# Innovative Cement Spacer System for Effective Zonal Isolation in Lost Circulation Zones

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## Abstract

Cementing is a critical operation for the construction of onshore and offshore wells. In recent years, cementing spacer developments have been heavily focused on mud removal and water-wetting properties, but minimal consideration has been placed on the abilities of a spacer system to have effective zonal isolation results in lost circulation zones, highly permeable zones, and shallow water flow potential zones. This study includes a specific description of the origins of an innovative spacer system for effective zonal isolation in the previously mentioned scenarios, laboratory testing, case histories and final conclusions.


## Introduction

The main objectives of oilfield cementing include sealing fluid flow paths in the open hole by casing annulus and obtaining excellent zonal isolation. A successful cementing intervention is designed to withstand different operations such as perforating, stimulation, and production. However, lost circulation problems while cementing have caused excessive non-productive time, costly remedial jobs, sustained casing pressure, casing failures, communication between zones, and catastrophic blowouts.

Critical success factors of cement spacers in the past have focused on drilling fluid displacement features and water-wetting capabilities. Unfortunately, there has been a lack of emphasis on cementing spacer's properties to protect the cement slurries from lost circulation zones and extremely permeable formations. M&D Industries of Louisiana, Inc. has focused on developing a robust spacer formulation that can effectively remove drilling mud, water-wet the formation and casing and form a non-damaging barrier along the surface of the formation to prevent invasion of cement filtrates and preserve the formation's normal permeability for optimum production.

## Product Development

Ultra Spacer® is a patent pending blend of functionalized polymers and bridging agents. Ultra Spacer® can be used as cement spacer to effectively remove drilling mud and form a non-damaging membrane, reducing fluid/filtrate invasion. Since the unique seal formed by Ultra Spacer® raises the formation's fracture pressure, cement can be placed at casing depth with higher equivalent circulating densities (ECD's) without increasing the risk of formation break down. This capability is highly beneficial in wells in which a narrow margin exists between the fracture gradient and pore pressure gradient. In addition, the Ultra Spacer® system can effectively remove drilling mud and water-wet the formation and casing. It is important to address the fact that poor mud removal creates a path of uneven flow leading to channeling of cement slurry through the mud. A robust spacer system must always address this issue because the partially dehydrated gelled mud and low-mobility mud provide regions of weakness, allowing the passage of water or gas that can result in poor annular isolation. For this reason, the spacer system's density can be designed from 8.34 -19.0 ppg (1.00-2.28 g/cm3) to make sure that a proper mud, spacer, cement density train is followed. The spacer system must also have excellent thermal stability up to 400 °F (204 °C).

## Laboratory Testing

In order to evaluate the spacer performance, M&D Industries of Louisiana, Inc. conducted a series of laboratory tests, including: spacer compatibilities with different mud systems and cement systems, and unique sealing abilities testing.

## Spacer Compatibilities Testing

The testing protocol included requirements made by operators to assure acceptable performance characteristics of the Ultra Spacer® product. Some key issues to address were stability of the spacer at circulating temperatures, compatibility with synthetic mud, and compatibility with cement. The results of one of several test samples are discussed below.

For the compatibilities between the mud and spacer, the procedures consisted of measuring the rheologies of the base systems at 80°F (ambient temperature) and the corresponding circulating temperature. Then, the spacer and mud systems were combined using low shear until a homogenous mixture was achieved. This method determined co-mixture rheologies at same temperatures.

The samples were then placed in sample bottles for 4 hours to assure no phase separation as seen in Table 1.

| FLUID MIXTURE | TEMPERATURE (°F) | 4-HOUR STABILITY TEST |
|---|---|---|
| 90% Mud 10% Spacer | 80 | Stable |
| 75% Mud 15% Spacer | 80 | Stable |
| 50% Mud 50% Spacer | 80 | Stable |
| 25% Mud 75% Spacer | 80 | Stable |
| 10% Mud 90% Spacer | 80 | Stable |
| 90% Mud 10% Spacer | 96 | Stable |
| 75% Mud 25% Spacer | 96 | Stable |
| 50% Mud 50% Spacer | 96 | Stable |
| 25% Mud 75% Spacer | 96 | Stable |
| 10% Mud 90% Spacer | 96 | Stable |

Table 1. Mud Spacer Stability Test

The rheologies of the co-mixtures were then reviewed as seen in Table 2 to ensure there were no unacceptable rheology or gelation results from mixing.

