GeoPro, Inc.

IMPORTANCE OF GROUT THERMAL CONDUCTIVITY

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THE IMPORTANCE OF GROUT THERMAL CONDUCTIVITY

In the world of geothermal heat pumps, thermally-enhanced 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 grout thermal conductivity (TC). Of those, grout TC plays the biggest part in determining the overall amount of bore required.

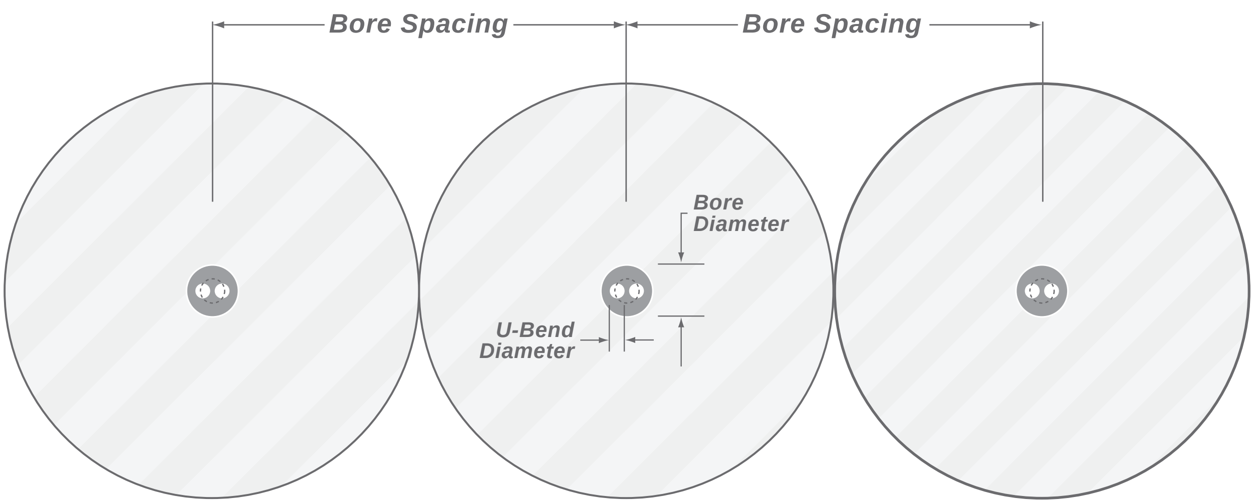
WHY IS GROUT THERMAL CONDUCTIVITY SO IMPORTANT?

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 grout TC 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 GROUT
THERMAL CONDUCTIVITY

In technical terms, the answer to the question of why grout TC 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

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

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

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

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 grout thermal conductivity on heat transfer, consider the following steady-state cooling example using 1.0" DR-11 HDPE u-bends with grout thermal 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 grout thermal conductivity. (Throughout this example, only grout thermal 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} = 1.860 in.**
D_{bore} = 5.00 in.		

