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Effect of Wet Soil on Thermal Performance of Air-Fluid Ground Heat Exchanger for Heating

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Abstract

The energy crises that emerged after the economic problems in the world increased the interest in alternative energy resources. The effects of global warming, which has a serious threat, will be reduced by the more efficient use of these energy resources. In this study, the thermal effects of wet soil were investigated experimentally using a ground source heat exchanger (GHE), which is an alternative energy resource, in an area on the Esentepe campus of Sakarya University. Researches on this subject are mostly directed to dry soil applications. In this study, the thermal performance of GHE was examined in terms of heat transfer. By means of the artificial pool formed under the ground, it is aimed to increase in heat transfer between the soil and the process fluid. In the experiments which are conducted, air is used as the process fluid. The system has a significant advantage in certain temperature ranges due to the passive heating method, in other words, the process fluid can be circulated under the soil without using a compressor. The purpose of this method is to reduce the cost of heating in the winter season. The temperature difference at GHE inlet and outlet is approximately 9.07 °C in the experiments. The heat transfer rate has been increased by 46.28% compared to dry soil application for the same air velocity speed.

Keywords: Ground-Based Heating, Earth-Air Heat Exchanger, Wet Soil.

1. INTRODUCTION

Nowadays, if the average annual price rise of energy resources such as electricity, LPG and diesel is taken into consideration, it will be seen that the renewable energy resources need to be expanded more. In addition, these systems produce less CO_2 emission than alternative systems. Fluctuations in ambient temperatures do not cause a significant temperature change in the lower layer of the soil. The GHE system, which is installed at a certain depth of the ground, benefits from relatively constant soil temperature. The soil layer temperature is warmer than the air

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temperature in winter seasons and cooler in summer seasons. This temperature difference can be utilized for cooling purposes in summer months and for heating purposes in winter months. The deepness of soil between 2 m to 3 m is suitable for most applications.

In the literature, there are a great number of studies about GHE systems. Hepbasli, A. et al. [1] examined the coefficient of performance (COP) of U-shaped ground heat exchanger in a 50 m deep soil well in heating process. They also determined the parameters affecting the yield of the ground based heat pump. M. Inalli and H. Esen [2] determined the COP values respectively 2.66 and 2.81 for the deepness of 1 and 2 m by utilizing a horizontal ground based heat pump in April and November. G. Mihalakakou et al. [3] developed a numerical model which is related to the heat and mass transfer to determine the thermal performance of a heat exchanger. Their numerical model is validated with many experimental results. In their study, some parameters such as pipe diameter and fluid velocity were investigated. They also have developed an algorithm to calculate the cooling potential. Y. Song et al. [4] examined the thermal properties of the soil and enhanced a horizontal ground heat exchanger. They investigated the effect of pipe thermal conductivity and the soil type on the system. They used polyethylene pipe as the buried pipe material because of its high density instead of polyvinyl chloride (PVC). The heat transfer rate increases by 100,8% when the thermal conductivity of the soil is increased to 2,5 W/mK. J. Xi et al. [5] investigated the GHE systems in the eastern China area. The variation of the underground thermal area and heat transfer analysis ensure remarkable experimental results. Desideri et al. [6] evaluated the installation costs of the facility in order to match the conventional cooling-heating system and the ground-based heat pump system (GHE). H. Esen et al. [7] examined the economic feasibility of two different systems for cooling and heating processes of a test room and compared the costs of the ground-based heat pump (GCHP) and the air-based heat pump (ACHP) systems using the annual value method. According to the economic analysis as a result of their studies, while the cost of installation of the ACHP system was more economical and feasible than the GCHP system, the operating expense of the GCHP system was appropriate than the ACHP system. Y. Al-Ameen et al. [8] investigated numerically and experimentally the applicability of recycling some relatively inexpensive industrial materials as probable backfills in horizontal ground heat exchangers. Metal fillers have increased the performance of HGHE by 77%. I. Bulut et al. [9] examined the earth-air heat exchanger (EAHE) consisting of galvanized pipes in winter season in Şanlıurfa. Their investigation is related to the dry soil application. The air outlet temperature, soil temperature, and air velocity measurements were conducted in December and February. The maximum temperature difference at the outlet and inlet of the system is determined as 11.6 °C. They found that the efficiency of the heating process was higher compared to the cooling applications.

