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Karsten Pruess

Tianfu Xu

Christine Doughty

Tracer Methods for Characterizing Fracture Stimulation in Engineered Geothermal Systems (EGS)

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Karsten Pruess
Lawrence Berkeley National Lab.

Overview

- The project started in the last quarter of FY09
- Expected end date is November 30, 2012
- Budget: 51 k$ (FY09), 93 k$ (FY10); 100 % DOE funding
- The research addresses the following barriers identified in the multi-year geothermal R&D plan: A, B, E, F, G, I, J, L, M, O, Y
- Collaboration with EGI, University of Utah (UoU, Pete Rose)

Relevance/Impact of Research

The objective of the project is to design and analyze laboratory and field experiments that would

- identify tracers with sorption properties favorable for EGS applications,
- apply reversibly sorbing tracers to determine the fracture-matrix interface area available for heat transfer, and
- explore the feasibility of obtaining fracture-matrix interface area from non-isothermal, single-well injection-withdrawal (SWIW) tests.

Scientific/Technical Approach

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- Develop mathematical models for the behavior of reversibly sorbing tracers.
- Use our TOUGH2 and TOUGHREACT simulators to explore the design of interwell and single-well tracer tests for determining fracture-matrix heat transfer area.
- Use numerical simulation to analyze laboratory and field tracer tests.
- Provide support to the U of Utah group (Pete Rose).
- FY10 milestone: Report on tracer testing for characterizing EGS reservoirs, September 30, 2010.

Accomplishments and Progress

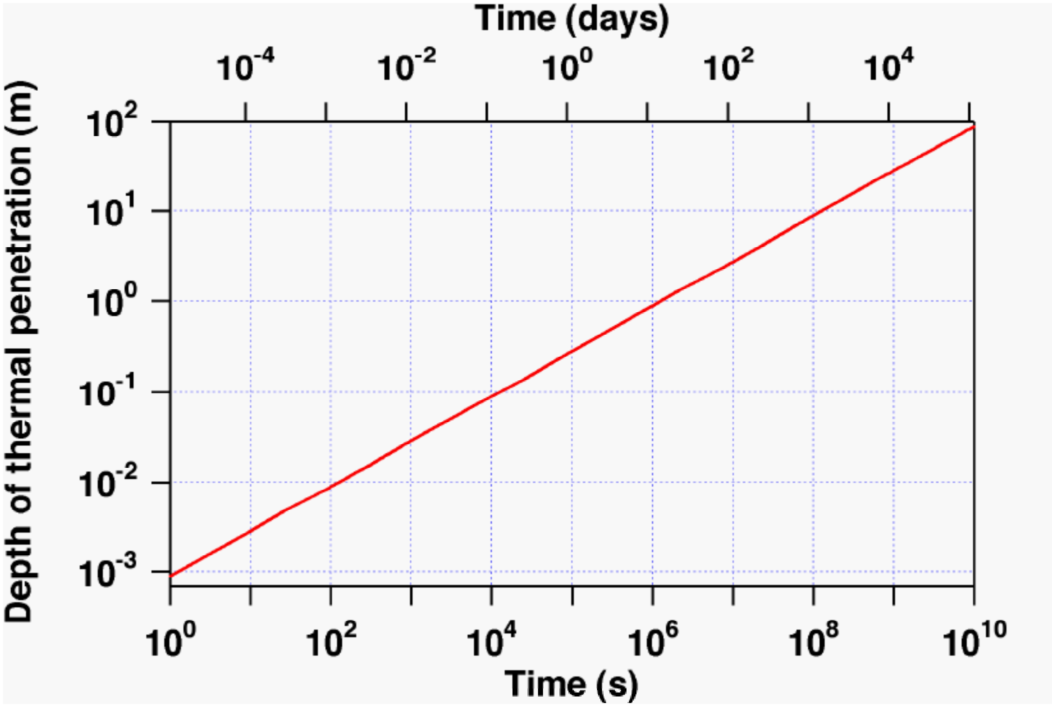
- Conceived of the novel idea of using temperature as a tracer in single-well injection-withdrawal tests (SWIW).
- Demonstrated that temperature recovery in SWIW tests is more rapid for larger fracture-matrix interface area.
- Demonstrated mathematical equivalence between reversibly sorbing solute tracers and temperature, where fluid-rock heat exchange plays the role of reversible sorption.
- Demonstrated excellent agreement between numerical and analytical solutions for fluid temperature in the fractures in non-isothermal injection.

