The Quest for High Temperature MWD and LWD Tools

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Efforts to expand the temperature limits of MWD and LWD tools have seen limited success. New approaches may will be necessary if industry is to meet the demand for gas from deep, high temperature reservoirs.

The search for hydrocarbons is heating up. As shallow, convenient reservoirs of oil and gas become depleted, exploration is extending into deeper horizons, and deeper means hotter. In the U.S., deeper gas reservoirs have been found in the Gulf of Mexico's Mobile Bay, other and deepwater areas, in South Texas, the Permian Basin, and Wyoming.

Earlier this year the U.S. Dept. of Energy's National Energy Technology Laboratory (NETL) initiated a program to fund and develop technology relevant to these deep environments. The "Deep Trek" program includes initiatives to develop high temperature sensors and electronics as well as other methods and tools to drill at depths greater than 20,000 feet. These depths generally exhibit temperatures >176ºC (>350ºF) and pressures >10,000 psi. Currently, at temperatures exceeding 175ºC, deviated drilling must be done without the benefit of MWD (Measurement While Drilling) technology. Further complicating the problem, LWD (Logging While Drilling) technology is essentially limited to 150ºC or less. By comparison, the temperature of deep gas reservoirs in south Texas and the Gulf of Mexico approaches 232ºC (450ºF).

Efforts to extend these capabilities however,however have been underway for some time. In the late 1990s, prior to the current Deep Trek program, NETL, *Maurer Engineering Technology Inc.*, *Sperry-Sun,* and *Halliburton Energy Services* recognized the future need for high temperature drilling and geological measurement technology. In 1997, NETL entered into two partnership projects to enhance the capabilities of high-temperature LWD and MWD tools. The LWD project was to extend the capability of tools (from 140ºC to 175ºC with survivability to 200ºC). The MWD project objective was to extend the temperature of the MWD suite of tools from 175ºC (347ºF) to 195ºC (383ºF).

Although a complete suite of MWD tools was not developed and the MWD project has been discontinued, the project did advance the knowledge base with significant lessons learned and provided important direction to additional research for both MWD and LWD tool development. Changes made as a direct result of work performed under these projects have resulted in improved life and a more robust MWD tool at the previous temperature rating of 175ºC, as well as limited use at higher temperatures. The LWD project, currently still active, also benefited from lessons learned in the MWD project. This article presents a brief summary of the MWD work and the lessons learned.

MWD Project Objectives

The overall objective of the two-phase MWD project was to develop a mud-pulse MWD tool that could be used where downhole temperatures are as high as 195ºC (383ºF). Phase I objectives were to: (1) identify components of existing systems that cannot operate at 195ºC; (2) locate high-temperature replacements or develop new designs,; (3) develop a cooling technology to keep components at acceptable operating temperatures; (4) test new designs and components under high temperatures in the laboratory; and (5) assemble two high-temperature MWD prototype tools and test each in at least one low-temperature well to verify total system performance.

The primary objective of Phase II was to test the prototype tools in up to five directional/horizontal wells where the bottom-hole temperatures were 195ºC (or at least 185ºC), to establish system reliability and collect mean-time-between-failure (MTBF) performance data. The project was discontinued before Phase II was initiated.

