

A TRACER TEST AT THE SODA LAKE, NEVADA GEOTHERMAL FIELD USING A SORBING TRACER

Peter Rose¹, Kevin Leecaster¹, Scott Clausen¹, Raphael Sanjuan¹, Morgan Ames¹, Paul Reimus²,
Mark Williams³, Vince Vermeul³, and Dick Benoit⁴

¹Energy and Geoscience Institute at the University of Utah
423 Wakara Way suite 300
Salt Lake City, Utah 84108
e-mail: prose@egi.utah.edu

²Los Alamos National Laboratory

³Pacific Northwest National Laboratory

⁴Magma Energy Corporation

ABSTRACT

A method was demonstrated for estimating the fracture surface area along an injection-production flow path within a geothermal reservoir. First, the flow retardation of a reversibly sorbing tracer was measured relative to that of a nonsorbing conservative tracer under laboratory conditions intended to simulate those of a geothermal reservoir. Next, a numerical model was developed, which, upon inversion, could serve to calculate the fracture surface area for sorption, which is the same as the fracture surface area for heat exchange. Finally, a tracer test was conducted at the Soda Lake geothermal field using a combination of sorbing and conservative tracers. Both the conservative and sorbing tracers were produced, although the sorbing tracer was severely thermally degraded. The tracer data were subsequently used to calibrate the flow model.

INTRODUCTION

Conservative tracers for use in liquid-dominated geothermal reservoirs have been successfully developed in the laboratory and demonstrated in field experiments throughout the world (Rose et al., 2001; Rose et al, 2002a; Rose et al., 2002b). Successful candidates for this application must be very detectable, nontoxic, environmentally benign, affordable, and available in bulk. In addition, in order to be classified as conservative tracers, they must behave as inert solutes as they are advected through the hydrothermal system. This demands that these compounds be thermally stable and non-sorptive on geothermal media at elevated temperature.

Reactive tracers, in contrast, are designed to interact with either the fluid or the rock as they are advected through a geothermal reservoir. In particular, sorptive tracers sorb and desorb rapidly as they pass through the system. Their passage is thereby retarded relative to a nonreactive (or conservative) tracer. Since reversible sorption is a function of the fracture surface area, sorptive tracers can, in principle, be used to measure the fracture surface area within a geothermal reservoir, which is the area for heat transfer at the interface between the rock and the fluid. In addition to being reversibly sorptive, successful candidates must also possess all of the desirable properties of conservative-tracer candidates, including good detectability, thermal stability, affordability, nontoxicity, etc.

Once a candidate sorptive tracer has been identified and characterized in the laboratory, it is ready for testing within a geothermal reservoir. In such a test, the sorptive tracer is injected into the reservoir simultaneously with a conservative tracer. Water sampled at production wells is analyzed for the reactive and conservative tracers. An appropriately constructed and calibrated reservoir model can then be inverted to solve for the fracture-surface area along the injection-production flow pathway.

This paper demonstrates a method for calculating the fracture surface area within a geothermal reservoir. Based upon laboratory tests to determine its sorptive and thermal stability properties, the candidate tracer Safranin T was selected for a field experiment at the Soda Lake geothermal field. Subsequent numerical modeling experiments were conducted for the purpose of determining the fracture surface area between the injection and production wells.

EXPERIMENTAL METHODS

Safranin T Sorption Studies

Sorption studies were conducted in the laboratory under conditions that simulate a geothermal reservoir. A tracer solution consisting of a conservative tracer 1,5-naphthalene disulfonate (1,5-nds) and the sorbing tracer Safranin T were pumped through a sand-packed column reactor. After equilibrating the column with a buffered aqueous solution without tracer, a valve was switched, allowing for flow of the tracer-dissolved solution through the column. Shown in Figure 1 are the responses of the tracers measured at the exit of the reactor, which, for this experiment, was maintained at a constant temperature of 160 °C. Details of this and related sorption experiments are reported elsewhere (Leecaster et al., 2012, these proceedings).

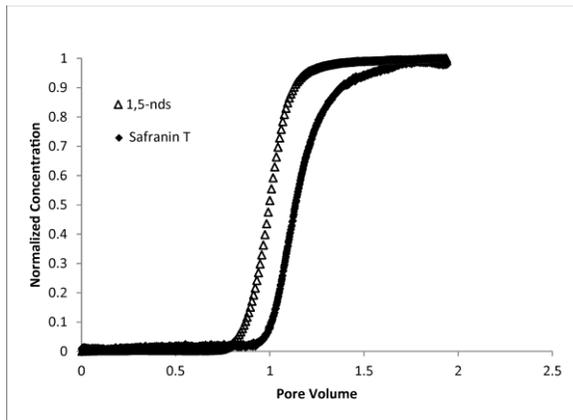


Figure 1: Measured concentrations of conservative tracer, 1,5-nds, and sorbing tracer, Safranin T, in a flow experiment using a sand-packed column at 160 °C.

Safranin T Thermal Decay Kinetics

The decay kinetics of Safranin T was determined under controlled laboratory conditions using an autoclave batch reactor. The experimental approach is described elsewhere (Rose et al., 2001).

