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Numerical Simulations of a Hybrid Geothermal Heat Pump System

Seongkyun Kim, Byoung-Ohan Shim and Youngmin Lee

C1-409, KIGAM, 124 Gwahak-ro, Yuseong-gu, Daejeon, Korea

kskinc@kigam.re.kr

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ABSTRACT

A hybrid geothermal heat pump (GHP) system and its monitoring system were installed at the SPOREX building in Korea Institute of Geoscience and Mineral Resources in Daejeon, Korea. This hybrid GHP system consists of a vertical closed-loop system that is connected to the second floor and an open-loop system that is connected to the third floor. Three wells (geothermal well, injection well, and monitoring well) were installed at the backyard of the SPOREX building. The reason that this GHP system is called hybrid is that the geothermal well consists of a single U-tube for the closed-loop system and well pump and production and reinjection pipe for the open-loop system. The advantages of this system are reduction in initial costs of installation and enhancement of the performance of the closed-loop system. Numerical simulations are performed to analyze the performance of each GHP system and thermal changes in the groundwater around the site.

1. INTRODUCTION

Geothermal heat pump systems or ground-source heat pump systems utilize low-enthalpy geothermal energy resources for heating and cooling purposes. They use almost constant temperature of the ground as the exchange medium instead of the outside air temperature. According to the EPA, geothermal heat pumps can reduce energy consumption up to 44% compared to air source heat pumps and up to 72% compared to electric resistance heating with standard air-conditioning equipment. There are three basic types of GHP systems: (1) closed-loop systems; (2) open-loop systems; (3) standing column well systems. The closed-loop GHPs circulate a mixture of water and antifreeze through a closed loop that is buried underground. The loop tubing can be installed horizontally as a loop field in trenches or vertically as a series of long U-shapes in boreholes. The open-loop GHP system produces groundwater directly from wells. Once the produced groundwater has circulated through the system, it returns back to the ground through injection wells or is discharged into the surface. The standing column well (SCW) system is a specialized type of open loop system. Groundwater is produced from the bottom of a deep well, passed through a heat pump, and injected back to the top of the well, where flowing downwards it exchanges heat with the geologic medium or groundwater. A hybrid GHP system and its monitoring system were installed at the SPOREX building in Korea Institute of Geoscience and Mineral Resources (KIGAM) in Daejeon, Korea. The reason that this GHP system is called hybrid is that a single U-tube for the closed-loop system and well pump and production and reinjection pipe for the open-loop system are installed one well. This hybrid system is constructed to figure out how these systems can reduce initial costs and improve air conditioning performance. Monitoring data obtained by operating the system in various modes and numerical simulations of this system will be used for the cost and performance analysis.

2. STUDY AREA

This hybrid GHP system consists of a vertical closed-loop system that is connected to the second floor and an open-loop system that is connected to the third floor. Three wells (geothermal well, injection well, and monitoring well) were installed at the backyard of the SPOREX building (Figure 1). The depth of each well is 150 m and the spacing between wells is 5 m. The open-loop system consists of a heat pump (HP1 in Figure 2), a circulation pump, a heat exchanger, a well pump. Groundwater pumped through the well pump in the geothermal well is discharged through the heat exchanger to the injection well, geothermal well or drain depending on the groundwater level. The vertical close-loop system consists of a heat pump (HP2 in Figure 2), a circulation pump, and a single U-tube. Five wattmeters are installed on each fluid pump and heat pump. Six thermometers are located on the points where the change in temperature (inlets and outlets of the heat pumps and heat exchanger). One flowmeter is on the closed-loop circuit and two flowmeters are on the open-loop circuit. The automatic valve determines where to move the injected groundwater as the groundwater level changes. Five thermometers are installed in each well to measure the groundwater temperature at various depths.

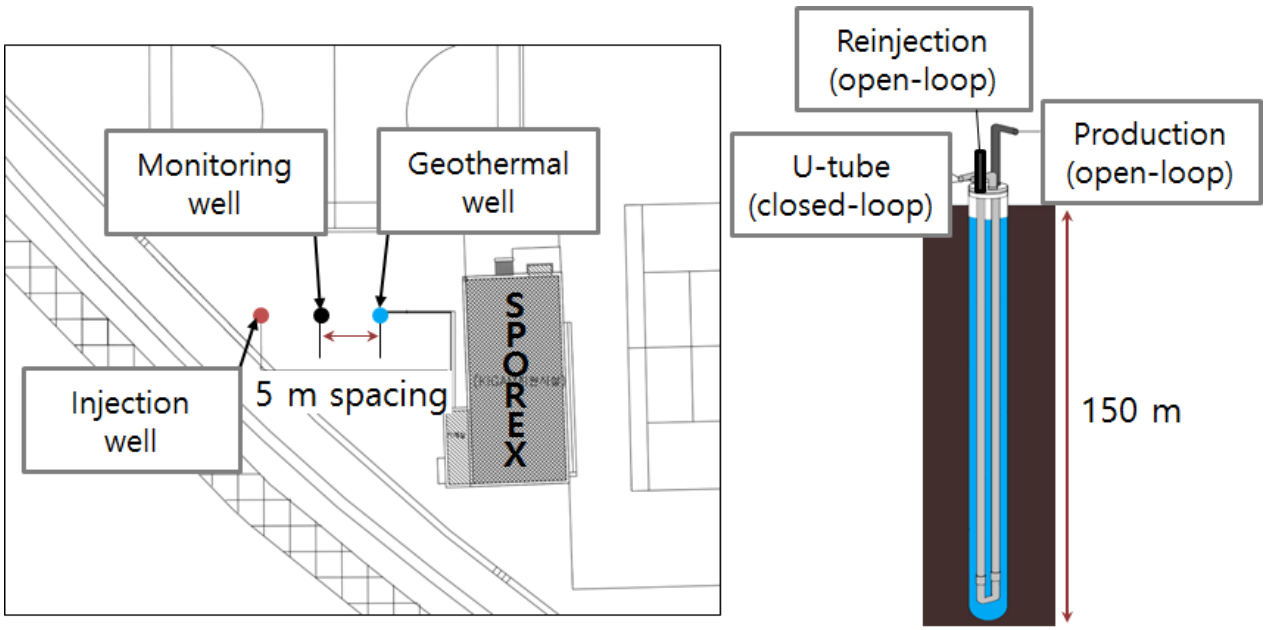

Figure 1: A layout of the SPOREX building and wells (left) and a side view of the geothermal well (right).

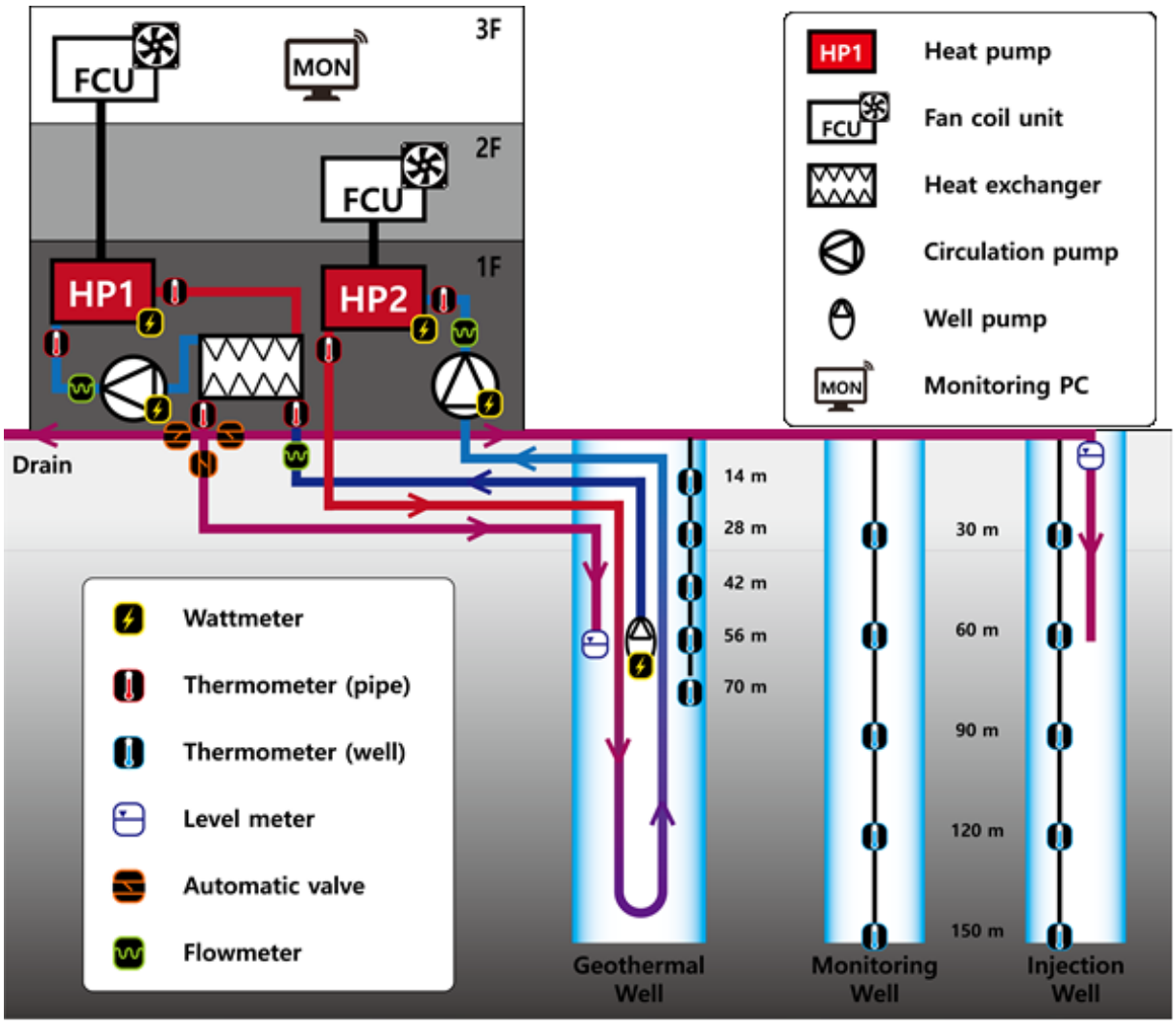

Figure 2: A schematic view of the hybrid GHP system and its monitoring system of the KIGAM SPOREX building.

3. METHOD

The hybrid GHP system consists of heat pumps, fluid pumps and wells. The heat pump is located indoors and move heat from indoor air to the circulating fluid using mechanical work. The fluid pump sends the circulating fluid through the well and the heat pump. The wells transfer heat to the ground and groundwater. A developed model is focused on temperature variation of the circulating fluid and in the vicinity of the well. The developed model is based on the TOUGH3 (Jung et al., 2018). TOUGH3 is a general-purpose numerical simulator for multi-dimensional fluid and heat flows of multiphase, multicomponent fluid mixtures in porous and fractured media. It is developed as an enhanced, more efficient version of the TOUGH2 suite of codes (Pruess et al, 1999). It can consider fluid flow occurring under viscous, pressure, and gravity forces according to Darcy's law and heat transport by means of conduction and convection including both sensible and latent heat. To take thermal and hydraulic processes related to the hybrid GHP system into account, three modules are developed and added to TOUGH3.

4. RESULTS

There are five operation modes for the performance experiment of this hybrid GHP system. In mode 1, only the closed-loop system is activated and in mode 2, only the open-loop system is activated. In mode 3, the closed-loop system is activated and the open-loop system is not activated, but the groundwater is pumped from the geothermal well and reinjected to the injection well. It can enhance the thermal performance of the closed-loop system but the groundwater level in the geothermal well is lower than the mode 1. In mode 4, the closed-loop system is activated and the open-loop system is not activated, but the groundwater is pumped from the geothermal well and reinjected to the geothermal well. This mode provides less thermal performance than the mode 3, but the groundwater level is not changed. In mode 3, both the closed-loop and open-loop system are activated. It also enhances the thermal performance of the closed-loop system. The reinjected groundwater, however, can be at risk for the thermal interference that degrades system performance. Heating season experiments were conducted during January and February 2019. First, the system was operating in mode 1 for four days. And the system was operating in mode 3 for four days, in mode 2 for 11 days, and in mode 5 for two weeks.

