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Polymer Flood Modeling Using Streamlines—Part 1

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Abstract

The successful design of a polymer flood relies on the ability to properly model the distribution of polymer concentration in the reservoir while accounting for effects on fluid properties such as water viscosity increases as a function of in-situ polymer concentration and loss of polymer due to adsorption. Despite advances in numerical techniques and computer hardware, the numerical modeling of polymer floods using Eulerian-based approaches such as finite differences remains a challenge: coarse grids tend to excessively smear concentration fronts masking the true benefit of polymers, yet introducing finer grids inevitably leads to excessive run times that make using modern reservoir engineering workflows unrealistic. This problem was already outlined in 1978 by *Lake et al.* . We revisit the same problem 30 years later in the context of modern streamline simulation techniques.

In this work, we present the extension of modern streamline simulation to field-scale polymer flooding, which represents a step-change from the hybrid, 2D steady-state models used in the 1970's. We apply the well-established numerical modeling of polymer flooding to captured the displacement efficiency in 1D, and couple it with a three-dimensional (3D) streamline simulator to efficiently capture the inter-pattern sweep efficiency caused by well rate imbalances, reservoir architecture, and reservoir heterogeneity. Because modern 3D streamline simulators account for changing well rates, non-uniform initial conditions, and gravity, adding polymer functionality means that real-field polymer floods can be modeled with sufficient confidence to be useful and with the necessary speed to be used for modern reservoir engineering workflows that center on assessing uncertainty and risk associated with design parameters.

In this paper we proceed to outline the basic architecture of a streamline simulator with a polymer option. We discuss streamline-specific issues, such as the data that must be exchanged between the Lagrangian streamline grid and the underlying Eulerian grid to allow streamlines to be updated as production/injection conditions change. We discuss advantages and disadvantages of the formulation and present numerical experiments in 1D, 2D, and 3D to illustrate our results.

Modern Streamline Simulation

In 1981 (originally presented in 1978), *Lake et al.* introduced a hybrid streamline approach to model large-scale chemical floods. The motivation for their approach was that finite-difference simulators with detailed physical descriptions could not be used for large-scale simulations, while streamtube-models that could account for large-scale simulations were "seriously" deficient in displacement physics. To solve this dilemma, they proposed to solve detailed cross-sectional simulations using finite differences and then map these pseudo-solutions along areal streamlines as a way to predict field performance of a chemical flood. Surprisingly, 30 years later this motivation still holds and the dilemma remains. Today's modern reservoir engineering workflows require many forward simulations, and the computational load using finite-differences to accommodate such workflows, particularly under the use of advanced displacement physics and geostatistics-driven reservoir models is simply too high for field performance predictions and management. While the compute-power has increased many hundredfold since 1981, so have model complexities. Finding an efficient and sufficiently accurate modeling technique for chemical flooding remains an important target, particularly under the current economic conditions of ever increasing oil prices (near $140/bbl at the time of writing of this article), which have sparked renewed interest in surfactant/polymer flooding.

Modern streamline-based flow simulation differentiates itself from cell-based simulation techniques such as finite-differences and finite-elements in that components are transported along streamlines rather than moved from cell-to-cell. This difference allows streamlines to be extremely efficient in solving large, field-scale, and geologically complex models. The