Reactive transport modelling of dissolved CO2 injection in a geothermal doublet. Application to the CO2 -DISSOLVED concept

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Reactive transport modelling of dissolved CO_2 injection in a geothermal doublet. Application to the CO_2-DISSOLVED concept

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This research was conducted in the framework of the CO_2-DISSOLVED project (Kervévan et al., 2014) funded by the ANR (French National Research Agency). This project aims at assessing the feasibility of a novel CO_2 injection strategy in deep saline aquifers, combining injection of dissolved CO_2 (rather than supercritical CO_2) and recovery of the geothermal heat from the extracted brine. This approach relies on the geothermal doublet technology, where the warm water is extracted at a production well and re-injected as cooled water, after heat extraction, in the same aquifer via a second well (injection well).

The objective of the work presented here was to identify and to quantify the thermo-hydro-geochemical processes induced by a massive injection of dissolved CO_2 into (1) a carbonated aquifer (Dogger of the Paris basin - 1,500 to 2,000 m deep - 70°C) and (2) a clastic reservoir (Triassic sandstones of the Paris basin - 2,000 to 2,500 m deep - 90°C), and to evaluate their possible consequences on the feasibility of the CO_2-DISSOLVED concept. For that purpose, several simulations were performed using the MARTHE-PHREEQC (Thiéry, 2015) and the MARTHE-REACT (Thiéry et al., 2009) reactive transport codes. Two distinct models were considered: (1) a 2D radial geometry centred around the injection well and (2) a pseudo-3D multilayer model focused on the doublet area and previously developed by Hamm et al. (2014) to assess the CO_2 storage efficiency of the CO_2-DISSOLVED approach. Thus, the space scale investigated ranged from the near-well zone area (a few meters) to the site scale (a few kilometres). The calculations assumed a 30 year CO_2 injection period (operational lifetime of the geothermal doublet commonly met in the Paris basin).

The modelling strategy used in this research included a sensitivity analysis on the key numerical parameters (time step duration, meshing, etc.) because it appeared that they might have a significant impact on the results (especially when using a sequential non iterative coupling algorithm, as in the MARTHE code). Basically, the observed numerical behaviour was an increase in the amplitude of the chemical impact of CO_2 injection (larger amounts of dissolved minerals) and a decrease in the extent of the impacted area, as both the time step and the mesh were refined. However, a convergence in the results was obtained beyond a small enough value of the time step, suggesting a consistency of the simulations performed. Moreover, all things being equal, only small differences were observed between the results obtained with MARTHE-PHREEQC and MARTHE-REACT. This strengthens the reliability of the calculations performed.

Whatever the code used, as well as the geometry and the geological formation considered, the simulation results showed:

- An increase of porosity (up to 100% for the carbonated reservoir) in the near-injection well area (a few decimetres to metres) due to the massive dissolution of carbonates (calcite and/or dolomite alterations).
- A weak reactivity of quartz (initially present in the mineral assemblages) even after 30 years of acidified-water injection. Indeed, the solubility of quartz does not depend on pH for values lower than 8 at 70 and 90°C.
- A slight carbonates re-precipitation a few tens of meters around the injection well, but none of the secondary phases selected in our simulations precipitated. Therefore, the injected CO_2 seems to remain stored mainly in the aqueous phase.

Besides, it can be observed that the injection of dissolved CO_2 into a clastic reservoir could also induce a slight dissolution of the K-Feldspar initially present in the reservoir. Furthermore, the simulations performed using the pseudo-3D multilayer model also indicated a weak dissolution of carbonates and K-Feldspar in the near field of the production well.

All these simulation results corroborate the expected great reactivity of the carbonated reservoir under the injection of a CO_2-rich brine that was observed experimentally (Randi et al., 2016). The impact of CO_2 injection in a clastic reservoir was confirmed to be much less important in both numerical and experimental results. However, this reactivity does not have a significant impact on the CO_2 mass balance at the site scale when compared with the non-reactive simulations carried out previously by Hamm et al. (2014). Moreover, and even in the “worst case” of the carbonated aquifer, the risk assessment study (de Lary et al., 2016) show negligible effects due to dissolution on surface subsidence and horizontal surface strain due to the great depth of the reservoir. Consequently, the results obtained provide new arguments confirming the feasibility of the CO_2-DISSOLVED approach.

Hamm V., Kervévan C. and Thiéry D. (2014) CO_2-DISSOLVED: a Novel Concept Coupling Geological Storage of Dissolved CO2 and Geothermal Heat Recovery – Part 4: Preliminary Thermo-Hydrodynamic Simulations to Assess the CO_2 Storage Efficiency, Energy Procedia 63, 4548-4560.

Kervévan C., Beddelem M.-H. and O’Neil K. (2014) CO_2-DISSOLVED: a Novel Concept Coupling Geological Storage of Dissolved CO_2 and Geothermal Heat Recovery – Part 1: Assessment of the Integration of an Innovative Low-cost, Water- based CO_2 Capture Technology, Energy Procedia, 63, 4508-4518.

de Lary L., Manceau J.-C., 2015 - CO_2-DISSOLVED: coupling of the underground storage of dissolved CO_2 and geothermal energy recovery - Preliminary risk study. Report BRGM/ RC-65363-FR. 91 p., 33 fig.

Randi A., Sterpenich J., Thiéry D., Kervévan C., Pironon J., 2016 - 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. Submitted to the GHGT 13 conference.

Thiéry D., Jacquemet N., Picot-Colbeaux G., Kervévan C., André L. and Azaroual M. (2009) Validation of MARTHE-REACT coupled surface and groundwater reactive transport code for modeling hydro systems. TOUGH Symposium 2009, Sep 2009, Berkeley (California), United States. 576-583.

Thiéry D., 2015 – Modélisation 3D du Transport Réactif avec le code de calcul MARTHE v7.5 couplé aux modules géochimiques de PHREEQC. Rapport BRGM/RP-65010-FR, 164 p., 88 fig.