Through-Bit Logging Pays Dividends

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HOUSTON—After drilling a number of horizontal wells several years ago to exploit a narrow oil window in the Eagle Ford play, engineers noticed that production varied erratically, even though they had completed all laterals using roughly the same geometrically spaced perforation clusters. Some wells produced high water volumes; apparently, hydraulic fractures had propagated into underlying formations.

The operator had acquired only measurement-while-drilling gamma ray logs to guide geosteering. However, this information was inadequate to properly characterize the reservoir properties that impacted production. Geoscientists and engineers needed additional log data to design more efficient completions, increase production, and reduce costs.

Traditional wireline logging methods face greater risks and logistical challenges in horizontal wells, especially in shale reservoirs. Typically, these boreholes are too small to easily accommodate standard logging tools. Also, running wireline technology in and out of hole without gravity assistance requires specialized conveyance methods—drill pipe or tractors, for example. These tend to be more complex, time-consuming, and expensive.

Therefore, many shale operators forego petrophysical logging altogether. This is why they typically position fracture stages at arbitrary intervals along the lateral. There is insufficient geomechanical data to optimize completions according to varying rock and fracture properties.

After weighing available conveyance options, the Eagle Ford operator decided to deploy a small-diameter, through-the-bit logging suite for his next horizontal drilling campaign. Once drillers tripped the directional bottom-hole assembly, they ran a special portal bit to condition the hole to total depth (Figure 1).

They then pumped down a 2½-inch tool string on wireline inside the drill pipe and out through a portal in the center of the bit. After verifying the tool string was operational, the logging engineer disconnected it from the wireline, which he reeled back to the surface.

The quad-combo suite recorded density, porosity, neutron, density, and acoustic logs in the wellbore. The log data were used to model the geomechanical properties of the formation and optimize the completion.

FIGURE 1

The typical through-the-bit logging sequence, as shown here, is to 1) drill to total depth; 2) pull the bit off bottom and lower the tool string on wireline, pumping the tool string out through a portal in the bit; 3) disconnect and remove wireline from the drill pipe; 4) log the hole while pulling the drill string out of hole; 5) draw the tool string back into the casing; 6) retrieve tool string on wireline; and 7) continue drilling or conditioning as needed.
neutron, resistivity and sonic data in memory mode as drillers pulled the pipe out of hole. When the tool string reached the casing shoe, the logging engineer retrieved it on wireline and downloaded all the data. By combining the logging run with a conditioning trip, the company saved a full 24 hours of rig time, compared with traditional pipe conveyance.

Using through-the-bit sonic, density and other log data, the operator’s team was able to infer anisotropy caused by natural fractures, derive elastic and mechanical properties, and group hydraulic fractures into optimal stages with similar rock properties. These “engineered completions” successfully confined fractures into optimally staged wells, while eliminating natural fractures, derive elastic and malleable, as illustrated in Figure 1.

One independent operator adopted through-the-bit deployment to log vertical wells in unconventional reservoirs, and even challenging vertical wellbores.

Following is a typical logging sequence as illustrated in Figure 1:

- **First**, drillers use the portal bit to ream to TD, conditioning the borehole for logging.
- **Next**, drillers pull the bit off bottom to provide sufficient room for the tool string, configured either with individual tools or as a triple- or quad-combo.
- **Where** gravity descent is not possible, engineers pump the logging tool string down through the drill pipe, through a 2½-inch portal in the bit, and into the open borehole. Once logging sensors are deployed, a hang-off sub just above the bit prevents the tool string from extending farther down by capturing a no-go collar near the top of the tool string.
- **Once** logging engineers verify operational functionality, they disconnect the wired drop-off tool from the tool string and remove the wireline from the drill pipe.
- **As** drillers trip the pipe out of hole, the tool string logs the open-hole section in memory mode.
- **Once** the logging tool string has reached the casing shoe, drillers pull the
portal bit and tool string up into the casing.

- Then logging engineers lower the wired retrieval tool through the drill pipe, latch onto the tool string, return it to the surface, and recover it from the drill pipe, without having to bring the rest of the pipe and bit out of the hole.

At this point, drilling and other operations can resume while the logging engineer reviews data recorded.

