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14

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1

Thermal performance of shallow spiral-tube ground heat exchanger for ground-source cooling system

Jalaluddin ^{1,*}, Akio Miyara², Rustan Tarakka¹, Andi Amijoyo Mochtar¹,
Muhammad Anis IR¹

¹ Department of Mechanical Engineering, Hasanuddin University, Tamalanrea,
Makassar, 90245, Indonesia

² Department of Mechanical Engineering, Saga University, 1 Honjomachi, Saga-shi,
840-8502, Japan

* Corresponding authors Email: jalaluddin_had@yahoo.com

Abstract. This study present an investigation of thermal performance of spiral-tube ground heat exchanger (GHE) buried in shallow depth of borehole. The spiral-tube GHE consisting of spiral pipe installed in the borehole provides a better performance in application of ground-source cooling system. Experimental study was carried-out by circulating water through the spiral-tube GHE which is buried in the ground of 3 m depth. Temperatures of inlet and outlet water in the GHE were measured and recorded periodically. The thermal performance of the GHE was calculated with different inlet water temperatures. Heat exchange rate for different inlet water temperature of the spiral-tube GHEs are 44 W/m (35 °C), 126 W/m (40 °C) and 110 W/m (45 °C). The results show that the utilization of shallow borehole of spiral-tube GHE is appropriated for application in ground-source cooling system especially for the hot climate like Indonesia.

Key words: Ground heat exchanger, spiral-tube GHE, ground-source cooling system, thermal performance

1 Introduction

The ground source cooling system shows potential technology in engineering application for air conditioning system in the building. Ground heat exchanger (GHE) is used in this system for exchanging heat with the ground. Thermal performances of a number of types of GHEs installed vertically and horizontally have been investigated. The performances of U-tube, double-tube and multi-tube types show that the heat exchange rate of the double-tube has the highest [1]. Operation modes of the GHEs including short-time period, discontinuous and continuous operations affected their heat exchange rates [2, 3]. Pipe thermal interferences, inlet water temperature and borehole depth also affected the heat exchange rate of the GHEs [4]. Recently, a spiral tube GHE is gaining interest due to its better thermal performance. In the spiral tube GHE, a spiral pipe is installed in the borehole or building foundation. Some studies have been carried-out to investigate the thermal performance of types of GHE. Analytical solutions for spiral coil type of GHE have been developed by Man et al. [5], Cui et al. [6], Man et al. [7] and Li and Lai [8]. In addition, comparison study of helical GHE with double U-tube and triple U-tube models have been presented by Zarella et al. [9, 10]. It is found that the helical GHE performance is better than others. The performance and pressure drop along the pipes of spiral tube GHE is a significant parameter in the GHE design [11]. Large investment cost is required to install a deep borehole of spiral-tube GHE. Several parameters should be considered in the design of spiral-tube GHE such as pumping power due to pressure drop and ineffective of outlet pipe due to thermal interference.



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In order to provide the possibility for reducing a borehole depth, a shallow spiral-tube GHE is taking interest. Dehghan et al. studied the performance and distance between shallow spiral-tube GHEs [12]. The heat transfer rate of shallow spiral-tube GHE becomes an important issue in application. However, there is a limited number on performance investigation of shallow spiral-tube GHEs. This study presents an experimental investigation of thermal performance of shallow spiral-tube GHE in order to study the possibility of application. The thermal performance of the GHE was calculated with different inlet water temperatures.

2 Experimental study

2.1 Spiral-tube ground heat exchanger

Spiral-tube GHE consists of a spiral pipe used as inlet tube and a straight pipe used as outlet pipe is shown in figure 1. Inlet and outlet pipes of the spiral-tube GHE are PEX-AL-PEX which is a multi-layered composite tubing consisting of an interior aluminum tubing lined with inner and outer layers of crosslinked polyethylene tubing with an inner diameter of 12 mm. The geometric parameter and material thermal properties of the spiral-tube GHE is shown in Table 1.



