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Hybrid Foam Cementing: The Answer to Powder River Basin Cement Tops?

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Abstract

The Powder River basin in Eastern Wyoming is known to have lost circulation challenges in the Teckla, Teapot, and Fox Hills zones. These losses are due to both natural and induced fracturing. Losses threaten well integrity because they occur near or below the top of known hydrocarbon zones.

In loss situations, cement tops are typically achieved by using hollow beads to create lightweight cement slurries. A 9.0ppg cement density is often required, which can only be achieved through high concentrations of expensive lightweight beads. Another solution could be the use of foamed cementing. Nitrogen bubbles are used to reduce density instead of expensive hollow beads. The compressibility of nitrogen can result in undesirable cement properties such as higher equivalent circulating density or higher porosity.

Alternatively, the nitrogen can be applied to the spacer ahead of the cement, instead of the cement slurry itself. With this technique, the compressibility of the nitrogen does not impact the cement slurry properties, but has the desired impact of reducing the hydrostatic pressure on the fractured formation. The addition of nitrogen to the spacer achieves wellbore pressure below fracture pressure at lower cost. This paper will evaluate the effectiveness of a hybrid foamed cement design to reduced or eliminate the need for lightweight beaded cement slurries, as well as any potential for additional benefits or risks resulting from this approach.

Background

Successful cementing of the intermediate casing can be a significant drilling challenge in the Powder River Basin (PRB). Currently typical PRB wells are drilled targeting the deeper of the multiple stacked zones in the basin such as the Turner, Frontier, and Niobrara. There are a number of shallower zones which must be drilled-through and successfully isolated by the intermediate casing and cement job. The requirement for zonal isolation is to cover the shallowest hydrocarbon zone, typically the Teapot. Many operators would prefer to ensure zonal isolation well above the minimum requirement, sometimes even desiring isolation to the surface casing shoe for casing protection during future well operations. The challenge in achieving cement tops required for these zonal isolation objectives is that multiple zones, including the Teapot, Teckla, and Fox Hills have a combination of low fracture pressure and natural fracturing frequently resulting in lost circulation during the cement job. These zones are near the shallowest hydrocarbon zone, making it a risk to isolation of all hydrocarbon zones. Currently this risk is mitigated through the use of lightweight cement slurries utilizing hollow beads. This approach is effective but expensive. It also makes cement evaluation challenging due to the response of the hollow beads to acoustic logs such as CBL/VDL (Nelson and Guillot, 2006).

Modeling Setup

This study will use mathematical modeling software to simulate the dynamic and static wellbore pressures of various cement designs. The wellbore pressures will be evaluated in terms of Equivalent Circulating Densities (ECDs), comparing the minimum and maximum ECDs across the intermediate hole section, as well as comparing the ECD with respect to time at key depths of interest. A representative well design will be used for comparison purposes to represent the intermediate casing hole section for most Frontier/Turner/Niobrara PRB wells.

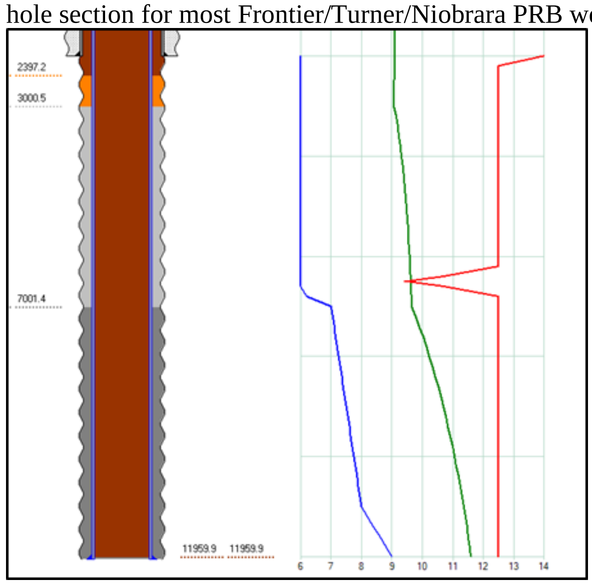

Figure 1 - Wellbore Diagram and Pore/Frac Pressures for Case Study

For the representative case, the target formation is at 12,600ft TVD, with the well drilled vertically to the kick-off point. Intermediate casing is set at 12,000ft, just above kick-off point. The lost circulation zone will be set at 6,500ft, with a fracture pressure equivalent of 10.0ppg. Top of cement is designed at 3,000ft, and acceptable top of cement objective is defined as 4,000ft. The cases to be considered are in Table 1.

