

Two Sub-Awardees

Frequency Management International,
Huntington Beach, CA
Electrochemical Systems Inc,
Knoxville, TN 37922

Well Monitoring System for EGS

Project Officer: Golden Co.

Total Project Funding: \$2.2M

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Randy Normann

Perma Works LLC

EGS1 Track 3

Project Objectives

- The startup of an EGS power plant will require constant monitoring of the production and injection wells to track changes in the newly stimulated reservoir. Existing technology requires a full time logging truck and crew on site at each well using time limited heat-shielded geothermal logging tools.
- This project targeted a Pressure/Temperature downhole monitoring system using HT electronics developed for the commercial aircraft industry. Impact of this research:
 - The system can be deployed during stimulation, well production testing and initial well power plant production saving on logging crews and equipment
 - The system data greatly improves reservoir tracking to optimize EGS power production or to head off complications
 - The measurement rates are programmable from the surface so that user can focus events as pressure build up and fall off during well stimulation
 - Basic tool design will support future sensors as solid-state flow measurement, vibration monitoring or future aircraft engine sensors benefiting geothermal
 - Project objectives are focused on making ALL internal system components and materials commercially available in order to support the PW well monitoring tool and future geothermal tools

- Perma Works started with a basic 250C design developed at Sandia Labs by myself and Joe Henfling. However, this design had significant performance issues above 250C.
 - Electronic amplifiers drifted with time and temperature
 - The frequency communication circuits simply did not work at higher temperatures
 - Ceramic circuit boards were hand made
- Our approach was based on years of working with many HT companies involved with HiTEC (High Temperature Electronics Conference). The technology was already there.
- Perma Works worked with these companies to grow the market for all high-temperature electronics applications.
 - No commercial limitations were placed on them
 - They were free to use our data and geothermal application for marketing
 - In short, all parts of the PW Tool are commercially available to support the geothermal industry
 - Under this grant, we had 5 commercial success outside of the geothermal tool:
 - 2 HT ICS, 1 Digital Clock Oscillator, 1 HT Well monitoring cable, HT IC Test Fixtures

- This project tackled 8 major objectives listed below. Each of these topics could fill a 20 minute presentation.
- *1. Commercial release of a 300C, 40K psi analog tool for real-time pressure and temperature monitoring EGS wells.*
 - Outcome: Our greatest accomplishment, Perma Works has released a barefoot 275C tool with operation up to 300C and 30K psi for real-time pressure and temperature monitoring during hydraulic-fracturing and reservoir. A reduction in reservoir pressure rating was done for two reasons: The highest pressure sensor at 300C we could find was 30K psi from Paine Electronics. Discussions with well stimulation experts like Susan Petty suggested that geothermal hydraulic-fracturing is normally below 20K psi.
- *2. Electrochemical Systems Inc. (ESI) will start small scale production of high-temperature rechargeable sodium-sulfur batteries.*
 - Outcome: ESI designed and demonstrated a rechargeable, safe battery, up to 250C. ESI worked at setting up a manufacturing process for sodium-sulfur batteries for 3 years under this program. However, they were never able to find a solution to a gas leak at the top of the battery.

