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# Studies on the Borehole Heat Exchanger Performance Enhanced by Ground Water Flow in a GSHP

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## ABSTRACT

The heat transfer rate (HTR) of BHE depends on the thermophysical parameters of the ground, and the ranges of HTR can be different based on ground water movement around the heat exchanger. It is generally known that the ground water flow over a certain velocity would increase the HTR even in closed loop BHE. The effect of ground water movement is critical for performance. This study was conducted to evaluate GSHP performance with a ground water flow condition associated with a complex BHE type. We installed a pilot GSHP system with closed loop type coupled with open loop type for three stories building having one BHE well, one injection well and one observation well. The BHE well is 200 mm diameter and installed with closed loop coupled with open loop. The hydraulic tests were conducted to measure the hydrogeologic parameters of the wells. HTR of the closed loop type GSHP were measured by two different pumping conditions associated with the control of ground water pumping and GSHP operation. From these tests we estimated the performance of the GSHP and conducted ground water temperature monitoring. The average circulation fluid temperature was converged at around 10 degrees Celsius during the test condition with ground water pumping during a specified heating load.

## 1. INTRODUCTION

Until recently GSHP with closed loop type BHE has been designed with no ground water movement condition in most cases. However, system performance highly depends on hydrogeologic conditions and BHE type (Nam and Ooka, 2010). Many types of borehole heat exchanger (BHE) have been developed in several countries according to the status of geologic and hydrological conditions. We installed a real scale pilot GSHP with unconventional type heat exchangers at a new building in South Korea. The BHE well with 150 m depth and the diameter is 200 mm. The inside between borehole wall and the pipes are not grouted and filled with groundwater and the casing is installed to the depth of 14 m. Two types of heat exchangers of closed loop and open loop are installed together in the BHE (Figure 1). The open loop type is doublet and the injection well having same depth is installed in the 10 m distance. The pilot system covers heating and cooling load of the 2nd and 3rd floor with 116 $m^2$ and 91 $m^2$ area respectively. The heat pump HP1 with the heating and cooling capacity of each 29 and 33 kW is connected at open loop and the heat pump HP2 has a capacity of 23 and 26 kW designed for the air-conditioning on the 2nd floor. The bedrock of the installation site is granite, and the ground thermal conductivity is measured as 3.2 W/mK by thermal response test. In the VDI 4640 (2010) the specific heat transfer rate for granite was suggested as 65-85 W/m for 1800 hours and 55-70 W/m for 2400 hours for only heating condition.

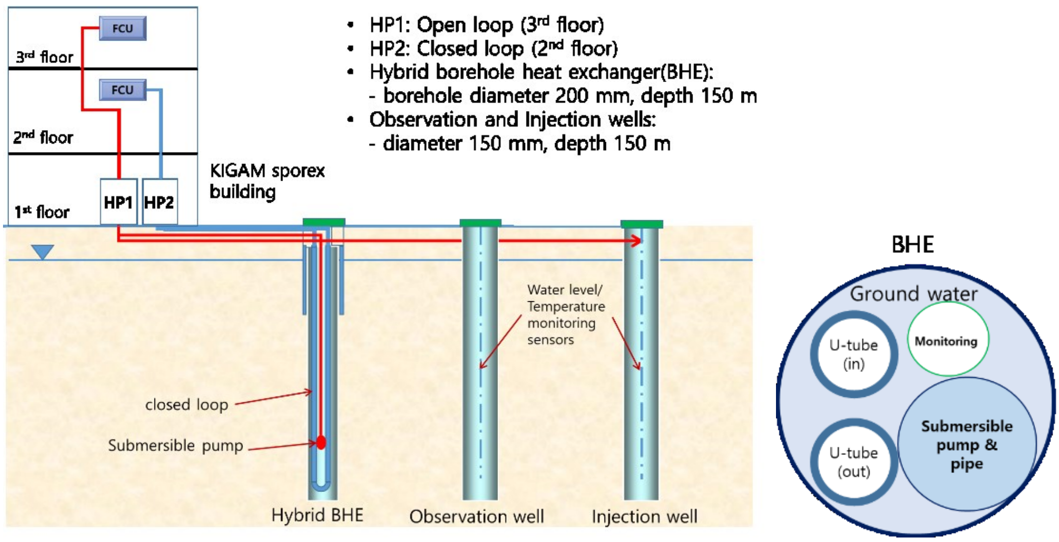


**Figure 1: This figure shows the schematic diagram of the pilot GSHP with a closed loop coupled with an open loop type above.**

