Fracture Evolution Following a Hydraulic Stimulation within an EGS Reservoir

May 18, 2010

Principal Investigator (always include)
Peter Rose
University of Utah

Track Name

Mandatory Overview Slide

- Timeline
  - This project has not yet started.
- Budget
  - DOE share = $159,976
  - awardee share = $40,000
- EGS Barriers:
  - Barrier J: Tracers—Inadequate tracers and/or tracer methodology to accurately define the subsurface system of fractures and mapping of fluid flow.
  - limited fracture detection capability
  - lack of high-temperature monitoring tools and sensors
  - limited flow path identification capacity
  - a lack of suitable tracers
- Partners: Lawrence Berkeley National Laboratory

View the PowerPoint "Notes" page for additional instructions

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 fracture and flow evolution within an EGS reservoir following a hydraulic stimulation(s).
- 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.
  - Flow “impedance” dropped during subsequent circulation tests at Fenton Hill
  - Injectivity in GPK-1 improved significantly during the Soultz 1997 circulation test
  - 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.
- This project will provide the first ever formal evaluation of fracture and fracture flow evolution in an EGS reservoir following a hydraulic stimulation.
- This project will allow for the first application of a suite of tracers for simultaneously measuring temperature changes and fracture surface-area changes in interwell tracer tests.
- A TOUGHREACT analysis of mineral dissolution/precipitation will accompany the fracture/flow evolution analysis and provide additional insights into fracture/flow evolution processes.

Summary of Scientific/Technical Approach

- Conduct repeat tracer tests in a recently stimulated EGS well using a suite of tracers including:
  - Conservative tracers as ‘controls’
  - Thermally reactive tracers
  - Reversibly sorbing tracers
- Analyze the data to measure changes in relevant parameters
  - Mean residence time, reservoir pore volume and fluid distribution along fast and slow pathways using INL’s tracer analysis code.
  - Changes in ‘effective’ reservoir temperature through inversion of tracer decay data
  - Changes in fracture surface area through inversion of tracer sorption/diffusion data
- Reactive transport modeling to explain effects of dissolution and precipitation on fracture/flow evolution

Scientific/Technical Approach

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

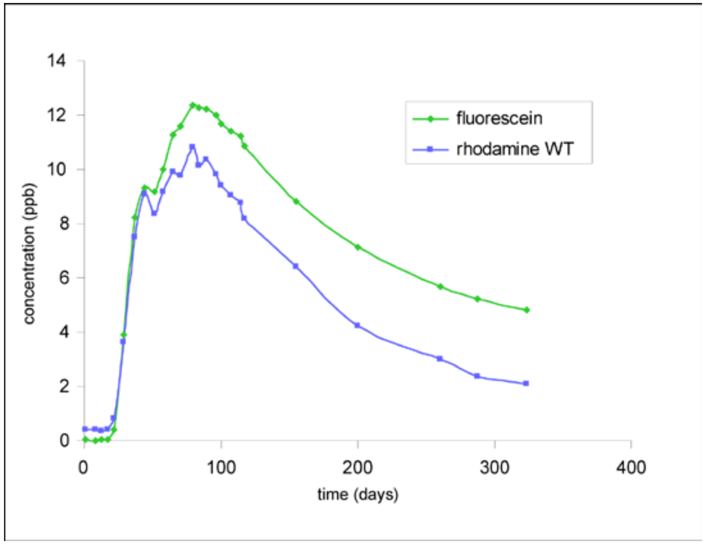
Features include:

- 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.

