AADE-20-FTCE-023

Evaluation of Cement-Conveyed Stimulation Technology in Horizontal Wellbores

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Abstract

Interstage isolation is vital for multistage fracturing. An interactive cement system (ICS) has recently been introduced and has been shown to enhance zonal isolation in horizontal wellbores drilled with nonaqueous fluids (NAFs) where mud removal is normally challenging. ICS implemented in the continental US has significantly improved the cement bond and isolation between stages, as proven by direct and indirect measurements.

In 2018, Kolchanov et al. (SPE-191561-MS) disclosed the evaluation of ICS using common cement bond log (CBL) tools, and in 2019, Turner et al. (SPE-196232-MS) described evaluation performed by both ultrasonic and CBL tools. This paper describes the first analysis of isolation provided by the ICS using advanced ultrasonic cement evaluation in horizontal wellbores.

The cement evaluation service logging tool was run with a standard CBL tool in two parallel wells, one cemented with the ICS and one with conventional cement. Data were recorded in both laterals and compared. The conventionally cemented well showed a continuous mud channel, as is common in horizontal wells where casing centralization is not optimized. In the well with the ICS, the cement evaluation service found a liquids channel presence in some intervals along with isolation in other intervals. Overall increase in cement bonding was visible on the logs, proving better isolation between future fracturing intervals. Fracturing breakdown pressure analysis corroborates the ultrasonic cement evaluation and indicates the likelihood of better fracturing operations on the ICS well.

Introduction

The development of unconventional oil and gas reservoirs has been driven by drilling horizontal wells that are subject to stimulation with multistage hydraulic fracturing to maximize reservoir coverage for better hydrocarbons recovery. Starting in 2010, the overall length of a common well's lateral has been increasing continuously, from 14,000 to over 17,000 ft today. At the same time, the stage count per well has increased, from a maximum of about 20 stages per well in 2010 to the average of 40 stages per well in 2017 (Weijers et al. 2019). Today's wells have denser fracture distribution as well, with more perforation clusters/fracture initiation locations per stage.

It is common to see more than eight clusters per stage now with less than 23.5-ft spacing between each cluster. Huckabee et al. (2017) have performed analysis that indicates that the smaller the distance between two neighboring stages, the higher the likelihood of communications between stages during hydraulic fracturing treatments.

As our industry moves to completions containing longer laterals with shorter stage spacing, we must dismiss the notion that cement quality in the horizontal portion of the wellbore is not critical. In fact, the stage-to-stage isolation provided by cement is needed for a successful stimulation job. Currently, cement placement is dependent on mud removal, which is harder to achieve in long horizontal wellbores with existing practices. To overcome these limitations, a new technology for an interactive cement system (ICS) was developed and first disclosed in a publication by Kolchanov et al. (2018).

The ICS improves zonal isolation for multistage stimulation by interacting with residual nonaqueous fluid (NAF) left after drilling to reduce mud mobility and the potential for fracturing fluid communication through mud channels. The ICS was extensively studied in the laboratory and has since been validated in a series of field studies. This paper describes several methods of evaluation of ICS that were not covered in previous publications.

Cement Bond Logging

Acoustic and Ultrasonic Logs

Acoustic cement bond results for the ICS were first described by Kolchanov et al. (2018), where two non-ICS wells were compared with four wells cemented using the ICS. Briefly, the reference logs showed a constant cement bond log (CBL) amplitude of 60 mV in the casing with a free pipe amplitude of 72 mV, which indicated channel formation, resulting in poor cement quality. Four wells with the ICS showed a significantly lower CBL of 20 to 10 mV, as well as a significant improvement in variable density log (VDL) response. The improved CBL and VDL amplitudes indicated that the ICS worked in the regions where it encountered NAF along the interface between the casing and cement and the interface between the cement and the formation, which eliminated the channeling problem observed at the reference wells. Perroni et al. (2020a) concluded that CBL improvement indicates effective performance of the ICS when a thin layer of NAF covers casing and formation walls.

The ultrasonic cement bond results for the ICS were described by Turner et al. (2019), where the ICS was evaluated in a well that was cemented without pipe movement and with a 20% standoff and compared with the base case. Briefly, annular isolation in the base cases varied along the wellbore. Although there were intervals with acceptable cement, the channel began to appear from the middle of the lateral to the heel of the well, and both logs showed the need to rotate the pipe to eliminate the channel from the bottom. Registration of the ICS cement response showed that the additive was most effective in the area of the well that had the worst drilling mud removal results. The VDL showed a higher quality of ICS bonding compared to the base case. ICS has improved the isolation between the casing and cement and the boundaries of the cement with the formation and is a viable option to mitigate low drilling mud removal efficiency, resulting in a low-side channel. The study showed that effect of the ICS could be seen by ultrasonic cement bond method.