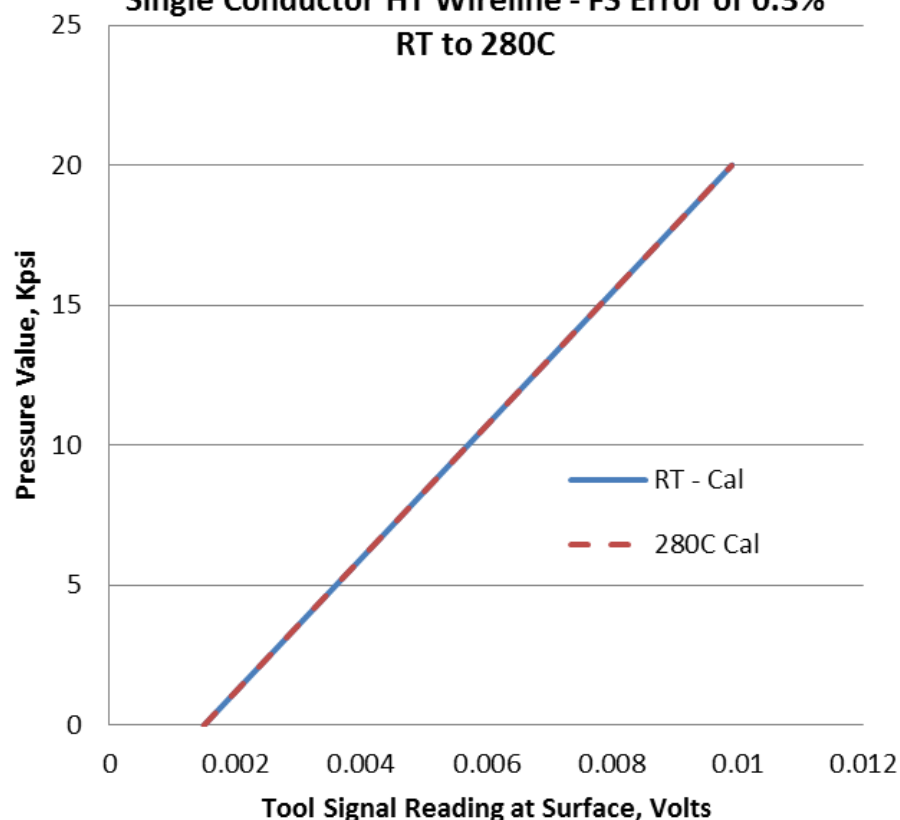
- *3. Perma Works will commercially release a fully digital 250C PT-Flow tool based on the Sandia HT SOI chips with new HT SOI parts coming from the NETL Deep Trek project.*
 - Outcome: A complete HT SOI digital circuit design has been completed. This work aided in the commercial release of the Honeywell EEPROM. The EEPROM IC is an electronically programmable device which can store either microprocessor execution code and/or well data. The EEPROM IC is a major high temperature technology enabler for the geothermal industry
- *4. Eclipse NanoMed will start commercial production of a new type of high-temperature large value ceramic capacitor for reliable operation at 300C.*
 - Outcome: Eclipse NanoMed was successful at producing a 300C rated capacitor. These capacitors were tested in the first set of prototype electronics for the 300C analog tool and at testing conducted by Sandia National Labs.
- *5. Draka Cableteq to complete testing of their upgraded 250C to 300C wire/fiber optic ¼ tubing for permanent geothermal well monitoring.*
 - Outcome: Draka Cableteq and Perma Works worked to develop a commercial version of wired ¼ inch tubing for permanent geothermal well monitoring. A custom 300C cable was built and successfully oven tested at 400C. Today, 260C wire (& fiber) tubing is commercially available from Draka Cableteq. Draka Cableteq also received a second DOE Geothermal Technology grant to continue development of combination fiber optic (DTS) and electrical wires for geothermal well monitoring. Draka Cableteq was the first successful deployment of system combining fiber optics and high temperature electronics for pressure measurements in a geothermal well.

- *6. Frequency Management International Inc. will start production of a family of 300C digital crystal clocks needed for digital tool electronics.*
 - Outcome: FMI was successful beyond expectation. They were able to solve the metal contact issues with the crystal which many thought was impossible. FMI built and ran crystal clock oscillators for over 2000 hours at 300C. These 300C crystal clocks are now commercially available from FMI.
- *7. Perma Works to add an optical LED driver to the PT-Flow tool for use in conjunction with fiber optical distributed temperature systems (DTS) built into Draka Cableteq cables.*
 - Outcome: Efforts at Perma Works to build an optical LED driver for use with DTS fibers failed. Perma Works' effort to focus the LED light into the fiber cable could not be thermally matched over temperature. Testing of off-the-shelf LEDs for 250-300C was successful which suggests other methods might work. Perma Works contracted with fiber experts at MagiQ to study this problem. They generated potential solutions which were outside this project's budget.
- *8. Perma Works to write feasibility report on moving HT SOI 300C electronics for permanent well monitoring and flow control for EGS power production.*
 - Outcome: Under this grant, Perma Works has developed a much keener understanding of the technology challenges for building monitoring and flow control systems for future EGS power production. A report on this topic has been completed and is available from DOE.

