

Ground Source Heat Pumps: Testing three mediums surrounding the piping in geothermal field beds to evaluate performance

Bruce W. Smith, CPC and Mark C Tatum, P.E.
Auburn University
Auburn, Alabama

The increased implementation of Ground Source Heat Pumps requires finding more cost effective designs for the external heat exchange loop. The current study is the comparison of different mediums (materials) surrounding the ground loop piping to evaluate the relative performance of the system based on the medium. The following is a preliminary test for comparing mediums. Since all materials have a thermal conductivity value (*k*), the authors wanted to test whether material with higher *k* values would perform better. If there were a significant difference in performance, more efficient systems could be constructed. The current study was the examination of three mediums. Since geothermal systems are designed for the region and soil type, all the current discussion will refer to a southeast region and clay soil. The three mediums tested were native clay soil, found in most of the non-coastal areas, medium coarse sand, and concrete. The test bed was designed and installed to simulate a residential installation. The test bed was monitored to record the temperature of the supply water, return water, medium, and surrounding soil for each of the three field beds. The initial calculations on the anticipated results indicated that the most effective medium would be the concrete, followed by the sand and finally the native soil. The results showed that the differences in the performance of the three beds were insignificant. The authors found the results differed from the anticipated results, and several aspects of the results are not discussed in depth. The conclusions lead to work for future studies.

Key Words: Ground Source Heat Pump, Heat Exchangers, Field beds

Introduction

The Ground Source Heat Pump (GSHP) has been shown to be more efficient that conventional air exchange heat pumps. Despite the energy savings related to the use of GSHP, there has been limited adoption of the system due to the first cost. The cost of equipment and installation for the GSHP system, excluding the ground loop, is the same as conventional systems (+/- 5%) (Miami Heat Pump 2012, Trane 2012). The increased first cost for the GSHP is due to the installation of the ground loop.

The cost of installing the ground loop depends on the system used. A vertical system utilizes wells from 100 to 500 feet deep. These systems are the most efficient due to the stability of the ground temperature below 20 feet, but are the most expensive. Horizontal systems utilize trenches from three to eight feet deep to install the loop. These systems are less efficient due to temperature changes in the soil with the change of seasons, but they are less expensive to install than the vertical systems. The least expensive system utilizes ponds or lakes. The piping is dropped to the bottom and requires no excavation. The efficiency will be dependent on the depth of the pond and the temperature of the water.

Most new homes do not have a pond or lake, and many residential lots are too small for long horizontal systems. The options available for most residential lots are either a vertical system or a horizontal system that can be adapted for use on small lots. From a cost standpoint, a short horizontal system would be the best option.

One type of short horizontal system uses a “slinky” technique, where a three foot wide trench is dug, and flexible pipe is looped with a three foot diameter and overlapped one and one-half feet (refer to Photo 1). This allows about two hundred linear feet of pipe to be placed in a thirty-five foot trench. The disadvantage of the shorter trench is the ability for the surrounding soil to dissipate the heat due to the pipe density. The slinky trench will have two linear feet of pipe for each square foot of trench as opposed to the longer straight pipe system which would have one linear foot of pipe for each square foot of trench.

Photo 1: Flexible Pipe Slinky Placed in a Trench

The increased density of the pipe increases of the heat transfer load placed on the medium surrounding the pipe. Since different mediums (water, soil, rock, etc.) have different thermal characteristics, this study performs an initial test to evaluate the performance of three mediums used to surround the pipes in a geothermal test bed.

The three mediums used in the evaluation were native clay soil, medium course sand, and dense concrete. These were chosen as logical options for residential lots in the southeast where many areas have clay soils. Concrete was used because many homes in the southeast are built with a crawl space, and the footings could be used for the placement of the piping. Sand can be placed in any trench if it were shown to have a benefit to match the cost. Coastal and low areas might be able to place the piping below the water table, which would increase the performance, but the option was not chosen for this test.

