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Competition between main meniscus flow and corner film flow in strongly wetting porous media: a pore network study

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Wetting film can develop in the corners of pore structures during imbibition in a strongly wetting porous medium, which may significantly influence the two-phase flow dynamics. Due to the large difference in scales between main meniscus and corner film, accurate and efficient modeling of the dynamics of corner film remains elusive. In this work, we develop a novel two-pressure dynamic pore network model incorporating the interacting capillary bundle model to analyze the competition between main meniscus and corner film flow in real porous media. A pore network with four-point-star-shaped pore bodies and throat bonds is extracted from the real porous medium based on the pore shape factor and pore cross-sectional area, which is then decomposed into several layers of sub-pore-networks, where the first layer of sub-pore-network simulates the main meniscus flow while the upper layers characterize the corner film flow. The accuracy of the developed model is validated with lattice Boltzmann simulation of imbibition in a strongly wetting square tube and microfluidic experiments of imbibition in strongly wetting porous structures. Then the model is used to simulate imbibition in a strongly wetting sandstone porous medium and the competition between main meniscus and corner film flow is analyzed. Wettability is the most significant parameter controlling corner film flow. The wetting film can develop in the corner only when the contact angle is below a critical value. Under a constant capillary number and viscosity ratio, the corner film flow becomes more significant with the decrease of contact angle. For a small contact angle, a phase diagram characterizing the competition between main meniscus and corner film flow is proposed, dominated by the capillary number and viscosity ratio between wetting and non-wetting fluids. In general, with the decrease of capillary number and viscosity ratio, the wetting corner film flow becomes more significant. The snap off phenomenon caused by swelling of wetting corner film is also analyzed, which happens more frequently with the more pronounced wetting corner film. In addition, the frequency of snap off phenomenon increases with the size ratio between pore body and throat bond. This work deepens our understanding on the imbibition mechanisms under strongly wetting conditions, which provides basic theories for imbibition related engineering processes, such as geological carbon or hydrogen storage.

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