GTO Code Comparison Study

Support of the DOE GTO Model Comparison Activity

Project Officer: Lauren Boyd

Total Project Funding: $1.84M

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PNNL-SA-109110

Track 3 EGS1: Reservoir Modeling

Relevance/Impact of Research

Project Objectives

Create a community forum for Enhanced Geothermal Systems (EGS) reservoir modeling code improvement and verification, building confidence in the suite of available numerical tools, and ultimately identifying critical future development needs for the geothermal modeling community.

New Look

- 1980 - 6th Annual Workshop of Geothermal Reservoir Engineering
- 2015 - 40th Stanford Geothermal Workshop
  - Roland Horne
  - John Pritchett

Relevance/Impact of Research

Numerical Simulation

- Upfront capital costs of the EGS technology (Wood, 2009)
- Numerical simulation has the potential for reducing investment risks and uncertainty

Study Design

- Benchmark problems to investigate specific coupled processes
- Challenge problems to investigate modeling approaches and application of numerical simulators to field-scale systems

Relevance/Impact of Research

1980 Objectives

The topic for panel analysis for the Sixth Annual Workshop in Geothermal Reservoir Engineering was selected in conjunction with the Department of Energy to assess the state of development and the appropriate role of geothermal reservoir simulator models in predicting geothermal reservoir performance as it affects investment decisions.

2015 vis-a-vis 1980

- State of development - TH versus THMC
- Appropriate role – “The models work!” versus accepted analytical tools
- Study design – hypothetical problems only versus benchmark and field site problems

Relevance/Impact of Research

Impacts

- Rigorous code comparisons on benchmark problems will 1) establish a foundation for modeling field sites, 2) identify needed code improvements, and 3) re-build confidence in numerical simulation.
- Demonstrated predictive capabilities of numerical simulation for field sites from the collective modeling community directly supports the goals for the Enhanced Geothermal Systems program.

Innovative Aspects

- Velo – Mediawiki-Alfresco based knowledge management platform for code comparison
- Dynamic results comparison tool
- ISO-13528 comparison standard
- Community of modeling groups

Approach

- Develop a suite of benchmark problems with problem champions
- Develop a catalog of numerical simulators
- Code description web-conferences
- Problem description web-conferences
- Preliminary problem submittals review
- Problem submittals and review
- Publication at Stanford Geothermal Workshop
- Final submittals and review
- Publication in peer-reviewed journal
- Archive study in the National Geothermal Data System

Scientific/Technical Approach

- **Problem 1: Poroelastic/thermal transport in a single fracture**
  - Problem Champion: Robert Podgorney, Idaho National Laboratory
  - Submission date: 17 July 2014 / **31 July 2014**
- **Problem 2: Shear stimulation of randomly oriented fractures via pore pressure increase and thermal stress**
  - Problem Champion: Sharad Kelkar, Los Alamos National Laboratory
  - Submission date: 21 August 2014 / **4 September 2014**
- **Problem 3: Fracture opening and sliding in response to fluid injection**
  - Problem Champion: Mark McClure, University of Texas at Austin
  - Submission date: 18 September 2014 / **25 September 2014**
- **Problem 4: Planar EGS fracture of constant, penny-shaped aperture in permeable hot rock**
  - Problem Champion: George Danko, University of Nevada at Reno
  - Submission date: 2 October 2014 / **9 October 2014**

Scientific/Technical Approach

- **Problem 6: Injection into a fault/fracture in thermo-elastic rock**
  - Problem Champion: Ahmad Ghassemi, University of Oklahoma
  - Submission date: 16 October 2014 / **23 October 2014**
- **Problem 7: Surface deformation from a pressurized subsurface fracture**
  - Problem Champion: Pengcheng Fu, Lawrence Livermore National Laboratory
  - Submission date: 6 November 2014 / **13 November 2014**
- **Problem 5: Amorphous Silica dissolution/precipitation in a fracture zone**
  - Problem Champion: Mark White, Pacific Northwest Natonal Laboratory
  - Submission date: 20 November 2014 / **4 December 2014**

Scientific/Technical Approach

$$d = 1.5\, s_P^*$$

$$P_i^* = \begin{cases} \bar{P}^* - d \text{ if } P_i < \bar{P}^* - d \\ \bar{P}^* + d \text{ if } P_i > \bar{P}^* + d \\ P_i \end{cases}$$

