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Numerical Investigations of Geothermal Heat Transfer in Shallow and Heterogeneous Media

Seong-Kyun Kim · Gwang-Ok Bae · Kang-Kun Lee

School of Earth and Environmental Sciences, Seoul Natl. University, Seoul 151-742, Korea
E-mail: kskinc@hanmail.net

ABSTRACT

Using shallow geothermal heat that maintains invariable temperature, a tremendous loss of energy used for air-conditioning can be saved. To use the shallow geothermal heat, accurate modeling is required because it is needed to know about the maximum pumping rate of groundwater, change of ground and groundwater temperature, and long-term change of thermo-hydrological system near the pumping and injection wells. There are some common modeling programs, such as SWIFT, FEFLOW, and FRAC3DVS. These can perform numerical simulation of groundwater flow and heat transfer simultaneously. Hydrogeological environment of Korea contains fractured media in spite of shallow and heterogeneous aquifer. Therefore, it is necessary to investigate geothermal heat transfer in shallow, heterogeneous, and fractured media. Furthermore, coupled T-H-M-C (Thermo-Hydro-Mechanical-Chemical) model is required to consider the change of chemical reaction due to change of temperature.

The below equations describe fluid flow, solute transport, and heat transfer in porous media, respectively (Bear, 1988; Holzbecher, 1998):

$$\frac{\partial}{\partial t}\{\phi\rho\} = -\nabla\{\phi\rho v\} \pm \Gamma_{mass}$$

$$\frac{\partial}{\partial t}\{\phi C\} = -\nabla J_{solute} \pm \Gamma_{solute}$$

$$\frac{\partial}{\partial t}\{(\rho\tilde{c})_b T\} = -\nabla J_{heat} \pm \Gamma_{heat}$$

where ϕ is the matrix porosity, ρ is the fluid density, v is the average fluid velocity, C is the solute concentration, t is time, ∇ is the divergence operator, $\tilde{c}$ is the specific heat of fluid, T is temperature, J is the flux and Γ is the sources and sinks.

Ultimate goal of this research including further study is to develop the T-H-M-C modeling code suitable for shallow, heterogeneous, and fractured media. The first step

for this research is to estimate the geothermal heat transfer of preexisted code, SWIFT & FEFLOW to simulate the heat transfer in shallow and heterogeneous media, using a synthetic data. Results may provide useful information for development of code suitable for shallow, heterogeneous, and fractured media. The following figures show horizontal hydraulic conductivity, vertical hydraulic conductivity, effect of hot water (25°C) and cold water (5°C) injection test using SWIFT, respectively. Simulations are for a vertical slice of unit thickness and having dimensions 74.00 m × 42.89 m. Carter-Tracy method are used to calculate aquifer-influence functions. Initial temperature of water is 15°C. For thermal heterogeneity, rock type 1 and rock type 2 are used. In first simulation, hot water is injected at between (1,6) and (1,17) in the domain during a month. In second simulation, cold water is injected at same position and period.

Table 1. Properties used in simulation.

Water Compressibility		4.350×10^{-10} Pa^{-1}
Rock Compressibility		1.103×10^{-8} Pa^{-1}
Water Heat Capacity		4.185×10^{3} $JKg^{-1}{}^{\circ}C^{-1}$
Rock Heat Capacity		1.810×10^{6} $Jm^{-3}{}^{\circ}C^{-1}$
Rock Thermal Conductivity	Rock Type 1	1.868 $Jm^{-1}s^{-1}{}^{\circ}C^{-1}$
	Rock Type 2	1.872 $Jm^{-1}s^{-1}{}^{\circ}C^{-1}$

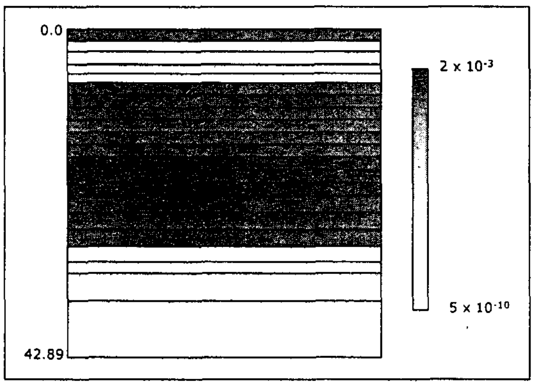

Fig. 1. Horizontal Hydraulic Conductivity

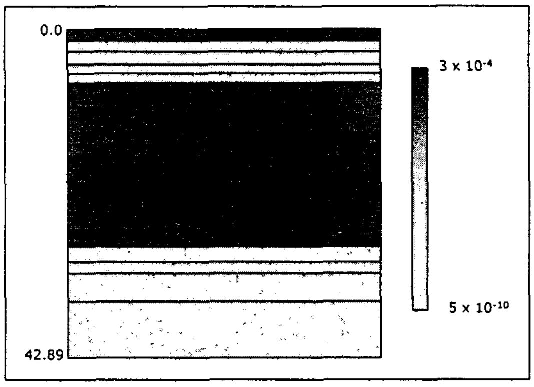

Fig. 2. Vertical Hydraulic Conductivity

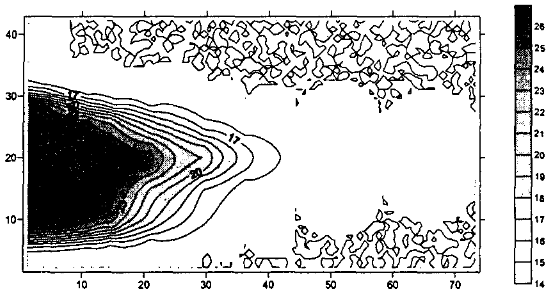

Fig. 3. Hot Water Injection

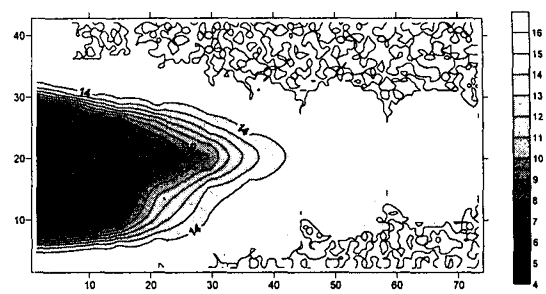

Fig. 4. Cold Water Injection

The results show that SWIFT & FEFLOW can be used for simplified heat transfer problem. However, these have some limitation to the simulation of heat transfer in heterogeneous fractured porous media. Further studies for this research are to estimate the FRAC3DVS code and to modify it suitable for shallow, heterogeneous, and fractured media and enable to treat fully coupled with T-H-M-C model. Then We'll compare the results with other codes.

Key words: geothermal heat transfer, heterogeneous media, SWIFT, FEFLOW