- Self Compensating Design

Calibration of Pressure over Temperature

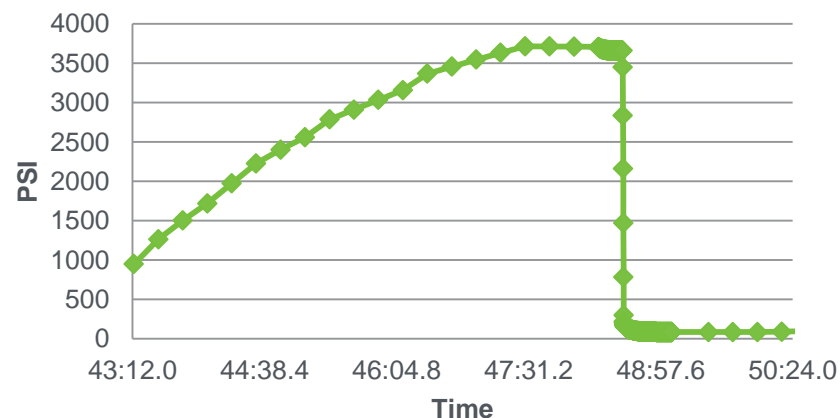
Single Conductor HT Wireline - FS Error of 0.3%
RT to 280C



- Operator Controls the Tool Downhole

Pressure Data Lab

HS Capture of Fall Off, 10sps

