



FORMATION THERMAL CONDUCTIVITY
TEST & DATA ANALYSIS

TEST LOCATION **A01583 Weston Road**
Woodbridge, ON

TEST DATE **August 23-25, 2022**

ANALYSIS FOR **Aecon Geoexchange Solutions Inc.**
20 Carlson Ct, Suite 800
Toronto, ON M9W 7K6

TEST PERFORMED BY **Aecon Geoexchange Solutions Inc.**

EXECUTIVE SUMMARY

A formation thermal conductivity test was performed on the geothermal test bore at the A01583 Weston Road site at 941 Weston Road in Woodbridge, Ontario. The vertical bore was completed on August 17, 2022 by Aecon Geoexchange Solutions. Geothermal Resource Technologies' (GRTI) test unit was attached to the vertical bore on the afternoon of August 23, 2022.

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 = 1.28 Btu/hr-ft-°F (2.22 W/m-K)

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 $\approx 0.99 \text{ ft}^2/\text{day}$ ($0.0107 \text{ cm}^2/\text{s}$)

Bore thermal resistance calculations were made on the test data using the method outlined in the Gehlin Doctoral Thesis¹. Since the average value listed below was empirically determined from the test data it may not directly correlate with values found in loopfield design programs.

Bore Thermal Resistance = 0.141 hr-ft-°F/Btu (0.081 m-k/W)

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

Undisturbed Formation Temperature $\approx 50.5\text{-}51.9^\circ\text{F}$ ($10.3\text{-}11.1^\circ\text{C}$)

The formation thermal properties determined by this test do not directly translate into a loop length requirement (i.e. feet of bore per ton) 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.

¹ Signhild Gehlin. "Thermal Response Test - Method Development and Evaluation," (Doctoral Thesis, Lulea University of Technology, 2002).

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 $\pm 2\%$. 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.

Bore thermal resistance was determined using the formula outlined in Gehlin's Doctoral Thesis². A serial development was used to approximate the exponential integral. The calculated bore resistance applies only to the test conditions, a bore in an operating loopfield could have a significantly different resistance due to changes in the loop fluid temperature, flow rate and presence of antifreeze.

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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²Gehlin, 12-13

TEST BORE DETAILS**(AS PROVIDED BY AECON GEODEXCHANGE SOLUTIONS INC.)**

Site Name..... A01583 Weston Road
 Location..... Woodbridge, ON
 Driller..... Aecon Geoeexchange Solutions
 Installed Date..... August 17, 2022
 Borehole Diameter..... 4 1/2 inches (114 mm)
 Casing..... Temporary 5 1/2 inch (140 mm) casing to
 308 ft (93.9 m)
 U-Bend Size..... 1 1/4 inch (32 mm) HDPE
 U-Bend Depth Below Grade..... 600 ft (182.9 m)
 Grout Type..... GeoPro TG Lite/PowerTEC 1.0 Btu/hr-ft-°F
 Grout Mixture..... 900 lb (408 kg) TG Lite, 216 lb (100 kg)
 PowerTEC, 315 gal (1192 L) water
 Grouted Portion..... Entire bore

DRILL LOG

FORMATION DESCRIPTION	DEPTH (FT)	DEPTH (M)
Top soil	0'-20'	0-6.1 m
Sand	20'-160'	6.1-48.8 m
Watery sand	160'-180'	48.8-54.9 m
Broken rock/shale/some sand	180'-308'	54.9-93.9 m
Shale	308'-600'	93.9-182.9 m

Note: Approximately 5-10 gpm water produced while drilling.

