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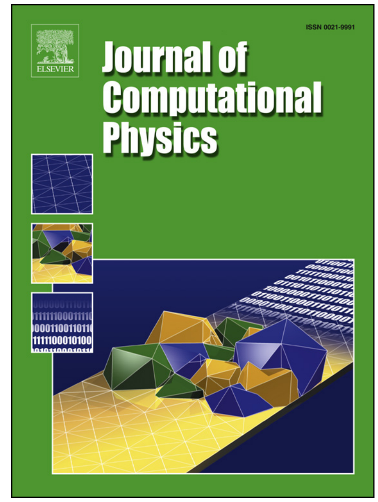

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Analytical and variational numerical methods for unstable miscible displacement flows in porous media

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Abstract

The miscible displacement of one fluid by another in a porous medium has received considerable attention in subsurface, environmental and petroleum engineering applications. When a fluid of higher mobility displaces another of lower mobility, unstable patterns - referred to as viscous fingering - may arise. Their physical and mathematical study has been the object of numerous investigations over the past century. The objective of this paper is to present a review of these contributions with particular emphasis on variational methods. These algorithms are tailored to real field applications thanks to their advanced features: handling of general complex geometries, robustness in the presence of rough tensor coefficients, low sensitivity to mesh orientation in advection dominated scenarios, and provable convergence with fully unstructured grids.

This paper is dedicated to the memory of Dr. Jim Douglas Jr., for his seminal contributions to miscible displacement and variational numerical methods.

Keywords: Miscible displacement, viscous fingering, flow instabilities, Hele-Shaw, variational methods, numerical simulation, Galerkin methods

1. Introduction

Two fluids are miscible when they can be mixed together in all proportions and all mixtures remain single phase. Understanding the role of miscibility has been a major concern in developing efficient enhanced oil recovery (EOR) processes. Here, miscible EOR involves injection of a solvent at certain wells in a petroleum reservoir, with the intention of displacing resident oil to other production wells. Since early 1950's, the search for an effective and economical solvent along with development and field testing of miscible-flood processes has received considerable attention. The economics of the process can be costly, because the chemicals it requires are expensive and the performance of the displacement may involve significant variability. Later on it was realized that the impact of the early miscible displacement investigations extended to a much broader range of applications, which included contaminant transport, bioremediation, carbon dioxide (CO_2) dissolution in saline aquifers, hydraulic fracturing, and various problems in the biomedical field.

Mathematically, the miscible displacement process is described by a strongly coupled, highly nonlinear system of nonlinear, parabolic, convection-dominated (near-hyperbolic) partial differential equations for each of the chemical components. By summing the component equations, an equation for the pressure is obtained, which is also nonlinear, and can be classified as elliptic or parabolic, depending on whether the system is incompressible or compressible. Often the coupled nonlinear dynamics arising from miscible displacement problems may result in complex chaotic

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