Background

The determination of performance of a medium is essential in the proper design for geothermal systems, and one of the greatest challenges. One method is to use an apparatus that imposes a thermal load on a test borehole and measures the results (Witte, van Gelder, Spitler, 2002). A second method is to use a numerical model (Xing et al. 2011). Regardless of the method, the performance is based on the thermal properties of the material adjacent to the piping to transfer the heat. Each material has a property know as thermal conductivity (k).

Thermal conductivity is the measure of the ability of a material to transfer a quantity of heat through a unit thickness in a direction normal to a surface of the material, due to a unit temperature gradient under steady state conditions. The capacity of the surrounding material to move the heat to or from the pipe more quickly improves the performance of the system. In this case, the medium is moving the heat to the surrounding soil. The formula for k below shows the conversion to Btu/(ft.hr.^{o}F), which are the units used for conductivity in the current research.

$k = 1\ W/(m.K) = 1\ W/(m.^{o}C) = 0.85984\ kcal/(hr.m.^{o}C) = 0.5779\ Btu/(ft.hr.^{o}F)$ (Engineering Tool Box 2012)

Materials with higher k values have a greater ability to transfer heat. For example, soft wood has a low ability to conduct heat, with $k = 0.048$, while copper (at 25 degrees Celsius) has $k = 401$.

The mediums (materials) used in the research were sand, concrete and clay. Table 1 shows that there is a range for these materials due to the variability in density and moisture content. The range is significant, so for calculations the means used. Not only can the medium have different properties, but the properties may change over time due to the moisture content. Using the mean leads to calculations that are not overly optimistic or pessimistic.

Table 1
Conductivity of Sample Materials

	Conductivity *(k)*		
	Low	High	Mean
Sand, moist	0.25	2	1.125
Concrete	1	1.8	1.4
Clay, dry to moist	0.15	1.8	0.975

(Engineering Tool Box 2012)

The conductivity can be used to calculate the conductive heat transfer for the area around the pipe. The formula to calculate the Conductive heat transfer (q) is:

q = k dT / s

- *q* = heat transfer per unit area (Btu/sq ft)
- *k* = thermal conductivity (Btu/ft.hr.°F) (from Table 1)
- dT = temperature difference
- s = thickness of material (used 3” as the pipe was centered in a 6” layer of the medium)

Table 2
Calculation of Conductive Heat Transfer (q)

Material	*k*	dT (°F)	S (ft)	q (Btu/sq ft)
Sand, moist	1.125	11	0.25	93.85
Concrete	1.4	11	0.25	116.79
Clay, dry to moist	0.975	11	0.25	81.34

From the data in Table 2, it would be expected that sand would provide 15% better results than the clay, and the concrete would have 43% better results. These would be the expected results if the pipe were running through the medium as one linear pipe. Since the system is truly a system with multiple variables, the results may differ from the results in Table 2.

Methodology

The testing measured the performance of the three mediums by creating separate trenches and field loops for each of the three materials. The field loops were installed using the “slinky” configuration.

The test site was a sixty foot by 100 foot area with water and power available. There are no other plans for this area, so the test area can be used for future projects using the same field bed, equipment and controls.

Figure 1 shows the layout of the trenches and the control room. Each trench was forty feet long, three feet wide, three feet deep, and 18 feet from the control room. The depth of three feet was chosen as it is deep enough to be stable and adaptable to future research. The current research is a comparison of the performance of the three mediums containing the tubing, so placing the tubing at the optimal performance depth was not critical. Each trench contains 290 feet of piping including the piping from the control room and returning to the control room. The return line followed the slinky loop back to the beginning of the trench. The return line was insulated from the end of the trench to the control room.

