Journal of Southeast University (English Edition) Vol. 26, No. 2, pp. 209 - 211 June 2010 ISSN 1003—7985

Performance analysis of U-vertical direct-expansion ground-source heat pump

Yang Wei Zhou Jin Zhang Guoqiang

(College of Civil Engineering, Hunan University, Changsha 410082, China)

Abstract: The performance of a direct-expansion ground-source heat pump (DX GSHP) system is theoretically analyzed. Compared with the conventional ground-source heat pump (GSHP), the DX GSHP has a lower condensing temperature in the cooling mode and a higher evaporating temperature in the heating mode, and the ground heat exchanger (GHE) in the DX GSHP has a low thermal resistance. Therefore, the coefficient of performance (COP) of the DX GSHP is higher than that of the GSHP. In addition, the system performance of the DX GSHP system is higher than that of the conventional GSHP system because there are no secondary solution loops and water circulating pumps in the DX GSHP system. The experimental energy performance of the DX GSHP system is also investigated based on the actual operational data. The tested DX GSHP system is installed in Xiangtan, China. The U-vertical GHE of the DX GSHP is buried in a water well. The length and the outside nominal diameter of the GHE are 42 m and 12. 7 mm, respectively. The experimental results show that the maximum (COP) and the average COP of the DX GSHP system in the heating mode are 5. 95 and 4. 72, respectively.

Key words: direct-expansion ground-source heat pump; energy consumption analysis; performance

As a renewable energy technology, the ground-source heat pump (GSHP) technology has received much attention from the international community for its advantages of energy-efficiency and environmentally cleanliness in recent years. And the GSHP systems have already been widely used in developed countries. By 2005, the installed capacity in the world had reached 15 384 MWt and the energy use had reached 87 503 TJ/year. Most of the GSHP systems were installed in North America and Europe. Meanwhile, the installed capacity in China was up to 631 MWt and the energy use was up to 6 569 TJ/year [1-3].

A direct-expansion ground-source heat pump (DX GSHP) is a type of ground-source heat pump. In the DX GSHP, a refrigerant is circulated through a buried copper piping network. Compared with the conventional GSHPs, the DX GSHP without secondary solution loops and water circulating pumps is more efficient and energy saving. Besides, it is well known that the coefficient of heat conductivity of copper is much greater than that of thermoplastic piping networks such as PE pipes.

Received 2009-11-17.

Biographies: Yang Wei (1981—), male, graduate; Zhou Jin (corresponding author), male, doctor, associate professor, zhoujin_y@263.net.

Foundation item: The National Key Technologies R&D Program of China during the 11th Five-Year Plan Period (No. 2006BAJ04B04, 2006BAJ04A05, 2006BAJ04A13).

Citation: Yang Wei, Zhou Jin, Zhang Guoqiang. Performance analysis of U-vertical direct-expansion ground-source heat pump[J]. Journal of Southeast University (English Edition), 2010, 26(2): 209 - 211.

There are numerous studies on the energy analysis of GSHP systems[4-11]. But few papers focus on the energy analysis of DX GSHP systems. Thus, it is of necessity to evaluate the performance of the DX GSHP systems. The analysis results are helpful for realizing the energy efficiency of the DX GSHP systems and promoting the application.

1 System Description

1.1 Experimental setup

The outside view of the DX GSHP system constructed in 2007 is shown in Fig. 1. The main characteristics of the elements are listed in Tab. 1, where the numbers in parentheses correspond to the elements depicted in Fig. 2. Conversion from a heating cycle to a cooling cycle can be obtained by a four-way valve.

Fig. 1 Outside view of experimental setup

Tab. 1 Main characteristics of elements of DX GSHP system

Element	Technical specification
Compressor(Ⅰ)	Model: 2KC-05. 2
Oil extractor(Ⅱ)	Model: A-W55824
Double-pipe heat exchanger(Ⅲ)	Inner copper pipe: outside nominal diameter of 12. 7 mm, length of 11. 5 m; Outer plastic hose: inside nominal diameter of 15mm, length of 11. 5m
Throttling valve(Ⅳ)	Model: BAE 1-1/2 HCA5FT1/ 2 × 5/80DF S/T
Geothermal heat exchanger(Ⅴ)	Length: 42 m; Outside nominal diameter: 12. 7 mm; Type: U-vertical ground heat exchanger; Material: copper
Four way valve(Ⅵ)	Model: B3-014

Note: The double-pipe heat exchanger acts as a condenser in the heating mode and as an evaporator in the cooling mode.

