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Numerical Evaluation of the Long-Term Performance of KIGAM Geothermal Heat Pump System

Seong-Kyun Kim, Gwang-Ok Bae, Uk Han, Kang-Kun Lee, and Yoonho Song

505, 25-1, Seoul National Univ., Seoul, Korea, 151-747

kskinc@hanmail.net

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ABSTRACT

Temperature change of the ground in the vicinity of borehole heat exchangers (BHEs) is important for the long-term operation of geothermal heat pump (GHP) systems. If there are differences between injected energy from heat pumps to BHEs in cooling season and rejected energy from heat pumps to BHEs in heating season and heat transfer is not sufficiently fast in the ground, temperature change of the ground affects on the performance of the GHP system. Vertical closed-loop GHP systems and monitoring systems were installed at the building of the Earthquake Research Center in Korea Institute of Geoscience and Mineral (KIGAM) in Daejeon, Korea. To evaluate the long-term performance of KIGAM GHP system where there are differences between injected energy from heat pumps to BHEs in cooling season and rejected energy from heat pumps to BHEs in heating season, numerical simulations are performed by using three-dimensional numerical model that can simulate temperature changes in the BHE with circulating fluid through the U-tubes as well as it computes groundwater flow and aquifer temperature changes. Temperature of the ground in the vicinity of BHEs is gradually increased during 25 years operation. The efficiency of the GHP system is decreased in the cooling season and increased in the heating season.

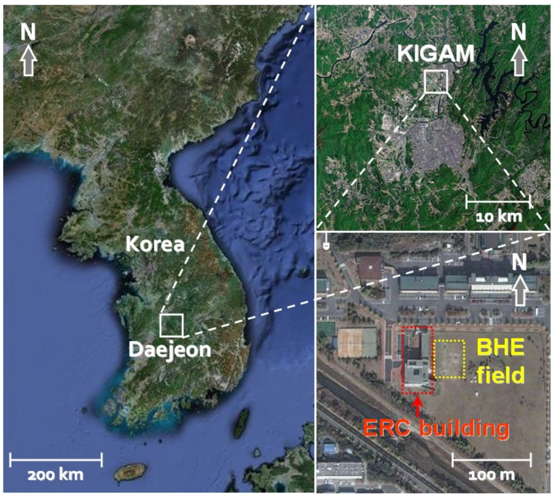


Figure 1: Map of the study area.

1. INTRODUCTION

The GHP system that utilizes shallow geothermal energy resources for heating and cooling purposes has been popular in various parts of the world. A vertical closed-loop GHP system that connects a heat pump to BHEs is the most widely used type of the GHP systems. A vertical closed-loop GHP system and its monitoring system were installed at the building of the Earthquake Research Center in Korea Institute of Geoscience and Mineral Resources (KIGAM) in Daejeon, Korea and have been operated since 2006 (Figure 1).

Temperature change of the ground in the vicinity of BHEs is important for the long-term operation of KIGAM GHP systems. To evaluate the long-term performance of KIGAM GHP system where there are differences between injected energy from heat pumps to BHEs in cooling season and rejected energy from heat pumps to BHEs in heating season, numerical simulations are performed by using three-dimensional numerical model that can simulate temperature changes in the BHE with circulating fluid through the U-tubes as well as it computes groundwater flow and aquifer temperature changes. Detailed discussions on the temperature change of the ground for 25 year operation is presented.

2. METHODOLOGY

The vertical closed-loop GHP system consists of heat pumps, fluid pumps and BHEs. 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 BHE and the heat pump. The BHE transfer heat to the ground. A developed model is focused on temperature variation of the circulating fluid and in the vicinity of the BHE. The developed model is based on the TOUGH2-MP (Zhang et al., 2008). The TOUGH2-MP is a massively parallel (MP) version of the TOUGH2 code (Pruess et al., 1999), a widely accepted three-dimensional numerical simulator for heat and fluid flow in geothermal systems. 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 vertical closed-loop GHP system into account, three modules are developed and added to TOUGH2-MP. The developed model is validated by comparing actual data sets measured at the KIGAM GHP system with simulated results (Kim et al., 2008).

3. STUDY AREA

The KIGAM GHP system consists of 79 heat pumps, 4 fluid pumps, and 28 BHEs. There are 16, 31, and 32 heat-pumps on the first, second, and third floor in the ERC building, respectively. Three fluid pumps supply the circulating fluid to heat pumps on each floor and to BHEs. The remaining one is an auxiliary fluid pump. There are 8, 10, and 10 BHEs connected to heat pumps on the first, second, and third floor, respectively, under the ground at the backyard of the ERC building. The area of the BHE field is 35 m in the East-West direction and 42 m in the North-South direction. Each BHE consists of a closed circuit with a double U-tube in a grouted 200-m-deep borehole. To measure temperature and flow rate of the circulating fluid at the BHE inlet and outlet, monitoring equipments are installed at three BHEs. Figure 2 represents layout of the GHP and its monitoring system of the ERC building. Characteristics of the BHE and the heat pump are summarized in Table 1.

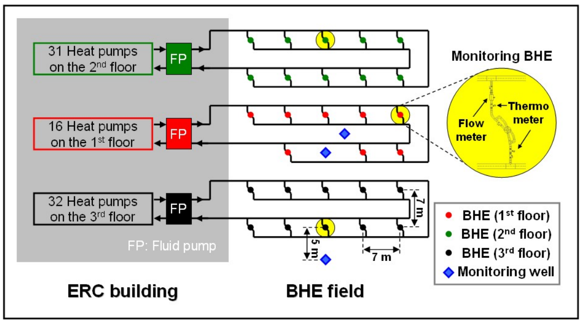


Figure 2: Layout of the GHP and its monitoring system of the ERC building.

Table 1: Characteristics of the BHE and the heat pump.

BHE Dimensions	Number of BHEs: 1st floor (8), 2nd floor (10), 3rd floor (10) Depth: 200 m Spacing between BHEs: 7 m Borehole radius: 82.5 mm U-tube radius (inner): 17 mm U-tube radius (outer): 21 mm
Thermal Conductivity (W/m-K)	U-tube: 0.366 (Polyethylene pipe) Grout: 0.800 (Sand – E-plug mixture) Circulating fluid: 0.580 (Water)
Specific Heat (kJ/kg-K)	U-tube: 2.09 Grout: 2.20 Circulating fluid: 4.20
Heat Pump	Type: FHP EM Series
Number of heat pumps	1F: EM024 (9), EM028 (5), and EM041 (2) 2F: EM012 (11), EM015 (16), EM024 (3), and EM028 (1) 3F: EM012 (10), EM015 (17), EM024 (4), and EM028 (1)

4. MODEL SETUP

The TOUGH2 (Pruess et al, 1999) and its descendants such as the TOUGH2-MP are based on the integral finite difference method (IFDM; Edwards, 1972; Narasimhan and Witherspoon, 1976). Contrary to typical finite difference methods, the IFDM has the advantage of irregular discretization in multi-dimensions. Spatial discretization is accomplished by the U-mesh program (Kim et al., 2008). It generates the IFD mesh and input files of the Modified TOUGHREACT, which are suitable to simulate the vertical closed-loop GHP system. Figure 3 illustrates IFD mesh used in simulations. Boundary conditions are listed in Table 2.

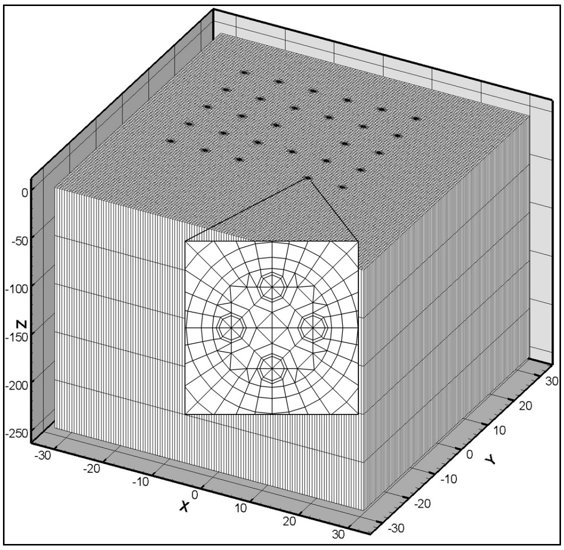


Figure 3: IFD mesh (x to z ratio = 5).

Table 2: Boundary conditions for the BHE simulations.

Water	No flow: top, bottom, front, back Constant head: left, right Constant flow rate: inlet of the BHE
Heat	Constant temp.: top (15°C) Constant temp.: left, right, front, back (depth dependant) Constant flux: bottom (Basal heat flow: 59.7 mW/m^2)

5. SIMULATION RESULTS

During 25 years, 4,000 W of heat is injected to the circulating fluid of each BHE in the cooling season and 2,400 W of heat is extracted to the circulating fluid of each BHE in the heating season. Figure 4 shows pressure field. Groundwater flows from left-top to right-bottom. Hydraulic gradient is 0.05 and hydraulic conductivity is 10^{-6} m/s. Figure 5 shows a temperature field after one year, 10 years, and 25 years.

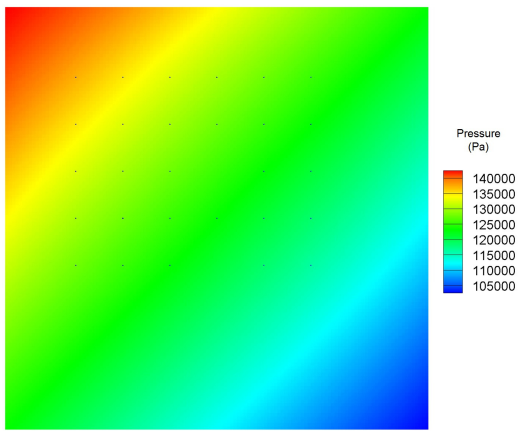
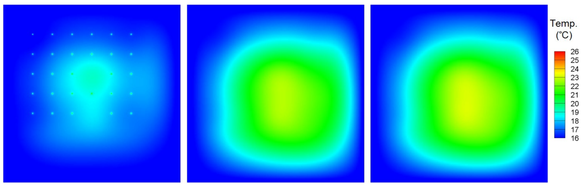
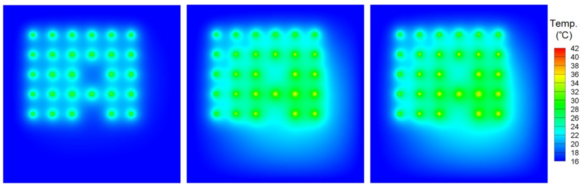


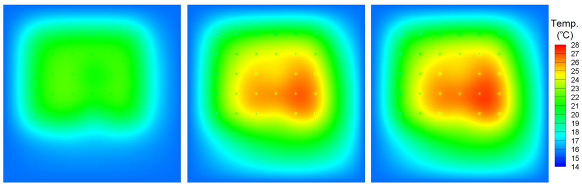
Figure 4: Pressure field.



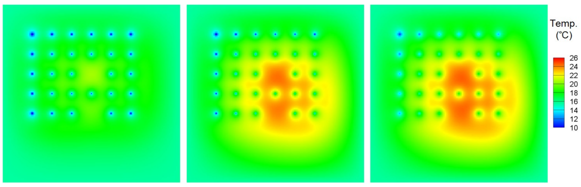
(a) Spring.



(b) Summer (cooling season).



(c) Autumn.



(d) Winter (heating season).

Figure 5: Temperature field after one year (left), 10 years (middle), and 25 years.

Temperature of the ground in the vicinity of BHEs is gradually increased. Thermal plume is moved along the groundwater flow direction. The efficiency of the GHP system is decreased in the cooling season and increased in the heating season.

6. CONCLUSION

To evaluate the long-term performance of KIGAM GHP system where there are differences between injected energy from heat pumps to BHEs in cooling season and rejected energy from heat pumps to BHEs in heating season, numerical simulations are performed by using three-dimensional numerical model that can simulate temperature changes in the BHE with circulating fluid through the U-tubes as well as it computes groundwater flow and aquifer temperature changes. Temperature of the ground in the vicinity of BHEs is gradually increased during 25 years operation. The efficiency of the GHP system is decreased in the cooling season and increased in the heating season.

ACKNOWLEDGMENT

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REFERENCES

Edwards, A.L.: TRUMP: A Computer Program for Transient and Steady State Temperature Distributions in Multidimensional Systems, National Technical Information Service, National Bureau of Standards, Springfield, VA (1972).

Kim, S.K., Bae, G.O., Lee, K.K., Shim, B.O., and Song, Y.: Model Development to Simulate Geothermal Heat Transport and Sensitivity Analyses on the Design Parameters of Closed-loop Geothermal Heat Pump System, *Korean Society for Geosystem Engineering*, **45**, (2008), 326-336.

Narasimhan, T.N. and Witherspoon, P.A.: An Integrated Finite Difference Method for Analyzing Fluid Flow in Porous Media, *Water Resour. Res.*, **12**, (1976), 57-64.

Pruess, K., Oldenburg, C., and Moridis, G.: TOUGH2 User''s Guide, V2.0, Lawrence Berkeley National Laboratory Report LBNL-43134, Berkeley, CA (1999).

Zhang, K., Wu, Y.S., and Pruess, K.: User's Guide for TOUGH2-MP - A Massively Parallel Version of the TOUGH2 Code, Lawrence Berkeley National Laboratory Report LBNL-315E, Berkeley, CA (2008).