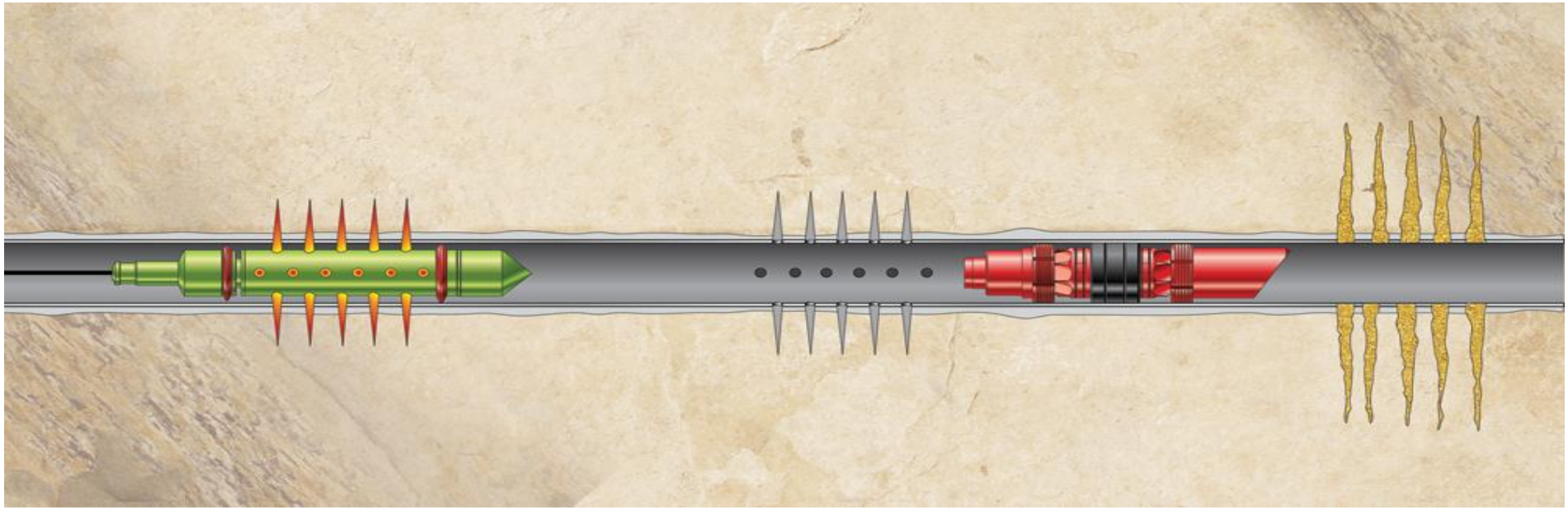

SURGE: Completing Horizontal Geothermal Wells

Project Officer: Eric Hass
Total Project Funding: $398k
May 11, 2015

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HRC: Reservoir Fracture Characterization & Fluid Imaging

Relevance/Impact of Research

Objectives

Adapt technology and operational techniques from the oil and gas industry to determine how they might be adapted to completing horizontal wells with multistage hydraulic stimulations for the construction of an enhanced geothermal system

1. Assess the applicability of oil and gas completion operations used in unconventional plays, such as multi-stage “plug and perforate” completions, to the higher temperatures, high water production flow rates, and large-diameter completions required for geothermal electricity generation.
2. Assess applicability of fracture creation tools and techniques used in unconventional petroleum plays to creating fractures in EGS reservoirs.

