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HIGH TEMPERATURE INSTRUMENTATION DEVELOPMENT AND COMMERCIALIZATION FOR GEOTHERMAL APPLICATIONS*

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ABSTRACT

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[1] is being conducted by Sandia Laboratories for the Division of Geothermal Energy (DOE/DGE). This program emphasizes the development and field test performance verification of severe environment components such as 275°C electronics, high temperature-high resolution pressure transducers, elastomeric and metal tool seals, cableheads, and cables. Since the report to the GRC last year, a number of these essential developments have come to fruition: a set of prototype geothermal logging tools (temperature, pressure, and flow), cables, and cableheads were successfully field tested to temperatures up to 275°C in a geothermal well during November 1978; an experimental high resolution quartz pressure transducer was successfully tested up to 275°C and 1000 psi; a gallium phosphide diode was developed and found to operate successfully up to 400°C; and the mechanical clocks in the Amerada gauge were upgraded in temperature and reliability.

INTRODUCTION

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.[2] 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 that are being developed by this industry based program;[3] 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. The near-term goal is to develop instrumentation for use at 275°C in pressures up to 48.3 MPa (7000 psi); subsequent goals are to extend the capabilities to 350°C and 138 MPa (20,000 psi).

GEOTHERMAL BOREHOLE MEASUREMENTS

The repertoire of tools needed to enhance geothermal development, their development sequence and performance requirements are listed in Table 1 based on information compiled by the 1975 Geothermal Workshop and updated by the industry based Geothermal Logging Instrumentation Steering Committee. Figure 1 displays the primary deficiencies in geothermal logging. To correct these deficiencies, the technical

TABLE 1

PROTOTYPE GEOTHERMAL LOGGING TOOLS (up to 275°C operation

Tool	Performance
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
Fracture Mapping	To be determined
Casing & Cementing Inspection	To be determined

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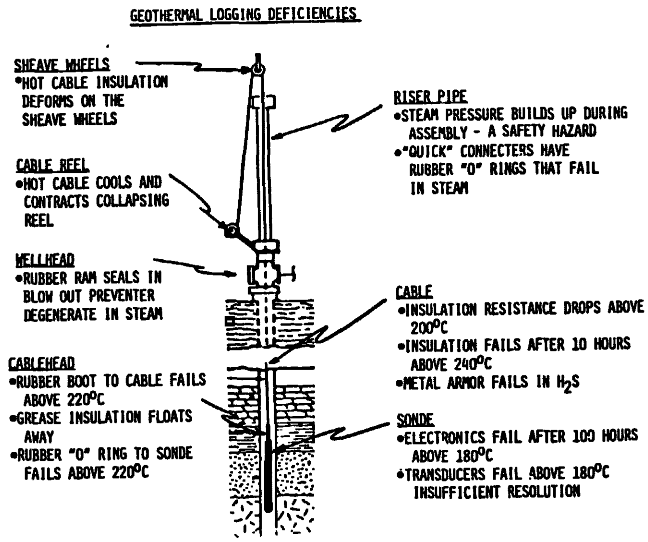

FIGURE 1

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.

HIGH TEMPERATURE ELECTRONICS

The thrust for a 275°C capability is the use of hybrid thick film microcircuit technology. Resistor and dielectric inks have been specially formulated for low values of thermal coefficient of parameter variation. These materials are now commercially available after having been tested in prototype circuits for thousands of hours at 300°C.

Several commercially available silicon junction field effect transistors (JFETs) have been found to operate satisfactorily at these high temperatures. These JFETs provide the amplification and switching functions in the hybrid circuits. While the popular bipolar silicon transistors are intrinsically limited to operation below about 300°C, compound semiconductors, such as gallium phosphide (GaP) and galium arsenide (GaAs) are capable of operating at much higher temperature.

For up to 275°C operation, prototype generic circuits, such as voltage regulators, line drivers, and voltage-to-frequency converters, are being commercially fabricated for the first time by Teledyne Philbrick, Inc. under contract to Sandia Laboratories. A sufficient, though limited, line of commercial components and fabrication techniques is beginning to be made commercially available for 275°C operation to fulfill basic circuit needs for amplification, switching and filtering. Development work is continuing toward expanding the repetoire of available devices and circuits suitable for 275°C operation. For example, Harris Semiconductor Corp. is working under contract with Sandia to develop a high temperature operational amplifier (op amp) that will be a direct functional replacement with the popular 4702 op amp except that the new op amp will operate up to 275°C.

HIGH TEMPERATURE MECHANICAL COMPONENTS

Elastomers and seals capable of withstanding temperature of 275°C and 7,000 psi in the presence of geothermal brine are required for geothermal well logging applications in seals, gaskets, connectors, cable sheathing wire insulation and wellhead pressure controls.

Test and evaluation of available materials have identified several promising candidates for use in specific components such as seals and wire insulation.

Two fluoro-elastomers, Kalrez and Viton G (peroxide cured), both made by DuPont, have shown promising results in "o" ring seals operated in geothermal brine up to 275°C and 7,000 psi.

