Study of Two Layers Horizontal Ground Heat Exchanger Performance Under a Different Operation Mode.

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Abstract

This paper presents the thermal performance of two-layer horizontal ground heat exchanger at various mass flow rates of water in cooling mode of alternating and continuous operations. Multi-layer composite pipe (MLC) was chosen as the ground heat exchanger tube material. Effects of mass flow rate variation and mode of operations on ground heat exchanger (GHE) performance are discussed. For this purpose, two-layer experimental GHE was fabricated. In alternative operation mode, heat exchange rate was always higher than continues operation mode in GHE. The outcomes achieved from this experimental investigation are utilized to measure the COP of the GHEs. The experimental results showed that the COP values at the alternating operation mode and after six hrs of operation period were ranged from 2.48 at 0.5 ℓ/min to 8.17 at 3 ℓ/min. While in continuous mode, the COP values ranged from 2.28 at 0.5 ℓ/min to 7.37 at 3 ℓ/min. The results also revealed that the GHEs can be used in cooling applications as ground source heat pump system in Iraq that is considered as a hot weather country.

Keywords: Geothermal heat exchanger, COP of: geothermal heat exchanger, Alternating operation mode for GHE.

1. Introduction
Sustainable and renewable energy allows a viable and potent solution to counter the effects of the emission of carbon dioxide and the effects of global warming. By utilizing any of the renewable energy technologies, one will be doing a significant personal enrichment to the wellbeing of future generations and can additionally gain from cheaper fuel charges.

The factors of the ground heat exchanger (GHE) classified to design and environmental factors. Environmental factors such as meteorological conditions, soil physical properties as well as cooling, and heating loads. Whereas design factors involve the scheme configuration, pipe spacing, pipe length, pipe diameter, burial depth and working fluid flow rate in GHE[1].

Heat transfer fluid velocity [2][3] and thermal conductivity of the pipe [4] are essential factors for ground heat exchanger thermal performance. The case of alternating operation, that increased the thermal performance, a short period interval of alternating operation is better than a long-time interval of alternating operation. Bae [5] Used seasonally stable underground temperature to meet demand of cooling, heating also hot water in buildings, determined that the GHE system has practical feasibility in good condition of geothermal gradient. Kayaci and Demir [6] examined a range of operating conditions of the horizontal GHE under specific loads. The outcomes revealed that when pipe spacing is more than two meters, the pipe spacing has an insignificant influence on the GHE heat transfer. Yet, most investigations on GHE were done for continuous operation.

In this work, experimental testing has been done to examine the horizontal GHE performance in continuous and alternating cooling mode operations. Two layers GHE was installed in the ground horizontal orientations (parallel to the ground surface). Water was considered as the working fluid. The flow rate ranging from 0.5 ℓ/min to 4 ℓ/min.

2. Experimental Setup
2.1. Ground Soil Characteristics and Material Selection
The present research was conducted at Engineering Technical College, Najaf region, Iraq. Table 1, present soil characteristics, where thermal conductivity was measured at soil laboratory of Engineering Technical College (Civil Technology Department), Najaf – Iraq, where the conductivity was 1.777 W/m.K with moisture of 7% ,and
based on ASHRAE Handbook-HVAC systems and equipment’s ch. 11, Atlanta, Georgia, 2000 [7] the soil type is light sand due to thermal conductivity and moisture content.

Table 1: Soil characteristics

| Soil type          | Thermal conductivity (W/m.K) | Dry density (kg/m³) | specific heat (kJ/(kg.k)) | thermal diffusivity (m²/day) |
|--------------------|------------------------------|---------------------|---------------------------|-----------------------------|
| Light Sind (5%water) | 0.9 - 1.9                   | 1285                | 0.73                      | 0.055 - 0.12                |

Multi-layer composite pipe (MLC) has been used, with total length of 100m per layer. Table 2 shows the features of the utilized pipes.

