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## ***FORMATION THERMAL CONDUCTIVITY TEST AND DATA ANALYSIS***

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Analysis for:

**Green Inq  
9413 Cedarview Way  
Elk Grove, CA 95758  
Phone: (916) 683-5151  
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Test location:

**Collaborative Support Facility  
NASA Ames Research Center  
Moffett Field, CA**

Report Date:

January 20, 2009

Test Performed by:

**Green Inq**

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## Executive Summary

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A formation thermal conductivity test was performed at the Collaborative Support Facility site at the NASA Ames Research Center in Moffett Field, California. The vertical bore was completed on December 19, 2008 by Guardino Well Drilling, Inc. GRTI's test unit was attached to the vertical bore on the morning of January 9, 2009. Geothermal Resource Technologies, Inc. analyzed the collected data using the "line source" method.

This report provides a general overview of the test and procedures that were used to perform the thermal conductivity test along with a plot of the data in real time and in a form used to calculate the formation thermal conductivity. The following average formation thermal conductivity was found from the data analysis.

⇒ Formation Thermal Conductivity = 0.88 Btu/hr-ft-°F

Due to the necessity of a thermal diffusivity value in the design calculation process, an estimate of the average thermal diffusivity was made for the encountered formation.

⇒ Formation Thermal Diffusivity  $\approx$  0.61 ft<sup>2</sup>/day

An estimate of the undisturbed formation temperature was determined from the initial temperature data at startup.

⇒ Undisturbed Formation Temperature  $\approx$  65-66°F

A copy of the original collected data is available either in a hard copy or an electronic format upon request.

## Test Procedures

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The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) has published a set of recommended procedures for performing formation thermal conductivity tests for geothermal applications. GRTI is committed to adhering to ASHRAE recommendations. Some of these recommended procedures are listed below:

- (1) Required Test Duration – A minimum test duration of 36 hours is recommended, with a preference toward 48 hours.
- (2) Power Quality – The standard deviation of the power should be less than or equal to 1.5% of the average power, with maximum power variation of less than or equal to 10% of the average power. The heat flux rate should be 51 Btu/hr (15 W) to 85 Btu/hr (25 W) per foot of borehole depth to best simulate the expected peak loads on the u-bend.
- (3) Undisturbed Formation Temperature Measurement – The undisturbed formation temperature should be determined by recording the minimum loop temperature as the water returns from the u-bend at test startup.
- (4) Installation Procedures for Test Loops – The bore diameter is to be no larger than 6 inches, with 4.5 inches being the target diameter. To ensure against bridging and voids, the bore annulus is to be uniformly grouted from the bottom to the top using a tremie pipe.
- (5) Time Between Loop Installation and Testing – A minimum delay of five days between loop installation and test startup is recommended if the formation is expected to have a low thermal conductivity or if low conductivity grouts ( $< 0.75$  Btu/hr·ft·°F) are used. A minimum delay of three days is recommended for all other conditions.

GRTI's testing procedures deviate slightly from those above with regard to item (5). While item (5) bases the delay between installation and testing on the expected formation conductivity, GRTI bases its delay on the type of drilling used in the installation. When air drilling is required, a five-day delay is recommended to allow the bore to return to its undisturbed temperature. For mud rotary drilling, a minimum waiting period of two days is sufficient.

For a complete list of recommended procedures, refer to the ASHRAE 2007 HVAC Applications handbook, pages 32.12-32.13.

## Data Analysis

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Geothermal Resource Technologies, Inc. uses the "line source" method of data analysis. The line source equation used is not valid for early test times. Also, the line source method assumes an infinitely thin line source of heat in a continuous medium. If a u-bend grouted in a borehole is used to inject heat into the ground at a constant rate in order to determine the average formation thermal conductivity, the test must be run long enough to allow the finite dimensions of the u-bend pipes and the grout to become insignificant. Experience has shown that the amount of time required to allow early test time error and finite borehole dimension effects to become insignificant is approximately ten hours.

In order to analyze real data from a formation thermal conductivity test, the average temperature of the water entering and exiting the u-bend heat exchanger is plotted versus the natural log of time. Using the Method of Least Squares, the linear equation coefficients are then calculated that produce a line that fits the data. This procedure is normally repeated for various time intervals to ensure that variations in the power or other effects are not producing erroneous results.

