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Multiphase flow gas transport in a deep geological repository

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Gas transport in porous media is of interest in many industrial applications, such as the oil and gas industry, geological storage, and deep geological repositories for radioactive waste. In a deep geological repository, gas will be generated due to the corrosion of metallic components and the degradation of organic materials. This leads to a build-up of gas pressure, which may activate gas transport through the host rock as well as the excavation-damaged zone around backfilled galleries.

In order to understand different transport mechanisms involved, numerical simulations were performed, and the results were compared with laboratory data. In the framework of the EURAD/GAS project, a gas pressure-dependent permeability model was implemented into the finite element code OpenGeoSys-6 (OGS-6) [1]. The permeability alteration in this model is a function of gas pressure. The laboratory experiments showed that the rate of permeability change are different at low and high gas pressures. Therefore, the permeability model employed a threshold pressure (p_{thr}) to categorize this behaviour.

$$\boldsymbol{K} = \begin{cases} (1 + a_1 p_g) k_0, & p_g \le p_{thr} \\ \left(\left(p_g - p_{thr}\right) a_2 + 1 + a_1 p_{thr}\right) k_0, & p_g > p_{thr} \end{cases}$$

a_1 and a_2 are empirical parameters. Moreover, two other permeability models were employed to study the hydro-mechanical behaviour of the host rock and permeability changes. In the strain-dependent permeability model, the permeability change was related to the elasto-plastic behaviour of the host rock, and in the embedded fracture model, it was related to the opening and closure of fractures [3] [4]. Thus, volumetric elastic strain ε_v and equivalent plastic strain ε_p are employed to be the controlling variables.

$$\boldsymbol{K} = \begin{cases} (10^{b_2 \varepsilon_v})(e^{b_1 \Delta\varepsilon_p}) k_0, & compaction \\ (10^{b_3 \varepsilon_v})(e^{b_1 \Delta\varepsilon_p}) k_0, & extension \end{cases}$$

where b_1, b_2, b_3 are empirical parameters.

The initial permeability of the intact rock samples were determined by applying a constant pressure at the upstream and downstream of the samples (i.e. constant pressure gradient). The imperical parameters were determined by matching experimental and numerical results.

Two types of gas injection tests carried out by the Institute for Rock Mechanics (IFG GmbH, See Figure 1) were used to investigate the gas transport through Opalinus Clay and to examine the permeability models [2]. The first experiment demonstrates an advective-diffusiion gas transport through the sample and an elastic deformation. The second experiment highlights the formation of a tensile fracture (plastic deformation and preferred flow path). In both experiments the advective transport is the dominant transport mechanism. The strain-dependent permeability model was successfully applied to reproduce the hydro-mechanical behaviour of the host rock in both elastic deformation test and tensile fracture test (see Figures 2 and 3). The hydro-mechanical response of a saturated single phase flow model was compared with the behaviour of a saturated two-phase flow model. Both single phase

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and two-phase flow models were able to describe the hydraulic as well as mechanical behaviour of the experiments performed. Therefore, one can conclude that in these experiments the water phase (wet-phase) was immobile.

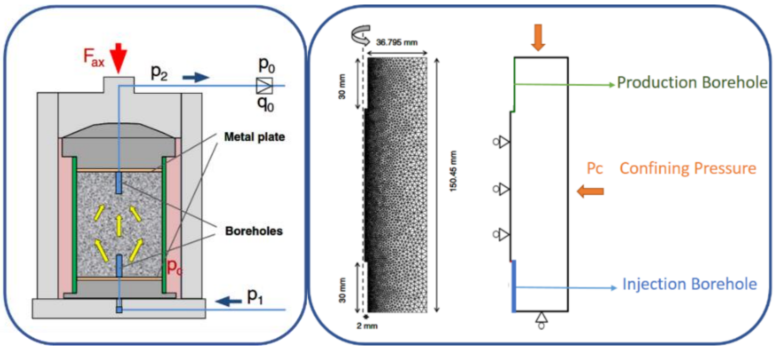

Figure 1: Sketch of laboratory experiment (left) and mesh of numerical model (right).

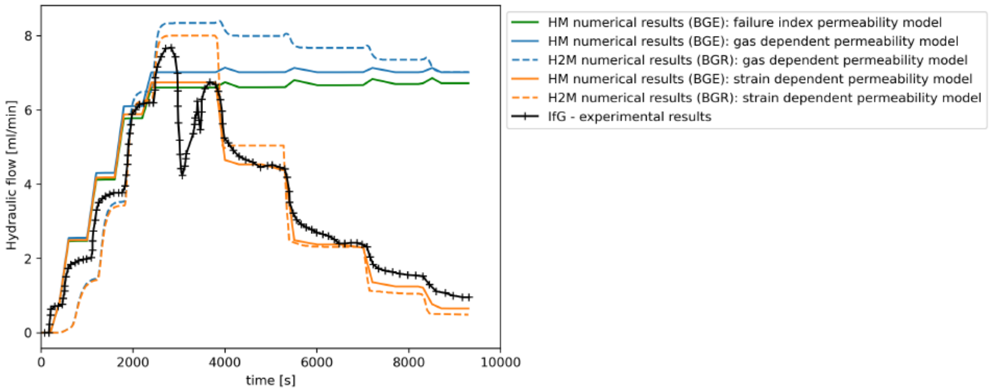

Figure 2: Comparison of experimental and numerical results for the IfG first experiment (hydromechanical modelling).