Scientific/Technical Approach

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

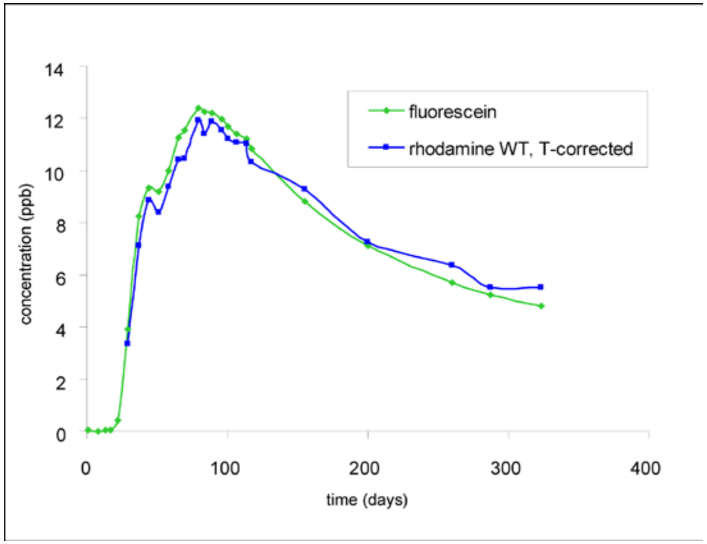


Tracer return curves from a test at Steamboat Springs involving the use of a thermally stable tracer in combination with a thermally reactive tracer.

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

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

T_{eff} = 163°C



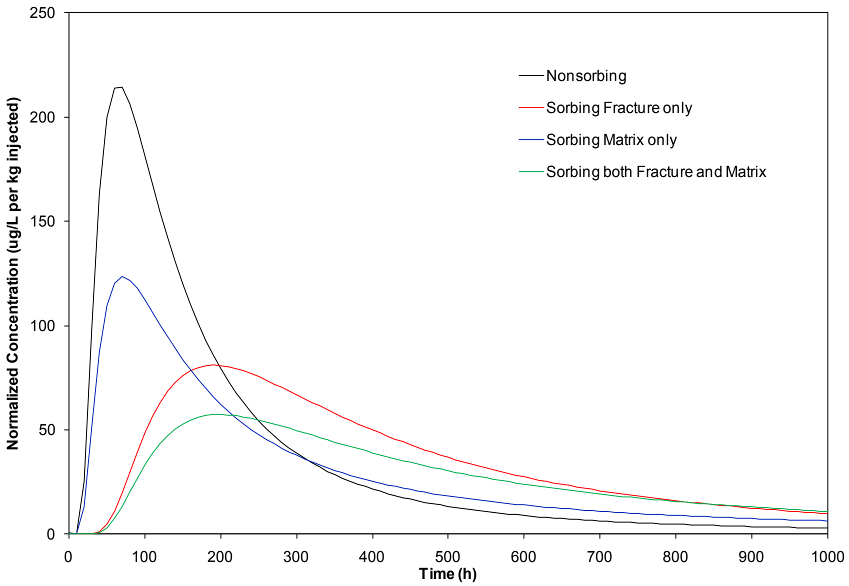
The curves now overlie each other because the concentration of the thermally decaying tracer was corrected by trial-and-error adjustment of the reservoir temperature.

---

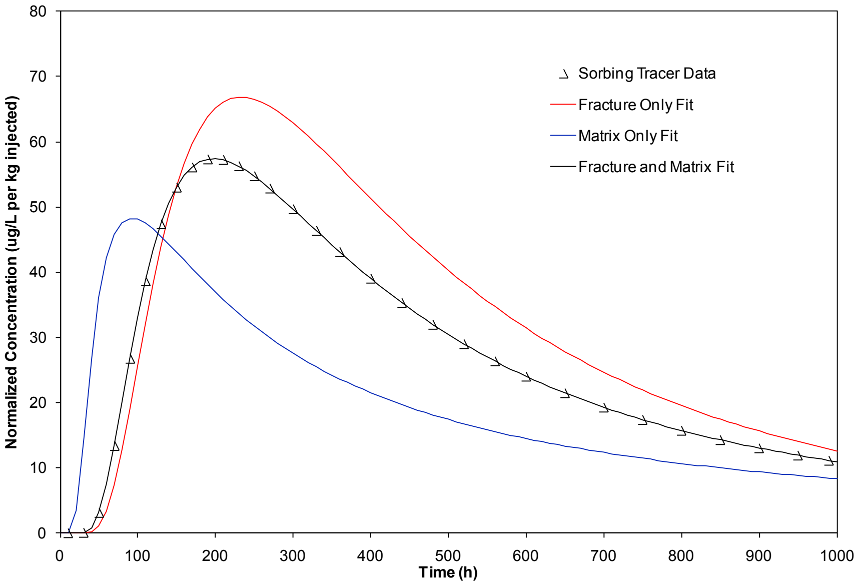
[2] Rose, P.E. and Adams, M.C. (1994) The application of rhodamine WT as a geothermal tracer, *Geothermal Resources Council Transactions,* **18**, pp. 237-240.