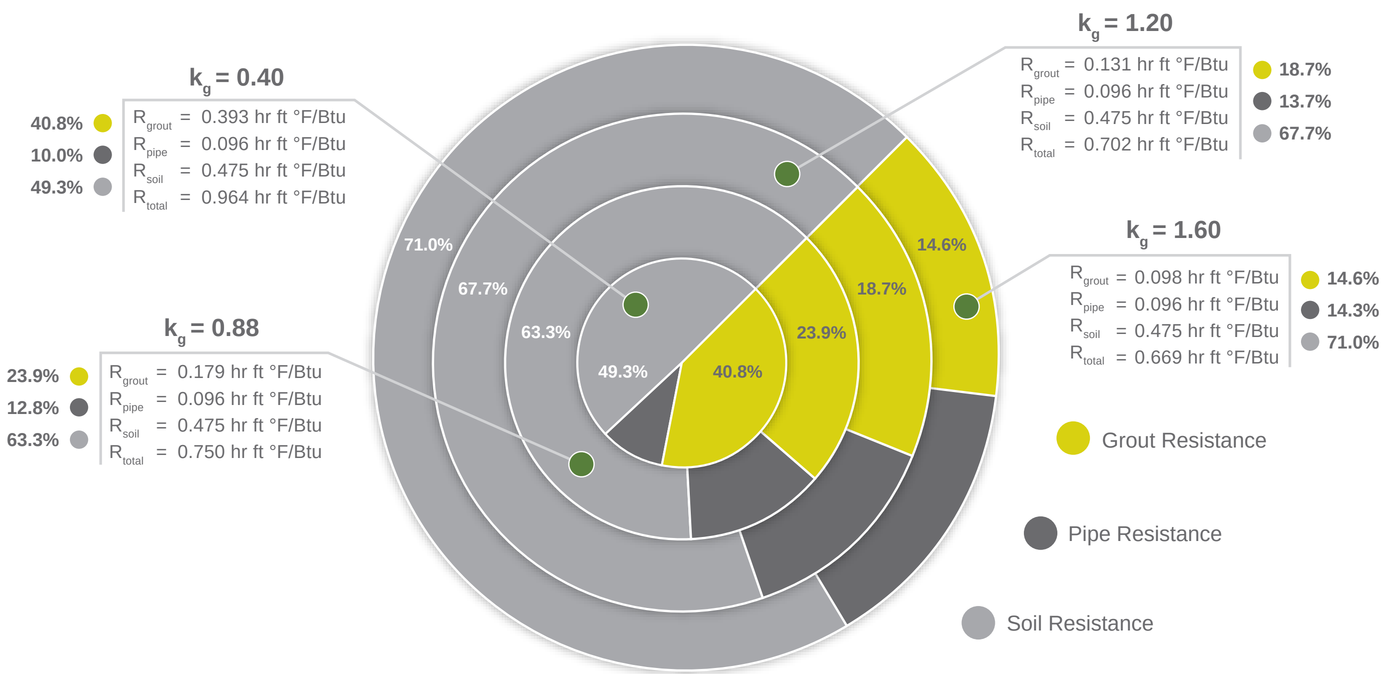
GROUT THERMAL
RESISTANCE

The net effect of using higher grout TC 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 grout TC values (from 0.40 to 0.88) but notice how the reduction trails off. For example, increasing grout TC from 0.40 to 0.88 reduces overall resistance by 22.2%. But increasing grout TC again from 0.88 to 1.20 only reduces overall thermal resistance by 6.4%.

Grout TC	Thermal Resistance Values				% Reduction	
k_{grout}	R_{pipe}	R_{grout}	R_{soil}	R_{total}	Incremental	Total
0.40	0.096	0.393	0.475	0.964	-	-
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 grout TC, 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 grout TC 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 thermally-enhanced grout to reduce overall borehole design lengths can lower the up-front, initial cost of the system, which brings us to our next point:

The system designer must perform an economic analysis in order to determine which grout thermal conductivity value will result in the best system performance for the least cost.

BIGGER ISN'T ALWAYS BETTER

When it comes to grout TC, the natural tendency is to believe that "bigger is better." As a system designer, you are faced with balancing physics against economics. From a pure calculation perspective, using the highest grout TC value will result in the shortest design lengths. But does the cost of using that grout result in the lowest installation cost for the system?

Remember, the objective in loopfield design is to deliver a certain level of performance for the lowest possible cost. The cost of materials for the grout, the cost of transporting those materials to the job site and the labor costs to mix and pump the grout all increase with higher thermal conductivities. The amount of raw material (measured by dry solids content per 100 gallons of grout slurry) increases very rapidly with grout TC value, as shown in the following table:

DRY SOLIDS PER 100 GALLONS OF GROUT SLURRY

Grout Type	Grout TC (Btu/hr ft °F)	Water (gal)	Grout (lb)	Sand (lb)	PowerTec	Yield (gal)	Solids / 100 Gal (lb)
BH20	0.40	24	50	0	0	26.7	187
TGLite	0.57	14.5	50	50	0	19.6	510
	0.69	15.5	50	100	0	23.0	652
	0.79	16.5	50	150	0	26.2	763
	0.88	17.5	50	200	0	29.3	853
	1.00	18.5	50	250	0	32.6	920
TGSelect	1.07	19.2	50	300	0	35.7	980
	1.14	20.4	50	350	0	39.1	1023
	1.20	21.6	50	400	0	42.2	1066
	1.40	22.0	50	300	25	30.9	1214
	1.60	18.0	50	50	50	26.1	575
Premixed* (As supplied by others)	1.40	8.0	50	0	0	10.0	500
	1.60	7.0	50	0	0	9.0	556

**Premixed (one-sack) thermally-enhanced grouting products are not available from GeoPro*

As you can see, the amount of dry solids in a 1.20 Btu/hr ft °F thermally-enhanced grout is nearly 6-times higher than the amount of dry solids in a standard, 20% solids grouting material (TC value = 0.40 Btu/hr ft °F). That additional material must be purchased, shipped, mixed and pumped, none of which can be done for free.

