HEAT EXCHANGE PERFORMANCE OF GROUND SOURCE HEAT PUMP BY WATER COOLING METHOD

T.Endo, S.Ishiguro, T.Takeda and S.Funatani
Department of Mechanical Engineering
University of Yamanashi,
4-3-11 Takeda, Kofu, Yamanashi, 400-8511,
Japan,
E-mail: g15mm009@yamanashi.ac.jp

ABSTRACT

Ground source heat pump (GSHP) is one of saving energy systems for air conditioning. However, the GSHP is not popular in Japan because an initial cost of the GSHP is higher than an air source heat pump. This paper describes the thermal performance of the GSHP using water cooled method. This system consists of commercialized water cooling heat pump which removed a cooling tower and then attached a heat exchanger. Ground water penetrates under 6 m in depth and there is natural flow of ground water. This system exchanges the heat between ground water and the circulating water in the heat exchanger. This system uses existing two wells. One is 40 m in depth and it is used as borehole. That is expected to save the digging cost of bore hole. A casing pipe whose surface was punched like slit was inserted in the borehole. Heat exchanger is in the casing pipe. The space between the casing pipe and the borehole was filled with silica sand which was performed as filler. The other well is 30 m in depth. Well pump is in the well. The pumping head is in the wall at 24 m. The pump feeds water into 38 m point of the borehole. This pump is used to recover the temperature of underground by feeding water. The proposed system is evaluated by coefficient of performance (COP) of this system. COP is used commonly as index of the performance of GSHP.

INTRODUCTION

Ground source energy as renewable energy attracts attention. By the influence of geothermal energy, temperature of the underground more than 10m depth will be constant throughout the year. 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. Ground source heat pump (GSHP) system is attracting an attention as one applications of ground source. A conventional GSHP uses a closed loop and vertical borehole system. In general, the performance of a heat pump system is described by its coefficient of performance. The GSHP system is one of saving energy systems for air conditioning. It also reduces the emission of carbon dioxide and prevent heat island phenomenon. The GSHP system is already popular in U.S., Europe and China but it is not known in Japan yet. It is because the initial cost of the GSHP is more expensive than the air source heat pump. The primary reason is high initial cost of digging bore hole and of an outdoor unit. Requisite length of bore hole is 100 m to 150 m typically. If we shorten the length of bore hole, we can cut down initial cost of GSHP system materially. This paper describes the experimental result obtained by using the established wells as bore hole and the water cooling of GSHP whose initial cost is lower than the conventional GSHP system.

EXPERIMENTAL APPARATUS

Figure 1 shows the outline figure of experimental apparatus. This system consists of commercialized water cooling heat pump which removed a cooling tower and then attached a heat exchanger. This system can be vouched by a maker because this system is not modified part of control. The cooling and heating power of water cooling heat pump is 22.4kW in cooling and 25kW in heating. Ground water penetrates under 6 m in depth and there is a natural flow of ground water. This system exchanges the heat between ground water and the circulating water in the heat exchanger. The water in the heat exchanger is circulated by Line pump. Its flow rate is controlled by inverter control. This system uses existing two wells. One is 40 m in depth and it is used as bore hole. That is expected to save the digging cost of bore hole. A casing pipe whose surface was punched like slit was inserted in the bore hole. The inner diameter and outer diameter of casing pipe is 204.7 and 216.3 mm. Heat exchanger is inserted in the casing pipe. The space between the casing pipe and the borehole was filled with silica sand which plays a role as filler. The other well is 30 m in depth. Well pump whose output power is 0.25 kW inserts in the well. There is the pumping head at 24 m in depth. The pump feeds water into 38 m point of the bore hole. This pump is used to recover the temperature of underground by feeding water. The well pump operates when the temperature of bore hole at 38 m point is lower than the setting temperature. The air condition area is 20 m^2 and 24 m^2. The cooling and heating power of indoor unit is 5.6 kW / unit and 6.3kW / unit establishes the air condition areas respectively.