Scientific/Technical Approach

Interwell Fracture Surface Area Can Be Measured through Inversion of Sorptive/Diffusive Tracer Data[3].



Breakthrough curve of a nonsorbing tracer and three possible breakthrough curves for a sorbing tracer depending on whether sorption is occurring only in fractures, matrix, or both.



Assuming sorption only in fractures or matrix (red and blue curves) results in much poorer fits to the sorbing tracer breakthrough curve than assuming sorption occurs in both domains. The fracture surface area to volume ratio can be deduced from the best-fitting model parameters for the black curve.

---

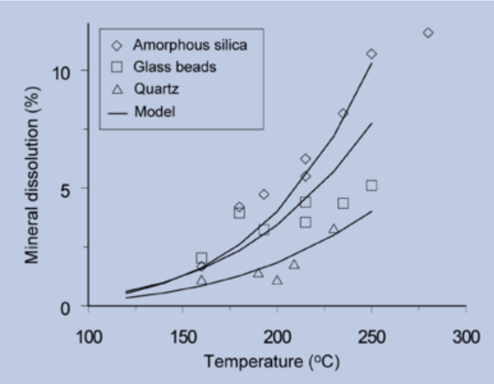
[3] Reimus, P. W., G. Pohll, T. Mihevc, J. Chapman, L. Papelis, B. Lyles, S. Kosinski, R. Niswonger, and P. Sanders. 2003. “Testing and Parameterizing a Conceptual Model for Radionuclide Transport in a Fractured Granite using Multiple Tracers in a Forced-Gradient Test”, Water Resources Research, 39(12), 1350, doi:10.1029/2002WR001597.

Scientific/Technical Approach

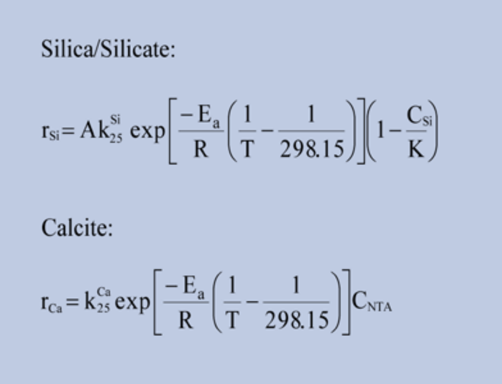
Reactive Transport Modeling Can Provide Valuable Insights into Fracture/Flow Evolution Processes in EGS Reservoirs[4].

Mineral	Weight %
Quartz	9
Calcite	12
Low-Albite	21.5
Anorthite	21.5
K-Feldspar	13
Chlorite	8
Illite	7
Others	8

Vein mineral assemblage obtained from drill cuttings from a well at the Desert Peak geothermal field.



Data from a mineral dissolution study of mineral standards.