Relevance/Impact of Research

Impact

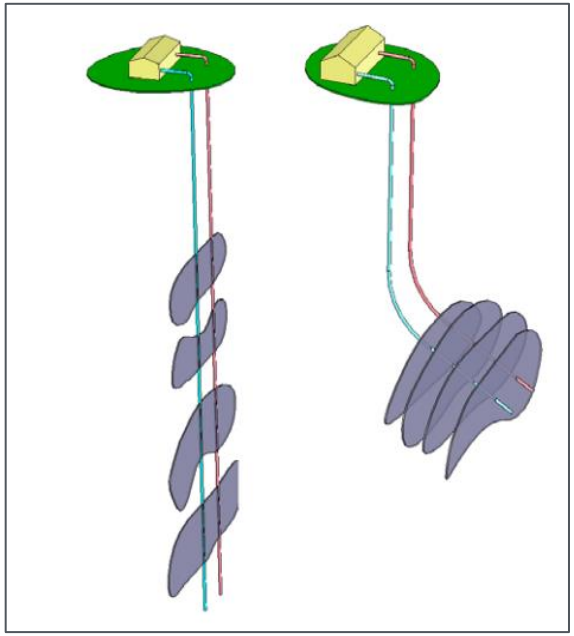
- Results of this study will:
  1) identify oil and gas technologies and techniques that can be adapted to completing and fracturing horizontal geothermal wells, and
  2) identify technical barriers that require additional R&D.
- The resulting designs would serve as a blueprint for field demonstration of horizontal drilling and fracturing techniques for geothermal systems, and could provide a workable, repeatable completion system that enables a revolution in producing geothermal resources similar to that seen in the shale gas community.
- The results would directly support GTO goals of
  1) Lower LCOE to 6 cents/kWh by 2030
  2) Drive industry deployment of a targeted 100+ GW of EGS

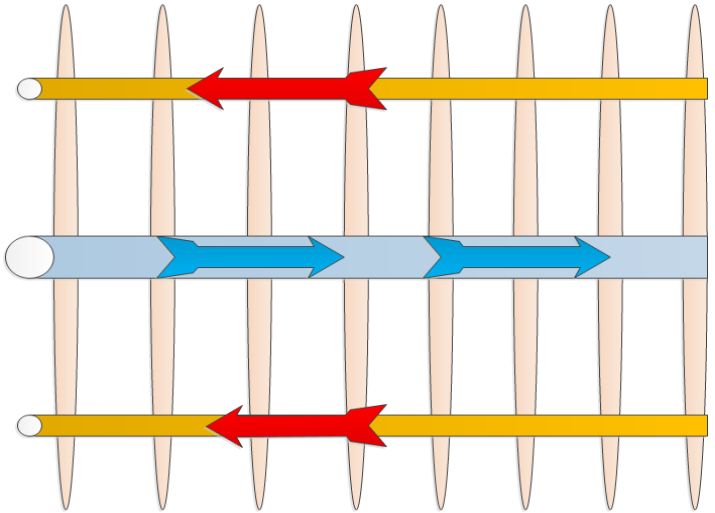
Scientific/Technical Approach

Envisioned Concept:

Develop a methodology for creating EGS reservoirs consisting of multiple fractures from horizontal wells
Complete horizontal well to control location and spacing of fractures

- Start with Horizontal Well
  - Open Hole
  - Cased (perforate)
- Isolate zones
- Pressurize and Stimulate
- Repeat
- Intersect fractures with two production wells
- Produce/Inject fluid
- Monitor Flow and Temperature





Scientific/Technical Approach

Specific Technical Approach

1. Identify unconventional petroleum completion techniques and technology as being applicable to geothermal setting, based on the size and temperature limitations of commercially available equipment
2. Develop injection well design based on flow and temperature specifications for geothermal well
3. Identify commercial software capable of predicting fracture creation in granitic settings and use it to develop stimulation programs that optimize fracture length and height.
4. Study options for intersecting fractures and competing production wells.

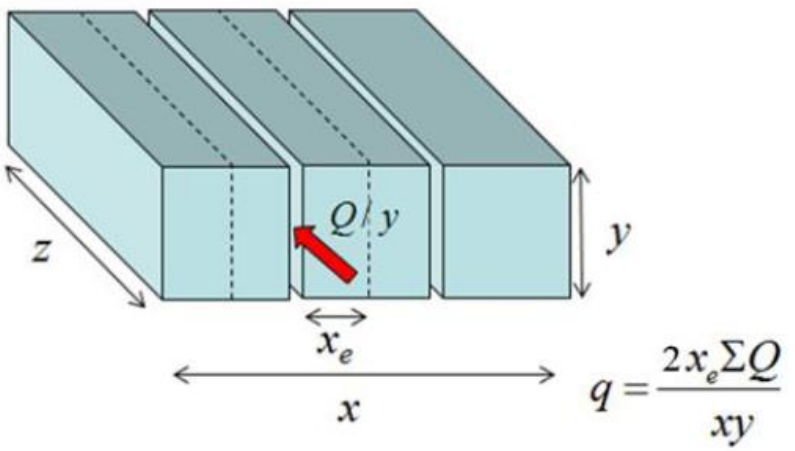
EGS System Requirements - guide completion design

