Transport in Porous Media
https://doi.org/10.1007/s11242-020-01480-3

A New Multiscale Computational Model for Low Salinity Waterflooding in Clay Bearing Sandstones

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Received: 27 September 2019 / Accepted: 12 September 2020

Abstract
We develop a new multiscale model to compute effective properties such as relative permeability, contact angle and partition coefficients in low salinity enhanced oil recovery processes for two-phase flow in sandstones containing reactive surfaces of kaolinite clay. In this setting, we construct a three-scale approach which entails the local nanoscale description ruled by the electro-chemistry of a confined electrolyte solution containing Na^+, Ca^{2+}, H^+, Cl^- and OH^- ions residing between bounded crude-oil droplets at residual saturation and clay substrate. Our analysis focuses on the case of surface complexation geochemical reactions between the ionic species of the invading water and the electrically charged kaolinite and oil–water interfaces. In this scenario, we construct a local electric double layer problem for the electric potential based on a non-symmetric Poisson–Boltzmann equation supplemented by nonlinear boundary conditions with the magnitude of the surface charge strongly dictated by the geochemical reactions. By invoking the local mechanical equilibrium of the electrolyte solution and solving numerically the nonlinear problem using the finite element method, we compute the local ionic profiles and reconstruct numerically the disjoining pressure and adsorption isotherms for each ionic species for a wide range of brine compositions and pH of the water phase. Furthermore, combining the disjoining pressure results with the Frumkin/Derjaguin wetting theory allows to compute the dependence of the contact angle on wettability, pH and salinity. Subsequently, the formal homogenization procedure is adopted to upscale the pore-scale flow and ion transport to the macroscale giving rise to a new Darcy scale coupled flow/transport model. The hyperbolic part of the nonlinear homogenized model is solved analytically in an 1D example of enhanced oil recovery.

Keywords Low-Salinity · Enhanced oil recovery · Poisson–Boltzmann problem · Electrical double layer · Disjoining pressure · Contact angle · Relative permeability · Adsorption isotherms · Riemann problem

List of Symbols

C_{ib}	Ionic bulk concentrations for $i = \{Na^+, Cl^-, H^+, OH^-, Ca^{2+}\}$ (mol/m)^3
D_i	Water–ion diffusion coefficients for $i = \{Na^+, Cl^-, H^+, OH^-, Ca^{2+}\}$ (m^2/s)

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