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Methane Migration in Water Saturated Formations — Applications to CO2 Sequestration and Groundwater Contamination from Leaky Natural Gas Wells

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Target formations for large-scale CO2 sequestration are often saturated with brines that contain dissolved methane and other light hydrocarbons. When CO2 is injected in such deep formation, non-trivial phase behavior may result in methane exsolving from the brine and forming a free gas phase. Because methane has a lower viscosity than the (generally supercritical) CO2, this methane-rich gas is swept up ahead of the CO2 front. On the one hand, such a 'bank'of methane may provide an early tracer warning of the approaching CO2 plume, e.g. in observation wells. On the other hand, the emergence of gaseous methane poses risks of releasing a potent (greenhouse) gas contaminant in overlying groundwater and potentially the atmosphere if the formation integrity is compromised by (open) fractures, faults, or leaky wells.

The transport of methane in water-saturated formations is also important in the context of natural-gas production from deep reservoirs. If a producing well is compromised, e.g., at shallower depths, leaking stray natural-gas may contaminate groundwater resources. Whether this contamination occurs in a small radius around the well (due to buoyancy) or travels significant distances laterally before contaminating groundwater wells depends strongly on the formation heterogeneity, notably fractures.

The modeling of these important processes is complicated by 1) strong heterogeneity in fluvial target formations for CO2 storage and fractured groundwater aquifers, and 2) the complicated phase behavior of mixtures of water and hydrocarbons. The latter can be modeled accurately by the cubic-plus-association (CPA) equation of state (EOS), which takes into account the polar nature of water molecules, its self-association, and the polar-induced cross-association between water, CO2, and methane molecules (as well as compressibility of the aqueous phase). While accurate, the CPA EOS is highly non-linear and computationally expensive. In this work, we develop new efficient algorithms to adopt the CPA EOS for large-scale simulations. Flow and transport are modeled by the mixed hybrid and discontinuous Galerkin methods, respectively, and discrete fractures are incorporated through a cross-flow equilibrium approach.

Simulation results are presented for 1) the Cranfield large-volume CO2 storage pilot project, and 2) for lateral migration of stray methane leaking from a compromised natural-gas well into shallow fractured groundwater aquifers for conditions representative of those overlying the Barnett formation in Texas.

References

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