Advanced Testing Method for Ground Thermal Conductivity

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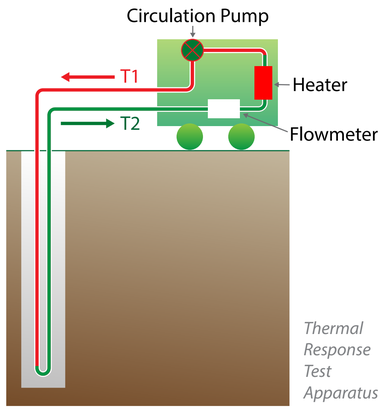
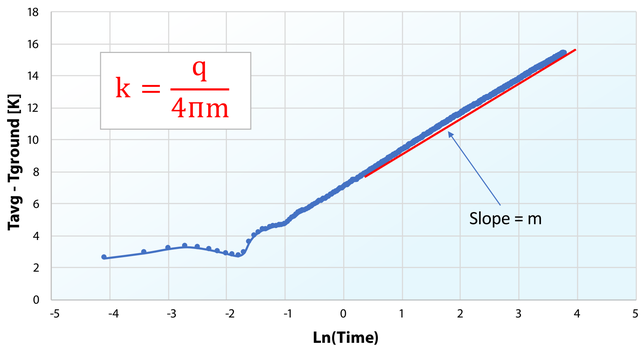
Introduction

Effective ground thermal conductivity (EGTC) is a critical parameter for designing geothermal (ground source) heat pump (GHP) systems. EGTC at a given location is usually measured with a thermal response test (TRT). Current Industry Standards (ANSI/CSA C448 Series-16) for TRT requires:

- Minimum 36–48 hours
- Stable power supply throughout the entire TRT (variation less than ±1.5% of the average, peaks less than ±10% of the average)



Thermal Response Test Apparatus



Current practice uses the line source model (Ingersoll and Plass 1948, Ingersoll et al. 1950) to determine EGTC value based on TRT results. The early 10-18 hours of data are usually discarded.

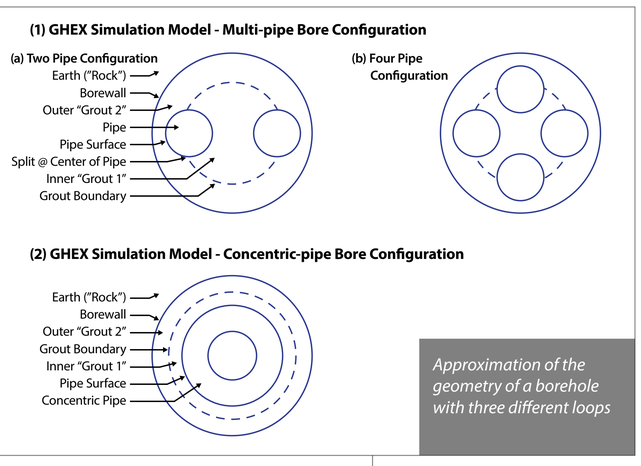
These rigid requirements make EGTC testing expensive so that it is under used commercially and rarely for residential GHP systems. The lack of accurate EGTC data often leads to either oversized, more expensive ground heat exchangers (GHEXs) or to undersized, poorly performing GHEXs. Requiring rigid power also forgoes any opportunity of using varying heat sources including a building's operating heat pumps or alternate sources of heat.

The **objective** of this study was to develop **a new method that determines EGTC with comparable or better accuracy, but with a shorter test time and without a highly stable power supply** for **an affordable EGTC testing for all GHP projects including post installation.** A further objective was to, for the first time, provide a means to analyze the installed grout thermal conductivity of a GHEX.

