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Connecting microfluidics experiments and pore network modeling in understanding multiphase flows in porous media

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In an effort in evaluating the effectiveness of enhanced oil recovery (EOR) techniques and geologic carbon storage (GCS), significant interest is recently growing in using microfluidic experiments. On the other hand, because solving the Navier-Stokes equation at complex pore geometry of natural porous media requires extensive computational resource and time, simulation techniques in simplified pore networks have been proposed to predict multiphase flow behaviors. However, lack of physical test results that can be used to validate such modeling techniques is hampering the advances in predictive modeling capability of pore-scale multiphase flows in porous media. This study attempted to connect the experimental results obtained from microfluidics (MF) experiments to the predictive pore network modeling (PNM) simulation method. First, a 2D 8x16 square pore network pattern was designed, which was composed of circular discs (or pores) with the mean diameter of 100 μm and randomly generated rectangular channels (or throats) with the mean width of 48.65 μm. This pattern was replicated in MF chips made of polydimethylsiloxane (PDMS). The channel surface of the fabricated MF chips were modified by polyvinylalcohol (PVA) coating to be water-wet, and by hexamethyldisilazane (HMDS) coating to be oil-wet, respectively. To simulate drainage processes during non-wetting fluid invasion, a simulant of crude oil as a non-wetting fluid was flowed at various fluid velocities, and the resulting distributions of the non-wetting fluid were captured using an optical microscope. We observed the capillary trapping of non-wetting fluid, such as snap-off and ganglia of non-wetting fluid. In addition, water flooding was also conducted in oil-wet MF chips initially saturated with oil. Then, incorporating these observations, the PNM simulation was conducted using Hagen-Poiseuille equation and Young-Laplace equation. This study provides observational insight into pore-scale multiphase flow behaviors in porous media, and validates the pore network based approach for predicting flow behaviors.

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