The Role of Geochemistry and Stress on Fracture Development and Proppant Behavior in EGS Reservoirs

May 18, 2010
Timeline

- DOE Start Date: 9/30/2008
- DOE Contract Signed: 9/26/2008
- Ends 11/30/2011
- Project ~40% Complete
### Budget Overview

<table>
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<tr>
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<th>DOE Share</th>
<th>Awardee Share</th>
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<td><strong>Project Funding</strong></td>
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Overview: Barriers and Partners

- **Barriers to EGS Reservoir Development Addressed:**
  - Reservoir Creation
  - Long-Term Reservoir and Fracture Sustainability
  - Zonal Isolation

- **Partners**
  - Independent Evaluation
Problem

- Maximizing initial conductivity of EGS domains
- Maintaining long-term conductivity
- Facilitate development of extensive stimulated domain via diversion

Solution

- Proppant placed in fractures

Challenge

- Proppant behavior at geothermal conditions poorly understood

Use of proppant recognized as potential technology under Task “Keep Flow Paths Open” in DOE EGS Technology Evaluation Report
OBJECTIVE

Develop Improved Methods For Maintaining Permeable Fracture Volumes In EGS Reservoirs

- Experimentally evaluate performance under geothermal conditions (200°C and depths to 10,000 ft)
- Effects of mineral deposition and dissolution on propped fractures
- Mechanical behavior of propped fractures
- Use of proppants and precipitates for diversion
- Geochemical effects on injected fluids
- Mechanical and geochemical simulation/prediction models for long-term conductivity
Relevance/Impact of Research

OBJECTIVE
Develop Improved Methods For Maintaining Permeable Fracture Volumes In EGS Reservoirs

ADDRESS CRITICAL NEEDS OF EGS RESERVOIR DEVELOPMENT
1. Fracture Characterization
2. Zonal Isolation
3. Controlling Fracture Propagation
4. Predictive Modeling
Expected Achievements

Task 1. Review and Select Test Materials
Select Proppants and Rock Samples
Select Flow Through Fluids

Task 2. Build Test Cells

Task 3. Baseline Flow Through Experiments

Task 4. Large Scale Flow through Experiments

Task 5. Petrologic Assessment of Proppant-Fluid Interactions

Task 6. Mechanical Testing of Core Specimens

Task 7. Geochemical Modeling of Proppant-Fluid Interactions

Task 8. Geochemical Modeling of Downstream Fluid-Rock Interactions

Task 9. Geomechanical Modeling of Proppant-Rock Behavior

Task 10. Assessment of Proppant Applications

Task 11. Reporting and Technology Transfer
Impact of Research

- **Costs**
  - Treatment Costs Will Increase
  - Operational and Maintenance Costs Should Decline
  - Premium Proppant May Still Be Required

- **Performance**
  - Some Uncertainty
  - Control Potential For Scaling?
  - Scaling Spread Through Reservoir Rather Than Immediately at Wellbore?
  - Anticipate Conductivity Maintained?
  - Value in Intercommunication of Shear-Induced Fractures?

\[ NPV = \sum_{n=1}^{n} \frac{\Delta S_n}{(1+i)^n} \]
Impact of Research

- **Proppant Applications**
  - **Diversion**
    [see Kiel, 1977]
  - **Diversion**
    [Fenton Hill, December 1983, CaCO₃]
  - **Scouring, Tortuosity Reduction**
    [Cleary, ... Many Others]
  - **Conductivity Maximization**
    [Raymond and Binder, 1966]
  - **Conductivity Preservation**
    [Hassebroek and Waters, 1964]
  - **Surface Area and Efficiency**
    [Gas Shale Technology]

- **Markets**

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When fracturing was first introduced, the value of the propping agent was not fully known. Theoretically it was a good thing, but some did not believe it to be essential. Comparative treatments with and without its presence soon demonstrated that, for sustained product ion increases, a proppant was important. Research has since substantiated these findings, and now the propping agent is considered a necessary ingredient incorporated in practically all treatments.

Hassebroek and Waters, 1964
Innovative Aspects of Project

- Applied Technologies From Other Disciplines
- In-Situ Conditions
- NOT THE FIRST
- Temperature
- Pressure
- Fluid Environment
- Geochemistry
Scientific/Technical Approach

- **Tasks 1-3**
  - Select appropriate rocks, fluids and proppants for testing
  - Infer/Determine chemomechanical effects through baseline tests
    - Ambient temperature conductivity measurements
    - Static, long-term exposure to representative temperature
  - Design and fabricate high-temperature conductivity apparatus

- **Tasks 4-7**
  - Conductivity measurements at temperature and pressure
  - Measure conductivity and chemical changes to constrain geochemical and geomechanical models
  - Back-analysis and modeling