Through the analysis process, the collected raw data is converted to spreadsheet format (Microsoft Excel®) for final analysis. A copy of this data can be obtained either in a hard copy or electronic copy format at any time. If desired, please contact Geothermal Resource Technologies, Inc. and provide a ship-to address or e-mail address at one of the following:

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Fax: (605) 692-2604

E-mail: [gstreich@grti.com](mailto:gstreich@grti.com)

# Formation Thermal Conductivity Test Report

Date ..... January 9-11, 2009  
 Location ..... Moffett Field, CA  
 Undisturbed Formation Temperature ..... Approx. 65-66°F

## Borehole Data – As Provided by Guardino Well Drilling, Inc.

Borehole Diameter ..... 6 inches

Drill Log .....	Adobe clay	0'-8'
	Sticky brown clay	8'-25'
	Sandy gravel	25'-85'
	Sticky brown clay	85'-90'
	Sand	90'-98'
	Brown clay	98'-102'
	Sand	102'-112'
	Brown clay	112'-119'
	Sand	119'-155'
	Brown clay	155'-160'
	Sand	160'-178'
	Brown clay	178'-183'
	Sand	183'-188'
	Blue sticky clay with sand streaks	188'-280'
	Brown claystone	280'-285'
	Sticky blue clay	285'-300'

Note: Water flow of 25 gpm noted.

U-bend Size ..... 1 inch HDPE  
 U-Bend Length ..... 210 ft  
 Grout Type ..... GeoPro TG Lite 1.0  
 Grout Solids ..... 250 lb sand per 50 lb bentonite  
 Grouted Portion ..... 0-210 ft

Note: Mix 111 cement grout installed at 150-152 ft, 100-102 ft, and 50-52 ft to prevent artesian water flow.

## Test Data

Test Duration ..... 50.1 hrs.  
 Average Voltage ..... 239.9 V  
 Average Power ..... 4,160 W  
 Total Heat Input Rate ..... 14,199 Btu/hr  
 Calculated Circulator Flow Rate ..... 7.5 gpm  
 Standard Deviation of Power ..... 0.12%  
 Maximum Variation in Power ..... 0.37%

# Collaborative Support Facility, Moffett Field, CA January 9-11, 2009

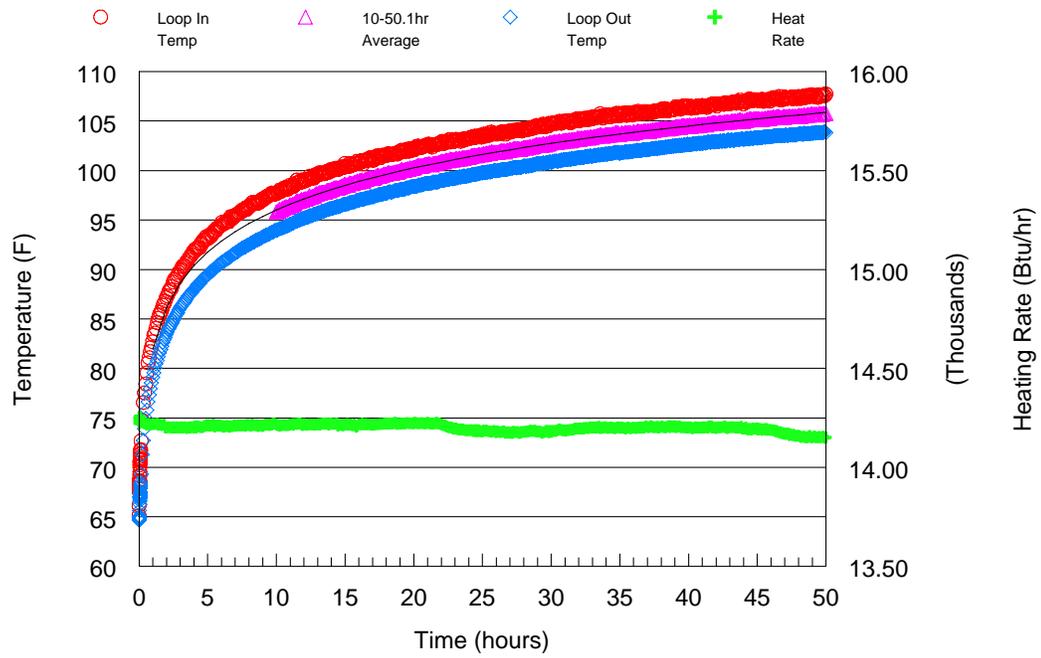
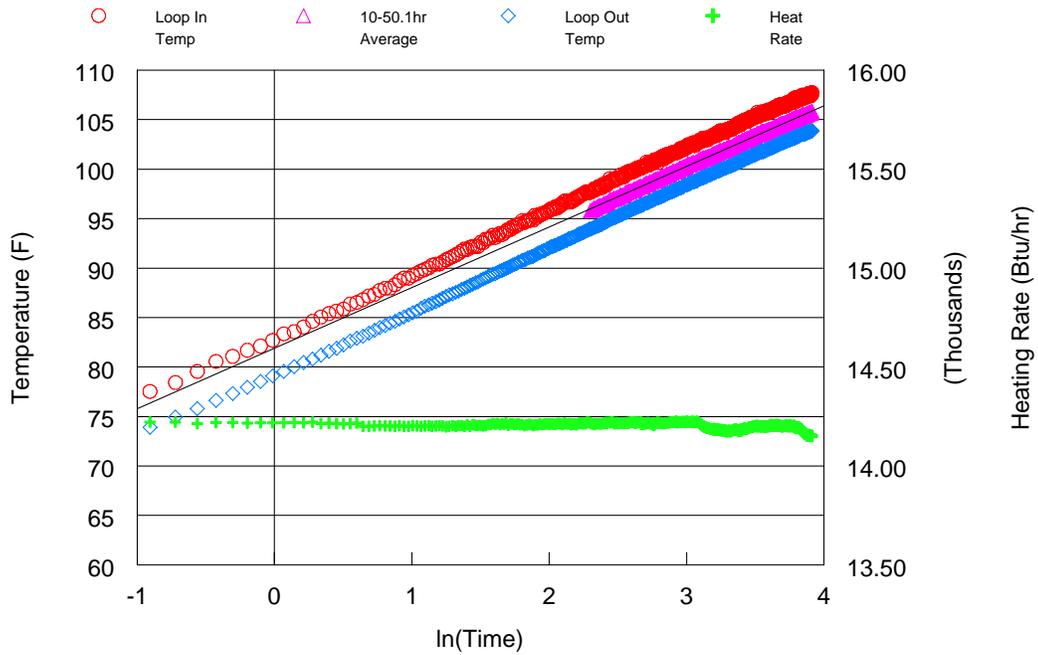


