PhD position at GeM, Ecole Centrale de Nantes
UTR Environmental Geomechanics

"Coupled hydro-chemo-mechanical instabilities in geomaterials: laboratory scale experimental analysis of phenomena occurring in CO_2 geological sequestration"

Responsibles of the research project: Giulio Sciarra, Siddhartha H. Ommi

Context

According to The Intergovernmental Panel on Climate Change (IPCC) AR6 synthesis report: Climate Change 2023 [1] in global modeled pathways, that limit global warming to 2°C or below, almost all electricity is supplied from zero or low-carbon sources in 2050, such as renewables or fossil fuels with CO_2 capture and storage (CCS). CCS in deep geological formations has consequently emerged as an important option to reduce greenhouse gas emissions and CCS facilities are continuing to grow in Europe. However, global rates of CCS deployment are far below those envisaged to limit global warming. It is the aim of LOCCO project ("hydro-chemo-mechanical LOCalization phenomena in CO_2 geological sequestration" financed by ANR – Agènce Nationale de la Recherche – in France) to increase knowledge of the interaction between the CO_2 injected in geological storage reservoirs and the surrounding rocks, which should act as sealing barrier, to the CO_2 migration and leakage, and guarantee long-term storage security.

In geological sequestration, CO_2 is injected in liquid form, but it transforms into a supercritical fluid ($scCO_2$). Having density lower than the aqueous brine, initially saturating the reservoir rock, $scCO_2$ tends to buoy through it, in continuous contact with the brine, and therefore to accumulate below the caprock. Different zones within the aquifer host rock at different distances from the injection well can be identified, which are differently affected by the $scCO_2$ concentration, see Figure 1; in particular a zone I, fully saturated by $scCO_2$, in the close vicinity of the injection well, a zone II, characterized by the presence of a two-phase mixture of $scCO_2$ and brine with possibly buffered pH, a zone III fully saturated with an aqueous solution acidified by CO_2 and a zone IV unaffected by CO_2 injection, see [2]. In the worst-case scenarios, the solution stored in zones I, II and III could be significantly acidified with respect to the almost neutral characteristics of natural brine.

Project overview

Significant contributions in the literature have been focused on the study of the response of the reservoir rock to CO_2 injection, however less results are available concerning the direct interaction between the acidified solution stored in the aquifer and the caprock. The following scenarios could be considered as the most representative of the hydro-chemo-mechanical interactions between the acidic brine solution and the caprock. S1) The pressure of the $scCO_2$ at the top of the reservoir is lower than the gas entry pressure of the caprock. As a consequence, the CO_2 cannot flow through the caprock but cations just diffuse through it. Geo-chemical alteration of minerals prone to acid attack, can occur because of the

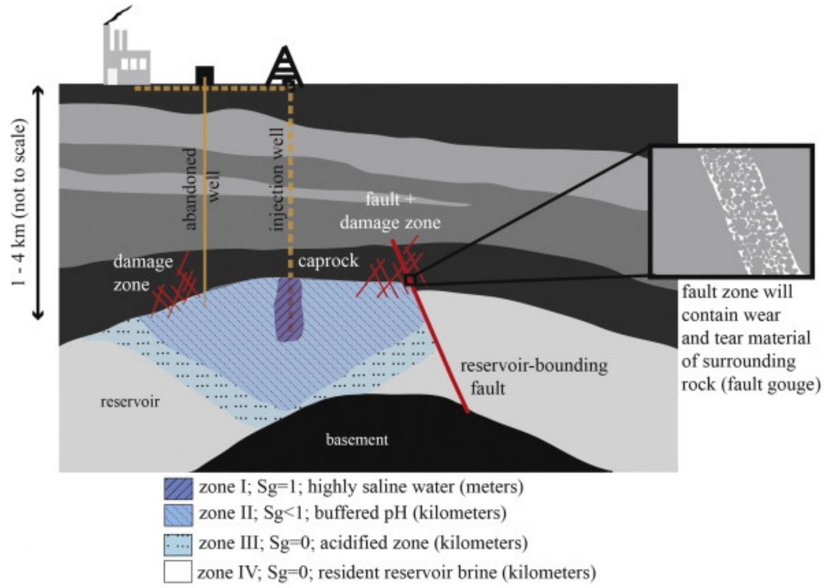
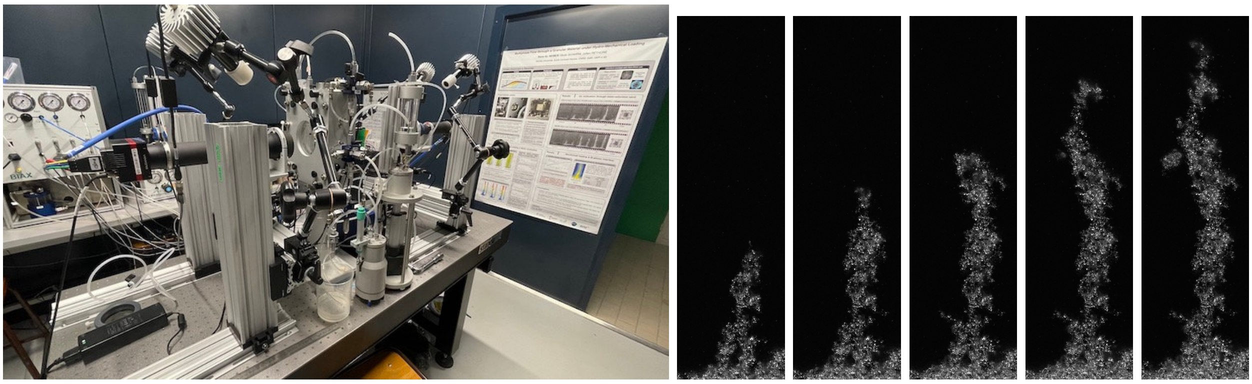


