Geothermal Resources Council, TRANSACTIONS, Vol. 2 July 1978

HIGH TEMPERATURE INSTRUMENTATION FOR GEOTHERMAL APPLICATIONS*

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INTRODUCTION

Instrumentation for making geothermal borehole measurements is limited by the temperature capabilities (~ 180°C) of existing logging equipment developed for the oil and gas industry. The Geothermal Logging Instrumentation Development Program being conducted by Sandia Laboratories for the Department of Energy (DOE), Division of Geothermal Energy is an industry based effort to develop and apply the high temperature instrumentation needed to make geothermal borehole measurements.[1] The near-term goal is to develop instrumentation for use at 275°C in pressures up to 48.3 MPa (7,000 psi); subsequent goals are to extend the capabilities to 350°C and 138 MPa (20,000 psi). Working closely with geothermal producers, logging service companies are conducting R&D to correct technical deficiencies so they may adequately serve the growing geothermal market. The basic impediments they face involve special technologies which are not normally required in their trade and for which there are insufficient incentives for them to develop. These technologies are precisely those which are being developed by this program; components development activities are directed toward stimulating industries' own inventions and field applications of geothermal logging instruments having improved reliability, appropriate size, reasonable cost and performance versatility which encompasses not only geothermal but conventional petroleum and hot, deep natural gas logging as well. Tools to be upgraded and/or developed include temperature, flow rate, high resolution downhole pressure, caliper and fracture mapping sondes.

GEOTHERMAL BOREHOLE MEASUREMENTS

In geothermal wells, temperatures frequently range up to 350°C while, at present, most of the commercially available logging tools, cables and seals are rated to only 180°C. Above their temperature rating and combined with the corrosive environment of a geothermal well, logging tools and cables have significantly reduced reliability and life expectancy.

The repertoire of tools needed to enhance geothermal development, their development priority and performance requirements are listed in Table 1 based on information compiled by the 1975 Geothermal Workshop[2] and updated by the industry based Geothermal Logging Instrumentation Steering Committee.

TABLE 1

PROTOTYPE GEOTHERMAL LOGGING TOOLS (up to 275°C operation)

Tool	Performance Goal
Temperature	1.0°C accuracy, 0.5°C resolution
Pressure	0-7000 psi, 0.1 psi accuracy, 0.01 psi resolution
Flow	0-2000 gpm in diphasic flow
Caliper	6 arm borehole geometry, 0.1 in. accuracy with fracture indication
Casing Collar Locator	Detect standard collars
Formation Resistivity	To be determined
Fracture Mapping	To be determined
Casing & Cementing Inspection	To be determined
Directional Survey	To be determined
Sonde Refrigeration	50 watts cooling to 125°C for at least 100 hours

GEOTHERMAL LOGGING DEVELOPMENT

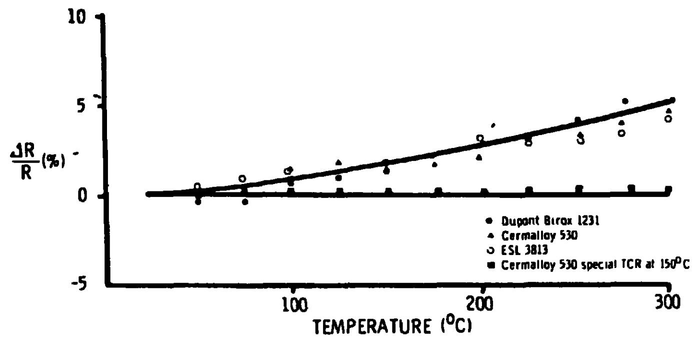
The technical development of geothermal borehole instrumentation is divided into three tasks: 1) severe environment components development, 2) prototype system development, and 3) borehole test and evaluation.

SEVERE ENVIRONMENT COMPONENTS DEVELOPMENT

Efforts in components development are directed toward alleviating existing technical deficiencies by identifying, testing and evaluating devices, materials, and components suitable for use in geothermal logging systems. Specific developments are under way in 275°C electronics, high temperature-high resolution pressure transducers, acoustic transducers, and high temperature corrosion resistant elastomers, ceramics and metals.

*Work performed under the auspices of the U.S. Department of Energy, Contract No. AT(29-1)-789 for the Division of Geothermal Energy (DGE).

High temperature Electronics - The thrust for a 275°C capability is the use of hybrid thick film microcircuits technology. This commercial technology is employed for small quantity production runs but typically limited to 125°C applications. The technology can be adapted to the required temperature range, has the necessary ruggedness and gives the desired level of miniaturization. Adaption of the hybrid thick film process to high temperature operation requires selection of resistor inks specially formulated for low values of thermal coefficient of resistivity as shown in Figure 1. Similarly, dielectric inks, for capacitors, are formulated to maintain stable low loss properties over a wide temperature range. Hundreds of these hybrid thick film resistor and capacitor devices have been laboratory tested for thousands of hours at 300°C.