The thermal decay of Safranin T can be modeled by the first-order differential equation:

$$-dC_S/dt = k_S \cdot C_S \quad (1)$$

where C_S is the concentration of Safranin T and k_S is a pseudo-first-order decay-rate constant. Solution of this equation results in the following relationship between C_S and t :

$$\ln \left(\frac{C_S}{C_S^0} \right) = -k_S \cdot t \quad (2)$$

where C_S^0 is the initial concentration of Safranin T. The temperature dependence of k_S can be described by the Arrhenius relationship:

$$k_S = A e^{(-E_a/RT)} \quad (3)$$

where A is the pre-exponential factor, E_a is the energy of activation, R is the gas constant and T is absolute temperature. A linearization of the Arrhenius expression results in the following:

$$\ln k_S = \ln A - \frac{E_a}{RT} \quad (4)$$

Figure 2 shows a fairly linear relationship between $\ln k_S$ and inverse temperature, indicating that the Arrhenius equation provides a reasonable means for expressing the temperature dependence of the decay rate constant.

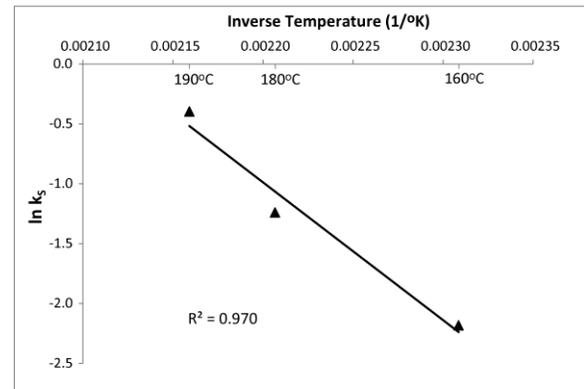


Figure 2. Arrhenius plot of the natural logarithm of the decay rate constant vs. inverse temperature for Safranin T under laboratory conditions simulating a geothermal reservoir between 160°C and 190°C.

The straight line in Figure 2 was determined by a linear least-squares fit to the data. Solving for the slope and intercept results in the following expression that can be used to determine the decay constant (in inverse days) at any temperature between 160°C and 190°C:

$$\ln k_S = 24.3 - \frac{11500}{T} \quad (5)$$

THE FIELD EXPERIMENT

On 8/30/2011, 50 kg of 1,6-naphthalene disulfonate and 90 kg of Safranin T were injected in Soda Lake well 45A-33. Produced brine was then injected into

45A-33 during the subsequent 28 days. Water was sampled at production well 32-33 and sent to EGI for analysis. The separation at depth between 45A-33 and 32-33 is approximately 550 m.

Shown in Figure 3 are plots of the returns of 1,6-nds and Safranin T, reflecting the very strong connection between the two wells. First and peak arrivals of the conservative tracer were at 1.8 and 4.8 days, respectively. In contrast, first and peak arrivals of the sorbing (and thermally decaying) tracer were at 2.8 and 6.3 days, respectively.

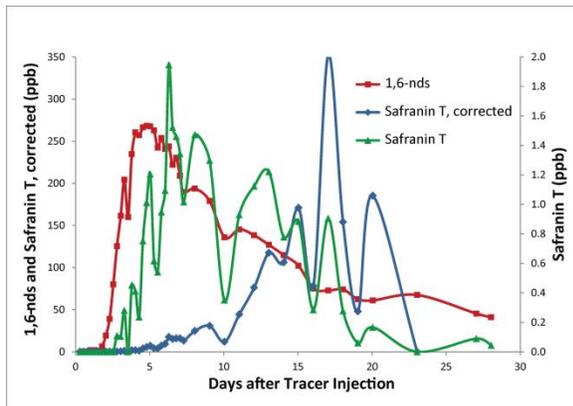


Figure 3: Tracer concentrations as measured in well 32-33 during the 28 days following tracer injection in well 45A-33. Shown in red are the concentrations of the conservative tracer 1,6-nds and in green the concentrations of the sorbing tracer Safranin T. The blue points plot the return of Safranin T after correcting for thermal decay assuming an effective mean interwell temperature of 180°C.

The amount of 1,6-nds returned to 32-33 was calculated to be 30%, not accounting for any recycle. After correcting for recycle, the ‘single-pass’ mass recovery was calculated to be 28.7%. This is the percentage of 1,6-nds that was recovered at 32-33 after subtracting the amount of tracer that was recycled through the plant and the subsurface and produced more than once at 32-33. The amount of recovered Safranin T was calculated to be 0.1%.

The Safranin T data were corrected for thermal decay based upon the kinetics described in the previous section. The effective temperature along the 45A-33-to-32-33 pathway was not known, but it was assumed to be between 70°C (the temperature of the injection fluid) and 190°C (the temperature of the produced fluid). For the purposes of this exercise, the effective temperature was assumed to be 180°C, given that

45A-33 is not on injection and therefore not cooled significantly by injection fluids.

