GeoPro, Inc.

IMPORTANCE OF THERMAL GROUT CONDUCTIVITY

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THE IMPORTANCE OF THERMAL GROUT CONDUCTIVITY

In the world of geothermal heat pumps, thermal grout is the only major component in the vertical ground heat exchanger (GHEX) that the system designer can control. Mother Nature controls the undisturbed soil temperature, its ability to transfer heat and to a certain extent, the drilling depths in a given region. When it comes to sizing the GHEX, the loopfield designer can only really control bore spacing, pipe diameter, overall field configuration and thermal grout conductivity (TGC). Of those, thermal grout conductivity plays the biggest part in determining the overall amount of bore required.

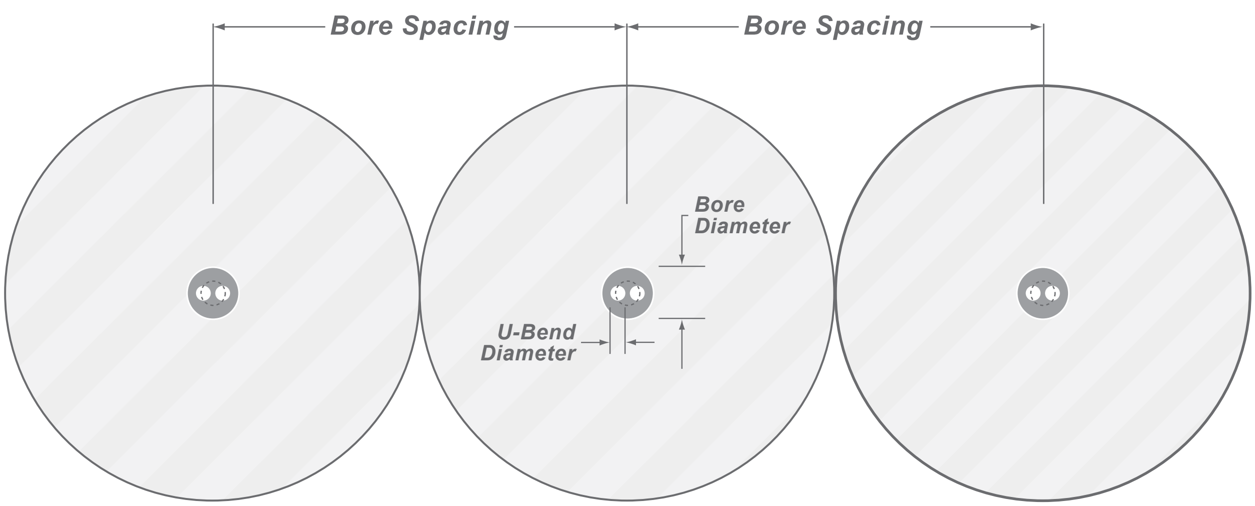
WHY IS THERMAL GROUT CONDUCTIVITY SO IMPORTANT?

Grout acts as the bridge between the pipe and the Earth in the GHEX. It is the only thing standing in the way of heat transfer between the two, so it makes sense to reduce the thermal resistance of the grout as much as possible (within reason, a subject we'll touch on in a bit). If you have to transfer a specific amount of heat through buried pipe, which scenario would be preferable?

1. Surround the pipe with insulation.
2. Surround the pipe with a highly conductive material, such as aluminum.

In both situations, you are trying to transfer the same amount of heat energy. Because the heat can more easily transfer between the pipe and the Earth when the only thing standing in its way is aluminum, it won't take as much pipe to do the same job. For obvious reasons, we don't put aluminum in the GHEX but you get the point; higher thermal conductivities between the pipe and the ground lend themselves to shorter pipe lengths and cheaper installations.

The GHEX system is typically modeled as a u-bend placed inside of a grouted column that is completely surrounded by native soil. The reason that bore performance is so sensitive to thermal grout conductivity is because the heat flux being transferred between the GHEX and the Earth is highest through the part of the system with the smallest amount of surface area (i.e. - just on the outer surface of the u-bend pipe). The material in direct contact with that outer surface (grout) will greatly affect the performance of the GHEX.



