EXPERIMENT FOR VERIFICATION OF GROUND SOURCE HEAT PUMP USING THE DIRECT EXPANSION METHOD

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ABSTRACT

The temperature beneath the about 10 m from the surface maintains a nearly constant temperature about 15-20°C. Ground Source Heat Pump (GSHP) absorbs energy from the earth by applying this constant temperature. Such the ground source heat can be used in radiators, in under floor and warm-air heating system, and in hot water heaters in house. This paper describes the experimental results and the performance of ground source heat pump using the direct expansion method. Authors paid attention to shallower depth than 100 m under the ground surface. In order to obtain the basic data, authors tried to experiment on GSHP based on direct expansion. Temperatures and pressures along primary loop were measured at 6 positions, and air temperatures at the entrance and exit of an air heat exchanger were measured. The preset temperatures were 27°C in the cooling mode and 20°C in the heating mode. Totally, COP of GSHP with direct expansion method is higher than that in air-source type heat exchanger or indirect heat exchange method. The performance of the ground source heat pump system was evaluated by coefficient of performance (COP), which is determined by the ratio of heat exchange rate to consumption power of the compressor. The COP approached to 9.3 in cooling mode and 4.3 in heating mode. Totally, COP of GSHP with direct expansion method is higher than that in air-source type heat exchanger or indirect heat exchange method.

INTRODUCTION

The need to think about energy issues has increased in Japan, which experienced electricity shortage due to the Great East Japan Earthquake disaster. The GSHP which can save energy by making good use of underground thermal energy, is attracting more attention as a renewable natural energy source. The GSHP system using geothermal energy helps save energy more efficiently and cost-effectively than the conventional air-source heat pump system. In addition, releasing the exhaust heat from air-conditioning underground can ensure reduced environmental impacts, including the heat island effect. In the GSHP, two kinds of systems are applied, namely, an indirect method and a direct expansion method. In the direct expansion method, refrigerant transfers thermal energy through primary loop without mediation. Therefore, it is expected that thermal energy is transferred effectively and performance is promoted. In the present experiment, authors focused on the shallower depth than 100 m from the ground surface and getting the basic data of GSHP based on a direct expansion method. In this experiment, performance evaluation was carried out during 24 hours operation.

EXPERIMENTAL APPARATUS

Figure 1 shows representatively a schematic diagram of the experimental apparatus in heating mode. In heating mode, it flow from the compressor to the air conditioner, the expansion valve and the borehole, a four-way valve and back to the compressor. The experiment apparatus was basically composed of a compressor, ground heat exchanger, an expansion valve and an air conditioner. A fin-type heat exchanger of air-source type air conditioner is replaced to a borehole-type ground heat exchanger.

The size of a borehole is 105.3 mm in diameter and 30m in depth. In the borehole, heat transfer tube is surrounded by water. In addition, outside of the borehole is covered with silica sand. R410A is worked as a refrigerant and oil was mixed to prevent from burning of compressor. In cooling mode, R410A and oil mixture runs from the compressor to the borehole, the expansion valve, the four-way valve and the air conditioner and back to the compressor. Conversion from the cooling mode to the heating mode was conducted by the four-way valve. After air temperature at a room is pre-set at 27°C and 20°C in cooling and heating mode, respectively, the compressor is operated and the working fluid (R410A and oil) flows through the system.

Figure 2 show the underground heat exchanger. The air/refrigerant heat exchanger of a ready-made air conditioner was replaced by the underground heat exchanger. The heat transfer tube was inserted into the casing pipe. The heat transfer tube made of copper is basically 3/8 inch in tube diameter and is separated to five paths with 1/4 inch in tube diameter in the ground heat exchanger. Flow direction of refrigerants go into the five tubes and return from the one tube. At the
cooling mode, refrigerants go into vapor in the underground heat exchanger and become liquid with releasing condensation heat. At the heating mode, refrigerants go into liquid in the underground heat exchanger and become vapor with extracting heat.

Figure 3 shows major measuring points of temperature, pressure, and flow rate. A platinum resistance thermometer and a thermocouple were used to measure temperatures. The direct expansion method is one in which the refrigerant pipe from the heat pump is buried underground, allowing direct heat exchange with the earth. This method does not require heat exchange with antifreeze solution or a circulation pump, which helps simplify the design and save energy. It is also an efficient method owing to the heat collection in the earth directly through the refrigerant. However, practical application of this method has not been made possible due to the resistance of the pipes underground for collecting and radiating heat and the instabilities in the primary refrigerant circulation such as stagnation of lubricant in the lower part.

Performance of the GSHP system was evaluated by Coefficient of Performance (COP), which is defined as the ratio of heat exchange rate in air conditioner to consumption power of the compressor, namely.

\[
COP = \frac{\rho Av (h_{in} - h_{out})}{Wp} \quad (1)
\]

where \(\rho\) is density of air, \(A\) is duct area, \(v\) is wind speed, \(h_{in}\) and \(h_{out}\) is inlet and outlet enthalpy the indoor unit, \(Wp\) is power consumption of heat pump, respectively. Experimental conditions described above were arranged in Table 1.