- **Tasks 8-11**
  - Large scale flow conductivity measurements
  - Compile and interpret mechanical and geochemical data
  - Assess applications of proppants in geothermal reservoirs
Milestones and Go/No Go

Contract Signed
09/30/2009

FY 09

FY 10

Go/No Go

FY 11

End Date
09/30/2011

40% Complete

Review and Select Test Materials
Build Test Cells
Baseline Flow Through Experiments
Large Scale Flow Through Experiments
Petrologic Assessment of Proppant-Fluid Interactions
Mechanical Testing of Core Specimens
Geochemical Modeling
Geomechanical Modeling of Proppant-Rock Behavior
Assess Proppant Applications

FY 09
FY 10
FY 11

= go/no go
= proposed
= anticipated
= % progress
Qualifications and Facilities

EGI:

- **J. Moore**: Principal Investigator: geothermal geology, geochemistry, hydrothermal alteration
- **J. McLennan**: Rock mechanics, rock property measurements, fracture stimulation in oil and gas/geothermal industry
- **Students**: D. Brinton (B.S./M.S), K. McLin (Ph.D.), J. Carnell (M.S.), T. Stoddard (B.S./M.S.), Prashanth Mandalaparty (Ph.D.)

Dept. of Chemical Engineering, University of Utah

- **M. Deo**: Reservoir engineering, rock property measurements, numerical simulation of fracture-fluid behavior

Available Facilities

- Laboratories for experimental studies at P and T
- Machine Shops
- SEMs, QEMSCAN, XRD, ICP-MS (water analyses) ....
Conductivity Measurements

- Non-API apparatus – intentionally
- Capable of 200°C but currently running at ambient temperature
- 30/60 Bauxite
- Granodiorite
- Saw-Cut and SPLIT
- ROUGH SURFACE

IMPORTANT Accomplishments, Expected Outcomes and Progress
Accomplishments, Expected Outcomes and Progress

- Reduced Conductivity Attributed to Surface Roughness
- Fracture Tortuosity
- Inertial Restrictions

![Graph showing Long Term Permeability of Ohio Sandstone - 2 lb/ft² - 2% KCl - 300 F]

![Graph showing Inferred Permeability of Proppant (D) over time with different flow rates]
# Static Exposure To Fluid At Temperature

<table>
<thead>
<tr>
<th>Series</th>
<th>Solids</th>
<th>Liquid</th>
<th>Temperature (°C)</th>
<th>Duration (weeks)</th>
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<tbody>
<tr>
<td>1</td>
<td>Proppant</td>
<td>DI Water</td>
<td>200</td>
<td>~4</td>
</tr>
<tr>
<td>2</td>
<td>Proppant</td>
<td>DI Water</td>
<td>200</td>
<td>~8</td>
</tr>
<tr>
<td>3</td>
<td>Proppant/Crushed Granite</td>
<td>DI Water</td>
<td>200</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>Proppant/Crushed Granite</td>
<td>DI Water spiked with silica</td>
<td>200</td>
<td>on-going</td>
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<tr>
<td>5</td>
<td>Proppant/Crushed Granite</td>
<td>DI Water spiked with silica</td>
<td>200</td>
<td>on-going</td>
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</tbody>
</table>
Surface Corrosion

“Fresh” Proppant (Typical) | After One Month (Typical)
Accomplishments, Expected Outcomes and Progress

1. Mobilization of Minerals
2. Re-Precipitation on Proppant
3. Cementation of Proppant

Two-Month Exposure
Management Activities **Principal Investigator: J. Moore**
- Responsible for overall management of project
- Establish schedules
- Prepare DOE reports
- Point of contact with DOE Project Managers

**Application of Leveraged Funds**
- Students

**Integration with Other Projects in Program?**
- Could be implemented at any field demonstration
- Was proposed at Raft River

**Coordination with Industry & Stakeholders**
- Independent assessment – no manufacturers or service companies
Future Directions

**FY10 Activities**

- Complete fabrication of high temperature vessel
- Initiate experiments at P and T
  - Obtain conductivity data
  - Roughness modeling and implications
- Continue experimental studies in static mode and collection of geochemical data
  - Analyze reacted water
- Geochemical modeling of water-rock interactions
Future Directions

FY11 Activities

- Complete experimental studies
- Conduct large scale conductivity tests
- Compile and interpret mechanical and geochemical data
- Assess proppant applications
Summary

- Few legacy geothermal applications of proppant
- Behavior at geothermal conditions uncertain
- Study well defined, addresses specific critical questions, and technically feasible
- Project conducted by highly qualified and experienced scientists and engineers from geothermal and oil and gas industries with expertise in geochemistry, rock mechanics, and reservoir stimulation
- Excellent facilities to conduct study
- Significant progress since project initiated
- Project on schedule
- Significant student involvement in project
- Students are conducting original research
- Several oil and gas and service companies interested