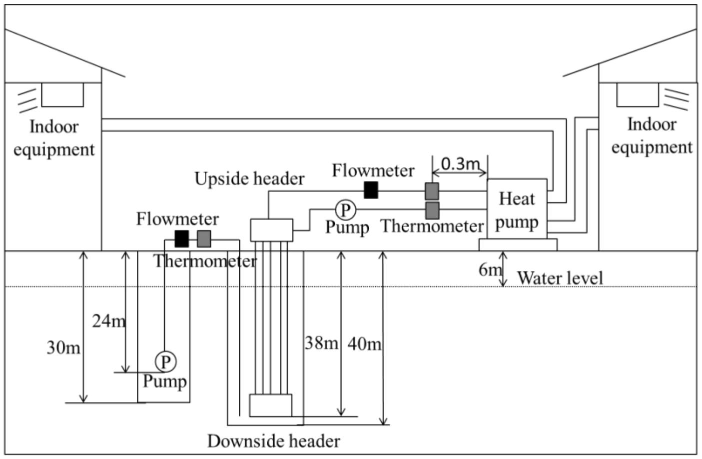

Figure 1 Outline of experimental apparatus

The heat exchanger consists of one pipe for downstream and four pipes for upstream. The header fits at upside and downside of the pipes. The water flows to upside header from downside in the one pipe and to downside header from upside header in the four pipes. The four pipes made of copper whose inner diameter is 21.6 mm and outer diameter is 27.2 mm and VP whose inner diameter is 41.6 mm and outer diameter is 48.6 mm. The pipes from upside header to 10 m in depth were made of copper and from there to downside header were made of vinyl chloride (VP pipe); because there is no ground water to 6 m in depth from ground. The length of the heat exchanger is 38 m. Thus, the length exchanging heat is 32 meter essentially. These pipes exchange the heat between ground and water. One pipe made of copper wrapped heat insulator in order to keep the exchanged heat.

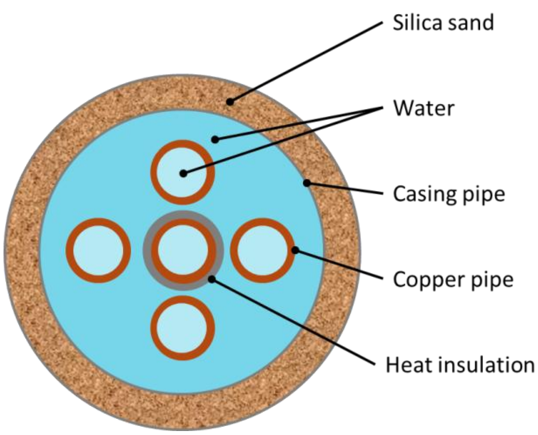

Figure 2 Sectional view of heat exchanger

PERFORMANCE EVALUATION

Coefficient of performance

The system is evaluated by coefficient of performance (COP) by Eq.(1).

$$\mathrm{COP} = \frac{\text{Heat gain}}{\text{Power consumption}} = \frac{c\rho q|t_{out} - t_{in}|}{W} \qquad (1)$$

ρ is density of water, q is flow rate of line pump, c is specific heat, t_{in} is inlet temperature of heat pump, t_{out} is outlet temperature of heat pump and W is Power consumption of compressor and line pump. COP was obtained by average of its instantaneous value every minute.

Cooling mode

The system had been operated from 9:00 to 18:00 (9 hours). Table1 shows set value of the indoor units, whether or not to pour ground water, the amount of pouring water, maximal heat gain, average heat gain and COP respectively. Figure 3, 4 and 5 show the temperature of the borehole (BH), inlet and outlet temperature of heat pump, heat gain and power consumption. In the case changing set value of the indoor units with pouring ground water, COP on August 14 and August 23 was almost the same because borehole recovered by pouring ground water. Temperature of pouring water was 12~13°C. Then, the temperature of borehole at 20 m and outlet temperature of heat pump increased to 27°C, 35°C respectively. Performance of the system is stable regardless of set value of the indoor units. Thus, COP doesn't independent set value of the indoor units. The higher set value of indoor units is, the more amount of pouring water increase. Therefore, when load to the system is large, COP is not influenced but the amount of pouring water increase. Power consumption of well pump is much lower than compressor and line pump. Thus, we can ignore power consumption of well pump when COP is obtained. If we can use pouring ground water positively, we think the length of borehole can be shortened. In the case without pouring ground water, COP on August 19 was almost the same as on August 14 and August 23. Then, the temperature of bore hole at 20 m and inlet temperature of heat pump are increased to 31°C and 41°C. Temperature of BH at 40 m was higher than at 20 m according to Figure 5. Thus, heat exchange was actioned at higher position than lower position. Figure 6 shows temperature of underground in 24hours on August 14. Temperature of BH at 20 m, 30 m and 40 m are 11°C, 13°C and 14°C respectively before the system operated. After the system operated, BH at 20 m, 30 m and 40 m are 11°C, 13°C, 13°C. In the case the system operate without pouring ground water, temperature of underground recover satisfyingly until next operating. The system can operate without pouring ground water in the cooling mode. Figure 7 shows the case that ground water inject point was changed to 20 m in depth. Set value of the indoor units was 27°C and COP was 3.2. Temperature of BH at 20 m vibrates up and down many times. Temperature of BH at 40 m is stable. Inlet and outlet temperature of heat pump hardly change. Reason is heat exchange is actioned at higher position than lower position in cooling mode. In the case ground water inject point was changed, COP wasn't influenced. However ground water was poured frequently.