THE IMPORTANCE OF THERMAL GROUT CONDUCTIVITY

In technical terms, the answer to the question of why thermal grout conductivity is so important can be traced back to the radial heat transfer equation, which describes the amount of heat transfer per unit length in the bore:

1

$$\frac{q}{L} = \frac{(T_{loop} - T_{soil})}{R_{total}}$$

Where
- q/L = Heat transfer per unit borehole length (Btu/hr ft)
- T_{loop} = Loop design temperature (°F)
- T_{soil} = Undisturbed soil temperature (°F)
- R_{total} = Total thermal resistance of the GHEX (hr ft °F/Btu)

The total thermal resistance of the GHEX is simply the sum of its parts (the thermal resistance of the pipe, grout and soil acting together in series) shown in equation 2.

2

$$R_{total} = R_{pipe} + R_{grout} + R_{soil}$$

Where
- R_{total} = Total Resistance
- R_{soil} = Soil thermal resistance (hr ft °F/Btu)
- R_{grout} = Grout thermal resistance (hr ft °F/Btu)
- R_{pipe} = 0.096 hr ft °F/Btu, the equivalent thermal resistance of the u-bend, which includes the film resistance of circulating fluid (assumed to be water with turbulent flow)

The grout and soil thermal resistance values are calculated using equations 3 & 4:

3

$$R_{grout} = \frac{\ell n(D_{bore}/\sqrt{2}\, D_{po})}{2\pi k_{grout}}$$

Where
- D_{bore} = Borehole diameter (in)
- R_{grout} = Grout thermal resistance (hr ft °F/Btu)
- D_{po} = Outside u-bend pipe diameter (in)
- k_{grout} = Grout thermal conductivity (Btu/hr ft °F)

4

$$R_{soil} = \frac{\ell n(D_{soil}/D_{bore})}{2\pi k_{soil}}$$

Where
- D_{bore} = Borehole diameter (in)
- D_{soil} = Diameter to undisturbed soil (in)
- k_{soil} = Soil thermal conductivity (Btu/hr ft °F)
- R_{soil} = Soil thermal resistance (hr ft °F/Btu)

The main thing to notice with these equations is that the grout resistance is the only term that you can control. It's effect on overall thermal resistance is best shown through an example:

STEADY-STATE COOLING EXAMPLE

To illustrate the importance of thermal grout conductivity on heat transfer, consider the following steady-state cooling example using 1.0" DR-11 HDPE u-bends with thermal grout conductivities of 0.40 Btu/hr ft °F, 0.88 Btu/hr ft °F, 1.20 Btu/hr ft °F and 1.60 Btu/hr ft °F. We will compare the resistance in the pipe, grout and soil and calculate the heat transfer per length of borehole for each thermal grout conductivity. (Throughout this example, only thermal grout conductivity will be varied. All other variables will be held constant).

R_{pipe} = 0.096 hr ft °F/Btu	**k_{soil} = 1.20 Btu/hr ft °F**	**T_{soil} = 62°F**
T_{loop} = 90°F	**D_{soil} = 15 ft = 180 in.**	**D_{pipe} = 1.315 in.**
D_{bore} = 5.00 in.		

