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Geothermal High Temperature Instrumentation Applications

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Abstract

A quick look at the geothermal industry shows a small industry producing about $1 billion in electric sales annually. The industry is becoming older and in need of new innovative solutions to instrumentation problems. A quick look at problem areas is given along with basic instrumentation requirements. The focus of instrumentation is on high temperature electronics.

DISCLAIMER

Background Information

The Geothermal Market

Geothermal energy is not a large industry. However, it's larger than most people realize. In fact, approximately 5% of the electric power generated within the United States is green geothermal energy. In dollars, that's 2,300 megawatts of geothermal power producing 14-17 billion kilowatt-hours per year of electricity worth approximately $1 billion annually, [1]. It's believed that a remaining untapped potential exists for meeting 25% of our nations energy needs. Unfortunately, geothermal power cost ~2 cents a kilowatt more than gas turbines burning natural gas. These units are inexpensive and are now available in units up to 500 MW. This cost difference and reduced government subsidizing has caused a slow down of geothermal power development in the United States over the past few years.

Overseas, geothermal power has fared better in resent times with increased plant production in the New Zealand, Philippines, Indonesia and Japan. Presently, about 7,000 megawatts of geothermal electric power is generated within some 20 countries.

Typical Geothermal Well

Although, geothermal wells very in size, shape and temperature the table below covers the vast majority of wells.

Geothermal Production Wells:
Depth: few hundred feet to 12 Kft
Temperatures: 200 to 315° C (180° C is considered minimal for electric power generation.)
Pressure: steam wells are < 200 psia and fluid dominated wells are < 10 Kpsia
Diameter: 12 to13 inches near surface and 6 to 12 inches at depth
Well Cost: $700K-$3,000K

Each power plant is dependent on approximately five to ten production wells to produce 55 megawatts of electricity, [2]. **In fact, the cost of wells is commonly 40 to 70% of the cost of the power plant.** Geothermal wells represent a large investment by the power plant operator.

Chicken and The Egg Problem

The chicken and the egg problem holds true for geothermal logging instrumentation. The operator/owner will not pay for a well log unless the service has been proven valuable or useful. The logging instrument developer can not afford to build a tool unless there is a market.

The adaptation of oil/gas downhole tools and technology into geothermal is limited by the higher temperatures. There is also a significantly different set of logs that are useful in the geothermal resource evaluation and management. Oil/gas wells are located in predominately sedimentary formations while geothermal wells are more often located in hard crystalline rock normally of volcanic origin.

There is starting to be an adaptation of the high temperature electronics developed for geothermal in high temperature oil and gas drilling and production. But these wells are still not normally as hot as the geothermal need. This oil and gas interest will increase the market for the development of higher temperature tools.

This instrumentation development problem is starting to resolve itself as well owners are seeing a loss in production because of aging wells and falling resources. Most of the US geothermal power plants were built following the oil embargo of the early 1970's. Many of these resources are being depleted. In this case, plant operators need more information to better understand and manage the reservoir.

Many of the geothermal well fluids are very corrosive. The wells contain CO_2, H_2S, chlorides, oxygen, water and high temperatures--almost the definition for a corrosion cell. There is an increasing need to monitor the downhole casing and cement conditions.

Operational questions such as:

- Production questions (initial well test and during the life of the well)
  - Flowing contribution of zones.
  - Temperature of production zones. (a survey and monitoring role)
  - Is colder water flowing downward in the well?
  - Is this downward flow affecting the reservoir?

- Well tubulars condition
  - State of general corrosion in the well casing.
  - What is the condition of the well?
  - Are there leaks in the casing?
  - Is there pitting in the casing?
  - Has shifting formations deformed the casing?
  - How badly is the casing damaged from the shift?
  - Is the well leaking due to the deformation?

- Completion evaluation / cement
  - What is the condition of the cement to casing bond?
  - Is cement breaking away from the steel casing?
  - Is the cement itself being damaged by $C0_2$?

