Cement-Bond-Log Interpretation Reliability

Two kinds of cement-bond-log (CBL) tools are run as part of a standard cement-evaluation program. The effectiveness of these tools and their evaluations often are challenged, and they are not regarded as a replacement for reservoir interzonal-communication tests performed between producing reservoirs. The value of continuing to run these tools was questioned by management. In response, the reliability of these tools and their ability to determine the existence of poor behind-casing cement quality were examined.

Introduction

Historically, three methods are used to check for isolation between reservoir units. Pressure tests are restricted to localized areas of the casing such as the casing/liner shoe and squeeze perforations. Communication tests, regarded as the most definitive method of testing behind-casing isolation, jeopardize casing integrity and are costly. Cement-evaluation logs are time-efficient, cover the majority of the casing, and are inexpensive compared to communication tests. Interpretations of these logs sometimes do not predict behind-casing communication, creating a perception of unreliability. Determining the confidence that can be placed in cement-log interpretations is an objective of this task force.

This article, written by Assistant Technology Editor Karen Bybee, contains highlights of paper SPE 101420, "Reliability of Cement-Bond-Log Interpretations Compared to Physical Communication Tests Between Formations," by ***Douglas Boyd,*** *SPE,* ***Salah Al-Kubti,*** *SPE,* ***Osama Hamdy Khedr,*** *SPE,* ***Naeem Khan,*** *and* ***Kholoud Al-Nayadi,*** *SPE, Zadco;* ***Didier Degouy,*** *Adma-Opco; and* ***Antoine Elkadi*** *and* ***Zaid Al Kindi,*** *SPE, Schlumberger, prepared for the 2006 SPE Abu Dhabi International Petroleum Exhibition and Conference, Abu Dhabi, UAE, 5–8 November.*

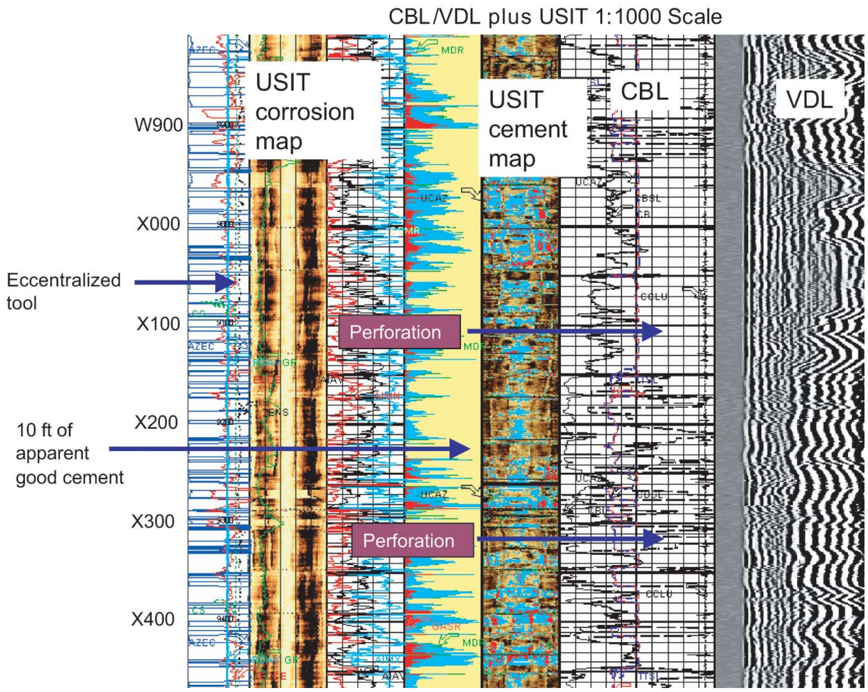

Fig. 1—Ten feet of apparently good cement on the USIT and VDL cement map was not sufficient to prevent communication between the perforations.

Behind-casing communication of hydrocarbons via the cemented annular space requires expensive remedial cement squeezes to cure the problem. Because of the importance and criticality for reservoir management of the zonal isolation between oil-bearing formations, Zadco's policy is to confirm isolation by physical communication tests regardless of the quality of cement interpreted from CBLs. Only cement barriers between formations where production is planned are tested. Intervals between reservoirs not planned for production are not tested.

Because the majority of cement-squeeze decisions are based on the results of physical-communication tests, the value of continuing to run CBLs was questioned. A task force comprising representatives from drilling, well integrity, petroleum engineering, petrophysics, and the primary service company was formed to review Zadco's communication-test policy and determine the reliability of CBLs to determine behind-casing cement quality and from this infer the presence or lack of isolation between formations.