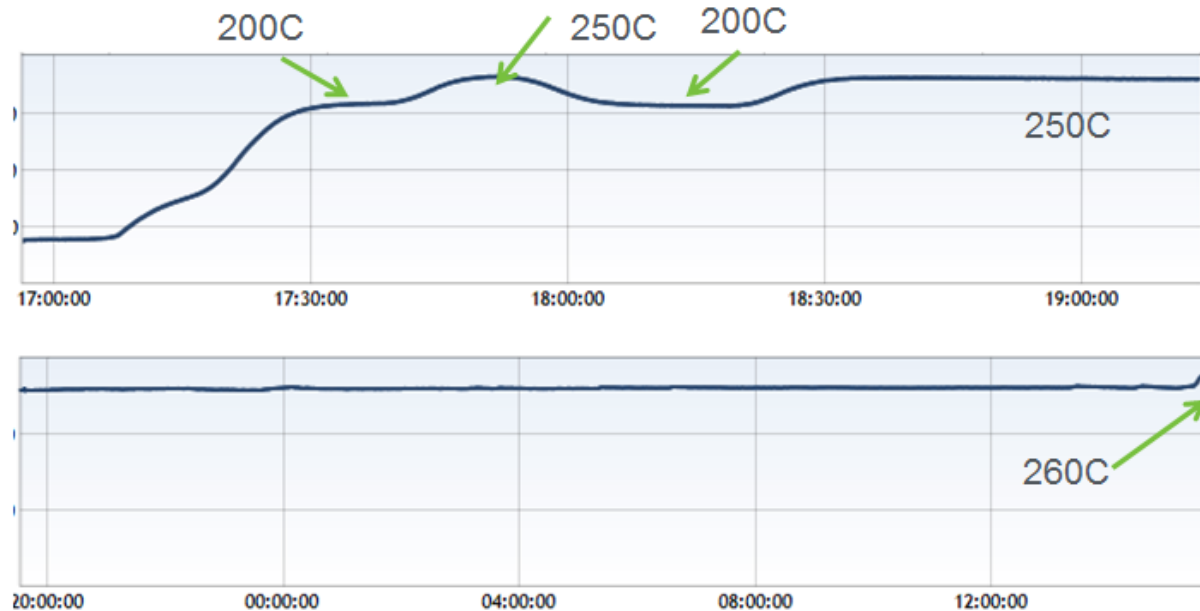


- 500C Circuit Boards

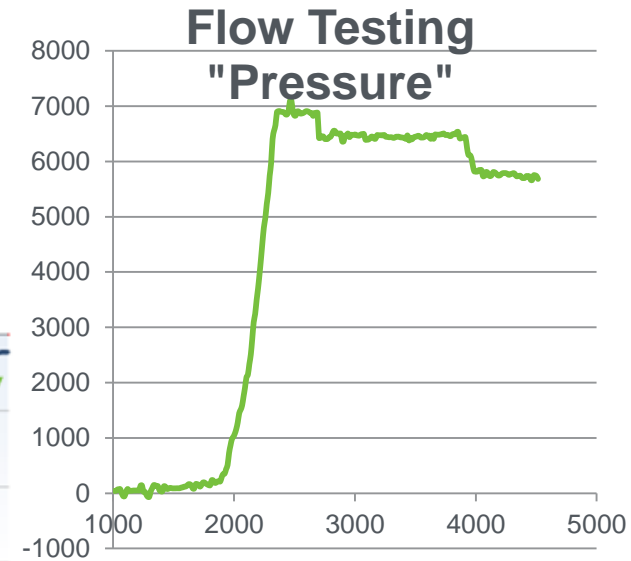


Accomplishments, Results and Progress

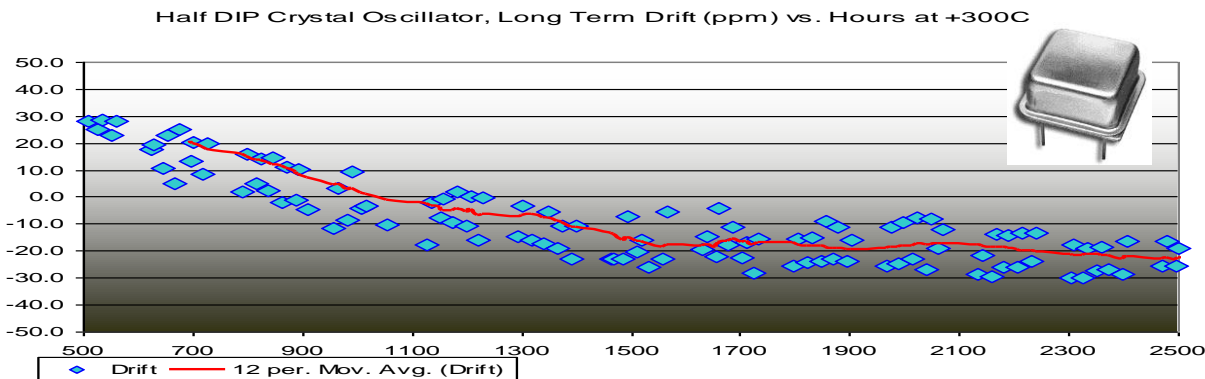
- 24Hrs well test measuring pressure at 250C/260C