A refrigerant circuit is built on closed loop copper tubing and the working fluid is R-22. The compressor discharges the refrigerant into a desuperheater, which is used as a plate heat exchanger in this study. During the test, the desuper-

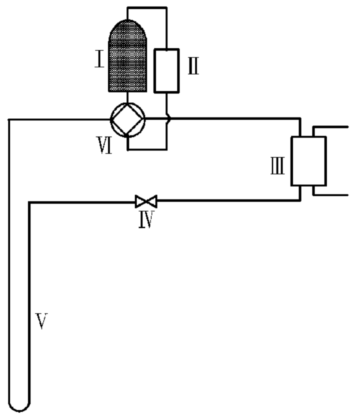

Fig. 2 Schematic diagram of DX GSHP system

heater is not put into operation.

1.2 Measurement system

A data acquisition network is designed to characterize the system performance. For this purpose, several sensors are set up to monitor the most relevant parameters of the system. Various data are regularly recorded for one period of operation as follows:

1) The temperatures are tested by using three-wire platinum resistance thermometers (Pt100) with an accuracy of ±0.3 ℃.

2) The water flow rates are measured by using a container of 1.5 L and a stopwatch.

3) The pressures of the refrigeration system are tested by using pressure sensors with an accuracy of less than 0.5%.

4) The electrical power inputs to the compressor and the circulating pump are measured by using a wattmeter with an accuracy of ±0.5% of the nominal value.

Except for the water flow rates, all the data mentioned above are monitored and controlled by a data-acquisition system. These data are recorded at one-minute intervals by a data logger. To deal with a large number of the experimental data, a custom software package is developed to automatically perform necessary database matching and statistical analysis.

2 Analysis

The coefficient of performance (COP) of the GSHP unit (COP_1) can be calculated by

$$COP_1 = \frac{Q_{cond}}{W_{comp}} \tag{1}$$

where Q_{cond} is the heat transfer rate from the indoor units; W_{comp} is the power consumption rate of the compressor. In this study, we define a new COP to evaluate the cooling performance of the overall system including the heat pumps, the water circulating pumps and the fans in the outdoor and indoor units. Thus, the coefficient of performance of the whole HP system (COP_2) can be calculated by

$$COP_2 = \frac{Q_{cond}}{W_{comp} + W_{pump}} \tag{2}$$

where W_{pump} is the power consumption rate of the water circulating pumps. Q_{cond} can be calculated by

$$Q_{cond} = m_w c_w \left| T_i - T_o \right| \tag{3}$$

where m_w is the mass flow rate of water; c_w is the specific heat capacity of water; T_i and T_o are the inlet and outlet water temperatures, respectively.

Because there are no secondary solution loops and water circulating pumps in the DX GSHP system, the energy efficiency of the HP unit is equal to that of the whole HP system. And this is an important reason for the high system performance of the DX GSHP system.

Generally, the cycle efficiency of a heat pump system is strongly affected by the condensing temperature in the cooling mode. In other words, with the decrease of the condensing temperature, the heat pump system becomes more efficient because it consumes less power. Without secondary solution loops, the condensing temperature of the DX GSHP system is about 5 ℃ lower than that of the conventional GSHP system. Fig. 3 describes the simplified pressure-enthalpy diagram of the cycles for the comparison of the conventional GSHP system and the DX GSHP system. It can be seen that compared with the conventional GSHP system, the DX GSHP system spends less power because the temperature of the condenser is much lower. On the other hand, the evaporating temperature of the DX GSHP system is higher than that of the conventional GSHP system in the heating mode. All of these indicate that the DX GSHP system has a better performance than the conventional GSHP system.

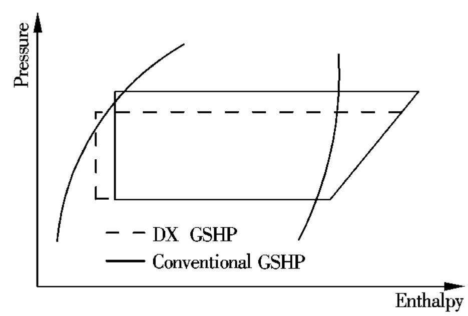

Fig. 3 Simplified pressure-enthalpy diagram of coventional GSHP and DX GSHP systems in cooling mode

3 Case Study

The tests were conducted on the DX GSHP system under steady-state conditions in the heating mode on July 24th, 2008. The daily average values of nine measurements from 13:05 to 24:00 with a time interval of one minute are listed in Tab. 2.

