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RESEARCH ARTICLE

EXPERIMENTAL ANALYSIS OF HORIZONTAL GROUND HEAT EXCHANGER

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ABSTRACT

In this study, soil temperature variation around horizontal soil heat exchangers (HGHEs), which are widely used for ground-based heat pump (GSHP) systems, was experimentally determined. To determine temperatures and analyse the ground massif temperature changes in the HGHE area, an experimental set-up has been constructed for climatic condition of Çorlu Town located in the Marmara region of Turkey. The experimental results were obtained from 4 August to 14 October in cooling and transition season of 2015. In the experimental study, the soil temperatures at six points at different depths and intervals, and the HGHE inlet and outlet temperatures were measured. The energetic potential of the ground massif was evaluated for operation period and stop periods (night period and transition season). It has been observed that the amount of heat rejected to the soil decreased over time in the working period. The energy accumulated during the working period was not completely destroyed during the night period. But the soil has renewed itself in great measure during the transition season. It has been found that the potential of self-renewal of the soil around the middle pipes of the GHE is less when compared with the soil around the edge pipe due to thermal interaction.

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INTRODUCTION

Horizontal ground heat exchangers (HGHEs) have been widely used as the heat source for GSHP systems in several regions of the world. In cases where there are few limitations on land space usage, the HGHE can provide a cost effective choice for ground heat exchangers (GHEs) because the excavation costs of horizontal trenches are significantly lower than the drilling costs for vertical boreholes (Fujii *et al*., 2012). The ground heat exchanger is an essential component of GSHPs. Therefore, care must be taken in the design and construction of a ground loop for a heat pump application to ensure long ground loop life and reduce the installation cost (Inalli and Esen, 2004; Esen *et al*., 2007; Benazza *et al*., 2011). In the literature (Esen *et al*., 2007; Naili *et al*., 2015; Congedo *et al*., 2012; Naili *et al*., 2012; Fontainea *et al*., 2011), the effects of various system parameters such as the buried depth of GHE, spacing of the heat exchanger pipes, its diameter and length, and mass flow rate of the working fluid on the performance of a horizontal ground-source heat exchanger were investigated experimentally and theoretically in cooling mode and heating mode. Moreover, there are some studies (Shang *et al*., 2011; Adamovsky *et al*., 2015; Šeďová and Adamovský, 2013) that focus on the recovery capabilities of the ground, taking into account operating strategy. In this paper, the ground heat exchanger with horizontal configuration was experimentally analysed and following studies were carried out.

1) Monitoring the temperature values and analysing ground temperature changes in both the cooling and shut-up periods,
2) Determining the specific heat rates rejected to the ground during the cooling period,
3) Assessing the regeneration capabilities of the ground massif in the shut-up periods.

MATERIALS AND METHODS

Experimental set up

The experimental set-up was established in Namık Kemal University in Çorlu, a town in the region of Marmara in Northwestern of Turkey. Fig. 1 illustrates a schematic diagram of the constructed experimental system. The experimental setup mainly consists of the ground heat exchanger, the circulation pump and the heating coil inserted in insulated tank.