Laboratory Preparations for Ultrasonic Logging

In a recently accepted manuscript by Perroni et al (OIL GAS-EUR MAG, 46. Edition, Issue 1/2020), we disclose our efforts to replicate how the ICS-affected mud can be acoustically logged. The acoustic impedance (AI) of a drilling mud that was in contact with the ICS was measured using a laboratory logging tool and compared with a reference slurry. The results showed that the average AI was 29.4% higher in the mud/ICS region compared to the mud/control cement region. This increase was related to the firmer solid structure exposed to the ICS.

Cementing Operation and Cement Evaluation Service Log Results

An operator in the northeastern United States agreed to cement two horizontal wells conventionally and then cement two comparable neighboring wells with the same design except for the addition of the ICS. To evaluate the difference, it was agreed to run cement evaluation logs on two wells; one well was cemented conventionally, and the other well was cemented with the ICS. Cement specifications are shown in Table 1. Both wells were similar in length, were drilled toe up in a north-northeast direction, and were the same deviation and build.

Well	Production Slurry	Centralized in Lateral	Geometry, Casing, and Hole Size
1 Baseline	14.8 lbm/USgal slurry (no ICS)	Solid body, 7 ¾ x 5 ½ in., every 132 ft	5 ½ in. in 8 ½ in.
Well 2 ICS	14.8 lbm/USgal slurry (with ICS)	Solid body, 7 ¾ x 5 ½ in., every 132 ft	5 ½ in. in 8 ½ in.

Table 1. Two wells for comparison

Cementing jobs for both wells were nearly identical, both in design and execution. Both wells were circulated with the same nonaqueous-based drilling fluid with a density of 12.8 lbm/USgal prior to cementing. Openhole size was 8 ½-in. with 5 ½-in. casing. The centralization placement program assumed a centralizer per four joints (solid body placed free floating every 132 ft) from toe up to top of cement (TOC), which gave up to 68% standoff at centralizers and 0% standoff between centralizers. The pumping schedule included 60 bbl of 13.2 lbm/USgal spacer pumped ahead of 200 bbl of mud recovery spacer fluid with the density of 13.5 lbm/USgal. Tail slurry with the density of 14.8 lbm/USgal was used. Pumping and mixing cement was performed in the range of flow rates between 5.5 and 8.5 bbl/min, and most of the displacement was done at 7.5 bbl/min with a decrease to 2 bbl/min during the last 20 minutes before bumping the plug. Maximum cement head pressure during the job did not exceed 4,000 psi. Slurry rheology of the ICS system was similar to that of a conventional cement system. A compatibility study of the ICS with NAF showed similar results compared to the conventional cement system. Both jobs were executed without service quality issues, plugs were bumped, and floats were holding fine with only 6.5-bbl backflow for each of the two wells.

A mud displacement simulator was used to predict the severity of a channel in the horizontal lateral. It was obvious that the lack of standoff along the lateral would lead to a continuous channel along the borehole, which was confirmed by the simulation. Fig 1 shows the well that utilized ICS is also predicted to have a long continuous mud channel, which is in agreement with our previous communication that the ICS only interacts with any mud channels after compressive strength begins to develop. It also highlights the importance of wellbore preparation best practices to ensure the least amount of mud left in the annulus.

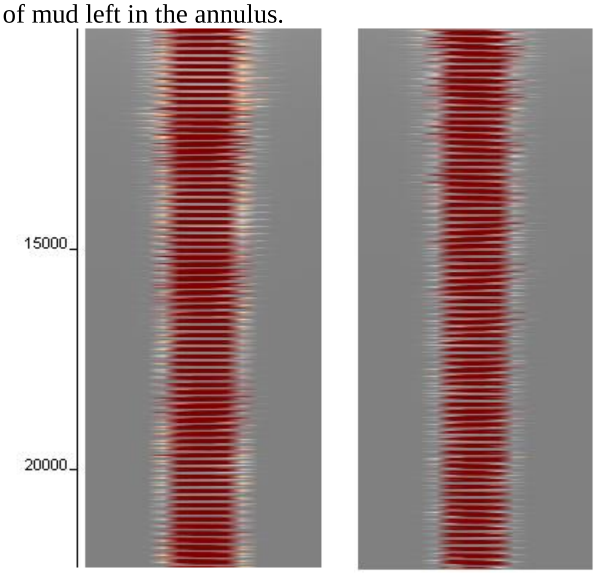

Fig. 1. Mud displacement simulators run for each of two wells. For both wells, a channel is clearly seen on fluids concentration maps, where mud is represented by brown color. Left, well cemented conventionally; right, well contained ICS.

