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Quantifying Uncertainty in the Predictive Power of Multi-Scale Pore-Scale Modeling of Complex Microporous Media

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In this study, we explore the complex behavior of multiphase flows, exemplified by CO2 movement in underground reservoirs, within the context of heterogeneous porous media such as carbonate rocks. These materials display a wide range of pore sizes, posing significant challenges for imaging-based models due to the inherent trade-off between image size and resolution. Often, finer details are sacrificed in order to capture a comprehensive view of the pore structure in carbonates.

Addressing this issue, our approach involves the detailed analysis of sub-resolution porosity within X-ray images. We employ differential imaging techniques to highlight the differences between dry scans and scans of rocks saturated with 30 wt% KI brine. Building on this analysis, we have devised a novel workflow that integrates this sub-resolution porosity into a network model, using elements we refer to as 'micro-links.' These are based on Darcy's law and link each grain voxel, identified with sub-resolution porosity, to the nearest resolved pores through an automated dilation process.

Our modeling framework extends to both single-phase and multiphase flow simulations, incorporating these micro-links and corresponding empirical models. We have fine-tuned these models to ensure that our predictions regarding effective permeability, formation factor, and drainage capillary pressure are in line with experimental observations. The calibrated model is further employed to predict relative permeability, with a particular focus on quantifying the associated uncertainties.

Moreover, we aim to thoroughly investigate and quantify how microporosity influences fluid distribution and phase behavior within these porous media. This quantification of uncertainty is pivotal in evaluating our model's predictive accuracy and enhancing our understanding of multiphase flow dynamics.

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