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Experimental and numerical simulation of the injection of a CO_2 saturated solution in a carbonate reservoir: application to the CO_2-DISSOLVED concept combining CO_2 geological storage and geothermal heat recovery

A. Randi[1], J. Sterpenich[1], D. Thiéry[2], C. Kervévan[2], J. Pironon[1]

[1]Université de Lorraine, CNRS, CREGU, GeoRessources laboratory, BP 70239, 54506 Vandœuvre-lès-Nancy, France
[2]BRGM, 3 av. Claude-Guillemin, BP 36009, 45060 Orléans Cedex 2, France

Abstract

This study was conducted in the framework of the CO_2-DISSOLVED project (Kervévan et al., 2013, 2014), funded by the ANR (French National Research Agency). The CO_2-DISSOLVED project proposes to assess the feasibility of a novel CO_2 injection strategy in deep saline aquifers, combining injection of dissolved CO_2 (instead of supercritical 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). As a consequence, the amount of CO_2 that can be injected in the geothermal aquifer is physically limited by CO_2 solubility in brine. For that reason and unlike the standard approach (supercritical CO_2) which focuses on very large CO_2 emitters (ca. > 1 Mt/yr), the CO_2-DISSOLVED concept targets specifically low tonnage emitters (ca. 10-150 kt/yr) compatible with a local single doublet facility.

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. However, since this injection option has been much less studied than the standard injection of supercritical CO_2, we need to improve our knowledge on these aspects. The work presented in this paper is devoted to fill this gap using a dedicated experimental facility.

The so-called MIRAGES-2 experimental device designed by GeoRessources is extensively described in Randi et al. (2014). MIRAGES-2 is designed for injection of a CO_2-rich aqueous solution in an injection well at the $1/20^{th}$ 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. An experiment lasting 30 days at 120 bar, 60°C with a flow rate of 150 mg/l of solution with 0.9 $mol.kg^{-1}$ of dissolved CO_2 was performed with a limestone (Lavoux oolithic limestone, Dogger). The ten first days correspond to a cure of the cement phase with no injection in the core plug. The main transformations of the materials (cement, steel and limestone) are investigated in terms of mineral dissolutions, precipitations, and petrophysical properties. The results are compared with those obtained by geochemical modelling with the MARTHE code (Thiéry, 2015). The core plug after experiment is shown in Fig. 1.

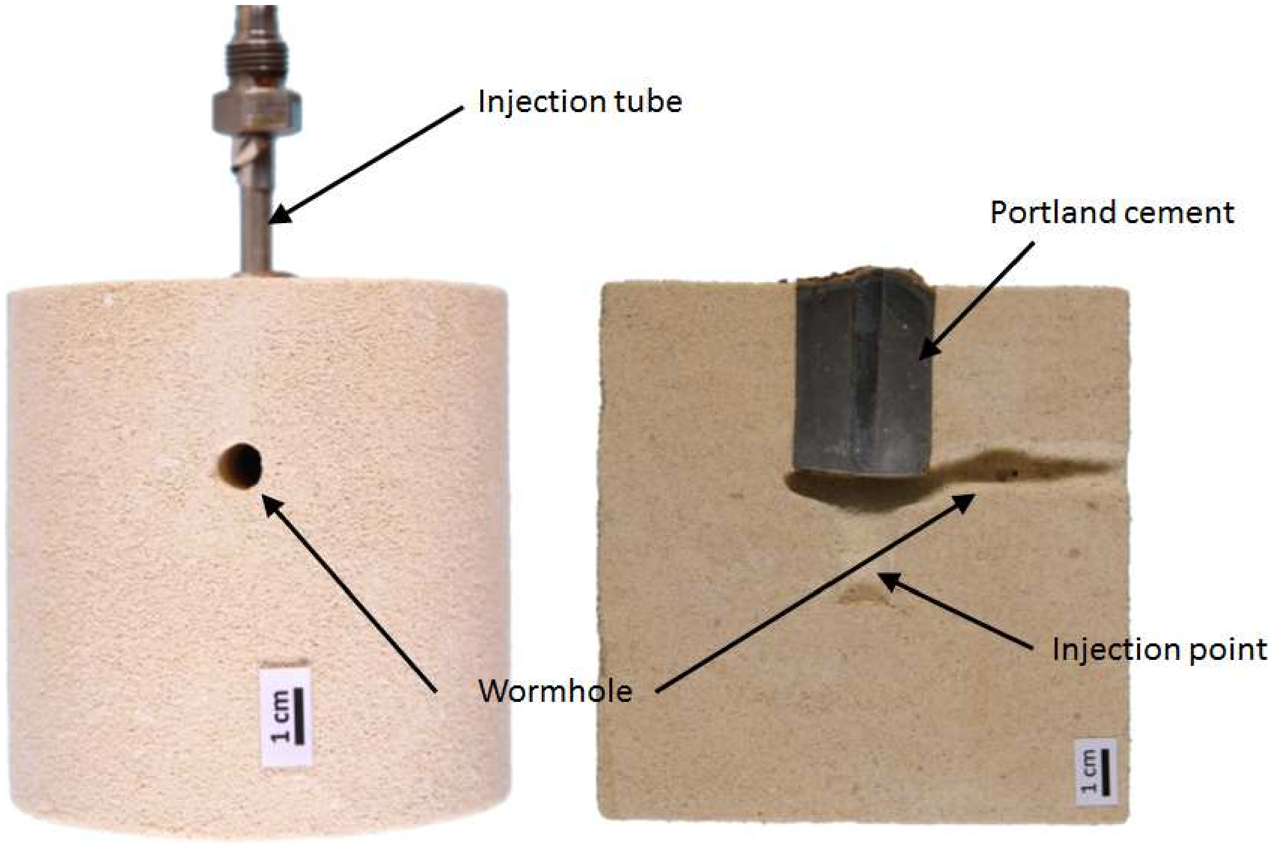

Figure 1: Core plug after experiment (left side) and its cross-section (right side) showing the development of a network of wormholes due to extensive limestone dissolution. Experiments at 120 bar, 60°C during 30 days with a flow rate of 150 g/h of a solution containing 0.9 mol.kg^{-1} of dissolved CO_2.

This study had three main objectives:

1) Assessing the behaviour of the near well region under the effect of an aggressive acidic fluid. In particular, the study of the porosity network and of its geometry give information on the evolution of the injection rate with time.
2) Following the evolution of the cement phase, its carbonation, and the evolution of the different interfaces to assess its durability with time and ensure that no damage of the injection well occurs on the long term.
3) Validating the MARTHE-PHREEQC coupling in this specific context (high reactivity, small-scale geometry) and evaluate its prediction capacity.

The main results of the study are:

1) The development of a fast and important network of wormholes in the limestone due to a preferential calcite dissolution (see Fig. 1)
2) The homogeneous carbonation of the cement phase and a good preservation of the different interfaces between rocks and well materials.
3) Modelling of the MIRAGES-2 experiment using a multilayer radial fine grid with an average cell size of 2.5 mm, has duplicated reasonably well the observed dissolution of calcite near the injection tube, and the formation of wormholes resulting to heterogeneity of hydraulic conductivity.

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