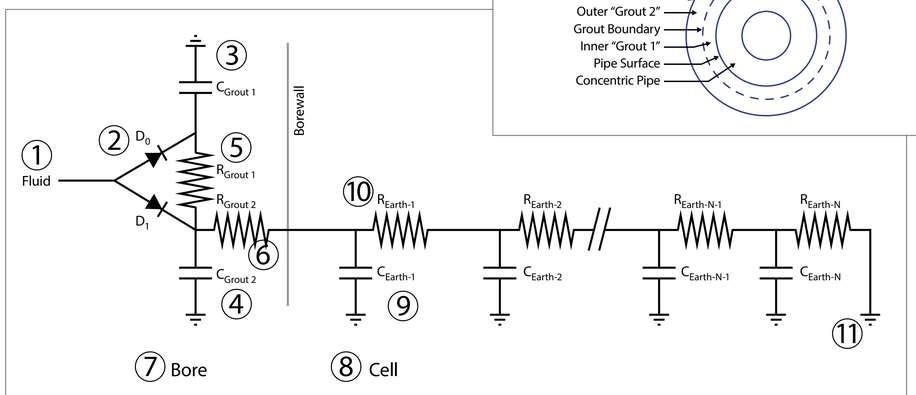
Methods

Improved heat transfer modeling for vertical bore ground heat exchangers

Account for transient heat transfer both inside and outside a vertical bore



Approximation of the geometry of a borehole with three different loops

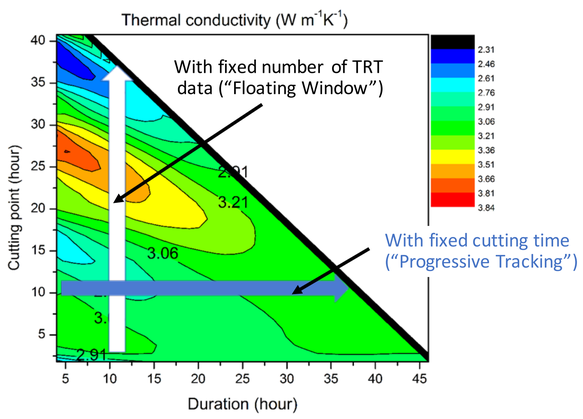


A resistor-capacitor circuit (R-C) model for the transient heat transfer process within a vertical bore and throughout the surrounding ground formation

This simplified R-C model is used to determine EGTC value through a parameter estimation approach

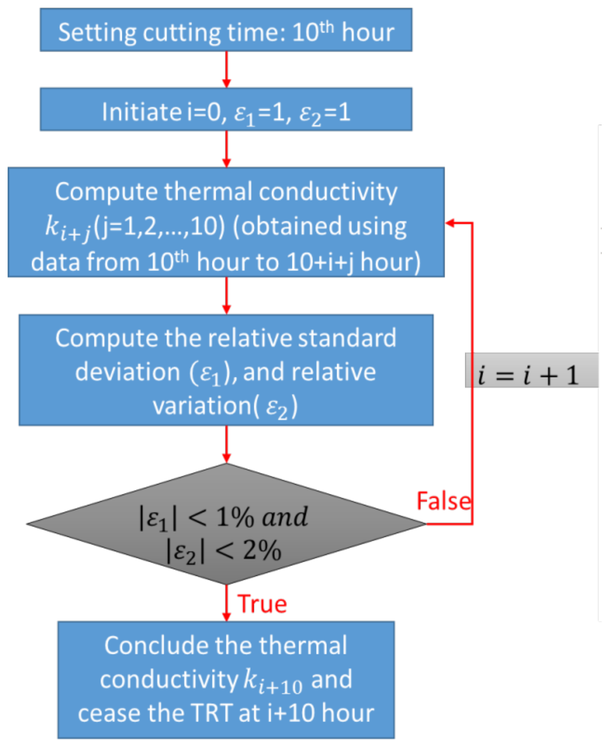
Better algorithm for analyzing TRT data

Dynamically determine minimum test duration



EGTCs calculated with two different approaches ("Floating Window" and "Progressive Tracking") during a TRT

The above case study shows that, EGTC can be evaluated within less than 24 hours during a TRT and the result is about the same as that determined with 36-48 hours of TRT data.