| FLUID MIXTURE | TEST TEMP (°F) | 300 RPM | 200 RPM | 100 RPM | 60 RPM | 30 RPM | 6 RPM | 3 RPM | 10 SEC | 10 MIN | 30 MIN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 100% Spacer | 80 | 142 | 110 | 80 | 64 | 48 | 24 | 20 | - | - | - |
| | 96 | 110 | 90 | 66 | 54 | 40 | 20 | 18 | 18 | 24 | 26 |
| 100% Mud | 80 | 90 | 70 | 50 | 36 | 26 | 18 | 12 | - | - | - |
| | 96 | 64 | 46 | 38 | 20 | 16 | 8 | 8 | 8 | 20 | 30 |
| 90% Mud 10% Spacer | 80 | 86 | 62 | 40 | 30 | 20 | 12 | 10 | compatible | | |
| 75% Mud 25% Spacer | 80 | 118 | 90 | 56 | 42 | 30 | 18 | 14 | compatible | | |
| 50% Mud 50% Spacer | 80 | 198 | 158 | 106 | 84 | 62 | 30 | 30 | compatible | | |
| 25% Mud 75% Spacer | 80 | 214 | 188 | 130 | 110 | 84 | 46 | 40 | compatible | | |
| 10% Mud 90% Spacer | 80 | 148 | 120 | 86 | 70 | 54 | 30 | 22 | compatible | | |
| 90% Mud 10% Spacer | 96 | 80 | 56 | 34 | 24 | 16 | 10 | 8 | compatible | | |
| 75% Mud 25% Spacer | 96 | 100 | 74 | 46 | 36 | 26 | 16 | 14 | compatible | | |
| 50% Mud 50% Spacer | 96 | 170 | 140 | 98 | 78 | 68 | 32 | 30 | compatible | | |
| 25% Mud 75% Spacer | 96 | 210 | 180 | 138 | 116 | 92 | 60 | 50 | compatible | | |
| 10% Mud 90% Spacer | 96 | 120 | 94 | 68 | 56 | 44 | 22 | 20 | compatible | | |

Table 2. Mud Spacer Compatibilities

The rheologies of the co-mixtures were then reviewed as seen in Table 2 to ensure there were no unacceptable rheology or gelation results from mixing.

| FLUID MIXTURE | TEST TEMP (°F) | 300 RPM | 200 RPM | 100 RPM | 60 RPM | 30 RPM | 6 RPM | 3 RPM | 10 SEC | 10 MIN | 30 MIN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 100% Cement | 80 | 276 | 204 | 122 | 84 | 50 | 14 | 8 | - | - | - |
| | 96 | 226 | 168 | 100 | 70 | 42 | 14 | 10 | - | - | - |
| 100% Spacer | 80 | 142 | 110 | 80 | 64 | 48 | 24 | 20 | - | - | - |
| | 96 | 110 | 90 | 66 | 54 | 40 | 20 | 18 | 18 | 24 | 26 |
| 90% Cement 10% Spacer | 80 | 310 | 234 | 146 | 110 | 66 | 24 | 18 | compatible | | |
| 75% Cement 25% Spacer | 80 | 280 | 220 | 148 | 116 | 86 | 60 | 58 | compatible | | |
| 50% Cement 50% Spacer | 80 | 220 | 174 | 118 | 94 | 60 | 48 | 44 | compatible | | |
| 25% Cement 75% Spacer | 80 | 212 | 170 | 124 | 100 | 80 | 52 | 48 | compatible | | |
| 10% Cement 90% Spacer | 80 | 162 | 130 | 94 | 76 | 60 | 38 | 34 | compatible | | |
| 90% Cement 10% Spacer | 96 | 292 | 220 | 138 | 98 | 62 | 20 | 14 | compatible | | |
| 75% Cement 25% Spacer | 96 | 268 | 208 | 138 | 110 | 78 | 44 | 40 | compatible | | |
| 50% Cement 50% Spacer | 96 | 270 | 212 | 150 | 120 | 90 | 60 | 58 | compatible | | |
| 25% Cement 75% Spacer | 96 | 200 | 166 | 120 | 100 | 80 | 54 | 50 | compatible | | |
| 10% Cement 90% Spacer | 96 | 140 | 110 | 82 | 64 | 50 | 30 | 30 | compatible | | |

Table 3. Cement Spacer Compatibilities

Also, a compressive strength test was performed with 5% contamination of the spacer as seen in Tables 4 and 5 to determine the acoustic impedance.

| SYSTEM | 50 PSI | 500 PSI | 24 HOUR | 48 HOUR |
|---|---|---|---|---|
| 95% Cement 5% Spacer | 13:16 hrs:min | 14:54 hrs:min | 2244 psi | 3065 psi |

Table 4. Compressive Strength Test

Also, a compressive strength test was performed with 5% contamination of the spacer as seen in Tables 4 and 5 to determine the acoustic impedance.

