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Cooling characteristics of ground source heat pump with heat exchange methods

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A R T I C L E I N F O

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A B S T R A C T

The objective of this study is to investigate the influence of the cooling performance for a water-to-water ground source heat pump (GSHP) by using the counter flow and parallel flow methods. The GSHP uses R-410A as a refrigerant, and its main components are a scroll compressor, plate heat exchangers as a condenser, an evaporator, a thermostatic expansion valve, a receiver, and an inverter. Based on our modeling results, the heat transfer rate of the counter flow evaporator is higher than that of the parallel flow evaporator for a heat exchanger length greater than 0.42 m. The evaporator length of the GSHP used in this study was set to over 0.5 m. The performance of the water-to-water GSHP was measured by varying the compressor speed and source-side entering water temperature (EWT). The cooling capacity of the GSHP increased with increased compressor RPMs and source side EWT. Also, using the counter flow method, compared to the parallel flow method, improves the COP by approximately 5.9% for an ISO 13256-2 rated condition.

1. Introduction

In 2004, the installation of renewable energy sources in public and residential buildings became mandatory in the Republic of Korea as a result of the Promotional Law of New and Renewable Energy Development. Geothermal energy has special advantages as a renewable energy source because the temperature under the ground is almost constant regardless of the location, climate, and season. Also, geothermal energy is more eco-friendly than other renewable energy sources, and has an advantage in terms of space utilization. The use of ground source heat pumps (GSHPs) is also increasing [1].

A GSHP system consists of a heat pump unit and a ground loop heat exchanger. Many studies of the use of heat pumps and ground loop heat exchangers to enhance the efficiency of GSHP systems are in progress worldwide.

Esen et al. [2] considered a vertical ground-coupled heat pump system with U-tube boreholes, and calculated the temperature distribution over time using the finite element method. Ozyurt et al. [3] measured the performance of a vertical GSHP for Turkey Erzurum's winter climatic conditions. They obtained values of 2.43–3.55 for the COP of a heat pump unit and 2.07 to 3.04 for the system COP. Hepbasli et al. [4] installed a vertical U-bend ground loop heat exchanger (GLHX) with a length of 50 m at the Solar Energy Institute at Turkey Ege University, and used it as a heat source for GSHP with refrigerant R-22. They reported that the heating COP result for the heat pump used in the experiment was not satisfactory.

Pulat et al. [5] performed experimental research on the performance of a horizontal ground source heat pump, and obtained results of 2.46–2.58 for the system COP, and 4.03 to 4.18 for the COP of the heat pump unit. Inalli et al. [6] reported that the heating COP ranged from 2.66 to 2.81 in a horizontal-type ground loop heat exchanger with a depth of 1 or 2 m. Zhao el al. [7]. performed experimental research on the performance of a GSHP system using an alternative refrigerant. Chung et al. [8] evaluated the performance of a water-to-water GSHP by controlling the secondary fluid flow rate and compressor speed.

A heat pump system can provide both cooling and heating by controlling refrigerant flow using a four-way valve. In designing a heat pump, the heat exchange method is determined based on the amount of heating and cooling load. If the heat exchange method for the load and heat source side is counter flow cooling, then parallel flow is used in the heating mode. On the other hand, if counter flow is set for the heating mode, parallel flow is set for the cooling mode. The use of parallel flow results in a decrease in heat exchange performance [9,10]. However, there are no quantitative

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studies available in the literature on the performance degradation of an actual system during the change from cooling mode to heating mode, or from heating mode to cooling mode.

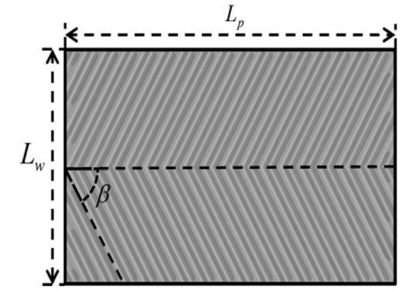
Fig. 1 shows a schematic diagram of the heating and cooling modes for the GSHP considered in this study. In order to compare the system's performance according to the heat exchange method, we considered a combination of the refrigerant switching method and water switching method.

