Curing Lost Circulation Issues and Strengthening Weak Formations with a Sealing Fluid for Improved Zonal Isolation of Wellbores

Brandl, A., Bray, W.S., Molaei, F.
Andreas.Brandl@BakerHughes.com
Baker Hughes
11211 FM 2920, Tomball, TX 77375, USA

An innovative fluid system was successfully applied to seal lost circulation zones and to strengthen the wellbore wall for improved cement slurry placement in highly permeable, fragile, and unconsolidated wells with low frac gradients. The fluid system, which contains a nano-engineered sealing material, has several operational and technical advantages (e.g. user friendliness, effectiveness up to 204 °C, no damage to producing formations) as compared with other common lost circulation systems. Lab test results, a model of the working mechanism, and case histories are presented to outline the performance and benefits of the sealing fluid in geothermal wells.

Keywords: Drilling, lost circulation, zonal isolation

Introduction

Geothermal wells typically have highly saline and corrosive environments with high temperature and pressure variations. Lost circulation is a common problem during drilling and cementing of geothermal wells due to fractures, fragile, unconsolidated, and highly permeable (>>1 D) formations with low fracture gradients. Conventional methods to reduce losses are pills with common lost circulation materials (LCMs) such as nut shells, granular materials, fibers, flakes, gunk, or cement plugs placed across the critical zones. All these options have disadvantages like inconsistent results, damage to producing zones, or temperature limitations, which result in failures, additional efforts, or complications that lead to delays and increased costs.

Low- and ultralow-density cementing systems are usually required in geothermal wells to prevent breakdown of weak formations. Failures of zonal isolation in geothermal wells have been directly attributed to corrosion of the cement sheath (Berra *et al.* 1988). Cement corrosion can be accelerated by poor cement bonds, cement sheath failures, and highly permeable cements, typically related to higher water content or lower density, respectively (Brandl *et al.* 2011).

The sealing fluid presented in this study addresses all these challenges - lost circulation control, strengthening the wellbore wall, and improving cement bond - to provide an operationally simple, all-in-one solution supporting zonal isolation. The fluid is usually pumped as a cement spacer to improve cement slurry placement where narrow equivalent circulation density (ECD) margins or low fracture gradients limit the density and constrain designs of cementing systems.

Fluid design and operational simplicity

The base fluid consists of a hydrophobically modified polysaccharide suspended in aqueous solutions with a concentration of 42 g/L. Rheologies are adjusted in the sealing fluid by varying the concentration of the polymer. Barite or any other common weighting material is used to modify the fluid density from 1.0 to 2.4 g/cm^3. Adding an organic bridging material in the range of 71 to 114 g/L improves the effectiveness of the base fluid to stop severe losses (e.g. due to fractures).

The materials can be stored as a dry blend in 60-lb sacks on the rig site and then mixed with any type of water (fresh, sea, or salt-saturated water) within 10 minutes. No special quality control is necessary, and the fluid system is tolerant of contamination.

The sealing fluid can be applied as a pill or designed as a spacer for proper mud removal before cement placement. The recommended spacer volume is 305 linear meters in the annulus or minimum of 10 minutes of contact time in the annulus (typically 40 to 50 bbl of spacer fluid). Flushing with clear water behind the sealing fluid will remove the seal. All components of the system are environmentally compliant (Pose Little or No Risk “PLONOR” certified) and can be disposed anywhere in the field.

Lab test results

The following performance tests for the sealing fluid system demonstrate its suitability for geothermal wells.

Fluid stability at HTHP

Fluid stability (solid support with minimal settling) at high temperatures is critical if pumping processes are temporarily stopped (for example, due to unforeseen operational issues). Settling can result in inconsistent fluid properties, increases in viscosity which can lead to pressure spikes when pumping is resumed. This can increase ECD pressures potentially leading to lost circulation.

