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An Image-based Micro-continuum Pore-scale Model for Gas Transport in Organic-rich Shale

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Gas production from unconventional source rocks, such as ultra-tight shales, has increased significantly over the past decade. However, due to the extremely small pores (~ 1-100 nm) and the strong material heterogeneity, gas transport in shale is still not well understood which poses challenges for predictive field-scale simulations. In recent years, digital rock analysis has been applied to understand shale gas transport at the pore-scale. A widely recognized issue with rock images (e.g., FIB-SEM, nano-/micro-CT images) is the so-called "cutoff length", i.e., pores and heterogeneities below the resolution cannot be resolved, which leads to two length scales (resolved features and unresolved sub-resolution features) that are challenging for flow simulations. Here we develop a micro-continuum model, modified from the classic Darcy-Brinkman-Stokes framework, that can naturally couple the resolved pores and the unresolved nano-porous regions. Gas flow in the resolved macropores is modeled with Stokes equation. For the unresolved regions where the pore sizes are below the image resolution, we treat them as a continuum and develop an apparent permeability model considering non-Darcy effects at the nanoscale including slip flow, Knudsen diffusion, adsorption/desorption, and surface diffusion. This leads to a micro-continuum pore-scale model that can simulate gas transport in 3D shale images. We present case studies to demonstrate the applicability of the model, where we apply the new micro-continuum model to 3D segmented FIB-SEM shale images that include four material constituents: organic matter, clay, granular minerals, and macropore. We populate the model with experimental measurements (e.g., pore size distribution of the sub-resolution pores) and parameters from the literature, and identify the relative importance of different physics on gas production. Overall, the micro-continuum model provides a novel tool for digital rock analysis of organic-rich shale.

References

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