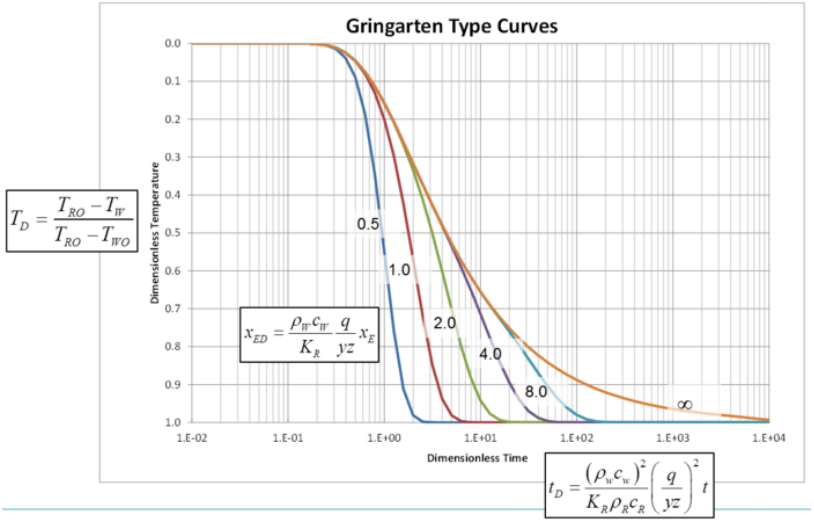
- Geothermal setting
  - 200˚ C (392˚ F)
  - ~2,700 m (~9,000 ft) depth
  - Reservoir properties (lithology, stratigraphy, permeability, etc.) from AltaRock/Newberry well logs
- Is a system – need to know other details of full system to do horizontal completion design
  - What does fracture network look like? - # fractures, fracture lengths, flow rate, rates per fracture, etc. (Gringarten)
  - What's needed to make these fractures? – flow rate and (esp.) pressure during stimulation (frac pressure) (Gohfer modeling)

Accomplishments, Results and Progress

EGS System Requirements

- Gringarten et al. (1975) and Doe et al. (2014)
- "Fracture networks with uniform spacing and hydraulic properties are a 'best case' scenario' for mining heat from EGS reservoir.
- Approximate power generation potential: 5.5 MWe/production well
- Flow rate: 160 kg/s (87 kbpd)
  - Assumes 2 production wells at 80 kg/s (43.5 kbpd)
- Lifetime – 30 years
  - Assumes 175˚ C cutoff production temperature
  - Fracture size (half-length): 800 m (2,600 ft) x 400 m (1,300 feet)
- Number: 12
- Spacing: >60 m (>200 ft)





