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Impact of corner-bridge flow on capillary pressure curve

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The capillary pressure curve is essential for predicting multiphase flow processes in geological systems. At low saturations, wetting films form and become important, but how wetting films control this curve remains inadequately understood. In this study, we combine microfluidic experiments with pore-network modeling to investigate the impact of corner-bridge flow on the capillary pressure curve in porous media. Using a CMOS camera and a confocal laser scanning microscopy, we directly observe the corner-bridge flow under quasi-static drainage displacement, revealing that corner-bridge flow serves as an additional flow path to drain trapped water. Consequently, the capillary pressure curve shifts towards lower saturations, resulting in a reduced water residual saturation. We establish a theoretical criterion for the occurrence of corner-bridge flow and develop a pore-network model to simulate quasi-static drainage, taking into account this additional flow path. Pore-network modeling results agree well with our experimental observation. On this basis, we employ our pore-network model to systematically analyze the impact of corner-bridge flow on capillary pressure curve across varying porosity, pore-scale disorder, and system size. Results indicate that the impact of corner-bridge flow becomes more pronounced as porosity decreases and shape factor increases. Our findings demonstrate that the maximum decrease of water residual saturation is 0.19 when porosity is at its minimum, and the shape factor is at its maximum. This work bridges the gap between the pore-scale mechanism and capillary pressure behavior and has significant implications for estimating the amount of extractable water and the CO2 storage capacity.

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