| SYSTEM | 3.27 Mrayls | 4.0 Mrayls | 5.0 Mrayls | 6.0 Mrayls |
|---|---|---|---|---|
| 95% Cement 5% Spacer | 12:29 hrs:min | 14:29 hrs:min | 17:02 hrs:min | 44:34 hrs:min |

Table 5. Acoustic Impedance Test

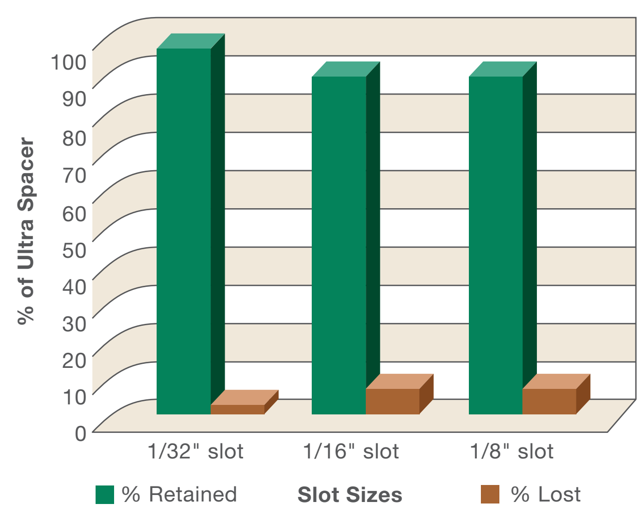
The Ultra Spacer® was compatible with both the mud and cement designs provided for this particular test. No phase separations between the spacer and mud were observed. All mixtures were homogenous with no gelling or settling observed. The compressive strength test and acoustic impedance test demonstrated that spacer had no considerable effect in the ultimate strength of the slurry

## Unique Sealing Abilities Testing

The goal of this lab testing was to demonstrate the unique properties of the Ultra Spacer® system. The slot tests were performed using a modified long fluid loss cell. A plug containing a slot was placed within the cell. Both ends were capable of being completely sealed. The Ultra Spacer® system was mixed with 40lb/bbl of Ultra Seal Plus, as it is commonly designed for wells with major lost circulation problems. The system was placed within the cell and 500 psi pressure was then applied to the cell and opened to allow the system to pass through the slot. A measurement of how much slurry escaped was used to determine the percentages of retained and lost fluid. Three different plugs with different slot sizes (1/32nd inch, 1/16th inch, 1/8th inch) were used for testing.

The Slot test results are displayed in Figure 1. For the 1/32” slot the Ultra Spacer® system had a volume loss of 2% with 98% of the system being retained. The Ultra Spacer® system for the 1/16” slot had a volume loss of 7% with 93% of the system being retained. For the 1/8” slot the Ultra Spacer® system had a volume loss of 8% with 92% of the system being retained. The Ultra Spacer® system was able to plug off all of the slot sizes tested.

Figure 1. Slot Test Chart



Low-pressure fluid loss testing was performed using a long fluid loss cell. A layer of 100-mesh silica sand was placed in the cell. The sand layer was saturated with de-ionized water. A Class "H" neat cement system was mixed and placed in the cell on top of the sand layer. The cell was then pressured to 500 psi at the top and opened at the bottom to allow the cement system to flow through the sand layer. Filtrate was collected over time. This test provided a comparison of the penetration rates of filtrate into cleats or high-permeability formations. Simulation of placing the spacer system Ultra Spacer® ahead of the cement system was then tested. A layer of 100-mesh silica sand was placed in the cell. The sand layer was saturated with de-ionized water. Ultra Spacer® was placed in the cell on top of the sand layer. The cell was then pressured to 500 psi at the top and opened at the bottom to allow the Ultra Spacer® to flow through the sand layer for 30 minutes. Pressure was then released and any excess Ultra Spacer® removed from the cell. The cement system was then mixed and placed on top of the sand layer. The cell was then pressured to 500 psi at the top and opened at the bottom to allow the cement system to flow through the sand layer for 30 minutes.

The low-pressure fluid loss tests across the sand bed demonstrated the ability of the Ultra Spacer® system to seal itself off against a formation. Figure 2 shows the neat cement system penetrating throughout the sand layer. The cement system had no fluid loss control and penetrated the sand layer within seconds resulting in a completely de-hydrated layer of cement on top of the sand layer. Figure 2 shows the Ultra Spacer® under the same conditions, only penetrating a very small amount into the sand layer.  A low permeability membrane is created across the formation, resulting in retention of the Ultra Spacer system on top of the sand layer. This excess of Ultra Spacer® is then removed from the test fixture and the neat cement system is placed on top of the sand layer containing the Ultra Spacer® membrane. Figure 4 shows the neat cement system not being allowed to penetrate past the Ultra Spacer membrane. There is no fluid lost to the sand layer by the cement system.

