Gas release from the SFL repository and migration to the geosphere

Orlando Silva, Alvaro Sáinz-García, Emilie Coene, Jorge Molinero: *Amphos 21 Consulting S.L., Barcelona, Spain*
Henrik von Schenk, Björn Gylling: *Swedish Nuclear Fuel and Waste Management Company, Stockholm, Sweden*

Key words: two-phase flow, gas migration, geosphere

Introduction

The Swedish Nuclear Fuel and Waste Management Company (SKB), plans to dispose long-lived low and intermediate level nuclear waste in the SFL repository [1]. Upon groundwater saturation of the repository, steel components in the waste will undergo anoxic corrosion to produce hydrogen gas. Gas production may: (i) cause pressure build-up potentially harmful to engineered barriers; (ii) affect the groundwater flow in the vicinity of the repository; (iii) affect the saturation level of the repository as well as in the bedrock and the geosphere. This could in turn affect the release and retention of radionuclides. The main objective of the present work is to analyze the above issues for a repository vault by means of multiphase flow modelling.

Model description

A 2D model was developed for simulating hydrogen production and release from the SFL repository and gas migration through the near- and far-field. The model accounts for immiscible two-phase flow through porous media, considering hydrogen generation due to steel corrosion under isothermal conditions. The mathematical approach is based on solving the flow equation of the gas phase and the sum of the liquid and gas flow equations [2]. Liquid density and viscosity are assumed constant at 14.7 ºC, the temperature of the host-rock at the repository depth (~500 m). Gas density and viscosity are calculated according to the Peng-Robinson equation of state [3] and Chung correlation [4], respectively. The water retention curve and relative permeabilities are described by van Genuchten functions [5] with representative parameters for each material [6]. The model domain consists of a cross-section of the host-rock around a repository vault, described by a waste compartment surrounded by a concrete backfill material. The model was implemented in COMSOL Multiphysics using the liquid pressure and the gas saturation as state variables. The approach has been verified with published benchmarks [2].

Results

Some selected results are highlighted below. The impact of hydrogen generation and migration in the repository near-field was evaluated considering homogeneous host-rock. Different groundwater flow fields were compared, describing different directions and magnitudes of the flow. A fracture zone intersecting the vault was considered in some simulations.

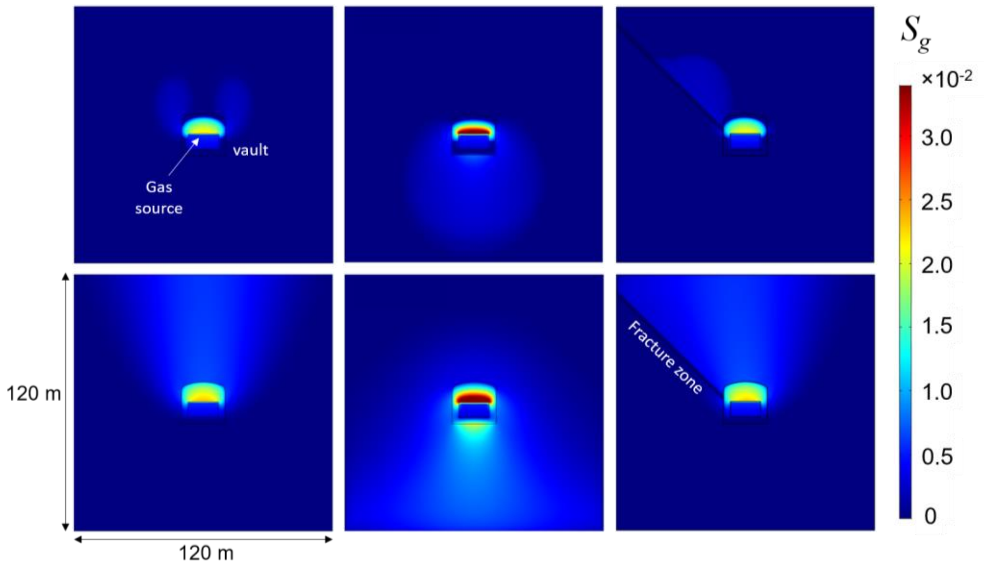

Figure 1: Gas saturation distributions at 100 years (top) and 1000 years (bottom) for hydrostatic conditions (left), vertical downwards groundwater flow (center), and host-rock including a fracture zone (right).

Gas buoyancy dominates gas migration under hydrostatic conditions (Figure 1 left). However, a sufficiently high downwards groundwater flow may counteract buoyancy, causing gas to migrate to the bottom of the rock domain (Figure 1 center). The presence of a fracture zone introduces a preferential pathway for gas migration (Figure 1 right). Moreover, the maximum gas saturations that could be expected are about 3.5%.

