Completion of a Small Scale Geothermal Heat Sink Experiment

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Abstract

The work presented in this paper represents the completion of a project first presented as a work in progress at the 2019 Southeast Section ASEE Conference. The goal of this study was to create a small-scale experiment for undergraduate mechanical engineering students capable of demonstrating the effectiveness of a geothermal heat pump's sink as a function of the medium used. The completed design consisted of a large reservoir that can be filled with three different mediums: water, dry soil, and wet soil. A separate reservoir held the working fluid, water in this case, that was heated to a relatively constant temperature and was pumped through a set of cooling coils placed inside of the sink. Both the inlet and outlet temperature of the working fluid was monitored, using K-Type thermocouples, as well as the mass flow rate using a Hall Effect flow meter. The temperature of each medium was also monitored at various locations away from the cooling coils. Using this information and a simple First Law of Thermodynamics analysis the effectiveness of the differing mediums could be quickly examined as well as possible issues regarding the increase in temperature of the medium over time. As expected, the most effective medium was the reservoir containing water only, while the wet soil outperformed the dry soil. It is anticipated that this, or a similar experiment, will be added to our university's senior mechanical engineering lab in the near future.

Keywords

Ground Source Heat Pump (GSHP), Heat Transfer Lab

Introduction

Worldwide energy consumption continues to increase at an alarming rate. The U.S. Energy Information Administration recently predicted that the world energy consumption would increase 50% by the year 2050.[1] While predictions for increases in overall energy consumption in the United States is considerably less over this same period, there is still a strong need to switch to alternative systems due to environmental concerns over traditional power generation methods such as nuclear and fossil fuels. One way of addressing this ongoing problem is to develop highly efficient systems that are capable of reducing the energy associated with performing a given task. One of the largest power consuming devices in the U.S. are heating and air conditioning systems for both commercial and residential use. An alternative to these relatively inefficient conventional systems are the high performing Ground Source Heat Pumps (GSHPs).

It is well known that the overall efficiency of GSHP's can be greatly impacted by the media used for the sink or source. [2,3,4,5] When possible ponds can provide an excellent source/sink for a GSHP. However, because these are often not practical, or available, the more common media used is soil. As might be expected, the level of humidity and type of soil play a key role in determining the effectiveness of these systems. This is because the thermal properties and contact area of differing types of soils greatly affect their ability to transfer heat to or from the system.

The main goal of the research presented in this paper was to create an experimental apparatus that could help introduce senior level mechanical engineering students to the benefits of GSHPs. Specifically our goal was to provide a small-scale controlled environment in which to test the heat transfer rate of different media. The system developed allowed one to observe the difference in heat transfer rate between water and soil and how the level of soil saturation could impact this heat transfer. If accurate data can be obtained for these conditions, it can provide useful predictions of how to best optimize GSHPs. While additional development is needed, this system serves as an excellent prototype for future systems.

Apparatus

The completed design consisted of a reservoir, sink, and data acquisition system. A 15 gallon, 22in x 28in x 8in tub was used as the reservoir that held the working fluid for the system. Four thermostat-controlled heaters, rated at 1150 W each, were placed inside the reservoir to maintain a temperature of 90°F/32.2℃. The reservoir was divided into multiple sections to force all water flow by each individual heater. The sink was a 100-gallon trough made of galvanized steel with a zinc coating. The water from the reservoir was transferred to the sink and then routed through 100 ft of coiled ACR copper tubing before being transferred back to the reservoir. Four K-type thermocouples were used to monitor various temperatures throughout the system. Two were placed at the inlet and outlet of the reservoir while another two were used to monitor the temperature of the sink. A ½ HP utility pump was used to supply the working fluid to the sink. The flow was controlled using a gate valve and monitored using a Hall effect flow meter located at the inlet to the sink. Soil saturation levels were monitored using a VH400 Soil Moisture Sensor Probe. The thermocouples were wired into a NI cDAQ™-9191 from National Instruments and a LabView Program was created to record temperature over the duration of each test. The completed system can be seen in Figure 1 below.

(a) (b)

Figure 1*: (a) Sink used to contain the chosen medium (b) Copper coil used to transfer heat from the working fluid to the sink.*

Results

As stated above, the main goal of this work was to create an apparatus that would be useful in introducing senior level mechanical engineering students to the benefits of GSHP's. Specifically we chose to examine the effects of two types of media: water and potting soil. Because the effectiveness of the soil is directly related to the moisture content, both wet and dry soils were evaluated. It was decided that the simplest and most effective way to determine the efficiency of the different media was to compare the rate of heat transfer of the working fluid to the media. This was completed by using a simplified version of the energy equation as shown below:

$$\dot{Q} - \dot{W} = \dot{m}C(T_{in} - T_{out})$$

where $\dot{Q}$, $\dot{W}$ and $\dot{m}$ represent the rate of heat transfer, work (the pump in this case), and mass flow rate respectively, C is the specific heat and T_{in} and T_{out} represent the inlet and outlet temperature of the working fluid. In order to insure the tests performed were completed under the same conditions the reservoir temperature was held at a constant temperature (32^{o}C), the mass flow rate was kept at a constant range (0.302 – 0.321 kg/s), and the starting condition for the sinks were between 20 and 23^{o}C (approximately room temperature).

