Experimental Research on Direct Expansion Ground Source Heat Pump System

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Abstract: Vertical closed-loop ground source heat pump systems (GSHP) have been installed widely in Korea since it can extract moderate temperature level of geothermal heat in a small area. As a ground heat exchanger, a vertical closed-loop type with brine circulation is mostly preferred since it is simple and less harmful to ground environment. However, it requires a secondary heat exchange loop between the refrigerant in a heat pump and the brine. By adding a geothermal heat exchanger in the secondary heat exchange loop, circulation pumps should be attached and the temperature difference between refrigerant and ground is increased, which are important parts of performance degradation. In this paper, performances of direct expansion (DX) geothermal heat pump were evaluated as an alternative of classical indirect geothermal heat pump.

Key Words: market challenges, technology challenges, technology competitiveness, technology integration

1 INTRODUCTION

Ground source heat pump (GSHP) has a benefit that it can extract a large amount of low temperature thermal energy in a relatively small area with ground loop heat exchanger (GLHX) in vertical configuration. Also the machine room of the system can be set up compactly by installing geothermal heat exchanger with connection to a ground heat exchanger where the ground loop is hidden. Since open-loop type is limited for the place where underground water exists, closed-loop type where circulating fluid resides inside ground loop is preferred.

In a typical GSHP system with closed-loop GLHXs, ethanol-water solution is used as brine in Korea. This anti-freezing fluid circulates in ground heat exchangers of high-density polyethylene (HDPE) pipes, which minimizes environmental damage in case of leakage. Since the secondary fluid circulates in HDPE GLHX to transfer heat, the system requires circulation pump which generally occupies 15% of the entire power consumption of GSHP system. (Kim et al., 2012) It also requires additional geothermal heat exchangers. So the total temperature difference between ground and refrigerant increases, which reduces the system efficiency.

This paper studied an alternative direct exchange (DX) GHX where refrigerant can exchange heat directly with ground. The DX is also mentioned as direct expansion in some articles. By annual performance evaluation, the performance enhancement of GSHPs with DX GLHX is compared with one with HDPE GLHX in this paper.

2 DIRECT EXCHANGE GSHP SYSTEM

Figure 1 shows the two GSHP systems with a typical HDPE GLHX (Fig. 1(a)) and a DX GLHX (Fig. 1(b)). As a first benefit of DX GSHP, the equipment configuration is simpler than a conventional HDPE GSHP. As seen in Fig. 1(b), DX GSHP has no need for a circulation pump and a geothermal heat exchanger (GHX) of a brine/refrigerant heat exchanger. By skipping the installation of the pump and the heat exchanger for the ground loop, about 15% of power consumption of the system can be reduced.

