AADE-14-FTCE-41

Cement Evaluation Using Slickline Distributed Temperature Measurements

R. Diarra, J. Carrasquilla, Y. Gonzalez, A. Friese, S. Severance, Jim Lin, Schlumberger

Abstract

Well cementing consists of the placement of cement slurry around the casing to provide zonal isolation and casing protection. Such cement slurries can vary significantly in density and composition depending on the well objectives.

After cementing the well, the coverage and bonding of the cement to the casing is commonly evaluated (logged) in order to ensure the cementing requirements are met and it is in compliance with regulations. Conventional tools used for cement bond evaluation are the CBL-VDL, focused primarily on the bonding to the casing, and the latest generation incorporates a combination of ultrasonic and flexural waves providing not only bonding to the casing but also at the interface with the formation.

Despite temperature logs are not new, a new approach to temperature monitoring means that optical fiber is embedded inside a 1/8-inch diameter of slickline cable, providing real-time Slickline Distributed Temperature Sensing (SL- DTS) measurements along the whole wellbore during a conventional slickline operation allowing to measure the temperature during the hydration of the cement. The curing of cement is an exothermic reaction and will increase the wellbore temperature that can be readily and accurately detected by using SL-DTS.

This paper discusses four field case studies where the use of SL-DTS in post-cementing operations allowed to verify a correlation between hole size and heat of hydration, determine tops of cements, identify loss zones, possible inflows and to some extend contamination of various systems, from conventional slurries to foamed cement, even thru casing coatings which normally alter the response of conventional logging tools. It has also been valuable in the verification of geothermal gradients. The SL-DTS derived results were integrated with sonic and CBL-VDL measurements run in the same wells validating the thermal analysis showing good correlation with these cement evaluation tools.

Introduction

The measurement of a temperature profile inside the wellbore was first reported by Schlumberger et al. (1937). Since then numerous publications discussing the use of temperature surveys made with production logging tools (PLTs) have demonstrated their usefulness in diagnosing a variety of wellbore conditions.

Conventional slickline temperature surveys can be used to produce either a log of temperature versus depth, or temperature measurements at pre-determined depth stations down the wellbore. However the logging sonde churns up the fluids in the wellbore while it is being moved up and down the hole during the course of the survey. This can change the temperature of the wellbore fluid it is measuring. Also, in many cases a transient thermal effect, such as a leak or a flow, will take place at a different depth than the current position of the logging sonde, meaning this event can be missed. In cementing application a temperature profile over time would require multiple runs, not always possible.

Consequently, there are benefits to a system that can be run from inside the wellbore in the same manner as conventional slickline and can monitor the whole wellbore at the same time; producing multiple temperature traces over time, without having to move a logging sonde to the position of the temperature anomaly (Gonzalez, et al. 2008).

Fiber-Optic Slickline

The slickline DTS system (SL-DTS) employs a standard mobile slickline unit and drum with slickline pressure equipment.

The fiber itself is a 125-micron-diameter polyimide fiber, located in a 0.033-in-diameter tube, surrounded by carbon weaves inside a 1/8-in-diameter Inconel 825 tube (Figure 1). The slickline is 18,500-ft long, H_2S-corrosion-resistant, with a working load of 1,000 lb, and a maximum temperature rating of 125 degC. This optical slickline can be deployed in exactly the same way as conventional slickline, and (similarly) can have weights, pressure gauges or even a production log installed at the end.

However, because the line is not as strong in tension as a conventional slickline it cannot be used for operations such as jarring.

The Distributed Temperature Measurement

The fiber-optic distributed temperature measurement uses an industrial laser to launch 10-nanosecond bursts of light down the optical fiber. During the passage of each packet of light a small amount is back-scattered from molecules in the fiber. This back-scattered light can be analyzed to measure the temperature along the fiber. Because the speed of light is constant, a spectrum of the back-scattered light can be generated for each meter of the fiber using time sampling;

allowing a continuous log of spectra along the fiber to be generated (Figure 2).
A physical property of each spectrum of back-scattered light is that the ratio of the Stokes Raman to the Anti-Stokes Raman bands is directly proportional to the temperature of the length of fiber from which it is generated. Consequently a log of temperature can be calculated every meter along the whole length of the fiber using only the laser source, analyzer and a reference temperature in the surface system, there is no need for any calibration points along the fiber or to calibrate the fiber before installation. Spectrum acquisition times can be varied from as little as 2 seconds to hours, and this defines the accuracy and resolution of the measured temperature log. Typically, a resolution of 0.05 degC is required for reservoir surveillance but observing transient thermal events such as water injection require fast acquisition times of 5 seconds, and these will have poorer statistical resolution.

