Geothermal
Resource
Technologies, Inc.

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FORMATION THERMAL CONDUCTIVITY TEST AND DATA ANALYSIS

Analysis for

LoopMaster International, Inc.
5700 West Minnesota Street, Building "E"
Indianapolis, Indiana 46241
(317) 246-5667 • Fax: (317) 246-5668

Test location

Community Tectonics
Pellissippi Parkway at Conard Mill Road
Knoxville, Tennessee

September 10, 2000

Test Performed by

Geothermal Resource Technologies, Inc.

Executive Summary

A formation thermal conductivity test was performed at the future site of Community Tectonics in Knoxville, Tennessee. The test unit was attached to the vertical bore on the evening of Thursday, August 31, 2000. The test bore used in this analysis is located at approximately 35° 57' 38" N. (latitude) and 084° 09' 47" W. (longitude). The collected data was analyzed by Geothermal Resource Technologies, Inc. under the supervision of Charles Remund, Ph.D., Director of Engineering.

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 = 2.634 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 ≈ 1.05 ft^2/day

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

Test Procedure

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 throughout the tests was 237.0 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

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 ..... August 31 – September 2, 2000
Location ..... Knoxville, TN

Borehole Data

Undisturbed Soil Temperature ..... approx. 57°F[1]
Borehole Depth ..... 300 ft.
Borehole Diameter ..... 4.75 in.
Drill Log .....

Clay	0 – 20'
Clay w/ Gravel	20 – 23'
Clay	23' – 53'
Limestone	53' – 300'

U-bend Size ..... 1.25 in. HDPE
U-Bend Length ..... 600 ft.
Grout Type ..... No Grout - Silica Sand
Grouted Portion ..... Entire Bore
Grout Solids ..... N/A

Test Data

Test Duration ..... 39.97 hrs.
Average Power ..... 4,332 W
Calculated Circulator Flow Rate ..... 8.66 gpm
Total Heat Input Rate ..... 14,743 Btu/hr