What Makes Thermal SWIW Tests Attractive?

- Temperature effects depend directly on heat exchange between fractures and matrix, the essential process of heat mining that we aim to characterize.
- Thermal diffusivity of rocks is of order 10^{-6} m^2/s, 4-5 orders of magnitude larger than effective solute diffusivities; so will get much stronger fracture-matrix interaction.
- Heat conduction is a diffusive process that is very "robust," depending as it does only on thermal parameters of rocks and fluids, whereas solute diffusion is sensitive to tortuosity effects that may be difficult to characterize and add uncertainty to interpretation.
- Local heat exchange between fluids and rocks is analogous to reversible linear sorption of solute tracer, but the process depends only on robust thermal parameters, not on highly heterogeneous and difficult-to-characterize mineral abundances and surfaces as for sorbing solutes.

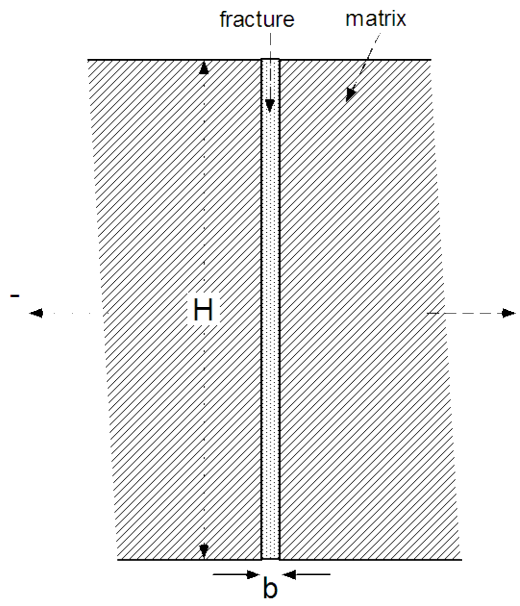
Accomplishments and Progress

Temperature changes penetrate far more rapidly into rocks adjacent to fractures than changes in solute concentrations. (In 10^6 s, T penetrates about 1 m, conservative solutes would penetrate a few millimeters, reversibly sorbing solutes would penetrate 1-3 orders of magnitude less.)

