Numerical Simulation of Impacts of Groundwater Hydraulic Gradient on Groundwater and Gas Flow at a Radioactive Waste Disposal Site in Korea

Jung-Hwi Kihm, Jun-Mo Kim, Chang-Lak Kim*
Seoul National University, Seoul 151-742, Korea
*Korea Radioactive Waste Management Corporation, Yongin 446-529, Korea
jung0209@hitel.net

1. Introduction

Gases such as hydrogen (H_2) and carbon dioxide (CO_2) are generated from radioactive wastes during long periods of time. Generation of such gases can lead to changes in groundwater and gas pressures in radioactive waste repositories and surrounding areas, and thus it have significant effects on hydro-mechanical-chemical stability of radioactive waste repositories. Hence, in order to ensure long-term stability of radioactive waste repositories, it is essential to analyze and predict groundwater and gas flow due to gas generation. Especially, in this study, impacts of groundwater hydraulic gradient on groundwater and gas flow at a low and intermediate level radioactive waste disposal site in Korea are evaluated quantitatively using a multiphase thermo-hydrological numerical model.

2. Setup of Numerical Simulations

The multiphase thermo-hydrological numerical model TOUGH2 [1] with the EOS5 module, which can consider thermo-physical properties of hydrogen gas, is used in this study. The model domain used in this study is 400 m long and 200 m high, and it consists of a radioactive waste repository (i.e., silo) surrounded by concrete liner, disturbed host rock, and host rock. The size of the repository is determined by considering the actual shape and scale of the silos, which are under construction at the radioactive waste disposal site in Gyeongju, Korea, so that its diameter and height are 23.6 m and 50 m, respectively. The lower part of the repository consists of a 35-m-high radioactive waste, whereas its upper part consists of a 15-m-high arch-shaped crushed rock. The thickness of the concrete liner is about 0.75 m to 1.20 m, while the thickness of the disturbed host rock is about 10 m. The model domain is discretized into 6,968 grids. The total volume of hydrogen gas, which is generated from the radioactive waste in a silo for 1,000 years, is 7.67×10^3 m^3, and it is converted into a hydrogen gas generation rate of 2.37×10^{-11} $kg/m^3/s$. The total simulation time period is 5,000 years including the hydrogen gas generation period of 1,000 years. A series of numerical simulations for the following four different cases of the groundwater hydraulic gradient is performed in this study to evaluate effects of the groundwater hydraulic gradient on groundwater and gas flow in the silo and surrounding area. The range of the groundwater hydraulic gradient is determined by considering the actual topography at the radioactive waste disposal site in Gyeongju, Korea. The groundwater hydraulic gradients for Cases 1-4 are 0.00 m/m (0.0 Pa/m), 0.02 m/m (195.7 Pa/m), 0.04 m/m (391.4 Pa/m), and 0.06 m/m (587.1 Pa/m), respectively, dipping from the left (i.e., west) into the right (i.e., east) of the model domain.

3. Results of Numerical Simulations

The hydrogen gas pressure increases in the silo as it is generated from the radioactive waste and accumulated in the silo, and then it increases in the upper surrounding area where groundwater and hydrogen gas coexist after hydrogen gas leaks buoyantly upward through the top part of the silo. During the early period of time, hydrogen exists only as an aqueous phase in the silo because hydrogen gas generated are all dissolved in groundwater. However, as time progresses, the hydrogen mass fraction in groundwater increases in the silo, and thus hydrogen also exists as a gaseous phase in the silo after about 16 years. Such hydrogen gas first moves buoyantly upward in the silo and accumulates in the upper crushed rock beneath the concrete liner which acts as an artificial barrier. Hydrogen gas then leaks through the concrete liner after about 80 years and moves upward and accumulates in the disturbed host rock beneath the host rock which acts as a natural barrier (i.e., geosphere). Finally, hydrogen gas leaks through the top boundary (i.e., ground surface). Hydrogen gas rises bisymmetrically from the silo for Case 1 in which the groundwater hydraulic gradient does not exist (Figure 1a), whereas it rises distortedly and spreads widely toward the right boundary from the silo along groundwater flow for Cases 2-4 in which the groundwater hydraulic gradient exists (Figures 1b-1d). As the groundwater hydraulic gradient increases, the skewness of upward hydrogen gas movement and the rate of hydrogen gas spread increase. Aqueous hydrogen dissolved in groundwater also shows the similar trends to those of hydrogen gas. These trends indicate that dissolution of hydrogen gas, which is generated from the radioactive waste, in groundwater can lead to abrupt changes in groundwater chemistry, especially pH, in the silo and surrounding area, and such an influence area extends widely along groundwater flow for Cases 2-4. For Case 1, the amounts of hydrogen gas and aqueous hydrogen decrease gradually after 1,000 years of the hydrogen gas generation period, and their small amounts still remain in the silo and upper surrounding area after 5,000 years. In contrast, for Cases 2-4, both hydrogen gas and aqueous hydrogen in the disturbed host rock and host rock move quickly toward the right boundary from the silo along groundwater flow, and they remain only in the silo after 1,130 years, 1,074 years, and 1,049 years, respectively.

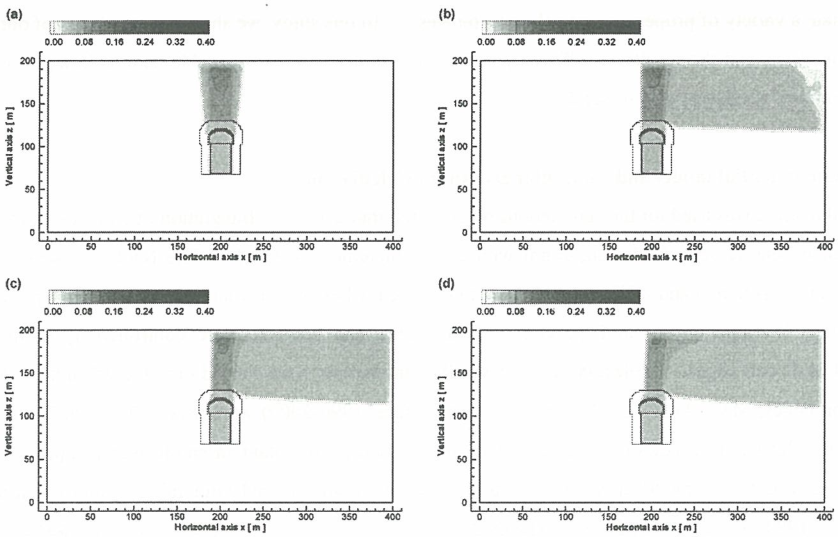

Figure 1. Spatial distributions of hydrogen gas saturation for (a) Case 1, (b) Case 2, (c) Case 3, and (d) Case 4 after 1,000 years of hydrogen gas generation from the lower radioactive waste (source zone) in the silo.

4. Conclusions

The results of the numerical simulations show that hydrogen gas generation from the radioactive waste leads to changes in groundwater and hydrogen gas pressures, and the groundwater hydraulic gradient has significant effects on groundwater and hydrogen gas flow. The results of this study can be utilized in understanding groundwater and gas flow at the radioactive waste repository due to gas generation and in ensuring long-term stability of the radioactive waste repository in Korea.

Acknowledgments

This work was supported by the Nuclear Energy Research and Development Program of National Research Foundation, Ministry of Education, Science and Technology, Korea.

Reference

[1] Pruess, K., Oldenburg, C., and Moridis, G., TOUGH2 User's Guide, Version 2.0, Technical Report, No. LBNL-43134, 198 p., Lawrence Berkeley National Laboratory, Berkeley, California (1999).