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MODELING TWO-PHASE FLOW WITH ENTRY PRESSURE AND HYSTERESIS: APPLICATION TO GAS TRANSPORT IN DEEP GEOLOGICAL STRUCTURES

TOPIC 03: Fluid (Water, gas) transport and solute migration

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Abstract

Introduction

This work concerns water-gas flow simulation in deep geological structures, such as deep geologic repositories (DGR) for radioactive waste disposal. In the case of a DGR, some gases will be generated after closure, mainly hydrogen. As gas pressure rises, a separate gas phase may be formed, and if gas pressure exceeds gas entry pressure, two-phase flow may occur, that might impact the efficiency of repository isolation (Saâdi et al. 2020). Therefore, a good characterization of rock hydraulic properties near full water saturation is required in order to better assess gas transfer in such a context. This work is also relevant for other applications such as CO₂ storage, where water-gas flow and gas migration may occur. We focus here on the case of a DGR, and we develop a parametric sensitivity study of water-gas processes to gas-entry pressure and to hysteresis in the nonlinear constitutive relationships of the porous rock materials.

Gas entry pressure modeling and the PGZ1 in-situ experiment

Several studies have focused on air-entry pressure as a parameter to correct the classical van Genuchten-Mualem (VGM) model used in unsaturated soil hydrology for water retention and permeability curves. However, numerical descriptions of gas-entry pressure effects in two-phase flows are not readily available. A new approach is developed here, consistent with experimental measurements of hydraulic properties of clay host rock and clayey materials. It is based on a modified VGM model (Vogel et al. 2001) accounting for gas-entry pressure in the two-phase flow properties, and has been validated on the in-situ PGZ1 experiment in terms of injection chamber gas pressure $P_g(t)$.

Hysteresis modeling and applications

Drainage and imbibition cycles can be represented by hysteresis models of hydraulic properties, based on scanning curves connected to the main drying-wetting curves for water retention and water-gas permeabilities. However, inconsistencies have often occurred in such models in the past (e.g. non-closed scanning curves, poor representation of gas entrapment). More recent models (Beriozkin & Mualem 2018) have not been tested

numerically yet. The problems are particularly acute near full water saturation (low gas content). Therefore, computational models simulating hysteretic two-phase flow in subsurface media need to be enhanced.

Concerning hysteresis, our objective is two-fold: (i) comparative study of conceptual hysteretic models (Mualem 1974, 1984; Haverkamp et al. 2002; Doughty et al. 2013; Beriozkin & Mualem 2018) against measured data for various porous materials (cement, sand, claystone): (ii) analysis of gas entrapment saturation by different models (Land 1968, Aissaoui et al. 1983). A two-phase flow laboratory experiment (Trevisan et al. 2014) is simulated with the iTOUGH2 code (Finsterle et al., 2007), aimed at comparing constitutive models with/without hysteresis, and with/without capillary trapping.

The two implemented phenomena are studied in the case of gas migration at the waste cell scale in order to quantify the impact of these phenomena on gas migration near a deep geological repository.