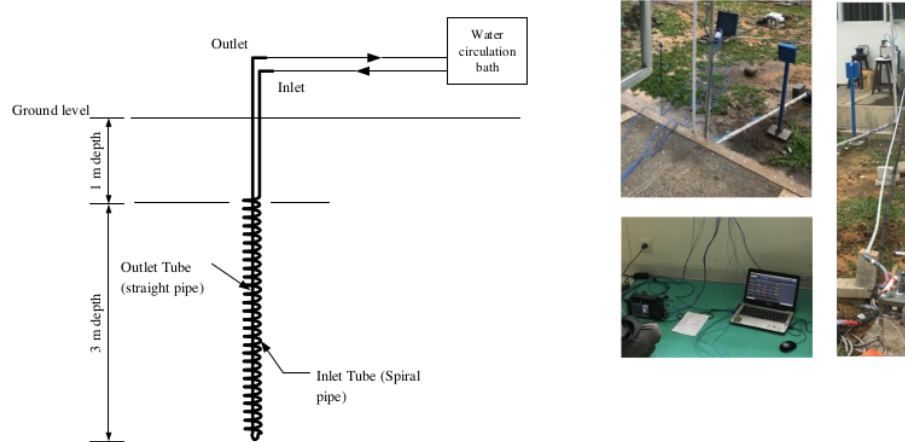
Fig. 1. Spiral-tube GHE.

Table 1. The geometric parameter and material thermal properties of the spiral-tube GHE.

Parameters	Value	Unit
Outer diameter, d_o	0.016	m
Inner diameter, d_i	0.012	m
Thermal conductivity, k_{pipe}	0.45	W/m K
Spiral diameter, D	0.25	m
Pitch (Spiral distance), p	0.2	m

2.2 Experimental set-up

The spiral-tube GHE is installed in the borehole of 3 m depth. The schematic diagram of experimental set-up is shown in figure 2. The spiral-tube GHE is placed 1 m depth from the ground level to protect from the effect of ambient climate. The experiment was carried-out by circulating water through the spiral-tube GHE with different inlet water temperatures. Inlet and outlet temperatures of circulated water and ambient air temperature were periodically recorded. Water was circulated into the spiral-tube GHE. Different inlet temperatures were applied of 35, 40 and 45 °C in the experiments. The flow rate of circulated water was set to be constant of 3.6 L/min.



9 Fig. 2. The Schematic Diagram of Experimental Set-up.

3 Results and discussion

3.1 Temperature distributions

The temperatures of inlet and outlet water of the spiral-tube GHE, ground and ambient air were measured periodically as shown in figure 3. Local ground temperature at Hasanuddin University Gowa campus (119° 30' 06.1" E and 05° 13' 52.4" S) was measured at 3 m depth. This ground temperature is also shown in figure 3. The initial ground temperature surrounding the borehole is 27-28 °C. Water was circulated through the spiral-tube GHE. The temperature of water decreased gradually along the spiral pipe. The average temperature differences of inlet and outlet water are 0.5 °C for inlet water temperature of 35 °C; 1.3 °C for inlet water temperature of 40 °C and 1.1 °C for inlet water temperature of 45 °C.

3.2 Heat exchange rate

The thermal performance of the spiral-tube GHE is evaluated by calculating its heat exchange rate. The heat exchange rate, Q , is calculated by the following equation:

$$Q = \dot{m}c_p\Delta T, \quad (1)$$

where \dot{m} is flow rate, c_p is specific heat, and ΔT is the temperature difference of inlet and outlet water.

For simplicity, the heat exchange rate per meter of borehole depth, \bar{Q} , is defined as

$$\bar{Q} = Q/L, \quad (2)$$

where L is borehole depth of spiral-tube GHE.

