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Performance evaluation of a new type of horizontal ground heat exchanger: Coil-Column System (CCS)

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Ground source heat pump system is well-known as an environmentally friendly and high-efficiency technology for heating and cooling the building. The horizontal ground heat exchanger (GHE) has been paid more attention to in recent years as it has a low construction cost and easy installation [1]. However, the drawback of horizontal GHE is the requirement of a large installation area [2]. In this study, the performance of a new GHE type, named Coil-Column System (CCS), is evaluated. CCS is expected to increase the total heat exchange rate of the GHE, which will result in reducing the required installation area.

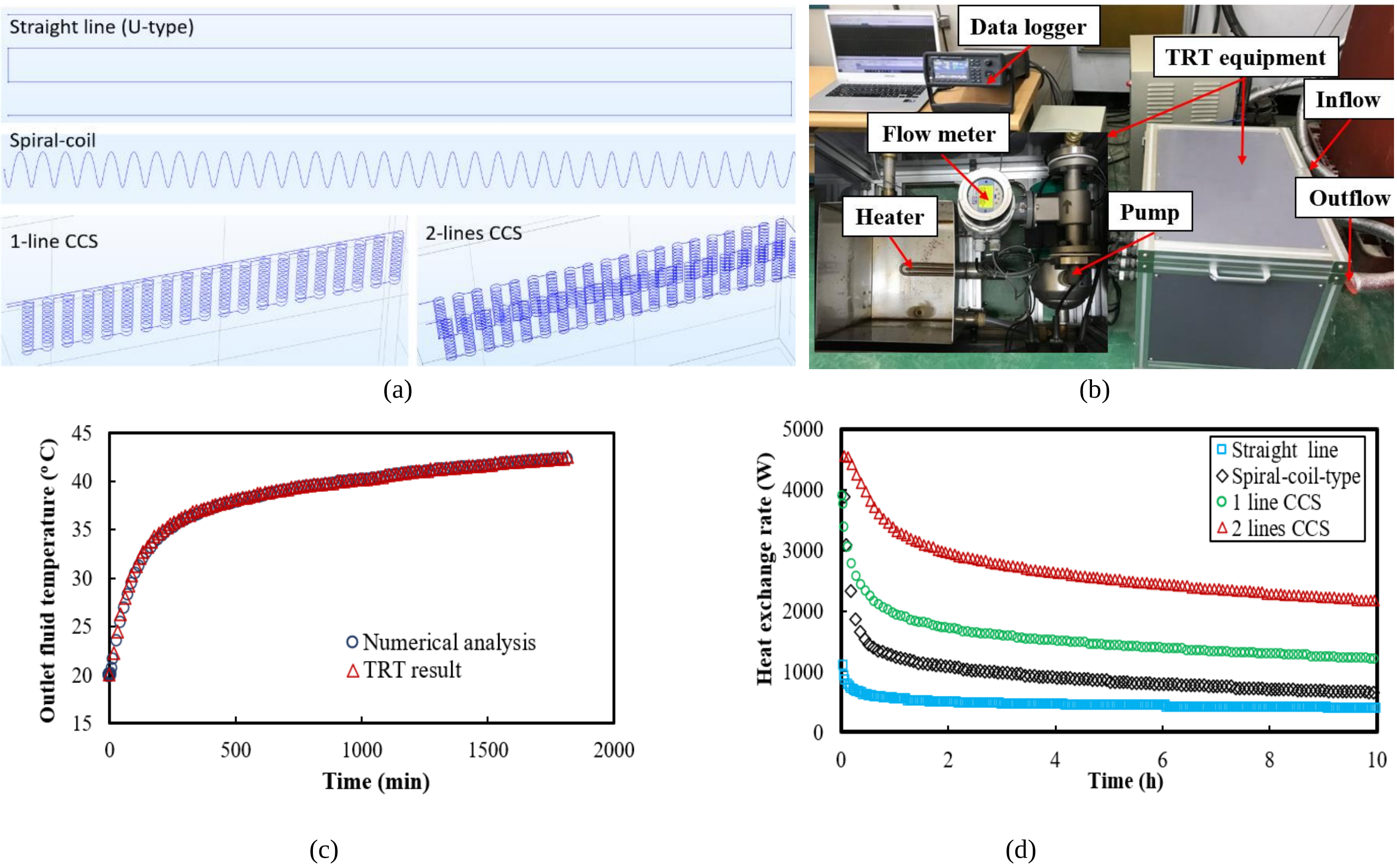

Figure 1: (a) Ground heat exchanger types, (b) in-door thermal response test, (c) validation results, (d) heat exchange rate of different types of ground heat exchanger

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Firstly, the numerical analysis was conducted using COMSOL Multiphysics to investigate the heat exchange performance of the CCS, and previous exchanger types (e.g., spiral-coil type and straight-line ground heat exchanger (Figure 1(a)). The numerical model was validated using an in-door thermal response test (TRT) in the mock-up steel box with a dimension of 5m × 1m × 1m (Figure (1(b)) [2]. Afterward, the parametric study was conducted to evaluate the effect of the pitch of the coil and installation depth on the heat transfer efficiency of the CCS. Finally, the feasibility of the CCS was comprehensively accessed through the heat transfer performance and economic parameters (internal rate of return, payback period).

Strong agreement between the outlet fluid temperature demonstrates that the proposed numerical model is suitable to simulate the heat exchange in the ground heat exchanger (Figure 1(c)). The comparison results of different GHE types indicate that the heat exchange rate of CCS is double that of the spiral-coil and even three times higher than that of the straight-line type (U-type, conventional type) (Figure 1(d)). The parametric study shows that a higher heat exchange rate is observed at a shorter pitch of CCS. However, the heat exchange rate of CCS is almost independent on the pitch after 168 h. This is attributed to the reduction in the temperature gradient of soil temperature and the inlet fluid temperature and thermal interference at the narrow space between pipes. In addition, an increase in installation depth results in an increase in the performance of CCS for both the short term and long term because the deeper CCS has a higher difference between fluid temperature and soil temperature.

Table 1. Economic analysis results of different GHE types

GHE type	PBP (year)	IRR (%)	Annual heat exchange (kW h)
Straight-line	12.0	7.3	1211
Spiral-coil	7.0	13.9	2632
Coil-column system	5.2	15.6	5115

It should be noted that using the shorter pitch (longer pipe length) or increasing the installation depth causes a significant increase in the material cost, and excavation cost, respectively. The economic analysis results of CCS indicate that the installation depth of 4 m and the pitch of 0.15 m has the highest internal rate of return and shortest payback period since they can compromise between the material cost and heat transfer performance. Furthermore, although the investment cost (construction cost) of a CCS is significantly higher than that of the straight-line type and spiral coil type, its high heat exchange performance results in a shorter payback period (5.2 years compared with 12.0 years for straight-line and 7.0 year for spiral-coil) and higher internal rate of return (15.6% compared with 7.3% for straight-line and 13.9% for spiral-coil [2]) (Table 1). Based on the heat exchange efficiency and economic aspects, it is feasible to use the CCS as a new type of horizontal GHE to increase the total heat exchange capacity or reduce the area required for the installation and expect to spread the use of geothermal energy. In further study, the factors that may influence the performance of the CCS (i.e., weather change, rainfall infiltration, soil-atmosphere interaction) will be evaluated.

Contributor statement

Huu-Ba Dinh: Writing – Original Draft, Conceptualization, Formal Analysis, Investigation; Gyeong-O Kang: Formal Analysis, Investigation, Validation; Young-Sang Kim: Writing – Review & Editing, Conceptualization, Validation, Project Administration.

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