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Experimental Study on the Impact of Two-Pipe and Four-Pipe Series-Mode Layout on the Heat Transfer in Thermal Response Test for Geothermal Heat Pump Project in Qanavat, Iran

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ABSTRACT

One of the effective parameters in calculating the coil length in geothermal heat pump systems is the value of soil thermal conductivity which can be obtained through different methods. This can greatly affect the excavation and coil installation process and consequently the total cost of the project. In case the coil length is reduced, initial cost decreases as the amount of excavation declines and helps the project become economically justified. It can also be possible to increase heat rejection or heat absorption in ground loop by rising thermal conductivity with various configurations.

In normal conditions, in each borehole, a U-shaped polyethylene pipe is laid and thermal response test is carried out. But, it is also possible to do the same test with a pair of U-shaped polyethylene pipes. In other words, in this scenario, two U-shaped polyethylene pipes can be used in parallel or series in one borehole. In this paper, the experimental results of thermal response test for normal single pair configuration and two pairs of U-shaped polyethylene pipes in series are presented. The project is located in Qanavat, Iran and the results indicated thermal conductivity improvement in series layout.

1. INTRODUCTION

Based on the normal procedure of geothermal heat pump projects, after excavating the initial geothermal well, piping installation and grouting, thermal response test to calculate thermal conductivity is taken into account(Oklahoma University, 2011). This operation is a mandatory process to optimize well depth and ground source heat exchanger. There are different ways to increase thermal conductivity value which as a result, could lead to piping length reduction, less excavation and finally total project cost reduction.

One way to affect thermal conductivity is to utilize multiple pipes while having the same amount of excavation. In other words, instead of using one pair of pipes for each well, two or more U-shaped pairs are installed. Increasing the level of heat transfer in closed loop coils of geothermal heat pump systems by a few percent increases the performance of ground coils. Due to the high cost and limitations of drilling in most projects, two pairs of u-shaped pipes can be used inside each well instead of one pair. By installing these coils in series or in parallel with each other, the performance of the ground coil can increase. This means with the same drilling cost, the heat transfer level of the coils are enhanced. In other words, more load can be transferred from a four-pipe coil. It is possible that by increasing the level of heat transfer while two pairs of pipes inside a well are connected in series compared to the case of using one pair of pipes, more heat load can be transferred to ground.

In fact, there have been a lot of practices since early 90s and appropriate literature featuring different methods is available in this regard. Saner et al. presented a thorough review of thermal response test methods beginning from 1995 with a mobile test equipment by Lulea Technical University to Germany's first TRT in 1999(Sanner, Hellström, Spitler, & Gehlin, 2005). Esen et al. showed how in-situ thermal response test matters and studied the effect of different well depths on the test results(Esen & Inalli, 2009). Lee et.al investigated the impact of ignoring ground layers in the thermal response test analysis and the subsequent system simulation. They found that the adoption of an effective ground thermal conductivity and an effective ground volumetric heat capacity for a multi-layer ground determined from a TRT analysis leads to very little error in the simulated long term system performance under various ground compositions investigated(Lee, 2011). Wang et al. presented a novel constant heating-temperature method (CHTM) for TRT. Further, a type of improved TRT equipment was developed by them and the mathematical model to deal with test data was presented. Based on the measurement of the natural ground temperature distribution, an in-situ TRT case was carried out. The experimental results by them showed that, compared with the conventional TRT with constant heating-flux method (CHFM), CHTM has an obvious advantage of reducing the time period reaching a steady heat-transfer state between the BHE and its surrounding soils(Wang, Qi, Du, & Gu, 2010). Zhang summarized the specifications for in-situ TRT, including test setup, minimum duration heat input rate, etc (Zhang, Guo, Liu, Cong, & Peng, 2014).

In this paper, experimental comparison of utilizing one pair and two pairs of U-shaped pipes in series and the effect it has on thermal conductivity is studied. The tests are carried out on a project located in Qanavat, Qom Province in Iran where the building with a 10-ton - of - refrigeration cooling capacity belongs to Gas Company of Qom province, in Iran.