So then, when it comes to the economics of loopfield design and installation, ask yourself one question: does higher grout TC necessarily translate into a more cost-effective loopfield? We already know that design lengths will decrease with higher grout TC values but will there be a point where the savings from reducing bore lengths (in drilling costs, pipe costs, etc.) are offset by the increased cost to obtain a higher grout thermal conductivity?

DESIGN LENGTHS VS. GROUT TC

Before you can look at the economics, you need an idea of how much design lengths will actually be affected by thermal grout TC. 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 GCHPCalc V4.2 to calculate the amount of bore required for various grout TC values.

IMPACT OF GROUT TC ON REQUIRED BORE LENGTH

There are two things to notice from the results of the calculations. The first thing to notice is that as grout TC increases, the amount of bore required to deliver the same performance decreases. The second and probably more interesting thing to notice is that as grout TC 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 TC 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 grout TC 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 grout TC value for a project in terms of installation cost. To better understand how the law of diminishing return affects our calculations, go back to the discussion about the effect of grout TC on bore resistance.

Grout TC (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

THE EFFECT OF GROUT TC ON INSTALLATION COST

PURCHASE AND DELIVERY COSTS

Now that we have an idea of how grout TC affects design lengths, it's time to look at the bigger picture. Clearly, using a grout TC of 1.60 Btu/hr ft °F yields the smallest bore length requirements. Does that also equate to the lowest overall installation cost for the system?

To answer this question, you need to have an idea of what every component will cost during the installation process. To continue with our example, we made the following assumptions:

- Contractor pricing of $3.75 per 50 lb bag of silica sand
- Contractor pricing of $44.50 per 50 lb bag of PowerTEC (for TC values 1.40-1.60)
- Contractor pricing of $60.00 per bag of premixed, high TC grout (for TC values 1.40-1.60)
- Freight costs of $2000 per truckload of grout and $1250 per truckload of sand and PowerTEC
- Contractor pricing of $6.50 for BH20, $8.00 for TG Lite and $11.00 for TG Select (per 50 lb bag)

LABOR COSTS

In addition to the cost for purchase and delivery of the materials, we needed to estimate the labor cost associated with handling each of these products.

- Hourly labor rates of $30/hour
- Headering cost of $500 per bore
- Pipe cost of $0.60 per ft. of completed bore
- A low pumping rate of 7 gpm for Thermal Grout Select products
- A mid pumping rate of 10 gpm for Thermal Grout Lite and PowerTEC products
- A higher pumping rate of 15 gpm for BH20 and for premixed (one-sack) grouting products
- Propylene glycol antifreeze cost of $20 per gallon, assuming 20% concentration by volume
- Approximate mixing time of 2 minutes per 50-lb bag of material in each batch (grout and sand)

To give full credit to savings from reduced headering requirements, we assumed a target bore depth of 300 ft. for the loopfield. Rather than reducing individual bore depths with increasing grout TC, we simply reduced the number of bores so that the total bore footage was divided up into even 300 ft. increments. This is common practice in loopfield design which we adhered to for this analysis.

