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Wettability-alteration and Its Impact on Immiscible Two-phase Relative Permeability Induced by Nanoparticles Non-uniform Adsorption in Heterogeneous Porous Media

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Nanofluid injection has been reported as a promising technique to enhance oil recovery in tight reservoirs. However, research pertaining to nanoparticles (NPs) is primarily confined to laboratory experiments, thus the microscopic enhanced oil recovery mechanism behind nanofluid injection remains unclear. Therefore, it is imperative to establish a micro-scale research and analysis methodology for the nanofluid injection on macroscopic reservoir. This methodology aims to address strategically significant oilfield concerns, including: 1) NP non-uniform adsorption: The manner in which internal mineral composition, roughness, and distribution within porous media influence the non-uniform adsorption of nanoparticles, and how this non-uniform adsorption affects the microscale wettability of porous media. 2) Relative permeability: The heterogeneity in microscale wettability induced by nanoparticles and its impact on immiscible two-phase relative permeability of porous media.

In answering the question above, a novel, hybrid pore-scale simulation method using Lattice-Boltzmann (LB) coupled with Langevin-Dynamics (LD) is proposed to depict the motion behavior of NPs during immiscible two-phase displacement. In a fashion of discrete LB forcing source distribution, the LD method is introduced to characterize the effects of Brownian motion, thermal fluctuation-dissipation, and particle-particle interactions. An Eulerian-host algorithm is adopted to ensure the computational efficiency. Based on physical experimental data, NP surface properties are mathematically characterized. This coupling enables the dynamic and precise depiction of localized wettability alters within the pore-throats of reservoir. Combining with the application of statistical analysis theory, conditions governing the formation of oil-phase preferential pathways are examined, and oil/water permeabilities in tight reservoirs are calculated.

The hybrid LB-LD approach embedded experimental data and statistical analysis theory achieves the efficient-yet-rigorous characterization of SiO2 NPs wettability alteration behaviors from representative pore-throat structures of tight oil sandstones. The results indicate: 1) Nanofluids induce a state of strong dynamic wettability heterogeneity in reservoirs by locally altering wettability. It exhibits a linear relationship with NP concentration and water-swept-area. 2) The probability density distribution of wettability in porous media exhibits a bimodal normal distribution trend. As the injection of nanofluid increases (with Sw increasing from 0.2 to 0.9), the proportion of strongly water-wet surfaces (water-wetting angle of 165°) rises from 23% to 66%, while the proportion of strongly oil-wet surfaces (water-wetting angle of 30°) decreases from 59% to 27%. 3) Quantitatively characterize the mathematical relationship between the heterogeneity in microscale wettability distribution and macroscopic permeability in porous media. Propose a probability density equation for the distribution of microscale wettability in porous media following exposure to nanofluid.

Using the method above, the microscopic mechanisms of NPs in altering wettability is examined in detail. A quantitative relationship between nanofluid injection and strong wettability heterogeneity is established, along with a clear connection between wettability heterogeneity and the reservoir permeability. The results provide important guidance not only for the prediction of micro-wettability of porous media, but also for the optimization of injection condition so that optimum oil recovery can be achieved.

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Primary author: KE, Can

Co-authors: Prof. YUAN, Bin (China University of Petroleum (Huadong)); Prof. DAI, Caili (China University of Petroleum (Huadong)); ZHANG, Wei (China University of Petroleum (Huadong)); Mr LI, Yue (China University of Petroleum (Huadong))

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