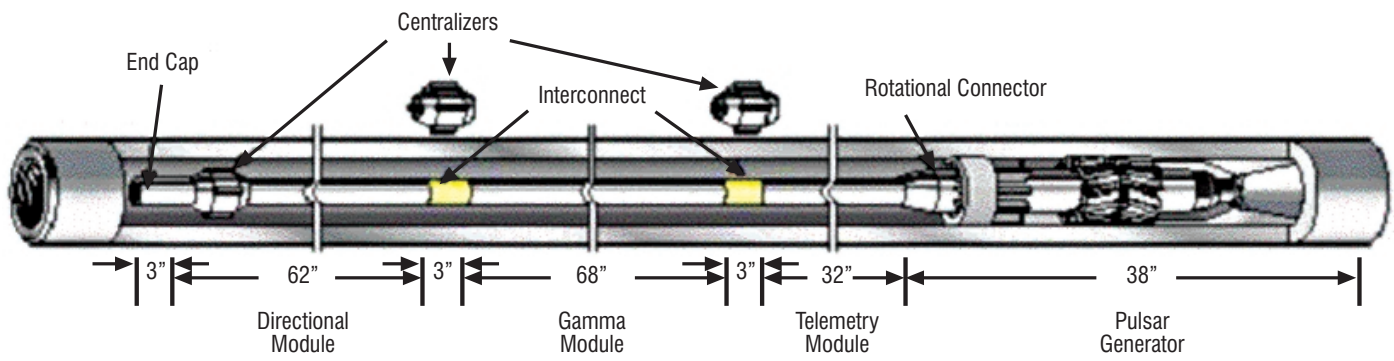

Figure 1: Schematic of MWD Tool

Merger Complicates Effort

The MWD project was co-proposed by *Maurer Technology Inc. (MTI)* and *Halliburton Energy Services (HES)* through its *Halliburton Drilling Systems Division.* During the course of the project, *HES* and *Dresser Industries* merged and Halliburton's MWD and LWD services became the responsibility of *Sperry Sun*, a former Dresser Industries company. Originally, HES was motivated to participate in the project to improve their standard tool's high temperature capability. After the merger, Halliburton acquired the *Sperry Sun Solar* 175 MWD tool, which boasted an industry maximum upper operating temperature of 175ºC. After some delay, Halliburton decided to continue with the project, with the goal of upgrading the Solar 175 tool for operations at 195ºC.

After the merger, some of the work accomplished by HES became superfluous (e.g., development of a high-temperature gamma detector based on Geiger Muller tubes was ended since Sperry Sun already had that type of detector). Overall project work continued however, and at the end of the project, *Sperry Sun* had constructed two prototype MWD tools that were successfully tested in the laboratory at 195ºC and then field tested (Phase I) at temperatures up to 180ºC.

Basic System Description

The high-temperature measurement-while-drilling (MWD) tool (Figure 1) includes five primary modules housed in sealed barrels hung inside a non-magnetic collar located above the drilling assembly. Descriptions of the modules and their functions follow.

Telemetry Module (TM) – The telemetry module communicates with other modules, gathering data from the gamma and directional modules, formatted formatting it for transmission, and storing it. The TM also conditions the electric power from the pulser/generator for use by the other modules.

Gamma Module (GM) – The gamma module measures naturally occurring gamma radiation to determine formation type and transition depths between formations. Geiger Muller tubes are used rather than conventional sensors based on scintillation technology, because they are rugged and able to survive high temperatures. Three stacked banks with four Geiger Mueller tubes each make up the sensor section of the GM.

Pulser/Generator – The pulser module generates electrical power and restricts drilling mud flow to create a pressure pulse that can be detected at the surface. It is always connected to the TM and is unique among the modules in this aspect. The pulser contains turbine blades that are driven by the flowing mud to turn a generator and a small hydraulic pump. The hydraulic pump is used to operate a poppet valve that blocks the flow of mud in the drill string, thereby creating a pressure pulse. The TM controls the pulser operations and encodes data into the pulses that are received and decoded at the surface using a pressure transducer and computer.

Battery Module (BM) – The battery module provides power to the tool when there is no flow of drilling fluid to operate the generator, using high-temperature lithium batteries.

Directional Module (DM) – The directional module uses magnetometers and accelerometers to measure the compass direction of the bottom-hole assembly and the angle of the hole. These data, along with depth, are used to calculate the trajectory of the well.

The DM is usually placed as close as possible to the drill bit.

Project Tasks and Work Completed

Work on many tasks was accomplished both before and after the *Halliburton/ Sperry Sun* merger. Each objective is highlighted below.

Identify Components and Design Cooling System – *Halliburton* and *Sperry Sun* were able to identify components or circuit designs that failed as temperatures were increased to 200ºC. For circuit design failures, eliminating components or altering the design addressed the shortcomings. Other failures required that new components be substituted for those that could not meet the temperature requirements.

Halliburton's goal was to identify, test, and use components that were either designed to operate or modified to operate at higher temperatures. *Halliburton* was successful in finding several components that demonstrated improved high-temperature performance, including a hybrid chip manufactured by *ELCON Technology* of Phoenix, Arizona, that was successfully tested at 200ºC for over 700 hours (Figure 2).

Sperry Sun chose to keep the same components (when possible), but identify batches from the manufacturer that functioned at elevated temperatures, believing that increasing temperature capability to 195ºC could be accomplished by locating exceptional batches of components that could survive even higher temperatures.

Halliburton subcontracted with APS Technology of Cromwell, Connecticut to develop an analytical model to simulate cooling of an MWD system and a dummy board, using resistance heating to simulate electrical components. Thermoelectric coolers (TEC) were used to remove heat from within a pressure barrel containing the dummy MWD board. The tests showed that TECs can reduce the temperature inside a pressure barrel and on the circuit boards to acceptable levels, providing a possible solution in the event that high-temperature components are unavailable.

