Geothermal
Resource
Technologies, Inc.

MAIN OFFICE:
1444 Rogers Court
ALLEN, TX 75013
(972) 390-1537
Fax: (972) 390-1851

REGIONAL OFFICES:
BROOKINGS, SD
(605) 692-9069
Fax: (605) 692-2604

ASHEVILLE, NC
(828) 225-9166
Fax: (828) 281-4139

WEB SITE:
www.GRTI.com

FORMATION THERMAL CONDUCTIVITY TEST AND DATA ANALYSIS

Analysis for: **Jim Sizemore**
Tennessee Valley Authority
10060 State Rt. 45N
Hickory, KY 42051
Phone: (270) 856-4578
Fax: (270) 856-4577

Test location: **Edmonson County Middle School**
Brownsville, KY

Report Date: June 25, 2002

Test Performed by: **Geothermal Resource Technologies, Inc.**

Executive Summary

A formation thermal conductivity test was performed at Edmonson County Middle School in Brownsville, KY. The vertical bore was completed on June 17, 2002, by Mid-South Geo & Water Resources, Inc. GRTI's test unit was attached to the vertical bore on the afternoon of June 21, 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 = 1.93 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 ≈ 1.31 ft^2/day

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

⇒ Undisturbed Soil Temperature ≈ 60° F

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

Test Procedures

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) has recently adopted a set of standards for performing formation thermal conductivity tests for geothermal applications. GRTI is committed to adhering to the published specifications. Some of these standards 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 ∗ 1.5% of the average power, with maximum power variation of ∗ 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 Soil Temperature Measurement – The undisturbed soil 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.

Data Analysis

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	June 21 - 23, 2002
Location	Brownsville, Kentucky
Latitude	N 37.19452°
Longitude	W 86.25089°

Borehole Data

Undisturbed Soil Temperature	Approx. 60°F
Borehole Diameter	6-1/4 inches

Drill Log

Dirt	0'-25'
Rock	25'-27'
Dirt & Water	27'-28'
Soft Limestone	28'-50'
Limestone / Shale	50'-105'
Shale	105'-115'
Water	115'-116'
Gray Limestone	116'-160'
Big Layer Shale	160'-163'
Good Limestone	163'-300'

Note: Water was encountered at 27 and 115 foot depths

U-bend Size	1 inch HDPE
U-Bend Length	297 ft
Grout Type	Agricultural Lime
Grouted Portion	NA
Grout Solids	NA

Test Data

Test Duration	43.4 hrs.
Average Voltage	240.9 V
Average Power	6,427 W
Calculated Circulator Flow Rate	6.7 gpm
Total Heat Input Rate	21,929 Btu/hr