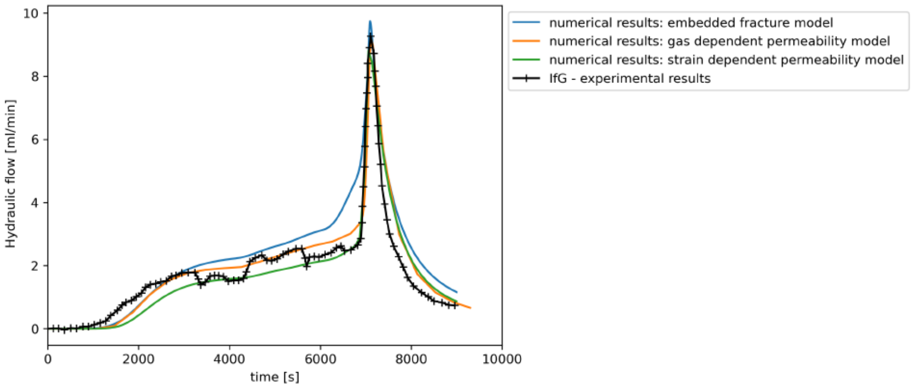

Figure 3: Comparison of experimental and numerical results by BGE for the IfG second experiment.

A gas injection test under triaxial conditions was performed by École Polytechnique Fédérale de Lausanne (EPFL) in saturated Opalinus Clay (Fig. 4). The numerical simulations reproduced the hydro-mechanical behaviour of the sample during the gas injection test. A two-phase flow model was applied to simulate the experiment. The relative permeabilities and capillary pressure functions followed Mualem approach and van Genuchten formulation, respectively. The outflow volume and mechanical response of the sample were measured. The experimental results were in good agreement with the numerical ones. The results of the modelling illustrated the penetration of gas into the sample and hence, the displacement of water (see Figures 5 and 6).

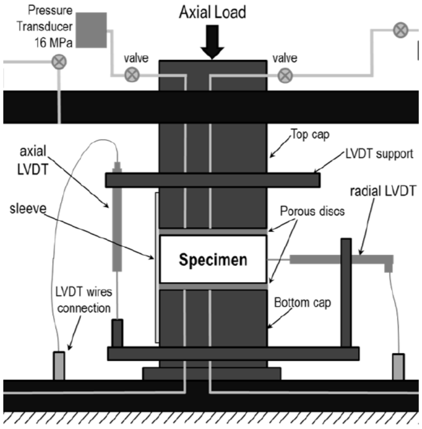

Figure 4: Schematic layout of the testing set-up used by EPFL.

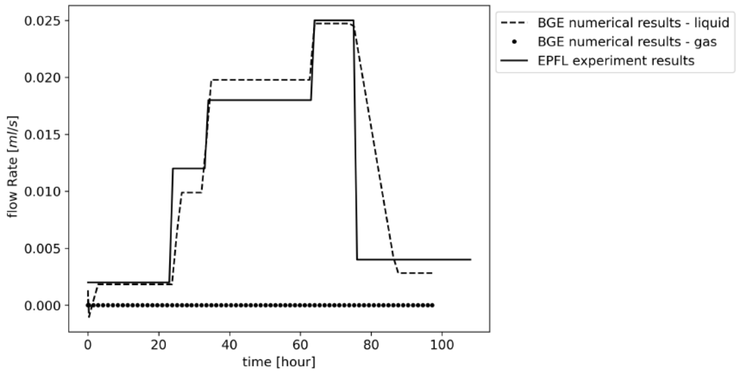

Figure 5: EPFL experiment. A comparison between experimental and numerical flow rates during injection.

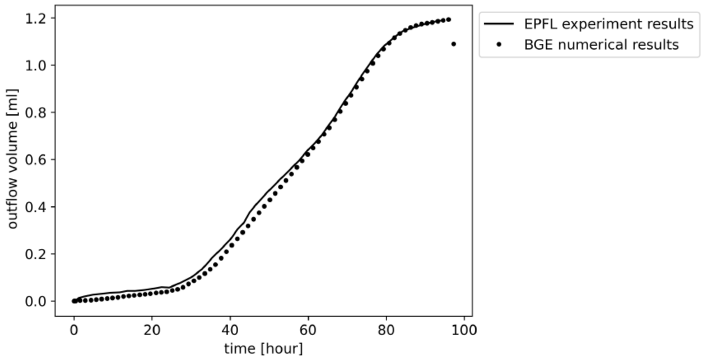

Figure 6: Ouflow volume as a function of time during gas injection.

Contributor statement

All authors contributed in this research by sharing their results, experience as well as their knowledge.

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