Cables, suitable for high temperature operation, have been evaluated for geothermal operation and the major problem identified is the degeneration of the polymeric insulation. This insulation is simultaneously exposed to high temperature, pressure and hot geothermal fluid. In a combined environments test series, two promising cable insulation materials have been identified: PFA (perfluoralkoxy) teflon and TFE (tetrafluorethylene) teflon, both by DuPont. The PFA teflon was fabricated into both multiconductor and single conductor logging cable and was found to be stable up to 260°C. TFE insulated logging cable was tested up to 315°C before any evidence of degradation was exhibited.

PROTOTYPE SYSTEM DEVELOPMENT

As listed in Table 1, the temperature, pressure, flow, and caliper tools are being addressed first since they are prerequiste to almost all other geothermal borehole measurements.

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

Pressure - One of the most useful borehole measurements for well testing is a high resolution, pressure logging tool.[4] Therefore, 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. This instrument is essential in correlating well flows with pressure or fluid level changes and drawing inferences about the reservoir's production potential and its ability to transport and store fluids.

Presently, the highest resolution pressure measurements are made with commercially available quartz resonator transducers. However, the present technology of these devices is limited to operation below 125°C; also, the measurement's resolution is severely impaired by temperature gradients typically encountered by instruments moving downhole.

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. The crystal is small enough to fit inside a miniature oven which precisely maintains the quartz crystal at its optimum temperature. Using this new configuration, laboratory measurements of pressures up to 1200 psi at 275°C have been accomplished.

Flow - A high temperature impeller type flux gate transducer signal feedthrough mechanism has been constructed and field tested.

Caliper - The caliper is necessary to identify the open borehole geometry and thereby establish a basis for log interpretation 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.

BOREHOLE TEST AND EVALUATION

On November 14, 1978, a prototype borehole temperature logging instrument and supporting electrical cable and cablehead achieved successful operation down to a total depth of 2452 meters (8045 ft) and up to the system's maximum rated temperature of 275°C in a Union-owned geothermal well.* This field test represents the highest operational temperature achieved for an uncooled, non-dewared borehole instrument package equipped with active electronics.

The downhole system was exposed in the borehole to the maximum temperature of 275°C for approximately 1½ hours. The system also functioned satisfactorily during a subsequent 18 hour soak test at 241°C in a shallower part of the borehole. Figure 2 displays the temperature log

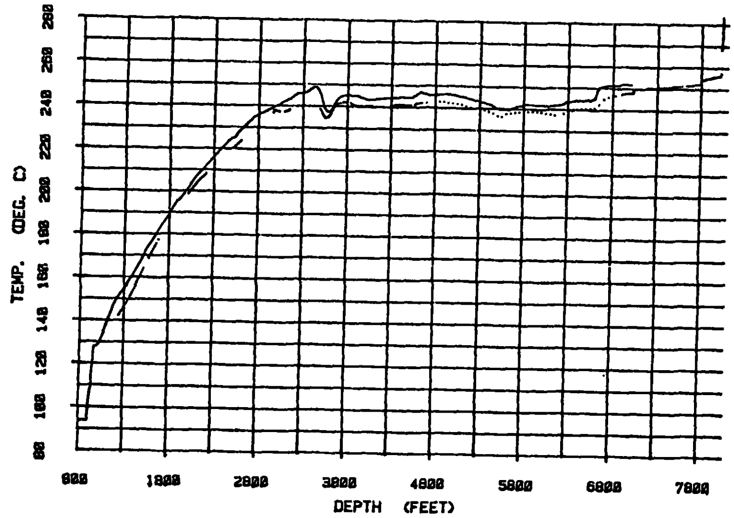

FIGURE 2

obtained. The downhole system contains active electronics developed by Sandia. This technology is based upon hybrid thick film circuitry and junction field effect transistors. The mechanical parts of the instrument were designed and fabricated by Gearhart-Owen Industries. The TFE insulated monoconductor cable was developed by Vector Cable Co., and the geothermal wellhead pressure controls were purchased from Bowen Tool Co. and upgraded by Sandia.

Although there was no flow in the well, a flow velocity tool was run and its computed velocity output checked against logging speeds. This was done to a depth

*The assistance of Union Geothermal personnel in CA and NM and of LASL personnel at GT-2, and Lawrence Berkeley Laboratories at CGEH-1 is gratefully acknowledged.

of 3023 ft. where the temperature was 221°C. Finally, a CCL unit was run to total depth (8045 ft) to get an accurate reference of depth measurements against known collar locations. The CCL functioned as intended and a maximum reading thermometer measured 282°C during this test.

Two other field tests have been conducted of the prototype temperature tool. The first test was conducted in the Hot Dry Rock Well, GT-2 of the Los Alamos Scientific Laboratory at the Jemez Mountains, NM;* a maximum temperature of 175°C was achieved at a depth of 2600 m. In another test conducted in the COSO Geothermal Well CGEH-1 at the China Lake Naval Air Station, CA;* data indicated a temperature of 189°C was achieved at 834 m. Performance of the instruments in all these tests is considered excellent.

The above experimental prototypes were field 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.

Additional field tests are planned in which upgraded Amerada gauges, originally manufactured by Kuster Co. and Geophysical Research Corp., will be run into geothermal exploration and production wells.

All the above field test activity is directed toward verifying new technology with logging service companies and geothermal producers, the ultimate suppliers and customers of that technology.

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