THICK FILM RESISTANCE CHANGE AS A FUNCTION OF TEMPERATURE. THE THREE STANDARD INK SAMPLES THAT WERE EXTENSIVELY TESTED PERFORMED ROUGHLY THE SAME. THE SPECIAL TCR CERMALLOY 530 HAD A ΔR/R OF LESS THAN 0.2%.

Figure 1

For active devices in the 275-300°C range, the popular bipolar silicon transistors are intrinsically limited. However, a few commercially available silicon semiconductors have been found to operate satisfactorily at these high temperatures. The majority of these devices are junction field effect transistors (JFETs). JFETs operate by means of electrostatic control of majority carrier current. Figure 2 displays temperature performance curves for a commercially available JFTE specially selected for its high temperature qualified construction. Several have been qualified for 275°C operation through active circuit tests for 1000 hours at 300°C.

Through laboratory testing of active and passive electronic devices, a sufficient, though limited, line of commercial components and fabrication techniques is now available for 275°C

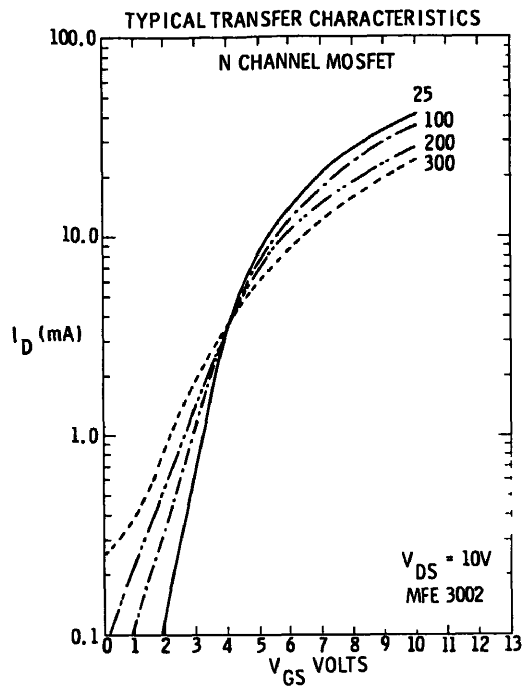


Figure 2

operation to fulfill basic circuit needs for amplification, switching and filtering. Development work is continuing toward expanding the repertoire of available devices suitable for 275°C operation.[4]

High Temperature Mechanical Components - Elastomers and seals capable of withstanding temperatures of at least 275°C and 7,000 psi in the presence of geothermal brine for up to 100 hours are required for geothermal well logging applications in seals, gaskets, connectors, cable sheathing, wire insulation, pressure controls, and borehole packers. The approach taken to develop high temperature mechanical components includes: 1) coordination of material needs and developments with DGE's Geochemical Engineering Program, 2) test and evaluation of available high temperature, steam resistant elastomers and metals as moisture barrier seals, and 3) investigation of special coatings to enhance the chemical and steam resistance of elastomers made from available polymers.

As shown in Tables 2 and 3, test and evaluation of available materials has identified several promising candidates for use in specific components such as seals and wire insulation. Other materials, along with specific prototype designs of cables, cableheads and tool seals will be tested in the coming months.

TABLE 2

HIGH TEMPERATURE ELASTOMERS				
Trade Name	Type	Decomposition Temperature °C	Cost $/LB	Components
BUNA N	NITRILE	150	6	Good Oil Resistance Poor Resistance to H_2S and Steam
VITON E- -C	FLUORO ELASTOMER	290	35	Fair Resistance to Steam Poor for H_2S
VITON G (Peroxide Cure)	FLUORO ELASTOMER	290	40	Improved Steam Resistance Poor for H_2S
KALREZ	FLUORO ELASTOMER (Fully Fluorinated)	400	2000	Best for H_2S Fair for Steam
EPR	POLYOLEFIN	250	8	Excellent Steam Resistance H_2S Unknown
SILOXANE	SILICONE	300	17	Poor Steam and Poor H_2S Resistance

TABLE 3

HIGH TEMPERATURE SEALS		
Type	Temperature Limitation	Components
Elastomeric O-Rings	Polymer Decomposition 300°C	Reuse Permitted Least Dirt Sensitive
Metal O-Rings	Metal Softening 500°C	Reuse Not Recommended Soft Plating Recommended Nick and Scratch Sensitive Minor Joint Motion Tolerated
Wave Rings	Metal Softening 500°C	Reuse Not Recommended Soft Plating Recommended Nick and Scratch Sensitive

PROTOTYPE SYSTEM DEVELOPMENT

Based on the priority of needs listed in Table 1, the temperature, pressure, flow, and caliper tools are being addressed first.

Temperature - Both printed circuit board and hybrid microcircuits have been completed and evaluated for a 275°C temperature tool. The design is based on a platinum resistance transducer with active downhole electronics. The design is compatible with both multi- and mono-conductor cables. A printed circuit board version has successfully completed 62 hours of testing at 275°C. A drift error of less than 0.28°C was obtained.

Fabrication of a complete tool including housing and interconnections has been accomplished. Test results are subsequently discussed.