**System Benefits**

This unique deployment and retrieval system offers operators a number of important benefits in challenging horizontal boreholes. For one thing, combining the logging run with a conditioning trip reduces the usual rig time—and costs—required to acquire log data. By not deploying the tool string until the bit has reached TD, logging tools undergo considerably less exposure to potentially damaging shocks, vibration, and high temperatures. Using a wireline drop-off and retrieval tool means operators recover the logging tool string faster, with lower risk.

If, for example, hole conditions deteriorate and the drill pipe becomes stuck while tripping out, the operator still can retrieve critical log data while avoiding the possibility of leaving radioactive sources in the hole. Finally, the system is extremely driller-friendly. Throughout deployment and logging operations, drillers maintain complete control of the drill string, circulating and rotating as needed, without any fear of damaging the tool string.

There are, of course, other ways to deploy through-the-bit logging tools. One alternative, for example, would be to rig the tool string inside a drill collar at the surface, run it into the hole, pump it out through the bit, and log in memory mode while tripping out of hole.

However, before engineers pump out the tool string, it could suffer damage from shock and vibration inside the drill collar. Without deploying the tool string on wireline after the bit has reached TD and verifying that it is fully operational prior to logging operations, engineers would have to wait until the entire assembly returned to surface before they could determine whether the tools recorded any data whatsoever.

**Dipole Sonic**

Until recently, through-the-bit logging offered only a monopole sonic tool, which provided a single shear measurement. However, optimally engineered completions require compressional slowness as well as fast- and slow-shear slowness—two independent shear measurements—to fully quantify variations in anisotropy, stress, and completion quality along a horizontal wellbore.

Engineers and geoscientists also need low-frequency Stoneley wave measurements and cross-dipole measurements to accurately detect and quantify the orientation and permeability of natural fractures. By combining dipole with Stoneley measurements, they can develop a full 3-D acoustic characterization of the formation, which makes it possible to identify fractures and borehole stress regimes. A fit-for-purpose cross-dipole sonic tool provides this data.

In the absence of a small-diameter dipole sonic tool, operators have had to base engineered completion designs on ad hoc methods of estimating shear, or use synthetic and offset well data to approximate missing acoustic measurements, which has not been terribly accurate. Otherwise, they had to run a standard wireline dipole sonic tool separately from the through-the-bit logging tool string, which incurred additional risks, time and costs.

Nevertheless, shale operators are proving that acquiring dipole sonic data is well worth the effort. Some time ago, for example, four Eagle Ford operators and Schlumberger formed a completion optimization consortium to determine how best to improve multistage completion designs in horizontal wells using log data. The operators were particularly interested in accounting for the impact on
perforation efficiency of variations in stress along the laterals.

A study of production log data in 17 wells over two years showed that, on average, only 64 percent of the perforation clusters in conventional, geometrically completed wells were contributing to total production. The consortium predicted that grouping reservoir rock of similar high quality into fracture stages, and positioning perforation clusters within those stages to minimize differences in stress, would achieve more efficient stimulation.

Proof Of Theory

To provide the petrophysical and geometrical parameters needed to model both reservoir and completion quality, each of the four operators acquired openhole logs in three wells. To minimize risks and accelerate data acquisition, the consortium ran slim, through-the-bit quad-combo tools in all 12 wells. Using tractor conveyance, each operator subsequently ran a standard-size dipole sonic tool to obtain full 3-D mechanical properties in selected wells.

Petrotechnical experts input the results from detailed petrophysical and geometrical analyses into automated stimulation design software to generate custom-engineered completions based on intervals of similar stress. Accurately determining stress variations along the laterals ultimately depended on the availability of advanced dipole sonic measurements.

Completion engineers stimulated each study well according to its uniquely engineered design, then ran production logs to evaluate the efficiency of individual perforation clusters. At the time the consortium published its study in October 2013, operators had assessed six of the engineered wells (Figure 3).

Perforation efficiencies ranged from 75 to 89 percent, with an average of 82 percent. This represented an 18 percent average increase over traditional geometric completions, including a full 50 percent reduction in nonperforming clusters. Net present value calculations based on production results showed an increase of 40,000 barrels—worth $1.5 million at the time—in the first year of production alone. This yielded a 15-to-1 return on investment for acquiring the comprehensive log data required to properly engineer completions.

