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DEVELOPMENT OF DOWNHOLE INSTRUMENTS FOR USE IN THE SALTON SEA SCIENTIFIC DRILLING PROJECT

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ABSTRACT

Sandia developed high temperature logging instruments for use in the Salton Sea Scientific Drilling Project. These tools -- Kuster mechanical tools for measuring temperature, pressure, and flow; a temperature and pressure tool built around an electronic memory; and a timing and control unit to power a downhole sampler -- were all designed for slickline operation to temperatures up to 400°C. The drilling of the scientific well and the application of these tools in it were successful. The technology advances made in the development of these tools have been transferred to industry. These advances should prove valuable in future scientific and commercial applications.

INTRODUCTION

As a portion of its Geothermal Technology Development Program,[1] Sandia National Laboratories developed slickline logging instruments for use in the Salton Sea Scientific Drilling Project (SSSDP). The SSSDP was funded by the United States Government through the Department of Energy (DOE) and was carried out during 1985 and 1986.[2,3] The purpose of the project was the scientific investigation of the deep hydrothermal system underlying the commercial geothermal fields along the southeastern edge of the Salton Sea, in the Imperial Valley of California. There were three facets of the investigation: extensive coring and study of the cores and cuttings from the well; two flow tests allowing study of temperature, pressure and fluids at the surface; and extensive downhole measurements taken during drilling, during flow, and after well shut in. Following shut in, the well has been kept available for six months for scientific experiments.

For several years, Sandia National Laboratories has conducted the Geothermal Technology Development Program, which is directed toward development of advanced technologies related to drilling, completing and logging geothermal wells. One aspect of the program has been the investigation and development of instruments for making measurements in the severe environments encountered in geothermal wells. Experience in this area provided the basis for our involvement in the SSSDP. Our role was to develop, for use by the on-site science team, tools that would allow measurement of temperature, pressure and flow and collection of downhole fluid samples.

BACKGROUND

The SSSDP was a research project initiated by Dr. W. Elders of the University of California at Riverside. The Geothermal Technology Division of the DOE provided major funding for the operation, with the Office of Basic Energy Science of DOE, the Geological Survey (USGS) and National Science Foundation (NSF) providing funds for research. The resource belongs to Kennecott, Bechtel was hired to manage the drilling, the USGS provided the on-site science team, and scientists came from several labs and universities. The logging of the well and scheduling of scientific experiments were the responsibility of the on-site science team; and the downhole instruments were developed for their use and designed with their participation.

The wellbore temperatures anticipated in the SSSDP well presented a challenge to logging systems. It was felt that temperatures in the well might approach 400°C, and so special efforts had to be made to provide downhole measurements. Wireline logging instruments generally consist of a sensor, electronic signal conditioning, and the wireline to the surface. High temperatures present no problems for many sensors; and in most tools, the electronics can be built to function at 200°C to 250°C and can be heat shielded to allow temporary use at much higher temperatures. The conductive wireline is usually the limiting component for high temperature application. For this reason, a state-of-the-art, seven conductor, TFE-teflon insulated, MP-35N armored wireline was purchased jointly by the DOE and

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the USGS for use in the SSSDP well. However, the teflon insulation in this cable is good only to temperatures slightly above 300°C, and so other logging systems had to be acquired to provide measurements deep in the hole where temperatures exceeded 300°C. In such cases when wellbore temperatures exceed the capabilities of conductive wirelines, relatively few options exist; and for the SSSDP well, the decision was made to rely on systems that could be run on nonconductive "slicklines", cables which provide only a mechanical linkage to the surface.

INSTRUMENT DEVELOPMENT

Five slickline logging systems were developed for application in the SSSDP well. These included: separate mechanical temperature, pressure and flow tools; a combined temperature and pressure system with a downhole electronic memory, and a special use power pack and control unit for a downhole sampler. Table 1 presents the specifications for these tools.

Objectives

The primary objective of these instrumentation development efforts was to provide, in a timely manner, logging systems that would work in the SSSDP well. Because the development efforts were part of Sandia's Technology Development Program, there were secondary objectives as well. One of these was to advance the state-of-the-art in very high temperature wellbore logging by providing a capability that did not previously exist; and another was to transfer the technology that would be developed to industry so that it would be readily available to others.

Design Criteria

There were three common elements in the design approaches taken for the five tools. The first involved tool design parameters. Because of the uncertainty concerning the thermal and chemical environment that would be encountered in the well, each instrument was designed to run on a slickline, each had its sensitive components protected by a heat shield, and each was built with a housing made from a corrosion-resistant alloy. The second common element was due to the short development schedules. (Depending on the tool, there were roughly six to eight months between the initial funding decision and application in the SSSDP well.) For each tool, an effort was made to utilize existing, proven technology and to combine it with new components or to package it in ways that had not been used before. The third common element was that the tools had to be simple enough to use that they could be run by a crew that had not had extensive training.