## 2. METHOD

The heat transfer rate of BHE is highly dependent on the hydrogeologic condition of the ground, and then the BHE performance would be affected by ground water movement. To identify the effect hydrologic characteristics of the installation site were surveyed by several pumping and injection tests. During the 24 hours pumping with 100 $m^3$/day at the BHE well, the drawdown was 17.07m at the BHE (Table 1). The hydraulic conductivity is between $3.93\times10^{-4} \sim 1.65\times10^{-3}$ cm/sec, and storativity is ranged from $2.93 \times10^{-3}$ to $1.92 \times10^{-8}$ by the interpretation of well drawdowns. Even though the distance between BHE well and injection well is only about 10 m, but the obtained hydraulic conductivity shows significant differences.

**Table 1. Specification for the pumping test conducted for 24 hours and the drawdowns at the wells.**

| Well | Initial ground water level (GL.-m) | Drawdown(m) | Pumping rate (㎥/day) | Pumping time (hr) |
|---|---|---|---|---|
| BHE | 5.79 | 17.07 | 100 | 24 |
| Observation Well | 5.52 | 7.49 | | |
| Injection Well | 5.42 | 0.55 | | |

The heating operation was conducted with several scenarios caused by groundwater movement described at Figure 2 during the winter season from January to March in 2019. Each performance of the GSHP with 3 operation modes was analyzed. The performance was calculated from the monitored data of groundwater and circulation water temperature and consumed electricity at each part. The mode 1 is HP2 operation with closed loop only without any induced ground water movement. The mode 2 is for the case of mode 1 and the enhanced ground water movement by pumping at BHE well. And the mode 3 is for the case of closed loop and open loop heating operations simultaneously causing the ground water flow. The operation tests were conducted during several days at each mode and the performance data was obtained. The pumping rate of the submersible pump installed at 48 m deep in BHE is 93 l/m and the flow rate of the circulation fluid at closed loop is 51 l/m.