Figure 2 below shows a typical Temperature vs. Time graph using water as the medium for the sink. At least three trials were taken for each medium and the average results are presented in Table 1 below. Four temperatures are shown on figure 2, two representing the inlet and outlet temperature of the working fluid, and two representing the temperature of the sink (one far from the coil (sink 1) and one in the center of the coil (sink2)).

Several observations can be made from figure 2. First, the initial rise in the outlet temperature is due to unheated water that was in the piping system when the test began, being replaced with the heated water of the reservoir. This leads to a relatively steep decrease in the inlet temperature as the colder water enters the reservoir. After approximately 180 seconds a relatively steady state condition is reached with regards to the inlet water for the system. However, it is easy to see that the outlet temperature continues to increase over time due to the increasing temperature of the sink. Using a first law analysis, it was determined that the average heat transfer rate for this test was 4.550 kW. It was also determined that the increase in the sink temperature was approximately 7 degrees leading to a degradation in the efficiency of the system over time.

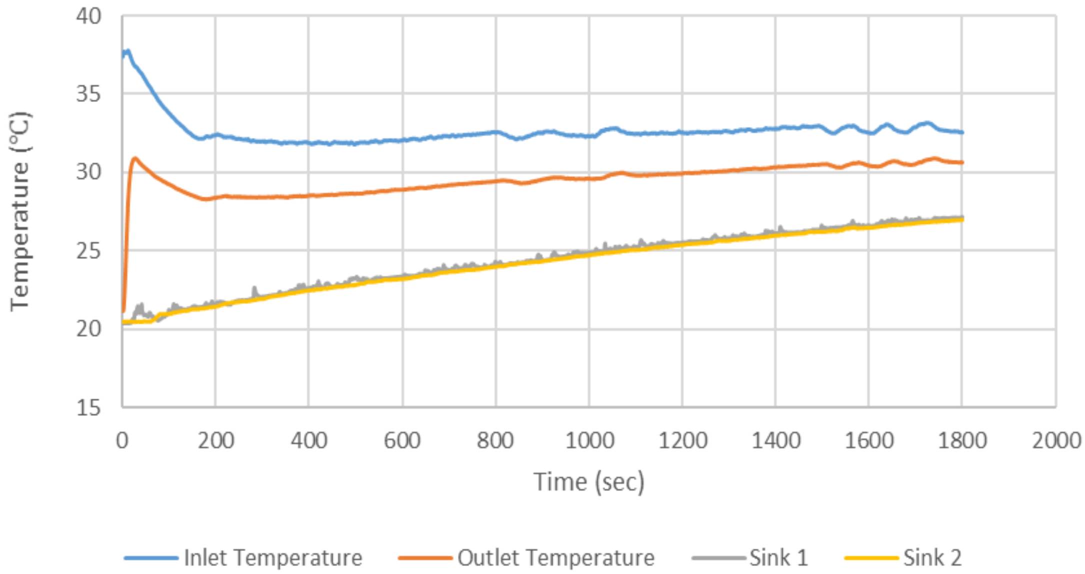

***Figure 2**: Temperature vs. Time with Water as the sink medium*

Figure 3 shows results after the sink containing water was replaced with fully saturated potting soil. The first observation is that the inlet and outlet temperatures are very close together when compared to the trials completed with water only. This led to an almost order of magnitude decrease in the average heat transfer rate to a value of 0.663 kW. It is also obvious that the change in the temperature of the soil remains almost constant throughout the trial which is to be expected due to the reduced heat transfer rate. The slight difference in the soil temperatures is because this test was completed after doing the dry soil test, which will be presented next. After waiting for a day, the temperature nearest the coil had not completely returned to the room temperature.