Table 1 Experimental condition and result

Date	August 14,2015	August 23, 2015	August 19, 2015
Set value of the indoor units [°C]	20	27	27
Whether or not to pour ground water	Pouring water	Pouring water	Not pouring water
The amount of pouring water[L]	1.3×10^4	8.3×10^3	0
Maximal heat gain[kW]	24.3	23.3	23.6
Average heat gain[kW]	21.2	15.7	16.8
COP	3.3	3.1	3.2

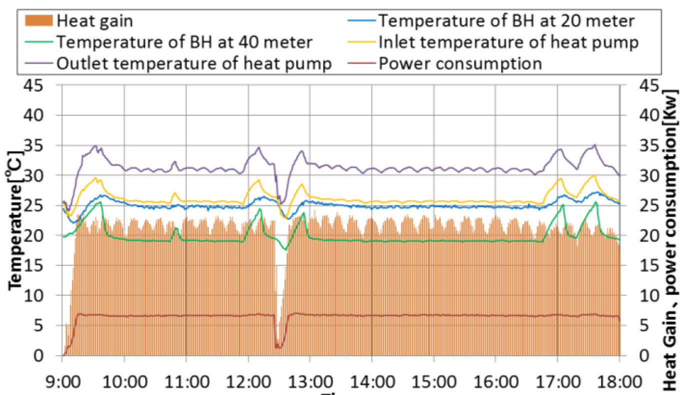

Figure 3 Performance of GSHP on August 14, 2015

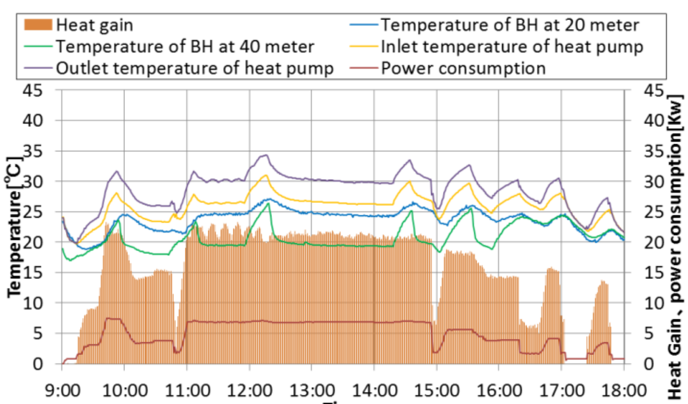

Figure 4 Performance of GSHP on August 23, 2015

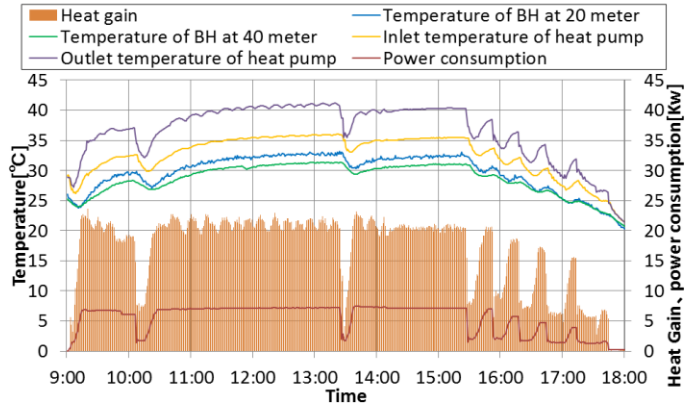

Figure 5 Performance of GSHP on August 19, 2015

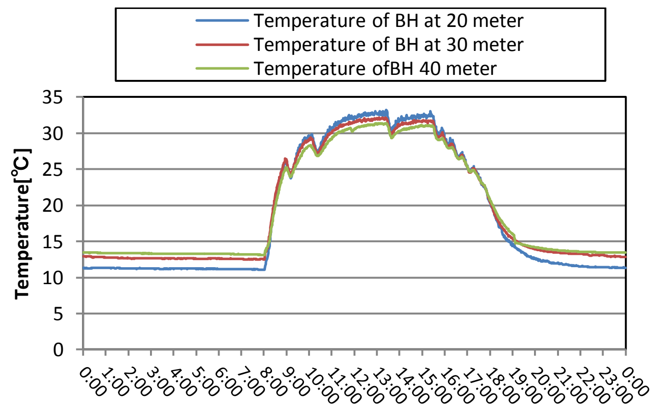

Figure 6 Temperature of underground on August 19

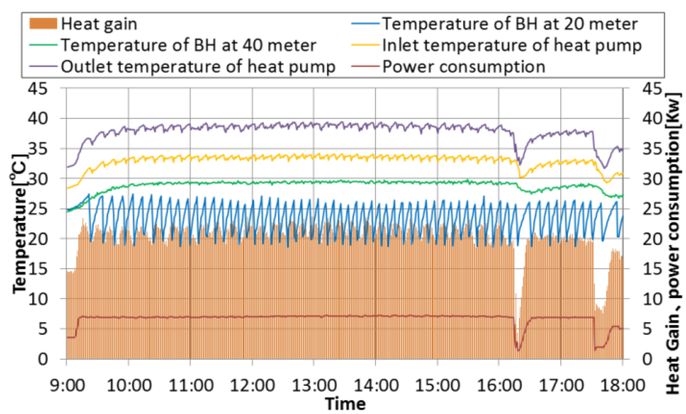

Figure 7 Performance of GSHP on July 13, 2015

Heating mode

The system operated from 22:00 to 5:00 (7 hours). Table 2 shows set value of the indoor units, whether or not to pour ground water, the amount of pouring water, maximal heat gain and COP respectively. Figure 8, 9 and 10 shows the temperature of the borehole (BH), the water in the heat exchanger inlet and outlet of heat pump, heat gain and power consumption. Diagonal of COP on December 12 mean that the system stopped. Operating time was 5 hours 12 minutes. When outlet temperature of the heat pump fall to 5°C, the system stop in order to prevent the water in the heat exchanger from freezing. Thus, this system couldn't operate without pouring ground water. COP on