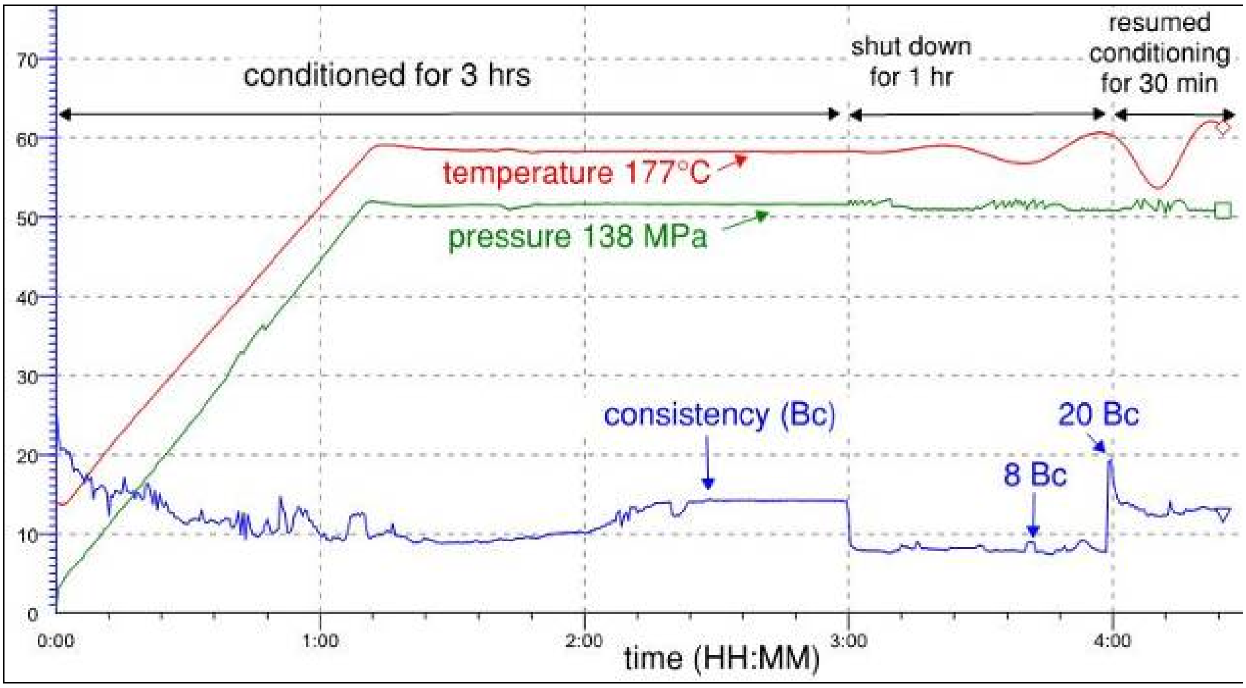

Figure 1: HTHP consistometer chart. Sealing fluid weighted with barite to 2.33 g/cm³, conditioned at 177°C, static for 1 h, and resumed conditioning without a huge spike in consistency indicates no settling and so fluid stability.

Fluid stability and solids support of the base fluid system weighted up to 2.33 g/cm³ with barite was tested in a high-temperature, high-pressure (HTHP) consistometer (Figure 1). The fluid shows a relatively consistent viscosity (10 to 20 Bearden units of consistency) during the increase to 177 °C at a pressure of 138 MPa. After 3 hours conditioning the circulation of the fluid was stopped ("shut down") for one hour. When the circulation of the fluid was resumed the consistency did not spike, but remained stable. This indicates that no settling of barite occurred during the shut-down period. After cooling, the visual evaluation confirmed a homogeneous fluid with no settling. The sealing fluid is stable at the tested temperature of 177°C.

