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Multiresolution Coupled Compositional Vertical Equilibrium Model for Fast Flexible Simulation of CO2 Storage

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CO_2 capture and storage is an important technology for mitigating climate change. Design of efficient strategies for safe, long-term storage requires the capability to efficiently simulate processes taking place on very different temporal and spatial scales. The physical laws describing CO_2 storage are the same as for hydrocarbon recovery, but the characteristic spatial and temporal scales are quite different. Petroleum reservoirs seldom extend more than tens of kilometers and have operational horizons spanning decades. Injected CO_2 needs to be safely contained for hundreds or thousands of years, during which it can migrate hundreds or thousands of kilometers. Because of the vast scales involved, conventional 3D reservoir simulation quickly becomes computationally unfeasible. Large density difference between injected CO_2 and resident brine means that vertical segregation will take place relatively quickly, and depth-integrated models assuming vertical equilibrium (VE) often represents a better strategy to simulate long-term migration of CO_2 in large-scale aquifer systems. VE models have primarily been formulated for relatively simple rock formations and have not been coupled to 3D simulation in a uniform way. In particular, known VE simulations have not been applied to models of realistic geology in which many flow compartments may exist in-between impermeable layers. In this work, we generalize the concept of VE models, formulated in terms of well-proven finite-volume reservoir simulation technology, to complex aquifer systems with multiple layers and regions. The result is a hybrid discretization strategy which couples different governing equations in different regions based on the correct local discretization of gravity and flow terms.

We also introduce novel formulations for multi-layered VE models by use of both direct spill and diffuse leakage between individual layers. This new layered 3D model is then coupled to a state-of-the-art, 3D equation-of-state compositional model. The formulation of the full model is simple and exploits the fact that both models can be written in terms of generalized multiphase flow equations with particular choices of the relative permeabilities and capillary pressure functions. The resulting simulation framework is very versatile and can be used to simulate CO_2 storage for (almost) any combination of 3D and VE-descriptions, thereby enabling the governing equations to be tailored to the local structure. We demonstrate the simplicity of the model formulation by extending the standard flow-solvers from the open-source Matlab Reservoir Simulation Toolbox (MRST), allowing immediate access to upscaling tools, complex well modeling, and visualization features. We demonstrate this capability on both conceptual and industry-grade models from a proposed storage formation in the North Sea. While the examples are taken specifically from CO_2 storage applications, the framework itself is general and can be applied to many problems in which parts of the domain is dominated by gravity segregation. Such applications include gas storage and hydrocarbon recovery from gas reservoirs with local layering structure.

References

https://arxiv.org/abs/1710.08735

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