Fracture Evolution Following a Hydraulic Stimulation within an EGS Reservoir

Project Officer: Bill Vandermeer

Total Project Funding: $199,976

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Objective

The objective of this project is to develop and demonstrate an approach for tracking the evolution of circulation immediately following a hydraulic stimulation in an EGS. A series of high-resolution tracer tests using conservative and thermally reactive tracers will be conducted at recently created EGS reservoirs in order to measure and track changes in fluid flow parameters such as reservoir pore volume, flow capacity, dispersivity, and effective reservoir temperature over time. Data obtained from the project will be available for the calibration of reservoir models that can serve to predict EGS performance following a hydraulic stimulation.

Relevance/Impact of Research

- In order to plan for the long-term operation of Engineered Geothermal Systems, it is necessary for operators and funding agencies to be able to predict the evolution of flow processes within an EGS reservoir following a hydraulic stimulation.
- No systematic studies of fracture/flow evolution have been conducted, but anecdotal evidence exists of rapid changes following hydraulic stimulations at the initiation of circulation.
  - At Fenton Hill, flow “impedance” dropped during sequential circulation tests
  - During the Soutlz 1997 3-month circulation test between GPK-1 and GPK-2, injectivity in GPK-1 improved significantly.
  - At Hijiori, some pathways became more permeable and some blocked due to anhydrite scaling during a long-term circulation test that followed the well stimulations.
  - At Coso, a well that was initially totally non-productive became a 3-MW well following an injection of cold steam condensate
- This project will provide the first ever formal evaluation of fracture and flow evolution in an EGS reservoir following a hydraulic stimulation.

Relevance/Impact of Research

This project addresses topics 4 and 5 of the GTP "areas of interest" identified in the Funding Opportunity Announcement:

- 4. Fracture evolution - Analyze the transient behavior (life cycle) of fractures and fracture systems in saturated and in under-saturated environments.
- 5. Fracture permeability - Develop an understanding of how fluids flow through rock. Provide the means to reliably measure and monitor the flow of fluids in fracture systems and determine variations in flow capacity over time.

Scientific/Technical Approach

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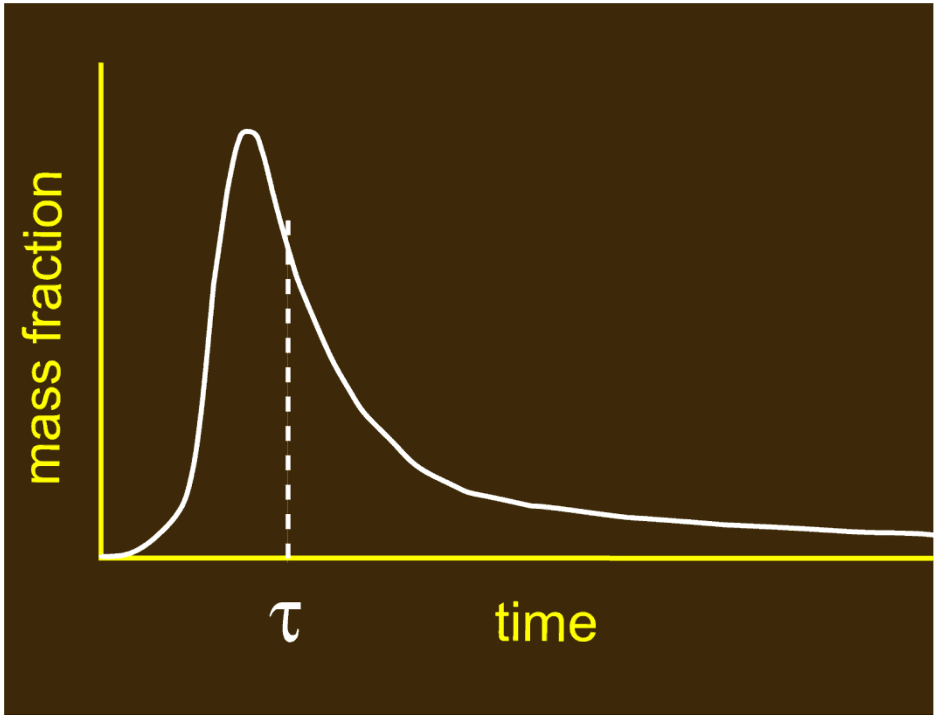
- Conduct repeat tracer tests in recently stimulated EGS wells using a suite of tracers including:
  - Conservative tracers as ‘controls’
  - Thermally reactive tracers with known decay kinetics
- Analyze the data to measure changes over time of relevant parameters:
  - Mean residence time, reservoir pore volume, flow capacity and dispersivity using a first-moment analysis of conservative-tracer return-curve data.
  - Measure changes in effective reservoir temperature through inversion of reactive-tracer decay data
- Correlate hydraulic/tracer data with microseismic data