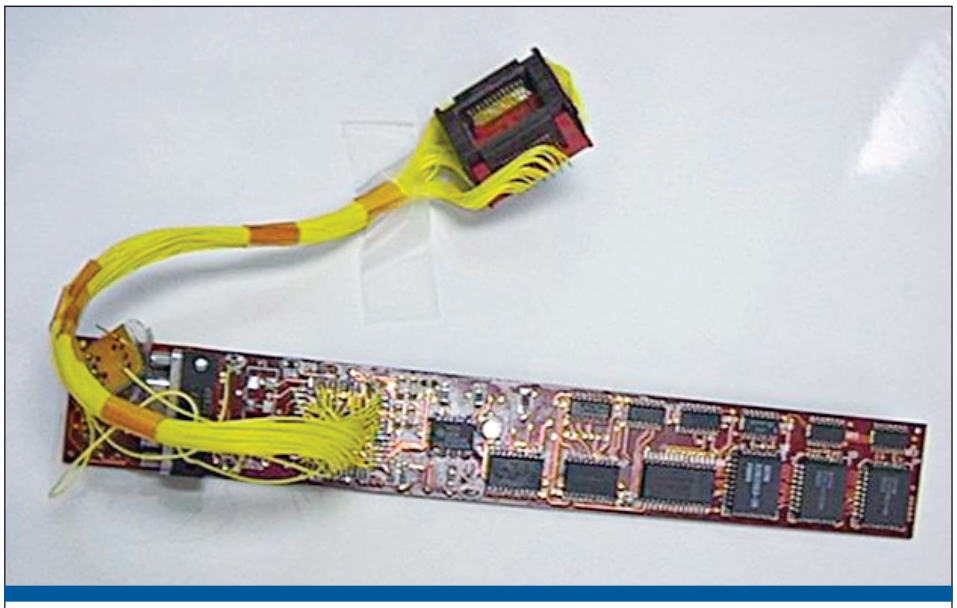

Figure 2: ELCON Hybrid Processing Chip

The test data also show, however, that a TEC would consume considerable electrical power, requiring the use of a turbine generator. Power would then only be available when the pumps were operating, so a Dewar-type pressure housing would be needed to insulate the MWD electronics and keep them at below rated temperatures for acceptable periods of time while the pumps were off. Both the generator and housing would increase the cost of this system. In addition, to achieve higher efficiency, the inside of the Dewar would need to be filled with a dielectric fluid, making assembly more difficult.

Design of a High-Temperature Gamma-Ray Detector – The best way to measure gamma radiation at higher temperatures is with *Geiger Muller* tubes. One advantage to the *Halliburton/Sperry Sun* merger was that *Sperry Sun* already had a gamma detector based on *Geiger Muller* tubes. Sperry Sun determined changes needed to upgrade their *Geiger Muller* unit to 195ºC. Testing highlighted problems in the unit's electronics, which were successfully modified.

Selection of High-Temperature Components for Use in MWD/Gamma Tool – Both *Halliburton* and *Sperry Sun* identified components or batches of components that performed adequately at high temperatures. Halliburton, working with Battery Engineering Inc. of Hyde Park, Massachusetts, developed a lithium-/magnesium battery that would operate in the temperature range of 125 – 214ºC. A size DD battery with 25 percent magnesium can be safely used to 200ºC. Current capacity, while reduced to 15 A-hr, is sufficient for at least 250 downhole circulating hours

downhole. The primary disadvantage of this recipe is that power output below 100ºC is poor.

Options for overcoming this problem include heaters to maintain the temperature of the lithium/magnesium batteries at minimum operational levels, or a sacrificial nickel-/cadmium battery pack used to power the tool at lower temperatures. The replaceable low-temperature battery pack would shut down and the high-temperature batteries come on-line as the tool's temperature rose above 125ºC.

Sperry Sun had difficulty in proving two directional packages for the test It took testing several packages of magnetometers and accelerometers, before individual magnetometers components could be proven for each of the tool tools, (magnetometers and accelerometers) for the test, the final individual components proven. This area remains as a key item requiring additional work.

Design, Fabricate and Test High-Temperature MWD/Gamma Tool – Both Halliburton and Sperry Sun took advantage of the opportunity presented by the project to make changes in the design of their MWD tools. Sperry Sun enhanced many areas of their tool (Table 1), using their current system as a base and modifying or substituting parts that qualified for higher-temperature service. The final prototype tools were tested in an oven at 193ºC.

A field test was conducted with the two prototype tools at elevated temperatures (180ºC) in Lavaca County, Texas in August 2001. While not the tool's design limit, this temperature range still represented an ambitious test. The tools were used to provide directional services on a sidetrack of a straight hole designed to intersect the formation up-dip above a gas/water contact. Conventional Solar 175 tools were used in the beginning of the operation and the first prototype 195ºC tool was run at 16,500 ft with the first recorded temperature at 178ºC. The tool stopped pulsing after operating on bottom for 59 hours. Data downloaded at the surface at the end of the test showed that the tool had continued to record data for an additional 27 hours. The second prototype tool was then run into the well. Total time for the second tool before data transmission was lost was 26 hours.