Inspection and monitoring work will grow in importance with the aging geothermal fields.

<u>The Goal of Sandia's Geothermal Research Department is:</u>

Designing a set of logging tools to answer the above questions and others is a goal of Sandia National Laboratories. Meeting this objective will require the continued development of high temperature electronic systems suited for drilling and logging applications. More than simply high temperature electronics but a complete system solution is required.

Sandia is also active in the development of additional logging methods that are not presently a normal part of the geothermal logging effort. Sandia looks to develop high temperature tools that have yet been proven as useful logging systems due to the fact that these tools have not existed. In this way the DOE funded programs are attempting to overcome the chicken-and-the-egg problem. Development of the high temperature spectral gamma ray log and the high temperature borehole televiewer are two examples.

At present, Sandia uses a Dewar-flask to protect electronics and sensors from the temperature extremes with the well bore. The flask is a double-walled evacuated housing protecting the internal components for approximately 10 hrs within a 300° C well.

Most commercial tools use heat shields to protect the electronics and batteries from the downhole temperatures. This requires that the tools be cooled between uses.

Tools Presently Under Development	**Primary Difficulty for HT Operation, Long Term**
Pressure/Temperature/Spinner Tool	Bearings for spinner
Natural Spectral Gamma Tool	NaI Crystal Limited to <150° C
Sonic Flow Tool	Signal Processing Electronics
Core-Tube-Data-Logger	No major limitation
Additional Tools Under Consideration	
Sonic Televiewer	Signal Processing Electronics
Casing Inspection Tool	No major limitation

There are three Types of Geothermal Instrumentation

<u>Logging Tools</u>

Logging tools are instruments deployed within the geothermal well for gathering information. They are only temporarily exposed to the high-temperatures while operating off of a wire-line or slick-line cable.

Wireline tools: The wire-line supplies electrical power along with data communications. However, cable materials limit wire-line operation to 275° C.

Memory tools: Above 275° C, a slick-line (solid steel) cable works best and the tool must then operate off of internal power supplies, primarily batteries and electronic memory. All of the logging data is record in on-board memory for down loading after the tool is retrieved from the well.

At present, most geothermal logging tools are encased within Dewar-flasks heat shields to hold off external temperature for as long at 10-15 hrs. The Dewar cost is between $4K and $18K.

The required minimum operational life of electronics inside the logging tool is the shortest of the three instrumentation applications. There are also problems with the mechanical systems for these downhole tools as well. Moving seals for these temperatures do not exist. The expected life of a logging tool is about 25-50 logs. Damage and downhole loss, take their toll. The geothermal well is a very hostile environment, besides elevated temperatures, the tools may be physically damaged or otherwise become lost within the well never to be seen again.

Although oil and gas logging tools make use of many of sensors, geothermal logging requires at least temperature, pressure, flow and wellbore diameter (caliper) measurements. Temperature is normally an RTD calibrated to be within one degree Celsius. Pressure is primarily used to detect fluid-steam interfaces and accuracy of a few tenths of a PSI is acceptable. The measure of flow currently uses a small turbine spun by the passing fluid. The rate of spinning provides an indication of fluid flow. Accuracy is limited, but variations in the spin rate are features that are of interest. Caliper measurement of the wellbore diameter would aid the utility of the flow measurement. This measurement is combined with the flow measurement and also is needed to monitor scale build up within the well. Calipers sensors still need development.

Requirements:
Minimum operating temperatures: 300° C
Minimum survivable temperature: 350° C
Minimum operational life at elevated temperature: 500-1000 hrs
Temperature cycling: Very High, cycles for each 10 hrs of operation
Required measurements: Temperature, pressure, flow and caliper

Measurement-While-Drilling Instruments, (MWD)

MWD instruments are used extensively in oil/gas directional drilling. MWD systems were first developed for directional drilling information, such as drift angle, azimuth and tool facing direction.

