FORMATION THERMAL CONDUCTIVITY
TEST & DATA ANALYSIS

TEST LOCATION **Windy Ridge Project**
Hinesburg, VT

TEST DATE June 10-12, 2024

ANALYSIS FOR Vermont Well and Pump
14337 Route 116
Hinesburg, VT 05461
Phone: (802) 482-4235

TEST PERFORMED BY Vermont Well and Pump

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EXECUTIVE SUMMARY

A formation thermal conductivity test was performed on the geothermal test bore at GPS location of N 44.3394° (latitude), W 73.115° (longitude) for the Windy Ridge Project in Hinesburg, Vermont. The vertical bore was completed on June 3, 2024 by Vermont Well and Pump. Geothermal Resource Technologies' (GRTI) test unit was attached to the vertical bore on the afternoon of June 10, 2024.

This report provides an overview of the test procedures and analysis process, along with plots of the loop temperature and input heat rate data. The collected data was analyzed using the "line source" method and the following average formation thermal conductivity was determined.

Formation Thermal Conductivity = 3.81 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 ≈ 2.55 ft^2/day

The calculated values are very high for the indicated formation and likely influenced by water flow across the bore. Caution should be exercised, as water flow in the formation may be only a seasonal or annual effect. The effect of water flow on heat transfer may also be less pronounced when a large number of bores in a loop field are present. Based on the formation type and previous tests in the area, lower values are suggested with potential increases due to water flow considered as a factor of safety.

Suggested Formation Thermal Conductivity = 2.10 Btu/hr-ft-°F

Suggested Formation Thermal Diffusivity ≈ 1.41 ft^2/day

The undisturbed formation temperature for the tested bore was established from the initial loop temperature data collected at startup.

Undisturbed Formation Temperature ≈ 48.3-49.0°F

The formation thermal properties determined by this test do not directly translate into a loop length requirement (i.e. feet of bore per ton). These parameters, along with many others, are inputs to commercially available loop-field design software to determine the required loop length. Additional questions concerning the use of these results are discussed in the frequently asked question (FAQ) section at www.grti.com.

Test Procedures

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) has published recommended procedures for performing formation thermal conductivity tests in the ASHRAE HVAC Applications Handbook, Geothermal Energy Chapter. The International Ground Source Heat Pump Association (IGSHPA) also lists test procedures in their Design and Installation Standards. GRTI's test procedures meet or exceed those recommended by ASHRAE and IGSHPA, with the specific procedures described below:

Grouting Procedure for Test Loops – To ensure against bridging and voids, it is recommended that the bore annulus is uniformly grouted from the bottom to the top via tremie pipe.

Time Between Loop Installation and Testing – A minimum delay of five days between loop installation and test startup is recommended for bores that are air drilled, and a minimum waiting period of two days for mud rotary drilling.

Undisturbed Formation Temperature Measurement – The undisturbed formation temperature should be determined by recording the loop temperature as the water returns from the u-bend at test startup.

Required Test Duration – A minimum test duration of 36 hours is recommended, with a preference toward 48 hours**.**

Data Acquisition Frequency - Test data is recorded at five minute intervals.

Equipment Calibration/Accuracy – Transducers and datalogger are calibrated per manufacturer recommendations. Manufacturer stated accuracy of power transducers is less than ±2%. Temperature sensor accuracy is periodically checked via ice water bath.

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.

Input Heat Rate – The heat flux rate should be 51 Btu/hr (15 W) to 85 Btu/hr (25 W) per foot of installed bore depth to best simulate the expected peak loads on the u-bend.

Insulation – GRTI's equipment has 1 inch of foam insulation on the FTC unit and 1/2 inch of insulation on the hose kit connection. An additional 2 inches of insulation is provided for both the FTC unit and loop connections by insulating blankets.

Retesting in the Event of Failure – In the event that a test fails prematurely, a retest may not be performed until the bore temperature is within 0.5°F of the original undisturbed formation temperature or until a period of 14 days has elapsed.

