Numerical simulation of the injection of a CO 2 saturated solution in a limestone sample

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Introduction

The CO2-DISSOLVED project [1] proposes to assess the feasibility of a novel CO_2 injection strategy in deep saline aquifers, combining injection of dissolved CO_2 and recovery of the geothermal heat from the extracted brine. This approach relies on the geothermal doublet technology (commonly used in the Paris Basin, France), where the warm water is extracted at the production well and the cooled brine re-injected in the same aquifer via a second well (injection well). The amount of CO_2 that can be injected in the geothermal aquifer is physically limited by CO_2 solubility in brine. Injecting CO_2-rich acidified water is expected to induce an enhanced reactivity at the immediate vicinity of the injection well, particularly in presence of carbonated minerals. Similarly, acidified water will be much more aggressive for the well casing and cement than standard cold brine in classical geothermal doublets. In order to improve our knowledge on these aspects a dedicated experimental facility, the MIRAGES-2 experimental device designed by GeoRessources [2] was used. MIRAGES-2 is designed for injection of a CO_2-rich aqueous solution in an injection well at the 1/20th scale. The well is made of a steel tube that is fixed to the core plug with a class G Portland cement. Well materials (cement and steel) and reservoir rocks (limestone) are used to reproduce elements and interfaces present in real conditions.

Reactive transport simulation

The experiments of limestone (calcite) dissolution have been modelled using BRGM geochemical reactive transport code MARTHE-PHREEQC [3] in order to evaluate its prediction capacity. This code results from the coupling of MARTHE code [4] for flow and transport in porous media with PHREEQC [5] using the PhreeqcRM modules [6] for geochemistry.

The simulations have been performed with a radial grid, supposing a radial symmetry around the well. This considerably reduces the number of cells and hence the calculations time, which is quite long despite the parallel computation of the chemical reactions. In order to get accurate results it is very important to use an adequate calculation time step. A first guess is approximately the residence time in the cells. This residence time in the cells ranges from 8 to 30 seconds, depending on the size of the cell and on the local velocity. It has been found that a time step of 2.4 seconds gives accurate results. For the simulation of a 20 days period, this corresponds to 0.72 million of time steps. In the simulations, the Portland cement has been assumed nearly impermeable but reactive.

Results

The calculation shows that after 10 days the calcite is dissolved radially about 1.5 cm from the injection chamber (Fig. 1 right part) which is coherent with the observations. The profile is relatively sharp, however attenuation is observed due to dispersion and dissolution kinetics. The simulation show that the portlandite is dissolved near the contact with calcite. However, as was expected, there is calcite precipitation in this zone.

In order to address the channeling effect due to heterogeneity, which has been observed in the laboratory experiments, a simulation has been performed with a radial zone with a higher permeability. The higher permeability

induced a higher velocity (and a higher dispersion) which pushed away more rapidly the water enriched in Ca ions resulting from the calcite dissolution which is faster. For this simulation, the hydraulic conductivity has been increased by a factor of 100 in a radial slice of vertical thickness of 2.5 mm intercepting the injection chamber. The calcite dissolution is fast (Fig. 1, center). After 10 days, the calcite has already been totally dissolved into the circular "fracture". On the other hand, the dissolution near the injection chamber is decreased because it is concerned by less flow. These simulation results are coherent with MIRAGES-2 observations (Fig. 1 right part, from [7]).

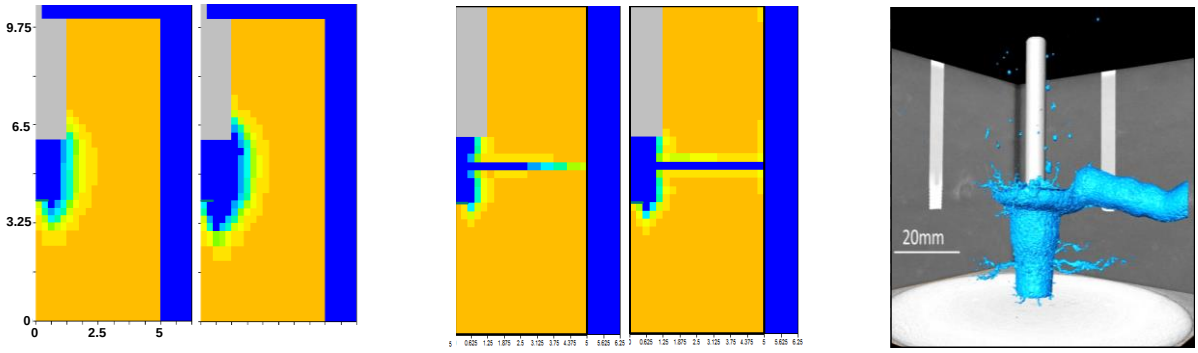

Figure 1: Calcite dissolution in the sample calculated after 5 days and 10 days. Center: with channeling effects. Right: observations (cyan color).

Conclusions

The numerical simulations reproduce reasonably well the experimental observations. This validates the use of the MARTHE-PHREEQC code and geochemical models to contribute in the prediction of the long term effects of the injection of a CO2 rich aqueous solution in a limestone aquifer.

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