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Experimental Performance Analysis of Shallow Spiral-tube Ground Heat Exchangers in Series and Parallel Configurations

Jalaluddin^{1,*}, Akio Miyara², Rustan Tarakka¹, and Muhammad Anis Ilahi Ramadhani¹

¹Department of Mechanical Engineering, Hasanuddin University, Bontomarannu, Gowa, 92171, Indonesia

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

Abstract. Ground source cooling system (GSCS) uses a ground heat exchanger (GHE) for exchanging heat with the ground. A spiral-tube GHE is gaining interest in recent year. This study presents an experimental analysis of thermal performance of shallow spiral-tube ground heat exchanger (GHE) installed in the ground at 3 m depth in series and parallel configurations. These GHE configurations offer a compromise between the conventional vertical and horizontal GHEs. The spiral-tube GHE which is consist of spiral pipe installed in the borehole provides a better performance in application of GSCS. The thermal performances of spiral-tube GHE in series and parallel configurations were investigated under actual condition. Inlet and outlet temperatures of the both configurations were measured and periodically recorded. The average heat exchange rates of the GHEs are 122.5 W m^{-1} in parallel configuration and 86.2 W m^{-1} in series configuration. Heat exchange rate of the spiral-tube GHEs in parallel configuration provides a better performance than that of in series configuration. The spiral-tube GHE in shallow depth can be applied in the GSCS.

Key words: Ground source cooling system, heat exchange rate, thermal performance.

1 Introduction

The ground source heat pump system (GSHP) has been widely used for space heating and cooling system in the building. The GSHP system used for cooling system is also known as ground source cooling system (GSCS). A ground heat exchanger (GHE) which is used for exchanging heat with the ground in the GSHP system consists of vertical and horizontal types. The horizontal types of GHE such as horizontal slinky and spiral coil have been investigated for application in the GSHP system [1–6]. In the vertical types, a number types of pipe configuration installed in the vertical borehole are applied [7–12]. The spiral-tube GHE which is consist of spiral pipe installed in the vertical borehole is gaining interest in recent years [13–18]. The spiral-tube GHE provides a better thermal performance than others. Some studies have been carried-out to investigate the thermal performance of this

*Corresponding author: jalaluddin_had@yahoo.com

type of GHEs. Analytical solutions have been developed for spiral coil type of GHE by Man et al. [13], Cui et al. [14], Man et al. [15] and Li and Lai [16]. Characteristics of spiral-tube GHE including outlet pipe position and spiral pitch were discussed [17]. The performance of shallow borehole of spiral tube GHE has been investigated. Using this type of GHE can reduce the borehole depth compared with using the conventional U-tube GHE [18]. Zarella et al. [19, 20] presented a comparison study of helical GHE with double u-tube and triple U-tube models. The result confirmed that the performance of helical GHE is better than others. In addition, the groundwater flow affected the thermal performance of spiral coil GHE [21–23]. In the GHE design, the performance and pressure drop along the pipes of spiral pipe is a significant parameter [24]. Also, 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 in the deep borehole. Moch et al. [25] investigated helical heat exchangers buried in the subsoil between 1 m and 4 m depth. Dehghan et al. [26] investigated the performance and the effect of distance between shallow spiral-tube GHEs. The performance of a conic helicoidal GHE for greenhouse heating buried in 3 m depth have been investigated by Boughanmi et al. [27].

In Horizontal GHE type, the large available land area is needed to install the GHE. Unfortunately, the large area is no longer available in urban areas. In addition, installing a deep borehole requires a large investment cost in vertical GHE type. In order to install the GHE in small land area and to reduce the borehole depth, a shallow spiral-tube GHE is taking interest to apply in engineering application. A number of shallow spiral-tube GHEs can be installed together in series and parallel configurations to meet the cooling demand of building. Furthermore, the performances of the shallow spiral-tube GHEs in both configurations are needed as a important parameter in application.

This work presents an experimental analysis of thermal performance of shallow spiral-tube GHE in series and parallel configurations under actual condition. Inlet and outlet temperatures of the both configurations were recorded periodically. The thermal performance of the GHE was evaluated by calculating its heat exchange rate.

2 Experimental set-up

Three shallow spiral-tube GHEs applied in the experimental study are shown in Figure 1. The spiral-tube GHE consists of a spiral pipe used as inlet tube and a straight pipe as outlet tube. 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. Table 1 shows the parameter and thermal properties of the spiral-tube GHE.



Fig. 1. Three Spiral-tube GHEs.

