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Numerical study of two-phase flows in porous media : extraction of a capillary pressure saturation curve free from boundary effects

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The capillary pressure saturation relationship is a key element in the resolution of hydrological problems that involve the closure partial-flow Darcy relations. This relationship is derived empirically, and the two typical curve fitting equations that are used to describe it are the Brooks-Corey and Van Genüchten models. The question we tackle is the influence of the boundary conditions of the experimental set-up on the measurement of this retention curve, resulting in a non physical pressure-saturation curve in porous media, due the "end effects" phenomenon.

In this study we analyze the drainage of a two-phase flow from a quasi 2D random porous medium, and compare it to simulations arising from an invasion percolation algorithm. The medium is initially saturated with a viscous fluid, and as the pressure difference is gradually increased, air penetrates from an open inlet, thus displacing the fluid which leaves the system from the outlet in the opposing side. In the initial stage, the liquid-air interface evolves from a planar front to the fractal structure characteristic of slow drainage processes, giving the initial downward curvature. In the final stage, air spreads all along the filter, and must reach narrower pores, calling for an increase of the pressure difference, reflected by the final upward curvature. Measuring the pressure-saturation (P-S) law in subwindows located at the inlet, outlet and middle of the network, we emphasize that these boundary effects are the fact of a fraction of pores that is likely to be negligible for high scale systems. We analyze the value of the air saturation at the end of the experiment for a series of simulations with different sample geometries : we observe that this saturation converges to a plateau when the distance between the inlet ant outlet increases, and that the value of this plateau is determined by the distance between the lateral walls. We finally show that the pressure difference between the two phases converges to a value determined by the cumulative density function of the capillary pressures distribution, until the filter is reached, triggering the upward curvature of the curve.

The boundary effects bring unphysical features to the P-S curve, that may be present in the results of widely used core sample tests. Far from the boundaries, the relationship between pressure and saturation shows a flat profile dominated by a unique constant determined by the capillary pressure distribution of the medium.