Local wettability characterization of porous media under two-phase condition using lattice-Boltzmann simulations

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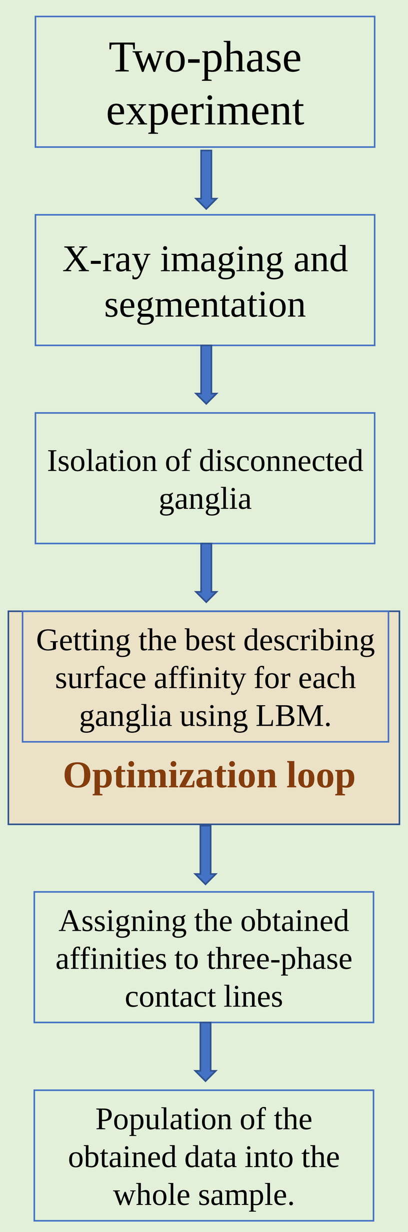
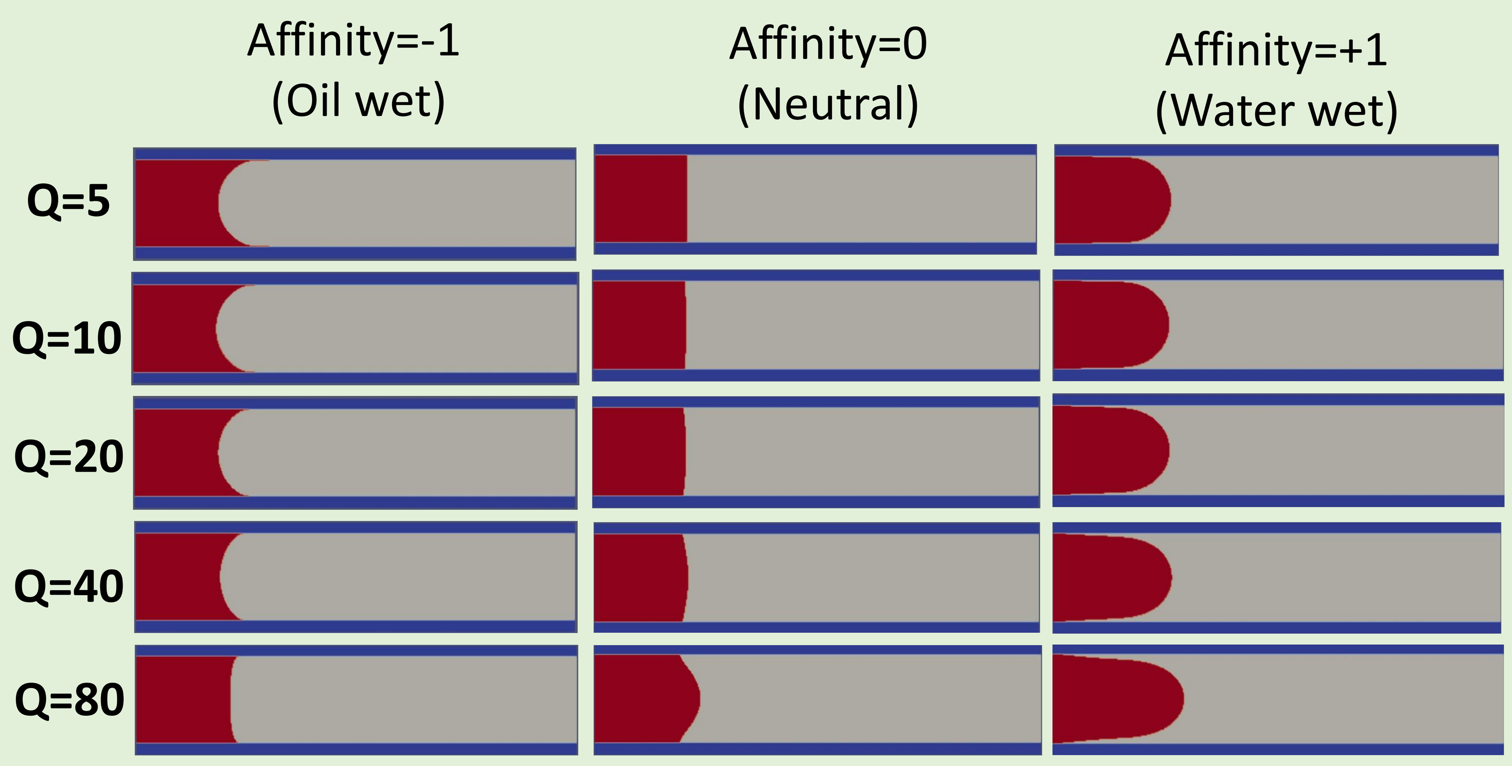
1. Introduction