Pore Volume Estimate through First-Moment Analysis of Return-Curve Data

(Danckwerts, 1953, 1958)

$$E(t) = \frac{Q \cdot C(t)}{m_p}$$

$$\tau = \int_0^\infty t \cdot E(t)\,dt$$



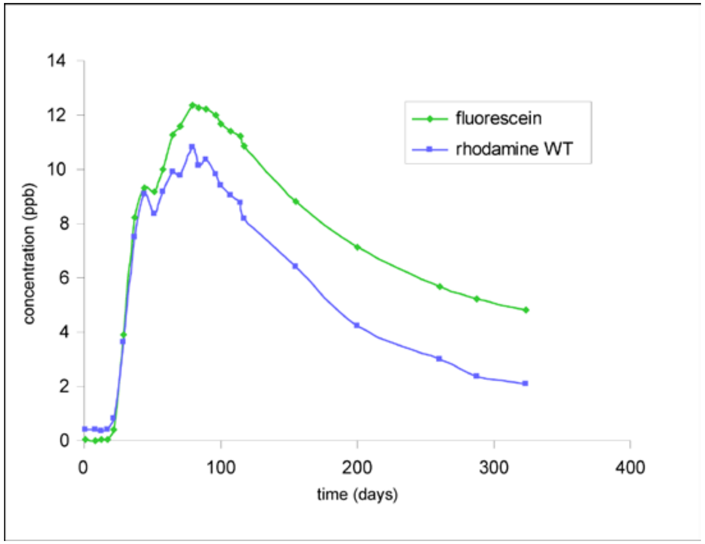
Standardized Approach Developed at INL Allows for Rigorous Analysis of Conservative Tracer Data[1]

Features include:

- A standardization and normalization of the return curve data to yield a residence-time distribution function
- A 'deconvolution' process to subtract out the effect of recycled tracer
- An extrapolation of the return curve to long times
- The calculation of the fluid's mean residence time to give the reservoir pore volume
- A calculation of flow 'geometry' to account for fluid distribution along fast-moving and relatively stagnant pathways

[1]Shook, G.M., Forsmann, J.H., (2005) Tracer interpretation using temporal moments on a spreadsheet, INL/EXT-05-00400, Idaho National Laboratory, Idaho Falls, Idaho.

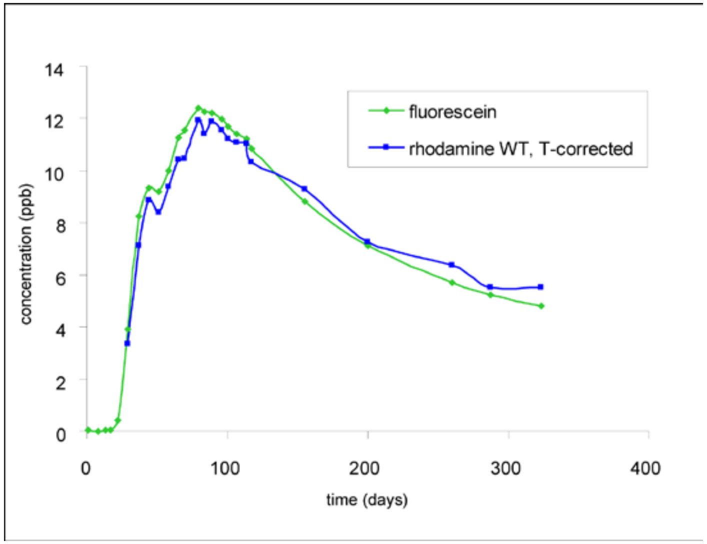
Effective Reservoir Temperature Changes Can Be Measured over Time through Inversion of Thermally Reactive Tracer Data[2]