The soil is an important characteristic element for GHE since the heat transfer is directly affected by the soil thermal conductivity. One of the best methods for increasing the soil thermal conductivity is to moisturize. The most important point that separates the existing system from other investigations is to examine the influence of wet soil on heat transfer. Durmaz and Ozdemir [10] investigated the GHE system which has an artificial pond where the process fluid is water for cooling applications. In this study, air is determined as the process fluid. The purpose of this study is to heat a test room where is at Sakarya University by using a passive method in January. The outlet and inlet temperatures of the ground heat exchanger were measured by means of a thermocouple and the influence of the artificial pond on heat transfer was investigated experimentally.

2. MATERIALS AND METHODS

The air-fluid is circulated in the GHE system, which has 80 m^2 area, 0.5 m height, and 2.5 m depth. The thermal influence of wet soil to heat transfer rate is examined in the energy laboratory of Sakarya University. It is aimed to increase the heat transfer between the soil and the process fluid by means of the artificial pond that is set up under the ground. In order for providing maximum heat transfer, GHE pipes are placed at intervals of 0.3 m [11] and a fan with 20 W, 1800 rpm is used to circulate air flow. In the experiments, inlet and outlet temperatures of 100 mm diameter pipes are measured at 2-minutes intervals by using K type thermocouple.

Figure 1. Artificial pond and underground pipe setup [10]

Figure 1 shows some pictures of the pipe system and artificial pond which are set up to examine the effect of heat transfer [10].

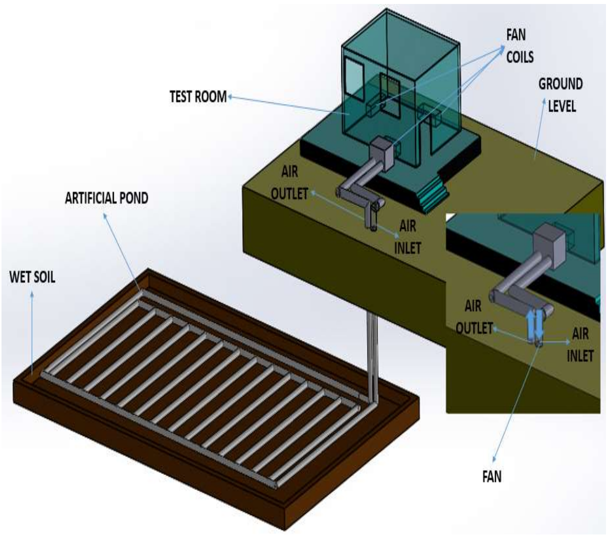

Figure 2. Overview of the GHE system and test room [12]

Figure 2 shows the solid model of the GHE system and the test room. There are three fan coils in the test room. GHE's inlet is the cold air of the environment to be heated. There is relatively hot air at the GHE's outlet. The cold ambient air in the test room is sent to the pipes of the GHE system with the help of a fan and relatively hot air under the ground is used for heating.

Uncertainty analysis for the measurements and the calculations have been determined according to the J. P. Holman [13].

$$\frac{T_{max}-T_{min}}{T_{average}} = \frac{9.75-9.55}{9.65} = 0.0207 \tag{1}$$

In temperature measurements, the error rate of the thermocouple is taken into consideration ± 0.1 °C. The maximum temperature measurement has been determined as 9.75 °C, the minimum is 9.55 °C and, the average is 9.65 °C in this study. The ratio of percentage change is calculated as 2.07%. As the pipe diameter remains constant, the mass flow rate is constant and local losses are negligible. Therefore, the error rate is not calculated.

3. RESULTS AND DISCUSSION

The soil can be used as a heat sink in summer and a heat source in winter since the soil is not affected by the temperature variations throughout the year. The heat transfer between the air in the pipes of the system and the test room is calculated with the following equation.

$$\dot{Q} = \dot{m}.c_p.\Delta T \tag{2}$$

Considering the first equation, the heat transfer is extremely dependent on temperature difference and mass flow rate. One of the most important factors affecting the temperature difference from these parameters is the moisture content of the soil. There are dry and moist soil applications for GHEs in the literature. The experimental investigation was carried out in the summer months for the dry soil application in Şanlıurfa province and the average GHE inlet and outlet temperature difference were determined as 6.2 °C [9]. In this study, the temperature graphs obtained from the wet soil applications are shown in Figure 3 and Figure 4.