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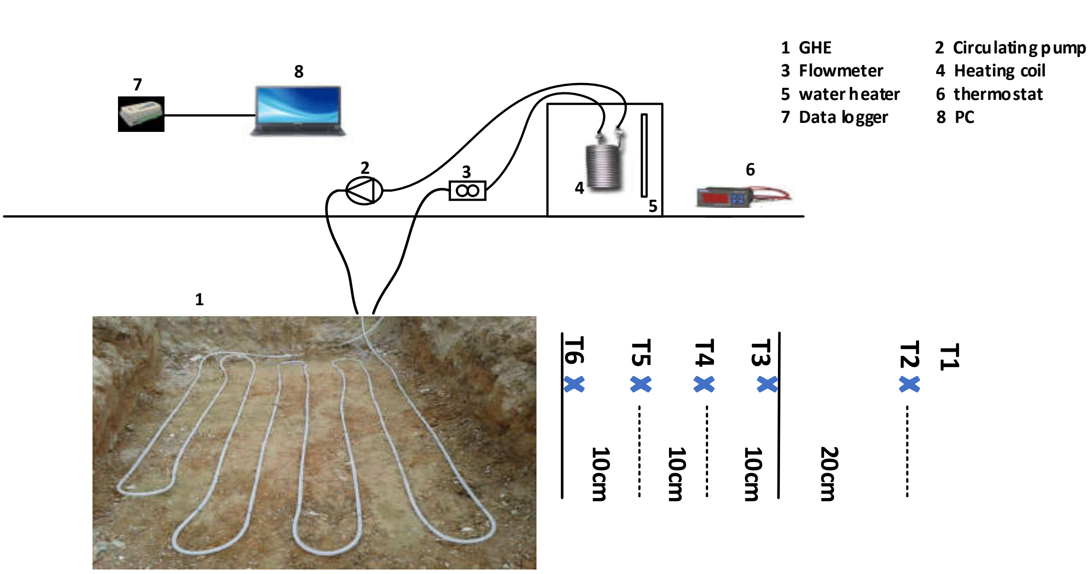

Fig.1. Schematic of the experimental system and installation of sensors

The polyethylene GHE with a pipe of 36 m. length was installed horizontally at a depth of 1.4 m. in the native ground as shown in Fig. 1. The inner and outer diameters of the polyethylene pipe were 0.018 m., and 0.025 m., respectively. The distance between the pipes was fixed at 0.03 m. The clamps were used to keep its shapes horizontally. The GHE is connected to the Laboratory of civil engineering by 2.5 m. insulated pipe. A copper fin tube coil heat exchanger with 0.225 m^2 surface area is connected with the GHE in series. It was immersed to water tank to heat circulating water. In order to simulate the condenser side of a heat pump, the water tank, the coil heat exchanger and a water heater were used as shown in Figure 1. The water heater simulates condenser operation, i.e. it provides thermal load to be rejected by the GHE. In this experiment, a domestic water heater which has power rate of 2 kW was used to heat water in tank with a volume of0.017 m^3. The temperature of water tank was set to a range of 32.5^{o}C - 34.5 ^{o}C by using a digital thermostat. Water was circulated by a three-stage variable flow rate circulation pump(DAB 35/130, 2465-1930-1150r/min) in GHE unit and the highest stage (3.38 L/min) was used during the experiment. In the studied area, there is no need to use anti-freeze solutions due to summer condition.

Test procedure and Measurement equipment

After piping, six copper-constantan thermocouples with accuracy ∓0.1 ℃ were installed to measure the soil temperature around the HGHE at various distances from pipes, in both horizontal and vertical directions. Termocouple 3 (T_3) was installed adjacent to the outside wall of the pipe at the distance of 2.5 m. from the soil surface to measure the pipe-soil interface temperature. Termocouple 2(T_2) was installed 20 cm. away in the horizontal direction from T_3 in the side of natural soil. Termocouples 4 (T_4) and Termocouples 5 (T_5) were installed between the first two rows by 10cm distance. Termocouple 6 (T_6) was installed adjacent to second row of piping (30 cm. away from T_3) to measure the pipe-soil interface temperature. Termocouple 1 (T_1) was installed at a depth of 0.4 m above the T_2. The location of sensors is shown in Fig.1. The inlet and outlet temperatures of the circulated water through the closed-loop HGHE were measured with PT100 with accuracy ∓0.1 ℃. The accuracy was obtained from a catalog of the instruments. The Volumetric flowrate of the circulated water through the closed loop HGHE was measured by using a turbine flow meter (model GT-TD-15,1-30 L/min, accuracy 1% max) and then mass flow rate was calculated. The measured ground temperatures and the inlet and outlet temperatures of the circulated water were recorded in every five seconds by using a multi-channel field logger data acquisition system, which were stocked in a PC. The ambient air temperature was measured with temperature probe at a height of 1m above the ground and 2m away from the horizontal ground heat exchangers. The measured data were recorded every hour by using another data acquisition instrument (Testo 454). Measurements have been performed from 4 August 2015 to 14 October 2015.