In terms of execution, the two wells had very similar pressure, rate, and density (PRD) plots (Fig. 2).

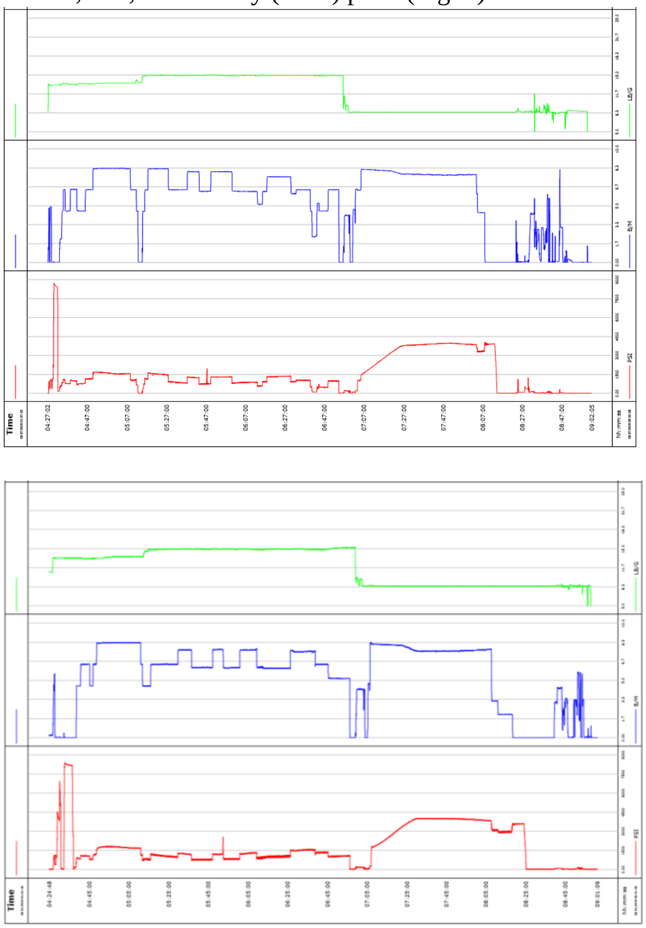

Fig. 2. PRD plots of two wells: top, conventionally cemented well; bottom, well cemented with ICS. Density ppg (green), pump rate bbl/min (blue), pressure psi (red)

With both well designs, the mud removal prediction and execution were the same. Therefore, the cement evaluation log results should be comparable, and any differences should be attributed to the difference in technology implemented. With all other variables controlled, the only difference between two wells was the use of the ICS.

Conditions for logging were also similar, with the same 5 ½-in. 20# P110 casings, 90°deviation, and pipe filled with fresh water (8.33 lbm/USgal) in both wells.

The ultrasonic cement evaluation service was chosen to run the bond log evaluation. The advantage of using ultrasonic techniques over conventional CBL is that it allows radial evaluation of the annular space. In addition, flexural attenuation (FA) can be recorded with the cement evaluation tool. Flexural wave imaging is the latest technique in cement evaluation; it allows the operator to evaluate characteristics of almost any type of cement, including lightweight formulations (Tian et al. 2011). It is expected that flexural wave analysis could reveal a better and more detailed picture of the ICS effect on mud channels. Azimuthal coverage of the cement evaluation tool allows the operator to quantify the quality of cement placement and, when comparing with offset wells, to evaluate the ICS effect on stage isolation.

Therefore, both the well with the ICS and the control well were logged with the selected cement evaluation system combined with CBL/VDL. Fig. A-1 demonstrates that in the control well, an impedance image shows that the material in the displacement channel is weak and uniform, which is a characteristic response to mud. Multiple areas are interpreted as liquid on the solid liquid gas (SLG) map. The VDL and CBL show a weak bond over the entire section pictured. The ICS well's impedance image demonstrates a higher impedance when compared to the control well. In some places, a uniform substance with some mechanical strength appears to be revealed as well, which is a similar trait to that seen when evaluating a known barite sag. Multiple areas are interpreted as solids on the SLG map. The VDL shows an improved bond as well in these areas. Although this is a very compressed log, we can see clearly that the control well exhibits a continuous liquid channel on the low side of the casing, as indicated by a continuous blue pattern in the center of the leftmost track. The well with the ICS shows a smaller liquid channel, but at several places we see areas of brown, indicating the material behind the casing has characteristics of a solid; given a radial presence of solids, this improves the chances of good diversion during fracturing operations. Also, the mud channel in the ICS well is not continuous, and with the increased mud rheology should provide stage isolation. The well cemented with the ICS technology showed better bonding and isolation both on the impedance boundary condition and the sonic tool.