These instruments are housed within the drill pipe, providing a number of measurements to guide the driller. These instruments must be highly reliable because of the high cost of drilling. (Daily drilling operations cost from $20-100K per day.) These instruments must be very tough, enduring the vibration and shock of continuous drilling. The long-term temperature exposure has prevented development of MWD systems for geothermal drilling. It is only possible to use MWDs in geothermal wells by limiting their use to the upper cooler sections of the well or cooling the well with water.

The use of MWD steering tools for geothermal exploration and field development has the potential of saving millions of dollars to the industry. This would allow greater freedom in the directional design of the wellbore and will permit the drilling of increased numbers of multi-lateral wells in geothermal production wells.

The MWD instrument primarily needs to measure hole inclination, hole azimuth direction and the direction the tool is faced. Other measurements are being included such as resistivity, natural gamma, neutron density, and a great variety of other logs that are already common to the oil and gas logging at more conventional temperatures. Some drilling measurements such as downhole weight on bit, torque, vibration levels, axial, lateral and rotary accelerations have also been incorporated into the measurement group.

There is drilling directional information, drilling parameter information and formation logging information being taken at the same time. There is a great need for a faster data link between the bit and drill operator. In this way the drill operator can obtain information in a timely fashion.

Requirements:
Minimum operating temperatures: 225-275° C
Minimum survivable temperature: 275° C
Minimum operational life at elevated temperature: 2000-4000 hrs
Temperature cycling: Lower than logging tools, cycles for each 2 to 14 days of operation for bit changes
Required Measurements:

- Environmental information: Temperature, pressure.
- Directional information: Well azimuth, inclination and tool facing direction.
- Formation logging information: Resistivity, gamma and the potential all of the logging concepts currently measured in oil and gas.
- Drilling information: Downhole bit weight, torque, axial, lateral and torsional accelerations.

<u>Situ Well Monitoring Equipment</u>

Geothermal plants normally operate from a matrix of wells. Several wells are producers while another set of wells are the injectors. Producers, as can be implied, are the source of hot steam and/or fluid for producing power. The injectors return cooled fluid back in the reservoir.

At present, many plant managers, monitor temperature and pressure at the surface with permanent monitoring equipment. Some managers pay to have a temperature, pressure and flow survey performed once a year inside each well. This survey costs about $4-12K. One manager was willing to pay $20-30K for a temperature in situ system which could survive up to 4 years.

Plant owners would enjoy the ability to deploy monitoring systems within each well while producing power. Some of the important measurements would be temperature, pressure, HCL levels and flow. Here again, this is a new area of development and the most difficult. Plant instruments need very long service lives at elevated temperatures and continuous vibration.

Requirements:
Minimum operating temperatures: 250-315° C
Minimum survivable temperature: 325° C
Minimum operational life at elevated temperature: 4 years
Temperature cycling: Constant operation at temperature
Required measurements: Temperature, pressure, flow, and various chemical sensors

Meeting Geothermal Instrumentation Needs

Sandia through the Department of Energy is continuously looking for industrial partnerships that can benefit the geothermal industry. At present, Sandia has a program for developing and evaluating high temperature electronics and sensors. The program is ambitious targeting a full system solution for operating logging instruments to 300° C without the normal heat shield flask.

Silicon-On-Insulator (SOI) products being developed at Honeywell offer a significant step for completing our goals. These devices comprise a set of electronic components needed for the heart of a logging tool deployed within geothermal wells. But to complete a full system solution requires additional development. Although this paper is focusing on geothermal applications, some areas needing development for high temperature electronics are out lined below.

Table: Short list of future development work

Device	Present Limitation	Present Solution for 300° C
Digital Clocks	Limited to ~250° C	LC oscillator, poor performance
Voltage Ref.	Limited to ~250° C	None
Batteries	Limited to ~150° C	Self heated molten salt batteries requiring addition insulation
Inclination Sensor	Limited to ~150° C	None

High Accuracy Pressure Sensor	Limited to ~150° C	Reduced accuracy strain gage transducers available

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