Ground Loop Design

Thermal Conductivity Report - 2/15/2012

Project Name:	**Geothermal Project Test**		
Project Address:	11225 Lake Street		
City:	Minneapolis	**State:** MN	**Zip:** 55444
Prepared By:	Staff Engineer		
Email:	info@bergersoncaswell.com	**Phone:**	763-479-3121
Drill Date	2/1/2012		
TC Test Date(s)	2/12/2012	>>	2/15/2012
Client Name:	**City of Minneapolis Example**		
Address Line 1:	350 South 5th Street		
Address Line 2:			
City:	Minneapolis	**Phone:**	612-673-3000
State:	MN	**Fax:**	
Zip:	55415	**Email:**	info@minneapolis.ci.mn.us

Calculation Results

Thermal Conductivity (Btu/(h*ft*°F)) :	**1.43**
Thermal Diffusivity (est.) (ft^2/day) :	**1.03**
Average Heat Flux (W/ft) :	**21.1**
BH Thermal Resist (BTR) (h*ft*°F/Btu) :	**0.23**
Average Flow Rate (gpm) :	**10.39**
Test Duration (hr) :	**28**
Calculation Interval :	**12.0 - 40.0 Hours**

Borehole Input Parameters

Undisturbed Ground Temperature (°F) :	**49.0**	(User-Estimated)
Depth (ft) :	**300.0**	
Borehole Diameter (in) :	**5.00**	
Pipe Size:	**1 in. (25 mm)**	
Grout Thermal Conductivity (Btu/(h*ft*°F)) :	**1.00**	
Drilling Method :	**Standard**	
Drilling Time (hr) :	**8.0**	

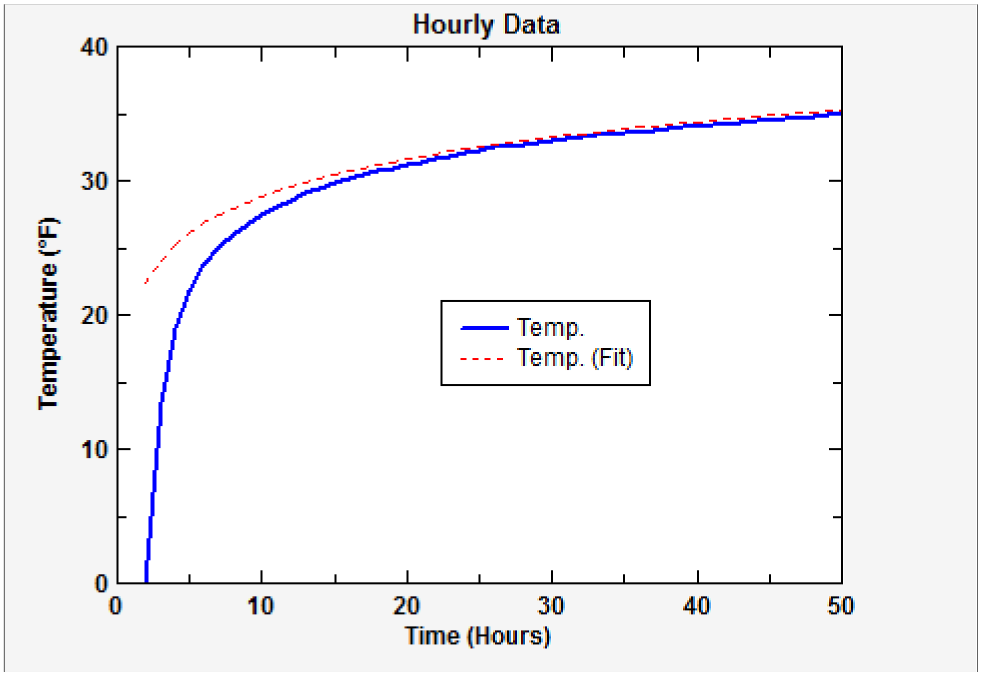
Diffusivity Input Parameters

Soil/Rock Specific Heat - Dry (Btu/(°F*lbm)) :	**0.200**
Soil/Rock Density - Dry (lb/ft^3) :	**100.0**
Moisture (0-100) (%) :	**20.0**