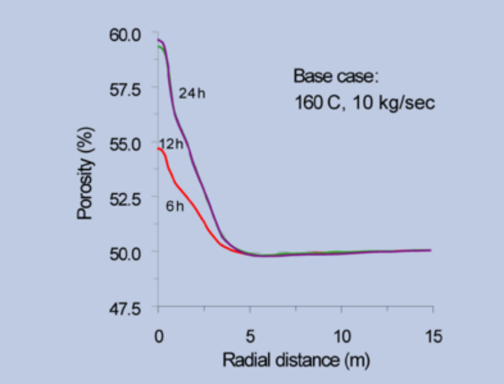
Silica/Silicate:

$$r_{Si} = Ak_{25}^{Si} \exp\left[\frac{-E_a}{R}\left(\frac{1}{T} - \frac{1}{298.15}\right)\right]\left(1 - \frac{C_{Si}}{K}\right)$$

Calcite:

$$r_{Ca} = k_{25}^{Ca} \exp\left[\frac{-E_a}{R}\left(\frac{1}{T} - \frac{1}{298.15}\right)\right] C_{NTA}$$

Mineral dissolution rate expressions used in the reactive transport model.



Results of TOUGHREACT Desert Peak mineral dissolution model.

[4] Rose, P.E., Xu, T. Scott Fayer, S., and Pruess, K. (2010), *World Geothermal Congress of the Geothermal Resources Council, Bali, Indonesia*

Project Management/Coordination

Tasks and Milestones	Year 1												Year 2											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Year 1																								
1.1 Select EGS site and well for 1st tracer test (EGI)	■	■	■																					
1.2 Select and purchase tracers for 1st tracer test (EGI)			■	■	■																			
1.3 Conduct 1st tracer test (EGI)				■	■	■	■	■	■															
1.4 Invert tracer thermal decay model to calculate T_{eff} (EGI)									■	■	■	■												
1.5 Develop sorption/diffusion interwell surface area model (LBNL and LANL)	■	■	■	■	■	■	■	■	■															
1.6 Invert sorption/diffusion model to constrain fracture surface area (LBNL and LANL)									■	■	■	■												
1.7 Obtain data to populate TOUGHREACT interwell dissolution/precipitation model (EGI)				■	■	■	■	■	■															
1.8 Build and run TOUGHREACT interwell dissolution/precipitation model to help explain fracture/flow evolution (LBNL)							■	■	■	■	■	■												
Year 2																								
2.1 Select and purchase tracers for 2nd tracer test (EGI)													■	■	■									
2.2 Conduct 2nd tracer test (EGI)																■	■	■	■	■	■			
2.3 Invert tracer thermal decay model to calculate T_{eff} (EGI)																					■	■	■	
2.4 Update sorption/diffusion interwell surface area model and update analysis of 1st tracer test (LBNL and LANL)													■	■	■	■	■	■	■	■	■			
2.5 Invert sorption/diffusion model to constrain fracture surface area based on 2nd tracer test (LBNL and LANL)																					■	■	■	
2.6 Update data (as required) to populate TOUGHREACT interwell dissolution/precipitation model (EGI)													■	■	■	■	■							
2.7 Run TOUGHREACT interwell dissolution/precipitation model to help explain fracture/flow evolution (LBNL)																	■	■	■	■	■	■		
2.4 Analyze data to assess and explain fracture/flow evolution resulting from circulation within a newly created EGS (EGI, LBNL and LANL)																■	■					■	■	■

Future Directions

Depending on the results at the end of the 2-year program, we may propose to continue the monitoring and modeling of the fracture/flow evolution for a more extended period.

Mandatory Summary Slide

Summary and Conclusions

- Anecdotal evidence exists of rapid changes following hydraulic stimulations at the initiation of circulation.
- This project will provide the first ever formal evaluation of fracture and flow evolution in an EGS reservoir following a hydraulic stimulation.
- This project will allow for the first application of a suite of tracers for simultaneously measuring temperature changes and fracture surface-area changes in interwell tracer tests.
- A TOUGHREACT analysis of mineral dissolution/precipitation will accompany the fracture/flow evolution analysis and provide additional insights into fracture/flow evolution processes.