Cement Hydration

Portland cement is the most common of the ”hydraulic” cements, which set and develop compressive strength through hydration. Such process involves chemical reactions between water and the cement compounds creating and exothermal reaction.
Because the thermal conductivity of cement is comparatively low, it acts as an insulator, and at the interior of large cement mass, hydration can result in a large rise in temperature.
Cement hydration does not happen at a fixed rate. The evolution of cement hydration has a characteristic behavior, as described in Figure 3.
The first stage also called pre-induction is brief (lasts for less than one minute) because of the rapid formation of an amorphous layer of hydration product around the cement particles, which separates them from the pore solution and prevents further rapid dissolution.
This is followed by the induction period, during which almost no reaction occurs.
During next phase, the rapid reaction period, the rate of reaction increases rapidly, reaching a maximum at a time that is usually less than 24 hours after initial mixing, and then decreases rapidly again to less than half of its maximum value
The slickline DTS system records the temperature curve which is the result of the effects occurring during the acceleration and the deceleration phase. The heat of hydration is proportional to the density of the cement slurry and volume of cement, important factors in the interpretation of temperature readings.

Cement Curing Evaluation.

All case studies here presented are wells cemented by operators in Midland basin or Delaware basin. Initially the DTS tool was run to identify the top of cement (just as conventional temperature log) but the anomalies identified became object of study. The presented field cases are examples of a qualitative method for cement evaluation.

Case History 1: Cement Top Location

This case presents the basic use of temperature measurement as a way to identify the top of cement. Figure 4 shows the shut-in SL-DTS profiles for Well 1. Despite it is recommended start to record the temperature traces no longer than 2 hours post-cementing operation, due to operational constrains, the temperature response were monitored 12 hours after cement placement. The acquired data indicate the top of cement is located at 6,060ft. (interpretation of the rise in temperature that occurs at this depth and below). In terms of the exothermal generation of heat, no significant thermal response was observed, implying the cement hydration rate should be in the deceleration phase at this point.
The SL-DTS survey also showed “hot spots” treated in this case as a temperature anomaly attributable to possible hole washout. At that time no caliper was available to confirm the hole enlargement scenario, but based on offset wells data, this would be consistent with a washout section identified in that field.

Case History 2: Geothermal Gradient Verification And Top of Foam Cement Location.

When drilling through the Wolfberry formation (Midland basin), lost circulation is likely to occur, thus lifting cement above Clearfork formation located at 4000-6000 ft is very challenging. The fracturing gradient can be as low as 9 ppg and contains highly corrosive formation water. In uncemented sections of the string operators have seen casing integrity loss as early as a year after the well is completed.
It is then of paramount importance to bring the top of cement above the top of the Wolfberry or plan for remediation rather soon in the well life.
In the following case study, the completion consisted of:

- 5 ½” casing run up to 11,000 ft with casing coating (fiber glass - epoxy) across the corrosive zone (4,500 -7,500 ft)
- Water based mud at 9.2 ppg
- Lead slurry was foamed to 9.5 ppg, designed to cover the sting up to 1,500 ft.
- Tail slurry at 12.5 ppg with desired top at 7,000 ft

The cement bond log evaluation of the above described completion faces several challenges:

- Traditional log requires the cement to be set and to develop some compressive strength, which usually takes several days at the top of the cement column sitting at much lower static temperature and contamination at the interface.
- Light weight systems have low acoustic impedance making them difficult to identify by conventional logging tools. This is particularly critical when the density difference between the cement and the mud does not exceed 0.2-0.3 ppg,
- Foamed cement slurries are not easily read by bond logging tools.
- Casing wrap alter the bond log response of the cement to the casing.

For this case study, the client run the SL- DTS to identify the top of cement is a scenario where the casing design and the slurry density combination will make it challenging for conventional tools to rapidly determine the actual top of cement (Figure 5).
The first thing that stands out from SL- DTS is that the BHST was measured 10 degF cooler than initially estimated (Figure 7). This can only be determined after enough elapsed time for the well to reach thermal stability. In certain cement jobs, such as kick off plugs where compressive strength development over time is critical, accurate temperature estimation is paramount.