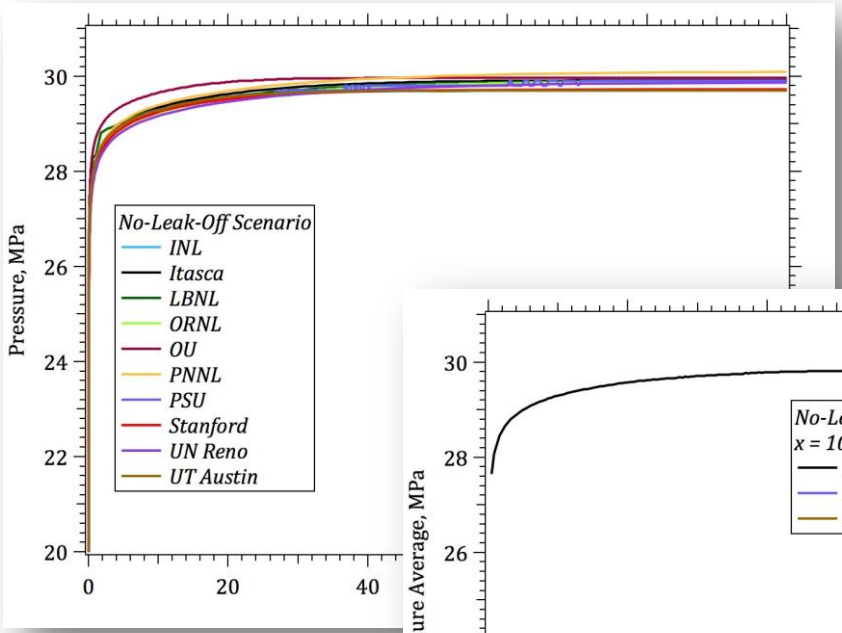
$$\bar{P}^* = \frac{1}{N}\sum_i^N P_i^*$$

$$s_P^* = 1.134\sqrt{\frac{1}{N-1}\sum_i^N \left(P_i^* - \bar{P}^*\right)}$$

$$\frac{D\bar{P}^*}{\bar{P}^*}\left(D\bar{P}^* / \bar{P}^*\right) < 10^{-6}$$

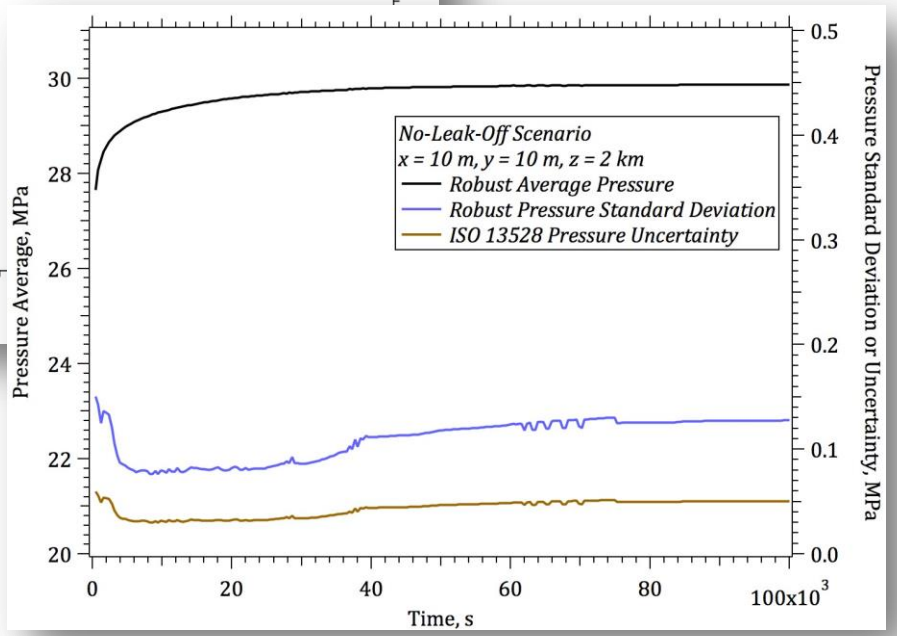
Convergence Criterion

- ISO-13528
  - Developed by the chemical and physical measurement community
  - Proficiency testing of computer codes for canopy reflectance
- Robust average and robust standard deviation



Uncertainty

$$u_P = 1.25\, s_P^* / \sqrt{N}$$



Weekly teleconferences/web-conferences held to describe codes, present problems, and discuss simulation results

- 7 benchmark problems have been developed
- 3 fracture opening problems
- 3 fracture shear problems
- 1 geochemistry problem
- problem champions/leads have been assigned
- participants completed submissions for all 7 benchmark problems
- 1 teleconference/web-conference per problem description
- 2 teleconferencs/web-conferences for result comparison & discussions
- comparison tool implemented into GTO-velo
- standard metrics created for each problem
- teleconferences/web-conferences recorded
- around 15 participants on the weekly teleconferences/web-conferences

2015 Stanford Geothermal Workshop Papers

- *Using GTO-Velo to Facilitate Communication and Sharing of Simulation Results in support of the Geothermal Technologies Office Code Comparison Study*; Signe White, Sumit Purohit, and Lauren Boyd
- *Influence of fracture shearing on fluid flow and thermal behaviour of an EGS reservoir – Geothermal Code Comparison Study*; Sharad Kelkar, Mark McClure, and Ahmad Ghassemi
- *Code comparison study fosters confidence in the numerical simulation of enhanced geothermal systems*; Mark White and Benjamin Phillips
- *Poro-elastic and self-propped single fracture THM models for EGS studies*; Robert Podgorney, George Danko, Davood Bahrami, and Pencheng Fu