Data Analysis

Geothermal Resource Technologies, Inc. (GRTI) uses the "line source" method of data analysis to determine the thermal conductivity of the formation. The line source method assumes an infinitely thin line source of heat in a continuous medium. A plot of the late-time temperature rise of the line source temperature versus the natural log of elapsed time will follow a linear trend. The linear slope is inversely proportional to the thermal conductivity of the medium. Applying the line source method to a u-bend grouted in a borehole, 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 approximately ten hours is required to allow the error of early test times and the effects of finite borehole dimensions to become insignificant.

In the analysis of the data from the formation thermal conductivity test, the average temperature of the water entering and exiting the u-bend heat exchanger was plotted versus the natural log of elapsed testing time. Using the Method of Least Squares, linear coefficients were calculated that produce a line that fit the data. This procedure was repeated for various time intervals to ensure that variations in the power or other effects did not produce inaccurate results.

The calculated results are based on test bore information submitted by the driller/testing agency. GRTI is not responsible for inaccuracies in the results due to erroneous bore information. All data analysis is performed by personnel that have an engineering degree from an accredited university with a background in heat transfer and experience with line source theory. The test results apply specifically to the tested bore. Additional bores at the site may have significantly different results depending upon variations in geology and hydrology.

Through the analysis process, the collected raw data is converted to spreadsheet format (Microsoft Excel®) for final analysis. If desired, please contact GRTI and a copy of the data will be made available in either a hard copy or electronic format.

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Test Bore Details
(As Provided by Vermont Well And Pump)

Site Name .... Windy Ridge Project
Location .... Hinesburg, VT
Driller .... Vermont Well And Pump
Installed Date .... June 3, 2024
Borehole Diameter .... 8 inches, 0-40 ft
6 inches, 40-505 ft
Casing .... Permanent 6 inch steel casing to 40 ft
U-Bend Size .... 1-1/4 inch DR11 HDPE
U-Bend Depth Below Grade .... 505 ft
Grout Type .... Baroid 3/8-inch HolePlug
Grouted Portion .... 0-120 ft
Note: U-Bend was suspended in bore of fractured rock and water from 120-505 ft.

Drill Log

Formation Description	Depth (ft)
Brown clay	0'-19'
Gray hardpan	19'-28'
Light gray limestone	28'-505'

Note: Bore produced 75 gpm water at 123 ft; 125 gpm at 255 ft.
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THERMAL CONDUCTIVITY TEST DATA

