Evaluation on heat exchange efficiency of coaxial-type ground heat exchanger

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ABSTRACT: The Ground Source Heat Pump (GSHP) system is the most effective way to reduce energy consumption in a building by utilizing geothermal energy for heating and cooling the building. In general, closed-loop vertical Ground Heat Exchangers (GHEXs) are most widely used in practice to induce heat exchange with the ground formation. However, the closed-loop vertical GHEXs demand relatively high initial construction costs including drilling boreholes. This construction costs of GHEXs can be reduced by improving the thermal performance of individual heat exchangers. In this paper, the coaxial-type GHEX has been considered to improve the thermal performance over the conventional U-type GHEXs because it possesses sufficient heat exchangeable area. Two 50-m-deep coaxial-type GHEXs with different pipe materials (i.e., high density polyethylene (HDPE) and stain less steel (STS)) were constructed. In addition, a closed-loop vertical GHEX was separately constructed in a test bed to compare the thermal performance with that of coaxial-type GHEXs. The effect of thermal conductivity of heat exchange pipes on the thermal performance of coaxial-type GHEXs was studied by performing a series of in-situ thermal performance Tests (TPTs).

Keywords: Thermal performance, Coaxial-type ground heat exchanger, Pipe material, In-situ thermal performance test, Thermal conductivity

1 INTRODUCTION

The Ground Heat Exchanger (GHEX) is a system consisting of heat exchange pipes, which is buried in the ground, utilizing the geothermal energy through heat exchange between the circulating fluid and the ground formation. The type of GHEXs is divided into various categories according to the arrangement of heat exchange pipes (i.e., single U-tube, double U-tube and coaxial tube, etc) (Zhao 2016). The coaxial-type GHEX using a concentric coaxial-tube can provide relatively high thermal performance than the conventional U-type GHEXs because it can ensure a sufficient heat exchange area, and induce turbulent flow conditions inside the pipe (Holmberg 2016, Miyara 2012, Wood 2012). However, the heat transfer mechanism of coaxial-type GHEX has not been clarified yet, and it is not widely used due to a lack of field performance and construction cost records.

Numerous trials are conducted to enhance the thermal performance of coaxial-type GHEX. For example, an outer pipe made of high thermal conductivity material can improve heat transfer between the outer pipe and ground formation (Zanchini 2010). In addition, the performance of coaxial-type GHEX can be improved by the flow direction, pipe cross-section, and ground thermal conductivity (Holmberg 2016).

In this paper, experimental studies on the GHEX were carried out to evaluate its thermal performance. Three types of GHEXs were constructed in a test bed separately. Two 50-m-deep coaxial-type GHEXs were constructed with different outer-pipe materials (i.e., high-density polyethylene (HDPE) and stainless steel (STS)), and a closed-loop vertical GHEX was additionally constructed. Then, a series of in-situ thermal performance tests (TPTs) was conducted to estimate the thermal performance of coaxial-type GHEXs compared to that of the closed-loop vertical GHEX and the effect of outer pipe material on the performance of coaxial-type GHEXs.

2 SUMMARY OF CONSTRUCTION CONDITIONS

2.1 *Overview of test bed*

The location of the test bed is in Dangjin city, South Korea. The boring investigations were conducted to evaluate the engineering properties in the test bed as shown in Table 1. The construction site comprises of the metamorphic rock masses and the biotite granitic rocks. As a result of the boring investigations, the stratigraphic distribution of the construction site is composed of colluvium, weathered soil, weathered rock, soft rock and hard rock.