Tab. 2 Experimental results of the system

Parameter	Nominal value
Condensation pressure/MPa	1.945
Condensing temperature/℃	50.1
Evaporating temperature/℃	[4.8, 13.5]
Evaporation pressure/MPa	[5.80, 7.55]
Temperature of GHE inlet/℃	13.53
Temperature of GHE outlet/℃	8.4
Pressure of GHE inlet/MPa	0.755
Pressure of GHE outlet/MPa	0.580
Current of compressor/A	2.05
Inlet water temperature/℃	30.0
Outlet water temperature/℃	46.9
Mass flow rate of water/($kg \cdot s^{-1}$)	0.052

Based on Eqs. (1) to (3) and the measured data from the experiments, the average coefficient of performance of the DX GSHP system in the heating mode is calculated to be 4.72 during the testing period. The highest value reaches 5.95, which is relatively higher than that of the conventional GSHP system.

4 Conclusions

The theoretical and experimental energy analyses of the DX GSHP system are presented in this paper. The following conclusions can be drawn out:

1) Because there are no secondary solution loops and water circulating pumps in the DX GSHP system, the energy efficiency of the HP unit is equal to the whole HP system. This is an important reason for the high system performance of the DX GSHP system.

2) In the cooling (heating) mode, the condensing (evaporating) temperature of the DX GSHP system is lower (higher) than that of the conventional GSHP system, indicating that the DX GSHP system has a better performance than the conventional GSHP system.

3) The average coefficient of the performance of the DX GSHP system in the heating mode is 4.72 during the testing period. The highest value reaches 5.95, which is relatively higher than that of the conventional GSHP system.

References

[1] Lunda J W, Freeston D H, Boyd, T L. Direct application of geothermal energy: 2005 worldwide review [J]. *Geothermics*, 2005, **34**(6): 691 − 727.

[2] Zheng K Y, Zhang Z G, Zhu H Z, et al. Process and prospects of industrialized development of geothermal resources in China—country update report for 2000—2004 [C]//*Proceedings of World Geothermal Congress*. Antalya, Turkey, 2005: 1 − 10.

[3] Hepbasli A, Akdemir O, Hancioglu E. Experimental study of a closed loop vertical ground source heat pump system [J]. *Energy Conversion and Management*, 2003, **44** (4): 527 − 548.

[4] Yang W, Zhou J, Xu W, et al. Current status of ground-source heat pumps in China [J]. *Energy Policy*, 2010, **38**(1): 323 − 332.

[5] Arif H M, Tolga B. A study on modeling and performance assessment of a heat pump system for utilizing low temperature geothermal resources in buildings [J]. *Building and Environment*, 2007, **42**(10): 3747 − 3756.

[6] Urchueguía J F, Zacarés M, Corberán J M, et al. Comparison between the energy performance of a ground coupled water to water heat pump system and an air to water heat pump system for heating and cooling in typical conditions of the European Mediterranean coast [J]. *Energy Conversion and Management*, 2008, **49**(10): 2917 − 2923.

[7] Onder O, Arif H. Experimental performance analysis of a solar assisted ground-source heat pump greenhouse heating system [J]. *Energy and Buildings*, 2005, **37**(1): 101 − 110.

[8] Michopoulos A, Bozis D, Kikidis P, et al. Three-year operation experience of a ground source heat pump system in Northern Greece [J]. *Energy and Buildings*, 2007, **39**(3): 328 − 334.

[9] Onder O, Arif H. Modeling and performance evaluation of ground source (geothermal) heat pump systems [J]. *Energy and Buildings*, 2007, **39**(1): 66 − 75.

[10] Hwang Y J, Lee J K, Jeong Y M, et al. Cooling performance of a vertical ground-coupled heat pump system installed in a school building [J]. *Renewable Energy*, 2008, **34** (3): 578 − 582.

[11] Kuang Y H, Wang R Z. Performance of a multi-functional direct-expansion solar assisted heat pump system[J]. *Solar Energy*, 2006, **80**(7): 795 − 803.

U 形垂直埋管直接膨胀式地源热泵的性能分析

杨 伟 周 晋 张国强

(湖南大学土木工程学院,长沙 410082)

摘要:首先,对直接膨胀式地源热泵的性能进行了理论分析. 与常规地源热泵相比,直接膨胀式地源热泵的地埋管换热器热阻更小,在制冷工况下具有更低的冷凝温度,在制热工况下具有更高的蒸发温度,因此它具有更高的性能系数. 直接膨胀式地源热泵系统无需二次换热回路和循环水泵,因此具有更高的系统性能系数. 然后,根据实测数据对直接膨胀式地源热泵实验系统的性能进行了分析. 该实验系统建立在中国湘潭,其 U 形垂直地埋管换热器置于水井之中,地埋管换热器的长度为 42 m,外径为 12.7 mm. 测试结果表明,在制热工况下此直接膨胀式地源热泵系统的性能系数最大值为 5.95,平均值为 4.72.

关键词:直接膨胀式地源热泵;能耗分析;性能

中图分类号:TU831.3