2. MATERIALS AND METHODS

The studied well is 110 meters deep with a 30-centimeter diameter where two pairs of U-shaped pipes are laid inside. Excessive diameter of the well is due to excavation limitation in the location of the project. The pipes are PE100 with SDR11 and they consist of two 90-degree bends that are butt-welded together. While installing the pipes, they were put in certain arrangement using spacers as shown in Figure 1.



Figure 1: Arrangement of two pairs of pipe as well as a pipe for grouting

The tests were carried out after grouting and taking care of the required timing for drying according to the standards. Thermal response test is performed based on the standard ASHARE 1118. In order to implement ASHRAE 1118 standard, the following equipment was used (Ashrae 1118 Determining Soil Thermal Properties from Short Term Field Tests, n.d.) as shown in figure 2.

- 200-liter Water tank equipped with 6 heating elements which are 3kw each.
- Circulation pump
- Rotameter in order to measure volumetric flow rate
- Control unit in order to implement the required thermal flux
- Data logging devices



Figure 2: installation of thermal response test devices

2.1 Testing Procedure

Based on the standard, the following parameters are required for calculating thermal conductivity.

- Time
- Entering water temperature to ground heat exchanger
- Leaving water temperature from ground heat exchanger

– Power consumption

Now, in order to calculate thermal conductivity, the following equation is taken into account:

$$K = \frac{P}{4\pi LS}$$

Where K is the thermal conductivity, P is the power consumption, L is the well length and S is the slope of the graph for average temperature to logarithm of time.

According to the pipe length, the heating capacity of elements which is required to provide enough heating flux to the fluid is 6kw. The volumetric flow rate is modified and regulated by means of the rotameters. With data logging devices, the entering water temperature to heat exchanger and leaving water temperature from it as well as the heating flux are recorded continuously. In the first step, thermal response test with a pair of U-shaped pipes inside the well was performed. In the second step, considering the time gap required between the tests, thermal response test was carried out with two pairs of U-shaped pipes inside the well. The pipes are connected in series and in both cases the volumetric flow rate is kept constant. In order to increase the precision of the tests, a period of 10 to 12 days was considered between the tests so that the ground thermal status turns back to its normal condition.

3. RESULTS AND DISCUSSION

3.1 Thermal Conductivity for Single-pipe ground heat exchanger

Having installed the devices and equipment and insulating the pipes outside the ground, heating flux with the 6kw-elements were injected to the ground for 72 hours with the volumetric flow rate of 5GPM. The following diagram, figure3, presents the results.