The SL-DTS was deployed less than an hour after the cement operation and the wellbore thermal response was monitored during 24 hours (Figure 6). A slight heating effect was observed below ~1,400 ft. This thermal behavior suggests that the casing was partially cemented below this depth. The exothermal effect is greater the deeper in the well, this is attributable to foam quality variation in the cement column. For this case the rise in temperature at 4,946 ft is attributable to the location top of lead cement. The maximum exothermal heating occurs from 5,154 ft to 6,302 ft and from 8,300 ft to 9,000 ft. The maximum exothermal effects for this well occurred at different times at different depths (Figure 8). A not expected thermal response was observed between 4500-5000ft, possibly related to the nitrogen (N_2) from the energized slurry.
The temperature data also allowed identifying the lead/tail interface, approximately 2,000 ft below the designed value at 7000ft.
Following the SL-DTS survey a conventional cement bond log was ran by the operator for further verification.
Figure 6 shows the correlation between the poor bond interval identified by the CBL-VDL results (8500-9000ft) and SL-DTS cement exothermic reaction at the cemented zone.

Case History 3: Correlation with Hole Size

This well was logged for caliper prior the cementing operation.
The DTS log was run several hours after cement placement and monitored for over 36 hours.
There is no separation of the curves corresponding to the different log intervals indicating that there is no further change in the heat of hydration.
DTS was once again run to determine top of cement, which was still possible despite the elapsed time from placement.
Since an open hole caliper was available, the temp and OH diameter were plot together in order to see the correlation (Figure 9).

The washed out sections, between 5000-6000ft and 8000-9000ft are correlated to the “hot spikes” in the temperature response, due to the increase cement sheath thickness at the hole enlargement location determined by the caliper log.

Case History 4: Location of Lost Circulation Zones

This last case study had SL-DTS tool run in a well which encounter severe loss circulation conditions. A temperature log (DTS) was run in order to identify the final top of cement.
The well was cemented 11.0 ppg extended lead system with top of lead at 3,500 ft and 12.5 ppg tail slurry designed to 7,500 ft. Figure 10.
From top to bottom: there is a slight heating event response above 3,200', which can be contaminated cement scenario. This wellbore condition that can be easily missed by bond logging tools since contaminated cement takes much longer to develop compressive strength or fall below solid-liquid detection threshold.

From 7,800ft to 9,000ft there is a strong temperature response, consistent with the severe loss circulation zone reported by the drilling department, below 7,000 ft.
The losses where mitigated during drilling, but during cement placement losses re-occurred, with an estimated top of cement in line with the lifting pressure towards the end of the cement displacement. Such strong temp response in the loss zone is explained by the accumulation of cement in one particular zone, increasing the volume and density of the cement.
The DTS also shows distinct temperature response at the interface between lightweight lead and tail systems.

DTS revealed that the strongest losses happened 800 ft deeper than observed during drilling which is valuable information when designing lost circulation control prior or during cementing.

Conclusions

The examples discussed in this paper show that SL-DTS is a powerful tool in the assessment of multiple cementing variables, outperforming traditional temperature logs and providing and excellent complement to conventional bond evaluations tools. Slickline is a cost effective and efficient logging method which can be combined with multiple memory tools in the same run.

Unlike wireline temperature logs, which require logging passes up and down the well, the SL-DTS system is ideally suited to identify top of cements, interfaces between lead and tail, flows, loss zones, washouts leaks.

While it remains a qualitative evaluation and does not allow cement bond quality determination, SL-DTS generates a unique data set for continuous improvement of cement job design, especially valuable with the strict well integrity regulations currently in place.

Acknowledgements

The authors would like to thank Schlumberger for their support during this study and for permission to publish the results.

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2. Y.J. Gonzalez, G.A Brown, A. Friese, A.Padilla, A. Sanchez and L. Ward, Schlumberger.SPE 154442 "Slickline DTS Measurements Provided Useful Information for Well Integrity Diagnostic, Stimulation Treatments, and Water Injector Wells Performance: North America Land Case Studies"his paper was prepared for presentation at the SPE/ICoTA Coiled Tubing & Well Intervention Conference & Exhibition held in The Woodlands, Texas, USA, 27–28 March 2012.