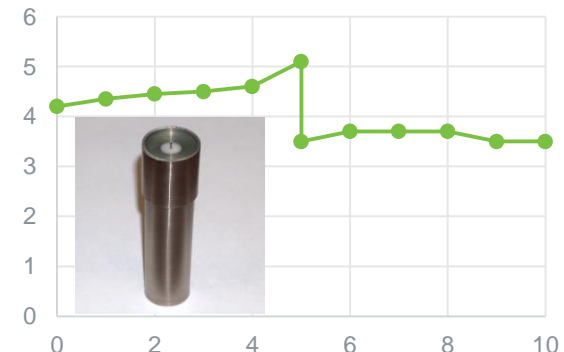
- EGS Flow Test



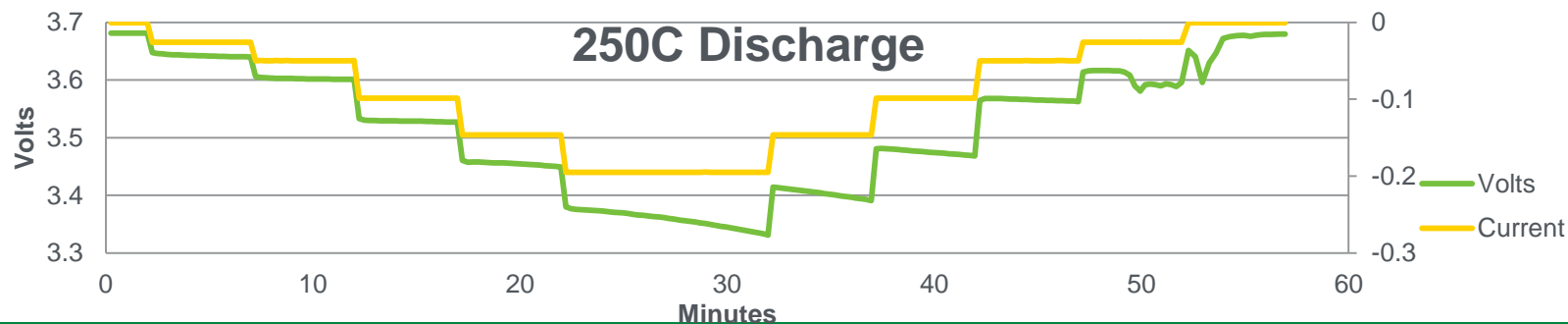
- 300C Digital Clock Oscillator



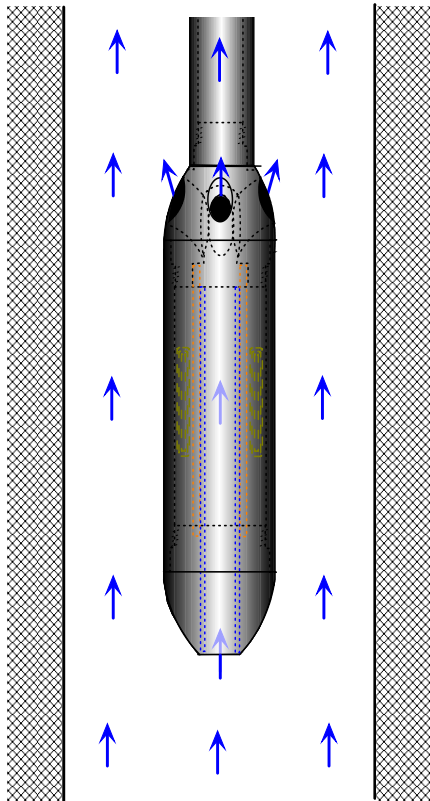
- ESI HT Battery Test
200C, 2AH, 400mA



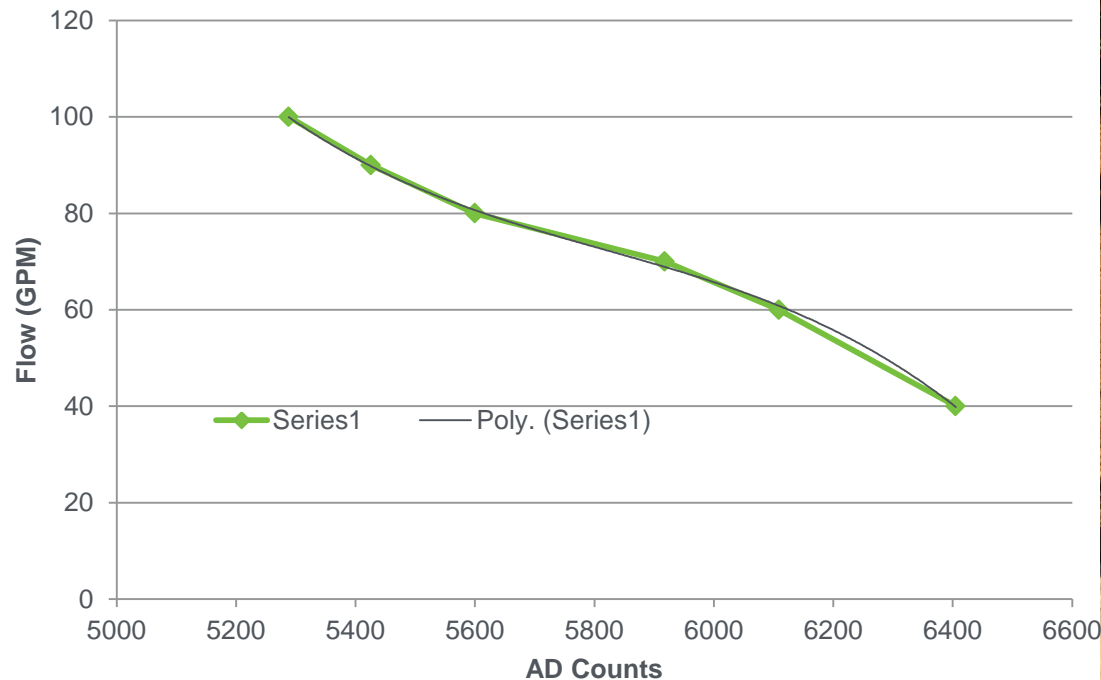
- The grant funding is over. Perma Works is still working on a number of improvements mostly directed at existing hydrothermal geothermal applications.
 - PW has a signed agreement on the development of a very low drift pressure sensor for geothermal temperatures as high as 500C. This is very real possibility given the test data at 750C.
 - PW has redesigned the surface electronics and tool hardware to make the well monitoring tool more applicable to conventional well logging while offering enhanced features of HT electronics.
 - The logging tool can stay in the well for days or weeks thanks to a new cable head currently being tested at Perma Works. This new cable head works with standard geothermal well logging cable found on 90% of industries logging trucks.
 - Tool set up time will be significantly reduced by new metal-to-metal seals being researched today. Note conventional tools often use \$200 worth of O-rings for each log!
 - PW is working on a university line of simple, low cost, high-temperature tools based on Raspberry PI surface electronics. This will enable anyone to program the tools DAQ using simple, well documented and public domain software as Python and WXPYthon.
 - PW is working with Dr. Potanin on new solid-state rechargeable batteries. These will enable flaskless memory mode tools using the PW fully digital HT SOI tool.



- One of the outcomes of this project was a feasibility report on future EGS well control systems. This report and others are available at OSTI.gov.
- Another outcome is a solid-state flow sensor for well monitoring. Existing spinners simply will not hold up more than a few hours and they lack sensitivity needed for EGS.



Downhole Flow Meter Preliminary Calibration
5/31/2013



- This project advanced high-temperature electronic technology benefiting the geothermal industry.
- Perma Works is now offering geothermal well monitoring systems supporting EGS from well stimulation to power production.
- Efforts undertaken by Perma Works provided real world insight on future technology needs for complete EGS well control systems.
- PW is still working to make this technology better and beneficial to hydrothermal geothermal and geothermal university programs.
 - Developing lower cost systems with greater flexibility
 - Working on better and lower cost metal-to-metal pressure seals
 - Working industry on improved lower drift at 300C pressure sensors
 - Continuing to support HT battery research
 - Continuing to support development of HT electronics for commercial aircraft under the SAE – Aircraft Power Systems Panel for HT Electronics.

- This slide is provided in order to allow space for any additional information/images that you would like to share with the Peer Review Panel. Insert this slide wherever you deem it most appropriate.

Optional slide- keep to one slide