Figure 2. Neat Cement

Figure 3. Ultra Spacer®

Figure 4. Ultra Spacer/ Cement

The Ultra Spacer system successfully plugged off all three-slot sizes and plugged off the sand bed layer.  In addition it allowed for the cement slurry to not have fluid loss and dehydrate thus maintaining an uncompromised cement sheath.

## Case Histories

The Ultra Spacer® case histories include successful cementing operations in depleted or naturally fractured zones, zones with narrow pore and fracture margins, zones with washouts and severely enlarged wellbores, production liners with tight clearances, deeper pay prospects in old depleted existing fields, and zones with shallow water flow potential in deepwater wells. Three of the most promising case histories were selected for this report.

## Powder River Basin - (Wyoming-USA)

Completion of coal bed methane wells in the "Powder River Basin" presented unique, technical and economical challenges. In order to be commercially viable, these wells must be drilled and completed quickly with excellent cement bond to isolate coal seams for fracture stimulation. Low-strength formations prevent the use of standard density cements or high rate cement placement. Lost circulation during cementing is a frequent occurrence, even with low-density cements.

This case study describes the use of the Ultra Spacer® system to cement wells with standard density cement without lost circulation. There was also an unexpected result of improved productivity from the completed formations. The initial field study included 37 wells completed with Ultra Spacer® and standard density cement compared to 26 wells completed with no Ultra Spacer® and low-density cement.

When the cementing data and production data from the study wells were analyzed, results of the field study indicated the modified cementing method with the Ultra Spacer® yielded significantly better primary performance and productivity. The cement volume needed to circulate cement to surface for the 37 wells cemented with the standard density cement/Ultra Spacer® was 7% excess while the 26 wells cemented with the low density cement averaged 36%.

In addition, production rates from the wells cemented using standard density cement + Ultra Spacer® were significantly greater than corresponding production rates from offsetting wells cemented with low-density cement.

## Haynesville Shale - (Shelby County, Texas-USA)

Fallback and loss circulation are a common experience while cementing the surface hole in this County, resulting in costly top out cementing jobs. Ultra Spacer® (@ 60 bbl's) was pumped as the primary spacer ahead of the 11.8 ppg lead cement. The density of Ultra Spacer® was 10.6 ppg and included 40 ppb of Ultra Seal Plus.

The well was cemented with cement to surface without lost circulation or fall back. Great hole cleaning along with good bonding resulted across the entire interval. Substantial savings were realized by eliminating the remedial cementing jobs that had been required in previous wells.

## Port Barre, La. (Parish: St. Landry-USA)

The operator requested a specialty spacer to cement a 22" casing at 4,130' MD. The losses encountered while drilling the interval were 8-12 bbl/hr. It was critical for cement to return back to surface to prevent future remedial interventions.

Our engineering team recommended 150 bbl of Ultra Spacer® @ 12.0 ppg to solve the operator's challenge. All the dry additives were shipped to the cement company's bulk plant facility in ICY prior to the job. During the job, the recommended volume of Ultra Spacer® was mixed on the fly at 6 bpm. After pumping 740 bbls of cement the Ultra Spacer® reached the surface, after 785 bbls were pumped the cement reached the surface. The Ultra Spacer® repaired the lost zone and a successful cement job was accomplished. The operator was able to resume downhole operations avoiding remedial interventions.

### Grand Isle Block 37 (GOM-USA)

A 7" open hole had been drilled to TD and a 5" liner run. The drilling fluid was 11.2 ppg OBM. A 30 bbl Ultra Spacer® was formulated and weighted up to 13.0 lb/gal. Ultra Spacer® was pumped as the lead spacer in front of a 16.0 lb/gal cement slurry.

Cement was displaced without loss circulation. Furthermore, there was no sustained casing pressure after the cement job, thus no gas migration issues and no remedial cement squeezes were required.

## Conclusions

With over a thousand case histories, the Ultra Spacer® technology has proven to the oil and gas industry that a unique cement spacer system is needed for the most complicated cementing jobs.  If operators embark on the challenge of cementing depleted production zones, lost circulation zones, washout zones or zones with a narrow ECD margins, the Ultra Spacer® technology, with a proprietary blend of functionalized polymers and bridging agents, can be used as cement spacer to effectively remove drilling mud and form a non-damaging membrane, reducing fluid/filtrate invasion and increasing effective zonal isolation.