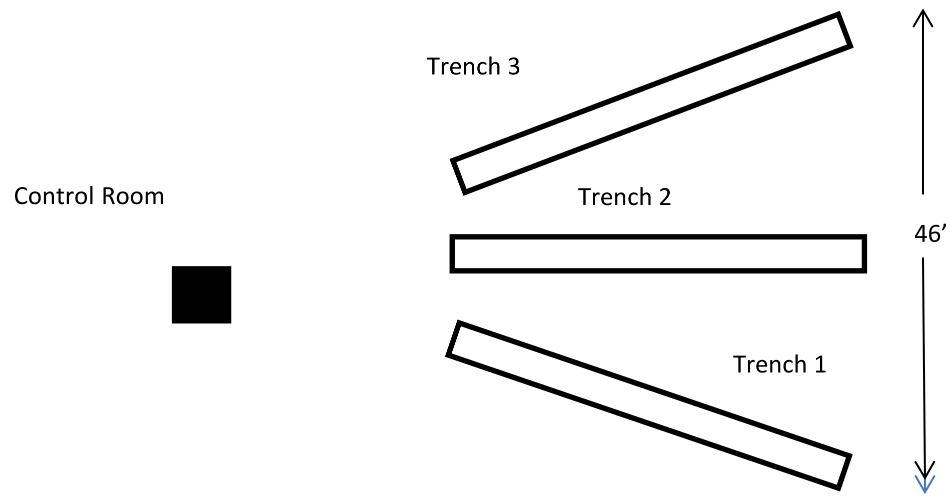

Figure 1: Field bed layout

Figure 2 shows the cross section of the three trenches. Trench 1 contains six inches of sand with the heat exchange loop located midway in the layer of sand. Trench 2 contains six inches of concrete, with the heat exchange loop midway in the concrete. Trench 3 contains native soil with the heat exchange loop on the bottom of the trench.

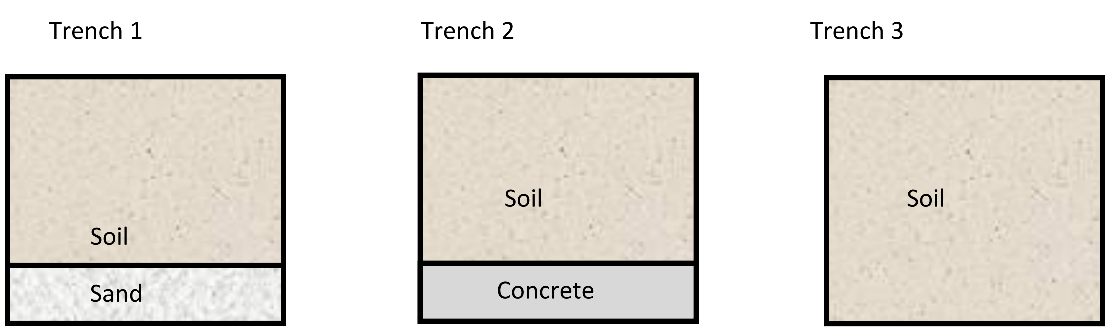

Figure 2: Schematic section of the trenches.

Water was heated and circulated through all three loops. The following temperatures were recorded: water entering and leaving each pipe, the temperature of the medium taken midway in the length of the trench , and the ambient air temperature. A schematic of the system is shown in Figure 3.

- The pump takes the water through the tank-less water heater to the manifold that feeds the supply line for all loops.
- The flow is regulated by a flow valve to maintain the same flow rate through each loop.
- The temperature of the water leaving the control room is recorded with a data logger.
- The water leaves the control room and circulates through the loop and returns to the Control Room.
- The temperature of the water returning is recorded by a data logger.
- The water returns to the pump to recirculate through the system.