To perform our experiment, a four-way valve was installed in the refrigerant loop, and three-way valves were installed in the secondary fluid loop for switching from heating mode to cooling mode, or from cooling to heating. We investigated the cooling performance characteristic with respect to heat exchange methods for counter flow and parallel flow in a GSHP using simulation and experiments.

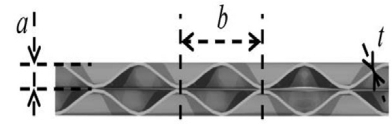
2. Evaporator modeling

The evaporator was modeled in order to find the appropriate heat exchanger length and superheat of the refrigerant side, based on the heat exchanger methods of the evaporator. The heat exchanger methods considered are the counter flow type and parallel flow type. The refrigerant was R410a and the secondary fluid was water as the working fluids for numerical modeling. In modeling the evaporator, specifications for a plate heat exchanger (Danfoss, 35 kW rated capacity) were used. In order to apply the characteristics of the heat transfer and pressure drop of the plate heat exchanger during evaporation, the Nusselt number and friction factor described by Han et al. [11] were used in Eqs. (1)–(6), where Ge_1, Ge_2, Ge_3, and Ge_4 are nondimensional geometric parameters that involve a corrugation pitch (P_b), hydraulic diameter (D_h), and chevron angle (β):

$$Nu_{R410a} = Ge_1 Re_{Eq}^{Ge_2} Bo_{Eq}^{0.3} Pr^{0.4} \quad (1)$$



(a) Top view.



(b) Front view.

Fig. 2. Geometry of plate heat exchanger used as an evaporator.

$$Ge_1 = 2.81\left(\frac{P_b}{D_h}\right)^{-0.041}\left(\frac{\pi}{2}-\beta\right)^{-2.83} \quad (2)$$

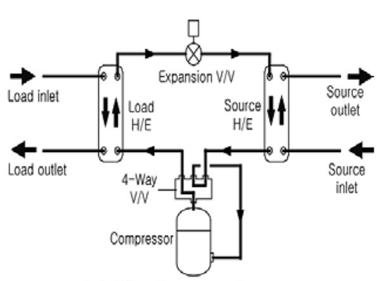
$$Ge_2 = 0.746\left(\frac{P_b}{D_h}\right)^{-0.082}\left(\frac{\pi}{2}-\beta\right)^{-0.61} \quad (3)$$

$$f_{R410a} = Ge_3 Re_{Eq}^{Ge_4} \quad (4)$$

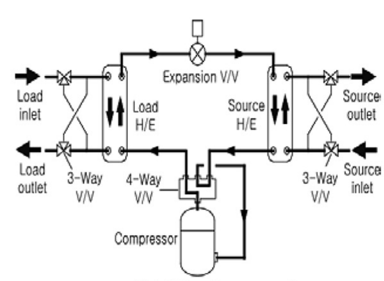
$$Ge_3 = 64710\left(\frac{P_b}{D_h}\right)^{-5.27}\left(\frac{\pi}{2}-\beta\right)^{-3.03} \quad (5)$$

Refrigerant switching

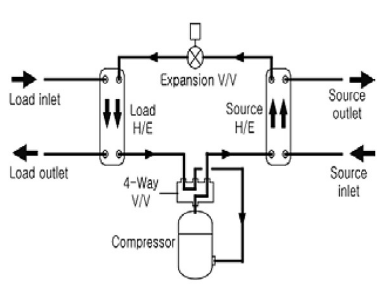
Refrigerant + water switching



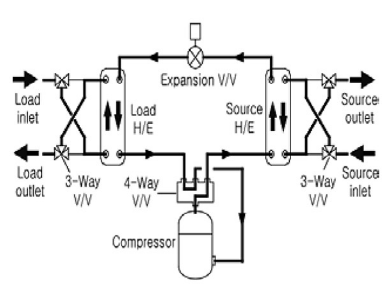
(a) Heating mode
(evaporator and condenser: counter flow).



(b) Heating mode
(evaporator and condenser: counter flow).



(c) Cooling mode
(evaporator and condenser: parallel flow).



(d) Cooling mode
(evaporator and condenser: counter flow).

Fig. 1. Schematic diagram of GSHP with heat exchanger method.