- Wettability is a controlling property for multi-phase processes, and therefore an important input to simulate multi-phase processes in porous media [1]. Conventionally, wettability is assumed to be a constant property throughout the medium, despite the common knowledge that it is not uniform in natural porous media. Under two-phase conditions, every three-phase contact line conveys information about the local wettability [2].
- In this work we use µ-CT images of the distribution of two phases to assess the wettability. We isolate the three-phase contact lines, and then conduct local lattice-Boltzmann (LB) simulations to replicate the relaxed fluid configurations in the pore-space [3]. we take the affinity parameter of the LB color-gradient model as the tuning parameter and optimize the fluid configuration compared to the observation from the µ-CT data to obtain local wetting descriptions. We later assimilate all the obtained information from different parts of the µ-CT image and populate the final data into the whole sample. The obtained wettability map can be used to simulate displacement processes for the two given fluid phases in the imaged porous medium for digital rock physics analysis.

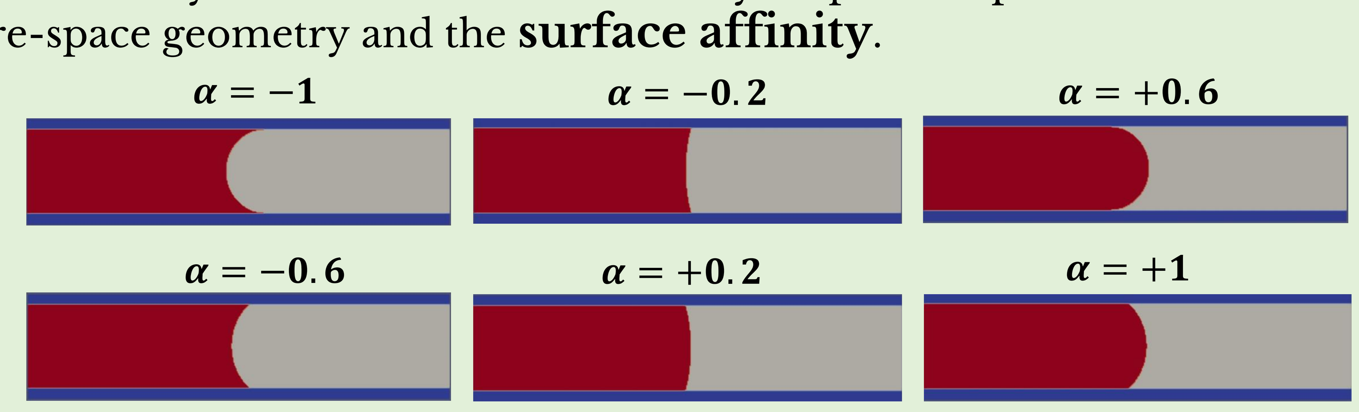
2. Methodology



Effect of flow rate on interface curvature (single capillary)