RESULTS AND DISCUSSION

Ground temperatures on cooling season

To determine initial natural ground temperatures at 1m. and 1.4m. depths, the circulation pump and the electrical heater inside the water tank were not supplied with electric power from 13:00p.m. on 4 August to 11:00a.m. on 5 August before experiment period. Fig. 2 shows the initial ground temperatures and hourly mean temperature of the outdoorair. The temperature differences between the ground and the outdoor air temperature show the importance to use ground as a heat sink.

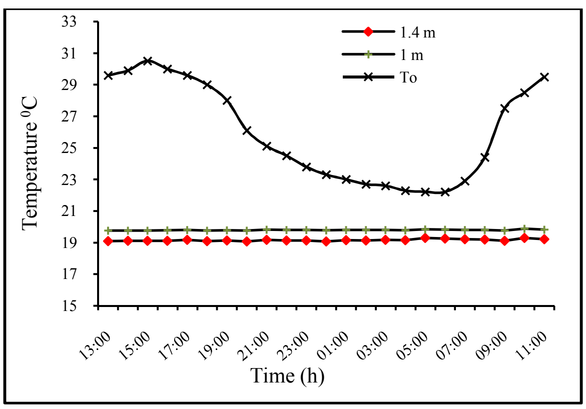

Fig. 2. The ground temperatures and air temperature before test

Fig. 3 shows the variation of the ground and outdoor air temperatures when the water circulation pump has been run from 09:00 a.m. to 19:00 p.m. on 19 August.

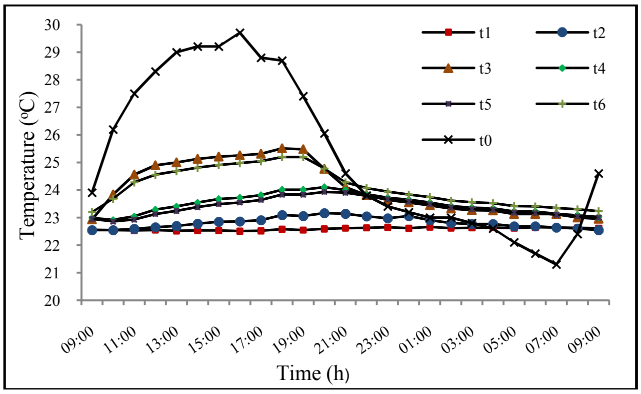

Fig. 3. The variation of the ground and outdoor air temperature versus time of day

It is clear from this figure that the outdoor air temperatures were higher than the all of ground temperatures during whole operating period but these are lower for most part of the night period, the system out of operation. These temperature differences allow the ground to recover during night period. When the system started to operate at 9:00 a.m., the ground temperatures adjacent to pipes (t_3, t_6) rised rapidly due to the temperature of circulation water. The gradients of the temperature for the first two hours were higher and then slightly decreased during operating period. Whereas, the ground temperatures between the first two rows by 10 cm. distance (t_4,t_5) increased slowly when compared with the temperatures (t_3,t_6) due to soil heat resistance. This conclusion corresponds to the result presented in (Pıechowskı, 1999). Both T_2 and T_5 were installed 20 cm. away from T_3 to compare ground temperatures for same distance. Maximum values of t_5 (23.93 ^{o}C) was bigger than thatt$_2$ (23.16^{o}C) as a result of the impact of thermal interaction between pipes. The difference between them was 0.77^{o}C. However, this value will become more smaller for next pipe rows based on the analysis of E. Pulat *et al*. (2009), concluding that thermal interaction can be treated as especially important for first three rows. When the system was stopped at end of the day, ground temperatures rapidly dropped within two hours then continued to cool during night period. The decreases of temperatures during night period were more than the increase during operating period. It will be causes heat accumulation.

