCM, but with higher lead slurry excess. On this job, 140 bbl of cement were returned to surface.

On the fourth and last well of the pad, the shoe was set at 1,716 ft, the loss circulation spacer and LCM were run resulting in 260 bbl of cement returned to surface.

The primary KPI for these surface casing jobs was to achieve cement return to surface. With the loss-preventative spacer and the paired LCM, not only was cement circulated to surface, but it was done on a single stage instead of using a DV tool and it was also done with conventional lead and tail cement slurries. Along with the visual observation of cement returns to surface, proof of a successful cementing job can be gathered from the job's pressure chart of the third job (Fig. 11) and fourth job (Fig. 12). The job log indicates a steadily increasing pressure line during the displacement stages and the last spikes are observed when the top plug lands in the collar.

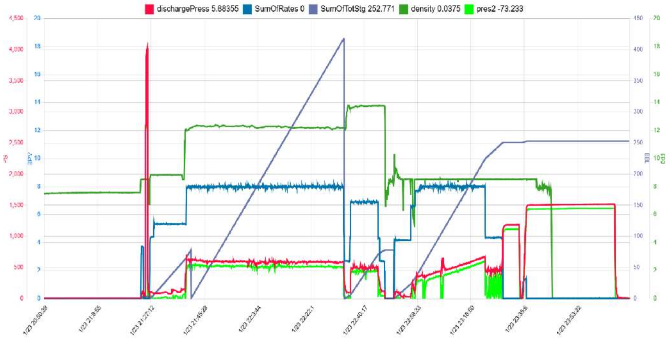

Figure 11 – Job log including pressure, density, and rate.

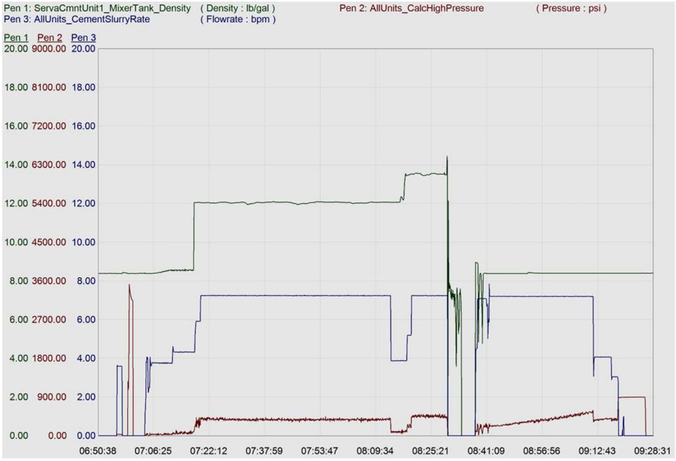

Figure 12 – Job log including pressure, density, and rate.

Case Study 2

An operator was drilling the production interval to set a 7-in. x 5.5-in. casing at 21,080 ft using an 8.6-lb/gal oil-based drilling fluid. While drilling the lateral at 9,747 ft, the rig encountered losses of 40 bbl/hr. Drilling fluid density was lowered to 8.4 lb/gal and a lost circulation pill was pumped at this depth with little success. The rig drilled the rest of the lateral while battling lost circulation even though additional lost circulation pills were pumped with little success throughout the drilling process until total depth was reached. When casing reached total depth and the rig began to circulate drilling fluid, there was no circulation seen at surface.

The anticipated ECD during the cement job posed additional risk of lost circulation due to the increased fluid densities, higher rheologies, and narrower annular clearance between casing and open hole when compared with drill pipe and open hole. Density of the spacer was 8.7 lb/gal, lead cement and tail cement were 13.2 lb/gal.

To increase the chances of successfully cementing this casing string, the cementing team proposed pumping the lost circulation spacer with 30 lb/bbl of LCM to give the best chance of sealing off the fractures already encountered in the openhole section.

The recommended lost circulation spacer allowed the cement to be successfully pumped, and full returns were achieved throughout all the displacement process. The pressure trace from the cement job (Fig. 13) indicated good cement lift during displacement. The cement bond log (CBL) further confirmed the success of the cement job.

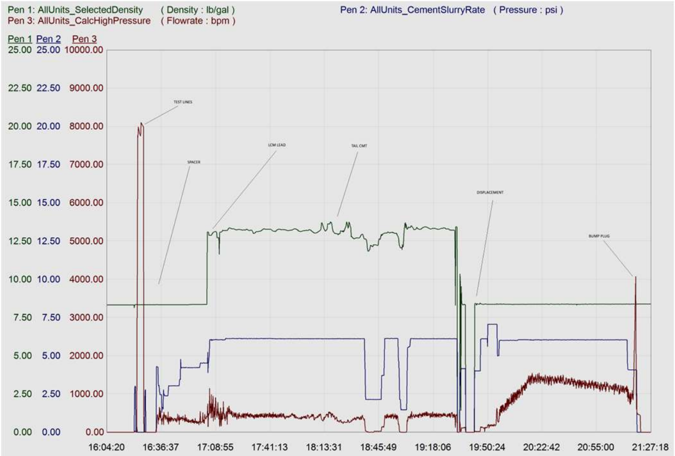

Figure 13 – Job log including pressure, density, and rate.

Conclusions

The laboratory results show that the combined spacer and LCM can deliver effective sealing capability up to 1,000 psi differential pressure across a 3,000-micron slot, which outperforms many other commercially available options.

Field data from the case studies show that the spacer and LCM combination assisted in overcoming difficult jobs where zonal isolation likely would not have been achieved otherwise.

Further studies aim to employ this technology in situations where traditional lost circulation spacers yielded inconsistent results.

Nomenclature

CBL = Cement Bond Log
ECD = Equivalent Circulating Density
LCM = Lost Circulation Material
PPA = Particle Plugging Apparatus
PSI = Pounds Per Square Inch
TD = Total Depth
YP = Yield Point

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