Sealing efficiency at HTHP

The sealing efficiency of the innovative fluid was tested in an HTHP filter cell against (1) a bottom cap with a 2-mm-diameter port, (2) 20/40 frac sand with 200-D water permeability, and (3) a coarse gravel pack with 3,000-D water permeability. A thorough testing program for various design features at different conditions revealed that the sealing fluid system works if mixed with fresh water, sea water, or salt-saturated brines and up to temperatures of 204 °C at differential pressures of 6.9 MPa (Brandl *et al.* 2011):

The sealing spacer instantly stops losses when pressed against the simulated highly permeable formations (Figure 2A), whereas a typical spacer fluid completely blows through the same frac sand within seconds (Figure 2B).

In another test, the sealing fluid (with added organic bridging material) was pressed against the coarse gravel pack and effectively stopped losses. After the test, the sealing fluid above the coarse gravel pack was poured out of the cell. A neat cement slurry (dyed red to track penetration depths, Figure 2C) with a density of 1.89 g/cm³ was placed on top of the treated coarse gravel pack. This simulated the displacement of the sealing spacer by a cement slurry pumped along a porous formation in the wellbore. Less than 1 cm cement filtrate invasion into the treated coarse gravel pack (3,000 D water permeability) was observed after 1 hour static at maximum differential pressure. The rapid stop of losses with low cement filtrate penetration confirmed the high efficiency of the sealing fluid and its ability to minimise damage effects to formations.

Return permeability tests

A permanent seal or plugging from any lost circulation material is undesirable along potential production zones. The damage to production zones would result in reduced production rates (such as for steam in geothermal wells).

In a previous study, 100% return permeability to oil was found after the sealing fluid was applied against *Berea* sandstones (water permeabilities of 9 and 0.3 D) at a differential pressure of 4.8 MPa in a *Hassler*-style core holder (Brandl *et al.* 2011). Further lab tests revealed that the seal generated by the innovative fluid against 20/40 frac sand at high differential pressure could be completely removed by flushing with fresh water. In particular, as soon as a water flow from the

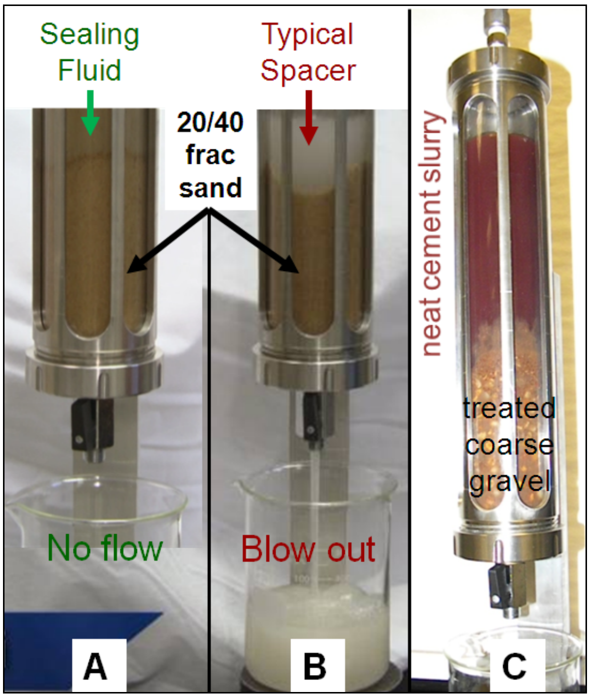

Figure 2: (A) Sealing fluid stops losses against 20/40 frac sand (200 D water permeability) at high differential pressure whereas a typical spacer (B) blows out. (C) Cement slurry on top of a coarse gravel pack (3,000 D water permeability) treated with the sealing fluid, shows minimal filtrate invasion at maximum differential pressure after 1 h.

opposite direction occurs, the seal is removed and the initial permeability is fully restored.

Reversible sealing mechanism

A simplified model, on a molecular level, describes the effective and reversible sealing mechanism of the nano-engineered fluid when applied against permeable formations or fractures in the wellbore. At a minimum concentration (critical micelle concentration (CMC) = 40 g/L) in aqueous solutions, the hydrophobically modified polysaccharides form micelles (Figure 3).