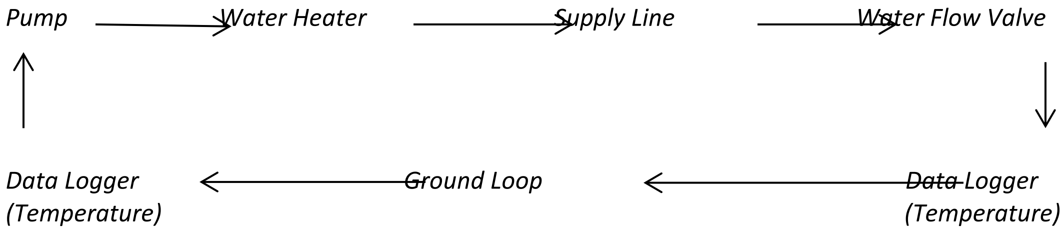

Figure 3: Schematic of the water system

The plan for the test was to run the system continuously over seven days. Usually systems would cycle on and off under normal conditions, so the continuous running would simulate extreme conditions. The continuous run test was chosen as a first test to understand how the systems work as the ground around the loop warms, forming a plume of heat around the loop. The test procedure was to run the system for a defined period of time and then analyze the data collected. The researchers will be able to compare the efficiency of each medium by comparing the temperature of the water returning to the Control Room from each loop over a defined period.

Results

The test was run with the setting of 90 degrees F for the supply temperature and a flow rate of one gallon per minute for each loop. Temperatures recorded from the data loggers are shown in the following graphs. Figure 4 shows the temperature of the return water for all three loops. The graph shows that the difference in the temperature was very slight. At no time did the difference exceed one degree, and after fifteen hours of operation, the difference was down to no more than 0.25 degree F. This graph is significant in that the performance of the system is based on the temperature of the water returning to the control room.

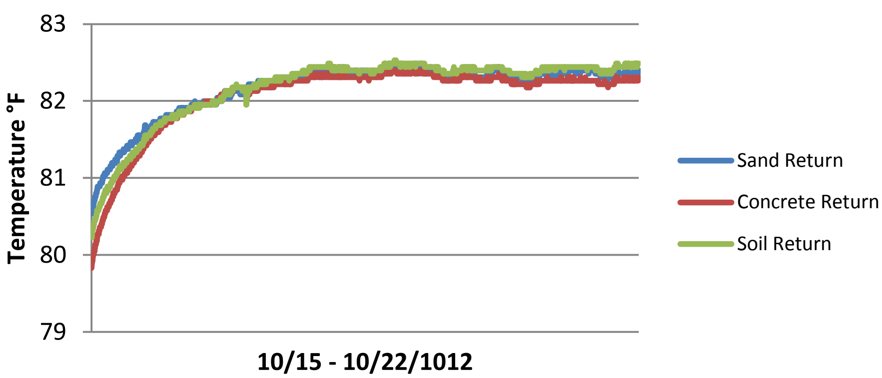

Figure 4: Return Water Temperatures

Figure 5 shows the temperature of the three mediums. Although there is not a great difference between the three mediums, the graph shows that the best performance comes from the concrete, as it maintained the lowest temperature. The next best performance came from the soil, and sand was the poorest performance. The differences went as high as two degrees between the best and worst performer. It is significant that the temperature difference between the mediums did not translate to the same temperature differences in the return water.

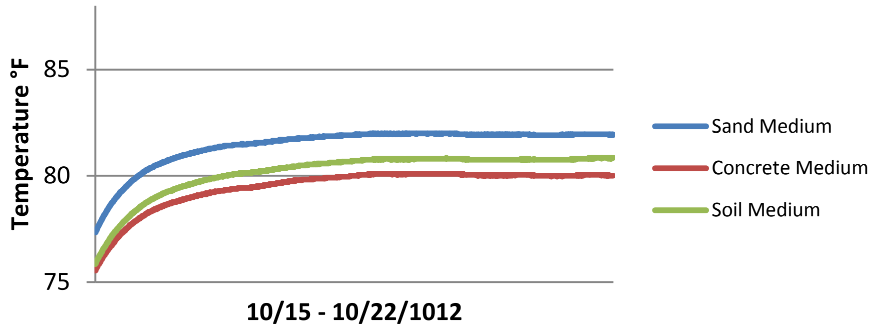

Figure 5: Medium Temperatures

Figure 6 below shows a graph of supply, return, and medium temperatures for concrete. This is shown to compare relative temperatures in a loop system. The other loops were similar and are not included to reduce paper length. The supply temperature was set at 90 degrees, but the actual temperature was 86.6 degrees. The temperature difference through the system started at 6.5 degrees and reduced to 4.25 degrees after 48 hours. The medium remained at a lower temperature that the return water, which means that there was some thermal capacity remaining in the medium.