Table 1. Results of boring investigation

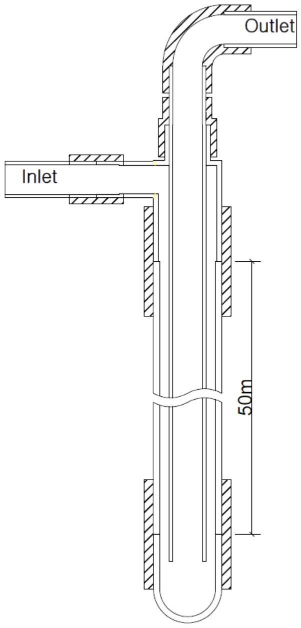
Type	Boring investigation	
	BH-1	BH-2
Colluvium	0.0~2.7 m	0.0~2.4 m
Weathered soil	2.7~9.8 m	2.4~9.8 m
Weathered rock	9.8~10.6 m	9.8~10.8 m
Soft rock	10.6~18.6 m	10.8~15.7 m
Hard rock	18.6~25.0 m	15.7~25.0 m

2.2 *Construction of coaxial-type ground heat exchangers*

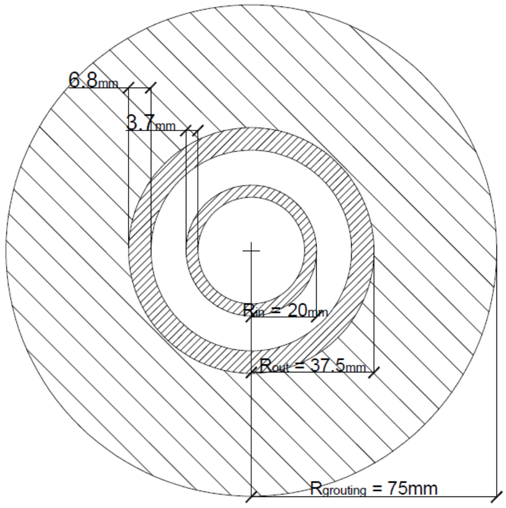
In the test bed, three types of GHEX were constructed. First, a closed-loop vertical GHEX and coaxial-type GHEX with the outer pipe made of high-density polyethylene (HDPE) were constructed to compare the thermal performance of each other. Second, the coaxial-type GHEX with the outer pipe made of stainless steel (STS) was constructed to evaluate the effect of outer pipe material on the thermal performance of coaxial-type GHEXs. The thermal conductivity of the surrounding medium (i.e., grouting material, ground formation, heat exchange pipe) is a critical factor in the thermal performance of GHEXs. In general, an increase in the thermal conductivity of surrounding medium leads to an increase in the thermal performance of GHEXs. However, the thermal conductivity of grouting material or ground formation is not controllable in practice because the construction condition generally predetermines them. Therefore, changing the thermal conductivity of heat exchange pipe material can be an effective way to increase the thermal performance of GHEXs. In this study, the STS (k=16 W/mK) and HDPE (k=0.4 W/mK) were experimentally compared as the outer pipe material of coaxial-type GHEX in terms of the overall thermal performance. On the contrary, the inner pipe is made of the HDPE pipe to reduce heat interference between the annular space and the working fluid in the inner pipe, which may deteriorate overall thermal performance. Table 2 and Figure 1 show the details of the construction conditions and pipe cross-sections.

Table 2. Construction conditions of GHEXs

Type	Pipe diameter	Pipe thickness (inner/outer)	Grouting material	Borehole diameter & pipe length
Coaxial-type GHEX with HDPE	40 mm (inner)/ 75 mm (outer)	3.7 mm/ 6.8 mm	Bentonite	Borehole diameter = 150 mm Pipe length = 50 m
Coaxial-type GHEX with STS				
Closed-loop vertical GHEX with HDPE	40 mm	3.7 mm		



(a) Longitudinal schematic of coaxial-type GHEX



(b) Cross section of coaxial-type D75-40

Figure 1. Schematics of coaxial-type GHEX

3 IN-SITU THERMAL PERFORMANCE TEST

A series of in-situ TPT was carried out to estimate the thermal performance of coaxial-type GHEXs with the cooling operation. The in-situ TPT is a field test to estimate the thermal performance of GHEXs by measuring the temperature difference between the inlet and outlet fluid (Park et al. 2017). The thermal performance of coaxial-type GHEX can be estimated by the heat exchange amount calculated by Eq. (1)

$$\mathrm{Q} = \mathrm{C} \times \dot{m} \times \Delta T \qquad (1)$$

where Q = heat exchange amount (W), $\Delta \mathrm{T} = T_{in} - T_{out}$, which is the temperature difference (°C) between the inlet fluid (T_{in}) and outlet fluid (T_{out}), $\dot{m}$= mass flux of circulating fluid (l/min), C = specific heat of circulating fluid (J/kgK).

