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A generic model for capillary imbibition in a liquid-liquid system: Non-Newtonian fluid as the wetting phase

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Capillary imbibition is a widespread phenomenon in both natural and industrial fields. While most studies focused on the imbibition between two Newtonian fluids or the fluid pair composed of a non-Newtonian liquid and air, the imbibition of a liquid-liquid system, where the wetting phase is a non-Newtonian fluid, remains relatively unexplored. Understanding the dynamics of flow for such fluid system is essential in petroleum engineering and the remediation of contaminated aquifers, as the flushing agent is often characterized as non-Newtonian. In this work, we proposed a generic mathematical model to describe the capillary imbibition of a system in which the non-Newtonian fluid acts as the wetting phase. Specifically, we derived the viscous force exerted on the non-Newtonian fluid based on the wall shear rate of Newtonian fluid. The resulting governing equation is applicable to various rheological models of non-Newtonian fluids. The Carruea-Yasuda model is adopted in this work, as it is able to describe the apparent viscosity over a wide range of shear rates. To verify the developed model, we conducted the capillary rise experiment in straight circular tubes, and compared the numerical solutions against physical observations. Two fluid pairs were examined: (1) liquid-air, and (2) liquid-liquid. In both cases, the wetting phase is non-Newtonian. Results show that the good agreement is obtained between the predictions from the developed model and experimental data across all investigated cases. In contrast, the traditional model falls short of capturing equilibrium rise height in the liquid-liquid case. We found that for a liquid-liquid system, incorporating appropriate viscous force into the governing equation is crucial for accurately describing the dynamics of capillary imbibition.

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