Modeling Darcian and Non-Darcian Porous Media with COMSOL Multiphysics® Software

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Abstract

Introduction: Displacement of a more viscous fluid by a less viscous one in porous media features a hydrodynamic instability, called viscous fingering (VF) [1]. For a given pressure gradient, the perturbations at the interface grow due to different mobility of the two fluids. Rectilinear displacement has particular importance in oil recovery [1], contaminant transport in aquifers [1], chromatography separation [2], to name a few. Different COMSOL® model for miscible VF are available: Holzbecher presented an equation-based model by coupling Poisson and convection-diffusion equations [3]; Pramanik et al. [2] used the "Two-Phase Darcy's Law" model of fluid flow module. Although both the models are successful to produce VF, these models are limited to capture instability in only Darcian porous media. Our aim is to design a model which could be able to capture instabilities in Darcian as well as non-Darcian porous media and also in channel. To achieve this goal we start with a simple model built using COMSOL® software for rectilinear displacement of miscible fluids in two-dimensional porous media.

Use of COMSOL Multiphysics® software: Miscible displacement in porous media is modeled by coupling two different physics interfaces: Darcy's Law (dl) interface from fluid flow in porous media and Transport of Diluted Species in Porous Media (tds) interface of COMSOL Multiphysics® software. Both the physics are solved simultaneously due to the two-way coupling of the model. The domain of simulation is rectangular region $Lx \times Ly$. The inlet boundary condition specifies normal inflow velocity, $U0$, and species concentration, $c = 0$. The outlet boundary condition is $p = 0$, which corresponds to free flow across this boundary. No flow, no flux boundary conditions are specified at the transverse boundaries. The initial condition is $c = c0$ when $x > x0$, zero otherwise, and $p = 0$. The dynamic viscosity of the fluid is $\mu(c) = \exp(Rc/c0)$, where $R = \ln[\mu(c0)/\mu(0)]$ is the log-mobility ratio. We choose $R > 0$, such that displacing fluid is less viscous than the displaced one. Extra fine mesh is used in our simulations.

Results: For $R = 2$, $U0 = 1$ mm/s, the spatio-temporal evolution of the species concentration shows development of finger patterns at the miscible interface (see Fig. 1). As time increases, coarsening of fingers and hence the reduction in number of fingers is observed in figure 1. Shielding of adjacent finger reduces the supply of less viscous fluid and results fading of advanced fingers. Intensity of fingering instability increases with R (see Fig. 2). This figure also depicts that the forward fingers propagate faster than the backward

fingers. We also verify the stabilizing effect of the diffusion of solute concentration [4].

Conclusion: Here we present a new model built with COMSOL® software to capture miscible viscous fingering in porous media. Our simulations successfully capture the nonlinear interactions of fingers, such as shielding, coarsening, fading and splitting of fingers. The effect of various flow parameters on the observed viscous fingering dynamics is discussed. Extension of this model to non-Darcy porous media flow and flow in channel [5] is under consideration.

Reference

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Figures used in the abstract

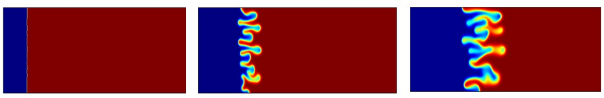

Figure 1: Spatio-temporal evolution of the species concentration at time t = 0, 5, and 10 seconds (from left to right) for R = 2, U0 = 1 mm/s.

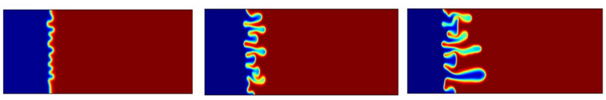

Figure 2: Spatio-temporal evolution of the species concentration at time t = 5 second for R = 1, 2, and 3 (from left to right), U0 = 1 mm/s.