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Multi-scale simulation study: integrated coupling of a steady-state two-phase dynamic pore-scale model with a reservoir simulator

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Pore-scale modeling using micro-computed tomographic images (digital rock technology) is a rapidly evolving approach to understand complex rocks such as carbonates and shale. One major challenge of digital rock technology is how it scales up to reservoir scales. We describe a multi-scale algorithm for coupling pore-scale network models into a reservoir model in real computational time. The algorithm is used to assess the impact of dynamic variables on reservoir oil recovery by allowing the pore-scale model to respond to transient events at the reservoir scale. In general terms, the reservoir simulator provides boundary conditions for the network model (pressure or fractional flows); the network model returns continuum properties (relative permeability) to the reservoir simulator. Examples that might benefit from a multi-scale algorithm include formation damage, precipitation/dissolution, stimulation (acidizing or hydraulic fracturing), factors associated with saturation history, and flowrate or viscosity ratio changes, and understanding why production history does or does not agree with the reservoir modeling predictions.

To achieve the coupling, we have developed a dynamic network algorithm that couples viscous forces and capillary forces. In contrast to most other dynamic models, we have developed boundary conditions that allow simulation of steady-state two-phase flow. The input to the pore-scale model is typically a high-resolution microCT image. We run the network simulator in steady-state mode even in the case of a transient displacement (at the reservoir scale) because time scales of a reservoir simulator are much larger than the typical time scale (order seconds) of a network simulator. In the demonstration case, two-phase dynamic network simulators are coupled to selected blocks in the reservoir and provide real-time two-phase flow properties to these blocks. Empirical formulas for two- phase flow properties are employed in the remaining blocks. Results (oil recovery ratio) are used to assess the impact of obtaining real-time two-phase properties. The computational efficiency of the simulation is governed by the efficiency of pore-scale network simulator. Hence, in the future, coupling may be possible in a larger number of gridblocks by running network models in grid blocks in parallel modes, or by using the results from selected blocks for other similar regions.