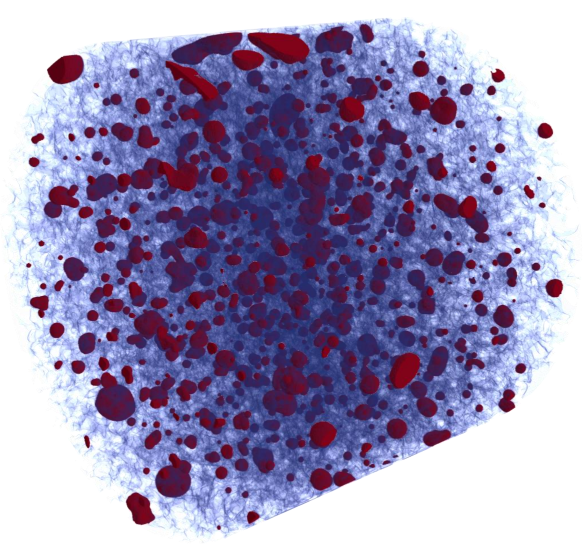
- To eliminate the effect of flow rate we consider the trapped ganglia which are stationary. In such scenario the only important parameters are the pore-space geometry and the **surface affinity**.



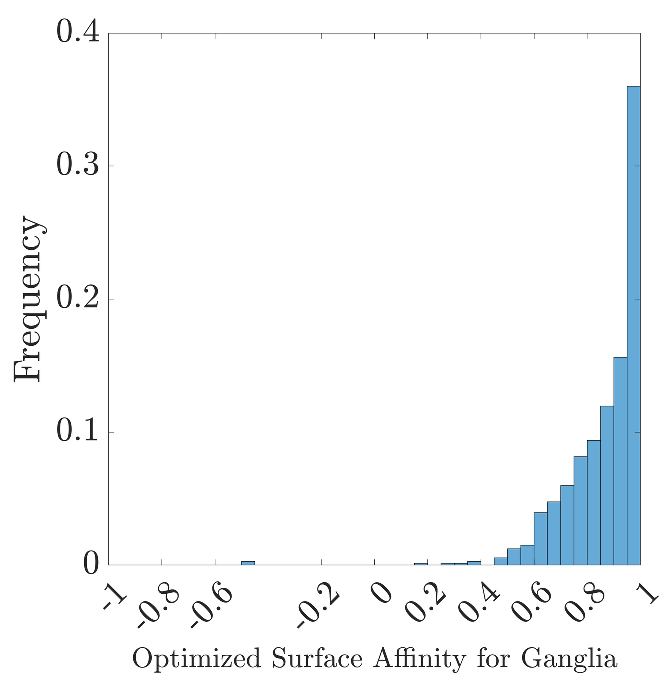
3. Simulation Results and Discussion

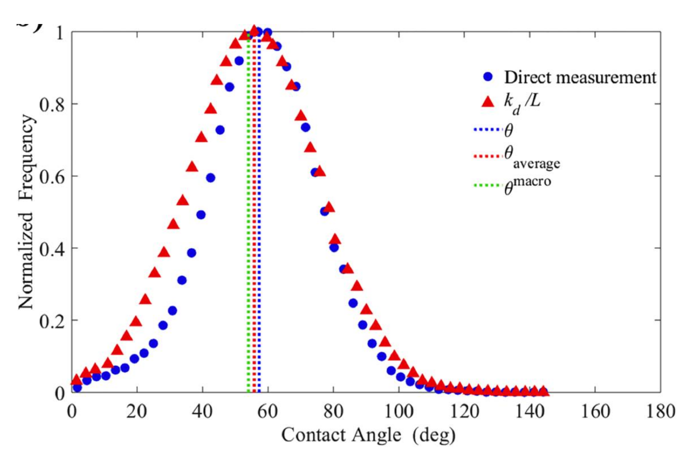
• Applying the workflow to gas-liquid sample.