Mechanical Instruments

Three mechanical tools were designed, built and run in the well: a temperature tool, a pressure tool and a flow tool. The tools were built by Kuster Company and designed by Kuster in conjunction with Sandia. Each was built to function for at least ten hours at 400°C. In order to provide this capability, existing high temperature components developed during a previous Sandia program were housed in a dewar (evacuated heat shield). This required a redesign of the sensor units to allow separation between the sensor, which must be exposed to the environment, and the timing and recording sections, which must be protected.

Each of the tools is 3 inches in diameter, roughly 8 feet long, and weighs approximately 100 pounds (20 pounds for the tool and 80 pounds for the pressure housing and heat shield). The temperature tool uses a bimetallic temperature sensor, the pressure tool uses a Bourdon tube, and the flow tool uses a spinner. The output of the temperature and pressure sensors is rotation of an axial shaft that goes into the recording section, while the flow sensor causes discrete deflections of the recording shaft corresponding to a fixed number of rotations of the impeller. In operation, a mechanical clock advances a chart downward at a constant rate through the recording section while the shaft from the sensor rotates a stylus that scores the chart. The result is a Cartesian plot of sensor output versus time recorded on the chart.

To a certain extent, the temperature and pressure tools were extensions of existing technology. However, the flow tool required development effort. Downhole measurement of the flow at rates that are realistic for geothermal wells would be difficult even at low temperatures. Both the building of a geothermal flow tool and the insertion of the mechanical tools into dewars were contributions to the state of the art in high temperature instrumentation, and both are now commercially available.

Electronic Memory Tool

The development of the electronic memory tool encompassed a new technology application. A few memory tools have been used for long term petroleum reservoir monitoring, but their application to slickline logging of geothermal wells is new. In a sense, the electronic temperature and pressure tool provides, in a much more compact package, an analog to a tandem hookup of the Kuster temperature and pressure tools. To a wireline crew they seem identical, but significant differences arise in data collection, storage and retrieval.

The tool contains a small computer and digital memory chips. These components and the sensor circuitry are contained in a dewar that gives them a lifetime of roughly 10 hours at 400°C. Pressure is sensed by a quartz crystal, linked by a capillary to the wellbore, while wellbore temperature is measured by a platinum resistance temperature detector (RTD). At the current time 1000 readings from each can be stored, though extension by a factor of ten is planned and even further expansion is possible. The tool was sized to fit a dewar width a diameter of 3-1/2 inches and a length of approximately 4 feet. The entire tool weighs approximately 100 pounds.

When the tool is to be run in a well, it is programmed to make measurements at specific times or at specified intervals, chosen by the operator. After the program is set, the tool's internal clock is started and synchronized with a surface clock. Once these two functions have been performed, the dewar is closed and the tool is run downhole, taking measurements at the programmed times. Simultaneously, the logging depth is recorded as a function of time. Following collection of the data, the tool is retrieved and the on-board data are dumped to a surface computer that performs data analysis and display.

The dewar that was used for this instrument was acquired specifically for the SSSDP well. It has an outer case of Inconel alloy (to resist corrosion) and it utilizes an integral pressure vessel -- i.e., the pressure vessel serves as the outer wall of the dewar. Both the dewar and the pressure/temperature tool were built on contract to Sandia specifications, based on cooperative designs. The dewar was supplied by PDA Engineering, and the tool by Service Systems Engineering.

In this development effort, the heat shielding of the pressure and temperature tool, setting it up to run as a slickline logging tool for geothermal, and the integral pressure/dewar system were all advances in the state of the art. Furthermore, all are now available commercially. The concept of the electronic memory, slickline logging tool is exciting and provides an excellent baseline for expansion to include other capabilities.

Power Pack/Control Unit

The fifth tool developed was a battery pack and timing unit for powering a downhole fluid sampler.[4] It was designed specifically to drive a sampler developed at Los Alamos National Laboratory for use in the SSSDP well. The sampler normally is run on a conductive wireline, and so the control unit was designed to simulate the signals that would be received on the wireline. Unlike the other tools, the sampler unit was both designed and built at Sandia. This was done because it is a single-purpose tool and because its design required continuous changing and upgrading as the sampling tool itself evolved.

The basic components of the tool are a rechargeable battery pack and a timing and current limiting circuit. These were designed to fit the same dewar as the electronic tool described above. In fact, the size of the dewar was selected to match the 3-1/2 inch diameter of the sampler. Together the sampler and control unit are roughly 10 feet long and weighed approximately 150 pounds. The critical elements in the design of the timing circuit were the selection and interaction of the timers and relays to avoid premature operation due either to the mechanical shocks that can be expected during a 300 feet per minute logging run or to the handling of the 100 volts required to run the sampler motor.