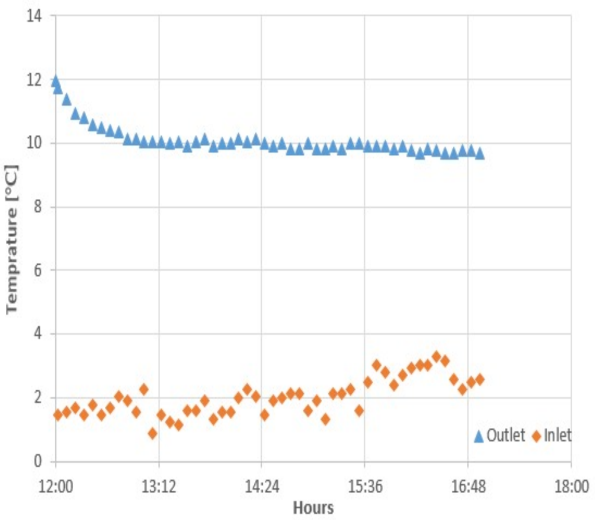

Figure 3. GHE inlet and outlet temperature variation for the first half of January

Figure 3 shows the GHE inlet and outlet temperature measurements. The experimental data in the graph is the average of the measurements in the first half of January. Considering the Figure 3, GHE outlet temperature remains constant at 11 °C on these days. From this experimental data, it is concluded that the soil acts as a heat source and the GHE inlet temperature increased initially from an average of 1 °C to a maximum of 3.5 °C. The average temperature difference during the test time is approximately 9.07 °C. However, if the air circulated under the soil is sent directly to the test room, the room temperature will increase from 1 °C to 11 ° C in a short time. This time depends directly on the mass flow rate.

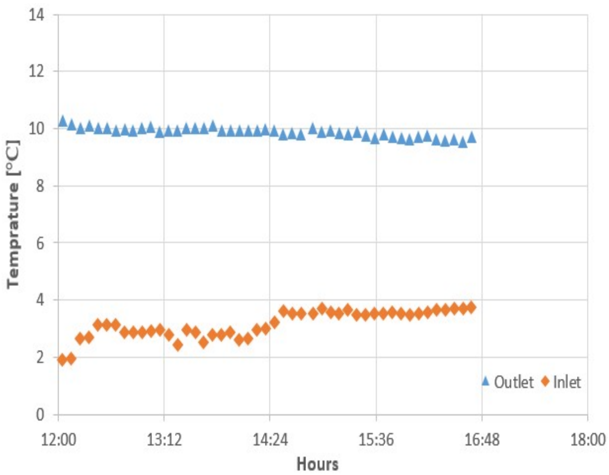

Figure 4. GHE inlet and outlet temperature variation for the second half of January

The temperature measurements at the GHE inlet and outlet in Figure 4 are the data for the average of measurements in the second half of January. Considering the graph, there is a similar characteristic to Figure 3. The soil temperature, in other words, GHE outlet temperature is measured as 10 °C. The GHE inlet temperature is initially 2 °C. This value shows a linear increase of approximately 4°C in four hours. In this case, the temperature difference decreases slightly in the second half of January. The reason for this decrease is due to the increase in the ambient air.

4. CONCLUSION

The annual average soil temperature and soil structure should be examined before the GHE application. Soils with high thermal conductivity and density are more suitable for the GHE systems. It is known that heat transfer increases when the moisture content of the soil improves. Considering the investigation in Sakarya, it is observed that the costs spent on heating processes can be reduced by using a wet ground-source heat exchanger in winter months. It is obvious that this system is more efficient in regions with colder climates. When the annual average soil temperature and soil structure consider before the GHE applications, the yield of the system will increase. In this study, GHE inlet and outlet temperature difference are determined as 9.07 °C. With the wet soil application, the average temperature difference for air fluid increased by 46.28% compared to dry soil in the GHEs. It is expected that energy efficiency will increase by using wet ground heat exchanger systems with other alternative systems. As the air under the ground will be sent directly to the test room, it is also recommended to apply a filtration process such as HEPA filter, taking into account the effect of the subsoil microorganisms on human health.

Acknowledgments

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