Table 1: Cases Evaluated

Case	Spacer	Lead Density	Top of Lead	Top of Tail
10ppg Lightweight	8.6ppg Spacer	10.0ppg	3000ft	7000ft
11.5ppg Conventional	8.6ppg Spacer	11.5ppg	3000ft	7000ft
Novel Hybrid Foam	Foamed Water	11.5ppg	3000ft	7000ft

Current Designs & Modeling Results

10.0ppg Lightweight

The 10.0ppg lightweight cement design uses a low-density lead cement to reduce the hydrostatic pressure on the loss zone. The objective of this design is to keep the wellbore pressure below the fracture pressure at all times. This will achieve designed top of cement by not inducing any losses. Per Figure 2, the 10.0ppg lightweight cement stays below the 10.0ppg fracture pressure at the loss zone. This design will achieve a top of cement at 3,000ft, meeting the objective.

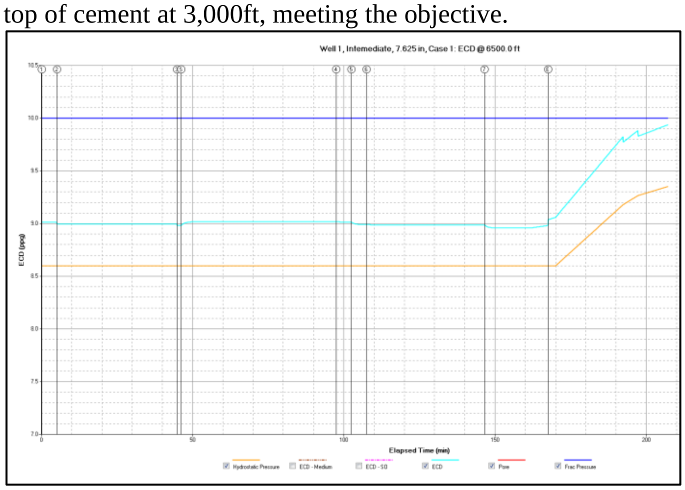

Figure 2 - ECD of 10.0ppg Lightweight Design at Loss Zone

The cement slurry in this design uses lightweight, hollow glass beads. Beads are an effective method of reducing the cement density, but have some drawbacks. Lightweight, hollow glass beads are an expensive alternative to conventional cementing additives. A 10.0ppg beaded slurry materials will typically cost 3 to 5 times more than an 11.5ppg conventional water extended cement design. Effectively doubling the total cementing job cost for a PRB intermediate. In addition to cost, cement evaluation becomes more challenging. The hollow nature of the beads means they do not effectively attenuate the long wavelength of CBL/VDL logs (API 10TR1). To properly evaluate these lightweight cements, an ultrasonic cement evaluation logging tool (USI) must be used. The USI tool uses a much shorter wavelength that is more easily attenuated by the cement when the hollow beads are present (Nelson and Guillot, 2006).

11.5ppg Conventional

The 11.5ppg lead cement design uses a conventional water extended lead cement. 11.5ppg is as low as can be reasonably achieved without hollow beads. Figure 3 shows this design exceeds the fracture pressure during the last 80bbls of displacement. With the wellbore pressure above fracture pressure, we know some portion of the cement slurry will be lost to formation. These losses will be between 50% and 100% of the total pumped volume during this time period. Figure 4 shows what the final fluid positions across this loss range.

