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Modeling Non-Newtonian Polymer Flooding in Heterogeneous Carbonate Rock: An Experimental and Simulation Investigation

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Polymer flooding is a widely used chemical Enhanced Oil Recovery (EOR) technique in carbonate reservoirs that can decrease water-oil mobility ratio and thereby enhance sweep efficiency. However, the accuracy of simulating polymer flooding in porous media relies on integrated characterization on polymer properties, especially rheological behavior of polymer. The objective of this study is to accurately model and predict shear-thickening and shear-thinning behavior of polymer injection of heterogeneous porous media by incorporating Special Core Analysis (SCAL), bulk rheology test, injectivity test and coreflooding experiments.
This study started with integrated fluid and reservoir rock characterization. Injectivity tests and coreflooding experiments were then conducted, including sea water flooding and polymer flooding in low-permeability (20 mD) and high-permeability (200 mD) outcrops. The pre-constructed polymer coreflooding simulation model was history matched with experimental results and uncertain parameters were calibrated by optimizing key indicators reflecting polymer non-Newtonian behavior in porous media. The calibrated model was then used to model the polymer in-situ rheology and EOR performance in a heterogeneous core sample combining high-permeability and low-permeability layers. Nuclear Magnetic Resonance (NMR) technology was used before and after polymer flooding to confirm the pore size distribution affected by polymer injection.
Following the rock characterization study, the base simulation model M1 was incorporated with data on porosity, end-point water and oil permeabilities, and fluid viscosity. After polymer rheology and adsorption studies, the model was upgraded to M2, which displayed increased accuracy in polymer in-situ rheology and integrity affected by adsorption. Model M2 was utilized to history match base water and polymer oil displacement efficiency experiments, and the initial match degree was evaluated. Uncertain parameters, including apparent viscosity, Inaccessible pore volume, and relative permeability curve, were then adjusted by optimizing an objective function that included pressure drop, water breakthrough time, and cumulative oil production. After multiple iterations of history match, significant improvements in accuracy were observed in the calibrated model, which was then utilized to forecast polymer coreflooding performance in the heterogeneous carbonate core sample. However, the initial match was insufficient due to the complex crossflow of polymer solution between the high permeability layer and low permeability layer. Adjustments to the vertical permeability resulted in the final model M3, which achieved a high history match degree with experimental results.
In this investigation, A polymer that has both shear-thickening and shear-thinning features was modeled and calibrated step by step based on experimental results. The outcome was the creation of highly precise simulation models with the capability of providing forecasts for polymer in-situ rheological behavior, viscous fingering phenomenon, and EOR performance in heterogeneous carbonate rock. This methodology is instrumental in advancing our understanding of the mechanisms behind the non-Newtonian flow behavior of polymers in Darcy-scale porous media through integrated experimental and simulation investigations.

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