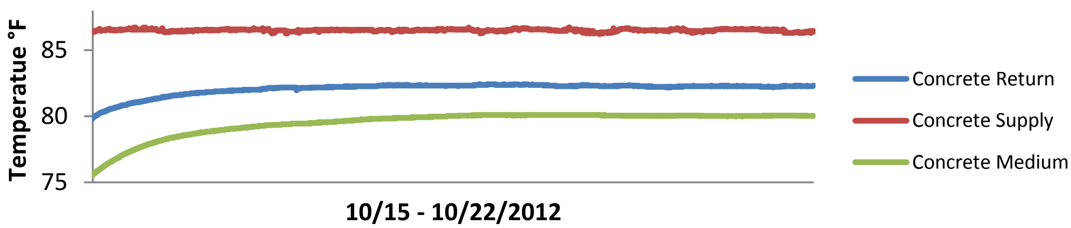

Figure 6: Return, Supply & Medium Temps for Concrete

Figure 7 below shows the ambient air temperature and ground temperatures. The ground temperatures are taken from data loggers positioned six inches below the medium in the sand and concrete loop trenchs. This graph shows that the ambient air did not impact the ground temperature during the test period. Over a change of seasons, the ground temperature at a depth of three feet would be likely to change.

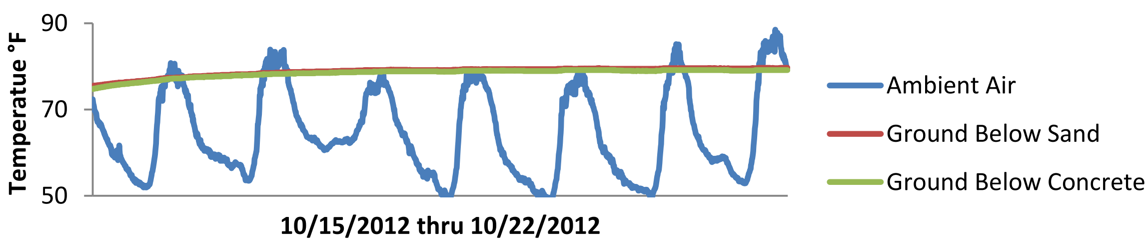

Figure 7: Ambient Air and Ground Temperatures

The overall performance of the ground loop is what is ultimately important. The purpose of the loop is to remove heat from the building and reject it into the medium. This heat transfer is expressed as quantities per unit of time and for water can be easily derived from the data using the formula:

Q = 500 x GPM x TD

- Q = heat transfer (Btu/hr or Btuh)

- GPM = flow rate (gal/min)
- TD = temperature difference (°F)

(Wujem and Dagostino, 2010)

Figure 8 shows the overall system performance for all 3 loops through the test period in Btu per hour (Btuh). Although the temperature rise of the return water shown in Figure 4 is less than two degrees the impact on the Btuh is significant. For concrete, the system started out at 3200 Btuh and dropped to under 2200 Btuh. It did take two days of continuous operation to reach that point, but it does illustrate that a small difference in the temperature of the loop translates to a large difference in the system performance. The sand and the soil performed in a similar fashion. The system appears to have multiple variables that need to be investigated in order to understand how the system works as a whole.