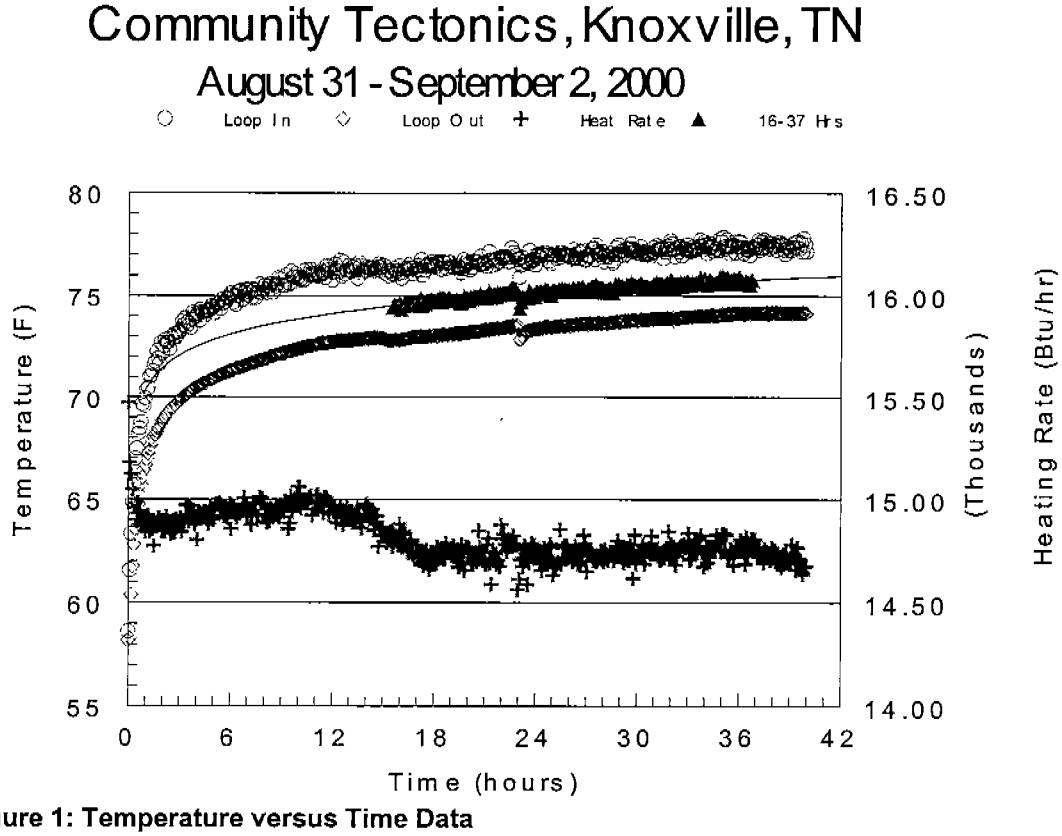

Figure 1: Temperature versus Time Data

Line Source Data Analysis

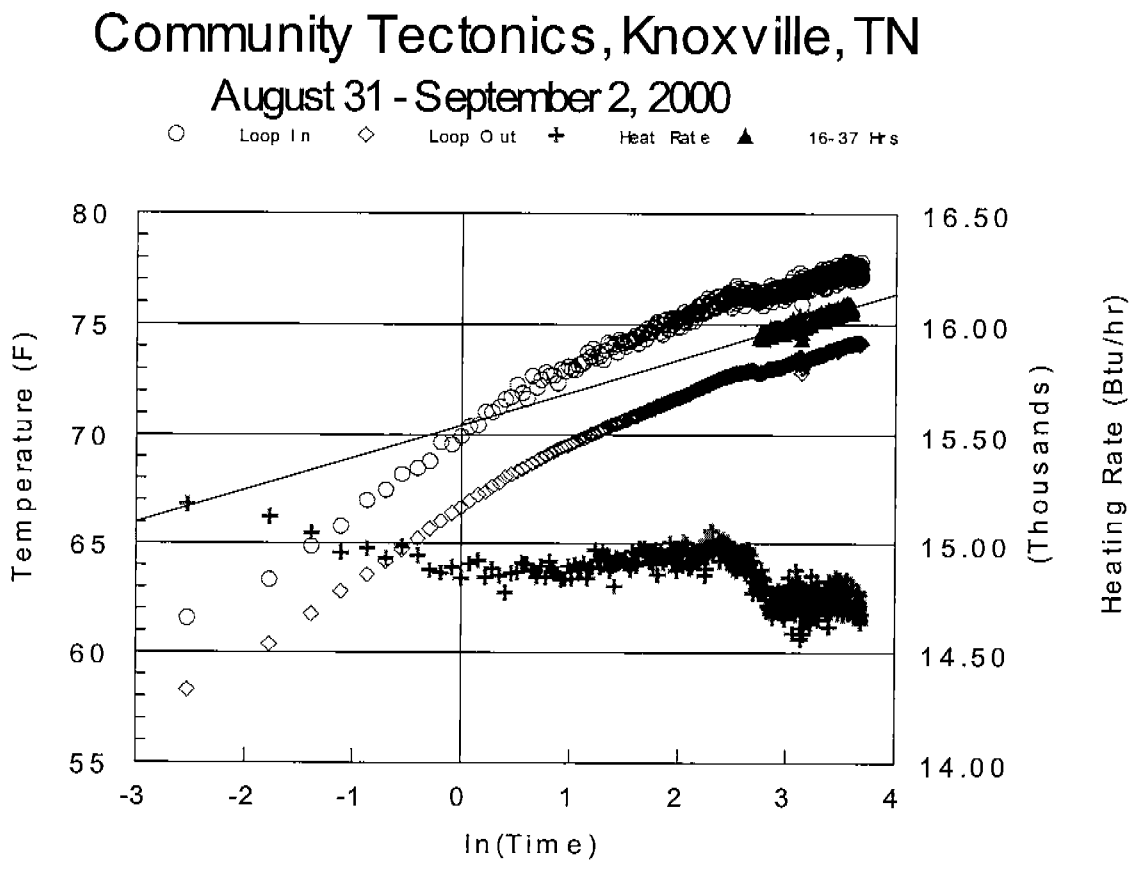

Figure 2: Temperature versus Natural Log of Time

Time Period	Slope: a_1	Average Heat Input (Btu/hr-ft)	Thermal Conductivity (Btu/hr-ft-°F)
15.58 – 36.8 hrs	1.485	49.14	2.634

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 15.6 and 36.8 hours. The slope of the curve (a_1) was found to be 1.485. The resulting thermal conductivity was found to be 2.634 Btu/hr-ft-°F.

