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Gas migration modelling in geological repository module in clay formation and sensitivity analysis

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ABSTRACT

Corrosion of steel canisters disposed of in a geological repository for high-level waste leads to generation and accumulation of hydrogen gas which may significantly affect long-term safety of the repository. Numerical modelling can be used to predict the likely hydraulic evolution of such a disposal facility and to estimate the influence of generated gas on repository safety.

This article presents a two-phase flow (not taking into account mechanical coupling) gas migration model developed in the original version of the computer code TOUGH2-MP (USA). An important and new aspect of this model is its capability to introduce a network of very thin interfaces in three-dimensional analysis of gas migration. This model was verified in the international benchmark exercises in the recent European Commission project FORGE (Fate Of Repository GasEs). The analysis was focused on the results of a second benchmark exercise, i.e. hydrogen gas behaviour in a part of a geological repository (module) situated in clay formation, and sensitivity analysis. The results showed that the interfaces, backfill and excavation disturbed zone are the main migration and accumulation media for gaseous hydrogen in the repository module. The peak pressure in the module did not exceed the geological environment pressure at a depth of 500 m, and is not sufficient to disturb mechanical stability and functionality of the system of engineered and natural barriers.

1. Introduction

The international consensus exist that the best option for spent nuclear fuel and long-lived high level radioactive waste is disposal in the geological repositories. Such a repository relies on a multi-barrier system which comprises the natural barrier provided by the repository host rock and the engineered barrier system (waste form, waste canisters, buffer, backfill, seals and plugs).

Long-term safety of a repository is an important issue for radioactive waste management programmes in all nuclear countries. During the past years, many of international projects, including theoretical, experimental and modelling, have been undertaken to investigate the gas problem in the context of the safety of the disposal of radioactive waste (Grupa and Schröder, 2009; Haijtink and Rodwell, 1998; Manai, 1997; Norris, 2015; Ortiz et al., 1997; Rodwell, 2000; Rodwell et al., 2003). It has been established that the main sources of gas generation in an underground radioactive waste repository are anaerobic corrosion of disposal packages (steel canisters) and steel components in the engineered barrier system, radiolysis of water and organic materials, and microbial degradation of organic materials (Ye et al., 2014). Hydrogen gas is expected to represent major part of gases generated in a geological repository (Enssle et al., 2012; Perko and Weetjens, 2011; Xu et al., 2008). The produced gas can potentially overpressurise the repository, alter the hydraulic and mechanical properties of the host rock and affect the long-term containment function of the engineered barrier and the natural (host rock) barriers (Fall et al., 2014).

Numerical modelling provides an effective approach to investigate the influence of generated gas on repository safety in a long-term perspective. Numerical models are able to simulate generated gas behaviour in a repository taking into account complex geometry of underground tunnels and various properties of the surrounding engineered and natural barriers. A wide range of models has been developed in past decades: from simplified two-dimensional models representing generated gas behaviour in a part of a repository to more complex three-dimensional models representing gas behaviour in a whole repository, which is computationally challenging. Participation in the international benchmark exercises is the way to verify these models and is an important step in their development and usage.

In 2007 the international multiphase flow simulation benchmark Couplex-Gaz (Talandier, 2007a; Talandier, 2007b) was launched to improve the understanding of gas migration in a repository situated in clay formation. Two benchmark exercises were designed to compare the performance of the numerical methods and to increase the confidence into the numerical tools used for two-phase flow modelling and evaluation of critical parameters such the peak gas pressure in a repository,

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the saturation around the canisters, and water flux induced by gas. Description of some of the models and the results of the participated teams can be found in Amaziane and Jurak (2008), Mikelič (2009), Smai (2009) and Zhang et al. (2011) studies. Good agreement between the results from different teams using various simulators for multiphase flow in porous media was achieved. Several problematic issues, while modelling two-phase flow in a repository, were also noticed. Main challenging issues arise due to high contrast in material properties and the phase appearance/disappearance in almost fully saturated materials.

In 2009 the European Commission project FORGE (Fate Of Repository GasEs) was initiated (Norris, 2015). This project was specifically designed to investigate uncertainties linked to the quantitative treatment of gas generation, migration and subsequent evolution of the repository system. This has been achieved by the acquisition of new experimental data coupled with modelling. The first work package among five was dedicated to treatment of gas in performance assessment. Investigations in this work package concentrated on the modelling of the behaviour of hydrogen gas generated in a conceptual geological repository in clay formation with special emphasis on the role of a network of thin interfaces (i.e., contact surfaces within an engineered barrier system), which could act as a preferential gas flow pathway. Representation of thin interfaces in numerical models is quite challenging. It is also the main difference comparing to the Couplex-Gaz case. Three benchmark exercises (Fig. 1) at different spatial scales – at single disposal cell (tunnel) scale, at the module scale (100 interconnected disposal cells) and at the whole repository scale (10 modules and the access infrastructure) – were analysed (Wendling et al., 2013a, 2013b). Some of the participated teams have already published their findings of the first (Amaziane et al., 2012; Dymitrowska et al., 2015; Sentis, 2014) and the third benchmark exercises (Bond et al., 2015). One team has published its results of an upscaling technique tested for gas migration in a repository module (Ahusborde et al., 2015).

