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Heat Transfer Characteristics of Various Kinds of Ground Heat Exchangers for Ground Source Heat Pump System

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Abstract. Three kinds of vertical-type ground heat exchangers, U-tube; double-tube; multi-tube, and two kinds of horizontal-type ground heat exchangers, standing Slinky; reclined Slinky, were experimentally and numerically investigated in order to clarify their heat transfer characteristics. Experiments and simulations were carried out under two operation conditions which are continuous operation mode and discontinuous operation mode and effects of temperature recovery and thermal storage on the heat transfer rate were shown. Differences of the heat transfer rate between standing Slinky and reclined Slinky were also indicated.

INTRODUCTION

Preserving the environment of human life is not only the surrounding problems of our living place. As well known, deceleration of the global warming is an urgent task to all over the world [1]. Therefore, many kinds of measures are being conducted in all the different fields, such as industries, transportations, buildings, domestic houses, etc., to reduce emissions of carbon dioxide and the other greenhouse gasses. In the field of air-conditionings, researches and developments for next-generation refrigerants which have low global warming potential are concentrately being conducted [2-5]. And, high efficient systems are also actively investigated for energy saving. Ground source heat pump or ground-coupled air conditioning are getting attention because of their low energy consumption operations. Use of the ground source heat was mainly developed for a heat pump in cold area because the temperature of the underground is higher than that of ambient air. Recently, the use in the warm area is also attracting attention. In the summer, the underground temperature is lower than the ambient temperature, and the energy consumption of air conditioner can be reduced. Expanding the use of underground thermal energy will be a promising measure to prevent the global warming.

A problem preventing the use expansion is the cost to install the ground heat exchanger. Unknowns of ground heat exchanger characteristics still remain and improvement of the performance is desired. In the present study, various kinds of ground heat exchangers are studied to clarify their characteristics and performance.

EXPERIMENTAL AND NUMERICAL METHOD

Three kinds of vertical-type ground heat exchangers and two kinds of horizontal-type ground heat exchangers was tested experimentally and numerically.

Figure 1 shows the vertical-type ground heat exchangers. Steel pipes which are used as foundation pile for houses were buried in the ground at a depth of 20 m and used as boreholes for the GHEs. The U-tube and multi-tube GHEs were inserted in the steel pile, and the gaps between the steel pile and tubes were backfilled with

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silica sand. The U-tube is a polyethylene pipe with an outer diameter of 33 mm. The multi-tube is a polyvinyl chloride pipe with an outer diameter of 20 mm as the central pipe and four polyvinyl chloride pipes with outer diameters of 25 mm placed around the central pipe. The central pipe is the outlet tube and the four pipes around the central pipe are the inlet tubes. The outlet tube is insulated to protect the heat exchange process from the inlet tubes. In the double-tube GHE, a stainless steel pipe with an outer diameter of 139.8 mm is used as the inlet tube of the GHE and a polyvinyl chloride pipe, 48 mm in outer diameter, is installed inside the stainless steel pipe as the outlet tube.

Figure 2 shows the horizontal-type ground heat exchanger. Slinky loops in two orientations: reclined (parallel to the ground surface) and standing (perpendicular to ground surface) were installed as a ground heat exchanger. The material of the Slinky loop is cupper tube coated with low-density polyethylene (LDPE). The loop diameter, length of trench and number of loop for both orientations were 1.0 m, 7.0 m and 7 m, respectively and the total length of LDPE coated copper tube was 39.5 m in each gourmand heat exchanger. The reclined loop was laid in the trench at a 1.50 m depth and 1.00 m wide. On the other hand, the center of standing loop was located at a depth 1.50 m and 0.50 m wide in the trench. The water of which temperature and flow rate are controlled is supplied to the heat exchangers as hot water for cooling mode and cold water for heating mode.