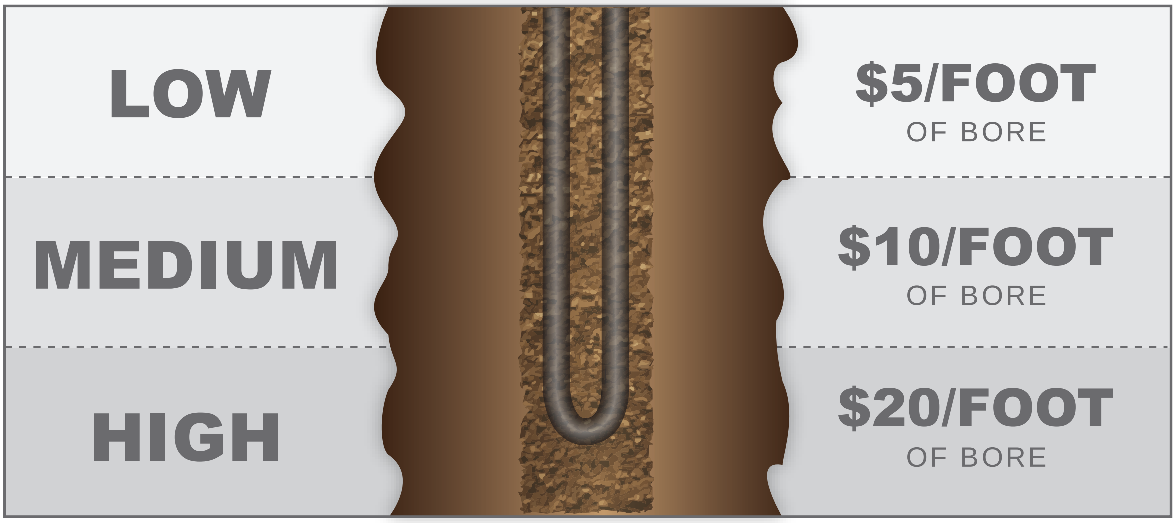
Notice that through all of our assumptions, we attempted to take into account the increased material costs along with the increased freight and labor requirements that come with using high TC grout. We also accounted for the savings that come from reduced drilling, pipe and headering requirements for those products.

But keep in mind that as grout TC increases, the degree of difficulty during installation also increases. Talk to any contractor and they will tell you that they would prefer to mix and pump lower TC grouts compared to higher TC grouts any day. Some contractors may even tack on additional charges for higher TC grout because of the added degree of difficulty, which was not considered here. In areas where sand is more expensive, using higher grout TC values (such as 1.20) will quickly become expensive.

THE EFFECT OF GROUT TC ON INSTALLATION COST

DRILLING RATES

The last assumption to make was on drilling rates. Obviously, the more it will cost to drill a hole, the more it makes sense to increase grout TC in an attempt to reduce drilling costs. For this example, we decided to explore three different drilling rates.



Just to give you a rough idea of how drilling rates vary across the United States:

- The $5/ft drilling rate could be seen in the middle of the country where labor rates and overhead costs are generally lower.
- The $10/ft drilling rate could be seen in more expensive parts of the country (on either of the coasts, for example) where drilling is still relatively easy and mud rotary drilling methods can be used.
- The $20/ft drilling rate could be seen in more expensive parts of the country (again, on the coasts) where drilling through hard rock is required and air hammer methods must be used.

As you will see in the following pages, the cost to drill a borehole will generally be one of the biggest factors when determining which grout TC value is best.

THE CASE FOR $5/FT DRILLING RATE

For the case of the $5/ft. drilling rate, first note the savings captured by bumping up from a standard, 20% solids grout (0.40 TC) to a 1.00 grout TC. The difference is more than $317 per ton. For the 100-ton project we've been looking at, that amounts to $31,700 in savings by making a moderate change in grout TC value.

You can also see that the lowest installation cost can be achieved using the 1.20 grout TC value. However, the installation cost difference between the 1.00 and the 1.20 grout TC value is only $21 per ton (1.1%). That means by using the more modest 1.00 grout TC value, you will be able to capture 98.9% of the maximum possible savings offered by the 1.20 grout.