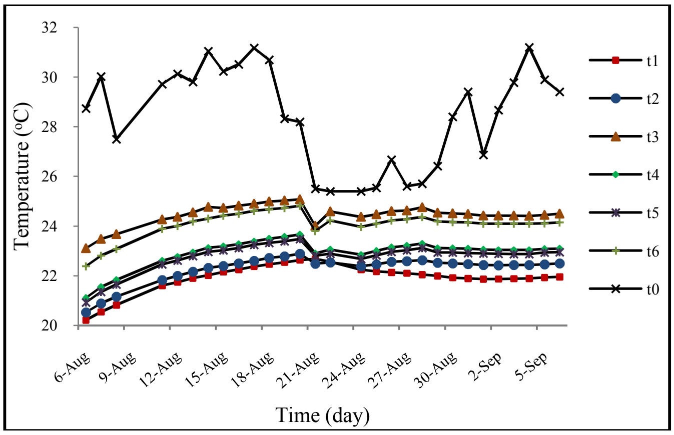

Fig. 4. The variation of outdoor air and soil temperature through cooling days

As seen Fig. 4, the ground temperatures increased until 20 August because of that the amount of thermal energy within the ground became higher and then decreased drastically on 21 August due to rainfall. The ground temperatures increased slightly after 21 August and then became relatively constant although the outdoor air temperature increased again. It is pointed that, the temperature difference $t_2 - t_1$ was bigger after 21 August due to decreasing outdoor air temperature. It shows that the effect of air temperature on ground temperature at 1m. depth was high.

Fig.5 shows heat accumulation in ground by considering the ground temperature at the end of night period on every day of cooling period. The ground temperatures at the end of night period of each day were getting bigger day by day and they reached maximum value on 20 August. It was concluded that the heat rejected to the ground in operating period could not be entirely compensated by the heat loss in night and thus heat rejection to the ground was difficult due to the rise of ground temperature.

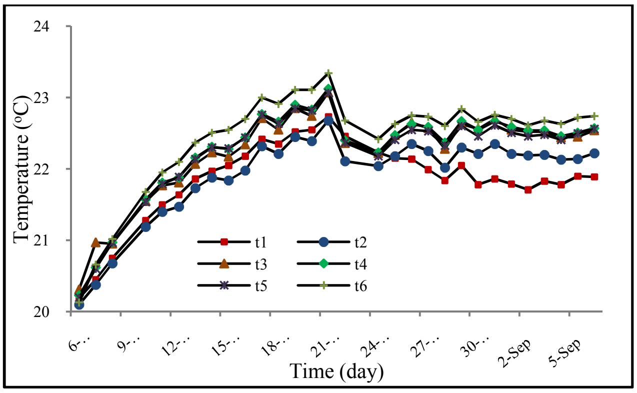

Fig.5. Ground temperatures at the end of night period on every day

Fig.6allows us to see the temperature differences from August 6 to 20 and from 20 August to 6 September. The temperatures of t_3 and $t_6$get closer to circulating water temperature during cooling season due to heat accumulation. This causes unsufficient heat transfer. Therefore, the increase of temperature of t_3(1.98^{o}C) between 6 and 20 August had the lowest value. The highest increases were obtained for t_4 and t_5. Because, the temperature difference between circulating water and the soil between rows is bigger relatively for heat transfer. The slower recovery of soil between pipe rows contributed to this situation substantially. The lower increase of t_2(2.36^{o}C) was due to the higher heat transfer and recovery capacity of the soil away from pipe. The increase of t_6 was bigger than that of t_3 due to lower recovery capacity of soil in T_6 vicinity.