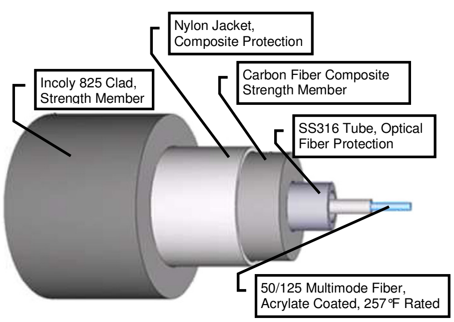

Figure 1: Fiber Optic, Slickline

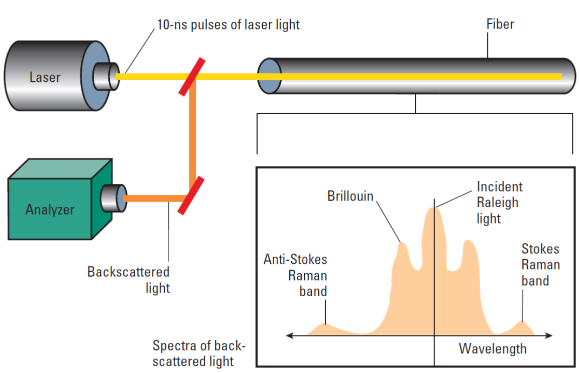

Figure 2: The principle of the DTS temperature measurement.

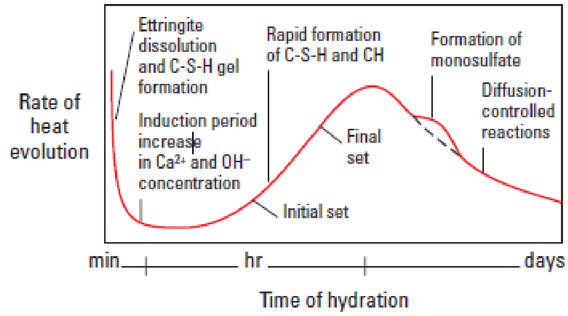

Figure 3: Cement Hydration

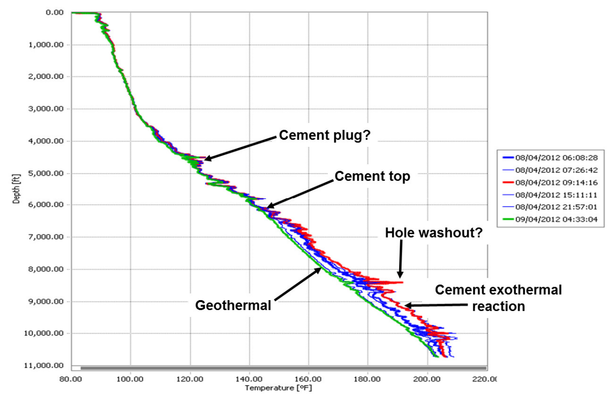

Figure 4: Well 1. Cement top Location

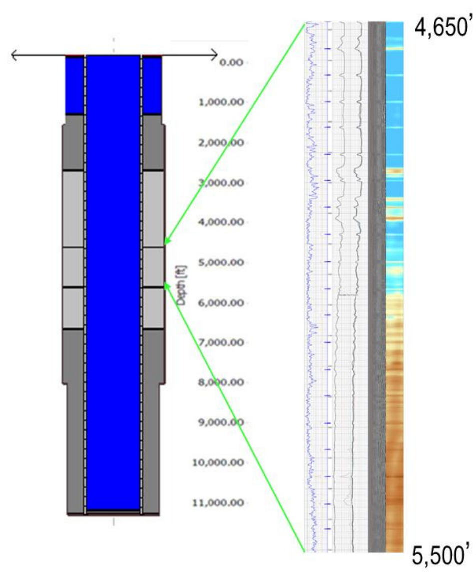

Figure 5: Bond log of foam cement (top)

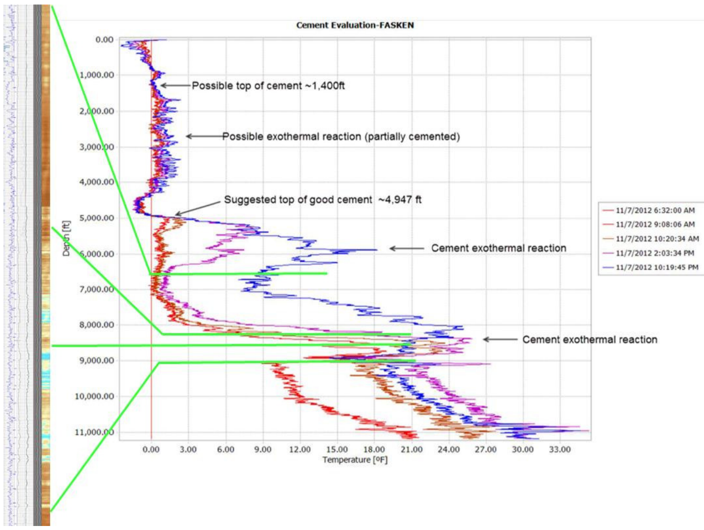

Figure 6: Top of Foam Cement Identification. Note: Temp differential from base line.