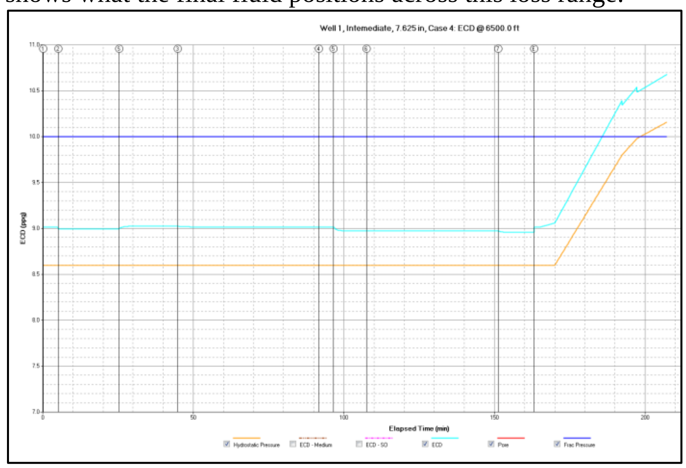

Figure 3 - ECD of 11.5ppg Conventional Design at Loss Zone

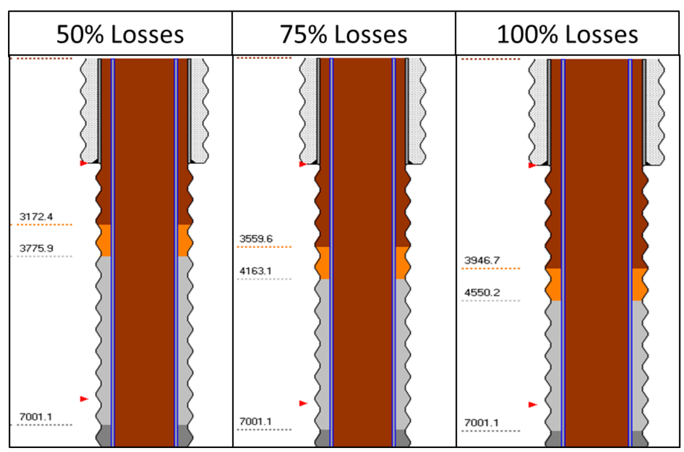

Figure 4 - Top of Cement from 50% to 100% Losses

Without hollow beads, the slurry does not reliably deliver an acceptable top of cement. Experience in the PRB dictates that once the fracture pressure is exceeded, losses are close to 100% resulting in a top of cement of roughly 4500ft. Meaning, this design does not achieve the stated minimum top of cement objective at 4000ft.

Novel Hybrid Foam Design

The novel hybrid foam design takes a new approach to achieving top of cement in PRB intermediate casings. The hybrid foam design reduces the hydrostatic pressure of the fluids above the cement versus the cement slurry itself. In this design, nitrogen is added to a water spacer to decrease the hydrostatic pressure and resulting ECDs. 200scf/bbl N^2 added to a 40bbl water spacer with an 11.5ppg conventional water extended cement lead cement is modeled for this design. The resulting ECDs at the loss zone can be seen in Figure 5.

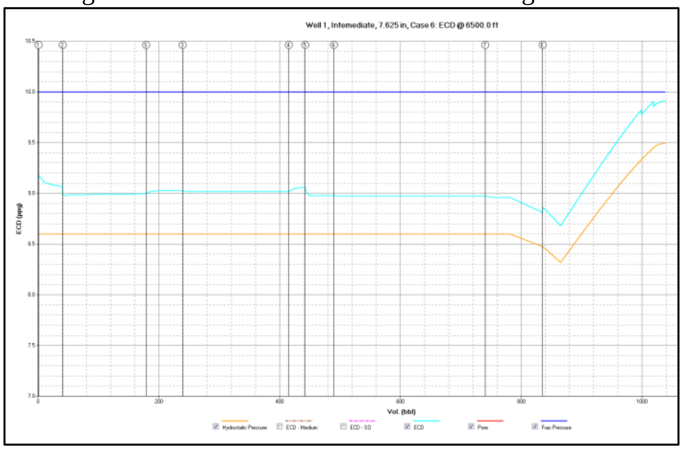

Figure 5 - ECD of Hybrid Foam Design at Loss Zone

Advantages of Novel Hybrid Foam

The hybrid foam design achieves a maximum ECD below 10.0ppg at the loss zone. The maximum ECD below fracture pressure eliminates the risk of lost circulation, achieving top of cement objectives. This solution is lower cost and provides technical advantages compared to the use of lightweight beads.

For the novel hybrid foam design, the only increase in material cost verses a conventional cement design is about 8000scf of nitrogen. Unlike a full foamed cement job, the hybrid foam only requires bottles of nitrogen. The total incremental cost increase between a conventional and hybrid foam cement job should be in the 5 to 10% range.

There are additional technical advantages of the hybrid foam design. These include improved hole cleaning and mud removal resulting in improved cement bonding. If natural or induced fractures are present in the wellbore, the foamed spacer is effective at plugging these fracture throats due to capillary effect. Finally, by keeping hollow beads and nitrogen bubbles out of the cement slurry itself, the evaluation of the cement job by CBL/VDL log is going to be more effective since the attenuation of the sonic wave will not be impacted by bubbles or beads in the set-cement.

An Even More Aggressive Loss-Prevention Design

In some parts of the Powder River Basin, there may be lost circulation zones that have a fracture pressure lower than 10.0ppg equivalent. In many of these wells, a 9.0ppg lightweight cement is used. Even at these low densities, achieving designed top of cement can be challenging due to friction pressure. A 9.0ppg lightweight cement will have a maximum ECD of roughly 9.5ppg at the loss zone. But, if we apply the novel hybrid foam concept with a 10.0ppg lightweight slurry, ECDs can be keep at roughly 9.0ppg, as seen in Figure 6. In this case, the maximum cementing ECD is equivalent to the drilling ECD. This means that if the well can be drilled, it can be successfully cemented using this technique.