Figure 1: Characteristic zones around the CO_2 injection well, see [2].

chemical disequilibrium between the brine, saturating the clayey rock, and the acidified solution. S2) Pre-existing fracture network/faults, having gas entry pressure lower than the $scCO_2$ pressure and intrinsic permeability higher than that of the surrounding clay-rich rock (typically two order of magnitude), act as a flow conduit for the acidified solution. In this case, the $scCO_2$ does not directly enter into the rock matrix but penetrates the caprock through the fractures. S3) The pressure of the $scCO_2$ at the reservoir top exceeds the gas entry pressure of the caprock matrix. In this case, the CO_2 penetrates the caprock and a drainage process takes place (a non-wetting fluid displacing a wetting one).

The experimental campaign will be firstly based on oedometer tests, which will be carried out during a secondment period at University of Strathclyde (UK), limited to 1D stress-strain paths allowing for injection of non-wetting fluid to test the effect of calcite dissolution on breakthrough. Samples for the oedometric test will be prepared with different pore-fluid chemistry in terms of pH (to simulate acidification due to scCO2) and electrolyte concentration (to simulate brine at various salt concentration). Ranging the pre-consolidation stress of the oedometer between 1 and 10 MPa will allow simulating open and close micro-structure and therefore establishing an equivalence between conditions representative of laboratory tests which are going to be carried out in the second part of the experimental campaign. The second part of the experimental campaign will be based on biaxial tests, carried out using BIAX a suitable experimental setup already available at GeM Laboratory in ECN, which is going to be adapted to let acidic solutions be used either to saturate or to diffuse/to inject the specimen. BIAX is a unique biaxial loading apparatus, which guarantees air-tightness of the specimen keeping it directly in contact with two sapphire windows, and whose control system allows to separately drive the upstream and the downstream fluid pressure, see Figure 2a. It recently allowed to identify fingering formation through granular media during drainage process, see Figure 2b.

Keeping the level of the upstream pressure lower than the entry pressure will give rise to CO_2 diffusion through the sample, maintaining the upstream pressure higher than the entry pressure, will give rise to percolation.



(a) (b)

Figure 2: (a) BIAX apparatus at GeM, https://research.ec-nantes.fr/en/research-facilities/geomechanics-1; (b) Air fingering through a sand sample initially saturated by water captured the BIAX via high resolution camera, [3].

Objectives and scientific program

The objectives of the research activity will be to reproduce at the laboratory scale the above-mentioned scenarios S1 and S3 representative of the interactions between the acidic solution stored in the reservoir rock and the sealing caprock. To this purpose analog materials will be designed which will allow to carry out tests within the loading capacity of BIAX (about 1.5 MPa) being representative of the response of real shale-like geomaterials under in-situ loading conditions (hundred of MPa).

The scientific program should respect the following itemized list of tasks

- developing the experimental campaign based on oedometer tests, during the secondment period at Strathclyde University (UK);
- calibrating the upgraded experimental apparatus;
- exploiting the experimental protocol relative to the campaign to be conducted together with a Post-Doc researcher (to be recruited) in the aim of investigating the above-mentioned scenarios at laboratory scale; a parametric analysis with respect to loading conditions should be taken into account;
- participating to the update of the Digital Image Correlation software Ufreckles, currently used at GeM, in direct correlation to BIAX, see [3, 4], to get quantitative measures of the full-field displacement caused by the different regimes of CO_2 transport through the specimen, and dissolution of solid inclusions.

Application and additional information

Application - Detailed CV including transcript of record and cover letter are to be sent to Giulio Sciarra (giulio.sciarra@ec-nantes.fr) and Siddhartha H. Ommi (siddhartha-harsha.ommi@ec-nantes.fr). Recommendation letters are also required.

Profile - Background in civil engineering/geosciences, recommended in mechanics of geomaterials. A solid background in chemistry of materials will also be appreciated. Advanced knowledge in scientific programming (e.g. Python, Matlab) is also required.

The PhD contract will start in September 2026. It will take place at the Laboratoire GeM, Ecole Centrale de Nantes (France) with a 6 months secondment period at Strathclyde University. The recruited researcher will be part of the UTR Environmental Geomechanics (https://gem.ec-nantes.fr/en/utr-geomec-2/) which is leading cutting edge investigations on multi-physics and multi-scale mechanics of geomaterials.

References

[1] Climate Change 2023 Synthesis Report. Contribution of Working Groups I, II and III to the 6th Assessment Report of the Intergovernmental Panel on Climate Change, doi: 10.59327/IPCC/AR6-9789291691647

[2] Rohmer, J. et al. 2016, Mechano-chemical interactions in sedimentary rocks in the context of CO_2 storage: weak acid, weak effects?, Earth-Science Reviews 157, 86-110.

[3] Al Nemer, R. et al. 2024, Robust detection and characterization of a bifurcated bi-phasic interface propagating through a granular medium: physically and morphologically, Exp. in Fluids 65(12), 182.

[4] Al Nemer, R. et al. 2025, Quantification of localised strains induced within a granular medium by a biphasic flow via digital image correlation, Strain 61(1), e12480.