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Combined effect of pore geometry and wettability characteristics on entry capillary pressure

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Immiscible two-phase flow in porous media is a universal phenomenon in various natural and industrial processes. Its invasion pattern is determined by the interplay between viscous and capillary forces, neglecting the influence of buoyancy at a small scale. In numerous scenarios in porous media, the capillary forces in drainage process are dominant, which emphasize the importance of precisely computing entry capillary pressure. Existing equations for the calculation of entry capillary pressure, based on the Young-Laplace equation and MS-P method, rely exclusively on cross-sectional geometrical details, and utilize wettability values obtained from flat surfaces to intricate three-dimensional pore structures. However, the effects of three-dimensional pore structures on the curvature of fluid-fluid interface along the flow direction are neglected in these equations. This work underscores the significance of three-dimensional pore geometry in influencing interface movement and entry capillary pressure, particularly in situations involving intermediate wettability that can introduce complexity to interface behavior. The dynamic evolution of capillary pressure and fluid-fluid interface morphology during two-phase drainage capillary-dominated displacement in both regular capillary tubes and irregular pores extracted from X-ray microtomography images of real porous media were investigated using the volume-of-fluid (VOF) method. The results indicated that the capillary pressure experiences a temporary decrease, or even becomes negative under intermediate wettability when the interface enters the converging segment as the specified contact angles in a three-dimensional space force the interface to decrease its curvature or even inverse the curvature. This phenomenon is the result of the complex interaction of the solid wall in flow direction, cross sectional geometry normal to the flow and the contact angle. This interesting finding challenges conventional expectations and emphasizes the importance of considering dynamic conditions and wettability effects. The statistical analysis of the interface curvature at the point of maximum capillary pressure revealed the effect of three-dimensional structure on local interface curvature under different wettability conditions. Additionally, the numerical results show that the corner flow becomes unstable under intermediate wettability which leads to less remaining saturation. This study raises doubt on the reliability of existing analytical methods for predicting entry capillary pressure as they overlook the geometrical details along flow direction and lack geometric validity across all range of contact angles. Considering the importance of entry capillary pressure in drainage invasion pattern, it is important to develop models that can improve prediction of entry capillary pressure.

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