<table>
<thead>
<tr>
<th>Table 1 Experimental condition</th>
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<tr>
<td><strong>Primary side</strong></td>
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<tr>
<td>Depth of borehole</td>
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<tr>
<td>Borehole diameter</td>
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<tr>
<td>Filed material</td>
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<tr>
<td>Refrigerant</td>
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<tr>
<td><strong>secondary side</strong></td>
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<tr>
<td>Power of indoor unit</td>
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<td>Air conditioning area</td>
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<td>Pre-set temperature</td>
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**RESULTS AND DISCUSSIONS**

**COOLING MODE**

Figure 5, 6, 7 and 8 show representative results on pressure and temperature (pre-set temperature 27°C). The experiment was continuously during 24 hours from 16 am on September 12, 2016 to 16 am on September 13, 2016.

Figure 5 shows the change in pressure at six locations in the primary side. The vertical axis is depth and horizontal axis is temperature. According to Figure 2, the temperature changes from stable along deeper layer than about 10m. The stable temperature is 18.4 °C in an average. In this connection, the average air temperature during one year is 14.7 °C at Kofu-city. The temperature under the ground becomes higher than that at Kofu-city.
and stabilized with a fluctuation amplitude of 2~3 °C. Both temperatures increased by 20 °C in 24 hours.

Figure 7 shows the performance evaluation summary. There was not large change in the output power, taking into account the relative enthalpy change between the air output and input, stabilized around 4 kW. COP decreased by 4, accompanying the rise in the borehole temperature starting however, the value was still high around 8.

Figure 8 shows that, we compared released heat with changing water temperature in borehole at 10m, 20m and 30m to research a characteristic of released heat to underground. If it is focused on temperature changing of borehole depth, it will be found that borehole temperature at 10m and 20m rises steeply with starting operation and the released heat raises the underground temperature of 20°C, on the other hand borehole temperature at 30m has constant value. At the cooling mode, refrigerants go into vapor in the heat transfer tube and become liquid with releasing condensation heat. We can’t confirm a state of refrigerants visually, but it infer from the changing temperature that Finish condensation process already, be able to exchange heat at 20m to 30m. However liquid refrigerants release only change of sensible heat at 30m and amount of heat exchange didn’t have much.

HEATING MODE

Figure 9, 10, 11 and 12 show representative results on pressure and temperature (pre-set temperature 20°C). The experiment was continuously during 24 hours from 14 pm on January 6, 2016 to 14 am on January 7, 2016.

Figure 9 shows the change in pressure at six locations in the primary system. The compressor output pressure increased to 2.6 MPa after the start of the operation and fluctuated between 1.8 and 2.3 MPa thereafter.

Figure 10 shows the temperature change at the six locations in the primary side corresponding to the pressure changes. After the start of the operation, the refrigerant temperature at compressor outlet fluctuated around 30°C - 50°C, incurring a load on the compressor.

Figure 11 shows the performance evaluation summary. On average over the operation period, COP ≒ 4.6, output power 2.7 kW, and consumed electric energy 0.6 kWh. The reason for the lower COP than in the refrigerating operation is likely that the underground heat exchanger acts as a vaporizer, and the liquid refrigerant became a resistance in the five outgoing thin pipes, which incurred a load on the compressor.

Figure 12 shows that we compared extracted heat with changing water temperature in borehole at 10m, 20m and 30m to research a characteristic of extracted heat from underground. If it is focused on temperature changing of
borehole depth, it will be found that the borehole temperature at 10m, 20m and 30m in each point decreases rapidly with starting operation and the extracted heat lowers the underground temperature of 10°C. Moreover, temperature decreased about amount of 10°C at 30m though not change in cooling mode. Temperature changes the whole borehole because of not finish vaporization process yet.

CONCLUSIONS
The experiment on the GSHP system using direct expansion method was carried out. The results are concluded as follows.

[1] Condition under ground is that invariable stratus temperature was 18.4°C and boreholes was 30m in depth.

[2] We did not observe the issues such as the resistance of the pipes underground for collecting and radiating heat and the instabilities in the primary refrigerant circulation such as stagnation of lubricant in the lower part. Therefore, operating of this GSHP using direct expansion method is possible.

[3] The COP value determined from the heat in the indoor equipment and the consumed power by the heat pump was COP ≈ 9.3 in a cooling mode with the secondary pre-set temperature 27°C, and COP ≈ 4.3 in a heating mode with the pre-set temperature 20°C.

[4] In the cooling mode, it was able to exchange enough heat with underground using one borehole of 30m depth because finish condensation process already, be able to exchange heat at 20m to 30m. In the heating mode, however, it was not enough extracted heat from underground. The reason that temperature changes the whole borehole because of not finish vaporization process yet.

[5] In order to enhance the performance of the ground source heat pump system using direct expansion method, the structure of underground heat exchanger should be improved.

NOMENCLATURE
\( \rho \) density of air
\( A \) duct area
\( v \) wind speed
\( h_{in} \) inlet enthalpy the indoor unit
\( h_{out} \) outlet enthalpy the indoor unit
\( WP \) power consumption of heat pump, respectively

REFERENCES