SEMI-ANALYTICAL COMPUTATION OF THREE-PHASE CAPILLARY ENTRY PRESSURES AND ARC MENISCI CONFIGURATIONS IN 2D ROCK IMAGES

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Simulation models for three-phase flow in porous media require knowledge of the relation between three-phase capillary pressure and the saturations. Pore-scale modelling of three-phase capillary pressure in realistic pore geometries could increase the knowledge of three-phase displacement mechanisms and also provide support to time-consuming and challenging measurements.
We have developed a model for computing arc menisci configurations and capillary entry pressures during drainage and imbibition in straight tubes where the cross-sections are represented by pore space geometries in 2D rock images. The cross-sectional fluid configurations are computed accurately at any capillary pressure and wetting condition based on a menisci-determining procedure that identifies the arc menisci as the intersections of two circles moving in opposite directions along the pore boundary. The contact angle is defined at the front arc of the circles. Based on free energy minimisation (i.e., the MS-P method), capillary entry pressures are calculated for all allowed combinations of the identified arc menisci, from which the thermodynamically favourable fluid configuration is obtained.
In this work, the semi-analytical model is extended to allow gas invasion into oil and water saturated pore spaces under uniformly-wet conditions, assuming gas is non-wetting, oil intermediate-wetting, and water is the wetting phase. This development requires that the menisci-determining procedure is run three times, by viewing the gas-oil, oil-water and gas-water systems separately. The resulting three sets of circle intersections are then combined in all allowed ways to account for three-phase displacements in which gas invades both water and oil, and gas surrounded by an oil layer invades water simultaneously, as well as the pure two-phase displacements where gas invades either water or oil. By applying the three-phase extension of the MS-P method, which has been published previously for idealised geometries, the most favourable capillary entry pressure and corresponding fluid configuration are determined iteratively based on all allowed arc menisci combinations.
The model is validated by comparing computed entry pressures and corresponding three-fluid configurations with analytical solutions in idealized triangular and star shaped pores. It is demonstrated that the model accounts for all scenarios that has been analysed previously in these idealised shapes. Finally, three-phase entry pressures and associated configurations are computed in SEM images of Bentheim sandstone. Because these geometries are irregular and include constrictions, we identify displacements and gas entry configurations that have not been identified previously in pore-network models that are based on idealised pore shapes.