Table 3 shows the test conditions of in-situ TPT and a schematic experimental setup is illustrated in Figure 2.

Table 3. Test conditions of in-situ TPT

Type	Test conditions
Operation state	Intermittent (8h operating – 16h pause)
Inlet fluid temperature	30°C (cooling operation)
Inlet fluid flow rate	11 lpm
Sample interval	5 min
Test duration per each GHEX	7 days

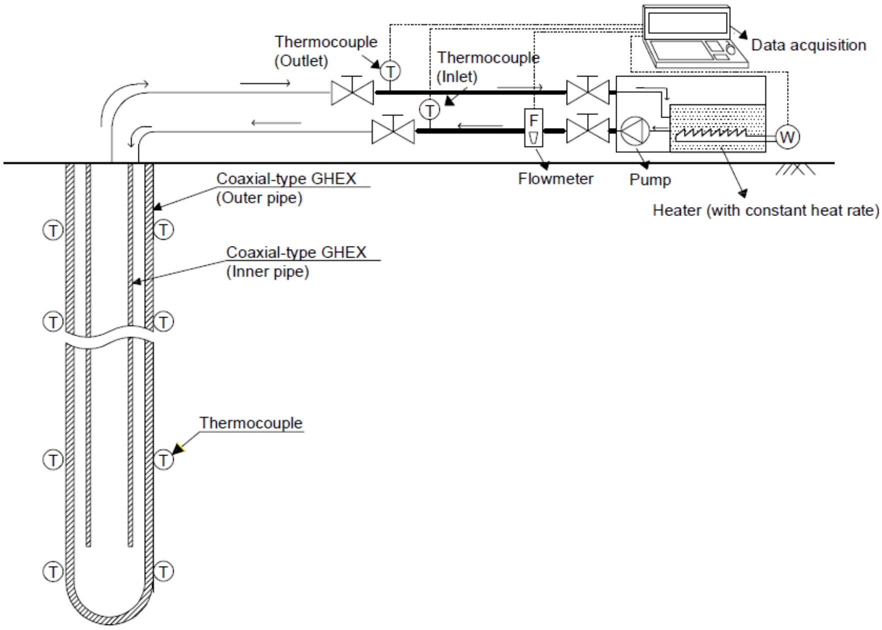


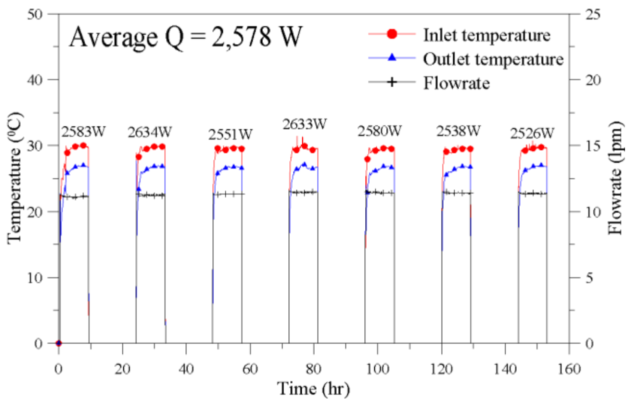
Figure 2. Experimental assembly of in-situ TPT

