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Influence of viscous fingering on dynamic saturation-pressure curves in porous media

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We study drainage-imbibition experiments on quasi-two-dimensional porous models. The models are transparent, allowing the displacement process and structure to be monitored in space and time. Results obtained in the case of quasi-static drainage cycles are compared to standard water retention experiments.

We show that the so-called dynamic effects referred in the literature of experimentally measured capillary pressure curves might be explained by the combined effect of capillary pressure along the invasion front of the gaseous phase and pressure changes caused by viscous effects.

A detailed study of the structure optically followed shows that the geometry of the invader is self-similar with two different behaviors at small and large scales: the structure corresponds to the ones of invasion percolation models at small scales (capillary fingering structures with fractal dimension D=1.83), whereas at large scales, viscous pressure drops dominate over the capillary threshold variations, and the structures are self-similar fingering structures with a fractal dimension corresponding to Dielectric Breakdown Models (variants of the DLA model), with $D\simeq1.5$. The cross-over scale is set by the scale at which capillary fluctuations are of the order of the viscous pressure drops. This leads physically to the fact that cross-over scale between the two fingering dimensions, goes like the inverse of the capillary number. This study utilizes these geometrical characteristics of the viscous fingers forming in dynamic drainage, to obtain a meaningfull scaling law for the saturation-pressure curve at finite speed, i.e. the so-called dynamic capillary pressure relations. We thus show how the micromechanical interplay between viscous and capillary forces leads to some pattern formation, which results in a general form of dynamic capillary pressure relations. By combining these detailed informations on the displacement structure with global measures of pressure, saturation and controlling the capillary number Ca, a scaling relation relating pressure, saturation, system size and capillary number is developed. By applying this scaling relation, pressure-saturation curves for a wide range of capillary numbers can be collapsed.