Table 2: Pipe features

| Pipe type (PE) | Inner diameter | Outer diameter | midsection layer | Outer layer | Thermal conductivity[8] |
|----------------|----------------|----------------|------------------|-------------|--------------------------|
| polyethylene   | 12mm           | 16mm           | Aluminum         | PE          | 0.4 W/m.K                |

2.2. Experimental Setup Details

Experimental measurements were conducted in Engineering Technical College, Najaf province, Iraq, for horizontal two-layer GHE to achieve two operational modes. Figure 1 present the two-layers horizontal GHE system schematic diagram.
The two-layer heat exchangers were fabricated identically with dimensions as mentioned above. The GHE layers were buried at depth of 2.5 m and 3 m with spacing of 0.5m from each layer. Figure 2 shows the photograph of the first and second layer installation of the GHE.

Figure 1: schematic diagram of the system.
After installing the GHE layers in the trenches, they were covered with soil; water was squirted on the sand to decrease the void space and therefore the thermal resistance around. Pure water as heat carrier liquid running in GHE layers which were supplied from 200-liter water tank, the mass flow rate for the experiment was (0.5, 1, 1.5, 2, 3 and 4 ℓ/min).

The experimental setup as well comprised a water circuit made of pump, heater and flow controllers, etc. The heater-maintained water temperature at 50 °C. K-type thermocouples were installed in the water inlet and outlet to measure the temperatures of each GHE layers using thermometer. Figure 3 shows the water circuit control unit.
2.3. Experimental Operation Modes

Two different modes of operation were considered; continuous and alternating, the working period for the tests were between 9:00 am to 3:00 pm. At continuous mode one of the heat exchanger layers (at 3 m depth) will be operational while in the alternating mode only one GHE layer operated for a period of 30 min before switching to the other GHE layer (at 2.5 m depth).

2.4. Analysis of the Experimental Data

To examine GHE performance, the experimental heat exchange rate is determined by:

\[ Q = \dot{m} \cdot C_p (T_{in} - T_{out}) \]  \hspace{1cm} (1)

Where \( \dot{m} \) is water flow rate (kg/s)

\( C_p \) is water specific heat (J/(kg.K))

\( T_{in} \) and \( T_{out} \) were inlet and outlet water temperatures, respectively.

The COP is defined by the relation[9]:

\[ COP = \frac{m C_p (T_{in} - T_{out})}{\text{Power input}} \]  \hspace{1cm} (2)
3. Results and Discussion

Based on the experiments of horizontal two layers GHE, the water temperatures in the outlet and inlet, ground temperatures at (0.5, 1.0, 1.5, 2.0, 2.5, 3.0 and 3.5 m) depth and water flow rates were measured for different cooling mode. All data were recorded by utilizing a data logger connected to a computer.

All tests were done without system prior operation. For all cases (continuous and alternating) the inlet water temperature were 50°C and flow rates ranging from 0.5, 1, 1.5, 2, 3 to 4 ℓ/min.

The distribution of temperatures in the ground are very significant for the performance [10] and the ground heat exchanger sizing [11]. For the best performance of GHEs, it is essential to know the ground temperatures to decide at which depth the GHE must be installed. Since ambient climatic conditions affect the temperature profile underneath the ground surface, ambient temperature as well requirements to be considered when designing a GHE [12]. Therefore, study of ground temperature distribution along with ambient air temperature is vital for GHEs application. The ground temperature distribution during five months (November 2019, to March 2020) at various depths up to 3.5 m presented in Figure 4. While Table 3 includes the minimum, maximum and average measured ambient temperatures. Ground temperature variations decrease with increasing ground depth. Ground temperature remains relatively close to each other at 2.5m to 3 m depth. So, these depths have been selected because it has very small temperature difference.