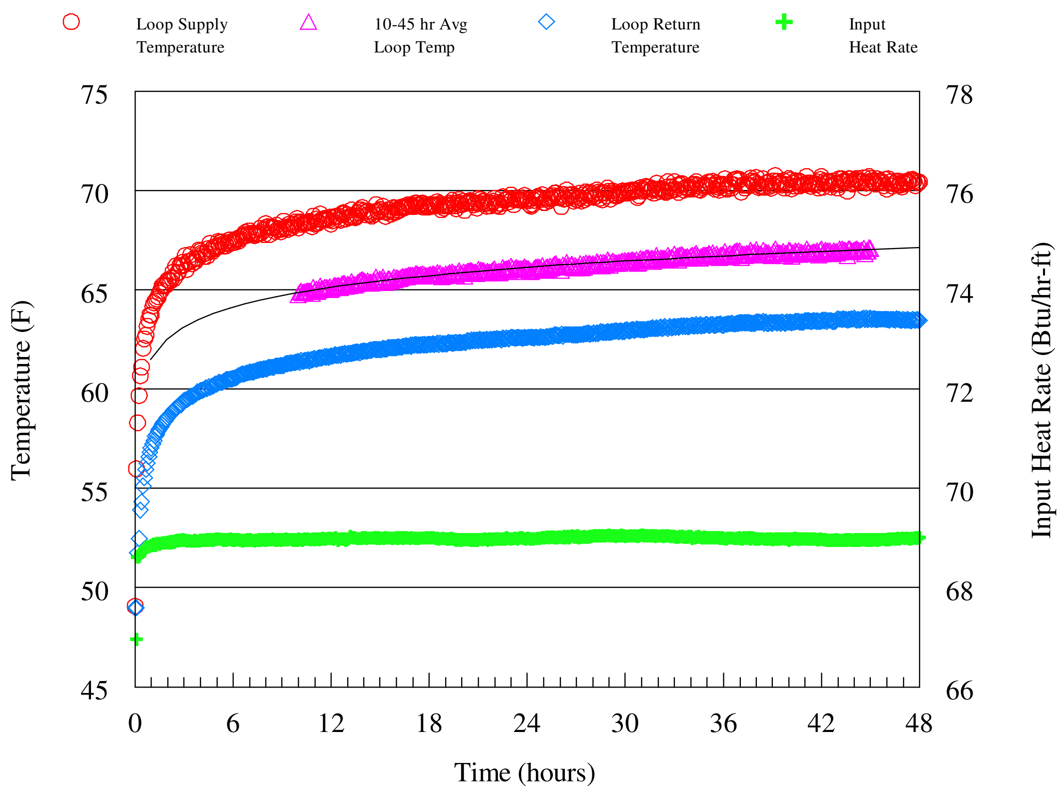

FIG. 1: TEMPERATURE & HEAT RATE DATA VS TIME

Figure 1 above shows the loop temperature and heat input rate data versus the elapsed time of the test. The temperature of the fluid supplied to and returning from the U-bend are plotted on the left axis, while the amount of heat supplied to the fluid is plotted on the right axis on a per foot of bore basis. In the test statistics below, calculations on the power data were performed over the analysis time period listed in the Line Source Data Analysis section.

SUMMARY TEST STATISTICS

Test Date	June 10-12, 2024
Undisturbed Formation Temperature	Approx. 48.3-49.0°F
Duration	49.2 hr
Average Voltage	240.6 V
Average Heat Input Rate	34,844 Btu/hr (10,209 W)
Avg Heat Input Rate per Foot of Bore	69.0 Btu/hr-ft (20.2 W/ft)
Circulator Flow Rate	10.0 gpm
Standard Deviation of Power	0.04%
Maximum Variation in Power	0.09%