When the sealing fluid is pumped into the wellbore, a dynamic equilibrium exists between the adsorption of the micelles at the solid interface of the formation and their dispersion in the aqueous fluid. When contacting a permeable formation or a fracture at high differential pressures, an increasing number of these micelles adsorb and fill the pores in the formation / fracture (Figure 4).

With increasing differential pressure, the micelles break off and realign along the pores / fractures, forming a sealing film. The intermolecular forces among the hydrophobically modified polysaccharides of the sealing film are greater than the differential pressure applied to the fluid and therefore stop its penetration into the formation / fracture (Figure 5).

When the differential pressure is released or a flow from the opposite direction of the formation occurs (e.g., producing from the reservoir) the

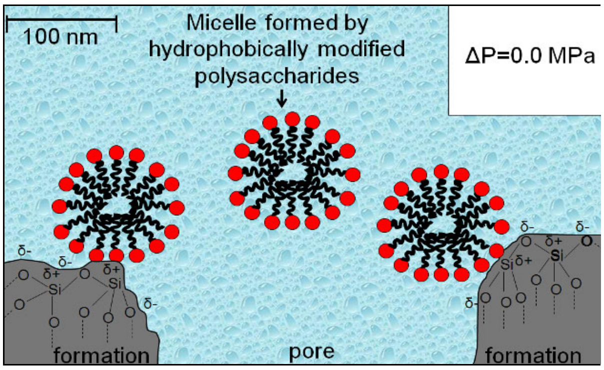

Figure 3: The hydrophobically modified polysaccharides within the aqueous sealing fluid form micelles. A dynamic equilibrium exists between adsorption at the formation and dispersion in the aqueous media.

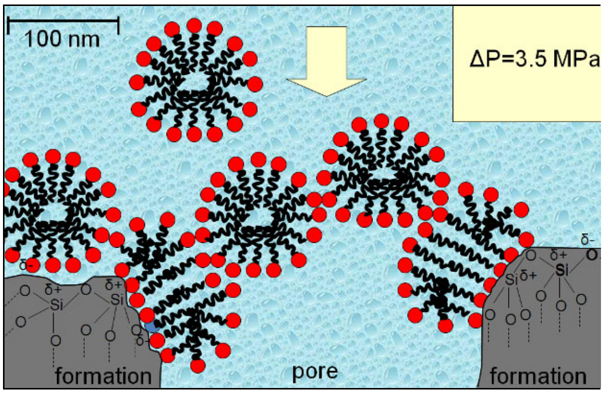

Figure 4: With increasing differential pressure, an increasing number of micelles adsorb and realign along the porous formation.

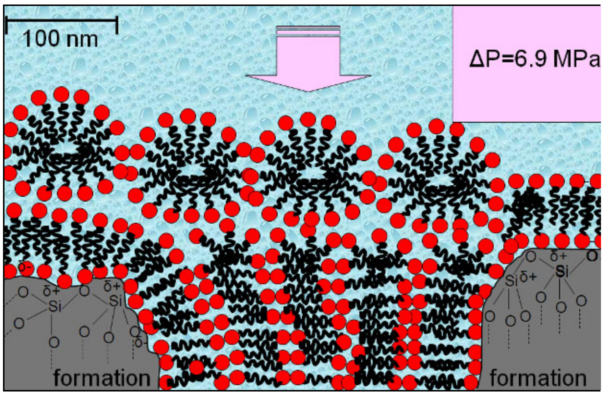

Figure 5: At maximum differential pressure, the adsorbed micelles have turned into a film, completely sealing the pore.

