Universal Scaling of Spontaneous Imbibition for Arbitrary Petrophysical Properties

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Abstract:

Spontaneous, counter-current imbibition (SI) is a key mechanism in many multi-phase flow processes, such as cleanup of non-aqueous phase liquids or CO2 storage. For upscaling and modeling SI data, scaling groups are an essential tool. The question of how to formulate a general scaling group has been debated for over 90 years. Here we propose the first scaling group that incorporates the influence of all parameters on SI that are present in the two-phase Darcy model. The group is derived rigorously from the only known exact analytical solution for SI by relating the cumulative water phase imbibed to the normalized pore-volume. We show the validity of the group by applying it to 55 SI studies for water-oil and water-air experiments, for a wide range of wettability states, viscosity ratios, different materials, initial water saturations, and length-scales. Our group serves as a `master equation' whose generality allows the prediction of the validity of a large number of specialized scaling groups proposed during the last 90 years. Furthermore, our results give strong evidence that the Darcy model is suitable for describing SI, and that including dynamic effects in capillary pressure is not necessary for SI, contrary to what has been hypothesized.