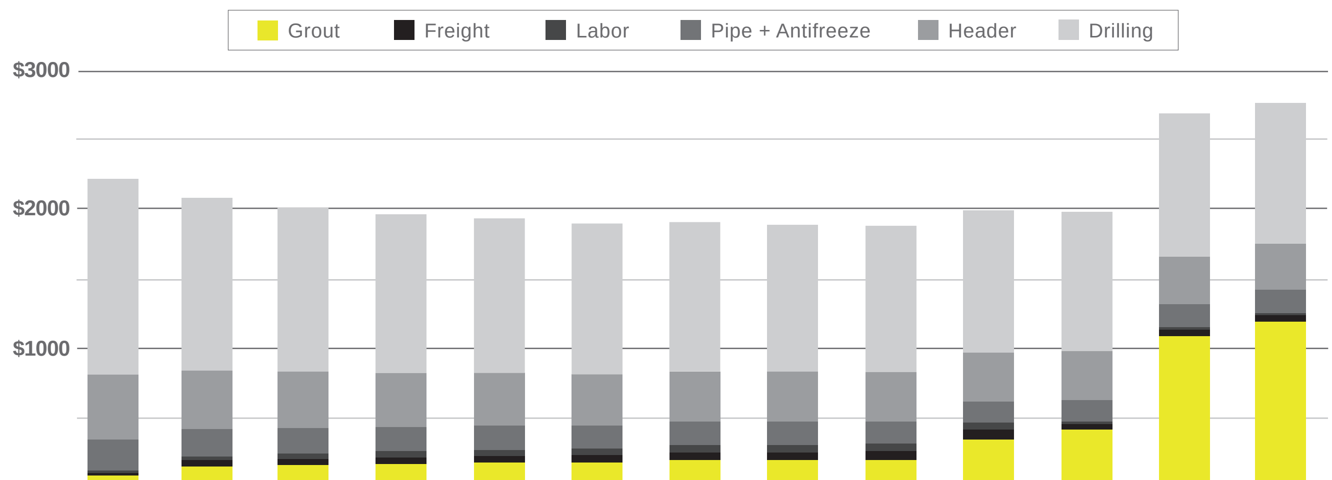
Because of this, it would be hard to argue against staying at or below the 1.00 grout TC value to reduce the degree of difficulty for the contractor, reducing the potential for error during installation. On a 100-ton project, $21 per ton amounts to a savings of $2,100 for a $185,000 project (GHEX cost only).

FROM 0.40 TC TO 1.00 TC SAVES
$317
PER TON

FROM 1.00 TC TO 1.20 TC SAVES
$21
PER TON

INSTALLATION COST DETAILS - $5/FT DRILLING RATE

Total Cost ($/ton)



		0.40	0.57	0.69	0.79	0.88	1.00	1.07	1.14	1.20	1.40	1.60	Premixed 1.40*	Premixed 1.60*
Total Cost ($/ton)		$2,188	$2,056	$1,978	$1,933	$1,908	$1,871	$1,877	$1,861	$1,850	$1,957	$1,945	$2,658	$2,733
Savings vs. 0.40 TC	($/ton)	-	$132	$209	$255	$280	$317	$311	$327	$338	$231	$243	-$470	-$545
	(%)	-	6.0%	9.6%	11.6%	12.8%	14.5%	14.2%	14.9%	15.4%	10.6%	11.1%	-21.5%	-24.9%
Difference from Minimum Value	($/ton)	$338	$206	$128	$83	$58	$21	$27	$11	$0	$107	$95	$808	$883
	(%)	18.3%	11.1%	6.9%	4.5%	3.1%	1.1%	1.5%	0.6%	0.0%	5.8%	5.1%	43.7%	47.7%

**Premixed (one-sack) thermally-enhanced grouting products are not available from GeoPro*

THE CASE FOR $10/FT
DRILLING RATE

For the case of the $10/ft. drilling rate, the difference between the 0.40 and the 1.00 grout TC values is $635 per ton.

The lowest installation cost can again be captured by using the 1.20 grout TC value. The installation cost difference between the 1.00 and the 1.20 grout TC value is $56 per ton (1.9%). That means by using the more modest 1.00 grout TC value, you will be able to capture 98.1% of the maximum possible savings offered by the 1.20 grout.

