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Gravitational instabilities in a 2D porous medium for carbon dioxide sequestration

Thursday, 3 June 2021 10:45 (15 minutes)

With an ever-increasing global warming scenario, geological sequestration stands as an effective mean to trap gases such as carbon dioxide (CO_2) towards long-term storage. The subsurface trapping mechanisms occurring upon injection of supercritical carbon dioxide (sCO_2) are structural, residual, solubility, and mineral trapping [1-3]. Among them, success of solubility trapping dictates the efficient long-term storage capability of geological sequestration [4-6]. During solubility trapping, the less dense sCO_2 positioned under the cap rock begins to dissolve in the aquifer water/brine, thereby creating an interface of aqueous mixture containing dissolved carbon dioxide over the aquifer [7,8]. That mixture is denser than the brine medium beneath it. This unstable stratification develops into a gravitational instability. A natural convection of dissolved CO_2 ensues within the brine and allows for more resident liquid to be subsequently available for dissolution of the sCO_2 into it [1,9,10]. The dynamics of CO_2 dissolution and gravitational fingering, as described above, has been mostly studied using Darcy scale simulations [6,8]. However, the applicability of the Darcy-scale approximation to the coupled convection and solute transport process at play in solubility trapping is not obvious. We present here an experimental study in a granular porous medium, aiming at investigating the range of the validity of the Darcy scale approximation and observe under which conditions, and to which extent, the numerical predictions for the time scales of CO_2 storage, based on such approximations, under- or over-predict the experimental results.
Our analogue experiment is based on refractive index matching of the fluid (a solution of Triton X-100, water and zinc chloride) to the solid grains (spherical PMMA beads, which renders the 3D porous medium transparent. The density contrast between the heavier and lighter (miscible) liquid phases comes from the amount of ZnCl2 added, while the heavier fluid also contains a dye (at a small concentration) to allow tracking the interface evolution and fingering structures. Varying the density of the heavier fluid and the PMMA bead size allows controlling the Rayleigh (Ra) and Darcy (Da) numbers. Measurements are performed in quasi-two-dimensional conditions. The data consists of images recorded at a regular time interval and post-processed using MATLAB. Darcy scale numerical simulations of the experimental configuration are performed using the software COMSOL Multiphysics. The experimental and numerical results are compared in terms of the mixing length, finger velocity and finger number density. We observe that the presence of the granular porous medium strongly impacts the gravitational instability dynamics (as compared to the simulated dynamics), and this all the more as the characteristic number $Ra\sqrt{Da}$ is larger. For $Ra\sqrt{Da}>1$ the simulation results largely under-predicts the experimental data. More importantly, this under-prediction doesn't cancel out entirely when the Darcy regime is valid ($Ra\sqrt{Da}<0.1$), i.e., when the typical scale of convection fingers is larger than the pore size. This finding mays suggest that the coupling between gravity-actuated Stokes flow and solute transport cannot be simply upscaled to the Darcy scale using coupled Darcy's law and a dispersive solute transport equation.

Time Block Preference

Time Block A (09:00-12:00 CET)

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