Chemo-mechanical effects of salt crystallization in 3D porous media: dynamic studies by X-ray tomography

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1 Introduction

Saline aquifers have a large capacity for gas storage, such as CO_2 or natural gas. This storage leads to perturbations of the underground environment, and might induce the precipitation of salts, natural constituents of brines present inside the host rock. When precipitation occurs inside the pores, the rock's permeability might decrease. Crystallization stresses might build up as well which can eventually fracture the rock [1]. As such, the injectivity can be highly impacted. Crystallization-induced fracturing is also a main cause of the weathering of building stones and construction materials, and as such can drastically reduce the lifetime of a building or structure.

It is therefore essential to understand the relationship between salinity, pore structure and the risk for pore clogging and fracture formation, to be able to control this risk in future geoengineering and civil engineering applications. In the framework of the ERC project PRD-Trigger (Precipitation triggered rock dynamics – the missing mesoscopic link), the purpose of this study is to identify the key correlations between morphological identifiers of the pore space (pore size, shape, connectivity), fluid and salt distributions and precipitation-induced damage based on quantitative image processing of 4D X-ray μCT experiments.

2 Experimental study

As a first step, artificial 3D porous media have been designed, allowing to precisely control the pore size distribution and porosity. The model porous media are composed of glass beads within a glass capillary tube (8 mm inner diameter) that are joined together by an epoxy-resin method [2], representative for an artificial rock core that is sealed circumferentially. By varying the mix of bead sizes, samples with unimodal or multimodal pore size distributions are created. The porosity, pore size distribution and connectivity are quantified from an X-ray tomographic scan of the artificial porous medium.

Two salts are used in this study, sodium chloride (NaCl) and sodium sulphate (Na_2SO_4). They are two of the most abundant salts found in building materials upon salt weathering damage. Sodium sulphate can be considered as a 'model' salt for hydration reactions, whereas sodium chloride can be regarded as a 'model' salt for coastal conditions, as well as for reservoir brines.

The thenardite (Na_2SO_4) → mirabilite ($Na_2SO_4 \cdot 10H_2O$) transition reaction of sodium sulphate at room temperature is known to induce cracking easily, due to the generation of high supersaturations and thus high crystallization pressures [3]. Thenardite crystallization is provoked in the samples by rapid drying-out in an oven. Thenardite crystals then serve as nucleation points for mirabilite precipitation, which is provoked by rewetting the sample at room temperature. Multiple drying-rewetting cycles at room temperature are subsequently imposed until the occurrence of damage.

NaCl is known to have the potential to create high crystallization pressures at high supersaturations (up to 200 MPa [4]), and its precipitation follows from the drying-out of a sample imbibed with sodium chloride solution. To that extent, dry gas is injected at a constant flow rate from the bottom of the sample, percolating upward due to buoyancy.

X-ray tomographic scans performed at regular time intervals and followed by image processing allow to determine different characteristics of crystals and their location in relation to the distribution of the brine and the pore space characteristics (pore size, connectivity). Furthermore, by tracking the motion of the individual glass bead, crystallization-induced deformations are quantified.

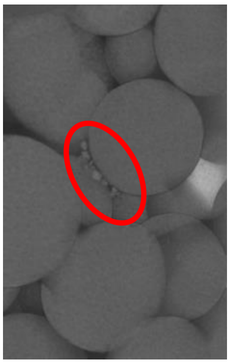

Figure 1: 3D view from CT scan of salt crystals (circled in red) in a glass beads porous medium

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