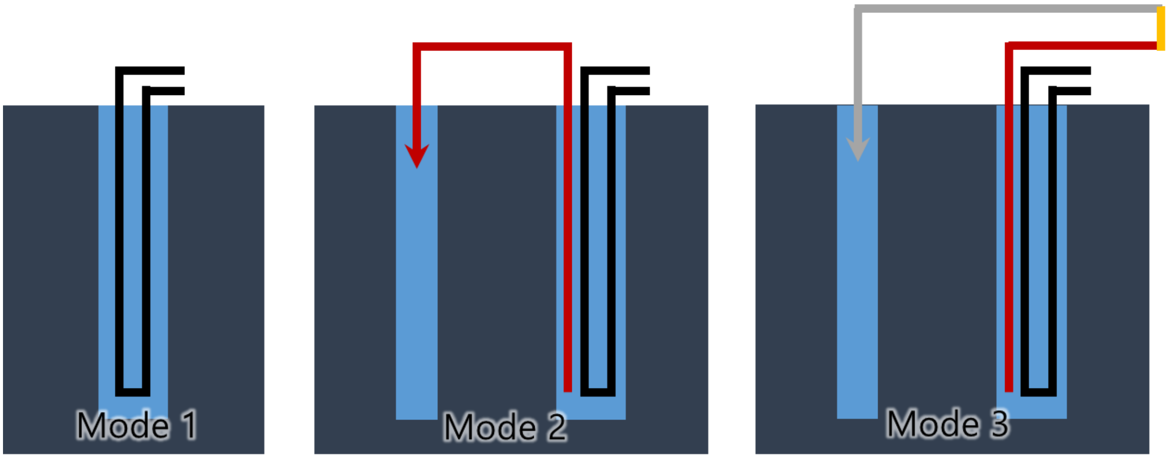


**Figure 2: The schematic diagram of the mechanics associated with the operation modes on the BHE.**

## 3. RESULTS

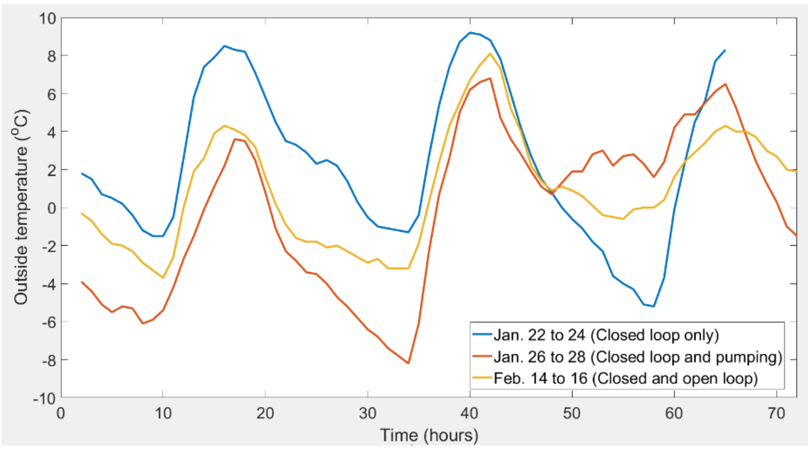


**Figure 3: Outside temperature variations during different test periods according to the operation modes**

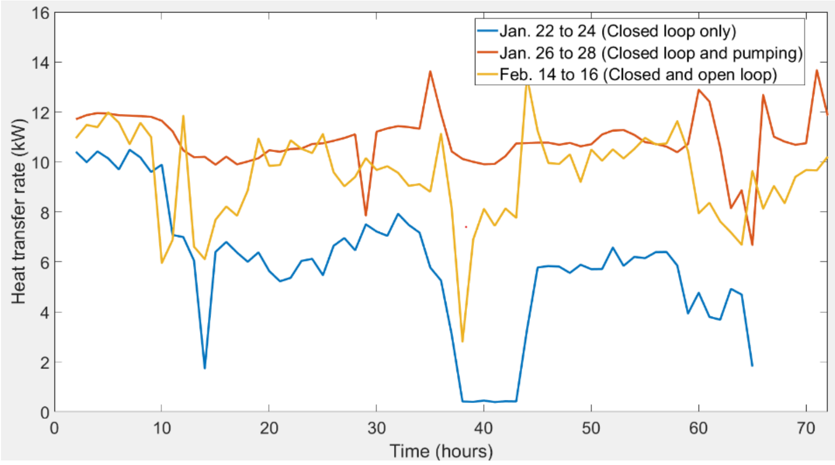


**Figure 4: The heat transfer rate comparison according to the modes of closed loop and ground water pumping, closed loop only, and both closed loop and open loop heat pump operation condition. The HTR time series were measured at different periods during the period from January to March of 2019.**

The outside temperature was plotted in Figure 3 because each test was conducted at different periods. The environment of each test could not be in accordance, so it is impossible to test under the same condition for the air-conditioning of the real scale building. For the test Figure 4 shows the HTR time series associated with the operation modes. The HTR graph of the heating season represents the trend at each operation mode. At the operation case with closed loop heat exchanger only, the value is decreasing slowly according to the operation time. The temperature difference of the circulation fluid between inlet and outlet pipe was 2.5 °C in the pick period of heating demand but it is decreased to 1.0 °C at other times. However other two cases show sustainable heat exchange trends and the temperature difference constant temperature difference ranges of 2.0 to 2.5 °C along the test period. Low values of HTR are obtained during the daytime around 12 o'clock which represents pick outside temperature. The results of the tests suggest that the performance of BHE has a close relationship with ground water movement.

## 4. CONCLUSION

There are many types of BHEs developed by the issues of the air-conditioning conditions such as operation period, latitude, geographical condition, geology, ground water flow and so on. In this study, we tested the effect of ground water movement on the performance. A pilot GSHP system in a new building is used for the test and a borehole heat exchanger is installed with a closed loop type coupled with open loop type. The results of several tests associated with the enhancement of ground water movement show that the HTR represents somewhat different trend. In the ground water pumping condition, the performance of GSHP is continued without any decrease. However, at the operation condition with closed loop only mode, the heat transfer is almost governed by the conduction mechanism between circulation fluid and the surrounding ground. Then HTR from the test was decreased continuously slowly because of the limited thermal capacity of the ground. The quantification of GSHP performance from the induced ground water movement is difficult in a real scale system. Despite the limited test condition, we could show that the ground water flow has a positive effect on BHE performance.

## ACKNOWLEDGEMENT

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