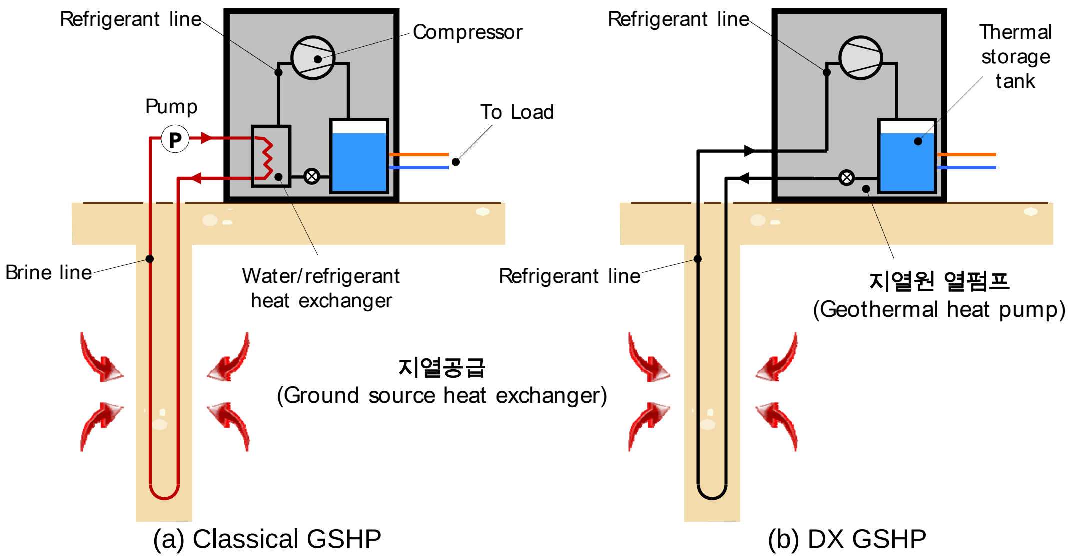

Figure 1: Comparison of a classical HDPE GSHP and a DX GSHP

Second, heat transfer of GLHX is enhanced on DX GSHP. Figure 2 shows HDPE pipe and copper tube, where the conductivity of copper tube is much higher than HDPE pipe. Also heat transfer resistance by low conductive grouting materials is reduced since DX coils can be installed in boreholes of 30% smaller diameter than the typical HDPE loop. Two-phase heat transfer of refrigerant inside GLHX will increase the total heat transfer as well.

Third, by direct exchange of heat, the DX GSHP can enhance the performance by reducing the temperature difference between ground and refrigerant. In the conventional GSHP, temperature level of ground circulating fluid is located between ground and refrigerant, which increases temperature difference heat source and heat sink. However, temperature difference between ground and refrigerant can be small by direct heat exchange. Thus, COP of the conventional GSHP will be lower than DX GSHP. Lastly, even though in a case of leakage in GLHX by a crack in ground loop, there is little impact on ground environment such as underwater contamination.

However, there are some disadvantages of DX GSHP system. Since refrigerant loop is extended to the ground, the amount of refrigerant charge is increased. Also due to longer pipeline of DX GLHX, pressure drop is increased which will increase compressor work which may reduce the third benefit mentioned above. Also since Cu tube are more corrosive than HDPE tube, special anti-corrosion system like CPS (cathodic protection system) is required.

Though there are several disadvantages above, researches on DX GSHP has been increased in several countries due to its potentials of performance enhancement and environmental benignancy.

2 EXPERIMENTAL SETUP

Figure 2 shows schematic diagram of DX GSHP system with a compressor, an expansion valve(EEV type), a load side heat exchanger(plate type), a 4-way valve, a geothermal heat exchanger and a storage tank. The system was designed to change its operating mode to the heating or the cooling mode by changing internal valves which alter the flow direction of refrigerant. Six borehole DX type GLHXs were installed symmetric hexagonal architecture, which ensures flow distribution. Details of specifications are as follows table 1.

