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An adaptive iterative Multiscale Finite Volume method to simulate density-driven flow instabilities

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In the process of geological CO2 sequestration, density-driven instabilities can trigger convection of CO2-saturated brine and increase the dissolution rate of supercritical CO2. The same effect can also increase the vulnerability of water resources by reducing the travel time of contaminants. To obtain a correct prediction of these processes it is important to accurately simulate flow instabilities. Although environmental applications require aquifer-scale models, flow instabilities are triggered by processes that occur at a much smaller scale. Hence there is a clear need for methods that allow simulating large field problems without loosing small-scale information. Standard upscaling techniques average out these small-scale effects that may lead to inaccurate predictions. Multiscale methods in contrast offer a valuable alternative by complementing the coarse problem with local small-scale problems.

Among others, the multiscale finite-volume method (MsFV) has been developed to simulate large nonlinear problems retaining information about small-scale details. Previous work has demonstrated that the standard MsFV method accurately models gravity effects in counter current flow or lock-exchange flow (Lunati and Jenny 2008). However additional tests have shown that the situation is different in presence of density-driven instabilities. For large upscaling factors, the method fails to accurately reproduce the evolution of gravity fingers since small errors grow in time (Kuenze and Lunati, 2010).

In the MsFV method errors can be reduced by a scheme that iteratively improves the quality of the localization assumption used to assign the boundary conditions of the small-scale problems (Lunati, Tyagi, and Lee, 2011). This enables an accurate simulation of unstable flow problems. To limit the growth of computational costs, we introduce an adaptive iterative MsFV (iMsFV) technique that solves local problems only in areas close to the unstable front. Therefore, the iterative elimination of errors is restricted to small regions. In this context, the iMsFV method can be viewed as an adaptive grid-refinement technique. The performance of the adaptive iMsFV method is demonstrated for saltwater fingering and for density-driven flow of CO2-saturated brine.

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