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Rayleigh-Taylor Instability of Miscible Displacements in Heterogeneous Porous Media

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Extended Abstract

The instability of miscible flow displacements in porous media that exhibit permeability heterogeneity is analyzed [1]. This instability known as the Rayleigh-Taylor instability is driven by density mismatch of the two fluids residing in the porous medium. Such flow instability is encountered in a variety of processes that include groundwater remediation, secondary and tertiary oil recovery and in-situ CO_2 sequestration [2,3]. The understanding and control of such instabilities are critical for the control and optimization of such a process, where fluids mixing is a major factor in the efficiency of the processes. The novelty of the present study is that it examines flow developments in porous media that exhibit a sinusoidally periodic heterogeneity that alternates between high and low heterogeneity regions along the flow direction. Furthermore, it is assumed that the flow is driven solely by density stratification with no external flow and that the two fluids have the same viscosity. The governing equations for mass conservation, species concentrations and conservation of momentum in the form of Darcy's law are solved with a heterogeneous permeability characterized by two parameters; the frequency of layers and the variance. The equations are solved using a pseudo-spectral technique based on the highly accurate Hartley transform in conjunction with a semi-implicit time stepping algorithm [4,5]. The numerical code convergence is ensured and its validation was established by comparison with the predictions of previous related studies [6,7]. The dynamics of the flow are characterized qualitatively by examining the time evolution of the fluids concentration and correlating the finger structures with the permeability distribution. New finger structures that exhibit a succession of expansions and contractions are observed. These novel finger structures were characterized through a spectral analysis based on the Fourier Transform of the longitudinally averaged concentrations. The observed trends were further quantified by determining the mixing length, mixing quality, mixing center of mass and breakthrough time. It is found that these quantitative measures depend strongly on the frequency and variance of the permeability. Opposite trends are reported when the permeability at the initial front between the two fluids is maximum vs. minimum.

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