GTO-CCS meeting at the Stanford Geothermal Workshop

Journal Paper Abstracts

- Codes Paper

  Numerical simulators for enhanced geothermal systems: GTO-CCS codes

  Davood Bahrani, George Danko, Derek Elsworth, Pengcheng Fu, Jason Furtney, Ahmad Ghassemi, Roland Horne, Sharad Kelkar, Mark McClure, Robert Podgorney, Jonny Rutqvist, and Mark White

- Single Fracture Deformation Paper

  Benchmark problems of single fracture deformation for enhanced geothermal systems: GTO-CCS Problems 3, 6, and 7

  Davood Bahrani, Kit-Kwan Chiu, George Danko, Derek Elsworth, Pengcheng Fu, Jason Furtney, Ahmad Ghassemi, Bin Guo, Roland Horne, Mark McClure, Jack Norbeck, Robert Podgorney, Jonny Rutqvist, Mark White, and Yidong Xia

- Multi-Dimensional Coupled THM Processes Paper

  Benchmark problems of multi-dimensional coupled thermal-hydrologic-mechanical processes for enhanced geothermal systems: GTO-CCS Problems 2 and 4

  Davood Bahrani, Kit-Kwan Chiu, George Danko, Derek Elsworth, Pengcheng Fu, Jason Furtney, Ahmad Ghassemi, Bin Guo, Sharad Kelkar, Mark McClure, Robert Podgorney, Jonny Rutqvist, and Yidong Xia

- Mechanical and Chemical Permeability Alteration Paper

  Benchmark problems of mechanical and chemical alteration of permeability for enhanced geothermal systems: GTO-CCS Problems 1 and 5

  Davood Bahrani, Charlotte Barbier, Kit-Kwan Chiu, George Danko, Derek Elsworth, Pengcheng Fu, Jason Furtney, Ahmad Ghassemi, Bin Guo, Roland Horne, Mark McClure, Jack Norbeck, Robert Podgorney, Jonny Rutqvist, Mark White, and Yidong Xia

Accomplishments, Results and Progress

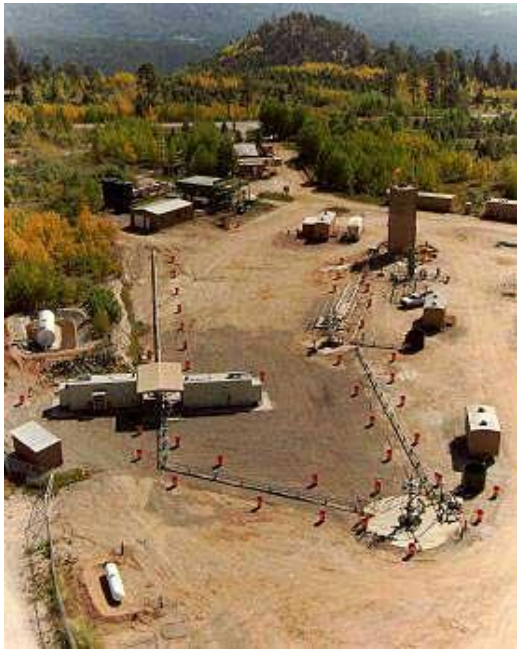
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Submit code descriptions.	Develop 9 benchmark problem descriptions and funding for at least four participating laboratory teams.	Q1 FY14
Review, refine, and solidify benchmark problems.	Submit descriptive information about participating codes to the Velo code catalog.	Q2 FY14
Apply codes to benchmark problems.	Initiate work on benchmark problems and develop full problem descriptions.	Q3 FY14
Participate in workshop to discuss results of benchmark problems and discuss challenge problems.	Submit 4 abstracts to the Stanford Geothermal Workshop documenting the GTO-CCS project.	Q4 FY14
Develop content for peer-reviewed journal manuscripts for benchmark problems.	Participants complete submissions of results to the benchmark problems	Q1 FY15
Finalize contributions to challenge problem suite.	Develop content for peer-reviewed journal manuscripts for benchmark problems.	In progress

Future Directions

Challenge Problems

- Two field sites
  - Fenton Hill, New Mexico, USA
  - Desert Peak, Nevada, USA
  - Soultz, Soultz-sous-Forets, France
  - Rosemanowes, Cornwall, UK
  - Habanero Pilot Plant, South Australia
- Two teams of problem champions
  - Jonny Rutqvist (LBNL) and Derek Elsworth (PSU)
  - Pengcheng Fu (LLNL) and Jason Furtney (Itasca)



Milestone or Go/No-Go	Status & Expected Completion Date
Option Period 1	Go Decision on March 5, 2015
Challenge Problem Completion	March 26, 2016

Summary

- EGS Coupled Processes
  - Thermal, Hydrological, Geomechanical, and Geochemical (THMC)
- 1980 Geothermal Reservoir Engineering Workshop
  - TH coupled processes
  - 1-, 2-, and 3-D flash problems
- U.S. EGS Simulation Community
  - Diverse suite of computational tools
  - Comparable results on benchmark problems
  - Code evolution impressive with work remaining
  - THMC modeling remains challenging

- ISO-13528
  - Allows for quantification of uncertainty without a target answer
  - Uncertainty increases with number of coupled-processes
- Confidence
  - Agreement among field experts with diverse perspectives
  - Understanding via open dialogue and discussions

Additional Information