

PhD thesis on Chemo-Mechanical effects of CO₂ sequestration on aquifer rocks

Polito-Stellantis agreement

General overview

Over the coming century, Carbon Capture and Storage (CCS) in deep sedimentary formations (i.e. saline aquifers and exhausted hydrocarbon reservoirs) might contribute to over 20% of CO₂ emission reduction.

The geosequestration techniques that have been applied to date are based mainly on knowledge and expertise gained from oil and gas production, providing reasonable near-term options for sequestration of CO₂. However, securing such a large volume in the long term requires stronger scientific bases, due to the coupled hydro-geochemical-mechanical processes that govern the long-term fate of CO₂ in the subsurface. Four storage mechanisms are expected to take place at increasing times (IPCC, 2005): (i) structural trapping (CO₂ is contained as a different fluid in the permeable layers) is the dominant mechanism during the first stage – approximately 50 years, (ii) residual trapping (CO₂ is contained at residual saturation in the pore space filled by brine), (iii) solubility trapping (CO₂ dissolves in water); (iv) mineral trapping - CO₂ enters in the structure of the rock minerals – is expected to become relevant for time scales above 1000 years.

As injected, CO₂ displaces the fluid originally in place in the reservoir and induces significant pore pressure built-up. A fraction of supercritical CO₂ also dissolves into brine, causing an acid plume which can last for thousands of years.

One of the major challenges for the storage performance assessment is thus the CO₂-induced alteration of rock properties, both in the short term (during the injection period, i.e. over 25–50 years) and in the long term (during the storage phase with time scales over 100 years, up to 10 kyrs). To date, this has mainly been tackled from a transport-chemical perspective, highlighting the effects on hydraulic and multiphase flow parameters. Changes in pore structure and the feedback between dissolution and flow that creates preferential flow paths in carbonate systems directly affect permeability and other continuum-scale transport properties. The triggered geochemical reactions depend on brine and solid phase chemistry and can induce changes in formation porosity and permeability.

Mechanical effects also depend on the rock mineralogy. Preliminary evidence showed that the flow of CO₂-saturated water leads to pore structure collapse in carbonate rocks, whereas salt precipitation and an increase in stiffness occurred in sandstones (16). The environmental success of the CCS depends on the chemo-mechanical interaction with the host rock, in terms of reactions, changes in the pore fluid composition and triggered mechanical behaviour: at the site scale. Pore structure collapse might lead to undesired settlements at the ground surface, while salt precipitation might lead to pore clogging and make the injection of CO₂ more difficult. Given the time scale of the CO₂ life in the underground and the complex geochemo-mechanical processes involved, the safe engineering of CCS requires an advancement of existing experimental data and modelling tools, to be implemented in coupled chemo-hydro-mechanical FE codes.

Research Program

The proposed PhD project focuses on the chemo-mechanical interaction in the host rocks. It aims to contribute to engineering knowledge by quantifying these effects to check their relevance in the practice and allowing their forecasts in planned operations. It might develop as follows:

- Providing an updated overview of the scientific state of the art;
- Providing experimental data on the impact on CO₂-rich water/low pH water and/or supercritical CO₂ interacting under in situ stress conditions with reservoir/aquifer rocks. Two materials might be

studied, one carbonate dominated, the other quartzitic, (month 20 from the beginning of the project);

- Checking the reliability of existing mechanical constitutive models for the type of degradation/enhancement phenomena described in the literature and obtained from experimental data;
- Contributing to the coupling between the transport-reaction models and their mechanical counterparts.