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Investigating Capillary Pressure Behavior in Mudrocks through Grain Scale Modeling

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The capillary entry pressure (P_{ce}) and corresponding pore throat size control the thickness of an oil or gas column that may be sealed beneath a mudrock. Mudrock seals typically have nanometer-scale pore throats, and the P_{ce} often exceeds the minimum horizontal effective stress in these rocks. Mudrock seals can fail through fracturing either by buildup of fluid pressure or during faulting or folding, creating fractures with much smaller P_{ce} than the pore space, allowing hydrocarbon to escape. Understanding the factors at the grain and pore scale that influence P_{ce} is an important component of risk assessment and prospect evaluation.

Prediction of capillary pressure and relative permeability behavior is especially difficult in shaly sands and mudrocks as the sediments are usually heterogeneous mixtures made of disparate grains shapes and sizes. Mudrocks are primarily a mixture composed of silt (coarse) and clay (fine) grains. The porosity for a mudrock varies according to the fractions of these components, and the minimum porosity is achieved when clay particles occupy all the interstitial space between the larger silt particles (Daigle and Reece, 2014). Schneider et al. (2011) showed that silt bridging, in which silt-sized grains are present in an abundance sufficient to create a connected stress chain through the rock matrix, preserves large pore throats, thereby affecting the permeability as well as P_{ce} .

To simulate these effects at grain scale, bidisperse sphere packs were generated by a cooperative rearrangement algorithm for efficient packing with the ratio of larger to smaller spheres as 5:1. We varied the different sphere volume fractions to mimic mudrocks. The generated sphere packs were subsequently converted to pore throat models by employing Delaunay tessellation similar to Mehmani and Prodanovic (2014). Following Mason and Mellor's (1995) approach, an invasion percolation algorithm was applied to the models to generate drainage and imbibition capillary pressure curves and relative permeability curves.

It was observed that on successive increase of the fraction of larger spheres in a sphere pack, the capillary pressure curves displayed a dual percolation threshold behavior. This can be explained by larger pores being preserved adjacent to the spheres due to the silt-bridging effect as implied by Schneider (2011). These larger pores are responsible for the lower percolation threshold, while smaller pores between smaller grains give rise to the higher capillary threshold. Increasing the larger sphere fraction also decreased the residual water phase saturation, possibly due to the trapped phase escaping through the larger pores. This confirmed that the concentration and radius-ratio of the grains strongly affect the capillary pressure behavior in dual-component systems like mudrocks.

The next step in this project will be exploring the capillary behavior at different sphere-radius ratios and distributions, and for sphere packs generated by sequential addition under the effect of gravity. The principal application of this work is improved assessment of seal capacity from microstructural data in deep-water, subsalt environments. Ultimately this work may affect estimates of reserve capacity of reservoirs and risk management efforts in developing prospects by providing a more accurate understanding of seal quality.

References

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