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

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Analysis for:

**Brent Grimes  
Marcum Engineering  
5937 Benton Rd  
Paducah, KY 42003  
Phone: (270) 898-4713  
Fax: (270) 898-4801**

Test location:

**Lone Oak Elementary School  
Paducah, KY**

Report Date:

February 28, 2002

Test Performed by:

**Geothermal Resource Technologies, Inc.**

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## Executive Summary

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A formation thermal conductivity test was performed at the site of Lone Oak Elementary in Paducah, KY. The vertical bore was drilled on February 12, 2002, by Burgess Water Wells. GRTI's test unit was attached to the vertical bore on the afternoon of February 25, 2002. 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 = 1.03 Btu/hr-ft-°F

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

⇒ Formation Thermal Diffusivity  $\approx 0.59 \text{ ft}^2/\text{day}$

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

## Test Procedure

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The procedure for the formation thermal conductivity test is as follows:

1. Connect the u-bend ground heat exchanger pipe to the portable FTC unit.
2. Connect the data acquisition unit to the wiring harness in the FTC unit.
3. Connect the FTC unit to 240 volt power supply (collected data indicated the average voltage over the analysis interval was 250.5 volts).
4. Fill and purge air from the FTC unit.
5. Insulate the exposed u-bend pipes (leading from the well bore surface to the FTC unit).
6. Simultaneously turn on the heating elements and initiate the data acquisition device.
7. Routinely monitor that the power supply remains connected and the water level of the fluid reservoir within the FTC unit stays at an acceptable level.
8. After the test is completed, turn off heating elements, the circulation pump, and the data acquisition device.

## 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:

Phone: (972) 390-1537

Fax: (972) 390-1851

E-mail: askouby@grti.com

## Formation Thermal Conductivity Test Report

Date ..... February 25-27, 2002  
 Location ..... Paducah, Kentucky  
 Latitude N 37.04111, Longitude W 88.66697

### Borehole Data

Undisturbed Soil Temperature ..... Approx. 60°F  
 Borehole Depth ..... 310 ft  
 Borehole Diameter ..... 8 inches

Drill Log .....	Clay	0'-24'
	Fine Sand	24'-30'
	Clay	30'-50'
	Sand & Clay	50'-58'
	Rock	58'-59'
	Black Clay	59'-310'

Depth to Water ..... Approx. 48 ft  
 U-bend Size ..... 1 inch HDPE  
 U-Bend Length ..... 290 ft  
 Grout Type ..... Fine Sand w/Bentonite (0'-60')  
 Grouted Portion ..... Upper 60 ft  
 Grout Solids ..... NA

### Test Data

Test Duration ..... 45.9 hrs.  
 Average Power ..... 6,706 W  
 Calculated Circulator Flow Rate ..... 7.1 gpm  
 Total Heat Input Rate ..... 22,882 Btu/hr

### Lone Oak Elementary, Paducah, KY February 25-27, 2002

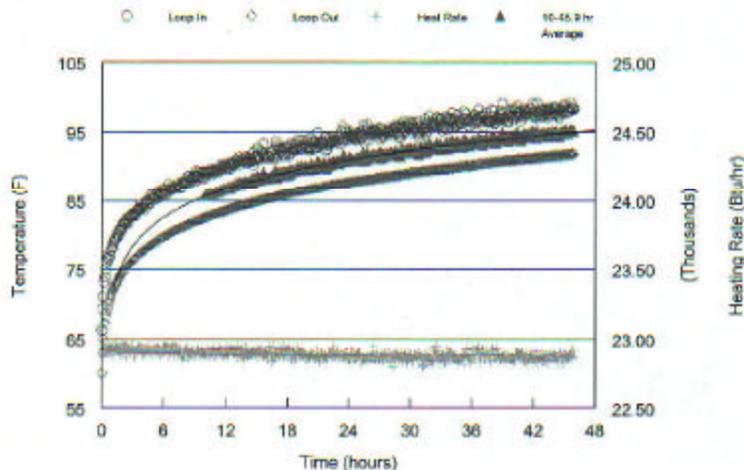


Figure 1: Temperature versus Time Data

February 28, 2002

## Line Source Data Analysis

Lone Oak Elementary, Paducah, KY  
February 25-27, 2002

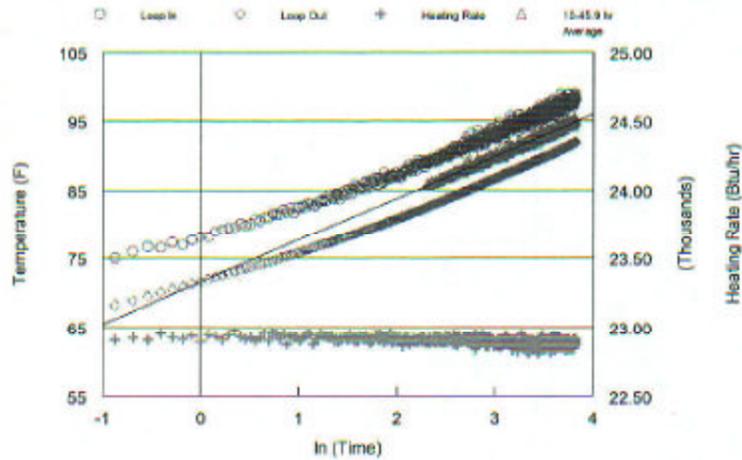


Figure 2: Temperature versus Natural Log of Time

Time Period	Slope: $a_1$	Average Heat Input (Btu/hr-ft)	Thermal Conductivity (Btu/hr-ft-°F)
10 – 45.9 hrs	6.11	78.90	1.03

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 45.9 hours.

The slope of the curve ( $a_1$ ) was found to be 6.11. The resulting thermal conductivity was found to be 1.03 Btu/hr-ft-°F.

## Estimated Thermal Diffusivity

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The reported drilling log for this test borehole indicated that the formation consisted primarily of clay. A saturated moisture content was assumed for clay in order to produce a value for heat capacity. A heat capacity value was calculated from specific heat and density values listed by Kavanaugh and Rafferty (Ground-Source Heat Pumps - Design of Geothermal Systems for Commercial and Institutional Buildings, ASHRAE, 1997). 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 approximately 0.59 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)
41.6	1.03	0.59