The Safranin T curve, corrected for thermal decay assuming an effective reservoir temperature of 180°C, is shown in blue in Figure 3 for the first 16 days of the tracer test. This is the shape that the curve would have had if the Safranin T were to sorb but not decay thermally.

A NUMERICAL MODEL

A numerical model was constructed for the purpose of simulating the advection of the conservative and sorbing tracers (see Reimus et al, these proceedings). Since tracer sorption is based upon the fracture surface area along the injection-production flow path, inversion of the tracer data allows for a calculation of the sorption surface area, which is equivalent to the heat transfer surface area.

Shown in Figure 4 are the conservative and sorbing tracer data and the fit to those data for several model realizations. The sorbing tracer data were corrected for thermal decay according to the Arrhenius model discussed in the previous section, assuming a temperature of 180°C. The model shows reasonably good fit to both the conservative and sorbing tracer data, and may indicate a slightly better fit for the model that includes high matrix diffusion.

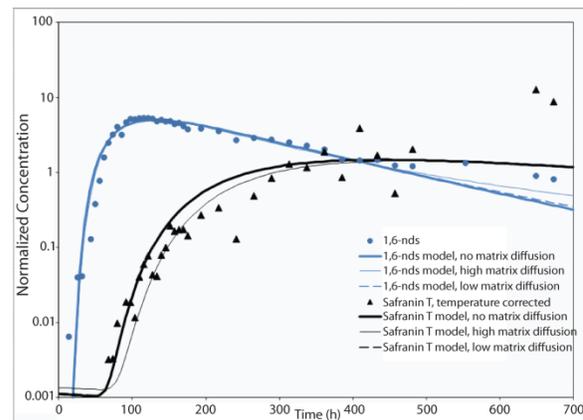


Figure 4: Modeled conservative and sorbing tracer data assuming an effective mean interwell temperature of 180°C.

DISCUSSION

The objective of this project was to demonstrate an approach for calculating the fracture surface area along an injection/production pathway within a geothermal reservoir using a reversibly sorbing tracer. Whereas the method shows promise, the sorbing tracer Safranin T was severely degraded after just a few days at the reservoir temperature at Soda

Lake. A sorbing tracer that suffers no (or very little) thermal degradation is needed in order that it can be produced in sufficient concentration to assure accuracy.

Another shortcoming is that the laboratory sorption experiments were conducted using silica sand particles, whereas the reservoir rock is quite different. Likewise, the laboratory sorption experiments were conducted between 120°C and 160°C, whereas the effective reservoir temperature is 180°C. In order to develop an accurate numerical model, laboratory experiments need to accurately reflect field conditions of reservoir temperature and rock type.

SUMMARY AND CONCLUSIONS

A method was demonstrated for calculating the fracture surface area along an interwell injection-production flow path. The flow retardation of a sorbing tracer, Safranin T, was measured relative to that of a conservative tracer, 1,5-naphthalene disulfonate, under geothermal conditions. A tracer test was then conducted at the Soda Lake geothermal field using this same sorbing tracer and a similar conservative tracer, 1,6-naphthalene disulfonate. Given that Safranin T was quite thermally labile, batch autoclave experiments were required for the purpose of measuring and modeling its thermal decay.

A numerical flow model was developed, which, upon inversion, can serve to calculate the fracture surface area for sorption, which is the fracture surface area for heat exchange. In spite of the thermal instability of the Safranin T and a lack of relevant relative retardation data, this project demonstrates the first successful use of a sorbing tracer in combination with conservative tracer to calculate fracture surface area within a geothermal reservoir ever reported in the open literature.

REFERENCES

Leecaster, K., Ayling, B., Moffitt, G., Clausen, S. and Rose, P.E. "Use of Safranin T as a Reactive Tracer for Geothermal Reservoir Characterization" (2012) *PROCEEDINGS, Thirty-Seventh Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, January 30 - February 1, 2012, SGP-TR-194.*

Reimus et al. (2012) *PROCEEDINGS, Thirty-Seventh Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, January 30 - February 1, 2012, SGP-TR-194.*

Rose, P.E., Benoit, W.R., and Kilbourn, P.M., (2001), "The application of the polyaromatic sulfonates as tracers in geothermal reservoirs": *Geothermics*, 30(6), pp. 617-640.

Rose, P.E., Capuno, V., Peh, A., Kilbourn, P.M., and Kasteler, C. (2002a) The Use of the Naphthalene Sulfonates as Tracers in High Temperature Geothermal Systems, *Proceedings 23rd PNOG Geothermal Conference.*

Rose, P.E., Johnson, S.D., and Kilbourn, P.M., and Kasteler, C. (2002b) Tracer Testing at Dixie Valley, Nevada Using 1-Naphthalene Sulfonate and 2,6-Naphthalene Disulfonate: *Proc. Twenty-Seventh Workshop on Geothermal Reservoir Engineering, Stanford University, SGP-TR-171.*

Acknowledgment: "This material is based upon work supported by the Department of Energy under Award Number **DE-GO18193**

Disclaimer: "This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof."