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Spatial characterization of wetting in porous media using local lattice-Boltzmann simulations

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Wettability is one of the critical parameters affecting multiphase flow in porous media. The wettability is determined by the affinity of fluids to the rock surface, which varies due to factors such as mineral heterogeneity, roughness, ageing, pore-space geometry, etc. It is well known that wettability varies spatially in natural rocks, it is still generally considered a constant parameter in pore-scale simulation studies. The accuracy of pore-scale simulation of multiphase flow in porous media is undermined by such inadequate wettability models.
The advent of in-situ visualization techniques, e.g., X-ray imaging and microtomography, enables us to characterize the spatial distribution of wetting more accurately. There are several approaches for such characterization. Most include the construction of a meshed surface of the interface surfaces in a segmented X-ray image and are known to have significant errors arising from insufficient resolution and surface-smoothing algorithms.
This work presents a novel approach for spatial determination of wetting properties using local lattice-Boltzmann simulations. The scheme is computationally efficient as the segmented X-ray image is divided into subdomains before conducting the lattice-Boltzmann simulations, enabling fast simulations. To test the proposed method, it was applied to two synthetic cases with known wettability and three datasets of imaged fluid distributions. The wettability map was obtained for all samples using local lattice-Boltzmann calculations on trapped ganglia and optimization on surface affinity parameters. The results were quantitatively compared with a previously developed geometrical contact angle determination method.
The two synthetic cases were used to validate the results of the developed workflow, as well as to compare the wettability results with the geometrical analysis method. It is shown that the developed workflow accurately characterizes the wetting state in the synthetic porous media with an acceptable uncertainty, and is better to capture extreme wetting conditions. For the three datasets of imaged fluid distributions, our results show that the obtained contact angle distributions are consistent with the geometrical method. However, the obtained contact angle distributions tend to have a narrower span and are considered more realistic compared to the geometrical method.
Finally, our results show the potential of the proposed scheme to efficiently obtain wettability maps of porous media using X-ray images of multiphase fluid distributions. The developed workflow can help for more accurate characterization of the wettability map in the porous media using limited experimental data, and hence more accurate digital rock analysis of multiphase flow in porous media.

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