December 22 and February 5 were almost the same. Heat gain and power consumption ware constant also. In the case with pouring ground water, the system exchange heat satisfyingly and COP doesn't come down regardless of set value of the indoor units. Temperature of pouring water is 17~18°C. Temperature of BH at 40 m was faller than at 20 m in all results. Thus, heat exchange was actioned actively at higher position than lower position in the borehole. Figure11 shows the case ground water inject point was changed at BH 20 m. Set value of the indoor units was 20°C.and COP was 2.7. Temperature of BH at 40 m vibrates up and down many times. Temperature of BH at 20 m is stable. Inlet and outlet temperature of heat pump hardly change. It is because that heat exchange is actioned at lower position than higher position in heating mode. When temperature of BH at 20 m was fallen, heat gain was also fallen because inlet and outlet temperature didn't recover. In this case, ground water inject point was at BH 20 m, the whole borehole can't recover by pouring ground water. Therefore, the system couldn't exchange heat satisfyingly in this case.

Table 2 Experimental condition and result

Date	December 12, 2014	February 5, 2015	December 22,2015
Set value of the indoor units [°C]	20	20	28
Whether or not to pour ground water	Not pouring water	Pouring water	Pouring water
The amount of pouring water[L]	0	2.7×10^3	1.1×10^4
Maximal heat gain[kW]	13	14.8	14.4
Average heat gain[kW]	7.1	9.8	9.7
COP		2.6	2.5