LINE SOURCE DATA ANALYSIS

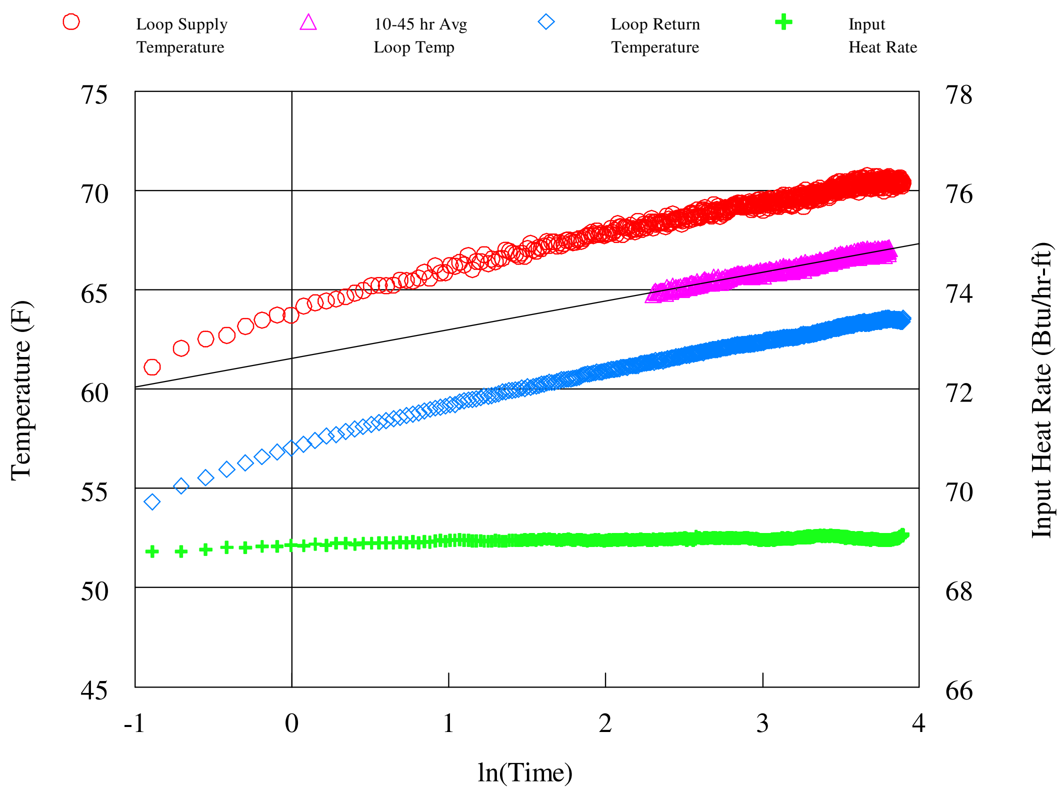

FIG. 2: TEMPERATURE & HEAT RATE VS NATURAL LOG OF TIME

The loop temperature and input heat rate data versus the natural log of elapsed time are shown above in Figure 2. The temperature versus time data was analyzed using the line source method (see page 3) in conformity with ASHRAE and IGSHPA guidelines. A linear curve fit was applied to the average of the supply and return loop temperature data between 10 and 45.0 hours. The slope of the curve fit was found to be 1.44. The resulting thermal conductivity was found to be **3.81 Btu/hr-ft-°F**. The calculated value is very high for the indicated formation and likely influenced by water flow across the bore. When water flow is encountered, heat transfer is driven by advection to water flowing past the bore in addition to conductive heat transfer through the formation. Loop field performance may then be dependent on both hydrological conditions and the thermal properties of the formation. It is the position of GRTI in these cases to suggest a conductivity value based on assumed saturated values for the formations encountered and data from previous tests in the area. Benefits due to water flow are not considered, as the effect of multiple bores or the future behavior of the water flow is unknown. A thermal conductivity value of **2.10 Btu/hr-ft-°F** is suggested.

THERMAL DIFFUSIVITY

The reported drilling log for this test borehole indicated that the formation consisted of clay, hardpan, and limestone. An average heat capacity value for limestone was calculated from specific heat and density values listed by Kavanaugh and Rafferty[1]. A weighted average of heat capacity values based on the indicated formation was used to determine an average heat capacity of 35.9 Btu/ft^3-°F for the formation. A 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 **2.55 ft^2/day**. Since the calculated thermal conductivity was high, a thermal diffusivity value was also determined using the suggested conductivity value. The thermal diffusivity was estimated to be **1.41 ft^2/day** using this approach.

[1]Stephen P. Kavanaugh and Kevin Rafferty, Geothermal Heating and Cooling: Design of Ground-Source Heat Pump Systems (Atlanta: ASHRAE, 2014), 75.

CERTIFICATE OF CALIBRATION

GRTI maintains calibration of the datalogger, current transducer and voltage transducer on a regular schedule. The components are calibrated by the manufacturer using recognized national or international measurement standards such as those maintained by the National Institute of Standards and Technology (NIST).

FTC Unit 204

DA Unit 52

Primary Equipment	
Component	**Calibration Date**
Datalogger	7/29/2021
Current Transducer	7/30/2021
Voltage Transducer	7/30/2021

GRTI periodically verifies the combined temperature sensor/datalogger accuracy via a water bath. Temperature readings are simultaneously taken with a digital thermometer that has been calibrated using instruments traceable to NIST.

Date	2/1/2024	8/12/2023	3/8/2022	9/20/2021
Thermocouple 1 (°F)	50.8 50.8 50.8	57.0 57.0 57.0	32.5 32.5 32.5	31.9 31.8 31.8
Thermocouple 2 (°F)	50.8 50.8 50.8	57.0 57.1 57.1	32.6 32.6 32.6	31.8 31.9 31.9
Thermocouple 3 (°F)	50.9 50.9 50.9	57.0 57.1 57.2	32.6 32.7 32.6	31.8 31.9 31.9
Thermocouple 4 (°F)	50.7 50.7 50.7	57.0 57.0 57.0	32.7 32.7 32.7	31.8 31.8 31.8
Digital Thermometer (°F)	50.9 50.9 50.9	57.1 57.1 57.2	32.6 32.6 32.6	32.0 32.0 32.0

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