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Rayleigh-Darcy convection in a three-dimensional granular medium: an experimental study

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The reduction of atmospheric greenhouse gas concentrations, for which CO2 contributes to 70% of the greenhouse effect, involves securely trapping CO2 in the subsurface. This is done by one of the four main mechanisms, namely structural, residual, dissolution, and mineral trapping [1-3], in the order of their storage security. Dissolution trapping in deep saline aquifers occurs when the supercritical CO2 trapped below the cap rock dissolves into the brine underneath. The CO2-enriched brine has a higher density than the ambient aquifer fluid, which causes it to form a gravitationally-unstable layer between the pure brine and the supercritical CO2. This unstable layer's destabilization develops into a natural convection that brings the dissolved CO2 to the lower regions of the aquifer while providing fresh brine to the brine-supercritical CO2 interface, in which the latter can further dissolve [4,5].
This convective dissolution of CO2 in a brine saturating a granular porous medium was recently investigated by Brouzet et al. [6] using refractive index matching and planar-laser-induced fluorescence. In their study, the growth dynamics of the instability was significantly different from Darcy-scale theoretical predictions. They explained this discrepancy by the coupling of heterogeneous advection and solute mixing at the pore scale, which cannot be accounted for by Darcy scale models, unless they take local porosity fluctuations into account. These results suggest that Darcy scale models of convective dissolution may underestimate the typical time scale of dissolution trapping by up to several orders of magnitude.
In line with the work of Brouzet et al., we focus here on experimentally chacterizing the Rayleigh-Darcy instability and resulting convection inside a three-dimensional (3D) granular porous medium. That is, we decorrelate the convection from the dissolution, and use analog fluids to study the former alone. The miscible light and heavy analog fluids'(solutions of Triton X-100, water, and zinc chloride) refractive index is matched to that of the porous medium's transparent PMMA grains, to render the medium transparent. The density difference between the fluids is achieved by adding a different amount of ZnCl2. The heavier fluid initially carries a uniform colouring dye (Nile blue) concentration. We control the Rayleigh (Ra) number quantifying the initial strength of the instability, and the Darcy number (Da) quantifying the model aquifer's vertical size by changing the densities of fluids and the size of the grains. A custom-made optical tomography scanner is used to reconstruct the 3D dye concentration field from horizontal cross-sections. The convection dynamics are analyzed from the growth rate of the fingers and the finger number density. Measurements are performed for various values of Ra, andand, independently, for each of them, for various values of the number $Ra\sqrt{Da}$, which quantifies the typical size of the most unstable instability mode with respect to the typical pore size. The results seem to be consistent with the findings by Brouzet et al.

Participation

In-Person

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Primary author: ASHRAF, Shabina (University of Rennes1)

Co-authors: DHAR, Jaybrata (Dr); Dr NADAL, Francois (2) Department of Mechanical, Electrical, and Manufacturing Engineering, Loughborough University, Loughborough LE11 3TU, United Kingdom); Dr MEUNIER, Patrice (3) Aix Marseille Université, Centrale Marseille, CNRS, IRPHE, 13384, Marseille, France); MÉHEUST, Yves (Geosciences Rennes, CNRS SCTD, 2 rue Jean Zay, 54519 Vandoeuvre les Nancy)

Presenter: ASHRAF, Shabina (University of Rennes1)

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