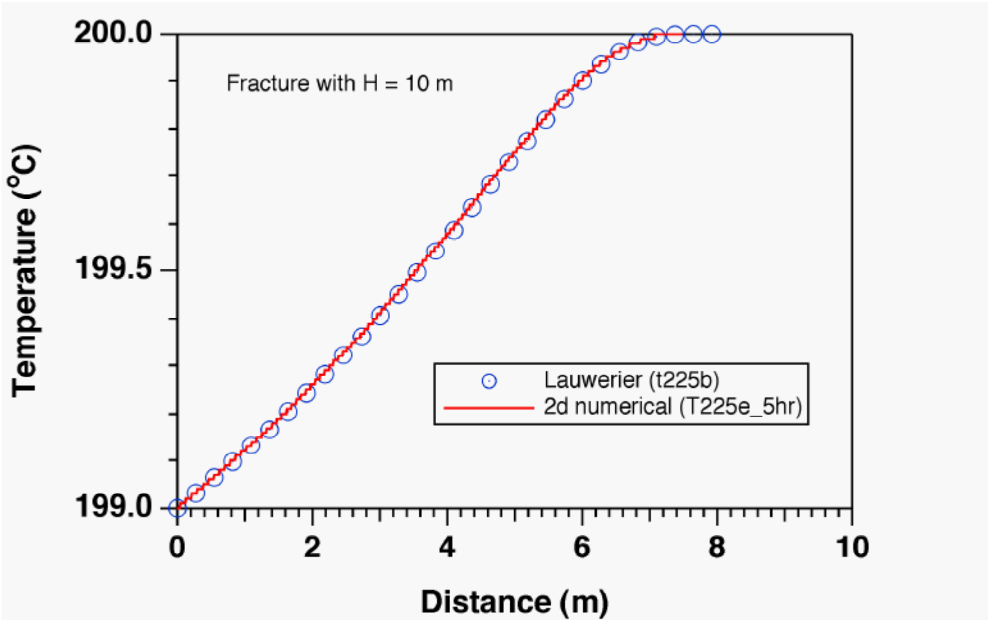


Accomplishments and Progress

Conceptual model of fracture-matrix system

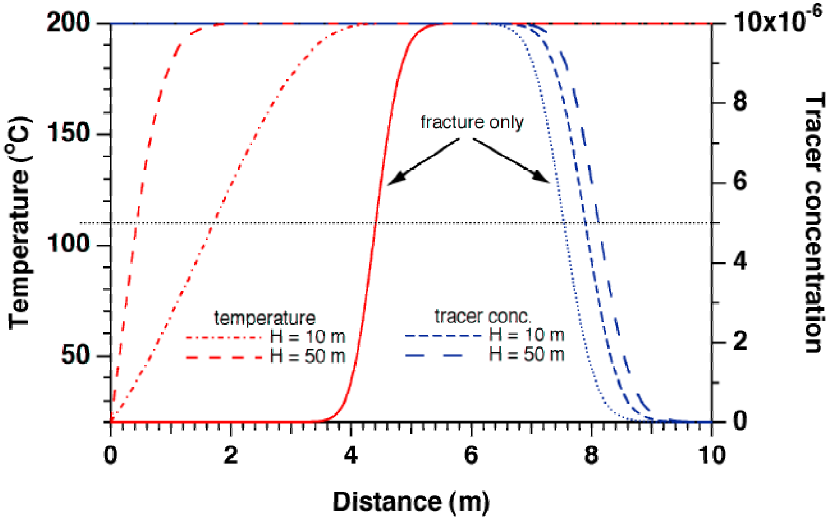


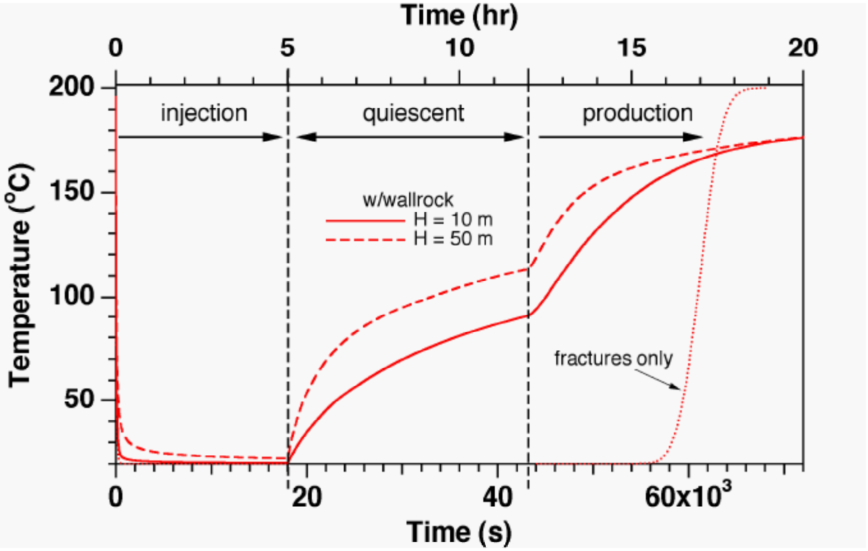
Temperature profiles in the fracture after 5 hours of non-isothermal injection