To test the developed algorithm, we first applied it to a water-air system in Bentheimer sandstone. The primary drainage and imbibition experiments were performed by using air and brine. The images were acquired at irreducible air saturation S_w=94%. This dataset was previously used to characterize wetting in complex subsurface multiphase systems by using principles of topology and integral geometry as well [4].

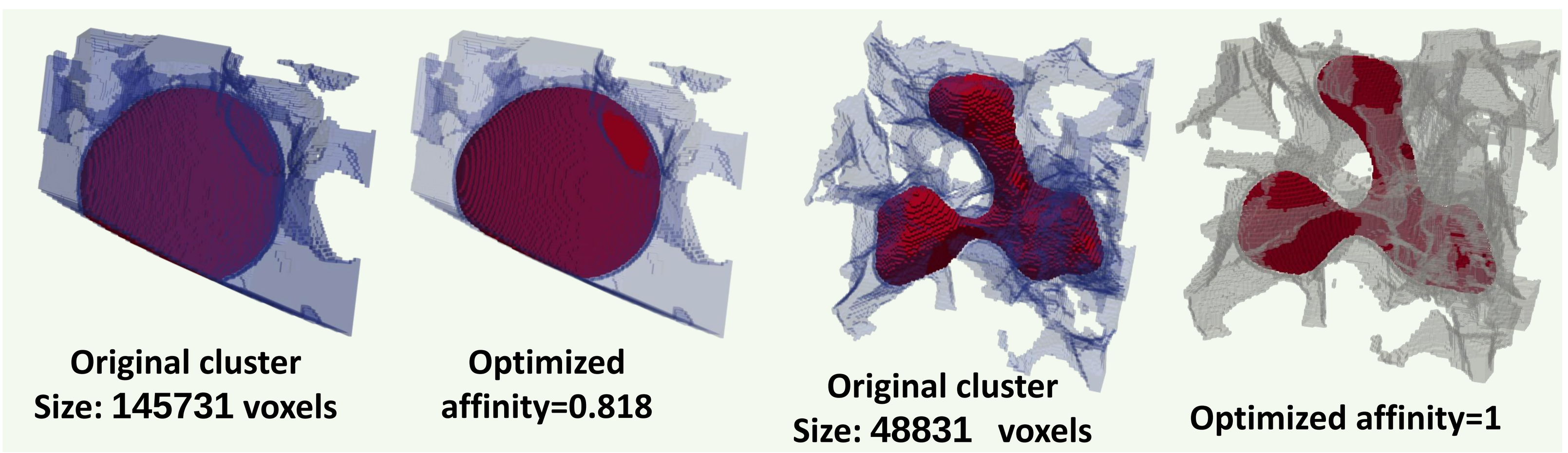


Total gas clusters: 980
Gas clusters after refining: 842



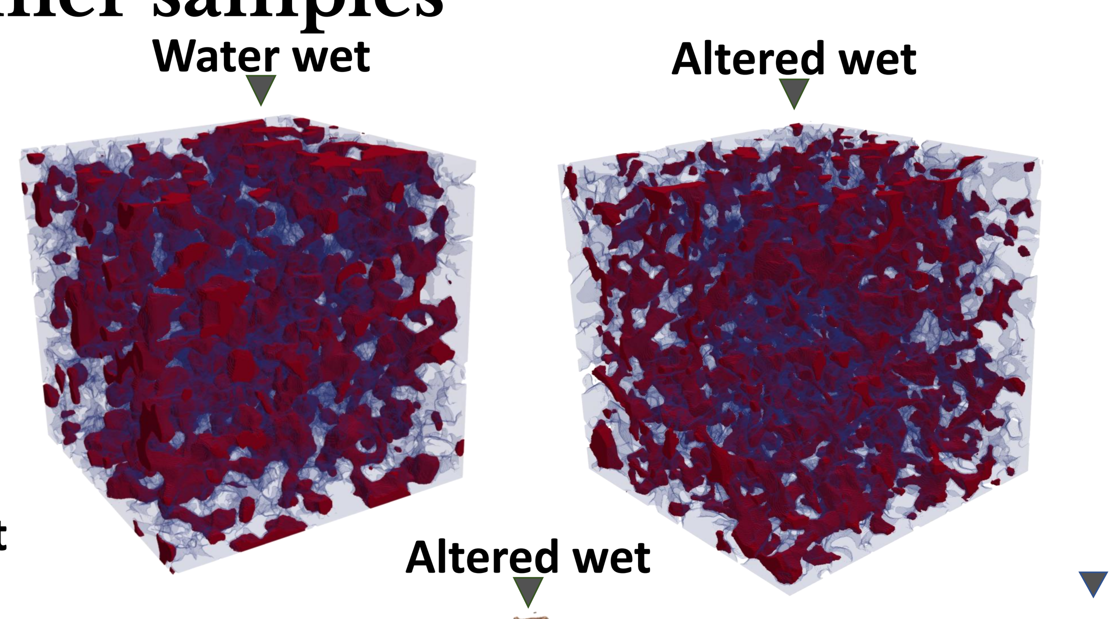


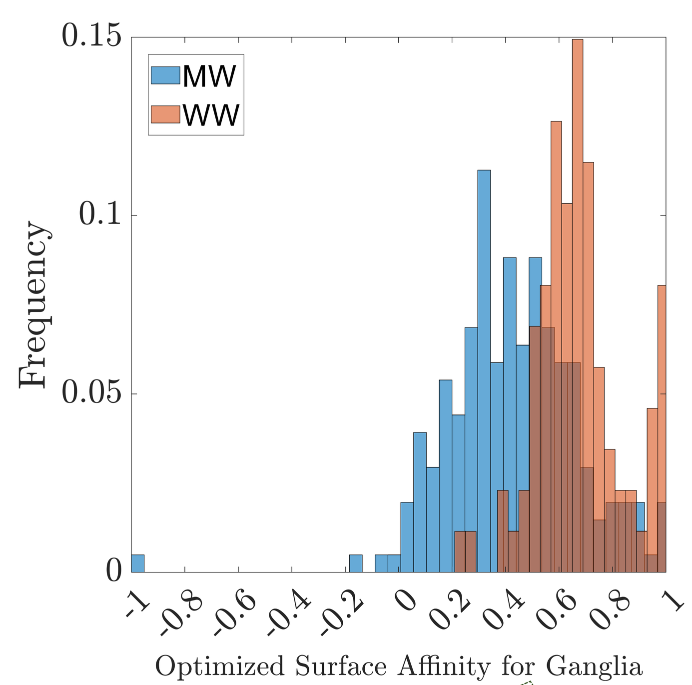
The normalized distribution of contact angle using local deficit curvature. The result is taken from Sun et al. (2019) [4].