THERMAL CONDUCTIVITY TEST DATA

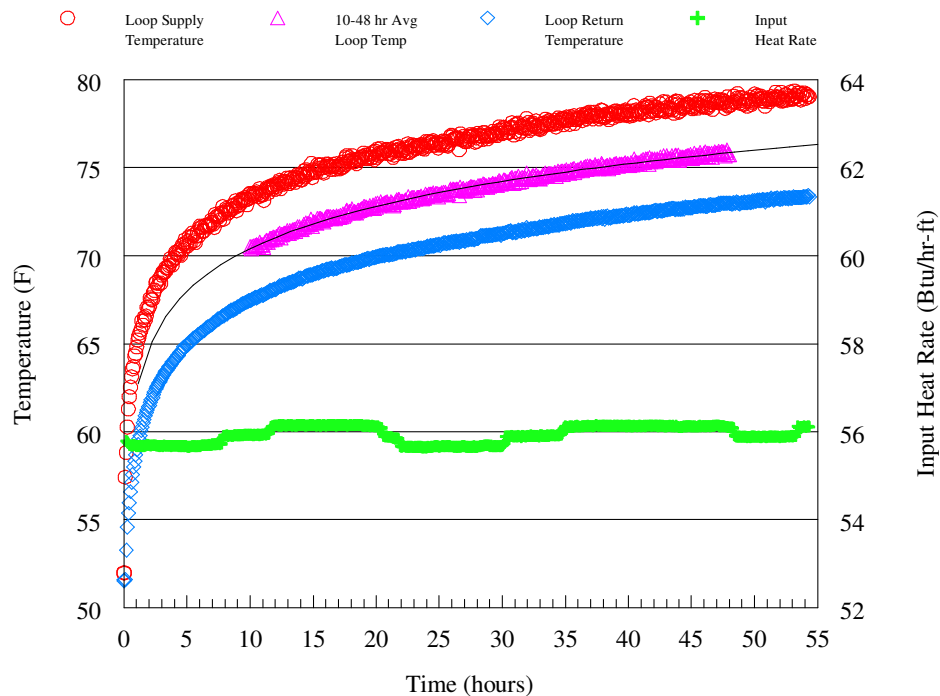


FIG. 1: TEMPERATURE & HEAT RATE DATA VS TIME

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	August 23-25, 2022
Undisturbed Formation Temperature	50.5-51.9°F (10.3-11.1°C)
Duration	54.3 hr
Average Voltage	244.1 V
Average Heat Input Rate	33,591 Btu/hr (9,845 W)
Avg Heat Input Rate per Foot of Bore	56.0 Btu/hr-ft (16.4 W/ft)
Circulator Flow Rate	11.5 gpm (43.4 L/min)
Standard Deviation of Power	0.34%
Maximum Variation in Power	0.61%

LINE SOURCE DATA ANALYSIS

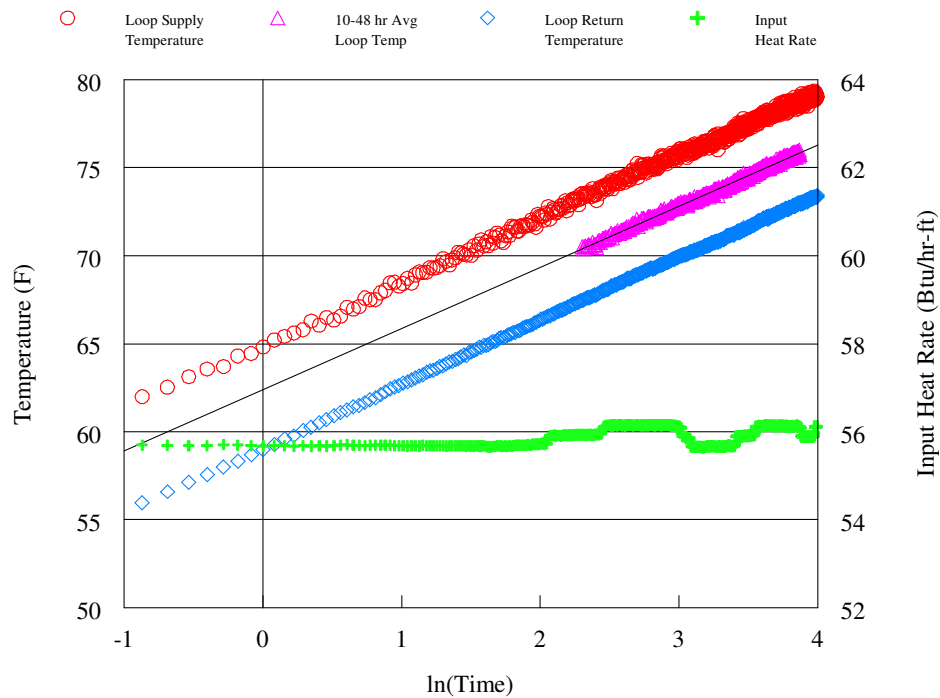


FIG. 2: TEMPERATURE & HEAT RATE VS NATURAL LOG OF TIME

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 48.0 hours. The slope of the curve fit was found to be 3.48. The resulting thermal conductivity was found to be **1.28 Btu/hr-ft-°F (2.22 W/m-K)**.