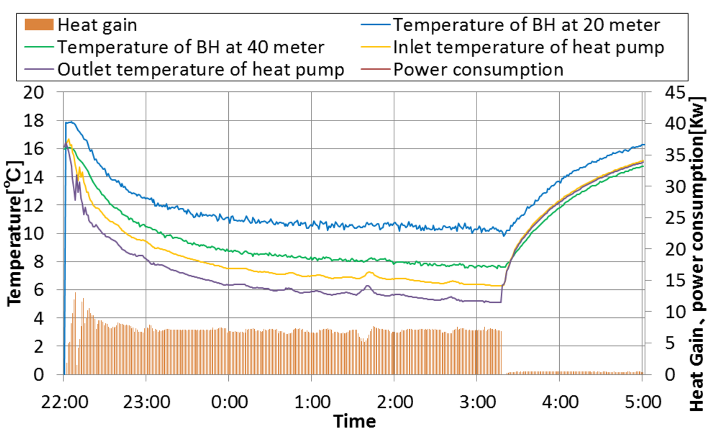

Figure 8 Performance of GSHP on December 12, 2014

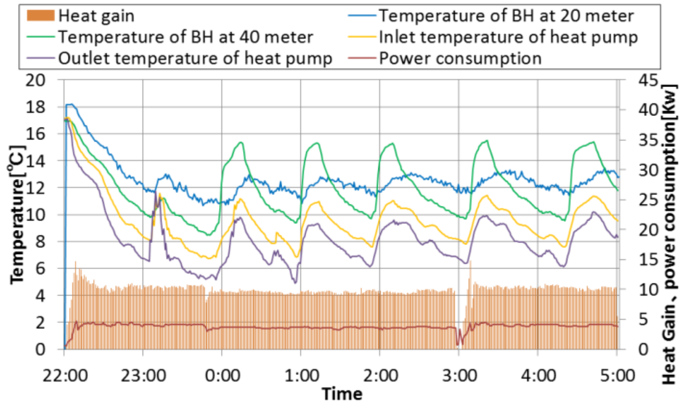

Figure 9 Performance of GSHP on February 5, 2016

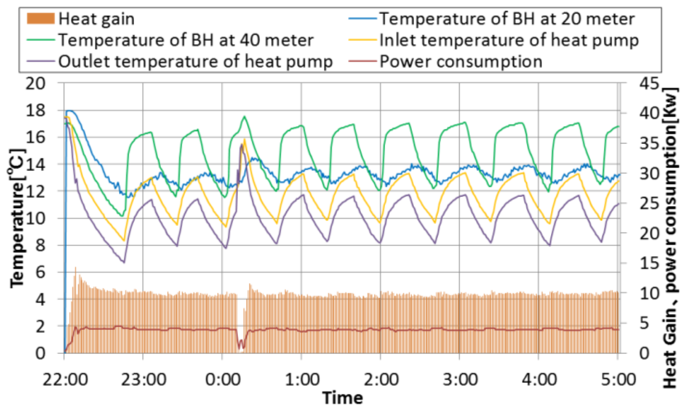

Figure 10 Performance of GSHP on December 22, 2015

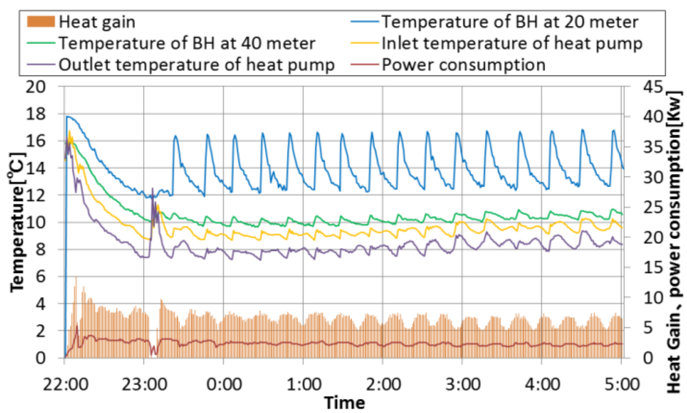

Figure 11 Performance of GSHP on December 7, 2014

CONCLUSION

The experimental results can be summarized as follows.

1. The system can exchange heat sufficiently without pouring ground water in cooling mode.
2. The system can't operate without pouring ground water in heating mode. With poring ground water, the system can operate.
3. Heat exchange action actively at higher position than lower position in cooling mode, and at lower position than higher position in heating mode.

4. COP was 3.1~3.3 in cooling mode and 2.5~2.6 in heating mode.
5. Ground water inject point should be not at 20 m in depth but at 40 m in depth.

REFERENCES

1. T. Endo, S. Funatani, S. Ishiguro and T. Takeda, (2015) : "Heat Exchange Performance of Water Cooling Methods of Ground Source Heat Pump during Cooling and Heating Operation". The Japan society of mechanical engineers annual convention in 2015, Hokkaido, Japan, NO.G0800306
2. A. Ohashi, K. Tsuthumi, T. Takeda and S. Funatani, (2013):"Study on Heat Exchange Performance of GroundSource Heat pump System". Proc. of the 24rd International Symposium on Transport Phenomena, Yamaguchi, Japan, Nov.1-5, Paper No.34
3. Ground Source Heat Pump Association, http://www.gshp.org.uk/index.html