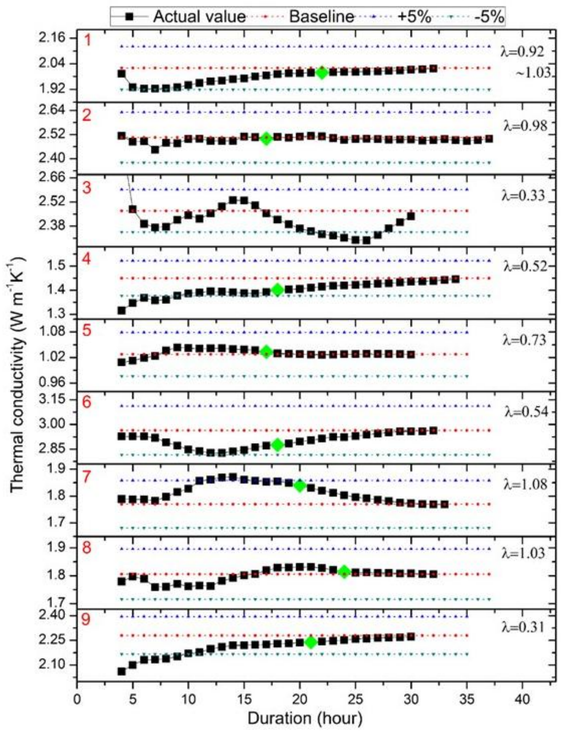
A new algorithm to determine whether a TRT has collected sufficient data to determine EGTC with acceptable accuracy

Results

1. Min. TRT duration for determining EGTC

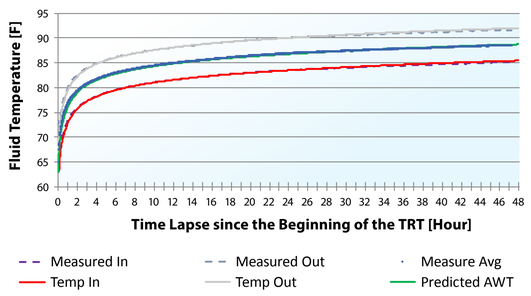
- 21%–46% shorter in all cases except case 3 (which had varying heat input) and the determined EGTCs are within ±5% of those determined with full ~48 hours of TRT data
- TRT time could be further reduced with earlier cutting time

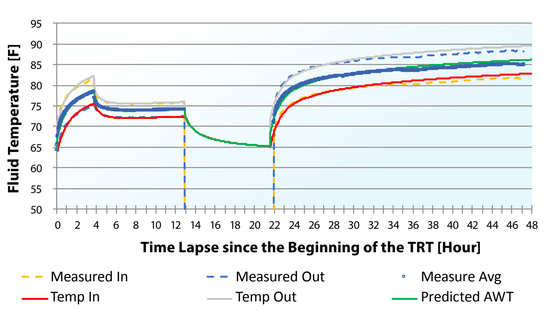
Green Dots indicate EGTCs determined with the new algorithm



2. Prediction of GHEXs fluid temperature

- Root Mean Square Error (RMSE) of the predicted average fluid temperature was less than 0.1°F compared with measured values when heat input is stable and continuous
- Predicted average fluid temperature matched measured values very well even when the heat input was interrupted





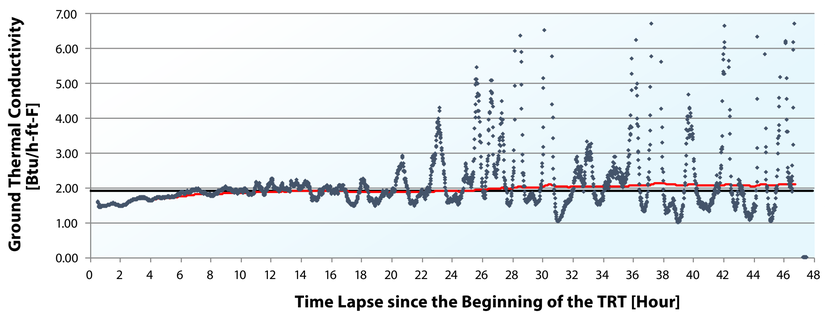
3. EGTC determined with the new R-C model