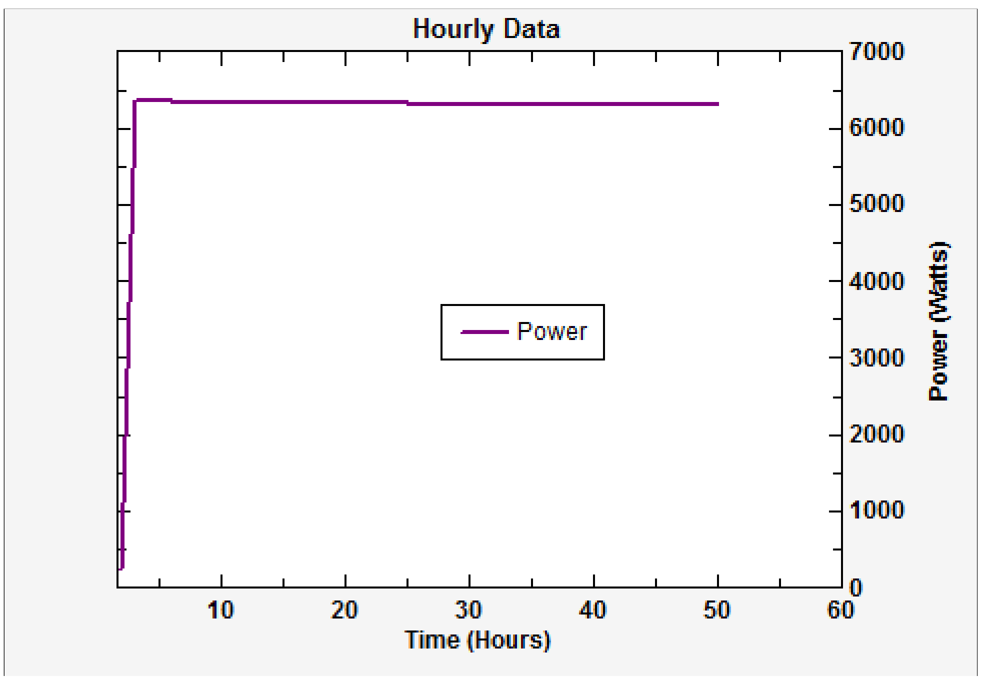
Flow Rate Input Parameters

TC Unit Model Name	**GeoCube Standard**

Temperature vs Time

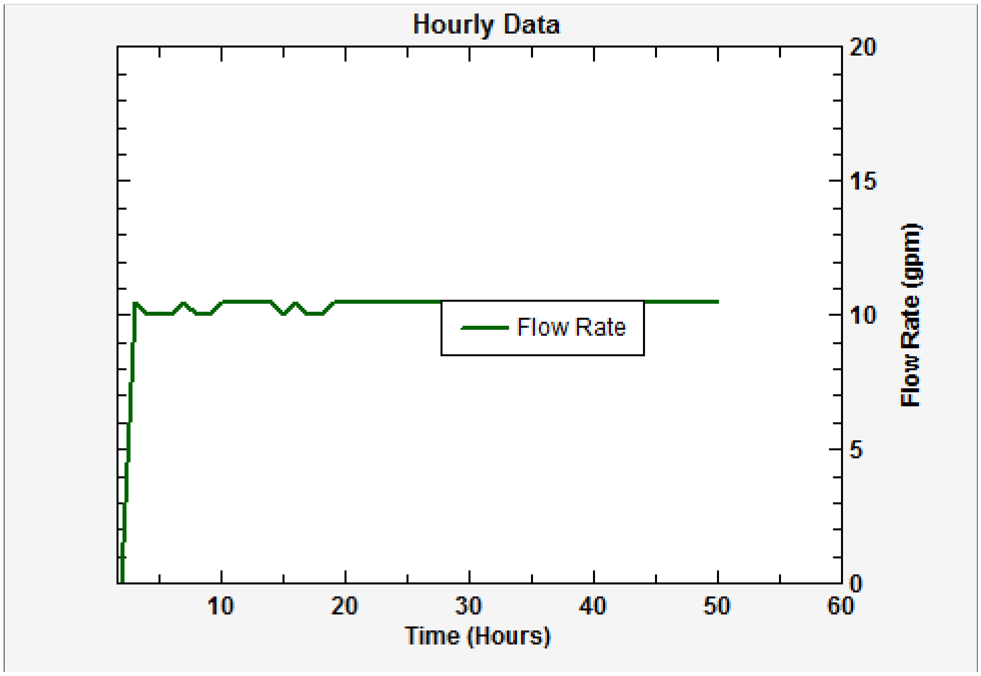


Power vs Time



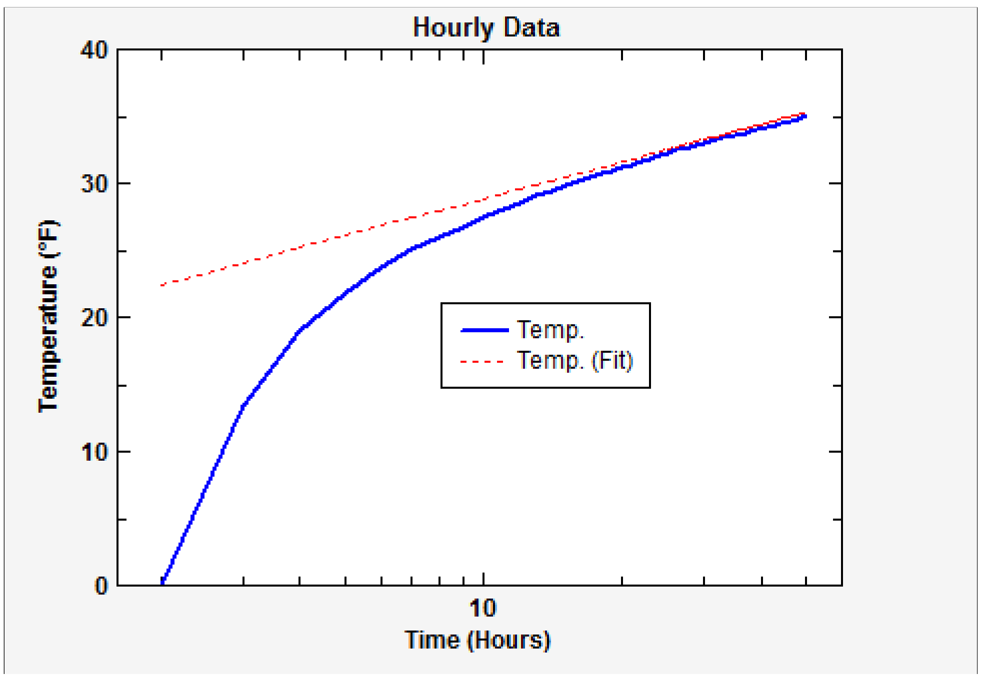
Average Power 6324.0 Watts

Flow Rate vs Time



Average Flow Rate 10.39

Temperature vs ln(Time)



Slope :	**4.00**
Calculation Interval :	**12.0 - 40.0 Hours**

Data Quality

		Threshold			Threshold
Power Standard Deviation :	**Pass**	**1.50 %**	Flow Rate :	**Pass**	**5.00 %**
Power Variation :	**Pass**	**10.00 %**	Slope Stability :	**Pass**	**15.00 %**
Temperature :	**Pass**	**5.00 %**	Water Flow Test :	**Pass**	**15.00 %**

Comments

Sample Thermal Conductivity/Response Test document for website. Data contained within is for ilustration purposes only and is not intended to be used for any other purpose. The data is an actual Thermal Response/Conductivity test from an actual test at an undisclosed location.