Edmonson County Middle School, Brownsville, KY
June 21 - 23, 2002

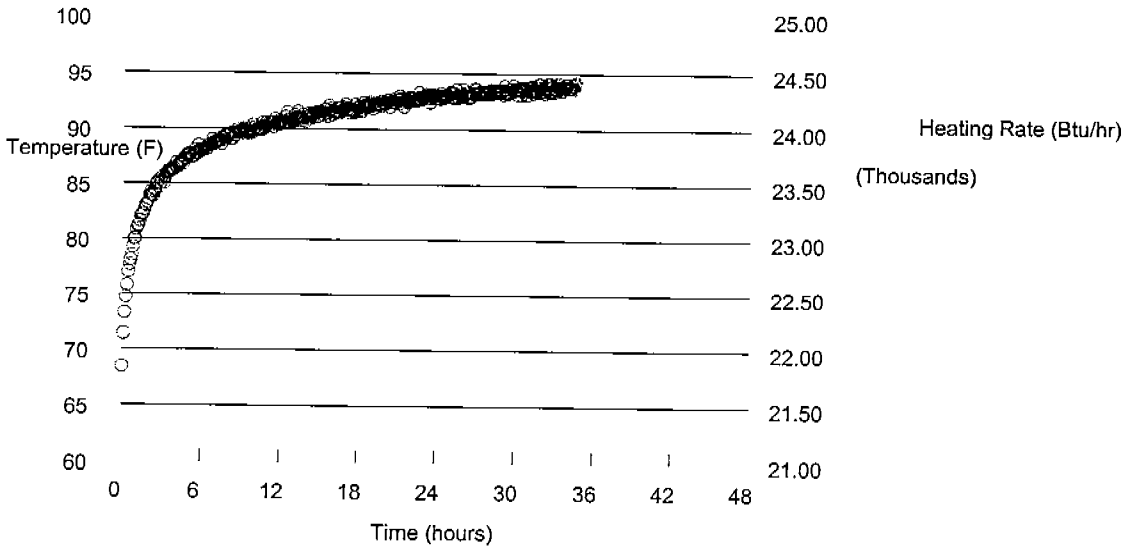

Figure 1: Temperature versus Time Data

Edmonson County Middle School, Brownsville, KY

June 21 - 23, 2002

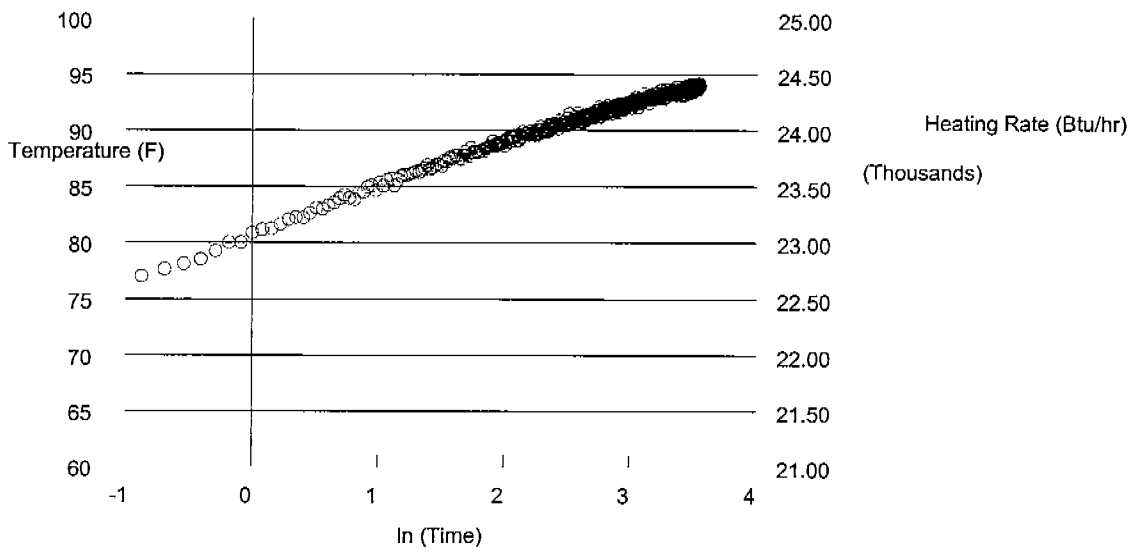

Figure 2: Temperature versus Natural Log of Time

Time Period	Slope: a_1	Average Heat Input (Btu/hr-ft)	(W/ft)	Thermal Conductivity (Btu/hr-ft-°F)
10 – 43.4 hrs	3.04	73.84	21.64	1.93

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 43.4 hours. The slope of the curve (a_1) was found to be 3.04. The resulting thermal conductivity was found to be 1.93 Btu/hr-ft-°F.

Estimated Thermal Diffusivity

The reported drilling log for this test borehole indicated that the formation consisted primarily of limestone and shale. 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 1.31 ft^2/day.

Est. Average Heat Capacity (Btu/ft^3 °F)	Thermal Conductivity (Btu/hr-ft-°F)	Est. Thermal Diffusivity (ft^2/day)
35.4	1.93	1.31

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.8F. 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 Soil 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). The software uses all of the inputs to determine the required loop length in bore depth per ton.

Q: Is the "Undisturbed Soil Temperature" value 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 Soil 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.