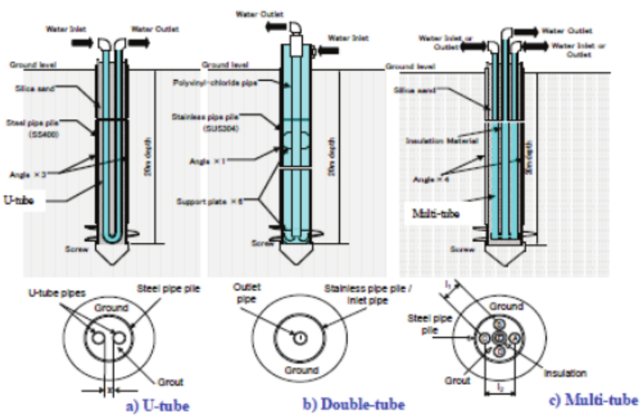


FIGURE 1. Vertical-type ground heat exchanger.

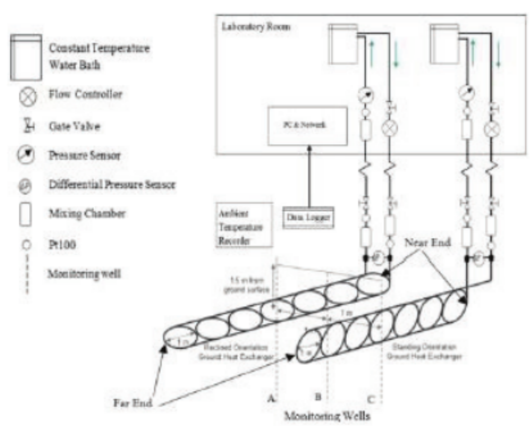


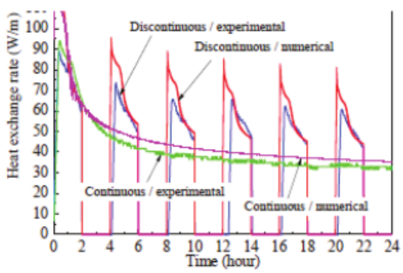
FIGURE 2. Horizontal-type ground heat exchanger.

Numerical simulations to obtain detail information of the heat transfer characteristic were also carried out by using a commercial software FLUENT [6]. Simulation models of each ground heat exchangers were built, and the simulations were carried out.

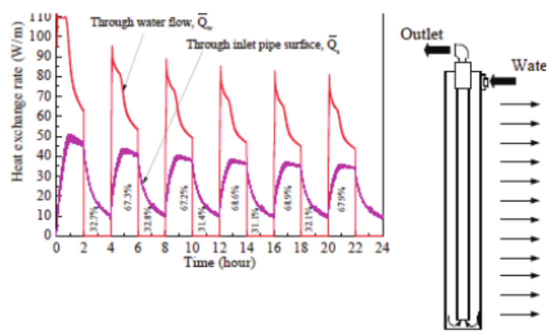
RESULTS AND DISCUSSION

Vertical-type ground heat exchanger

Figure 3 shows the heat exchange rates of the double tube under a continuous operation and 2-hour discontinuous operation for cooling mode. As shown in Figure 3(a), in the case of continuous mode, the heat transfer rate has the highest at the operation start point and decreases with operation time. The degree of decrease is larger at the beginning then becomes gentle according to the operation time. This gradual decrease is obviously caused by a temperature increase of the soil surrounding the ground heat exchanger. In the case of the discontinuous operation, although the trend of heat transfer rate during the operation is similar to the continuous mode, the heat transfer rate is higher than that of the continuous operation mode. Simulation results of each mode reasonably agree to the experimental result. Figure 3(b) indicates the comparison between the heat transfer rates calculated from the temperature difference between inlet and outlet of the water, which is the same value obtained from experiment, and the heat transfer rate calculated from heat flux at the surface of the outer tube. Both the heat transfer rates show the different behavior. The heat transfer at the surface occurs during the operation stops. From the simulation result, it is inferred that the thermal storage effect of the water remained in the double tube is remarkable. On the other hand, the thermal storage effects of U-tube and multi-tube were small though it is not shown.