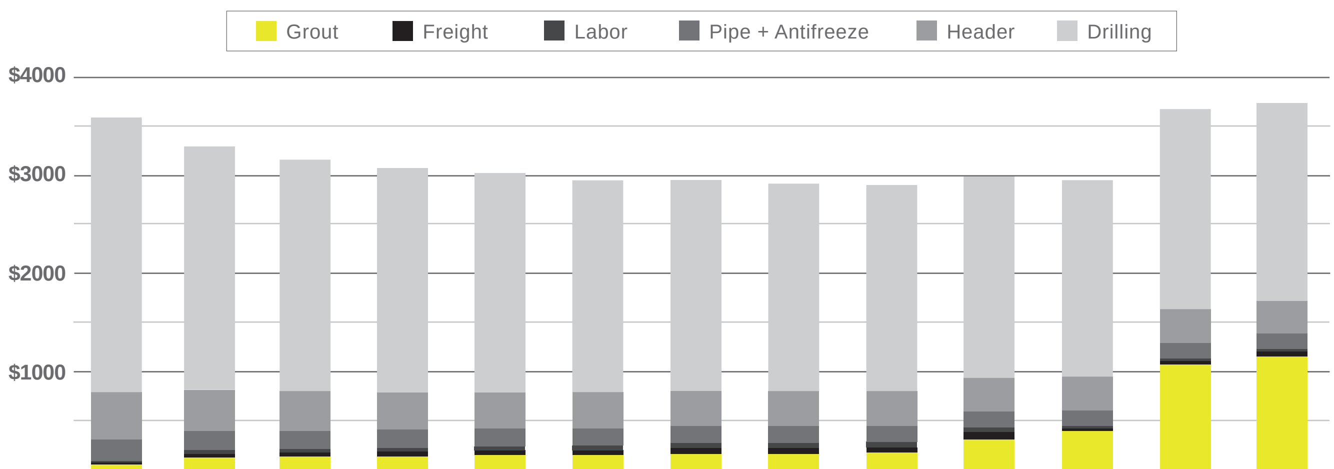
On a 100-ton project, $56 per ton amounts to a savings of $5,600 for a $289,200 project (GHEX cost only). As before, it would be hard to argue against staying at or below the 1.00 grout TC value to reduce the degree of difficulty for the installing contractor.

FROM 0.40 TC TO 1.00 TC SAVES
$635
PER TON

FROM 1.00 TC TO 1.20 TC SAVES
$56
PER TON

INSTALLATION COST DETAILS - $10/FT DRILLING RATE

Total Cost ($/ton)



		0.40	0.57	0.69	0.79	0.88	1.00	1.07	1.14	1.20	1.40	1.60	Premixed 1.40*	Premixed 1.60*
Total Cost ($/ton)		$3,583	$3,293	$3,151	$3,067	$3,015	$2,948	$2,941	$2,913	$2,892	$2,974	$2,943	$3,675	$3,731
Savings vs. 0.40 TC	($/ton)	-	$290	$432	$516	$569	$635	$643	$671	$691	$609	$640	-$92	-$148
	(%)	-	8.1%	12.1%	14.4%	15.9%	17.7%	17.9%	18.7%	19.3%	17.0%	17.9%	-2.6%	-4.1%
Difference from Minimum Value	($/ton)	$691	$401	$259	$175	$123	$56	$49	$21	$0	$82	$51	$783	$839
	(%)	23.9%	13.9%	8.9%	6.1%	4.2%	1.9%	1.7%	0.7%	0.0%	2.8%	1.8%	27.1%	29.0%

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THE CASE FOR $20/FT
DRILLING RATE

For the case of the $20/ft. drilling rate, the difference in total installation cost between the 0.40 and the 1.00 grout TC values is more than $1,271 per ton! That amounts to $127,100 in savings on our 100-ton project (GHEX cost only).

The lowest installation cost in this case would be captured by using a 1.60 grout TC value (PowerTEC required). Because the drilling rates are so high, it makes sense to pay the premium for the more expensive PowerTEC additive to reduce the drilling lengths as much as possible. Remember, contractor pricing for PowerTEC was assumed to be $44.50 per 50lb bag.

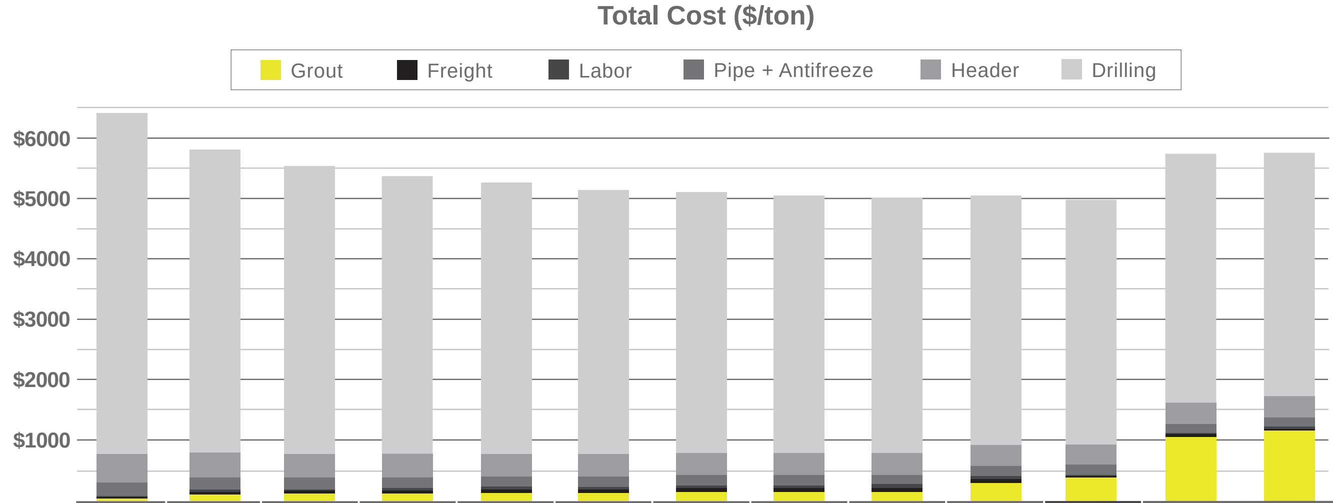
The installation cost difference between the 1.00 and the 1.60 grout TC value is $164 per ton (3.3%). On a 100-ton project, $164 per ton amounts to a savings of $16,400 for a $493,900 project (GHEX cost only).

