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Capillary filling rules and displacement mechanisms for spontaneous imbibition of CO_2 for carbon storage and EOR using micro-model experiments and pore scale simulation

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In the 1980s, Lenormand et al. carried out their pioneering work on displacement mechanisms of fluids in etched networks [1]. Here we further examine displacement mechanisms in relation to capillary filling rules for spontaneous imbibition. Understanding the role of spontaneous imbibition in fluid displacement is essential for refining pore network models. Generally, pore network models use simple capillary filling rules and here we examine the validity of these rules for spontaneous imbibition. Improvement of pore network models is vital for the process of 'up-scaling' to the field scale for both enhanced oil recovery (EOR) and carbon sequestration. In this work, we present our experimental microfluidic research into the displacement of both supercritical CO_2/deionised water (DI) systems and analogous n-decane/air – where supercritical CO_2 and n-decane are the respective wetting fluids – controlled by imbibition at the pore scale. We conducted our experiments in etched PMMA and silicon/glass micro-fluidic hydrophobic chips. We first investigate displacement in single etched pore junctions, followed by displacement in complex network designs representing actual rock thin sections, i.e. Berea sandstone and Sucrosic dolomite. The n-decane/air experiments were conducted under ambient conditions, whereas the supercritical CO_2/DI water experiments were conducted under high temperature and pressure in order to replicate reservoir conditions. Fluid displacement in all experiments was captured via a high speed video microscope. The direction and type of displacement the imbibing fluid takes when it enters a junction is dependent on the number of possible channels in which the wetting fluid can imbibe, i.e. I1, I2 and I3 [1]. Depending on the experiment conducted, the micro-models were initially filled with either DI water or air before the wetting fluid was injected. We found that the imbibition of the wetting fluid through a single pore is primarily controlled by the geometry of the pore body rather than the downstream pore throat sizes, contrary to the established capillary filling rules as used in current pore network models. Our experimental observations are confirmed by detailed lattice-Boltzmann pore scale computer simulations of fluid displacement in the same geometries. This suggests that capillary filling rules for imbibition as used in pore network models may need to be revised.
[1] G. Lenormand, C. Zarcone and A. Sarr, J. Fluid Mech. 135 , 337-353 (1983).