Numerical Modeling of Methane Migration from Leaky Natural Gas Wells and in Geological Carbon Dioxide Storage

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Target formations for CO_2 sequestration are often saturated with brines that contain dissolved methane and other light hydrocarbons. When CO_2 is injected in such deep formations, phase behavior may result in methane exsolving from the brine and forming a free gas phase. Because methane has a lower viscosity than the CO_2, this methane-rich gas is swept up ahead of the CO_2 front. On the one hand, such a `bank' of methane may provide an early tracer warning of the approaching CO_2 plume. 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 is also important in the context of natural-gas production from deep reservoirs. If a producing well is compromised leaking natural-gas may contaminate groundwater resources. Whether this contamination occurs in a small radius around the well (due to buoyancy) or travels significant distances before contaminating groundwater wells depends on the formation heterogeneity, notably fractures.

Modeling these processes is complicated by heterogeneity in fluvial formations for CO_2 storage and fractured groundwater aquifers, and complicated phase behavior 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, CO_2, and methane. While accurate, CPA EOS is highly computationally expensive. We develop new efficient algorithms to adopt the CPA EOS for large-scale simulations. Flow and transport and discrete fractures are modeled by higher-order finite element methods.

Simulation results are presented for 1) the Cranfield large-volume CO_2 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.