4 RESULTS OF IN-SITU THERMAL PERFORMANCE TEST (TPT)

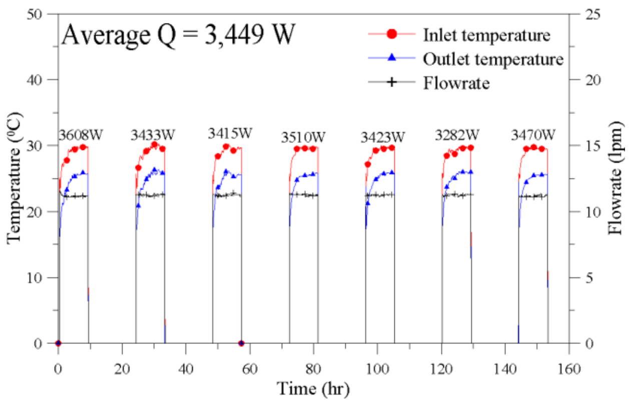
Figure 3 represents the variation in the inlet and outlet temperature, and the flow rate during the TPT according to the outer pipe materials and the type of GHEXs. In addition, the average heat exchange amount and the temperature difference between the inlet and outlet fluid are calculated in Table 4.

The heat exchange amount of coaxial-type GHEX was similar to that of the closed-loop vertical GHEX (Figure 3(a), 3(c)). The reason is that even if the heat exchanging area was larger in case of the coaxial-type GHEX due to the use of a coaxial tube, the thickness of outer pipe of the coaxial-type GHEX is great enough to interrupt heat exchange between the surrounding medium and the circulating fluid (refer to Table 2). From this result, if the coaxial-type GHEX is constructed of similar pipe thickness with the closed-loop vertical GHEX, the coaxial-type GHEX is expected to have better thermal performance than the closed-loop vertical GHEX.

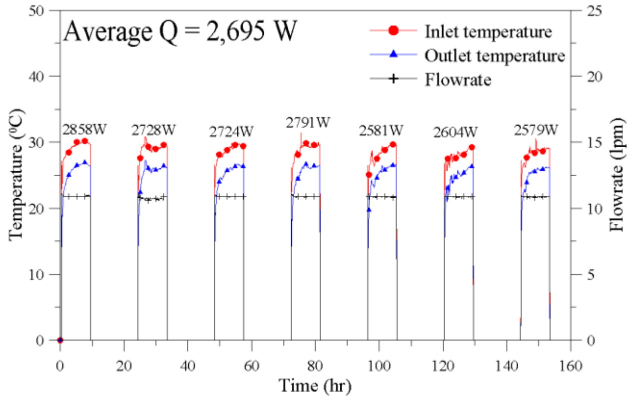
The effect of the outer pipe material is evaluated by comparing Figure 3(a) and 3(b). The heat exchange amount of the coaxial-type GHEX with STS pipe is increased by 33.8% due to the high thermal conductivity of the STS pipe (k=16 W/mK) that is remarkably higher than that of the HDPE pipe (k=0.4 W/mK). This result indicates that the higher thermal conductivity of outer pipe induces sufficient heat exchange with the surrounding medium. In other words, increasing the thermal conductivity of the outer pipe can be an effective way to enhance the thermal performance of coaxial-type GHEXs.



(a) Coaxial-type GHEX with HDPE



(b) Coaxial-type GHEX with STS



(c) Closed-loop vertical GHEX with HDPE

Figure 3. Results of in-situ TPT

Table 4 Comparisons of average heat exchange amount and temperature difference of inlet/outlet

Type	Coaxial-type GHEX with HDPE	Coaxial-type GHEX with STS	Closed-loop vertical GHEX with HDPE
Heat exchange amount	2578W	3449W	2695W
Temperature difference	3.26℃	4.40℃	3.55℃
Heat exchange amount per unit length	51.7W/m	69.0W/m	53.9W/m

5 CONCLUSION

In this paper, two 50-m-deep coaxial-type GHEXs with different pipe materials were constructed in a test bed to evaluate the effect of the pipe material. A 50-m-deep closed-loop vertical GHEX was additionally constructed to compare the thermal performance with the coaxial-type GHEXs. Experimental analysis was performed according to the type of GHEX and pipe material, and it was found that the pipe thickness and the thermal conductivity of pipe material are critical factors affecting the thermal performance of coaxial-type GHEXs. Thermal performance of coaxial-type GHEX can be enhanced with proper pipe configurations (i.e., pipe thickness and material). Therefore, it is crucial to determine the optimum pipe thickness and material considering the thermal performance.

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