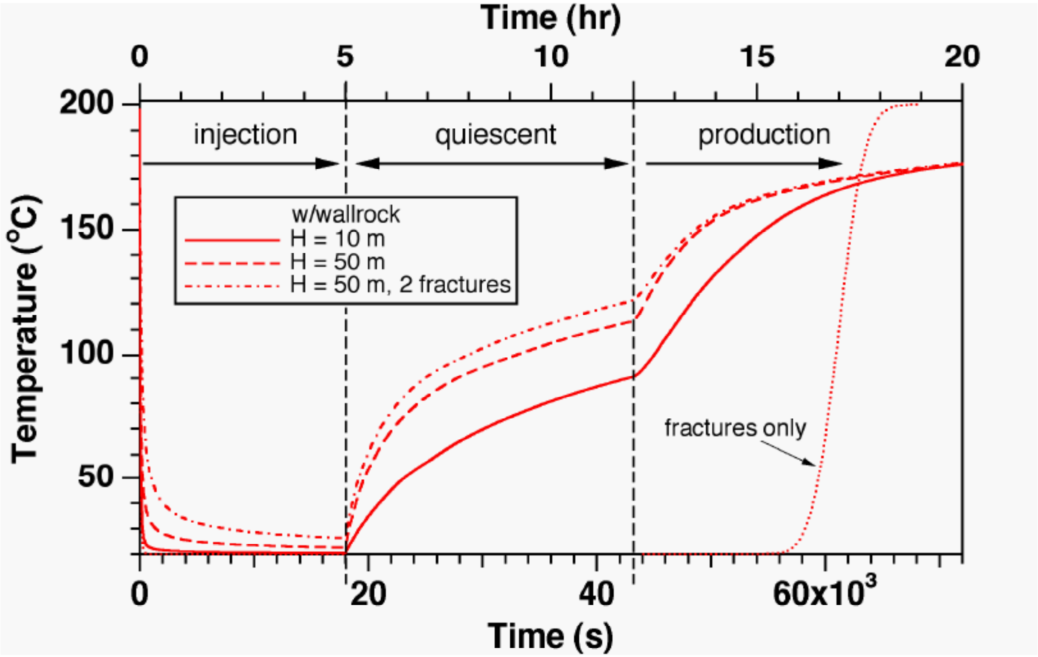
Temperature profiles show excellent agreement between analytical results (Lauwerier) and TOUGH2 simulations (numerical).

Temperature recovery subsequent to cold water injection is more rapid for larger specific fracture-matrix interface area.





Increased fracture-matrix interface area, as would be induced by stimulation, will accelerate temperature recovery.



Accomplishments and Progress

Mathematical equivalence between transport of reversibly-sorbing solutes and heat.

	Solute	Heat
Governing eq.	$\frac{\partial}{\partial t}\left[\phi + (1-\phi)\rho_R K_d\right]C = -\operatorname{div}\mathbf{F}$	$\frac{\partial}{\partial t}\left[\phi\rho_w c_w + (1-\phi)\rho_R c_R\right]T = -\operatorname{div}\mathbf{G}$
Flux	$\mathbf{F} = \mathbf{u}C - D_{eff}\phi\nabla C$	$\mathbf{G} = \mathbf{u}\rho_w h_w - K\nabla T$
Retardation coef.	$R_C = 1 + \frac{(1-\phi)\rho_R K_d}{\phi}$	$R_{th} = 1 + \frac{(1-\phi)\rho_R c_R}{\phi\rho_w c_w}$

Project Management/Coordination

- This is a small project, carried out primarily by myself, with additional efforts provided by my colleagues Tianfu Xu and Christine Doughty.
- An essential aspect of the project is close collaboration and coordination with Pete Rose's group at U of Utah (UoU).
- Collaboration involves exchange of technical information, technical discussions, and guidance and support for the development and application of mathematical models.
- Specifically, LBNL modeling advances provide guidance for the design and analysis of laboratory and field experiments performed or promoted by UoU; UoU test designs and results motivate LBNL model development and applications.

Future Directions

- Continue development and application of mathematical models for design and analysis of laboratory and field tracer experiments.
- Work with UoU to develop and analyze tests with reversibly sorbing tracers.
- Explore (optimal) design of thermal SWIW tests for determining f-m interface area and quantifying the success of stimulation treatments.
- Explore application of a dispersion-free particle tracking method for analysis of thermal SWIW.

Summary

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- In non-isothermal injection tests, temperature behaves like a reversibly sorbing solute tracer, with fluid-rock heat exchange playing the role of sorption (mathematical equivalence).
- Fracture-matrix interaction is much stronger for heat than for solutes, and depends only on robust thermal parameters, as opposed to highly variable solute diffusion and sorption.
- Single-well injection-withdrawal tests (SWIW) with temperature as tracer look promising as a tool for determining f-m interface area.

Publications and Presentations

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Pruess, K. and C. Doughty. Thermal Single-Well Injection-Withdrawal Tracer Tests for Determining Fracture-Matrix Heat Transfer Area, *Proceedings,* Thirty-Fifth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, February 1-3, 2010.