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Use of Analytical Solutions to Optimize Simulation of Multicomponent Three-Phase Displacements

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The conservation law for oil/water/gas flow in porous media can be highly sensitive to numerical dispersive effects, particularly in systems with substantial partitioning of components between the gas and oil phases. As a consequence, it is not typically possible to perform field-scale simulations with a sufficiently fine-grid to accurately model compositional displacements such as CO2 injection into oil fields for storage or enhanced oil recovery (EOR). The purpose of this study is to use analytical results to demonstrate the numerical errors in water and gas injection simulations in one dimension (1D) and to discuss the applicability of simplified models in obtaining an accurate simulated solution.

Recently analytical solutions have become available for simultaneous water and gas (sWAG) flooding for three-phase multicomponent compositional systems (LaForce and Orr, 2009). This work showed the surprising result that excessive water injection can interfere with the development of multicontact miscibility (MCM) between the oil and gas phases. Multicontact miscibility occurs when a combination of thermodynamics and flow through porous media cause the formation of a single hydrocarbon phase. When MCM occurs hydrocarbons are displaced from the reservoir much more efficiently than in an immiscible gas or water flood.

This presentation will compare and contrast the predicted displacements to a variety of models for sWAG flooding, including injection of water and a first-contact miscible (FCM) gas, three-phase compositional systems with developed miscibility and inert water (the aqueous phase contains only water, and water exists in only the aqueous phase) and compositional systems with developed miscibility in which all of the hydrocarbon components partition between all of the phases, but the water remains in the aqueous phase. Simulated solutions for each of the models are compared with the analytical solutions for various injection mixtures. This analysis can be used to determine when compositional simulation is necessary to achieve accurate results and when it is not worth the computational cost.

The key results of this work are:
1) In compositional models where water is inert the analytical displacements using MCM and FCM models are nearly identical. In this case, 1D simulations using the MCM model are less accurate than the simulations of the simpler FCM system due to increased numerical dispersion in the compositional displacement. In this case the FCM model should be used for simulation in the reservoir.
2) In compositional models where there is a substantial partitioning of hydrocarbons into the aqueous phase the presence of excessive water can cause miscibility to fail to develop in compositional systems. For these displacements use of the FCM model will give an incorrect displacement and the fully compositional model must be used in simulations. However, when miscibility is developed, numerical effects again cause the 1D MCM simulation to be less accurate than the FCM solution.

Reference:
LaForce, T., and Orr, F.M, Jr. (2009) “Four-Component Gas/Water/Oil Displacements in One Dimension: Part III Development of Miscibility,” Transport in Porous Media, 10.1007/s11242-008-9311-z