Each of the tools was given a post-mortem examination. The first was found to have a failed pulser resulting from failed seals. Data from the tool's telemetry module were successfully downloaded after the operation, demonstrating that the electronics had not failed. Battery voltage was very low (which could have been caused by exposure to high temperatures).

With the second tool, the pulser was also found to have failed, this time due to a bearing that had been inadvertently left out during assembly. It was also determined that the back-up battery in the telemetry module had vented, damaging wiring and electronic components. It was not apparent why the battery had vented. Heat could have been a factor, although these batteries should have been capable of operations up to 214ºC.

Economic Analysis

Preliminary analysis of the economics of the 195ºC tool highlights the greatest obstacle to future commercialization. Costs to screen individual components, then subassemblies, and finally completed tools for high-temperature operations are very high. Tests to date also show a relatively short life for high-temperature tools – on the order of 300 hours (as compared to approximately 1000 hours for a commercial MWD tool operating at temperatures up to 150ºC). Together, these factors mean that the daily cost of the 195ºC tool will be about $14,750 versus $3000 to $4000 for a conventional tool. In addition, high-temperature MWD tools are difficult to prepare, trouble-shoot, and maintain on a continuing basis. It is difficult to predict whether operational experience could increase operational life and reduce manufacturing and maintenance costs, and thereby reduce the daily rate.

Results of the MWD development effort showed that, while it is possible to build a mud-pulse MWD tool that can operate at 195ºC, performance is not yet sufficient for commercial success. The current temperature limit of 175ºC is apparently the practical limit for conventional electronics. This conclusion is further supported by Sperry Sun's decision to market two tools, one for service up to 150ºC and another (the Solar 175) tool for service from 150 to 175ºC. Currently, the bulk of commercial MWD work is at temperatures below 150ºC.

However, industry's perception of future MWD/LWD requirements appears to be changing. Market studies indicate that deeper, higher temperature gas wells are the trend. The DOE can help bridge the gap in perception by presenting data and funding projects that help determine how much gas is located in high-temperature reservoirs. These data may then serve to encourage the MWD industry to place resources into the development of tools for high-temperature operations.

New Platform May Be Required

Increasing the operating temperature (>175ºC) of current MWD (and LWD) tools may require development of a new platform for the electronics used in these tools. This technology already exists in a limited number of

components and has been used to develop some special geothermal tools. Sandia National Laboratory has taken the lead role in this area and is developing or interested in the development of tools based on silicon-on-insulator (SOI) technology to overcome high geothermal temperatures.

SOI electronic components have been demonstrated at temperatures of up to 250ºC for hundreds to thousands of hours. Oilfield systems could make use of SOI technology to develop a next generation of tools that could allow raising the current temperature limit (175ºC) to as high as 300ºC. Two other major design changes for high-temperature applications are ceramic packaging and gold wire bonding.

There are several barriers to the development of SOI tools for the oil and gas industry. First, programming would have to be extensively modified. Completely new circuits would have to be developed to use the SOI chips now available. In addition, some components still need to be improved for high-temperature use including magnetometers and accelerometers needed used for determining direction and trajectory of the well. This project has advanced the development of these components, but more work is needed, including the examination of other non-conventional technologies to measure primary MWD parameters, angle, and direction. Perhaps one of the most challenging obstacles to the development of the next generation of MWD tools is the (understandable) reluctance of companies to render obsolete their current inventories of tools.

LWD Tool Development Underway

The LWD project is still underway to develop a 175ºC tool to include directional (geometric position), natural gamma ray, resistivity, Stabilized stabilized Litho litho Density density (SLD), compensated thermal neutron (CTN) porosity, and a pulser to send the reduced formation evaluation data back to the surface by way of pressure pulses in the drilling fluid. Much of the knowledge learned for the LWD project was gained in developing the higher-temperature MWD project.

The LWD tool is 4 ¾ inches in diameter and the entire tool string is approximately 100 feet in length. A 4 ¾ inch Solar (175ºC) SLD measurement tool is in the process of being built and will be rigorously tested at Halliburton's North Belt manufacturing facility before being integrated with the remaining components of the tool in February 2003 for further field testing.

Field- testing has been accomplished on five of the tool components in the North Sea at depths in excess of 15,000 feet MD and temperatures up to 186ºC with excellent success. Field tests have been run in Oman (174ºC), Saudi Arabia (162ºC), and the Gulf of Mexico (154ºC). With the addition of the SLD tool currently under development, testing of the integrated tool string will begin in February or March of 2003 and continue for several months.

Next Steps

DOE leadership and partnership with industry can play a significant role in encouraging the development of high-temperature tools to prepare for the future. The DOE can provide funding to help reduce the risk and offset the loss due to obsolescence of current inventories. ■

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