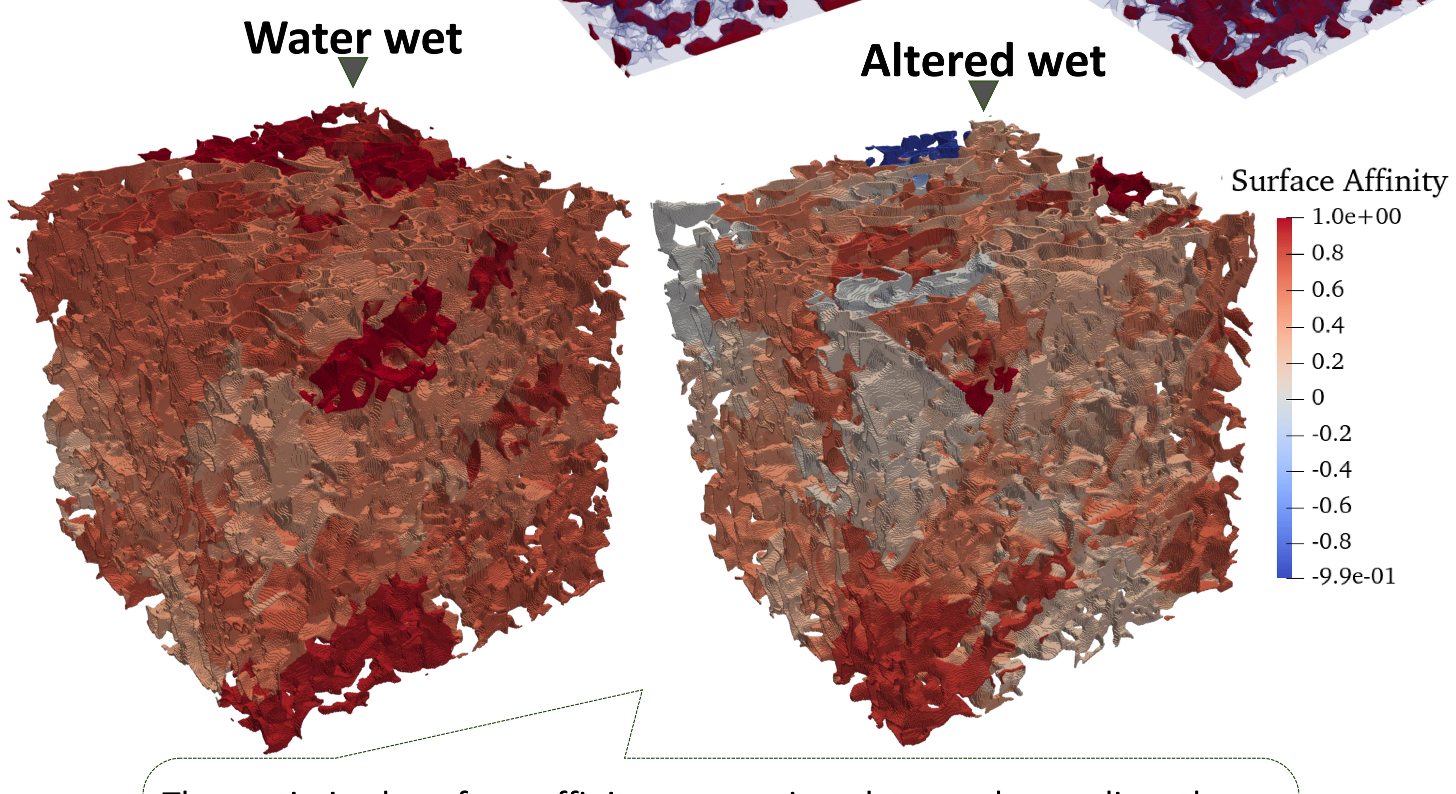
• Unaltered and Altered Bentheimer samples

In the next step, we applied the developed wettability optimization workflow into two Bentheimer sandstone under oil-water steady state two-phase flow [5]. In these experiments, the oil (Decalin) and water were injected in 1:1 volumetric ratio and the injection was conducted long-enough to reach steady state condition. Each subdomain was 400^3 voxel size. The water-wet and mixed-wet samples had 87 and 204 oil ganglia, respectively.





The obtained results show a distinct difference between the water-wet and mixed-wet samples. As expected, the mixed wet sample show a shift toward oil wetness.



The optimized surface affinity was assigned to each ganglion three-phase contact line. Then, the 3D linear interpolation was used to obtain the surface affinity for all solid-fluid voxels to obtain the wettability (surface affinity) map for the whole samples

4. Conclusions

- In this study we developed a new workflow to obtain the local wettability of rock samples under two-phase condition. The local lattice-Boltzmann simulations on individual ganglia were used to obtain the best describing surface affinity for each three-phase contact line.
- The developed workflow is computationally efficient as the simulation is run locally on each individual ganglion. It can also be parallelized easily as the simulations of different ganglia are independent of each other.
- The algorithm was used to get the special distribution of wettability in a sandstone using air-water fluid pair. For this case we obtained strongly water wet wetting properties as expected for air-water system.
- The spatial distribution of wettability was also examined on water-wet and mixed-wet Bentheimer samples using oil-water fluid pair and consistent results were obtained.

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7. References

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