CO2-MATE publishable summary

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Carbon dioxide (CO_2) sequestration in geological formations containing saline water has been proposed as solution to reduce gas emission to the atmosphere. In spite of the great progress achieved in the area during the last 10–15 years and the experience gained from oil exploration and energy recovery studies, geological storage of CO_2 is still a young technology and many questions remain open. This project focuses on the processes that govern CO2 flow and transport in saline aquifers. In this context CO2-MATE aims to advance in the understanding of the trapping mechanisms and their numerical modelling so as to obtain realistic representations of actual trapping.

CO2-MATE studies CO_2 sequestration by means of means of high resolution numerical simulations. Experiments with fluids that behave in a similar way to the CO2-brine system are used to validate the numerical models (Figure 1). Two codes were developed to study the dissolution and migration of CO2 in saline aquifers.

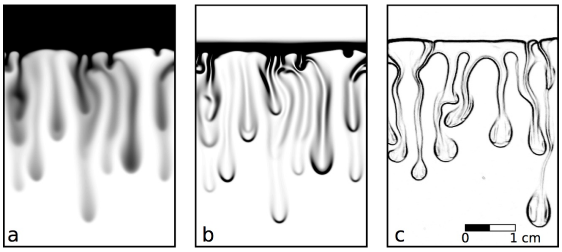

Figure 1: (a) Snapshot of a numerical simulations showing the fingering pattern of fluid system analogue to CO_2 and brine undergoing convective dissolution. (b) Corresponding snapshot showing the mixing state of the system. (c): Snapshot of a surrogate of the mixing state obtained from light intensity from a laboratory experiment.

CO_2 dissolution was studied using a Darcy-Boussinesq model, which is govern by one parameter, i.e., the Rayleigh number. We used a newly developed theoretical relation to show that the dissolution flux and the rate of fluid mixing are determined by the scalar dissipation rate. The analisys of the scalar dissipation rate provided computational evidence that the classical model of convective mixing in porous media exhibits, in the regime of high Rayleigh number, a dissolution flux that is constant and independent of the Rayleigh number. Our findings support the universal character of convective mixing and point to the need for alternative explanations for nonlinear scalings of the dissolution flux with the Rayleigh number, recently observed experimentally. Several factors, including effect of viscosity and CO_2-brine mixture density dependence on concentration, were considered to reconcile our results with previously proposed non-linear scalings.

We studied the impact of solubility trapping driven by convective dissolution on the up-dip migration of a buoyant gravity current of CO_2 in a sloping aquifer (Figure 2). We analysed the dynamics of the dissolution flux along the moving CO_2-brine interface, including its decay as dissolved CO_2 accumulates in the brine beneath the buoyant current. We show that the dynamics of the flux and the macroscopic features of the migrating current, including its shape, its mass, and the position of its leading edge, can be reproduced by using upscaled parameters in a one-dimensional sharp-interface model.

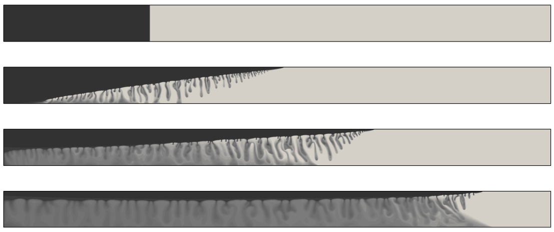

Figure 2: Sequence of snapshots from a high-resolution simulation of convective dissolution from a buoyant current in a sloping aquifer.

The impact of aquifer heterogeneity on the migration of the CO_2 was studied. Heterogeneity is an important factor in the mixing of CO_2 and brine. In the presence of density effects, heterogeneity enhances the mixing between CO_2-and brine.

Finally, we studied the calcite dissolution during the convective-driven mixing of CO_2 in a carbonate aquifer. This is a fast equilibrium reaction controlled by mixing. We explored the evolution of the porosity and the permeability by means of numerical simulations of a CO_2 stationary layer dissolving into brine. Our findings showed how the developed porosity patterns depend on the fingering instabilities caused by the convective-driven dissolution of the CO_2, the movement of the receding CO_2-brine interface, and the chemical system properties (Figure 3).

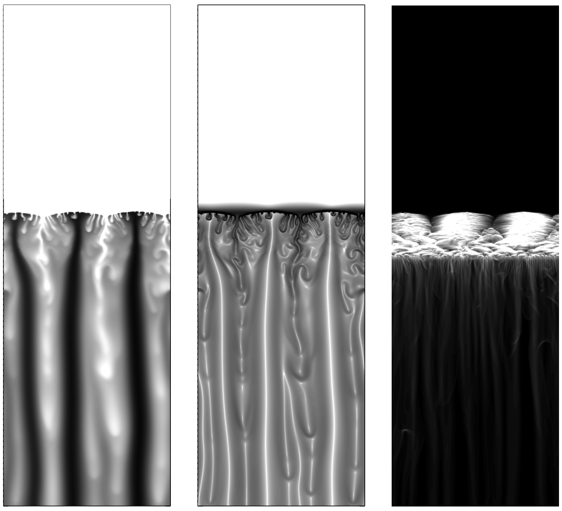

Figure 3: From left to right: Fingering concentration, corresponding reaction rate (logarithmic scale), and resulting porosity pattern.

CO2-MATE is expected to provided further insight in the process of CO_2 sequestration in saline aquifers. The results of CO2-MATE project will help in the development of numerical tools of practical applicability, which are essential in the planning and monitoring of CO_2 injection sites.