Thermal Conductivity Test Overview

The thermal conductivity, or thermal response, test is a way to determine ground thermal properties that are critical for ground source heat pump system design. The test is performed by injecting a known and constant heat power into a borehole heat exchanger and then measuring the temperature response. A competent test can provide the undisturbed formation ground temperature, the calculated thermal conductivity, the calculated borehole thermal resistance and an estimate of the thermal diffusivity. These values, critical for the optimal design of a geothermal system, can be used in a geothermal design program to design an optimized, cost effective system.

Undisturbed Ground Temperature Determination

The undisturbed ground temperature is the constant temperature of the formation. Typically, this temperature is measured before starting the active thermal conductivity test. The TC module automatically estimates this value from the first few temperature measurements collected via the TC test unit data logger. The organization that performs the test also has the option of manually estimating this value with temperature probes or the like. If the TC test is initiated too soon after the installation of the test bore, the undisturbed ground temperature may be inaccurate. In general, it is recommended that the testing company waits a minimum of 3-5 days after installing the borehole before initiating the test so as to ensure that the ground has returned to its native and undisturbed temperature state.

Thermal Conductivity Calculation

Because thermal conductivity cannot be measured directly, The Ground Loop Design Thermal Conductivity Module uses the line source heat transfer model to calculate the required results. The line source model, which assumes an infinitely thin heat source in a homogeneous medium, is very broadly-referenced in the published literature and is considered to be the standard analysis methodology. To analyze test data, the average temperature of the water entering and exiting the heat exchanger is plotted versus the natural log of time. Using regression analysis, a best-fit line is plotted to match the empirical data and the slope of the line is used to calculate the thermal conductivity of the formation. Typically, the data analysis procedure may be repeated several times for several different time intervals to ensure the closest fit between the empirical data and the derived best-fit line. In addition, approximately the first 10 hours of temperature data are not included in the analysis so as to ensure that the conductivity value is determined from steady state rather than transient heat conduction processes.

Borehole Thermal Resistance Calculation

The borehole thermal resistance cannot be measured directly but can be calculated from the recorded in-situ measurements. After determining the thermal conductivity, the resultant value can be used in the line-source equation to calculate the borehole thermal resistance. Note that the calculated borehole thermal resistance is representative of the entire test bore configuration including the pipe type, pipe spacing, grout resistance and borehole diameter, etc. The empirically derived borehole thermal resistance may be entered into a design program such as Ground Loop Design for final loopfield design assuming the parameters for the boreholes in the final installation are equivalent to those in the test bore. Details pertaining to the general equation used for the calculation can be found in the research literature (Mattison, et al., 2007 for example).

Thermal Diffusivity Estimation

Thermal Diffusivity may be estimated from a combination of the calculated thermal conductivity value (which is inversely related to the diffusivity) in conjunction with estimates of the specific heat, density and moisture content of the test bore. The thermal diffusivity reflects the rate of conductive heat transfer in the soil and helps determine the impact of neighboring borehole interactions on the final geothermal loopfield design.

Test Procedure Recommendations

The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) offers a set of procedural recommendations for in-situ thermal conductivity/thermal response tests. These can be found in the ASHRAE 2007 HVAC Applications Handbook. Several of the key recommended procedures are as follows:

A) Time between test bore installation and start of TC test: A 5 day minimum wait time is recommended.

B) Undisturbed ground temperature measurement: The undisturbed ground temperature should be recorded prior to test start up.

C)Test Duration: Test duration typically should be for 48 hours or longer.

D) Power Quality: The power standard deviation should be equal to or less than 1.5% of the average power and the maximum power variation should be less than 10% of the average power. The average heat flux should fall within the 15 W/ft to 25 W/ft range to best simulate the expected peak loads in the borehole.