HIGH TEMPERATURE ELECTRONICS APPLICATION
IN WELL LOGGING

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SAND--87-2593C

DE88 001677

Commercial systems used in well logging are available for routine use at temperatures to 160°C and other hostile environment systems have advertised capabilities to 260°C. However, scientific wells, deep gas wells, geothermal wells and boreholes used for the diagnostics of in situ processes such as fire and steam floods can have borehole temperatures up to 500°C which eliminate the use of existing logging tools or borehole diagnostic systems.

In the late 1970's and early 1980's a significant effort was mounted by the DOE/Geothermal Technology Division to develop and commercialize high temperature logging systems. Results of this effort are summarized in the proceedings of several meetings^(1,2,3) and a Source book.⁽⁴⁾ In the early 1980's, prototype components were available that could be used in logging tools for use at 250-300°C. However, in the 1980's the need for such high temperature systems was insufficient for suppliers to routinely provide these components.

Looking ahead at future high temperature logging applications, we recognize that electronics are only one part of a logging system, and all aspects and hardware must be compatible with high temperature use. Therefore, an overall system design must consider:

1. the market needed to assure supply of specialty components,
2. measurement needs in terms of time, temperature and environment;
3. the effect of temperature on the formation being interrogated; and
4. that electronics, interconnections, cables, cable heads, sensors and housings are all system components which individually or interconnected may be the source of the temperature limit.

Some of these items will be reviewed in the following paper in terms of tools used for neutron logging.

Measurement Needs

Logging measurement needs can be split into two areas, i.e., reservoir evaluation logging and production logging. The reservoir evaluation logs are run as fast as possible whereas production logging may require that tools stay in the wellbore for much longer periods of time. The neutron tools are for reservoir studies and have round-trip times on the order of 10 hours. As long as temperatures are below the cable degradation levels, high temperature problems on the tool itself can be mitigated by the use of dewars and heat sinks, a common practice in the industry. This will be discussed later for neutron tools.

Logging System

Common logging systems consists of:

1. the wellbore and its environment;

2. surface instrumentation to provide diagnostic signals, and to record and analyze the data;
3. a logging cable that transmits power and data;
4. a cable head that ties the cable to the logging tool; and
5. the logging tool which in turn consists of the mechanical housing, the sensor, and the electronics.

Wellbore and Environment: The logging tool measures a response of a perturbation in the formation, i.e., a change in the thermal neutron absorption. The design of any tool must include consideration of change to the signal (i.e., neutron scattering) due to the changing environment (i.e., temperature). Some of these calibration considerations are discussed in Section V.

Surface Instrumentation: High borehole temperatures do not effect the surface hardware but may be important in the software analysis of the data.

Logging Cable: Logging cables are a weak link in logging systems operating to 300°C. Multi-conductor cables using teflon TFE are stated for use to 320°C. However, electrical failures above 300°C are common. Furthermore, mechanical failures of the armor are often related to the corrosive environment of a hot borehole.

Steel sheathed, MgO insulated cables are available for use to 600-800°C. The high capacitance of the MgO leads to high power loss and low bandwidth and the small size of the conductors limits power transmission. Field-compatible cable heads and take up systems are not standard, and problems caused by work hardening the sheath during reeling have not been addressed.

A possible future solution is the use of metal sheathed, fiber optics. Chevron⁽⁵⁾ has recently tested optic logging cables at low temperature and metal sheathed fiber optics have been tested to 400°C. Many technical problems need to be solved before considering optics systems for high temperature use but this is obviously a trend for future logging.

Cable Head: The cable-to-tool connection made in the field continually presents the major reliability problem in high temperature logging. Cable heads often rely on elastomer seals and elastomers are unstable above 250-300°C. Other concepts, as metal-to-metal seals, are possible at higher temperatures but present many field assembly problems.

Logging Tool: The structural case of the tool can be made of high temperature, corrosion-resistant materials, and usually does not limit the design.