Figure 1: Temperature versus Time Data

# Line Source Data Analysis

## Collaborative Support Facility, Moffett Field, CA January 9-11, 2009



**Figure 2: Temperature versus Natural Log of Time**

Time Period	Slope: $a_1$	Average Heat Input (Btu/hr-ft)	(W/ft)	Thermal Conductivity (Btu/hr-ft-°F)
10 – 50.1 hrs	6.12	67.6	19.8	0.88

The temperature versus time data was analyzed using the line source analysis for the time period shown above. An average linear curve fit was applied to the data between 10 and 50.1 hours. The slope of the curve ( $a_1$ ) was found to be 6.12. The resulting thermal conductivity was found to be 0.88 Btu/hr-ft-°F.

## Estimated Thermal Diffusivity

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The reported drilling log for this test borehole indicated that the formation consisted of clay, sand and gravel. A weighted average of heat capacity values based on the indicated formation was used to develop an average heat capacity for the formation. An estimated diffusivity value was then found using the calculated formation thermal conductivity and the estimated heat capacity. The thermal diffusivity for this formation was estimated to be 0.61 ft<sup>2</sup>/day.

Est. Average Heat Capacity (Btu/ft <sup>3</sup> °F)	Thermal Conductivity (Btu/hr-ft-°F)	Est. Thermal Diffusivity (ft <sup>2</sup> /day)
34.6	0.88	0.61

## Frequently Asked Questions (FAQ's) Regarding FTC Testing

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**Q:** Thermally-enhanced grout is specified for the final loop field design. The test bore was grouted with a low conductivity, 20% solids, bentonite grout. How do I adjust the thermal conductivity value to account for this?

**A:** While the conductivity of the grout is important for the loop field design, it is not important for determining formation thermal conductivity. We use the “line source” method to analyze data, which assumes an infinitely thin line rejecting heat at a constant rate into an infinite medium. The initial ten hours, which is influenced by the bore dimensions and grout conductivity, is ignored in the analysis. However, once the heat has penetrated into the formation, the temperature rise of the formation approaches steady-state. It is the slope of the temperature rise that is used in the analysis. Hence, no adjustment to the reported formation thermal conductivity is required.

**Q:** The software I use to design the loop field requires that I input a value for “soil conductivity”. Is this the same as formation thermal conductivity?

**A:** Absolutely. Formation, soil, and ground are all used interchangeably to describe the conditions in which the u-bends will be installed. The use of the word “formation” simply implies that the installation conditions may be soil, rock, or some combination of the two.

**Q:** I've just received your report. I have a formation conductivity of 1.54 Btu/hr-ft·°F. How do I translate that into a loop length requirement, in terms of bore depth (in feet) per ton?

**A:** The formation thermal conductivity test provides values for three key parameters required for the ground loop design. These are the “Undisturbed Formation Temperature, Formation Thermal Conductivity, and Formation Thermal Diffusivity.” These parameters, along with many others, are inputs to commercially available loop design software (e.g. GchpCalc, available at [GeoKiss.com/software](http://GeoKiss.com/software)). The software uses all of the inputs to determine the required loop length in bore depth per ton.

**Q:** Is the “Undisturbed Formation Temperature” listed in the report the temperature that I enter into my loop design software where it calls for the “Deep-Earth Temperature”?

**A:** Generally, yes. The “Undisturbed Formation Temperature” is the constant temperature of the formation. We attempt to determine this value by measuring the temperature of the water entering the test unit at the beginning of the test. However, the value we measure and report may be inaccurate if the test is initiated too quickly after the installation of the test bore, or if the testing operator failed to activate the data acquisition unit prior to energizing the heating elements. If you suspect the temperature we are reporting to be too high or too low, we recommend that you investigate further through other sources.