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

Parameters	Value	Unit
Outer diameter of pipe, d_o	0.016	m
Inner diameter of pipe, d_i	0.012	m
Thermal conductivity, k_{pipe}	0.45	$\text{W m}^{-1} \text{K}^{-1}$
Spiral or borehole diameter, D	0.25	m
Pitch (Spiral distance), p	0.2	m

The three spiral-tube GHEs namely SGHE#1, SGHE#2 and SGHE#3 were installed in the borehole of 3 m depth. The schematic diagram of experimental set-up is shown in Figure 2. The three spiral-tube GHE is placed 1 m depth from the ground level to protect from the effect of ambient climate. Distance between each the GHEs is 5 m. The experiments were carried-out by circulating water through the three spiral-tube GHE in series and parallel configurations. In the series configuration, water was circulated through the SGHE#1, SGHE#2 and SGHE#3. Circulated water flowed to the inlet pipes of each GHE in the parallel configuration. Inlet water temperatures were approximately 40 °C to 42 °C in the experiments for the both configurations. Inlet and outlet temperatures of circulated water and ambient air temperature were periodically recorded. The flowrate of circulated water was 3.6 L min^{-1} to 3.8 L min^{-1} .

The thermal performance of the spiral-tube GHE is evaluated by calculating its heat exchange rate (Q):

$$Q = \dot{m} c_p \Delta T \tag{1}$$

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

The heat exchange rate per meter of borehole depth (\bar{Q}) is defined as:

$$\bar{Q} = \frac{Q}{L} \tag{2}$$

where L is borehole depth of spiral-tube GHE.

3 Results and discussion

3.1 Temperature distributions

Temperature distributions including ambient air, inlet and outlet water were measured and recorded 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. The average ground temperature at 3 m depth approximately 27 °C to 28 °C. In the series configuration, water was circulated through the SGHE#1, SGHE#2 and SGHE#3. The average temperatures of inlet water in SGHE#1 were 40 °C and outlet water in SGHE#3 were 35.6 °C as shown in Figure 3(a). Circulated water flowed to the inlet pipes of each GHE in the parallel configuration. The average temperatures in total of inlet and outlet water are 41 °C and 37 °C respectively as shown in Figure 3(b). The inlet and outlet water temperatures of each GHE are shown in Figure 3(c).