- 12 datasets (36–48 hours) of TRTs were used to determine EGTCs with both the conventional line-source (LS) and the new R-C model
- EGTCs determined with the new R-C model are very close to those determined with the conventional line source method (with less than 10% variance) except in cases 2 and 5 (cases 1-6 were all within a 2 block area making the R-C model likely more accurate)
- Difference between the reported grout thermal conductivity values and those determined with the R-C model are significant in most cases. It is found that some reported grout thermal conductivity values were not correct (e.g., in case 4, due to difficulties of grouting, grout was pumped into the borehole from the ground surface instead of from bottom up as required by industry standard)

A Summary of 12 TRT Cases and GTC Values Determined by the New R-C Model

Case #	Loop Design	Depth ft	Grout Type	Ground Temp. F	Mea. Kgrd (LS) Btu/h-ft-°F	Mea. Kgrd (RC) Btu/h-ft-°F	Difference	Rep. Kgrt Btu/h-ft-°F	Mea. Kgrt (RC) Btu/h-ft-°F	Difference
1	Co-axial (2.5" SDR-21)	214	Barotherm Max	62.8	2.05	1.93	-6%	1.79	0.80	-55%
2	Single U-tube (1" DR11)	319	Barotherm Gold	63.7	2.22	1.93	-13%	1.00	0.99	-2%
3	Double U-tube (1" PEX)	260	Barotherm Gold	63.2	NA*	1.93	NA*	0.88	1.73	96%
4	Co-axial	120	Barotherm Max	63.0	1.85	1.92	4%	1.6	0.42	-74%
5	Co-axial	150	Barotherm Gold	63.6	1.61	1.93	20%	0.88	0.78	-11%
6	Double U-tube (1" DR11)	260	Barotherm Gold	63.4	2.08	1.93	-7%	0.88	1.98	125%
7	Single U-tube (1.25" DR11)	600	PowerTECx	57.8	1.20	1.20	0%	1.20	1.18	-2%
8	Single U-tube (1.25" DR11)	402	Thermally enhanced	67.4	1.55	1.55	0%	1.00	1.32	32%
9	Single U-tube (1.25" DR11)	415	Std bentonite	64.8	1.64	1.64	0%	0.41	1.01	146%
10	Single U-tube (1.25" DR11)	300	Thermally enhanced	65.4	1.75	1.75	0%	1.00	1.29	29%
11	Single U-tube (1.25" DR11)	450	Std bentonite	56.4	1.88	1.97	5%	0.41	1.09	166%
12	Single U-tube (1.25" DR11)	450	Std bentonite	56.9	2.06	1.97	-4%	0.41	0.97	137%

Notes: Kgrd in case 3 was not be able to be determined with the conventional line source method due to large variations of heat input, but it was determined with the R-C model.



EGTC determined with the "floating window" method showed spikes at the later time of some TRTs while heat input was stable, which may indicate heterogeneous thermal properties of the ground in radial direction.

Conclusions

- A new method for analyzing TRT data is developed, which uses a R-C model for vertical bore GHEX developed by Geothermal Design Center and a new algorithm developed by ORNL for determining the minimum TRT duration
- This new method can reduce testing time by 40%–60% compared with the current practice while retaining same level accuracy (±5%). It can reasonably estimate EGTC value even with varying and disrupted heat inputs
- This method can also be used to estimate other parameters of the GHEX, including grout conductivity and the heat capacity of the ground and the grout, to help verify whether the GHEX was installed to the design specification

Proposed Future Work

- Determine the causes for the spikes of EGTC values determined with data at the later time of some TRTs
- Further develop the method so that it can be used to reliably verify installation quality of GHEX

Acknowledgments

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Small Business Vouchers Pilot
U.S. DEPARTMENT OF ENERGY

Final report of this project is available at http://info.ornl.gov/sites/publications/files/Pub74344.pdf