Effect of ICS on Hydraulic Fracturing Operation

The most popular technique to study near-wellbore effects during hydraulic fracturing operation is the measurement of stage-to-stage isolation via sliding sleeves completion. This type of completion uses a coiled-tubing-deployed packer that isolates the stage being stimulated from all other stages that have already been stimulated by sealing off the inside of the casing. The packer can be equipped with pressure (and temperature) memory gauges below and above the packer. Comparing pressure (and temperature) on the heel and toe sides of the packer provides a method to measure communication behind the casing during fracturing treatment that can travel down the annulus and back up into the wellbore below the packer via sleeves left open from previously stimulated stages. Because cement is an integral part of the near-wellbore environment, some conclusions about cement integrity could be made from the recorded data. An example of cementing quality evaluation using the downhole pressure and temperature data was published recently (Perroni et al. 2020b). The three wells cemented with conventional technology achieved from 58 to 78% stage isolation whereas the well cemented with the ICS technology yielded a full 100% isolation during all 102 fracturing stages.

Because most wells use plug-and-perf completion, the technique using memory gauges for stage-to-stage isolation is limited to the few wells that use the sliding sleeves completion method. At the same time, it is thought that in some cases, fracturing breakdown pressure could be a good, indirect indication of effective stage-to stage-isolation, i.e., quality of wellbore cementing.

There are several conditions that should be met to apply that technique. First, two neighboring wells under consideration should be drilled in the same direction and in the same formation. Second, the technique assumes breakdown pressure heterogeneity along lateral section of the wellbore. Usually, reservoirs that are drilled through are not homogeneous: The stress profile along the wellbore can change multiple times throughout the length of the lateral. There will be multiple zones of low-stress and multiple zones of high-stress rock (Fig. 3).

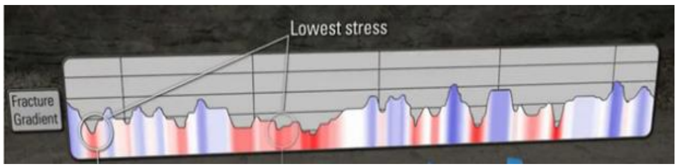

Fig. 3 – Stress profile along a horizontal lateral.

During hydraulic fracturing, if there is no isolation along the horizontal lateral, the fracturing fluid will tend to fracture the rock with lower formation stresses. This will result in low breakdown pressures of the treatments. However, in the case of good isolation along the lateral, the fracturing fluid will not have the opportunity to escape to a lower-stress zone and instead will fracture the rock it was designed to fracture, i.e., the rock in front of the perforation intervals, which will not necessarily be the rock with lowest formation stress, but rather will have a mixture of different stress values along the lateral. In this case, the overall breakdown pressure should be higher in an isolated well, assuming other variables are the same between two compared wells. Under these conditions, monitoring and comparing the breakdown fracturing pressure of two wells can be a good, indirect indication of isolation.

The operator in the northeastern US that was running the cement evaluation service logs on two of four wells to compare the ICS with conventional cement also noticed that, in addition to the improved bonding, the two wells cemented with ICS had an average breakdown pressure of 800 psi higher during stimulation than the two wells cemented with conventional cement systems. Higher breakdown pressure is associated with improved stage-to-stage isolation, which enables more efficient fracture placement.

The hydraulic fracturing job analysis supports results of cement evaluation service analysis and demonstrates that noncontinuous mud channels and mud viscosification inside the channel is an effective approach for stage isolation in plug-and-perf multistage stimulation. Laboratory data that demonstrate ICS interaction with drilling fluid were described in Kolchanov et al. (2018).

Conclusions

With more production casings cemented with the ICS (at the time this paper was written, there were more than 400 production casings cemented with the ICS across all major US unconventional basins), more cases of successful implementation of the technology become available. There are different ways to evaluate the ICS performance, including bond logs, in-situ pressure measurements, breakdown pressure monitoring, and last, but not least, production monitoring (although slowly as that method will require time to become publicly available). The ICS system leads to significant bond log improvement for CBL/VDL, ultrasonic imaging, and the latest ultrasonic technology with flexural wave analysis. Breakdown fracturing pressure data from subsequent stimulation treatments agreed with the CBL analysis and with the laboratory study of ICS-drilling fluid interactions.