Even though the savings from a 1.00 to 1.60 grout TC represents a small percentage of the overall system cost (3.3%), the latter is definitely worth considering to reduce the first cost of an already expensive system.

FROM 0.40 TC TO 1.00 TC SAVES **$1271** PER TON

FROM 1.00 TC TO 1.60 TC SAVES **$164** PER TON

INSTALLATION COST DETAILS - $20/FT DRILLING RATE



		0.40	0.57	0.69	0.79	0.88	1.00	1.07	1.14	1.20	1.40	1.60	Premixed 1.40*	Premixed 1.60*
Total Cost ($/ton)		$6,374	$5,768	$5,496	$5,335	$5,228	$5,103	$5,068	$5,016	$4,976	$5,008	$4,939	$5,709	$5,727
Savings vs. 0.40 TC	($/ton)	-	$606	$878	$1,039	$1,147	$1,271	$1,307	$1,359	$1,398	$1,366	$1,435	-$665	-$647
	(%)	-	9.5%	13.8%	16.3%	18.0%	19.9%	20.5%	21.3%	21.9%	21.4%	22.5%	10.4%	10.2%
Difference from Minimum Value	($/ton)	$1,435	$829	$557	$396	$289	$164	$128	$76	$37	$69	$0	$770	$788
	(%)	29.1%	16.8%	11.3%	8.0%	5.8%	3.3%	2.6%	1.5%	0.7%	1.4%	0.0%	15.6%	16.0%

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FINDING THE
PERFECT BALANCE

We have shown that when drilling costs are high, it pays more to go to the higher grout TC value. But, the underlying principle in all of this is to find the most cost-effective solution for a specific problem. Using the most expensive grouting product with the highest grout TC value won't always be the best solution.

In all of these examples, relatively large cost savings were realized through moderate increases in grout TC.
By increasing grout TC from 0.40 Btu/hr ft °F to 1.00 Btu/hr ft °F, we captured more than 96% of the maximum possible savings in all cases.

The goal of loopfield design is to achieve the desired system capacity and efficiency at a justifiable cost. Higher grout TC values may or may not equate to a more cost-effective loopfield. A complete analysis should be made including the cost of handling the grouting materials at the job site.

Although an analysis like this sounds complicated at first blush, GeoPro has an online calculator that makes it a snap. This free calculator, 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** and get free access to all we have available.

As always, 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.

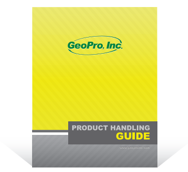
Sincerely,

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.

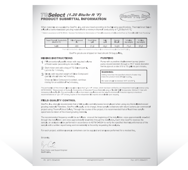
geoproinc.com/resources/product_handling_guide.html

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

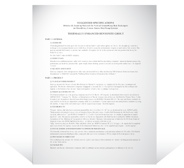
PRODUCT SUBMITTAL SHEETS



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

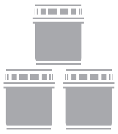
RECOMMENDED GROUTING SPECS



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

geoproinc.com/resources/documents.html#specs

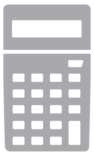
SAMPLING GUIDELINES



Accurate grout thermal 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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