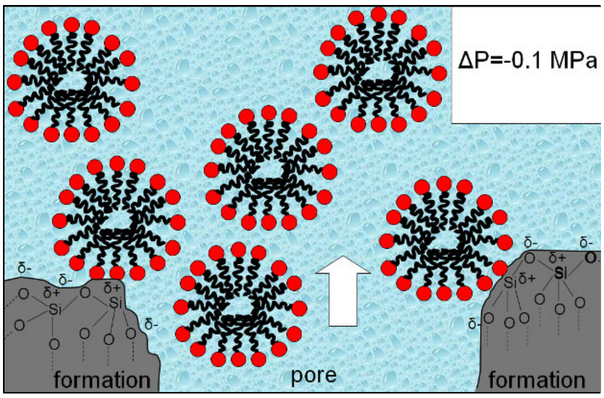

Figure 6: A flow from the opposite direction (e.g. producing from the reservoir) easily returns the micelles into solution.

sealing film turns back into micelles, dispersing in the aqueous solution, as demonstrated by the 100% return permeability test results (Figure 6).

The reversible sealing mechanism is based on differential pressure controlling the thermodynamic equilibrium of the micelles - either forming a film or being dispersed in aqueous solution. Neither cross linking nor any chemical reaction with the formation is taking place to seal the formation and to stop the losses.

Performance in the field

Two case histories demonstrate the benefits of the sealing fluid, first used as a pill to cure total losses and second used as a spacer to strengthen the wellbore wall prior cementing. Case histories showing that the sealing fluid used as a spacer improved cement bond logs were recently published by Metcalf *et al.* 2011.

Curing total losses

An operator in Texas experienced complete circulation losses of drilling fluids in several wells at around 2,000 m measured depth. Various pills and sweeps with different types of LCMs were pumped with no success in restoring circulation. Finally, 50-bbl pills of the sealing fluid containing 84 g/L of the hydrophobically modified polysaccharide and having a fluid density of 1.05 g/cm^3 were pumped down the drill string at 2 bbl/min, followed by drilling fluid. Within 12 to 18 hrs, a minimum of 60% returns had been established and most wells saw 100% returns within 18 to 24 hours.

Strengthening the wellbore wall

Strengthening the formation can be advantageous in situations where the predicted ECD to achieve good cement placement or top of cement to a certain point is greater than the maximum allowable ECD to prevent losses. Increasing ECDs during placement of the cement slurries can cause breakdowns of weak formations and lead to induced losses, contributing to a poor quality cement job. By strengthening the wellbore, losses can be prevented or minimized even at the higher ECDs encountered during the cement job.

Recent cementing operations in Spain were conducted using a stage tool because ECDs to bring the cement top to the desired height would have exceeded the maximum allowable ECD of 1.31 g/cm^3 based on a formation integrity test at the shoe. After successive operations in which the stage tool did not close properly, the operating company chose to cement the section in a single stage, hoping it could achieve sufficient height even with losses. To aid in this goal, 88-bbl of the sealing fluid spacer were pumped at the end of a spacer train preceding the cement. The final ECD at the shoe was calculated to be 1.44 g/cm^3. No losses were encountered during the job for the planned 1,000 m high cement column, and the top of cement was found by logging to be within 30 m of the desired top.

Using the sealing spacer allowed an increase to the ECD of 0.13 g/cm^3 without losses. In this case, the ability of the spacer to strengthen the wellbore and enable effective cementing in a single stage reduced rig time and simplified the job, reducing costs and improving quality.

Conclusions

The innovative sealing fluid offers several benefits:

1. Reduces lost circulation issues at temperatures up to 204 °C
2. Strengthens the wellbore & allows higher ECDs during cementing without cement top fallback.
3. Does not damage producing formations (minimum fluid invasion and 100% return permeability)

The favorable properties of the sealing fluid in combination with its operational simplicity have drawn interest among operators to solve potential lost circulation issues and to improve the quality of the cementing job. Test results demonstrate the sealing fluid is applicable at geothermal conditions. Since its introduction in February 2007, over 63,000 bbl of the sealing fluid have been pumped in more than 1,500 operations.

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