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THERMAL DIFFUSIVITY

The reported drilling log for this test borehole indicated that the formation consisted of top soil, sand, clay, and shale. An average heat capacity value for shale was calculated from specific heat and density values listed by Kavanaugh and Rafferty³. A weighted average of heat capacity values based on the indicated formation was used to determine an average heat capacity of 31.0 Btu/ft³-°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 **0.99 ft²/day (0.0107 cm²/s)**.

³Stephen P. Kavanaugh and Kevin Rafferty, Geothermal Heating and Cooling: Design of Ground-Source Heat Pump Systems (Atlanta: ASHRAE, 2014), 75.

BORE THERMAL RESISTANCE

Resistance to heat transfer from a geothermal bore can be viewed as consisting of two components, bore resistance and ground resistance. This relationship is diagrammed in Figure 3, where t_f is the loop fluid temperature, t_b is the bore wall temperature and t_g is the ground temperature. The ground resistance is dependent upon the formation thermal conductivity and diffusivity. Factors that affect bore thermal resistance include the resistance of the pipe material, diameter of the heat exchanger, position of the heat exchanger in the bore, bore diameter, casing length and type, and thermal conductivity of the grout/backfill in the bore annulus. A detailed examination of bore resistance is discussed by Kavanaugh and Rafferty⁴.

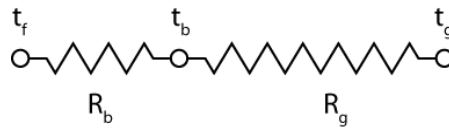


FIG. 3: RESISTANCE DIAGRAM FOR A GEOTHERMAL BORE

Bore thermal resistance calculations were made on the test data according to the formula below as outlined in the Gehlin Doctoral Thesis⁵. The calculated formation thermal conductivity and thermal diffusivity from the Line Source Analysis were used in the formula. The average undisturbed formation temperature of 51.2°F (10.7°C) was used as the undisturbed temperature, and the average bore thermal resistance from 10-48.0 hours was found to be **0.141 hr-ft-°F/Btu (0.081 m-K/W)**.

The calculated bore resistances apply only to the test conditions, and a bore in an operating loopfield could have a significantly different resistance due to changes in the loop fluid temperature, flow rate, and presence of antifreeze. Additional information on bore resistance may be found in the study by Oklahoma State University and Oklahoma Gas & Electric where various vertical bore heat exchanger configurations were tested⁶.

$$R_b = \frac{H}{Q} * \left\{ T(t) - T_g - \frac{Q}{4\pi\lambda_g H} * \left[Ei \left(\frac{r_b^2}{4\alpha_g t} \right) \right] \right\}$$

Where:	R_b	Borehole thermal resistance (hr-ft-°F/Btu)
	H	Active U-bend depth (ft)
	Q	Average heat injected (Btu/hr)
	$T(t)$	Temperature dependent on time t (°F)
	T_g	Undisturbed ground temperature
	λ_g	Formation thermal conductivity (Btu/hr-ft-°F)
	r_b	Average borehole radius (in)
	α_g	Formation thermal diffusivity (ft ² /hr)

⁴Kavanaugh and Rafferty, 58-67.

⁵Gehlin, 12-13.

⁶Beier, R. and Ewbank, G. (2012, August). *In-Situ Test Thermal Response Tests Interpretations, OG&E Ground Source Heat Exchange Study*. Retrieved from <https://igshpa.org/research/>

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 215

DA Unit 51

PRIMARY EQUIPMENT		
COMPONENT	CALIBRATION DATE	CALIBRATION DUE DATE
Datalogger	10/29/2021	10/29/2024
Current Transducer	11/11/2021	11/11/2024
Voltage Transducer	11/11/2021	11/11/2024

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	3/8/2022	11/11/2021	3/8/2022	
THERMOCOUPLE 1 (°F)	32.2 32.2 32.2	32.2 32.2 32.2	32.2 32.2 32.2	
THERMOCOUPLE 2 (°F)	32.1 32.0 32.0	32.2 32.2 32.2	32.1 32.0 32.0	
THERMOCOUPLE 3 (°F)	32.1 32.0 32.1	32.3 32.3 32.2	32.1 32.0 32.1	
THERMOCOUPLE 4 (°F)	32.1 32.1 32.1	32.2 32.2 32.2	32.1 32.1 32.1	
DIGITAL THERMOMETER (°F)	32.2 32.1 32.1	32.3 32.3 32.3	32.2 32.1 32.1	