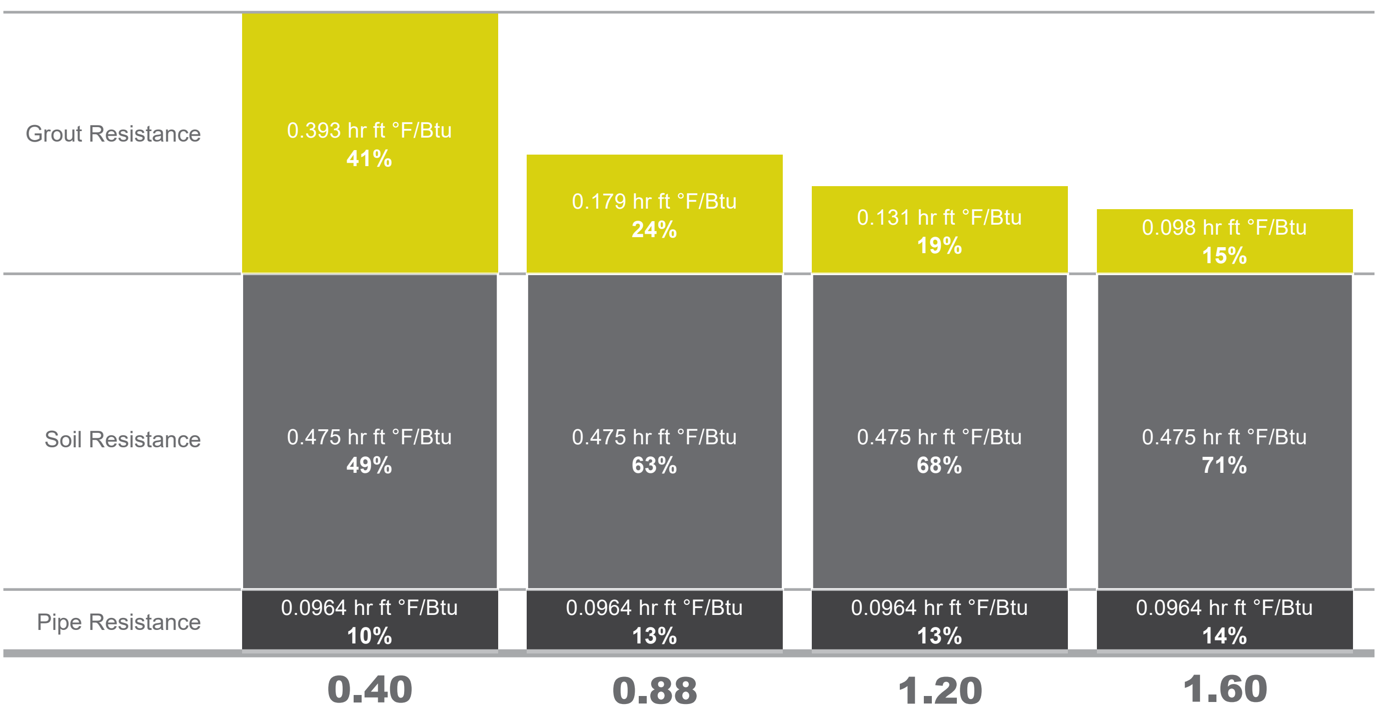
THERMAL GROUT
RESISTANCE

The net effect of using higher thermal grout conductivity (TGC) values will be to reduce the overall thermal resistance in the GHEX. That means you will be able to deliver the same amount of heat with less bore (see insulation vs. aluminum example on page 1). In this example, there is a notable reduction in thermal resistance from the first jump in thermal grout conductivity values (from 0.40 to 0.88) but notice how the reduction trails off. For example, increasing thermal grout conductivity from 0.40 to 0.88 reduces overall resistance by 22.2% while increasing again from 0.88 to 1.20 only reduces overall thermal resistance by 6.4%.

TGC	Thermal Resistance Values				% Reduction	
k_{grout}	R_{pipe}	R_{grout}	R_{soil}	R_{total}	Incremental	Total
0.40	0.096	0.394	0.475	0.965	-	-
0.88	0.096	0.179	0.475	0.750	22.2%	22.2%
1.20	0.096	0.131	0.475	0.702	6.4%	27.2%
1.60	0.096	0.098	0.475	0.669	4.7%	30.6%

THERMAL RESISTANCE IN THE BOREHOLE

Keep in mind that we have no control over the soil's thermal resistance. As we increase thermal grout conductivity, soil resistance will eventually become the bottleneck that restricts the heat transfer in the system. In this example, grout resistance goes from 40.8% of the total (with 0.40 grout) to 14.6% (with 1.60 grout). Across the same range, soil resistance varies from 49.3% to 71.0% of the total.



Clearly, with the effect that thermal grout conductivity has on resistance to heat transfer in the GHEX, it also directly affects design lengths (the amount of bore required to deliver a certain level of performance) and thus the drilling, pipe and labor costs to install the system. So, it's safe to say that using thermal grout to reduce overall borehole design lengths can lower the up-front, initial cost of the system.

DESIGN LENGTHS VS. THERMAL GROUT CONDUCTIVITY

Before you can look at the economics, you need an idea of how much design lengths will actually be affected by thermal grout conductivity. Let's use the following information in an example:

- 62°F undisturbed soil temperature
- 1.20 Btu/hr-ft-°F soil thermal conductivity
- Turbulent flow through 1" u-bends in a 5" diameter bore
- 100-ton (1200 MBH) balanced peak heating and cooling loads
- GSHP heating efficiency, COP=3.92 for a 30°F entering water temperature
- GSHP cooling efficiency, EER=15.7 for a 90°F entering water temperature

Based on that information, we used LoopLink® PRO to calculate the amount of bore required for various thermal grout conductivity values.

IMPACT OF THERMAL GROUT CONDUCTIVITY ON REQUIRED BORE LENGTH

There are two things to notice from the results of the calculations. The first thing to notice is that as thermal grout conductivity increases, the amount of bore required to deliver the same performance decreases. The second and probably more interesting thing to notice is that as thermal grout conductivity increases, the incremental bore reduction from value to value becomes less and less:

- Note how jumping from a 0.40 to a 0.88 thermal grout conductivity reduces bore lengths by 57.8 ft per ton while jumping from a 0.88 to a 1.20 only reduces bore lengths by an additional 12.9 ft per ton.

