Energetic Materials for EGS Well Stimulation (solids, liquids, gases)

Project Officer: Lauren Boyd
Total Project Funding: $1.6M
April 24, 2013

Mark Grubelich, Sandia National Lab

Track Name: HT Tools
• Objective: Develop environmentally safe and field deployable, energetic systems (liquid, gas, and solid phase) that enables branching, far field fracturing and/or stimulate existing fractures.

• Problem: Enhanced Geothermal Systems (EGS) require reservoir stimulation. Typically used energetic methods/materials are:
  – High Explosives; causes local damage and thus little far field fracture propagation
  – Propellants; predominantly extends existing fractures, less effective at generating multiple fractures

• Solution: Energetic methods/materials for controllable pressurization rates and peak pressures – key innovation
  – Rapid pressure rise to below the reservoir “rubblization” strength (lower than high explosives) yet above that achieved by propellants
  – Design and demonstrate a engineered energetic materials to produce a tailored pressure pulse to initiate multiple near well bore fractures and propagate these fractures to the far field.

- All systems are designed to have benign environmental interactions and be safe enough for field deployment at large scales.
• Impact on geothermal energy development:
  – Reduced risk and costs associated with development
  – Increased fracturing efficiency
  – Safe, economical systems
  – Reduced borehole impedance

• Impacts Geothermal Technologies Program goals:
  – Lower development cost: EGS well productivity is essential to 5 MW demonstration and LCOE Program goal. This stimulation technology is directly aligned with achieving higher productivity from EGS reservoirs and wells.

Cost impact example:

<table>
<thead>
<tr>
<th>Flash/Binary</th>
<th>Temperature (°C)</th>
<th>Improvement</th>
<th>Cost of Power 2010 (cent/kw)</th>
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<td>250</td>
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<tr>
<td>Flash</td>
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<td>3x flow rate</td>
<td>6.88 (40% Less)</td>
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<td>Binary</td>
<td>175</td>
<td>3x flow rate</td>
<td>16.02 (50% Less)</td>
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</table>

Note: Assumed 30 kg/sec base flow rate, 4 km well depth.

From S. Petty et al. Stanford 2011
Scientific/Technical Approach

• Scientific/technical approach for current year’s activities:

Gas system:
- Complete lab scale system validation and shakedown at scheduled pressures (150 to 500 psi gas mixture pressure)
  - Compare computational pressure profiles to measured data
- Demonstrate system in shallow test well
  - Measure pressurization rates and peak pressure
  - Videography of well bore features
  - Permeability measurements via gas pressurization and leak-off

Solid system:
- Down select candidate(s) binary systems based on measured properties for safety (most important), maximum reaction rate (secondary), peak pressure (tertiary).
  - Compare computational pressure profiles to measured data
- Design of high pressure hydro-bomb
- Lab scale testing of selected solid energetic system in fluid environment
  - Pressure time history measurements
Scientific/Technical Approach

• Key issues & significance:
  - SAFETY!
    - Gas system field demonstration – safety built into test plan, Purdue & New Mexico Tech. written test plan, 100% remote operation
    - Solid system – friction, electrostatic discharge, impact, and thermal stability characteristics being measured.
  - ‘Tunable’ = Demonstrate variable pressure generation so the technology can be adopted in a variety of formations
    - Achieved through chemistry modifications (solids) and density control (gas)
  - Scalability
    - Achieved successful scale up from system validation in the lab to field demonstration (gas)
    - Ready path to commercial deployment = low material costs, materials safe for handling and transport, benign environmental interactions

• Additional diagnostics: seismic imaging could not be afforded for the given budget & GPR would suffer from unacceptable attenuation through shallow weathered zone
The systems:

- $\text{H}_2\text{O}_2 \rightarrow \text{Steam (water)} + \text{Oxygen}$

- $\text{N}_2\text{O} + \text{C}_2\text{H}_4 \rightarrow \text{Steam (water)} + \text{Nitrogen} + \text{Carbon Dioxide}$

- $\text{KClO}_4 + \text{Si} + \text{H}_2\text{O} \rightarrow \text{Potassium Chloride (salt substitute)} + \text{Hydrogen}$
Accomplishments, Results and Progress

Major accomplishments during reporting period:

– Proof-of-concept liquid mono-propellant, liquid decomposition/gas generation rate
– Proof-of-concept gas bi-propellant, pressure vs. time data
– Safety characterization of solid system
– Shallow test well demonstration of gas phase bi-propellant

<table>
<thead>
<tr>
<th>Original Planned Milestone/Technical Accomplishment</th>
<th>Actual Milestone/Technical Accomplishment</th>
<th>Date Completed</th>
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<td>Proof-of-concept gas bi-propellant (lab testing) 9/2012</td>
<td>Proof-of-concept gas bi-propellant (lab testing)</td>
<td>02/2012-2/2013</td>
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<tr>
<td>Solid system safety, reaction rate, and peak pressure measured by 6/2013</td>
<td>Candidate solid system safety properties measured</td>
<td>2/2013</td>
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<td>Shallow well field test of gas phase system by 4/2013</td>
<td>3x shots at New Mexico Tech. testing range (150/150/250 psi)</td>
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HP H2O2 Pump System

Patent in process
H$_2$O$_2$ Gas Generator Pump Test
4000 HP

Patent in process
## Solid system safety testing:

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<tr>
<th>Sample</th>
<th>Batch</th>
<th>Impact (cm)</th>
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<th>BAM (friction, N)</th>
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<th>Ignition Sensitivity (kV)</th>
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</table>
Accomplishments, Results and Progress: Proof of concept (gas phase) lab test

SNL Testing at Purdue Zucrow Labs - 150 psia Stoichiometric Nitrous Oxide & Ethylene - 2/21/2013

Fill Pressure

Pressure [psi]

Time [sec]

Patent in process
Gas phase hardware

Tree

Gas regulator

Control diagram

Patent in process
Field demo gas phase bi-propellant
Test well W-1

Test location: Blue Canyon Dome, EMRTC

Core shows the test well rock is competent rhyolite with a few fractures.

‘Tree’

1 joint of 5 inch schedule 160 pipe (purple) cemented in a 10 inch hole

Cement

Centralizer

Cement

Epoxy

35' 6” casing depth

20' cored (2.96”) section

Bottom hole Assemble, 43000 psi 1” tubing and coupler

Patent in process
From field demo:
N2 fill rate data from the field (2 of 2)
Future Directions

- Additional gas phase bi-propellant field testing in W-1 at EMRTC
- Based on shallow well demonstration testing, design, fabricate hardware for, and execute full/commercial scale test – to be completed by end of FY2015
- Possible high pressure injection of liquid (H2O2) in shallow test well FY2014
- Proof-of-concept test of solid system by end of FY2014

<table>
<thead>
<tr>
<th>Milestone or Go/No-Go</th>
<th>Status &amp; Expected Completion Date</th>
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<tbody>
<tr>
<td>Solid system reaction rate and peak pressure measurements by 6/2013</td>
<td>5 weeks behind schedule; completion as expected</td>
</tr>
<tr>
<td>Design and fabricate hydro bomb by 9/2013</td>
<td>May adapt existing hardware (detonation calorimeter), on schedule</td>
</tr>
<tr>
<td>Testing solid system in fluid environment by 10/2013-12/2013</td>
<td>Completion as expected, on schedule</td>
</tr>
</tbody>
</table>
• Proof-of-concept achieved for H2O2 pump-fed system
• Proof-of-concept achieved for bi-propellant gas phase system
• Successful field demonstration of bi-propellant gas phase system; 3 shots at variable pressures
  – Measured change in permeability
  – Data measurement for peak pressure
## Project Management

**Timeline:**

<table>
<thead>
<tr>
<th>Planned Start Date</th>
<th>Planned End Date</th>
<th>Actual Start Date</th>
<th>Actual /Est. End Date</th>
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<td>2/25/2010</td>
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**Budget:**

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<th>Federal Share</th>
<th>Cost Share</th>
<th>Planned Expenses to Date</th>
<th>Actual Expenses to Date</th>
<th>Value of Work Completed to Date</th>
<th>Funding needed to Complete Work</th>
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<td>$4,000,000</td>
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</table>

**What you don’t see:** $1.5 M in direct leveraged funds (hardware & labor)

Coordination between proof-of-concept testing at Zucrow Labs, Purdue University and Energetic Materials Research and Testing Center, New Mexico Tech