The reported drilling log for this test borehole indicated that the formation consisted of 17.7% clay and 82.3% limestone. Kavanaugh and Rafferty (Ground-Source Heat Pumps - Design of Geothermal Systems for Commercial and Institutional Buildings, ASHRAE, 1997) have compiled expected thermal conductivity and diffusivity ranges for various soil and rock types. The

measured thermal conductivity for this test is compared to the expected range for limestone, in Figure 3. Also provided in Figure 3 is an estimate for the thermal diffusivity for the formation based on Kavanaugh and Rafferty (Ground-Source Heat Pumps - Design of Geothermal Systems for Commercial and Institutional Buildings, ASHRAE, 1997). The measured thermal conductivity value falls toward the high end of the expected range for limestone. An estimate of the thermal diffusivity for the formation is taken from Figure 3 to be approximately 1.26 ft^2/day.

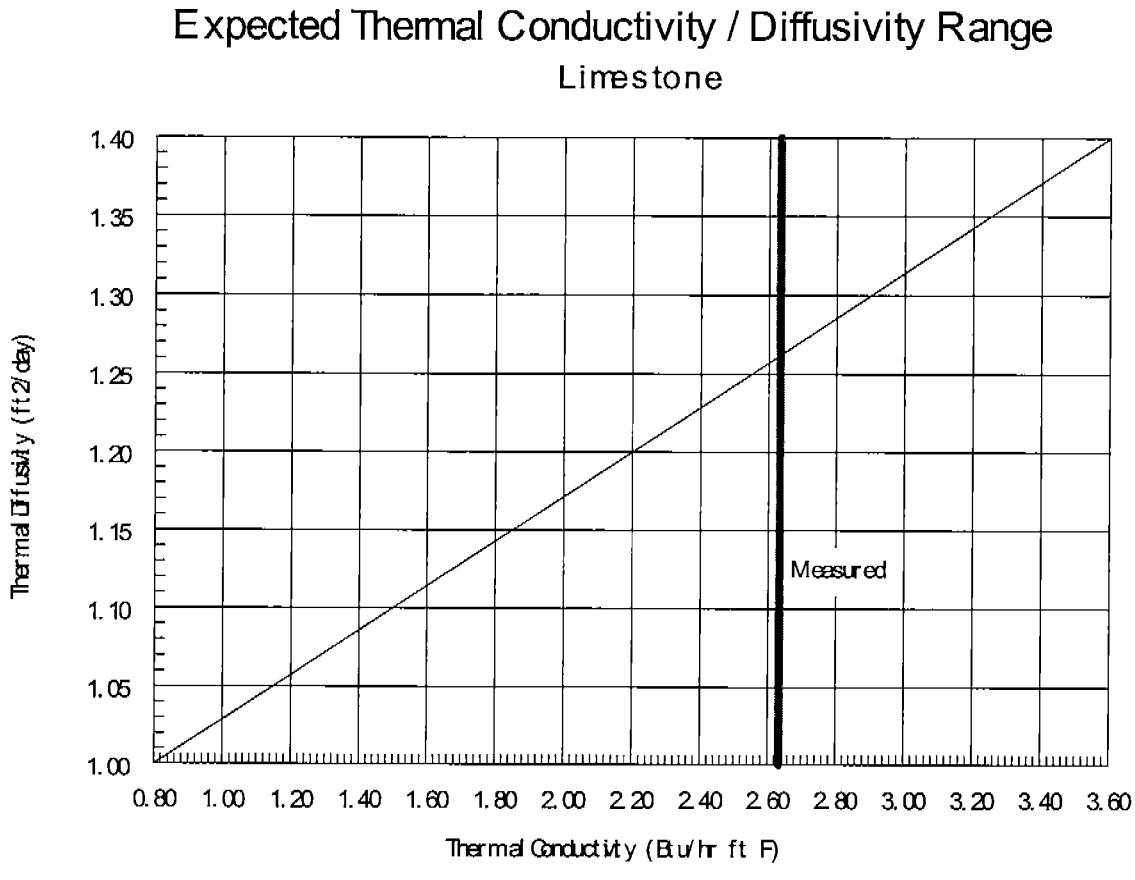

Figure 3. Measured thermal conductivity compared to expected thermal conductivity range for the formation along with estimated thermal diffusivity for this soil type.

1. "Undisturbed Soil Temperature" was determined from data collected during the test start-up sequence. Due to the fact that the test bore was completed within a short time period of when the test began, it is very likely that there was some residual heat present at start-up resulting in an artificially high reported value.

N/A = Information not available. This specific information is not utilized in the calculation of the formation thermal conductivity and therefore is not critical to the conclusion. This information is typically supplied as a courtesy and to provide a more complete information package.