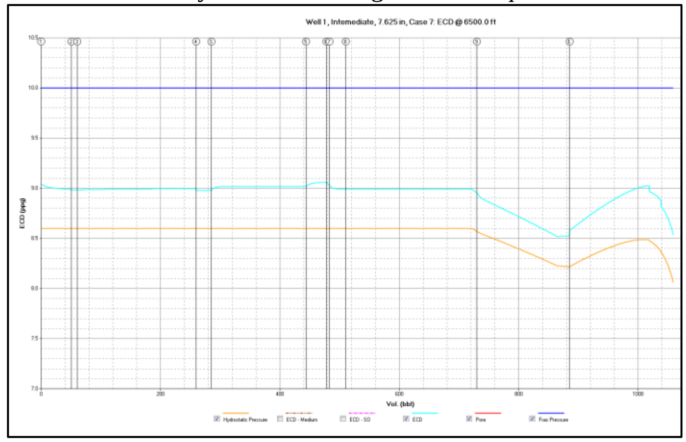

Figure 6 - ECD of Hybrid Foam Design Combined with 10.0ppg Lightweight Cement

Drawbacks & Risks

When nitrogen is added to a cement design, consideration of drawbacks and potential risks is required. The hybrid foam design does require nitrogen, which presents some safety risks associated with pumping energized fluids. In this case, the hybrid foam design can be executed utilizing high pressure gas cylinders instead of pumping nitrogen with a positive displacement pump. The addition of nitrogen introduces more equipment and operational complexity compared to a completely non-foamed design.

The hybrid foam design does add a fluid with density below water weight to the beginning of the cementing train. This results in ECDs as low as 7.2ppg at around 3000ft, as seen in Figure 7. If there are formations with pore pressures that might flow at these low wellbore pressures, or if there are geomechanically unstable formations that might cave in at low pressure, the hybrid foam design may not be applicable.

In the PRB, there are virtually no pore pressures at these depths. In most parts of the PRB, intermediate hole sections can handle extremely low wellbore pressures (minimum ECDs) without any adverse effects.

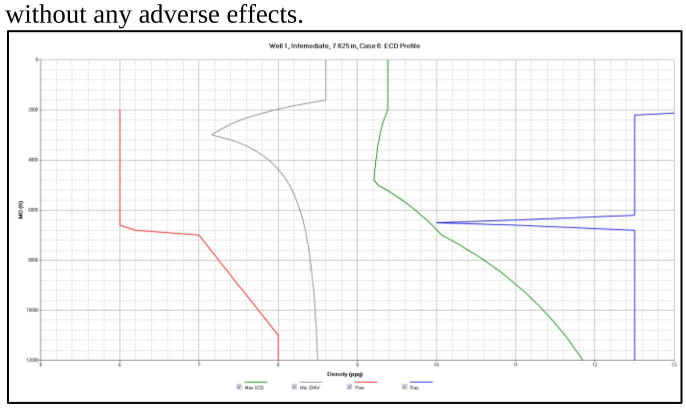

Figure 7 - Minimum ECD of Hybrid Foam Design

Why Not Foam the Cement Slurry?

Cement designs using nitrogen to foam the cement slurry have been around since the 1970's, and are still used today as an alternative to lightweight slurries using hollow beads. There are a number of disadvantages of a traditional foamed cement that are not present in the novel hybrid foam design, primarily foam quality variability of foamed cement.

The final set cement properties of foamed cement depend on the confining pressure under which it is set. Nitrogen bubbles in the cement slurry expand/compress related to the pressure around them, so the density or foam quality of the cement is highly variable (Dooply et al. 2013). In fact, the density of the cement slurry is constantly varying during the placement of a foamed cement job to the point that a foamed cement slurry in the PRB is likely to be less than 7ppg, and more than 12ppg at different times during placement. This is especially true in unconventional plays such as the PRB where detailed hole diameter information is not known due to the lack of open hole logs. Without detailed information on the presence, absence, or location of washouts and other hole geometry variations, the final slurry density and foam quality can vary widely. Most meaningfully, these foam quality variations can greatly affect the mechanical properties of the final set cement potentially leading to a weaker cement than originally designed.

Do I Need a Foam Cross & Foam Stabilizer?

When applying the hybrid foam design in basins such as the PRB, a foam cross and liquid additive system for foam stabilizing surfactant is typically not required. Due to the fact that we are not adding nitrogen to the cement slurry itself, the final state of the foamed fluid as having a well-controlled foam quality with stable, well dispersed nitrogen bubbles is not important because the foamed fluid is not going to set or provide any long term zonal isolation or mechanical properties. As discussed earlier, this greatly reduces the operational complexity of the hybrid foam design. If the hybrid foam design is being applied to an area with a more pronounced pore pressure or geomechanical concern requiring the wellbore pressure to stay above a certain value, then a foam cross for consistent nitrogen dispersion and a liquid additive system for foam stabilizing surfactant may be required to ensure that the nitrogen stays as close as possible to the location and the foam quality of the design simulations.

Conclusions

- Hybrid foam design using nitrogen in the spacer ahead of cement is an effective technique for achieving required top of cement in PRB intermediate casings.
- Hybrid foam design is lower cost than lightweight beaded cement slurries.
- Hybrid foam design is more effective than traditional foamed cement.

References

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