Pressure - This development is directed toward a high resolution quartz crystal based pressure sensor which strives for 0.01 psi resolution in temperatures up to 275°C. Currently available, high resolution pressure gauges utilize quartz crystals but are temperature limited because of: crystal geometry employed; the bonding of the crystals to the substrate; and the temperature range of the associated electronics. The approach taken for the high temperature design begins with a new quartz crystal configuration that is specifically designed to operate optimally at 275°C rather than over a wide range of temperatures. The crystal is small enough to fit inside a miniature oven which precisely maintains the quartz crystal at the optimum temperature. Deficiencies in the associated electronics are corrected by utilizing the repertoire of high temperature hybrid thick film circuit components already developed.

Flow - A high temperature impeller type flux gate transducer signal feedthrough mechanism has been constructed. The associated hybrid electronics for 275°C operation are presently under development.

Caliper - A caliper tool is a necessary adjunct to the impeller type flow tool in order to compute flow rate. The caliper is also necessary to identify open borehole geometry and thereby establish a basis for log instrumentation and well completion strategy. In addition, a caliper is also useful in gross fracture mapping where the fractures are at least 0.1 inches wide. Development efforts are directed at correcting major deficiencies in existing caliper's susceptibility to the corrosive, high temperature geothermal environment.

Fracture Mapping - Most liquid dominated hydrothermal reservoirs appear to be fracture dominated permeable zones rather than the intergranular dominated permeable zones common in petroleum reservoirs. The development of fracture mapping techniques for geothermal reservoir assessment is, therefore, of very high priority.

DOE/DGE is currently sponsoring Westinghouse Research Laboratory to improve and temperature harden transducers for a Borehole Televiewer (BHTV). The BHTV is patented by the Mobil Oil Corp. and incorporates a high frequency (1.5 MHz) acoustic transducer system which provides an acoustic image of the borehole wall to indicate cracks and associated fracture zones.

Activities in acoustic fracture mapping are directed toward further development of the BHTV because such development will complement industries' own efforts. Also, pioneering work by the USGS and Simplec Manufacturing Co. indicates that the BHTV has a high potential for satisfying geothermal needs.

Other Prototypes - Available thermal protection devices such as eutectic heat sink equipped dewar flasks are presently the industry's staple in packaging and protecting state-of-the-art electronics for logging geothermal wells. However, the best available dewars are limited to no more than 12 hours of operation in boreholes up to 275°C. A reliable instrumentation refrigerator, capable of operating for 100 hours or more, will enable long-term operation of existing downhole electronic packages and thereby open up the geothermal logging market to conventional logging services. Due to the high potential payoffs, this sonde refrigerator is currently being contracted to industry with appropriate technical support from Sandia.

BOREHOLE TEST AND EVALUATION

The above experimental prototypes will be tested in geothermal boreholes using a special trailer mounted skid unit, a 50 foot mast truck and auxiliary support equipment for long term experimental tests of prototype borehole instruments. The skid unit is equipped with 16,000 ft. of seven conductor and 15,000 ft. of monoconductor high temperature cables.

Two field tests have been conducted of the prototype temperature tool developed by Sandia and Gearhart-Owens, Inc. (GOI) which consisted of a printed circuit board version of the high temperature electronics design, a high temperature casing collar locator, and a GOI tool housing. The first test was conducted in the Hot Dry Rock Well, GT-2 of the Los Alamos Scientific Laboratory at the Jemez Mountains, NM.* Figure 3 presents the data from the test run conducted in this well.

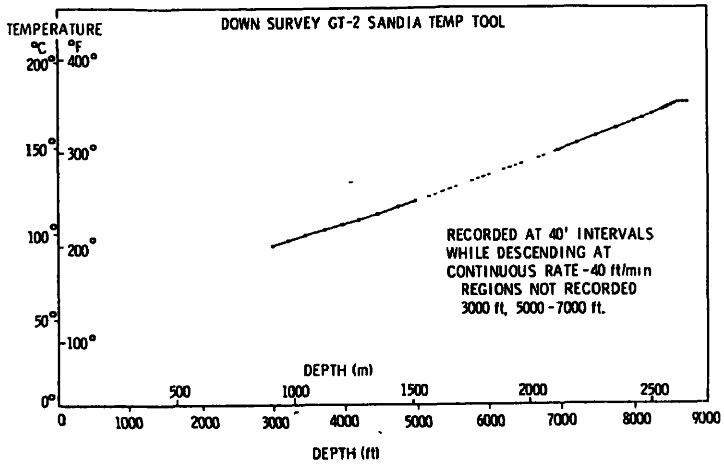


Figure 3

The second test was conducted in the COSO Geothermal Well CGEH-1 at the Chino Lake Naval Air Station, CA.* Data from this test run indicated a maximum borehole temperature of 189°C at 834 m. Performance of the instrument is considered excellent. Subsequent tests will be conducted to assess reliability and accuracy up to 275°C.

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*The assistance of LASL personnel at GT-2 and Lawrence Berkeley Laboratories at CGEH-1 is gratefully acknowledged.