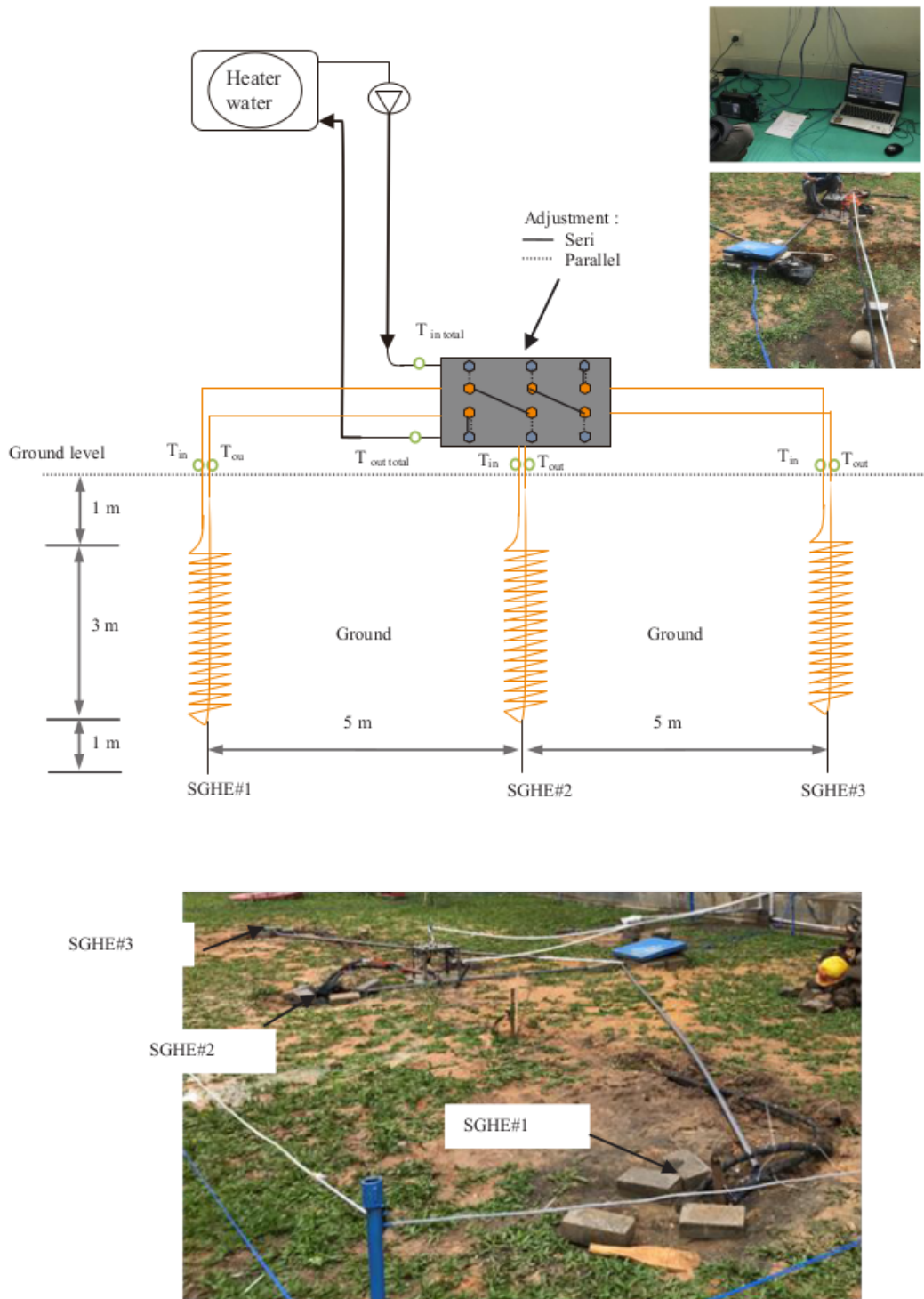


Fig. 2. The schematic diagram of experimental set-up.

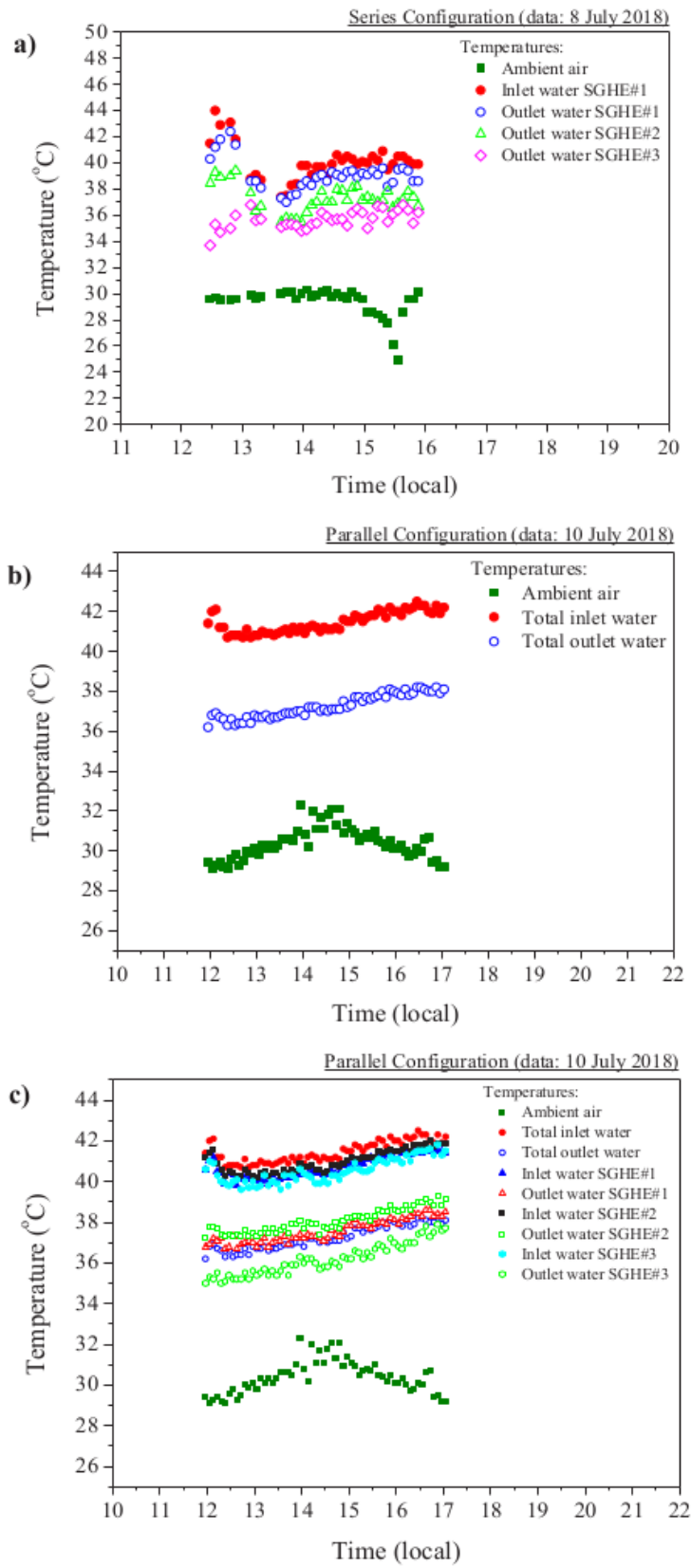


Fig. 3. Temperature distributions of spiral-tube GHE.