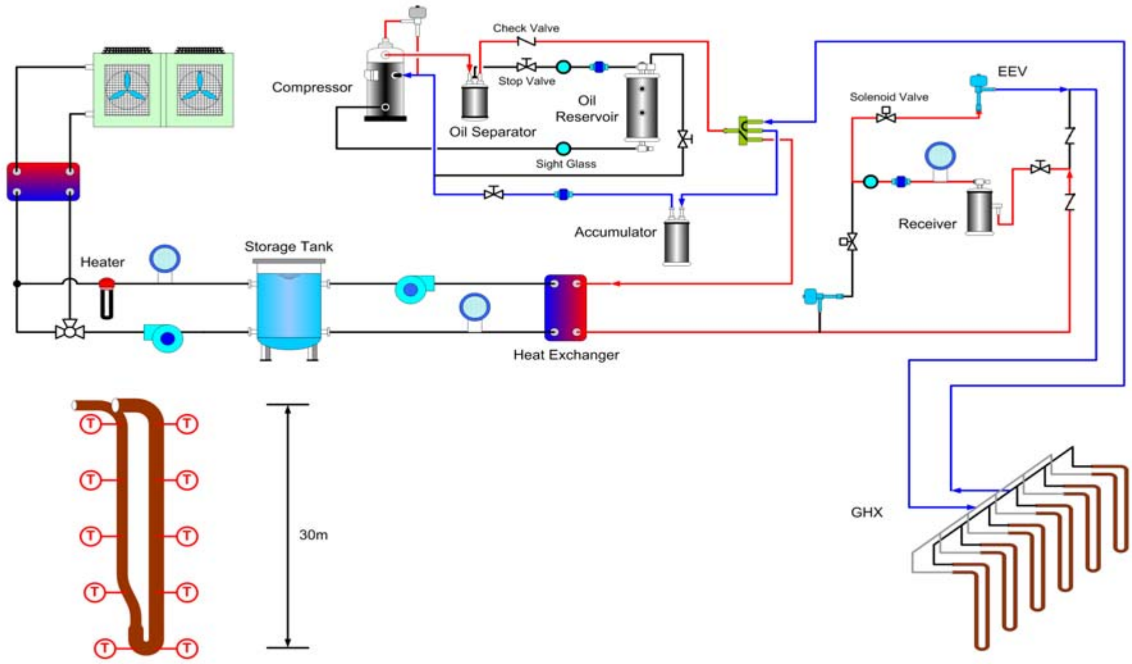

Figure 1: Schematic diagram of DX system

Table 1: Specifications of DX system

Components	Specifications	Values
Ground heat exchanger	Vertical length	30 m
	Horizontal length	15 m
	Diameter	0.635 to 1.27 cm
	Number	6 EA
Compressor	Type	Scroll
	Nominal capacity	10.5 kW_{th}
	Electricity input	380V 60Hz 3PH
Expansion valve	Type	EEV
	Power	DC 24 V
Load side heat exchanger	Type	Plate
	Capacity	116.3 kW_{th}
	Max. pressure	180 kg/㎠
	Temperature	-160 to 185℃

The entire system with the DX GSHP was tested using heat storage tank and chilled water systems. Pressures, temperatures, and secondary fluid flow rates of refrigerants were measured. Power consumptions by the compressor and pumps were measured. Pressure transducers have a measurement range from 0 to 3.4 MPa. T-type thermocouples with a measurement range from -200 to 200°C were used. The flow rate is measured with the electromagnetic flow meter. Its measuring range is 0 to 20 m^3/h. The uncertainty of the water flow rate is 0.5%. Consumption power is measured using digital power meter, basic accuracy is 0.1%.

3 EXPERIMENTAL CONDITION

Performance of DX GSHP was tested based on the KS B ISO 13256-2. But ground source side condition is not set as the standard since we cannot control the ground condition arbitrarily. Details of performance test conditions are as follows Table 2 and Table 3. Since the ground condition is also unsteady state with the ground temperature variation, est results of DX GSHP system used average data during 30 minutes within the fixed load side temperature.

Table 2: Comparisons of heating test conditions

	Water-loop heat pump	DX heat pump
Liquid entering indoor side	40℃	40℃
Air surrounding unit, dry bulb	15 to 30℃	15 to 30℃
<u>Standard rating test</u> Liquid entering heat exchanger	20℃	Ground temperature
<u>Part-load rating test</u> Liquid entering heat exchanger	20℃	Ground temperature

Table 3: Comparisons of cooling test conditions

	Water-loop heat pump	DX heat pump
Liquid entering indoor side	12℃	12℃
Air surrounding unit, dry bulb	15 to 30℃	15 to 30℃
<u>Standard rating test</u> Liquid entering heat exchanger	30℃	Ground temperature
<u>Part-load rating test</u> Liquid entering heat exchanger	30℃	Ground temperature

To compare the performance of a DX GSHP and a classical GSHP with HDPE pipes case, the influence of ground circulation pump for a classical GSHP was considered. Minimum performance standards of the classical GSHP are 4.31 W/W at cooling mode, 3.62 W/W at heating mode. Where, system COP was calculated on the basis of the circulation pump of calculated in this study (0.2 kW) as follows Figure 3. COP is expected to increase about 7.5% at cooling mode, 6.4% at heating mode.

$$COP_{sys} = \frac{Q_{tot}}{W_{comp} + W_{PL}} \quad (1)$$

Where, Q_{tot} is total capacity of DX GHP system, and it assumed about 10.5 kW_{th}. W_{comp} and W_{PL} presents compressor work and circulation pump load, respectively. For DX GSHP, W_{PL} should be zero. For a classical GSHP, W_{PL} is regulated to have less than 13% of the total power consumption in Korea.

4 EXPERIENTAL RESULTS

The amount of refrigerant charge of DX GSHP is estimated. Entering water temperature to load side set to 40°C, and then, measured data used during 30 minutes after steady state at storage tank. According to Figure 4, the optimum charge of the system was estimated about

6 kg. The charge test could not go over this value since the system experiences liquid flood entering the compressor.