The Lithuanian Energy Institute (LEI) has participated in the modelling activities of the first work package of the FORGE project. A two-phase flow (not taking into account mechanical coupling) gas migration model, capable to introduce a network of very thin interfaces, was developed in the original version of the computer code TOUGH2-MP (USA). The results of the first and the second benchmark exercises achieved using this model were provided to other benchmark participants. Comparison of the results revealed that the model predictions obtained by LEI are in good agreement with the results obtained by other teams that participated in FORGE benchmark. LEI results of the first benchmark exercise are presented in Justinavicius et al. (2012), and Justinavicius and Poskas (2015). In this article, LEI results of the second benchmark exercise and the sensitivity analysis results that evaluate the influence of characteristics of thin interfaces and the excavation disturbed zone (EDZ) on gas migration are presented.

2. Task definition

The geological repository concept analysed in FORGE benchmark exercises is based on a French disposal concept for high level waste (HLW). The type of the engineered barriers and host rock is assumed the same as foreseen in the French disposal programme. Steel HLW canisters are placed into horizontal disposal cells situated in Callovo-Oxfordian clay at a depth of about 500 m. A shaft, main and access tunnels are used for HLW transportation. A geological repository is divided into modules on both sides of the main tunnel. Each module has 100 interconnected disposal cells that are symmetrically arranged on both sides of the access tunnel. A general scheme of the repository module is presented in Fig. 2.

After placement of HLW canisters, the disposal cell is sealed with bentonite. After all disposal cells in the module are filled with HLW, the tunnels and the shaft are backfilled with mixture of bentonite and crushed clay. In order to reduce water and gas outflow from the modules, they are separated from each other by 20 m long bentonite plugs. During excavation, the natural geological environment around the tunnels is disturbed, thus the excavation disturbed zone (EDZ) forms. A very important task in this exercise is to take into account the network of thin (centimetre-thick) interfaces e. g. contact surfaces between the

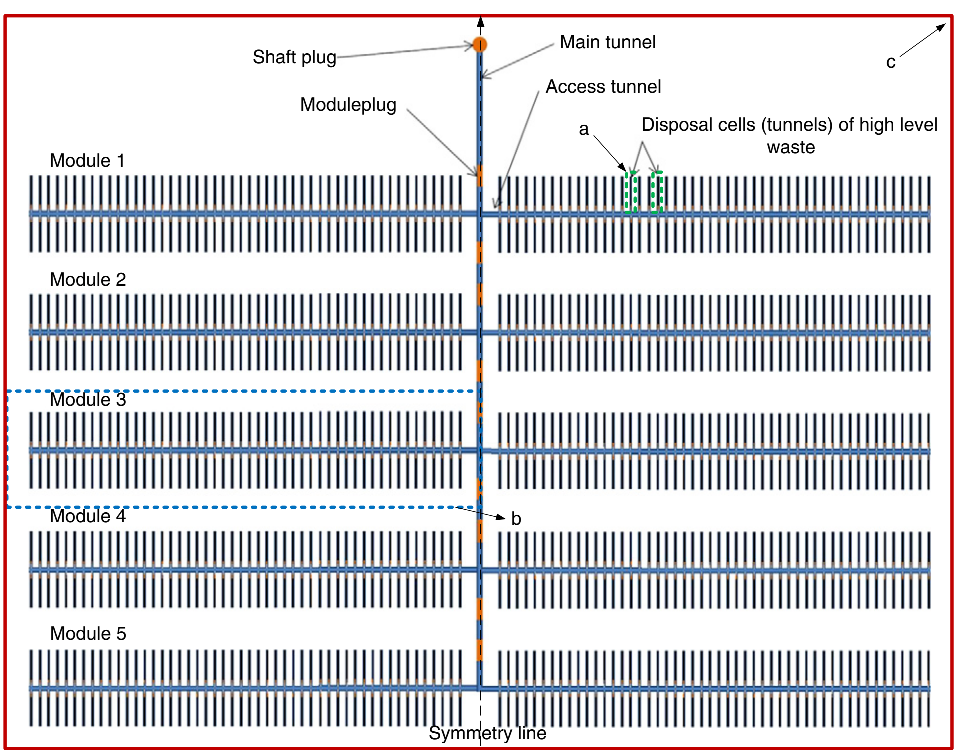

Fig. 1. A conceptual repository for high level waste analysed in FORGE benchmark: a – single disposal tunnel (1st exercise); b – repository module (2nd exercise); c – whole repository (3rd exercise) (Wendling et al., 2013a).