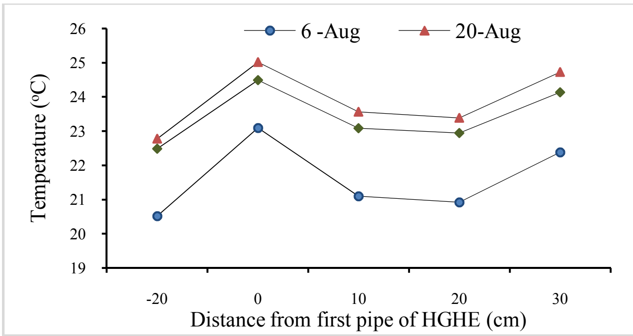

Fig. 6. The temperature distribution around pipes

Inlet and outlet water temperatures

As seen from Fig. 7, the inlet and outlet water temperatures of GHE unit rised rapidly when the system started to operate at 09:00 a.m. and t_3 also had the same trend. Then, the temperature difference slightly decreased during the day, because of decreasing heat transfer between the water in the GHE unit and the soil in the vicinity of pipe. Maximum temperature difference between inlet and outlet of the GHE occurred at the start-up stage as expected and had a value of 0.76°C. The mean temperature difference was obtained to be 0.66 °C during the day. This difference temperature value was extremely low when compared to the values of 4.71°C, 1.2°C, 2.5°C, given in the literature (Coskun *et al*., 2008; Hepbasli *et al*., 2003; Zhang *et al*., 2016) respectively. The primary reason for this is that the low temperature difference between water temperature in GHE and soil temperature, the important parameter for heat transfer.

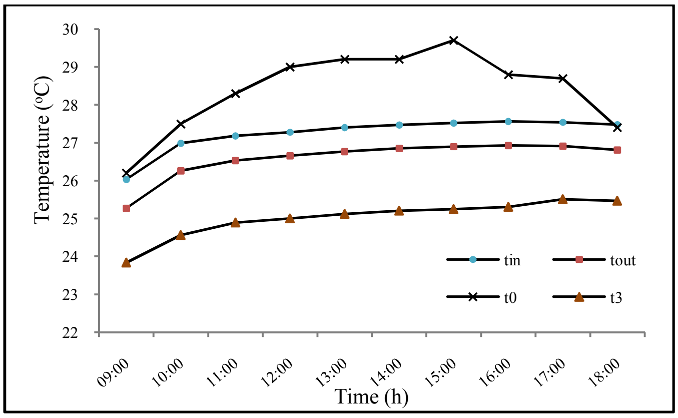

Fig.7. The temperatures on 19 August

Energetic performance of the GHE

The heat rejected to the ground by the GHE can be calculated from the inlet and outlet temperatures of the heat exchanger;

$$\dot{Q}_r = m_f c_f (t_{out} - t_{in}) \quad (1)$$

Where; t_{in} and t_{out} are the inlet and outlet temperature, respectively and they were measured directly from experimental system, m_f is the mass flow rate (0.057 kg/s) and c_f is the specific heat of water assumed to be equal to 4186 J/kgK.

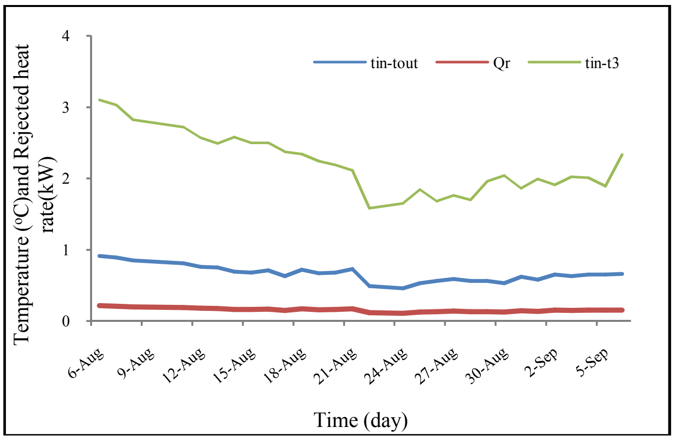

Fig.8. The temperature differences and rejected heat versus time

Fig.8shows the variation of the temperature differences (t_{in}-t_{out} and t_{in}-t_3) and the rejected heat rates to ground versus day of cooling season. The minimum temperature difference between water temperature at GHE inlet (t_{in}) and pipe-soil interface temperature (t_3) was 1.58°C on 6 August and the maximum temperature difference was 3.1°C on 22 August. The average value over cooling season was 2.2°C. This value is very low for adequete heat transfer from circulating water. As a result, maximum and minimum values of temperature differences of water between inlet and outlet of GHE unit were obtained as 0.91°C on 6 August and 0.46°C on 24 August. The temperature differences decreased over cooling season as a result, the rejected heat to the ground decreased. Maximum and minimum value of the rejected heat were calculated as 214 W on 6 August and 108 W on 24 August from Equation 1. The heat rejection rate to the ground was obtained to be on average 156W. This corresponds to a heat rejection rate of 4.33W/m of pipe lenght and this is very low due to the low temperature difference between the outlet and inlet of the HGHE.