To study the hydrogen migration in the far-field, two cross sections of heterogeneous host-rock were considered: Section A, with a very low permeability zone enclosing the vault, and Section B, with a zone of high permeability crossing the vault, also connected to very high permeability zones located at lower depths. Buoyancy forces drive the gas flow and no or little influence of the regional water flow is found. The gas accumulates in areas of lower rock permeability (Section A in Figure 2). The gas flows upwards preferentially through the highly permeable zones. When these zones are connected (Section B in Figure 2), the gas migrate quickly to the surface. By contrast, if highly permeable areas are separated by low permeable zones (Section A), the gas requires more time to reach the surface. Consequently, low flow or stagnant zones with higher gas saturation occur.

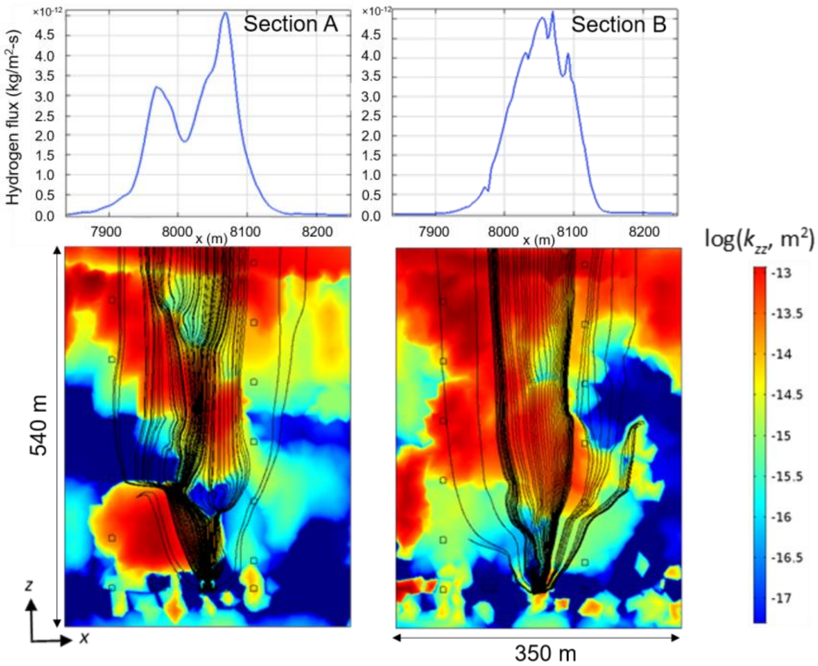

Figure 2: Hydrogen gas flux through the geosphere-bedrock interface (top) and gas streamlines (bottom) at 70000 years. Vertical rock permeability is included as color map.

Conclusions

It was found that gas migration depends on the groundwater flow conditions and the presence of fracture zones intersecting the repository vault. The overpressures in the vault caused by gas generation are similar for all groundwater flow scenarios, ranging from 1.5 to 2.5 bars. Gas generation does not significantly alter the groundwater flow or saturation conditions in the repository near-field. Nor does it influence the hydraulic behavior of the concrete barriers in the vault. The simulations at far-field scale showed that the hydrogen fluxes at the surface are controlled by the gas production rate and the permeability of the host-rock. A highly heterogeneous rock induces multi-modal distributions of hydrogen fluxes. In contrast, a homogeneous rock causes single modal distributions of gas fluxes at the surface. For the heterogeneous cross-sections considered, buoyancy causes most of the gas to exit through the center of the top surface. Moreover, the evolution of hydrogen fluxes at the surface follows the dynamic of gas production within the repository vault.

References

[1] M. Elfwing, L.Z. Evins, M. Gontier, P. Grahm, P. Mårtensson, S. Tunbrant. SFL concept study. Main report. SKB TR-13-14, Svensk Kärnbränslehantering AB (2013).

[2] O. Silva. *Two-phase flow models of gas generation and transport in geological media*, https://www.comsol.com/paper/download/359971/silva_abstract.pdf, Comsol Conference, Münich (2016).

[3] D.-Y.Peng and D.B. Robinson. A new two-constant equation of state. *Industrial and Engineering Chemistry Fundamentals*, **15**, 59–64 (1976).

[4] T.H. Chung, M. Ajlan, L.L. Lee, K.S. Starling. Generalized multiparameter correlation for nonpolar and polar fluid transport properties. *Ind. Eng. Chem. Res.*, **27**(4), 671-679 (1988).

[5] M.T. van Genuchten. A closed-form equation for predicting the hydraulic conductivity of unsaturated flow. *Soil Science Society American Journal*, **44**, 892-898 (1980).

[6] SKB. Data report for the safety assessment SR-PSU. SKB TR-14-10, Svensk Kärnbränslehantering AB (2014).