Transducers and Sensors: Transducer and sensor limitations obviously depend on the measurements being made and if the sensor can be protected in the housing. In neutron tools, the generators and the sensors can be located in the housing as long as that housing has no high cross section elements.

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This work was supported by the US
Dept. of Energy at Sandia National
Laboratories under Contract No.
DE-AC04-76DP00789

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Electronics: Electronics limitations are discussed below.

High Temperature Electronics

Active and passive devices plus interconnections are the three components of an electronic system. Fundamental limitations automatically put a temperature cap of 300-350°C for organic materials (insulators, coatings, elastomers, adhesives, etc.) and 250°C for silicon devices.^(6,7) Consequently, most commercially available components limit systems to below 275-325°C.

Interconnections: The most commercially and technically available high temperature interconnection systems use hybrid, thick film technology for putting conductors, bonding pads, etc., on alumina substrates. Production of thick film systems require firing at 800-1000°C and consequently the circuits are inherently stable. Wire or ribbon connections can be made by welding or brazing to provide stability at high temperature. A thick film circuit operating at 400°C was recently proposed as a gas sensor.⁽⁸⁾

If maximum temperatures are limited to the 250-300°C range, polyimide-glass printed wiring boards can be used with high temperature solders or brazes.

Passive Devices: Discreet capacitors, resistors, and inductors almost always include organics and low melting point materials for ease of assembly. However, proper design and material selection can provide components usable at 250-275°C. Some of the problems and solutions are mentioned for these components in the Source book.⁽⁴⁾

The thick film technology can also provide screen printed, high temperature resistors and capacitors.

Active Devices: Semiconductor components currently limit the high temperature potential of electronic systems. Although junction isolation can be built into devices, leakage and recombination rates increase rapidly with temperatures. Silicon devices generally fail above 250-275°C because of leakage. Zipperian^(6,7) recently reviewed the temperature limitations of active devices and indicated that experimental GaP devices have functioned satisfactorily at 550°C.

Active thermionic devices, that use principles of vacuum tubes, have been built that operate at 500-600°C.⁽⁹⁾ These require a power supply to maintain that temperature and a mechanism to remove the heat. In general, the thermionics are difficult to use with other components in high temperature environments.

Dewared Systems

In considering technical and commercial aspects of building high temperature logging tools, we are limited to 275-300°C operation by the cable/cable head problem. For lithologic logging, the best system appears to be the TFE logging cable connected to a dewared logging tool. Thus, commercially available components can be used. The length of time at temperature then depends on the insulating capabilities of the dewar, the heat sink on board the tool, and the most temperature sensitive electronic component.

Efficient head sinks can be made by utilizing the latent heat of the solid-liquid transition of an appropriate alloy. A eutectic alloy of 55% Bi and 45% Pb is attractive for neutron tools due to its low thermal neutron absorption cross section. Its melting temperature is 125°C and the enthalpy charge of this transition is 712 cal/mole.

The limitation of the cable can be removed by using a self-contained downhole tool with power, data processing

and storage, and timers. The tool would be lowered on a structural, nonelectrical cable. This concept was used to measure temperature and pressure in a geothermal well over 300°C; the tool was designed to operate for ten hours at 400°C.⁽⁸⁾

Calibration Considerations

Environmental Effects: One difficulty is presented by the thermal dependence of the scattering and absorption properties of rock and fluid materials. In regard to fluids, one must take into account the decrease in density caused by expansion effects. Such a correction requires a knowledge of the borehole temperature.

Another problem is that the energy of a "thermal" neutron at 300°C is about twice that of a thermal neutron at 10°C. For many crustal elements, i.e., O, Ca, Mg, Si, C, etc., the absorption cross section decreases as energy^{-1/2}. If all elements behaved in this manner, the corrections would be straightforward. However, some trace elements with very large microscopic cross sections do not possess an energy^{-1/2} behavior and they may preclude a simple interpretation of log data.

Temperature effects such as those discussed above are difficult to explore experimentally. Computer simulation codes are available which can be used to evaluate the calibration problem.

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