Figure 4: Temperature distribution at different ground depth.
Table 3: Ambient temperature profile for Najaf region

|                | Aug 2019 | Sep 2019 | Oct 2019 | Nov 2019 | Dec 2019 | Jan 2020 | Feb 2020 | March 2020 | April 2020 |
|----------------|----------|----------|----------|----------|----------|----------|----------|------------|------------|
| Minimum Temperature (°C) | 25       | 21       | 15       | 7        | 5.5      | 5.1      | 0.2      | 8.9        | 10         |
| Maximum Temperature (°C)   | 48       | 45       | 42       | 29       | 22.6     | 21.3     | 27.4     | 30.7       | 37         |
| Average Temperature (°C)   | 37       | 33       | 27       | 19       | 14.03    | 12.36    | 14.72    | 19.48      | 24         |

The performance of a GHE system depends on the temperature difference between the inlet and outlet of circulate working fluid in the GHE. Thus, it is necessary to have a higher temperature difference between the inlet and outlet for higher performance of GHEs. The temperature difference between inlet and outlet working fluid for various flow rates is shown in Figure 5. After a six hour of operation the temperature difference value (ΔT) between the alternating and continuous modes of the working fluid as follow per case; A (2°C), B (1.8°C) C (1.6°C), D (2.8°C), E (1.4°C), F (2.5°C), show great performance for alternating mode which highest difference at 2 ℓ/minute.
At the beginning, the water outlet temperatures deference were high for continues operating mode (continuous) and gradually decrease (that is due to heat accumulation rejected from GHE in the surrounding soil), while alternating mode shows more stable temperature difference. The variation of the alternating mode which has a saw-like magnitude due to switching between the two layer GHE, that has less declination tendency during the operation period. Whereas the alternating mode after six-hrs of operation period shows a notable performance increase compared to the continuous mode With the highest percentage enhancement of 15.9% at 4 ℓ/min, and lowest percentage enhancement of 6% at 0.5 ℓ/min, due to little cumulative effect of thermal in soil.

Figure 6 shows the heat exchanger rate (Q). At the beginning of the tests, the heat exchange rates for GHE continuous operation shows near identical behavior to alternating mode. This occurs because of higher temperature difference between ground soil around the GHE and circulating water at the beginning. After a short time of operation, the heat exchange rate declined. The declination happened due to heat extraction from around GHE happened. Which led to the surrounding ground soil temperature raised and decreased the temperature difference between the soil around the GHE and the circulating water inside the GHE. However, in alternating mode the
surrounding ground soil temperature fluctuated in a manner that allows a small
difference heat transfer rate to occur during operation. As presented in Figure 6 the
heat transfer difference achieved between alternating and continuous modes A
(69.54397W), B (125.1791W) C (166.9055W), D (389.4462W), E (292.0847W), F
(695.4397W)

![Figure 6: Heat transfer rate Vs time.](image)

Figure 7 represented The COP (coefficient of performance) of the system,
determined based on the experimental data, And The values of it after six-hrs of
operation period was determined for continuous and alternating operation modes
during January and February that were ranged from 2.48 at 0.5 ℓ/min to 8.17 at 3 ℓ/min for alternating mode while for continuous mode the COP results ranged from 2.28 at 0.5 ℓ/min to 7.37 at 3 ℓ/min. In the same point, Naili et al. [9] study documented that the COP were found to be 2.3 to 4.5.

![Figure 7: COP Vs time](image)

The performance of alternating mode during long operation hours prove that the effectiveness of this technique, which is the reality of using GHE in cooling applications, even with more complicated control circuit to operate. The COP of all cases shows that alternating mode have good enhancement over continuous mode, As
presented in Figure 7 the difference between the two operation modes, A (0.197344), B (0.353115), C (0.468047), D (1.086624), E (0.805085), F (1.896481).