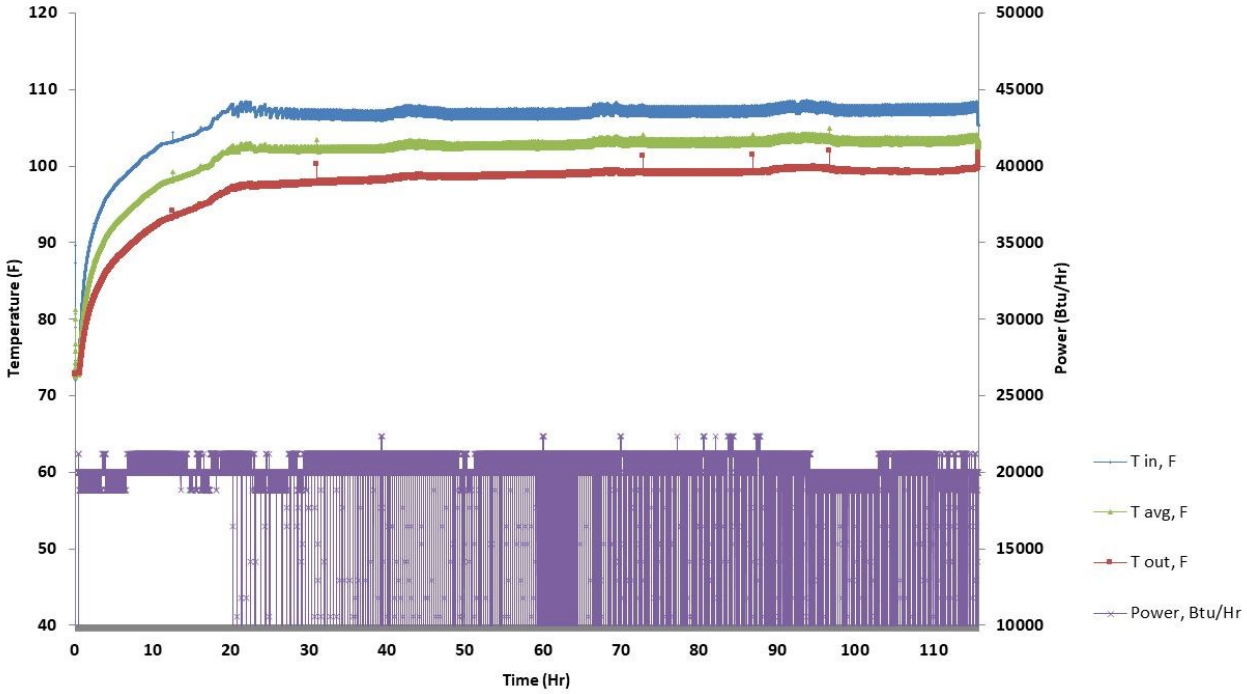


Figure 3: Diagram for single pair of U-shaped pipes

Based on the temperature – time graph, the average temperature-time graph is drawn and illustrated in figure 4.

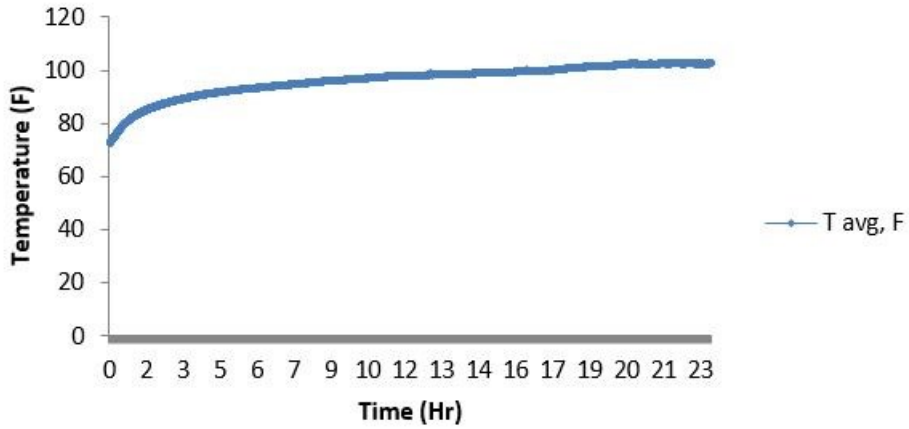


Figure 4: Average temperature graph

And in the end, graph of average temperature to logarithm of time is illustrated in Fig.5. The tangent line is drawn on the graph. The slope of this line is *S* value.