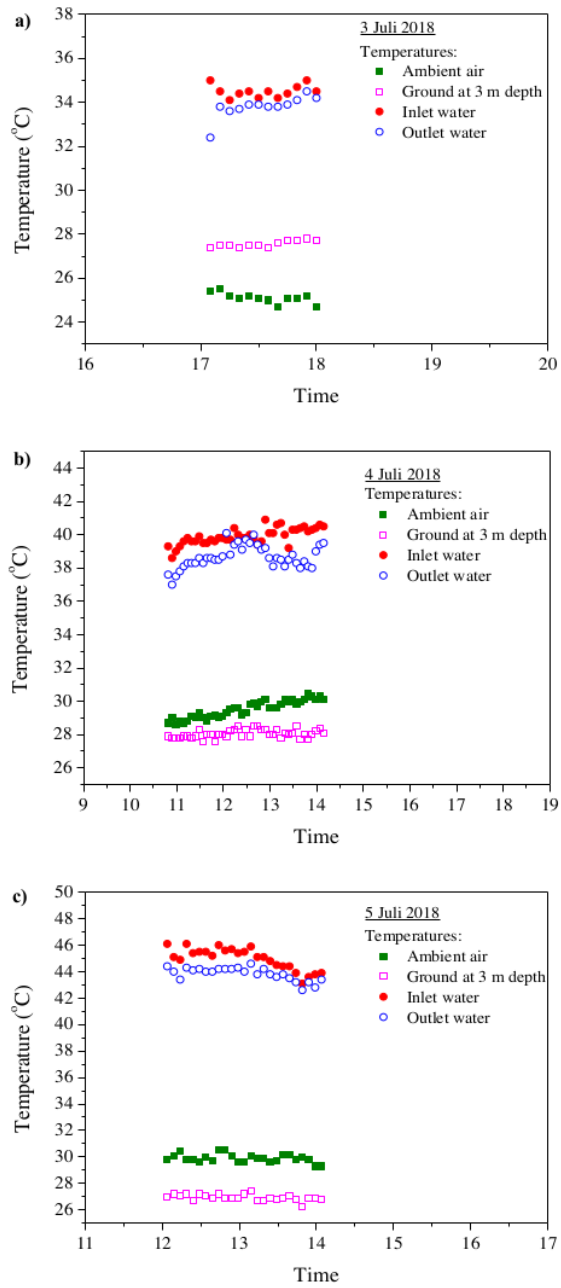


Fig. 3. Temperatures Distribution of Spiral-tube GHE.

The heat exchange rates of the spiral-tube GHE with different inlet temperatures are shown in figure 4. Heat is rejected to the ground surrounding the borehole through water flowing in the spiral-tube GHE.

The high rejected heat to the ground will increase the performance of the GHE. The thermal performance of the GHE was calculated with the different inlet water temperature. Heat exchange rate for different inlet water temperature of the spiral tube GHEs are 44 W/m (35 °C), 126 W/m (40 °C) and 110 W/m (45 °C). The high heat exchange rate of the shallow spiral-tube GHE indicates that this GHE is appropriated for application in ground-source cooling system especially for the hot climate like Indonesia.

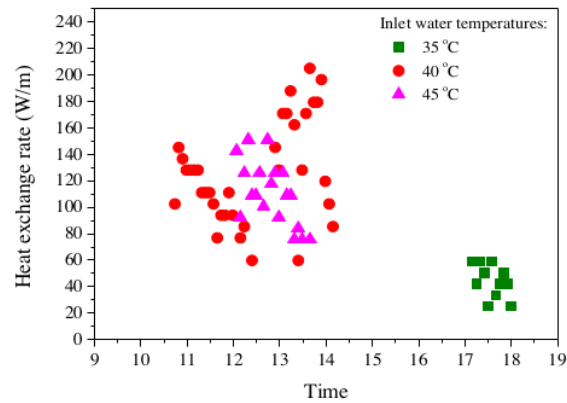


Fig. 4. Heat Exchange Rate of the Spiral-tube GHE.

4 Conclusions

The experimental study of shallow spiral-tube GHE which was buried in the ground of 3 m depth has been carried-out. The thermal performance of the GHE was evaluated by calculating its heat exchange rate. Based on the results of this study, the following conclusions are drawn:

- 1) The average temperature differences of inlet and outlet water are 0.5 °C for inlet water temperature of 35 °C; 1.3 °C for inlet water temperature of 40 °C and 1.1 °C for inlet water temperature of 45 °C.
- 2) Heat exchange rate for different inlet water temperature of the spiral tube GHEs are 44 W/m (35 °C), 126 W/m (40 °C) and 110 W/m (45 °C).
- 3) The high heat exchange rate of the shallow spiral-tube GHE shows that the utilization of this type of GHE can be applied in ground-source cooling system especially for the hot climate like Indonesia.

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