(a) Comparisons between experiments and simulations

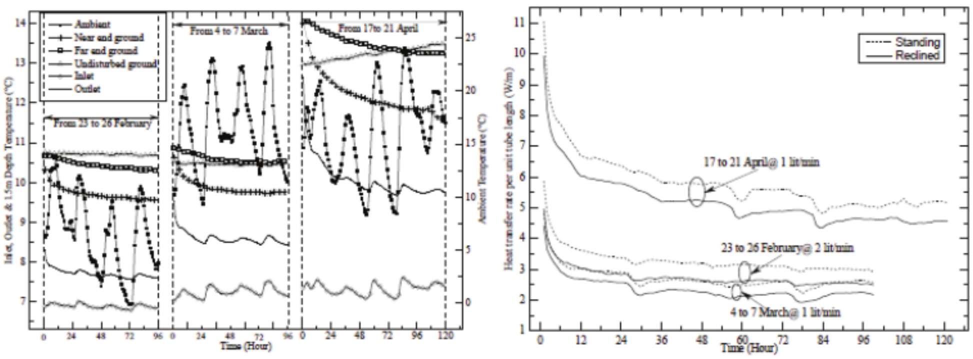


(b) Heat transfer rates calculated from inlet and outlet water temperature and from heat flux of heat exchanger surface

FIGURE 3. Experimental and simulation results of double tube ground heat exchanger under the condition of continuous operation and discontinuous operation of cooling mode with an inlet temperature of 27°C.

Horizontal-type ground heat exchanger

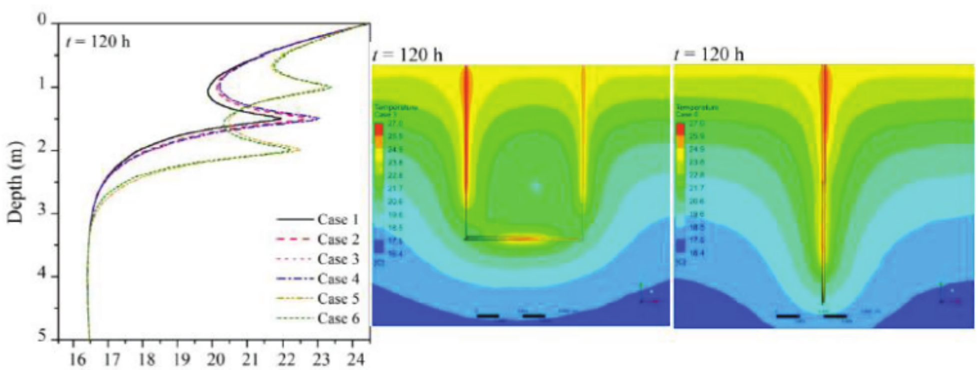
Figure 4 (a) shows the hourly average temperature variations of ambient, near end ground, far end ground, inlet and outlet water. Although the inlet water temperature was set at 7°C as a heating mode, the temperature fluctuates somewhat because of the ambient temperature variation. The heat transfer rate can be calculated from the flow rate and the temperature difference between inlet and outlet of water. Figure 4(b) shows the time variation of heat transfer rate of standing and reclined Slinky ground heat exchanger under the different flow conditions. Like the vertical-type mentioned above, the heat transfer rate gradually decreases with time. In the comparison between standing and reclined, the heat transfer rate of standing Slinky shows a higher value than that of reclined Slinky.



(a) Time variation of temperatures

(b) Time variation of heat transfer rate temperature and from heat

FIGURE 4. Time variation of temperatures at several points and heat transfer rates for horizontal type standing and reclined Slinky ground heat exchanger.



(a) Temperature distribution in depth

(b) Temperature contour around ground heat exchangers

FIGURE 5. Temperature distribution in the ground around horizontal-type standing and reclined Slinky ground heat exchangers

CONCLUSION

Experiments and simulations have been conducted for various kinds of ground heat exchangers, such as vertical-type U-tube, double tube, multi-tube, and horizontal-type standing Slinky and reclined Slinky. Although the further investigation has to be carried out, some valuable characteristics have been clarified.

ACKNOWLEDGEMENTS

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