During operation, a delay timer is set at the surface and the control unit is inserted into the dewar. The tool is then fastened to the wireline and inserted in the lubricator at the top of the well. In order to minimize exposure to well fluids and temperatures, the tool is held at the surface until only the anticipated travel time and the residence time at the sample point are left on the initial delay. The tool is then lowered to the sampling point. After the initial delay, the control circuit provides 100 volts to the sampler motor to open a valve. After 18 seconds, the current stops and the sampler stays open for roughly 20 seconds; then the circuit reverses the current to close the sampler. When the valve is closed, the circuit shuts itself off to avoid the possibility of a malfunction causing loss of the sample.

This tool used existing components in a unique circuit design. Since this was a special-use tool, no attempt was made to transfer the technology to a company that could make the tool commercially available. However, the design has been documented and the related testing results are available.

RESULTS

The drilling and early testing phases of the SSSDP were quite successful. The well reached its target depth, and the lost circulation and other drilling problems were no more severe than are common in deep geothermal wells. At shallow depths, the well encountered somewhat lower thermal gradients than were anticipated, but the 300°C temperature was reached at about 6000 feet. The well reached a final depth of roughly 10,500 feet, and at that depth, the temperatures exceeded 350°C. The well flowed very easily in both flow tests (at 6000 feet and total depth) and loss/flow zones were encountered all the way to the total depth.

The results of the data collection activities were also quite good, especially considering the downhole environment and the developmental nature of the instruments. The five tools developed for the project provided nearly all of the high temperature data from the well. In general, the tools functioned quite well during the flow test; and the two temperature tools continue to be used on a regular basis during the six-month period for scientific experiments.

At the suggestion of Sandia material specialists, Inconel 718 and stainless steels (17-4 and 13-8) were used in the pressure housings for the instruments. It was hoped that the logging runs could provide comparative corrosion data. However, the number of runs has so far not been large enough for the housings to show any effects of corrosion.

Mechanical Tools

The pressure tool worked well and provided a good log every time it was used. It did have a seal failure on one run, but the tool continued to function. This tool provided the only downhole measurements of reservoir pressure during and following the two flow tests.

The temperature tool also worked every time it was run. After several runs, it was reworked to correct a scorched bushing, but this tool provided the only downhole temperature data during the flow test. It was run in tandem with the pressure tool.

The flow tool was run during the final flow test and worked intermittently. The impeller seemed to jam and clear as the run was made. For a developmental tool in such a harsh environment, its performance was not surprising.

Electronic Memory Tool

This development was funded later than the mechanical tools, and so this instrument was not scheduled for use until after the flow test. It has been used during the six-month science period and has worked well and provided a complete log each time it has been run.

Sampler Control Unit

The combined sampler/power pack tool had mixed results due to a valve problem, a motor problem, and a series of seal problems. But when these problems were finally solved, the unit functioned as designed and collected a sample from the bottom of the well. The indications were that the battery pack and control circuit worked during every run. This tool has demonstrated the viability of replacing a wireline with a self contained, programmed power pack.

CONCLUSIONS

Several conclusions can be drawn from the experiences related to the development and application of these downhole instruments:

1. It is possible to collect information and make measurements downhole in difficult environments if enough leadtime is provided for instrumentation development. As successful as the SSSDP logging was, even better and more reliable tools could have been used had more time been available for tool development.

2. Scientific drilling projects can provide the impetus for technology development and advances in the state of the art.

3. The feasibility of the electronic memory tool has been demonstrated, and the tool provides an attractive basis for expansion to new capabilities and measurements.

4. The concept of using self-contained slickline instruments proved to be beneficial and can be adapted to various tools and measurements.

REFERENCES

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2. Sass, J. H., Elders, W. A.,Salton Sea Scientific Drilling Project: Scientific Program submitted for presentation at the 1986 Annual GRC Meeting.

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Table 1. Specifications for SSSDP TOOLS

Mechanical Tools

- 3" diameter, 8' long, approximately 100 lbs each tool
- dewared to perform 10 hours at 400°C
- can be run in tandem

Pressure Tool

- Bourdon tube
- 0-6000 PSI range
- 10 PSI accuracy

Temperature Tool

- Bime
allic element
- 0-425°C range
- 2°C accuracy

Flow Tool

- Spinner with rotating magnets
- Developmental sensor, range and accuracy uncertain

Electronic Tool

- 3-1/2" diameter, 5' long, approximately 100 lbs
- dewared to perform 10 hours at 400°C
- can be run with Kuster tool

Pressure Measurement

- Quartz crystal gauge
- 0-15,000 PSI range
- 3 PSI accuracy

Temperature Measurement

- RTD circuit
- 0-600°C range
- 2°C accuracy

Memory

- Programmable time steps
- 3800 data points

Sampler Power Pack

- 3-1/2" diameter, 4-1/2' long, approximately 75 lbs
- dewared to perform 4 hours at 400°C
- can be run with Kuster tools
- programmable time delays
- designed to power LANL fluid sampler