- The difference between a 0.88 and a 1.20 thermal thermal grout conductivity is again only 12.9 ft. per ton, but the mix ratios differ by a factor of 2 with respect to sand content (see Dry Solids table).

This phenomena, commonly referred to as the "law of diminishing return", is an important factor in determining the best thermal grout conductivity value for a project in terms of installation cost. It is up to the system designer to perform a separate economic analysis to determine which thermal grout conductivity will result in the best system performance for the lowest cost.

Thermal Grout Conductivity (Btu/hr ft °F)	Bore Length (Total ft)	Reduction (ft/ton)	
		Incremental (Starting at 0.40)	Total
0.40	27,910	-	-
0.57	24,750	31.6	31.6
0.69	23,450	13.0	44.6
0.79	22,680	7.7	52.3
0.88	22,130	5.5	57.8
1.00	21,550	5.8	63.6
1.07	21,270	2.8	66.4
1.14	21,030	2.4	68.8
1.20	20,840	1.9	70.7
1.40	20,340	5.0	75.7
1.60	19,960	3.8	79.5

FINDING THE PERFECT BALANCE

When it comes to thermal grout conductivity, the natural tendency is to believe that "bigger is better". The reality is that a system designer will always need to select the correct grout for each design by carefully balancing physics against economics.

From a purely mathematical perspective, using the highest thermal grout conductivity will always result in the shortest design lengths. In reality higher thermal grout conductivity values often come at an increased unit price and so may not equate to a more cost-effective loopfield. A cost analysis including the cost of materials, delivery and labor should always be made prior to choosing a thermal grout conductivity.

GeoPro has an online calculator that makes this type of analysis quick and easy. The calculator is free for all to use, along with an ever-growing collection of geothermal and thermal grout related resources and tools can be found on our website. Just go to **www.geoproinc.com** for free access to all of our available resources.

If you aren't comfortable performing this type of analysis on your own, we are here to help you work through any specific problems you may have. Please give us a call at (877) 580-9348 and a member of our experienced staff will be available to help.

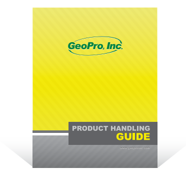
Sincerely,

Ryan Carda, Lead Support Engineer
GeoPro, Inc.

INFORMATION AND RESOURCES

GeoPro has collected a lot of useful information throughout our years in the geothermal industry. Our resources are here to shed some light on topics like grout selection, ground heat exchanger design and just generally useful bits of information for geothermal system installers and designers. All of this information can be found in the resources section on our website at: www.geoproinc.com.

PRODUCT HANDLING GUIDE



Learn how to select and handle the correct GeoPro grout. This document is a great resource for designers and contractors.

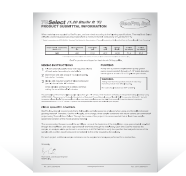
geoproinc.com/resources/product_handling_guide.html

THERMAL GROUT COMMISSIONING

This document is intended to serve as a road map for ensuring the success of your system through the design and installation process from a grouting perspective.

geoproinc.com/resources/thermal_grout_commissioning.html

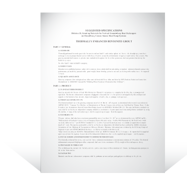
PRODUCT SUBMITTAL SHEETS



Submittals provide proper mixing and pumping instructions for every thermal grout product we sell with all the specifications for accurate loopfield grouting.

geoproinc.com/resources/documents.html#submittals

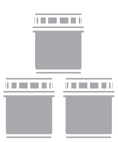
RECOMMENDED GROUTING SPECS



Suggested specifications for the correct materials, target thermal conductivity, proper installation and inspection of each borehole.

geoproinc.com/resources/documents.html#specs

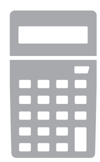
SAMPLING GUIDELINES



Accurate thermal grout conductivity testing results for geothermal applications start in the field with proper sampling.

geoproinc.com/services/grout_sample_collection_101.html

GROUT VOLUME & COST CALCULATOR



This calculator will allow you to estimate the installed volume of grout required for your project, help to estimate total project costs including: material, freight and labor.

geoproinc.com/calculators/grout_calculator.htm

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