

Vertical Hele-Shaw Cell Flow Displacements Involving Reversible Chemical Reactions

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Extended Abstract

Instabilities at the interface between flowing solutions in a Hele-Shaw cell, which is a prototype for homogeneous porous media, can develop as a result of viscosities and/or densities mismatch between the fluids. This instability manifests itself in the form of fingers and is referred to as viscous fingering or Saffman-Taylor instability in case of viscosities mismatch, and as density fingering or Rayleigh-Taylor instability in the case of densities mismatch between the fluids (Homsy 1987; McCloud and Maher, 1995). The instability is further complicated by the presence of chemical reactions, which are encountered in numerous applications such as in-situ oil recovery, carbon dioxide sequestration, in-situ groundwater remediation and chromatographic columns (Hejazi and Azaiez, 2013). Previous studies have examined the effects of chemistry in the case of non-reversible reactions (Almarcha et al. 2010,) as well as those of reversible reactions but in horizontal flows where density does not play any important role in the flow (Alhumade and Azaiez, 2013).

The objective of the present study is to analyze the effects of chemical reversibility on displacements where both the viscosity and density of the chemical species vary in the flow. The combined effects of these two physical properties are known to induce interesting flow dynamics in non-reactive displacements, and it is intended to examine how these effects will be affected by chemical reversibility. The analysis will focus on bi-molecular reversible reactive flows with a generic reaction of the form $A+B\leftrightarrow C$.

The fluid flow equations are based on the conservation of mass, conservation of momentum in the form of Darcy's law and convection-diffusion-reactions equations for the chemical species. The governing equations are linearized under the assumption of infinitely small disturbances. Adopting the quasi-steady-state approximation whereby the disturbances are assumed to grow faster than the base-state, we used a normal mode expansion to derive a set of eigenvalue differential equations that determine the instability characteristics. An algebraic equation is obtained in the case where diffusion is slow and the concentration profiles of all chemical reactants are steep and can be represented by a Heaviside function. The characteristics equation is validated for limiting cases of both non-reversible reactive as well as non-reactive flows. Furthermore, a first order asymptotic expansion is derived for longwave instabilities to determine the condition for the growth of instabilities for disturbances with small wavenumbers. The stability equation is also solved numerically to determine the effects of the viscosity, density parameters as well as those of the reaction coefficients, namely the Damkohler number and the chemical reversibility coefficient. It is found that depending on the distribution of the reactants viscosity and density which determines the nature of the initial [A-B] reactive front, as well as the properties of the chemical product (C), the reversibility of the reaction can lead to either an enhancement or an attenuation of the growth of the instability. Instability characteristics will be presented and the effects of the chemical reversibility coefficient will be analyzed and discussed for different flow scenarios.

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