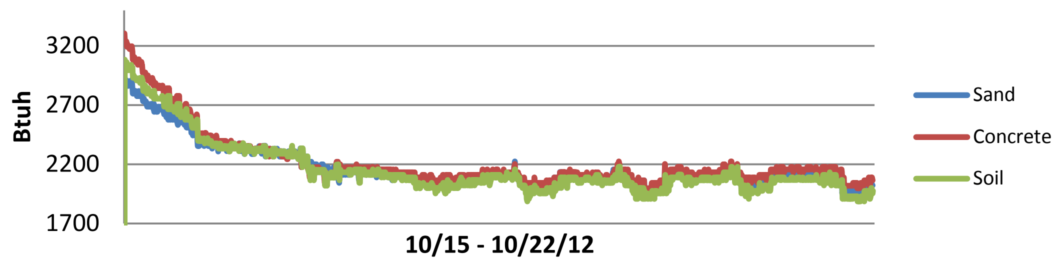

Figure 8: Heat rejection of all three loops

The fluctuation in the performance of the system as shown in Figure 8 shows that the ambient temperature makes a slight difference. Figure 9 represents a 12 hour period graph in Figure 8 taken from noon to midnight and shows a rise in temperature. Since Figure 7 shows that there is no variation in the ground temperature through the day and night cycle, the effect may be caused by the heating of the control room during the day due to solar gain and ambient air temperature. It may be necessary to stabilize the temperature in the control room if it appears the situation would significantly skew the results. The current test shows a 100 Btuh variation, which is significant, but it did not influence the comparative performance between the three mediums.

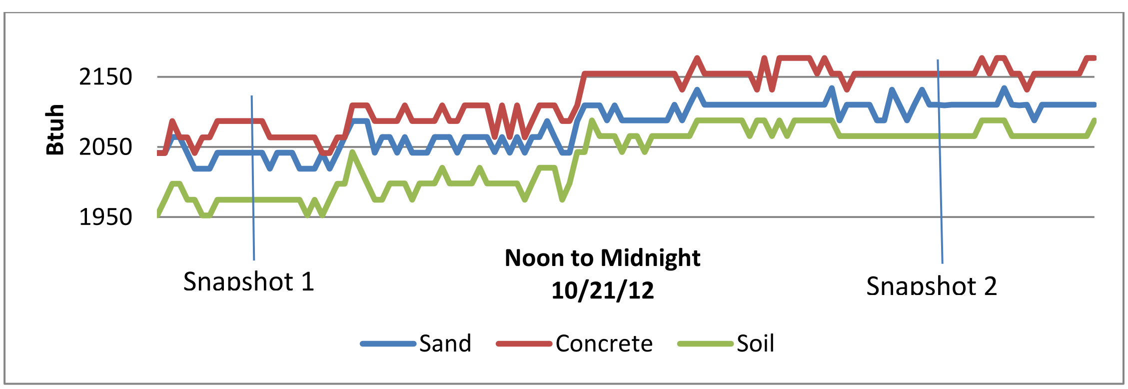

Figure 9: Heat rejection of all three loops over a 12 hour period

Conclusions

The expected results discussed at the end of the background section, were that concrete would perform the best, followed by the sand, with clay being the poorest performer. The expectation was based on the relative *k* values for the three mediums. The test actually showed that the performance of the three systems were the same. The performance was based on the temperature of the return water from each of the three beds. There are several actions that will need to verify the results.

- First, the testing procedure needs to be evaluated to make sure that there is not a flaw in the system and process.
- Second, the evaluation process needs to be revisited to look at other ways the data can be compared.
- Third, additional testing will need to be conducted. The additional tests may use shorter duration, different temperatures, and different flow rates to make comparisons of the medium under different conditions.

The results indicate that there was no difference in the performance between the three mediums. There are several explanations for the results that will need to be examined.

- The variation in the k values between the materials may be significant when compared to each other, but when compared to other materials, such as copper with a k value of 401, are insignificant.
- There are variables within the system besides the k values that may impact the performance, so one element of the system cannot be used as a predictor of the performance.
- The system needs to be viewed as a system, and the performance of the system is the sum of all the parts.

The results that showed that the medium did not make a significant difference in this test will lead to more testing to verify or disprove the results of the current test. The final results may have a significant impact on future designs. If the medium surrounding the pipes does not make a significant difference, some standardized designs could be created based on the location and size of the system, ignoring other variables. The pipes may be placed under the footings or below crawl spaces to reduce the installation costs. Further testing would be required to find out the impact on the heating and cooling loads on the house above.

The testing system that has been built can be used for these and other tests relative to geothermal ground loops. The authors are looking forward conducting further research and to collaboration with other university partners interested in geothermal heat pump systems.

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