Identification to Future Research for High Temperature Instrumentation for Geothermal Applications

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Abstract

This work reviews the critical improvements needed to enhance high temperature (HT) geothermal instrumentation towards reliable characterization of deep subsurface geothermal wells and reservoirs. To close the current technology gap R&D efforts must be rationally prioritized; Sandia National Laboratories interviewed multiple experts from geothermal industries who have firsthand experience with evaluating the geothermal subsurface, including Original Equipment Manufacturer (OEM) geothermal instrumentation developers and service providers for well evaluation. To support the rigorous advancement of geothermal energy production as a global renewable energy resource, we identify four priority R&D needs: HT embedded electronic system, HT high pressure harsh fluid sensing hardware, HT means for communications, and HT energy storage.

Key words

Geothermal, Technology Gap, High Temperature, Electronics, Instrumentation

I. Introduction

Geothermal wells, the core of every geothermal plant, require large investments to support drilling, stimulating, and ongoing maintenance efforts. Over the decades, high temperature (HT) instrumentation tools have been developed to characterize the condition of the wells and their fracture networks. In most cases, the tools are embedded with electronics and sensors that collect data and then either store the data within the tool or transmit the data back to the surface in real time (Figure 1).[1] However, to operate reliably in harsh geothermal conditions, the tools must be hardened for operation at high temperatures (200 °C to 320 °C), high pressures (≥ 3,000 psi), extreme well depths (5,000 to ≥ 10,000 feet), and harsh chemical conditions (high or low pH). For example, for the great depth measurement, a local embedded electronic system (EES) is required within the HT instrumentation tool to capture/process the sensors' low signal. Likewise, to mitigate corrosion or other degradation in harsh fluids, the sensors and the tool housing must be made of exotic materials.

Considering the harsh conditions and the various measurements required, it was decided to conduct a survey with industry that is directly familiar with the various challenges to HT instrumentation tools and those that use the hardware to capture the data. This compiled set of surveyed information will promote the growth of new technology to enable effective and economical means to making required measurements of the system. The information collected from industry has been compiled and summarized into the following sections.

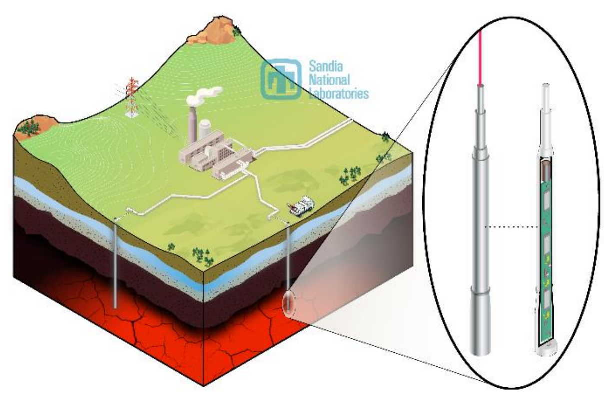

Figure 1: Illustration of Geothermal subsurface instrumentation emplaced in a multi-thousand foot well.[1]

II. Enhanced Geothermal System

A major challenge identified is the growing need for long-term measurements in the geothermal well (under this study, short-term measurements will be defined as measurements that require less than 24 hours and long-term measurements for over 24 hours). This is primarily due to the necessary growth of enhanced geothermal systems (EGS). Typically to build a geothermal plant, a natural occurring geothermal system requires three major elements for a geothermal plant to generate electricity: heat, fluid, and permeability. These systems are known as a hydrothermal system. For hydrothermal systems, majority of the time short-term measurements are viable. Considering this, subsurface instrumentation can use low temperature electronics that are emplaced within a flask (a pressure housing with a vacuum liner and reflector that slows down the propagation of heat to the electronics). With the flask, it enables the tool and service providers (industry that surveys a well) to evaluate a well for multiple hours with economical instrumentation tools.

Unfortunately, it is challenging to find a region within the earth that meets all three requirements, specifically permeability in the rock. This is where EGS can create a human-made ‘permeability’ creating the necessary flow of fluid between the injection and production geothermal wells. To realize Geothermal Technologies Office (GTO)’s goal of significantly reducing cost of EGS by 2035[2], the need for novel technology long-term high temperature instrumentation is imperative, and so is the need for creation and stability of human-made ‘permeability’. This means that the electronics will have to be operable at elevated temperatures of 250 to 320 °C.

II. Challenges Identified

With the growing need of subsurface instrumentation that operates at high temperature for long-term, multiple industry challenges have been identified in this study. For long-term subsurface tools there are four primary categories of focus that need further improvement, this includes EES, sensing, local energy storage, and communications to the surface.