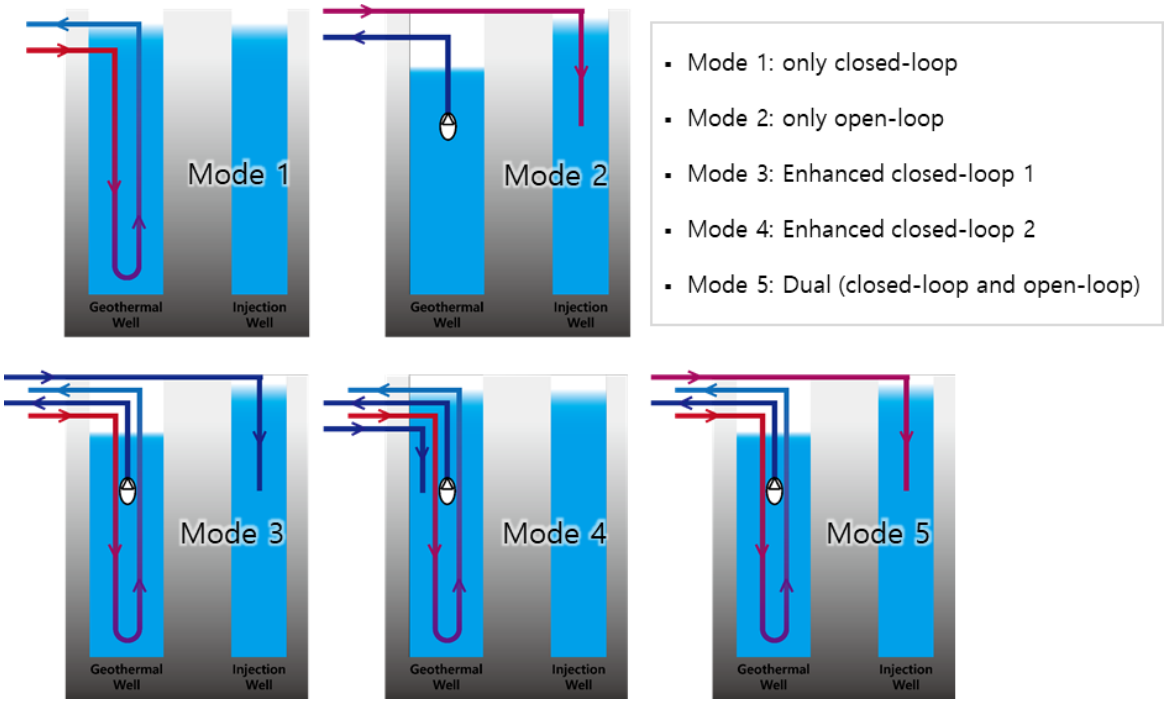

Figure 3: Five operation modes for performance experiments of the hybrid GHP system.

Cooling season experiments were conducted during July and August 2019. First, the system was operating in mode 1 for 8 days. And the system was operating in mode 3 for 3 days, in mode 1 for 3 days, in mode 4 for 3 days, in mode 1 for 4 days, in mode 5b for 4 days, in mode 5a for 3 days, in mode 1 for 6 days, in mode 5b for 5 days, and in mode 5a for 15 days. Mode 5a is operated in a similar manner to mode 3 and mode 5b is operated in a similar manner to mode 4. Mode 5 at the beginning of the experiment was run for only 6 hours a day and mode 5 at the end of the experiment was run all day. Figure 4 shows the results of the cooling season experiment. These experimental data will be used to verify and calibrate the developed numerical model.

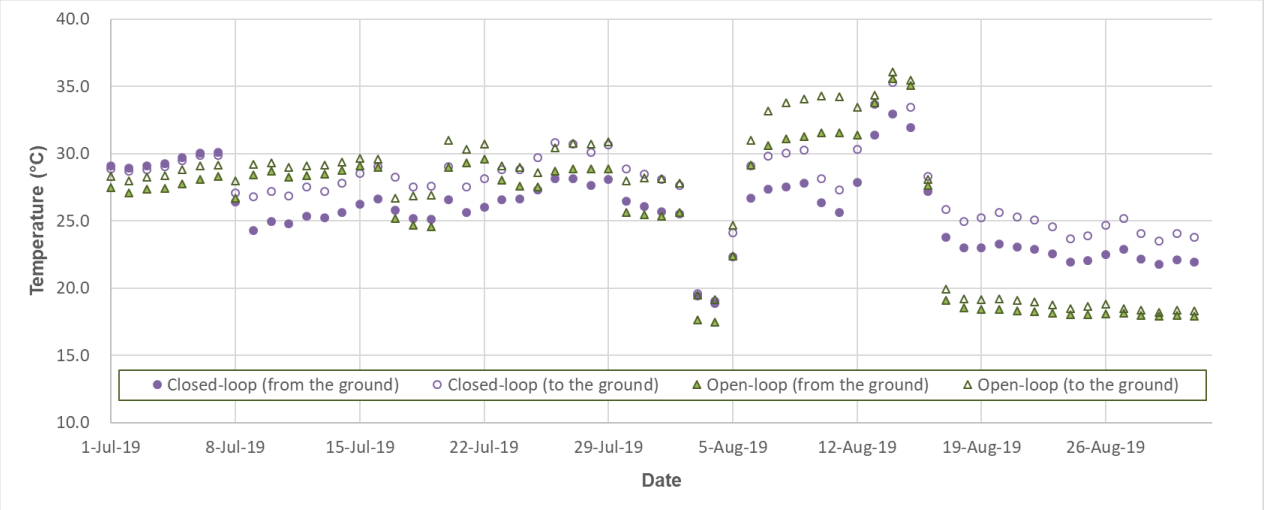

Figure 4: Temperature of the circulating fluid in the closed-loop and open-loop systems (cooling season).

5. CONCLUSION

To evaluate the hybrid GHP system which consists of a single U-tube for the closed-loop system and well pump and production and reinjection pipe for the open-loop system, experiments in five modes are conducted during heating and cooling seasons and numerical simulations are performed by using three-dimensional numerical model that can simulate temperature changes in wells and pipes with flowing fluid through the pipe as well as it computes groundwater flow and aquifer temperature changes.

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