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Calculation of Threshold Capillary Pressures from Irregular Pore Geometries Taken from Unconventional Reservoir Rock Images

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ABSTRACT

Unconventional reservoirs comprise a growing portion of producible reserves due to increasing knowledge of their nature as well as advances in production technology. Development of advanced pore network models has allowed accurate estimation of reservoir flow characteristics including relative permeability, saturation distributions, and capillary pressure. Although pore network modeling takes into account the pore throat connectivity and the appropriate fluid/solid properties, highly simplified pore cross-sectional shapes are still employed when estimating the threshold capillary pressure for a displacement in pore element. As a result, there is a growing need for better predictive models to estimate threshold capillary pressures based on real pore cross-section images. To this end, a modified semi-analytical model is presented that allows the prediction of threshold capillary pressure as well as the capillary pressure and saturation relationship within real pore geometries taken from unconventional reservoir rock images. The model reads pixelated images that are obtained using an X-ray nano-CT scanner and a focused ion beam scanning electron microscope (FIB-SEM). All possible arc menisci (AMs) in the pore cross-sections are identified using physical and geometrical criteria. Finally, thermodynamic analysis is performed to determine the most favorable fluid configuration among all possible scenarios. The presented model has a particular advantage in that it rigorously considers all fluid configurations during thermodynamic analysis, thereby allowing for the calculation of both local capillary pressures for subsections of a particular pore cross-section in addition to the global, pore threshold capillary pressure. The model was validated on three different idealized pore geometries and the results were compared against analytical solutions producing an error of less than 1% for all cases. In order to apply the model to pore geometries seen in unconventional reservoir rocks, fluid configurations were predicted and compared to nano-CT images from an oil imbibition sequence into a miniature shale sample. The capillary pressure versus wetting phase saturation relationship was also determined for a slice from FIB-SEM imaging. The presented model shows promise for enabling more advanced pore network modeling platforms to model flow through pore networks of ultra-tight reservoir rocks such as those in shale oil systems.