$$\frac{C_1}{C_2} = \frac{C_1^o}{C_2^o} \cdot e^{(k_2 - k_1)t}$$

$$\frac{C_R}{C_F} = 1.2 \cdot e^{-.00358\ t}$$

$T_{eff} = 163^oC$



Tracer return curves from a test at Steamboat Springs involving the use of a thermally stable tracer in combination with a thermally reactive tracer.

The curves now overlie each other because the concentration of the thermally decaying tracer was corrected by trial-and-error adjustment of the reservoir temperature.

[2]Rose, P.E. and Adams, M.C. (1994) The application of rhodamine WT as a geothermal tracer, *Geothermal Resources Council Transactions,* **18**, pp. 237-240.

Accomplishments, Results and Progress

This project has not yet started.

Future Directions

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Milestone	Expected Completion Date
Background tracer test at Desert Peak well 27-15 using conservative tracer started Feb., 2013	May 31, 2013
Series of 3 reactive-tracer tests at Desert Peak well 27-15 starting May, 2013	Jun 30, 2014
Background tracer test at Raft River EGS well using conservative tracer starting May 2013	Jul 31, 2013
Series of 3 reactive-tracer tests starting July, 2013 at Raft River EGS well	Aug 31, 2014
Series of 3 reactive-tracer tests starting Nov, 2013 at Geysers Prati 32 EGS well	Nov 30, 2014
Analysis of cuttings from Prati 31 to determine evidence of mineral dissolution/precipitation as a result of injection	Nov 30, 2014
Modeling of results of Desert Peak well 27-15 to 74-21 tracer tests to show fracture/flow evolution	Sep 30, 2014
Comparison with microseismic measurements at Desert Peak	Sep 30, 2014
Modeling of results at Raft River EGS well to show fracture/flow evolution	Nov 30, 2014
Comparison with microseismic measurements at Raft River	Nov 30, 2014
Modeling of results of Prati 31 tracer tests to show fracture/flow evolution	Jan 31, 2015
Comparison with microseismic measurements at The Geysers	Jan 31, 2015
Interpretation of results and final report to describe flow and fracture evolution following hydraulic stimulation in an EGS	May 31, 2015

Mandatory Summary Slide

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- A series of thermally-reactive tracer tests will be conducted at three EGS sites:
  - Desert Peak
  - Raft River
  - The Geysers
- Pore volume, ‘effective’ reservoir temperature, dispersivity, and flow distribution will be measured as functions of time after the start of circulation.
- The hydraulic data will be correlated with microseismic activity.
- The obtained data will be available for the calibration of models for simulating the evolution of flow in an EGS over time.

Project Management

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Timeline:

Planned Start Date	Planned End Date	Actual Start Date	Current End Date
August, 2006	August, 2008	Not yet	2 years from start date

Budget:

Federal Share	Cost Share	Planned Expenses to Date	Actual Expenses to Date	Value of Work Completed to Date	Funding needed to Complete Work
$159,976	$40,000	$199,976	$0	$0	$199,976

- Summary of management approach:
  - The project has not yet started since it was intended to begin only after the successful completion of an EGS project
  - It will observe and model the evolution of reservoir flow processes immediately following a successful hydraulic stimulation during the subsequent circulation test
  - Industry stakeholders include Ormat Technologies, U.S. Geothermal, and Calpine