Evaluation Tools

Acoustic cement logs are the only diagnostic technology available to the industry to evaluate cement quality

For a limited time, the full-length paper is available free to SPE members at www.spe.org/jpt. The paper has not been peer reviewed.

behind casing. Acoustic bond logs do not measure hydraulic seal. They measure the loss of acoustic energy as it propagates through casing. This loss of energy is related to the fraction of the casing perimeter covered by cement. Two classes of sonic logging tools exist, sonic [CBLs/variable-density log (CBL/VDL) or segmented bond tool (SBT)] and ultrasonic [ultrasonic imaging tool (USIT)]. USIT logs provide a high-resolution, 360° scan of the condition of the casing-to-cement bond, while CBL/VDL gives an average volumetric assessment of the cement in the casing-to-formation annular space. SBT is a combination of CBL/VDL and pad sonic devices that provides a low-resolution map of the cement condition behind casing. Zadco most frequently runs USIT and CBL/VDL CBLs in combination; SBTs are run less frequently.

Log Quality

Affecting Factors. Many factors affect the response of bond-log tools. These factors can be broken into three categories: those that are controllable during running the tool, those that are controllable during the cementing operation, and those that are constraints imposed by the wellbore or formation.

Microannulus. A microannulus is defined as a very small (approximately 0.01 to 0.1 mm) annular gap between the casing and the cement sheath. A microannulus can result in a misinterpretation of the CBL/VDL. All cement logs are sensitive to microannuli to varying degrees. Microannuli are caused by temperature, mudcake deposits, pipe coatings, and constraining forces. Common procedure is to place approximately 1,000 to 1,500 psi pressure on the casing to close the gap. Microannuli affect ultrasonic tools much less than the CBL/VDL and SBT (pads) when the gap contains liquid. The opposite occurs when the gap is filled with gas.

Eccentralization. It is difficult to predict the exact bond status behind casing if it is eccentralized. Most likely there is no cement at the low side where the distance between casing and formation face is small. Direct casing contact with the formation is indicated by the presence of galaxy patterns on the USIT log. The CBL/VDL and SBT (pads) may detect fast formation arrivals.

Logging-Tool Centralization. It is mandatory that the USIT and the CBL/VDL tools are well centralized. The SBT pads with their articulated arms are relatively unaffected by the centralization issue, although the CBL/VDL part of the tools is affected negatively. Tool centralization can be checked in the log presentations. Combining eccentralized tools such as a gyroscope may affect CBL-tool centralization negatively. Centralizers attached to the tool must allow for smooth, even tool movement. As the number of centralizers increases, the risk of jerky, erratic tool movement increases.

Fast Formations. Formations with very high velocity and short transit time are called "fast formations." Acoustic signals from anhydrites, low-porosity limestone, and dolomites often reach the receiver ahead of the pipe signal. Signal amplitude is high but not as high as free pipe. Fast formations affect the CBL/VDLs and SBT logs but do not affect USIT interpretation because the measurement principle is different. If there are fast-formation signals present, it is assumed that the CBL/VDL cannot be interpreted, though the arrival of the fast-formation signals suggests that the cement-to-formation bond is present.

Lightweight Cement. Cement evaluation relies on a contrast in the acoustic properties of the cement and liquid. The higher the contrast between liquid and hardened cement, the easier the log is to interpret. The acoustic properties of set lightweight cement are close to those of cement slurry, making it difficult to distinguish the two. Lightweight slurries use hollow ceramic microspheres, nitrogen, and other low-specific-gravity materials to achieve a light density while providing good compressive strength. These cements commonly are used in areas of weak formation.

Cement Setting Time. An important consideration in CBL interpretation is the length of time to wait for cement-slurry solidification before running the bond log. If the bond log is run before the cement is fully set, a pessimistic interpretation will result, followed by an unnecessary squeeze operation. If the log is run well after the cement is set, an expensive rig sits idle unnecessarily. The hardening time of cement slurries depends on their type and formulation, the downhole temperature profile and pressure conditions, and the degree of drilling-mud contamination. Increasing levels of drilling-mud contamination lengthen hardening time, lower the ultimate compressive strength, and reduce cement-impedance value, hindering cement-log interpretation. The cement near the top of the cement column may not develop the same compressive strength as cement near the bottom of the well. The U.S. Environmental Protection Agency (EPA), charged with protecting potable-water sources in the U.S., recommends letting the cement cure for 72 hours before logging. Both the American Petroleum Inst. and Alberta Energy and Utilities Board, which deal with hydrocarbon reservoirs, suggest a shorter 48-hour waiting period. To reach maximum compressive strength may require 7 to 10 days. With the advent of the ultrasonic cement analyser (UCA), a determination of when to log is available. This information has shortened waiting-on-cement (WOC) time. The UCA also provides cement-impedance information for entry into logging-tool software. The average WOC time for eight Zadco wells was 64 hours, with an 82-hour maximum and a 52-hour minimum.