Ground temperatures on transition season

The system was shut down during the transition season since there was no need for either heating or cooling. We can see from Fig.9 that the mean daily outdoor air temperatures were lower than the ground temperatures for most part of the transition season. This causes regeneration of ground during transition season. After the transition season was over (at the beginning of heating period), the ground temperatures at 1m. and 1.4m. are 17.04°C and 18.05°C respectively, which are a little smaller than those at the beginning of cooling period, 19.8°C and 19.2°C respectively. However the ground temperatures after the transition season can be bigger due to heat accumulationwhen rejected heat to the ground is higher. This heat accumulation in ground in cooling season can be use for the winter heat demand.

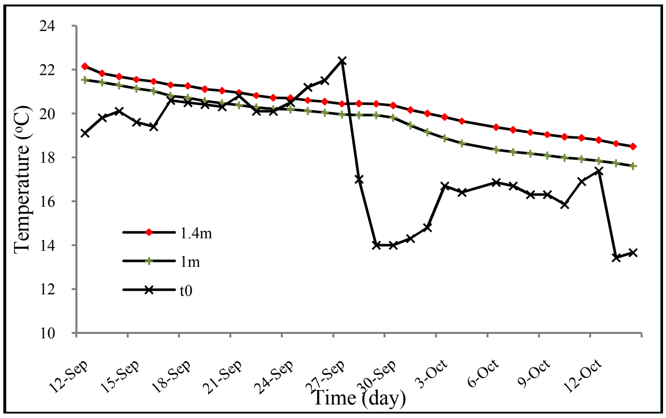

Fig. 9. The variation of the ground and outdoor air temperature for transition season

Conclusion

In the present study horizontal ground heat exchanger was buried at 1.4m. and tested in Çorlu, Turkey. The following results were obtained. When the system started to operate, the ground temperatures adjacent to pipe rows (t_3,t_6) rised rapidly due to the temperature of circulation water. Whereas, the ground temperatures between the first two rows by 10 cm distance (t_4,t_5) increased slowly when compared with the temperatures (t_3,t_6) due to soil heat resistance. The temperature values obtained from probes that were installed 20 cm away between first two rows by 10 cm. were very close to each other. The temperature differences between them were nearly constant during cooling period and the mean value was 0.018°C. Therefore, the distance of 30 cm. between rows which was evaluated as a reasonable assumption in the literature (Pulat *et al*., 2009; Inallı and Esen, 2005), can be treated as adequate by considering this small difference due to small capacity system, intermittent operation and lower inlet water temperature. However, when the operating conditions are changed, this approach may not be accurate. Therefore, care must be taken in pipe spacing to decrease the impact of thermal interaction. It is pointed that if the temperature difference between water temperature at GHE inlet and soil increases, heat transfer will be bigger and hence the difference between inlet and outlet water temperature at GHE. However, an increase in the entering water temperature would make the soil temperature higher, leading to an augmented thermal interaction. Therefore, the inlet temperature should be controlled properly in order to guarantee an appropriate heat transfer during the operation of system. After the transition season was over, the ground temperatures at 1m. and 1.4m. are 17.04°C and 18.05°C respectively, which are a little smaller than those at the beginning of cooling period, 19.8°C and 19.2°C respectively. However the ground temperatures after the transition season can be bigger due to heat accumulationwhen rejected heat to the ground is higher. This heat accumulation in ground in cooling season can be use for the winter heat demand. Therefore, it is assumed that ground heat pumps can be use in Çorlu/Tekirdağ without thermal imbalance for several years.

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