Through-The-Bit Tool

Since the Eagle Ford consortium study was completed, a through-the-bit dipole service has been commercialized that applies the latest acoustic technology to acquire borehole-compensated monopole, cross-dipole, and low-frequency Stoneley wave measurements. It is capable of measuring both fast- and slow-shear slownesses, as well as compressional slowness and low-frequency Stoneley waves, in a single small-diameter sonic tool.

As a result, operators may place engineered completions with greater confidence, based both on accurate fracture detection and direct anisotropic stress measurements at every point along the lateral. What is more, they can eliminate the risks, rig time and costs associated with additional logging runs to acquire standard dipole sonic logs.

Extensive field trials of through-the-bit dipole sonic technology in both vertical and horizontal wells determined that the measurement quality of the slim tool varied only 1-2 percent from that of leading standard-size dipole sonic tools. More than 50 logging jobs—most in unconventional plays across North America—have employed the new service.

An operator in the Wolfcamp Shale of West Texas was one of the early adopters of the small-diameter dipole sonic tool, despite having already achieved considerable success using monopole and synthetic shear data to plan engineered completions.

Not only is the Wolfcamp reservoir deep and highly pressured, but it consists of laminated, clay-rich layers under variable stress. Historically, therefore, the company found it challenging to produce the field efficiently. Among other problems, its geometrically spaced perforation clusters often suffered screen-outs in parts of the wellbore that happened to land in rocks of higher stress. Costs to mitigate screen-outs exceeded $300,000 per incident.

By incorporating a full suite of through-the-bit logging tools, measuring petrophysical and mechanical rock properties along the lateral, and optimizing perforation intervals based on computed stresses (Figure 4), the operator was able to boost 90-day cumulative oil production by 39 percent in his first horizonal well with engineered completions.

Compared with three geometrically completed wells in the same area, three subsequent horizontal wells using through-the-bit logs and engineered completions delivered, on average, a 103 percent increase in
90-day cumulative production. In addition, eliminating screen-outs saved hundreds of thousands of dollars in operating expenses.

Since then, the operator has used the same logs and engineered workflow for every new well in the field. However, petrophysicists never have been able to directly measure all the reservoir’s acoustic properties or fully quantify stress anisotropy. Field testing of the new through-the-bit dipole sonic tool enabled them to reliably measure up to 30 percent anisotropy in one Wolfcamp well for the first time (Figure 5). This allows the operator to further refine engineered completions, and gives completion engineers substantially greater confidence in the accuracy and reliability of their designs.

Another operator, who was targeting the Buda Limestone in South Texas, now is using Stoneley wave measurements from through-the-bit dipole technology for independent fracture detection, especially in the absence of borehole imaging. In this case, it is vital to position hydraulic fracture stages on either side of natural fractures to prevent proppant from being lost, which can have a significant impact on costs.

Not only do Stoneley measurements confirm the presence and location of fractures, but increases in Stoneley slowness indicate probable gas entry points in the lateral (Figure 6). After initial through-the-bit dipole sonic logging, the operator confirmed these results by logging the interval again, using standard-size sonic and formation microimaging tools.

**Conclusion**

One of industry’s greatest challenges in unconventional plays—especially at today’s oil prices—lies in designing completions that increase production significantly while simultaneously controlling costs. A good example would be eliminating stages in intervals with poor reservoir or completion quality.

An increasing number of operators have come to realize that it is no longer wise to forego logging horizontal laterals just because the borehole may be difficult to access. Without comprehensive petrophysical and geomechanical data, it is impossible to engineer completions to ensure optimal perforation placement and efficiency in heterogeneous, anisotropic shale reservoirs.

Through-the-bit logging technology now offers a full suite of tools designed specifically for challenging boreholes, empowering operators to save time, lower costs, and optimize production.

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**FIGURE 6**

Stoneley measurements (red) from through-the-bit dipole sonic recorded in a lateral well in the Buda Limestone—indicating natural fractures—are shown along with other indicators, including Stoneley reflection coefficients, negative Thomsen’s gamma, and attenuation from slowness frequency analysis.