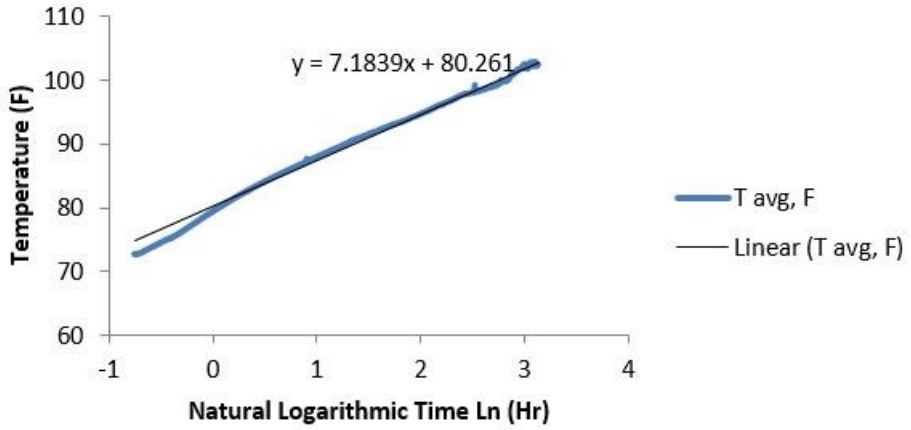


Figure 5: Average temperature to logarithm of time graph for calculation of S

As of project results, the following values are defined:

$S = 7.1839$

$L = 36$ ft

$P = 6$ kW = 20472 BTU/HR

In the equation, thermal conductivity in single pair scenario equals to 0.63 BTU/HR.

3.2. Thermal conductivity for ground heat exchanger with two pair of pipes in series

As the pipes are connected in series, heating flux is transferred to the fluid through the 6 kW elements and the volumetric flow rate is taken 5 GPM. After 72 hours, the following results are obtained, as shown in figures 7 and 8.



Figure 6: Connection of heat transfer coefficient testing device to ground coil in series mode

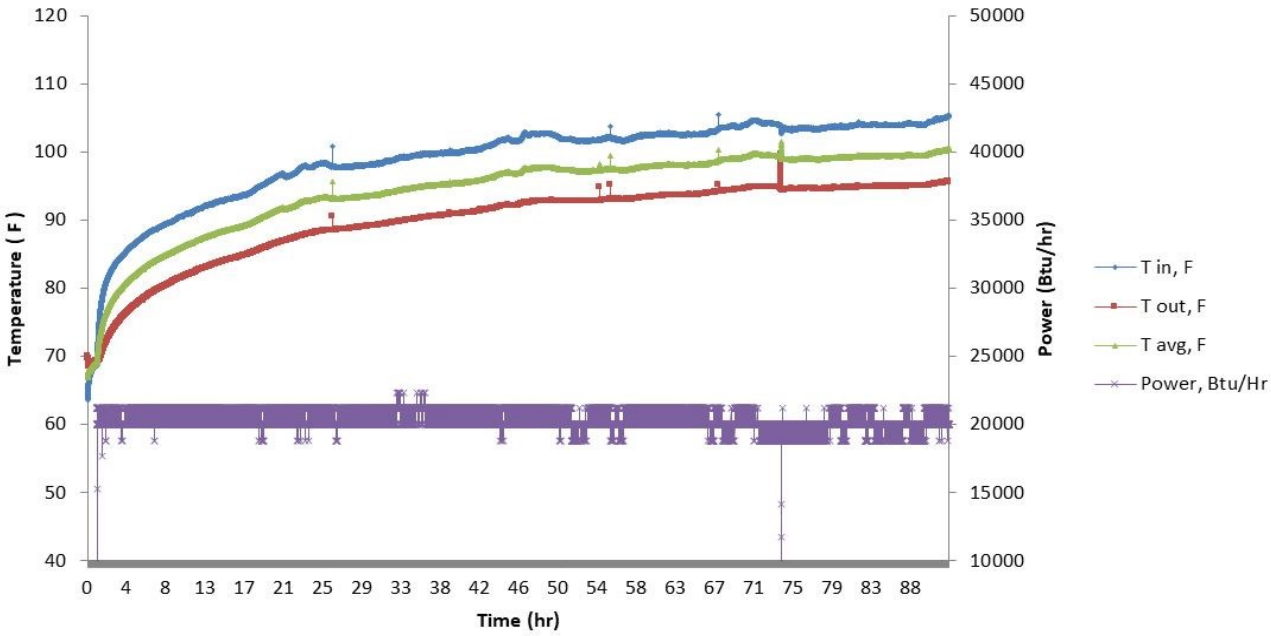


Figure 7: Entering water temperature, leaving water temperature and average temperature as well as power

