Geophysical Research Abstracts
Vol. 21, EGU2019-17594, 2019
EGU General Assembly 2019

Solubility Trapping Of CO_2: Analog Experiment and Three-Dimensional Numerical Modeling

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Solubility trapping is one of the trapping mechanisms by which CO_2 can be stored in deep aquifers. The CO_2 being less dense than the resident brine, it rises to the top of the aquifer, above the brine, after injection. It is also partially miscible into the brine, so a layer of CO_2-brine mixture appears at the interface between the brine and CO_2. This mixture happens to be denser than the brine, which triggers a gravitational instability. The subsequent convection, fuelled by the continuous partial dissolution of CO_2 at the top, allows irreversible storage to occur at the bottom of the aquifer. Most studies of this complex process have so far been performed using Darcy scale (mostly 2D) simulations and Hele-Shaw-based experiments. In order to unravel the timescales and efficiency of this solubility trapping, we have simultaneously developed a lab experiment based on a granular porous medium and a 3D numerical model. We first study the gravitational instability, convection and mixing without coupling to the continuous partial dissolution at the upper boundary of the system, using analogue fluids. The largest dimension of the medium is 45 cm, while the grain size ranges between 1mm to 3mm. The optical index of the lower, less dense, fluid is matched to that of the transparent solid grains, which renders the medium transparent and allows for optical visualization of the convection's 3D structure. This visualization is based on a laser dye that is added to the denser liquid, and on swiping the medium with a laser sheet. Simultaneously, a numerical 3D in-house code is developed using the multigrid method solution and finite difference approximation, to better understand the instability phenomenon and convection development. The flow is modelled using the Brinkman equation, with the permeability and porosity corresponding to those measured in the experimental setup. The present Multigrid solver developed has the advantage of being fast and can run in parallel for large systems. We attempt to achieve consistency between the pore-scale results of the experiments and the Darcy-scale results of the simulation. We characterize the trapping efficiency as a function of the medium's permeability, and the miscibility and density difference of the two fluids.