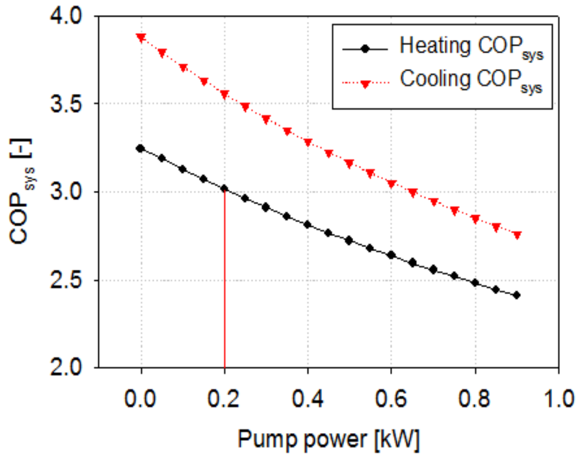

Figure 3: System COP with pump power

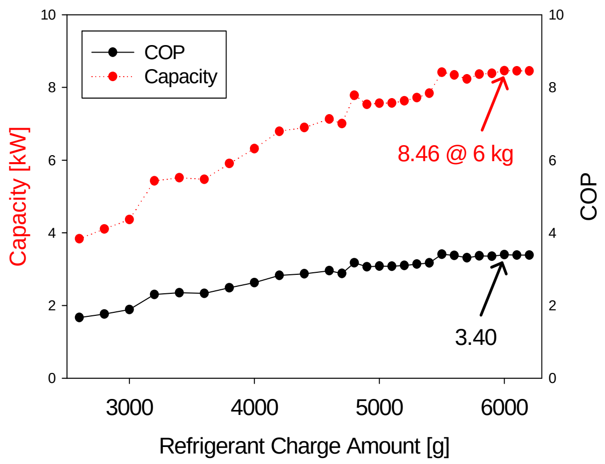

Figure 4: Capacity with refrigerant charge amount

The heating and cooling experimental result of the DX GSHP system were shown in Figure 5 and Figure 6, respectively. From the pressure(P)-enthalpy(h) diagrams, there are little pressure drop at load side heat exchangers, condenser for heating and evaporator for cooling. However, DX GLHX has pressure drop about 400 to 500 kPa because of the length of DX GLHX. From the heating experiment, heating capacity is 8.4 kW and COP is 3.25 at condition of table 1. From the cooling experiment, cooling capacity is 8.6 kW and COP is 3.88 at condition of table 2.

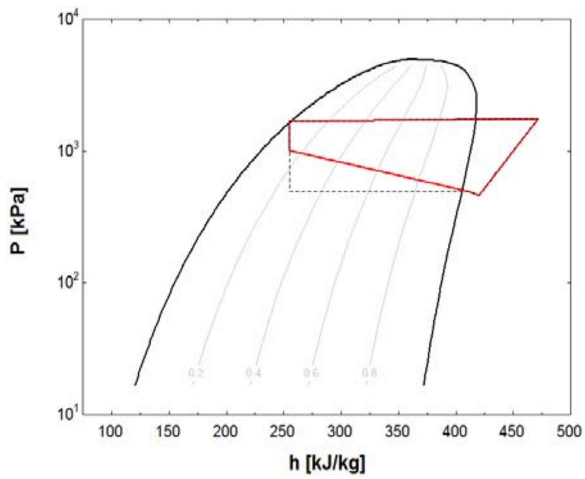

Figure 5: Heating cycle of DX system

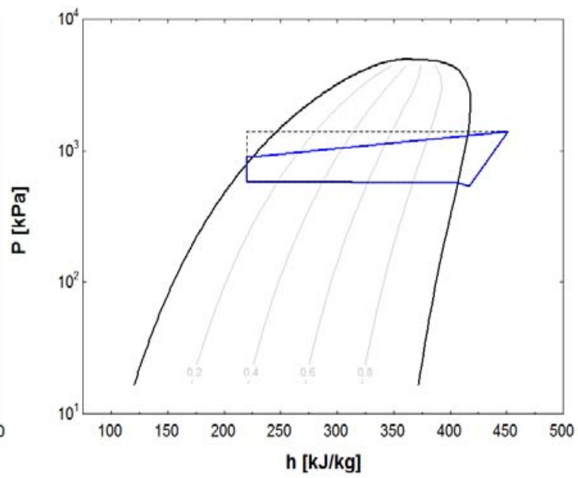

Figure 6: Cooling cycle of DX system

5 CONCLUSION

DX GSHP system were tested preliminarily to check its performance and field applicability. Since DX GSHP has no ground water circulation pump, it has a benefit compared to a classical GSHP. From the experiments, heating capacity was 8.4 kW, heating COP was 3.25, cooling capacity was 8.6 kW, cooling COP was 3.88. From the results, design of the GLHX to reduce refrigerant side pressure drop is a key parameter to enhance the performance of DX GSHP.

6 ACKNOWLEGEMENT

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