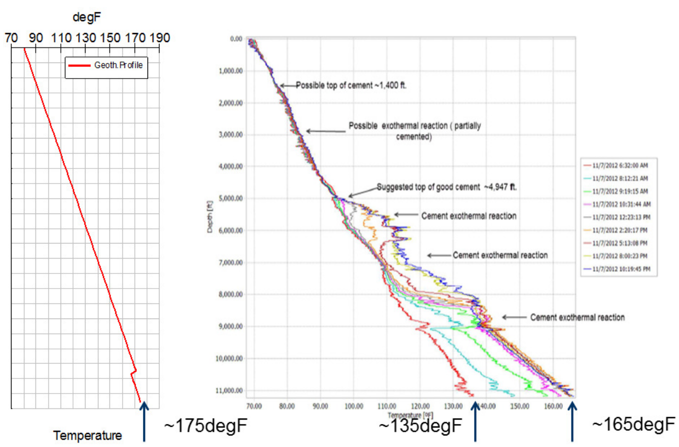

Figure 7: Geothermal Gradient Verification

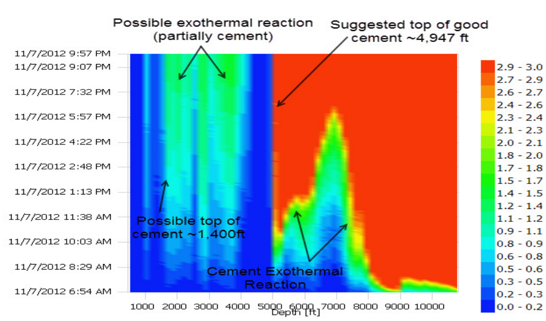

Figure 8: 3D Thermal Plot. Cement Exothermal reaction

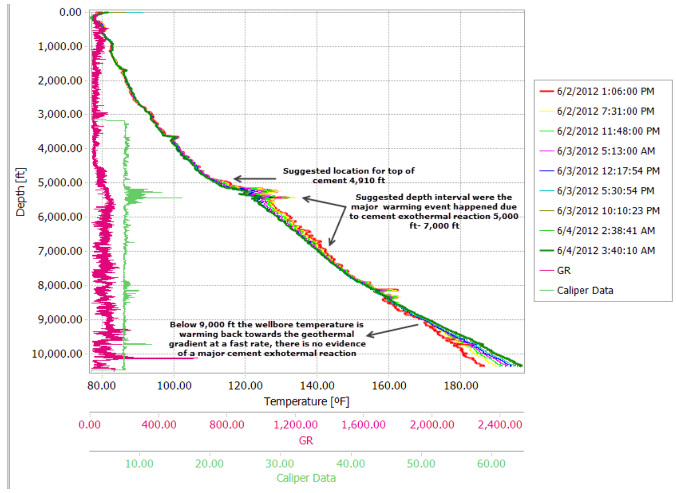

Figure 9: DTS vs Open Hole Caliper

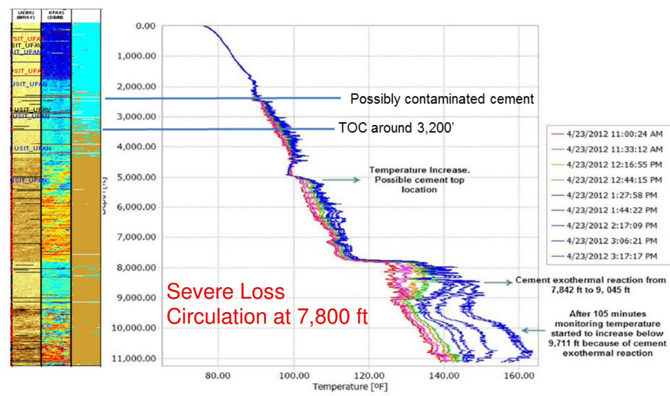

Figure 10: Location of Lost Circulation Zone