Continuous Bonded Interval

To declare probable behind-casing annular isolation between two points, a minimum length of continuous good-quality cement should exist. A recommendation of 33 ft of continuous good cement for 7-in. casing and 45 ft for 9⁵⁄₈-in. casing was found in a publication of the EPA. Oil-industry service-company recommendations for continuous good-quality cement before declaring the interval isolated are 10 to 11 ft for 7-in. casing and 15 ft for 9⁵⁄₈-in. casing. The EPA and service companies' stricter criteria for the length of good-quality cement behind 9⁵⁄₈-in. casing compared to 7-in. casing is supported by Zadco and Adma-Opco drilling experts. From their experience, good-quality cement jobs are easier to achieve behind 7-in. casing than behind 9⁵⁄₈-in. casing.

Communication-Test Results

The task force focused its analysis on wells with modern CBL suites. Twenty-eight wells were selected on the basis of availability of communication tests, CBLs, and cementing data. With the exception of three wells out of 28 cases, all log interpretations were in agreement with the physical-communication tests. One well with 8 ft of moderately good cement between two formations on the USIT-CBL/VDL **(Fig. 1)** failed the communication test. Close examination of the log found poor centralization of the cement-bond tools made the cement appear better than it was. Two wells had full communication despite 40 ft of good Class G cement on the USIT-CBL/VDL and the SBT logs.

Bond Logs

Indication of apparent good to excellent cement quality on logs yet having full communication during physical tests is not isolated to Zadco. Other oil companies have had similar experiences. The reason or reasons behind this are not established and are a source of constant speculation. A possible explanation or contributing factor is that the 15%-concentration HCl used to improve injectivity damages the cement or creates channels through easily dissolved residual calcium carbonate mudcake. For Zadco's two cases, no injectivity/communication was observed while testing with brine. Injectivity/communication was established only after squeezing acid into the perforations.

It is commonly accepted that acid has minimal effect on cement because of the slow reaction when HCl is placed on a flat cement surface. The low permeability of cement limits the decomposition to its surface. However, HCl/hydrofluoric acid (HF) combinations are very destructive to cement. It was found in Prudoe Bay that 37% of primary-cement jobs developed zonal-isolation problems after HCl/HF was applied, and 73% of squeeze cement jobs broke down after HCl/HF stimulations. Factors influencing rate of dissolution besides acid composition and concentration are the ratio of acid volume to cement surface area and acid shear rate at the cement/acid interface.

Statistical Estimate

Cement-log interpretation has one of two outcomes: Either the interpretation agrees with the communication test, or the interpretation disagrees with the communication test. This is a binary system. There are several calculators available on the Internet that can analyze the confidence interval and confidence level statistically for the 95% agreement between cement-log-interpretation results and physical-communication tests.

For the 28 cement logs examined, the success rate was 89% (25 successes out of 28 tests) with a confidence interval of 72 to 97% at the 95% confidence level. Improving the confidence in the estimate of 89% CBL-interpretation reliability to less than ±10% requires an appreciable increase in the number of wells examined. What interpretation failure rate is acceptable and what degree of confidence is the answer depend on the level of risk a company is prepared to accept.

Economic Evaluation

Discontinuing physical-communication tests and relying on CBL interpretation is an economic risk. The cost of repairing a well in the drilling phase is much less than that of moving the rig back on location at a later time and pulling the completion. If this happens too often, the cost of well repair exceeds the economic benefits of relying entirely on CBLs and cementing parameters for behind-casing-communication detection. The break-even failure rate for CBL interpretation for horizontal wells in Zadco is estimated roughly at 10 to 11%. This is equal to Zadco's current best estimate of its CBL-interpretation failure rate of 11% with a confidence interval of 3 to 18% at the 95% confidence level. At what percentage failure rate it is economic to dispense with physical-communication tests is largely a question of the number of days it takes to repair a well. At what failure rate does fixing a communication problem after the rig has left the location exceed the economic benefits of not performing communication tests and relying on the CBL interpretation (i.e., if the money saved and additional drilling days gained outweigh the cost of discovering communication after the rig has left location)? Moving the rig back to the well to repair a poor cement job is more costly than fixing the problem while the well is being drilled. Zadco consequently concluded it was not justified to discontinue physical-communication tests unless the reliability of CBL interpretation improved or the cost of repairing a communication problem after the rig moved off location was reduced. A much larger data set (more than 50 wells) is required to improve the confidence in the estimate of CBL-interpretation reliability appreciably. **JPT**