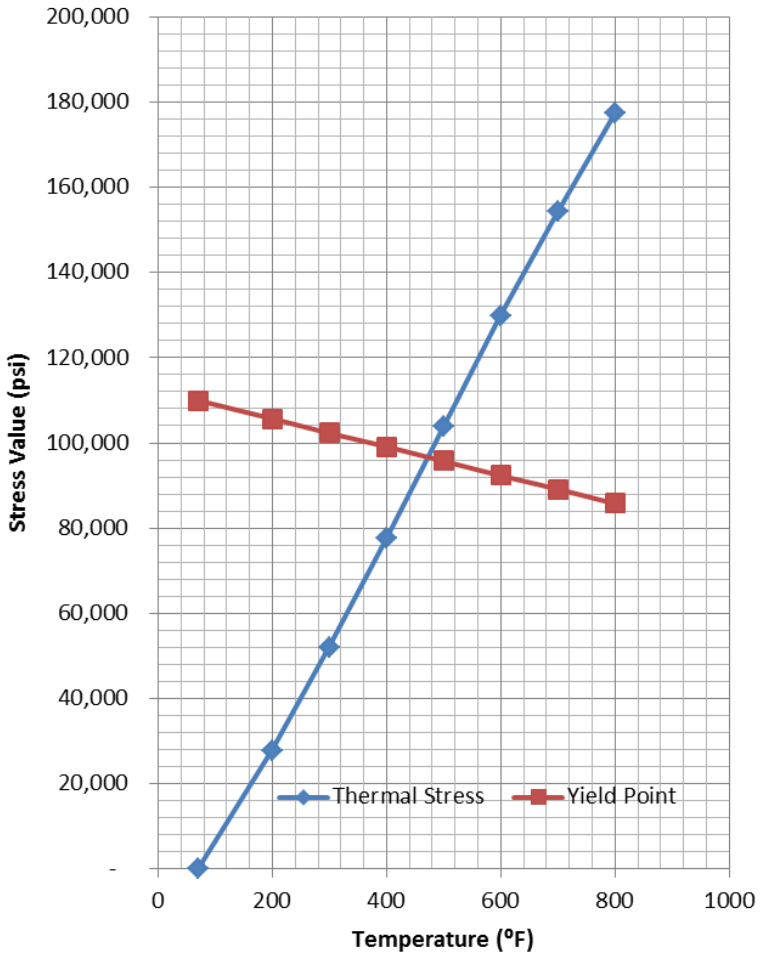
Design Requirements – Pressure

- Needed to give rough order of magnitude the rates and pressures for stimulation
- Used GOHFER, an industry stimulation model available at CSM
- Used well logs from Newberry EGS Demonstration site (AltaRock) to create model of reservoir
- Lessons learned
  - Long fractures, but not tall
  - Rate and pressure were factors (faster rate = taller) - System can be "optimized"
  - Interactions with stratigraphic layers
  - Model not designed for igneous (as a default rock type)
  - Fracture creation scheme needs improvement (FY15 goal)

Casing Design

Design considers:

- Burst Pressure
- Collapse Resistance
- Thermal Cycling
  - Assumed 20^{0}C to 200^{0}C Casing connections
  - Thermal cycling will be close (if not exceed) the load limit of API Buttress thread (BTC)
  - Use of a premium connection would make the connection “stronger” than the casing.
- Pressure losses (in well and through perforations)



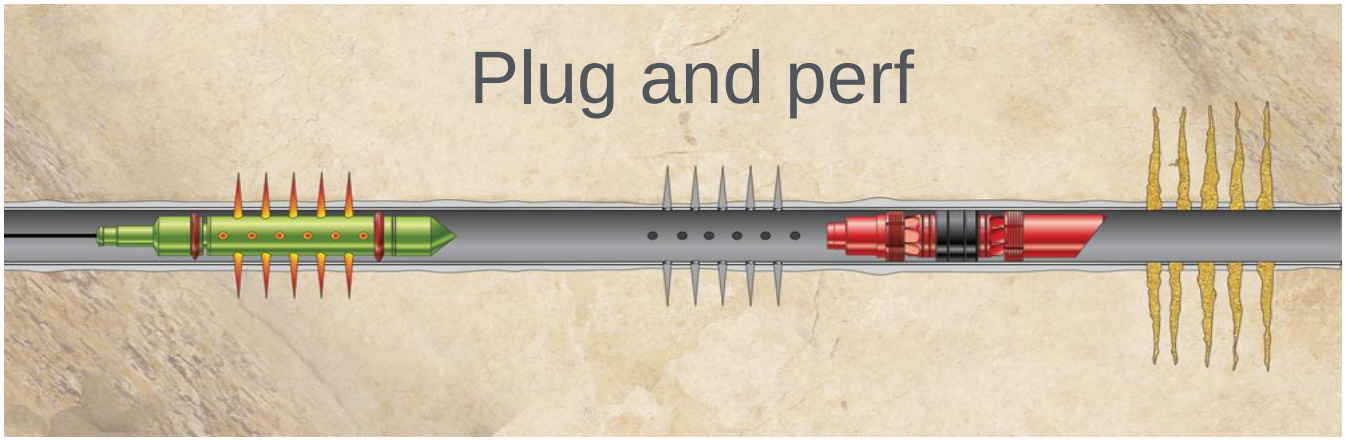
Casing Design Results

- 9 5/8” 53.5 lb/ft P110 casing with premium connections (ex. Tenaris Blue) will meet design specs (as assumed) in geothermal setting
  - Pressure loss in fractures could change this
- “Standard” geothermal cement
- Pressure losses down well and through perforations acceptable
  - Pressure loss in fractures may be problematic – need to check and revisit casing design