3.2 Heat exchange rate

The heat exchange rates of each spiral-tube GHEs in series configurations are shown in Figure 4(a). Heat rejected to the ground around the borehole through water flowing in the spiral-tube GHE. The performance of the GHE is affected by rejected heat to the ground. The thermal performance of the GHE was calculated based on the flowrate and temperature different between inlet and outlet water. In series configuration, the heat exchange rates are 79.9 W m^{-1} for SGHE#1, 92.3 W m^{-1} for SGHE#2 and 76.4 W m^{-1} for SGHE#3. The heat exchange rate in parallel configuration was calculated based on the temperature difference between inlet and outlet of the three GHEs. Finally, the heat exchange rates in average are 122.4 W m^{-1} in parallel configuration and 86.2 W m^{-1} in series configuration as shown in Figure 4(b). This result confirms that the shallow spiral-tube GHE for the both configurations can be applied in the GSCS. The GHEs in parallel configuration provide a better performance than that of in series configuration. Inlet water temperature for each spiral-tube GHE in parallel configuration is similar. It also contributes to the high heat exchange rate in this configuration.

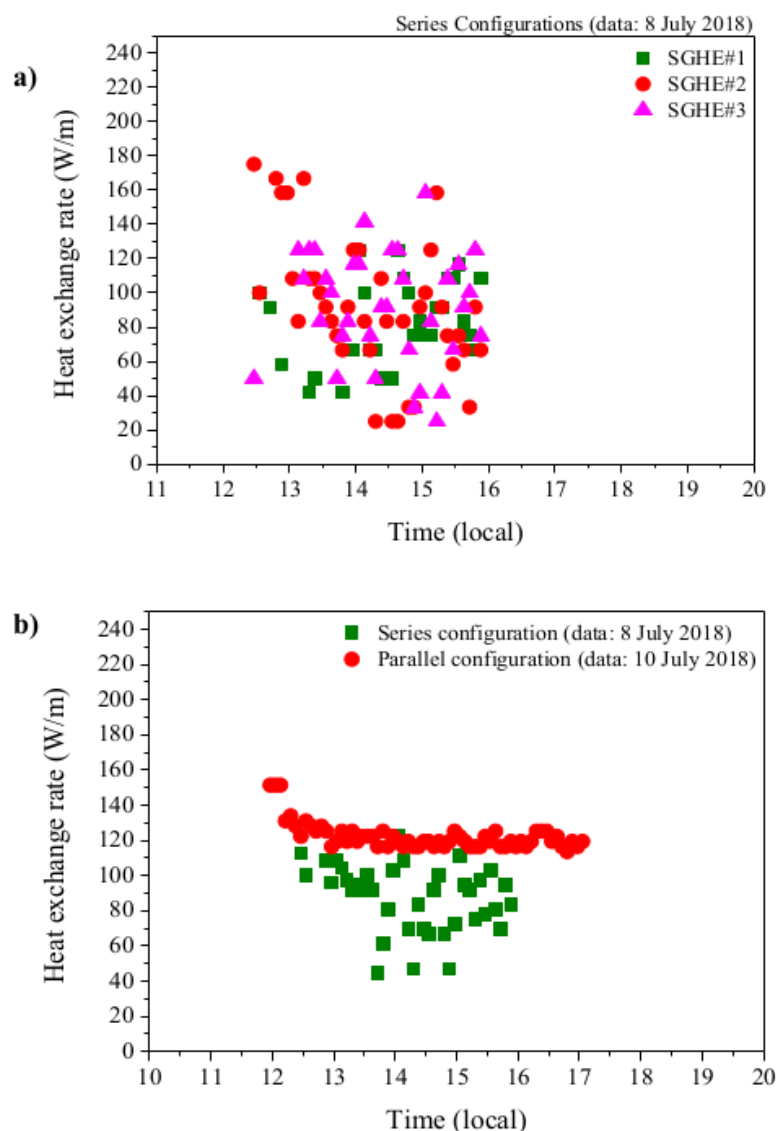


Fig. 4. Heat exchange rate of the spiral-tube GHE.

4 Conclusions

The experimental study of three shallow spiral-tube GHEs in series and parallel configurations has been carried-out. The GHE performance was evaluated by calculating its heat exchange rate. The conclusions of this study are drawn as following:

- i. The heat exchange rates are 79.9 W m^{-1} for SGHE#1, 92.3 W m^{-1} for SGHE#2 and 76.4 W m^{-1} for GHE#3 in series configuration. In parallel configuration, the heat exchange rate is calculated based on the temperature difference between inlet and outlet of the three GHEs.
- ii. The heat exchange rates in average are 122.4 W m^{-1} in parallel configuration and 86.2 W m^{-1} in series configuration. The shallow spiral-tube GHE can be applied in engineering application of the GSCS in series and parallel configurations.
- iii. Finally, the GHEs in parallel configuration provide a better performance than that of in series configuration.

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