4. Conclusions

In the present study the thermal performance of two layers GHE with two operation modes in horizontal arrangements installed at Engineering Technical College, Najaf region, Iraq, was examined. The influence of different parameters like; circulating water flow rate and modes of operation was examined. The outcomes show that:

1. Geothermal potential in Iraq suggestions a good utilization of horizontal ground source heat exchanger; certainly, the experimental ground temperature shows that, at sufficient depth, be relatively stable Where the average earth temperature was during the test period at depth of (2.5m, 3 m) was (21.4 and 22.7 °C), respectively, for months (January, February, and March).

2. The heat exchange rates are low with small mass flow rates and increase proportionally when increasing the flow rate.

3. The inlet and outlet water temperature from the GHEs, which represent the influence of soil thermal response, which in alternating mode presented a better performance for maintain its performance in a narrow fluctuation manner.

4. Alternating mode shown better performance in all cases of the experimental tests, due to small influence period on the surrounding soil of the GHE’s layers.

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References

[1] K. Neupauer, S. Pater, and K. Kupiec, “Study of ground heat exchangers in the form of parallel horizontal pipes embedded in the ground,” Energies, vol. 11, no. 3, 2018, doi: 10.3390/en11030491.

[2] V. R. Tarnawski, W. H. Leong, T. Momose, and Y. Hamada, “Analysis of ground source heat pumps with horizontal ground heat exchangers for northern
[3] P. M. Congedo, G. Colangelo, and G. Starace, “CFD simulations of horizontal ground heat exchangers: A comparison among different configurations,” *Appl. Therm. Eng.*, vol. 33–34, no. 1, pp. 24–32, 2012, doi: 10.1016/j.applthermaleng.2011.09.005.

[4] Y. Song, Y. Yao, and W. Na, “Impacts of Soil and Pipe Thermal Conductivity on Performance of Horizontal Pipe in a Ground-source Heat Pump,” *China Renew. Energy Resour. a Greener Futur.*, vol. 8, no. 2, pp. 2–7, 2006, [Online]. Available: https://core.ac.uk/download/pdf/79624551.pdf.

[5] S. M. Bae, Y. Nam, and B. O. Shim, “Feasibility study of ground source heat pump system considering underground thermal properties,” *Energies*, vol. 11, no. 7, 2018, doi: 10.3390/en11071786.

[6] N. Kayaci and H. Demir, “Numerical modelling of transient soil temperature distribution for horizontal ground heat exchanger of ground source heat pump,” *Geothermics*, vol. 73, no. January, pp. 33–47, 2018, doi: 10.1016/j.geothermics.2018.01.009.

[7] A. Handbook, *Heating, Ventilating, and SYSTEMS AND EQUIPMENT*. 2000.

[8] A. Kalantar Mehrjerdi, S. Naudin, and M. Skrifvars, “Development of Polyolefin Compound and Post-polymerization Treatments for Ground Heat Exchangers,” 2017, doi: 10.22488/okstate.17.000534.

[9] N. Naili, M. Hazami, I. Attar, and A. Farhat, “In-field performance analysis of ground source cooling system with horizontal ground heat exchanger in Tunisia,” *Energy*, vol. 61, no. November, pp. 319–331, 2013, doi: 10.1016/j.energy.2013.08.054.

[10] H. Esen, M. Inalli, and M. Esen, “Numerical and experimental analysis of a horizontal ground-coupled heat pump system,” *Build. Environ.*, vol. 42, no. 3, pp. 1126–1134, 2007, doi: 10.1016/j.buildenv.2005.11.027.

[11] U. Durmaz and O. Yalcinkaya, “Experimental investigation on the ground heat exchanger with air fluid,” *Int. J. Environ. Sci. Technol.*, vol. 16, no. 9, pp. 5213–5218, 2019, doi: 10.1007/s13762-019-02205-w.

[12] G. Florides and S. Kalogirou, “Ground heat exchangers-A review of systems, models and applications,” *Renew. Energy*, vol. 32, no. 15, pp. 2461–2478, 2007, doi: 10.1016/j.renene.2006.12.014.