Phase I Project: Fiber Optic Distributed Acoustic Sensing for Periodic Hydraulic Tests

Project Officer: William Vandermeer
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EGS Track

This presentation does not contain any proprietary confidential, or otherwise restricted information.
Objectives:

• Optimal hydraulic connectivity between wells is the key to geothermal reservoir efficiency. Tracer tests are expensive, result in operational downtime, and can only evaluate connectivity between existing perforations.

• We develop and test periodic hydraulic tests that can be conducted during operations and provide greater spatial information than constant rate or pulse injection tests.

• We develop distributed acoustic sensing (DAS) technology that will allow periodic pressure signals to be evaluated the entire length of a geothermal well.

• The combination of periodic hydraulic tests and DAS will allow for adaptive recompletion of geothermal wells which will improve efficiency and lifetime of heat extraction.
Relevance/Impact of Research

pressure sensing by DAS cable informs a new perforation which expands thermal sweep of reservoir

periodic pressure signal

original sweep

adapted sweep

DAS pressure response

DAS cable
Scientific/Technical Approach

• The project is organized into four major Tasks:
  – Task 1: Prove in the laboratory that DAS can be extended from the seismic kHz range to periodic testing mHz range in frequency. Silixa is subcontractor for this technology.
  – Task 2: Demonstrate the technology in a geothermal analog field site. DAS will be deployed in wells completed in the well-characterized Mirror Lake Fractured Rock Hydrology site.
  – Task 3: Perform numerical modeling to elucidate the sensitivity of periodic hydraulic signals to hydraulic connectivity and interpret the field results obtained in Task 2.
  – Task 4: Document, report, and publish the results.

• There is a go-no/go decision point following Task 1, prior to performing field tests.
Accomplishments, Results and Progress

- Task 1 Laboratory Tests:
  - Experiments were performed in the CSULB laboratory in which an oscillating pressure signal was sensed using the Silixa iDAS™ system.
  - The go-no/go milestone of measuring at least 100 Pa (1 cm water) pressure at periods of at least 10 min was achieved.
  - We have submitted our decision point D1 report which is under review at this writing.
- Task 2 Numerical Models
  - Hypothetical models of periodic hydraulic tests were created in COMSOL in frequency domain.
  - Sensitivity of amplitude and phase change to hydraulic structure was tested.
  - Periodic tests were simulated in measured aperture field from Altona Flat Rock.

<table>
<thead>
<tr>
<th>Original Planned Milestone/Technical Accomplishment</th>
<th>Actual Milestone/Technical Accomplishment</th>
<th>Date Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1.1 Construct Pressure Vessel</td>
<td>Completed ahead of schedule</td>
<td>11/1/2014</td>
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<tr>
<td>M1.2 Lab DAS Tests</td>
<td>Completed ahead of schedule</td>
<td>2/28/2015</td>
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<tr>
<td>D1 Lab Target (100 Pa, T=10 min)</td>
<td>Completed ahead of schedule</td>
<td>3/18/2015</td>
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Accomplishments, Results and Progress

- Task 1 Laboratory Tests:
  - Oscillating pressure was generated by moving a “slug” attached to a rotating disc, controlled by a stepper motor. High-resolution transducer measured pressure.
  - The iDAS system measured laser backscatter as a function of strain rate along a coiled 100 m cable at 0.25 m intervals.
  - iDAS reports longitudinal strain in the fiber optic as nm/m. Strain must be converted to pressure through physics (i.e. Poisson ratio) and calibration.
Task 1 Laboratory Tests continued:

- Strain is measured in frequency domain. A Fast Fourier Transform (FFT) algorithm is used to extract strain amplitude over a range of frequencies.
- FFT amplitude and transducer amplitude show a power-law relationship which is linear for short periods of oscillation. At larger periods relationship becomes poorer and regression degrades.
- More work with signal processing and instrument tuning is necessary to improve long-period response.
Task 2 Numerical Models

- COMSOL Multiphysics was chosen as a modeling platform for its ability to work in time and frequency domain and to couple flow, heat, and geomechanics.
- Simulations of periodic pressure propagation were developed for the frequency domain and tested for various structures of permeability.
- Phase shift appears to be more sensitive to heterogeneity in permeability (and therefore connectivity) than amplitude.
Accomplishments, Results and Progress

- Task 2 Numerical Models
  - Simulations in a single fracture with a realistic aperture distribution. Aperture derived from GPR imaging for previous EERE project.
  - Sensitivity studies show
    - Phase more sensitive to heterogeneity than amplitude
    - Higher frequencies are best for discerning local connectivity
    - Frequency can be use to “tune” hydraulic test to scale of interest
## Project start October 1, 2014

<table>
<thead>
<tr>
<th>Milestone or Go/No-Go</th>
<th>Status &amp; Expected Completion Date</th>
</tr>
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<tbody>
<tr>
<td>Task 2: Prep field equipment/tracer</td>
<td>Underway but need to pass decision point to purchase equipment / supplies</td>
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<tr>
<td>Task 2: Field hydraulic/tracer tests</td>
<td>July 15-Aug 8, 2015: collaborating with Cornell on tracer work at Mirror Lake Fractured Research Site</td>
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<td>Task 2: Complete field DAS testing</td>
<td>8/15 completion: will monitor six bedrock wells and use flexible liners to observe individual fracture zones</td>
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<tr>
<td>Task 2: Interpret field results</td>
<td>1/16 completion: signal processing to improve long period resolution will be important</td>
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<td>Task 3: COMSOL modeling</td>
<td>6/16 completion: 2-D cross-section representations of tracer and hydraulics field tests in COMSOL</td>
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<tr>
<td>Task 3: Numerical sensitivity study</td>
<td>8/16 completion: evaluate ability to measure connectivity in fracture network using PHT</td>
</tr>
<tr>
<td>Task 4: Publications / Reporting</td>
<td>Final report 9/16: 1 paper sensitivity to heterogeneity (in draft), 1 paper PHT field, 1 paper PHT/Tracer comparison</td>
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Future Directions

Field tests will be conducted this summer at the Mirror Lake Fractured Rock Hydrology Site, Grafton, County, NH.
Future Directions

• Revised field design:
  – Original proposal was to deploy FO cable in open borehole to sense PHT response
  – To get response from individual fractures, we will push cable against borehole wall using a flexible liner (FLUTe™)
  – We will compare open hole to lined response to evaluate ability to measure local signals
  – The revised field design will better mimic conditions in a grouted well
  – FLUTe liners will cost about $2000 per well, in 5 wells, which will be diverted from cost savings in the laboratory

After Cherry, et al. (2007), Ground Water Monitoring & Remediation, 27(2), 57-70
• We have demonstrated for the first time that distributed acoustic sensing (DAS) can be utilized as distributed pressure sensing (DPS)

• We have adopted the Silixa iDAS technology for DPS but instrument tuning and improved signal processing is still needed to measure long period pressure oscillations

• Numerical simulations suggest that observing phase shift is best for measuring hydraulic connectivity, and frequency should be tuned to resolve target features

• Field experiments are set to start this July once we obtain permission to proceed past decision point