Modeling of Salinity Effects on Waterflooding of Petroleum Reservoirs

Modeling of Salinity Effects on Waterflooding of Petroleum Reservoirs

Smart Water flooding is an enhanced oil recovery (EOR) technique that is based on the injection of chemistry-optimized water with changed ionic composition and salinity into petroleum reservoirs. Extensive research that has been carried out over the past two decades has clearly demonstrated that smart water flooding can improve the ultimate oil recovery both in carbonate and sandstone reservoirs. A number of different physicochemical mechanisms of action were proposed to explain the smart water effects, but none of them has commonly been accepted as a determining mechanism. Most of the experimental studies concerning the smart water effects recognize importance of the chemistry of reservoir rocks that manifests itself in dissolution and precipitation of rock minerals and adsorption of specific ions on the rock surface. The brine-rock interactions may affect the wetting state of the rock and in some cases result in mobilization of the trapped oil.

In this thesis, we set up a generic model for the reactive transport in porous media to investigate how different mechanisms influence the oil recovery, pressure distribution and composition of the brine during forced displacement. We consider several phenomena related to the smart water effects, such as mineral dissolution, adsorption of potential determining ions in carbonate rocks, and mechanisms that influence mobilization of the trapped oil and its transport. Dissolution of minerals occurs due to the different compositions of the injected brine and the formation water that is initially in equilibrium with the reservoir rock. We consider a displacement process in one dimension with dissolution affecting both the porosity/permeability of the rock and the density of the brine. Extending previous studies, we account for the different individual volumes of mineral in solid and in solution, which is found to affect slightly the velocity of the displacement front. The rate of dissolution is found to have a significant influence on the evolution of the rock properties. At low reaction rates, dissolution occurs across the entire region between the injection and production sites resulting in heterogeneous porosity and permeability fields. Fast dissolution resembles formation of wormholes with a significant change in porosity and permeability close to the injection site.

Further, we study the mechanisms that can govern the mobilization of residual oil and its flow in porous media. The oil trapped in the swept zones after conventional flooding is present in a form of disconnected oil drops, or oil ganglia. While the macroscopic theory of multiphase flow assumes that fluid phases flow in their own pore networks and do not influence each other, the flow of disconnected oil ganglia requires an alternative description. We address this problem by considering a micromodel for the two-phase flow in a single angular pore-body.

On the micro-level, both fluids can be present in a single pore body and interact during the flow. Considering water-wet systems, we find that presence of the water on the surface of the rock and in the corner filaments of pore bodies results in a larger velocity of the viscous flow of the oil phase due to the increased area of the moving oil-water interface. Moreover, the flow of oil may be induced solely by the action of viscous forces at the oil-water interface, which appears to be a new mechanism for the transport of disconnected oil ganglia in porous media. We derive correlations that allow calculating the flow velocities of fluid phases in single pore bodies based on the pore fluid saturations. Based on the microscale considerations, we develop a macroscopic model of displacement accounting for the effects associated with oil ganglia.

The model is based on the assumption that wettability alteration toward increased water-wetness caused by the presence of active species in the injected brine results in formation of the wetting films on the surface of the rock. Oil ganglia are mobilized and carried by the slow flow of wetting films. Considering simplistic pore-network model, we derive the macroscopic system of equations involving description of the transport of oil ganglia. As a result of numerical modeling of the tertiary recovery process, it is found that production of oil ganglia may continue for a long time of injection of around 10 to 20 PVI.

Unlike the conventional models of chemical flooding, where mobilized oil bank travels ahead of the concentration front, the oil ganglia model predicts that the mobilized oil is produced after the active species reaches the effluent. Further extension of the model is achieved by introduction of the non-equilibrium alteration of wettability and non-instantaneous oil mobilization. Such modifications may explain the delay observed in some experiments, where mobilized oil is produced during a long time after several pore volumes of injection.

One of the possible chemical mechanisms through which the mobilization of the residual oil may occur in carbonates is alteration of the electrostatic potential of the surface. Reduction of the surface charge due to adsorption of the potential determining ions results in the decrease in oil affinity towards the surface of the rock. We establish a mathematical model that takes into account adsorption of the potential determining ions: calcium, magnesium, and sulfate, on the chalk surface, to investigate how the composition of the injected brine affects the equilibrium surface composition and how adsorption process affects the composition of the produced brine. We use experimental data on the produced brine composition from the flow-through experiments to estimate the parameters of the adsorption model. The computations suggest that there is no evidence of usually assumed stronger adsorption of magnesium ion compared to calcium at high temperatures. In order to investigate the effect of surface composition on the flooding efficiency, we combine the adsorption model with the Buckley-Leverett model and perform simulations of the experiments concerning flooding in the water-wet outcrop chalk. Computations of the equilibrium surface composition demonstrate a correlation between the concentration of the adsorbed sulfate and the ultimate recovery observed in the experiments indicating that a more negatively charged surface of chalk could be a factor that affects the recovery efficiency without wettability modification.

General information
Publication status: Published
Organisations: Department of Chemical and Biochemical Engineering, CERE – Center for Energy Ressources Engineering
Contributors: Alexeev, A.