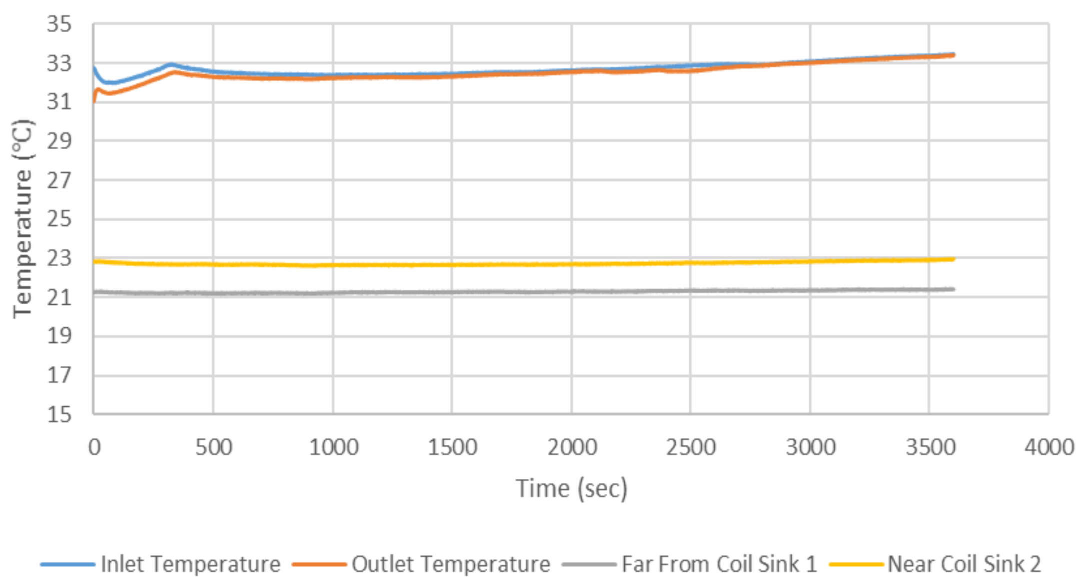

***Figure 3**: Temperature vs. Time with Wet Soil as the sink medium*

The final test conducted for this study, shown below in figure 4, considered dry soil only as the sink. It should be noted that the dry soil still had a relatively low saturation level of 34.2% – 35%. As in the saturated soil it is evident that there is a very small change between the inlet and outlet temperature of the working fluid. This test resulted in an average heat transfer rate of only 0.590 kW. While still an order of magnitude lower than that of water only, this shows that the wet soil has a 12.4% improvement over dry soil, proving the importance of keeping GSHP sinks appropriately saturated.

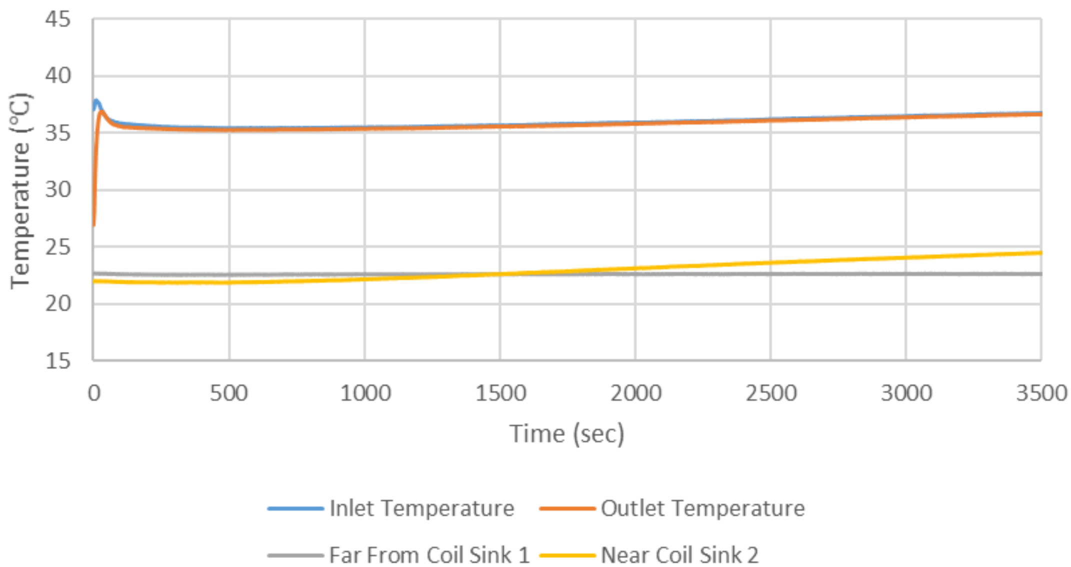

***Figure 4**: Temperature vs. Time with Dry Soil as the sink medium*

Table 1 below presents the final averaged values of the data gathered for the three tests that were completed. As mentioned above, this shows the vast improvement in the rate of heat transfer when using water as the sink media.

***Table 1**: Average Heat Transfer Rate at Maximum Flowrate*

Trial	Average Flow Rate (kg/s)	Steady State Average Heat Transfer Rate (kW)
Water	0.309	4.550
Wet Soil	0.303	0.663
Dry Soil	0.317	0.590

Conclusion and recommendations for Future Work

As expected, the data showed that water was, by far, the superior heat transfer agent with an average heat transfer rate of 4.550 kW. Comparatively the saturated soil provided an average heat transfer rate of 0.663 kW, and the dry soil 0.590 kW. It was also determined that the water had a significant increase in temperature compared to both of the soil tests.

Future improvements to this system will include automating all of the instrumentation including the flow rate of the water and the humidity of the soil. To date only the temperature values are recorded continuously. Once this is complete, there are several future studies that may be examined. First, for this study, only a single type of soil was considered. However, based on our research, it is well known that different soils can provide significantly different heat transfer rates. It would be desirable to have two independent systems set up that would allow us to run different soil types at the same time so that results could be taken in a single laboratory session. We have also considered increasing the size of this system in order to achieve a larger change in temperature for the working fluid while decreasing the speed in which the sink temperature increases. It is hoped that this experiment will be added to our lab in the next few years.

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