11.75	10.75	9.625	OD (in)
60.0	60.7	53.5	WPF (lbf/ft)
P110	P110	P110	Grade
10.8	9.66	8.54	ID (in)
17.29959	17.47267	15.54649	Cross Sectional Area in ^{2}
1,903,000	1,922,000	1,710,000	Tensile Strength (lbf)
3,610	5,880	7,950	Collapse Resistance (psi)
8,010	9,760	10,900	Pipe Body Burst (psi)

Stage Isolation Techniques Evaluated

Plug and perf



Packer and port

Sand and perf

Accomplishments, Results and Progress

- Focus on ability of techniques to handle high temperatures (200+^{o}C/400+^{o}F) encountered in geothermal systems
- Three zonal isolation techniques evaluated
  - Plug and Perf – most reliable, but most expensive
  - Sand and Perf – cheapest, but sand placement in horizontal well and interaction with fractures could be problematic
  - Port and Packer – elastomer external packers could be a problem, but faster than plug and perf
- No “showstoppers” identified at 200^{o}C assumed setting, but…
- Approaching temperature limit of available “off-the-shelf” equipment

Accomplishments, Results and Progress

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Original Planned Milestone/ Technical Accomplishment	Planned Date	Date Completed
Complete NREL/CSM workshops discussing state-of-the-art in oil and gas horizontal completion techniques, and requirements for EGS production wells.	12/31/2013	12/31/2013
Develop flow and temperature specifications for geothermal well.	2/28/2014	3/14/2014
Finalize list of petroleum completion techniques and technologies identified as being applicable to geothermal setting.	4/30/2014	5/23/14
Complete preliminary horizontal EGS well completion design for specified flows and temperatures. Presentation to GTO on preliminary horizontal EGS well completion design results.	8/15/2014	10/21/14
Draft paper of results for review by GTO. Completed paper to be published in journal or presented at conference.	9/30/2014	1/31/15

Future Directions

1. Model Creation of fracture system with commercial software
2. Intersecting the fractures
   - How does certainty of fracture location influence choice of drilling target? What are remediation options in case of poor hydraulic connection?
3. Production well design

Milestone or Go/No-Go	Status & Expected Completion Date
Identify software adequate for modeling hydraulic fracturing in igneous rock.	Using Mangrove and CMG STARS – completed
Preliminary results of optimized fracture creation from model runs	6/30/15 (delayed)
Preliminary design for intersecting fractures and production well	6/30/15
Report of final results of fracture creation and production well completion design	9/30/15

Challenges:

- Problems getting access to commercial software
- Problems getting Masters Student to perform fracture creation model runs

Summary

- Developed conceptual model for EGS comprised of horizontal well with fractures created using zonal isolation techniques from unconventional petroleum industry
- Developed injection completion design for horizontal well in geothermal settings using commercially available components
- Evaluated 3 zonal isolation techniques. Found that equipment is commercially available that can handle temperatures encountered in geothermal settings
- Future work will continue to explore the next steps of creating fractures, intersecting the fractures, and completing production wells to achieve the ultimate goal of creating EGS reservoirs consisting of multiple fractures from horizontal wells.

Additional Information

- **Publications and Presentations, Intellectual Property (IP), Licenses, etc.**
- Olsen, J., C. Augustine, A. Eustes and W. Fleckenstein, 2015. "Design Considerations for Applying Multi-Zonal Isolation Techniques in Horizontal Wells in a Geothermal Setting." Fortieth Workshop on Geothermal Reservoir Engineering, Stanford University, CA, January 26-28, 2015, p. 5.
- Submitted 3 Records of Invention (ROI's) to NREL intellectual property office. These are in the process of being reviewed for potential patent applications.