A. *Embedded Electronic Systems*

The major electronics components that were identified to be crucial include the microcontroller, high resolution analog-to-digital converter (ADC), non-volatile memory, and voltage regulators. Some IC solutions do exist in the market that are rated for 225 °C and can operate at 250 °C or even 300 °C, though the components will begin degrading. For long-term 300 °C operation, the service providers, will be required to replace the EES constantly, thus making it non-economical. There is a great need for EES that can operate reliably and continuously at 300 °C for longer than one year.

B. *Sensing Measurements*

Several types of sensing measurements have been identified under the study that are required to operate ≥250 °C. The list includes pressure, fluid chemistry, high finger count caliber (tool that mechanically measures the diameter of the well and surface build up), orientation, magnetic single/multi shot (measures inclination), mapping fractures, feed zone rate, scale, corrosion, and cement/rock integrity. These various sensing needs would utilize HT pressure transducers, solid state chemical sensors, gyroscope, magnetometers, accelerometers, piezo transducers, geophones, spinner, or hydrophone. Most of the sensors would be outside the tool housing thus directly exposed to the heat, pressure, and harsh fluid of the system. Optical-based hardware has been identified as a potential emerging technology due to their recently demonstrated ability to operate at high temperature and mitigated sensitivity to hydrogen darkening (an effect of hydrogen in the well attacking the doping within the optical fiber severely attenuating the optical signal). Optical sensing has therefore been recognized as a fantastic approach for pressure, temperature, or acoustic measurements, however, electronics are still required for the many other measurements identified above.

C. *Energy Storage*

When using a memory tool, energy storage (battery or high-density capacitor, e.g. high voltage capacitor or super capacitor) is required within the tool to continuously record data from the sensors. As of 2024, there is no commercially available energy storage products that can operate above 200 °C. Current energy storage devices even limit the operating time of short-term instrumentation tools. There is a need for energy storage devices that can operate reliably long-term ≥250 °C.

D. *Communications*

The survey identifies a strong need for real-time data for the customer. Real-time data enables customers to make quick decisions based on the dynamic performance of the well, especially when identifying the connection zone between the injection and the production well. The primary means of transmitting information from the instrumentation tool to the surface is a wireline with a single conductor or more, and rarely with fiber optics. As identified in section II.B., optical sensing hardware is a promising emerging technology in the field of geothermal instrumentation tools. Consequently, there is a need for cables that contain HT non-hydrogen-darkening optical fiber, and in some cases, a combination of conductors in parallel with the fiber.

Typically, wirelines use polytetrafluoroethylene (PTFE) as the insulator for the conductor for its ability to continuously operate at around 260 °C. However, PTFE enters a liquidous state when operating above 260 °C, making it not viable for wells operating at >300 °C well. Additionally, these cables are wrapped in a wire rope to enhance their strength (required for it to be able to hold the weight of the tool that 100 – 300 lbs). The cable then transitions to the instrumentation tool via a cable head. Since the cable uses a wire rope, thus a non-continuous circle on the cable diameter, there is not a good way to mechanically seal between the cable and cable head, thus allows for a leak path. To mitigate electrical shorts, the cable head is filled with a HT grease which is known to dissolve over time in the harsh HT geothermal fluid, thus limiting the cable's long-term operation.

To summarize, there is a need for a HT wireline with conductors or HT non-hydrogen-darkening fibers or both within a cable that uses a ≥300 °C dielectric material that can be mechanically sealed with a cable head, without the need for HT grease to enable long-term operation of the cable.

III. Conclusion

To direct ongoing research efforts, Sandia National Laboratories and the Department of Energy Geothermal Technologies Office are working to identify -crucial and urgent challenges associated with geothermal subsurface instrumentation. This study identifies long-term HT instrumentation as a growing need for effectively evaluating EGS. Four primary categories require further technological advancements to meet this need. These include EES, sensing, energy storage, and communications. Timely realization of EGS is crucially dependent on Advancements in these areas. To add to this study, Sandia has identified the direct electronic component required for future geothermal EES. This includes the need for non-volatile memory that can function reliably at or above 300 °C, >=16-bit resolution with >= 100kHz sample rate ADC, 40 MHz modern architecture microcontroller, charge-mode amplifier, and a 1-amp voltage regulator.

Along with the technical challenges addressed, there is also the challenge with the continuous supply of the identified hardware. Although several HT technologies had become available in the market, most of these had not met -the necessary demand to have a marketable continued supply, leading to them fading away. Effective long-term solutions to the challenges identified in this paper are crucial to reduce risks for HT instrumentation tool developers, service providers, and to the success of geothermal technology.

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