Acknowledgments

The authors would like to thank Montage Resources and Schlumberger for permission to publish this work.

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Appendix A

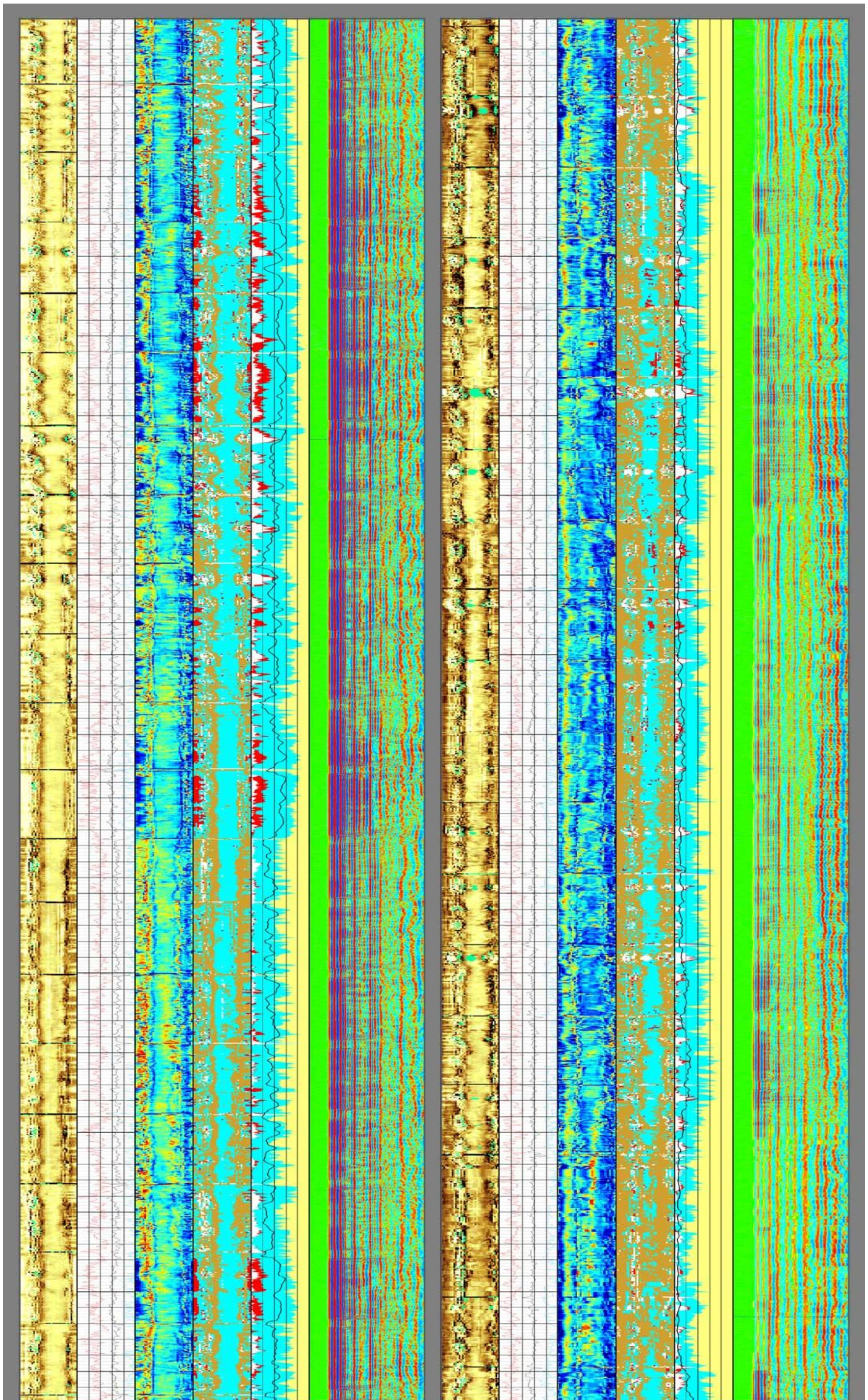

Fig. A-1 – In the conventionally cemented well, left, the cement bond is poor, and material in the channel is weak and uniform, which is common for drilling fluid. In the well cemented with the ICS, cement bond is improved, and the higher impedance with texture in places indicates a uniform substance with some mechanical strength.