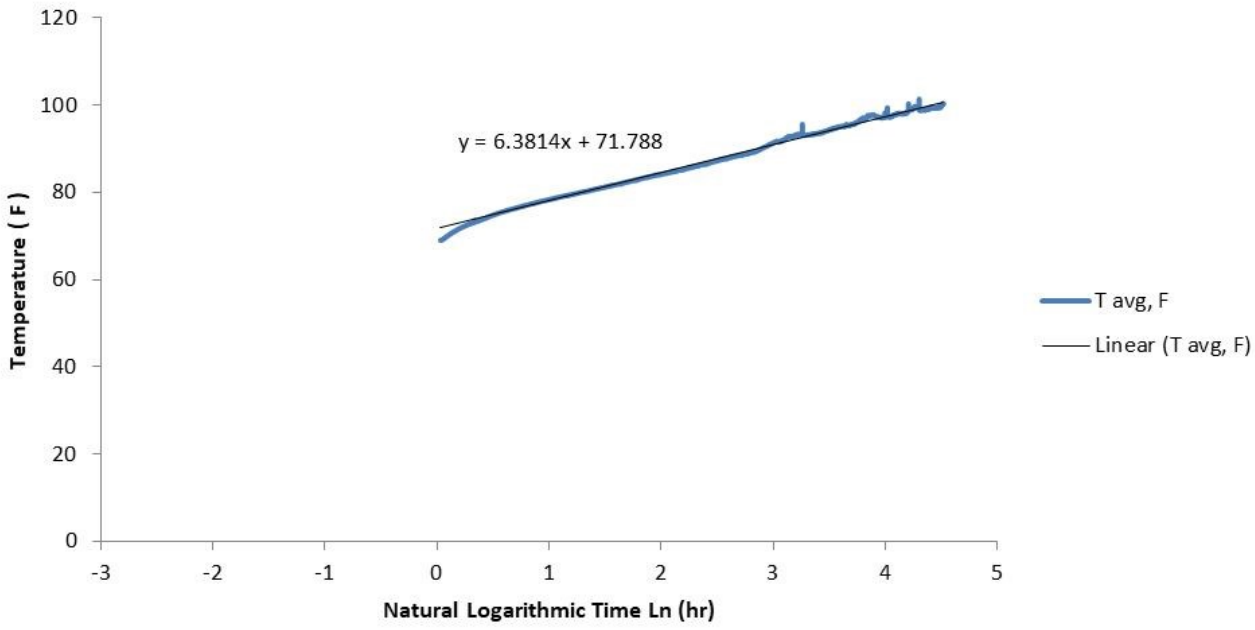


Figure 8: Average temperature to logarithm of time

According to the mean temperature graph over time, the mean temperature graph is plotted on the logarithm of time and the tangent line is plotted on the graph. The slope of the line in this case is 6.3. According to the test, the following results are obtained.

P = 20240 btu/hr

L = 360 ft

S = 6.3

By solving the equation, the thermal conductivity value in the case of two coupled series of pipes is 0.71 btu/hr.ft.f.

4. CONCLUSION

Performing thermal response test for geothermal heat pump project is compulsory within the common construction procedure. As ground heat exchanger and excavation require over half of the project budget, it is recommended taking more precise calculation process to minimize construction cost. To do so, the most reliable method is thermal response test based on Ashrae 1118 which could correct the initial assumption of the designer based on the soil type to a great deal. Now, experimenting different configurations could even result in better solution for optimal coil length. This paper tested two different piping configurations. By comparing the thermal conductivity value in both single-pair pipe and two-pair mode in series, the thermal conductivity increased by 13% over the single-pair mode. This test showed that by utilizing an extra pair of pipes and intubation operations for two pairs of pipes configured in series, the thermal conductivity can be enhanced significantly while grouting volume is reduced.

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