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Microscopic mechanism investigation of counter-current imbibition in tight reservoirs using the Lattice Boltzmann method

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Tight oil reservoirs are typically developed through hydraulic fracturing to create a network of fractures, with counter-current imbibition between fractures and matrix playing a crucial role. However, during the counter-current imbibition process, as water displaces oil, it increases water saturation and leads to water blocking phenomena, resulting in reduced oil relative permeability and heightened flow resistance in the oil phase. The oil relative permeability is pivotal in determining the matrix's ability to elastically expel oil, rendering counter-current imbibition with both advantages and disadvantages. To quantitatively characterize the damage caused by counter-current imbibition in tight reservoirs, we employed the lattice Boltzmann method to simulate counter-current spontaneous imbibition in Jimsar tight rocks. We also introduced a novel method for assessing reservoir damage: the water-to-solid transformation method.

During counter-current imbibition, the water phase occupies the flow space of the oil phase, acting as a solid, consequently diminishing the oil's flow capacity. Given the challenge of calculating the relative permeability of two phases during counter-current imbibition, we transformed the water phase into a solid phase to construct a new digital core. This transformation allowed for the computation of unidirectional permeability, which was then used to characterize the reduction in oil relative permeability during counter-current imbibition. The study elucidates that the reduction in oil relative permeability in the digital core of Jimsar during counter-current imbibition is limited, ultimately establishing a relatively stable oil flow channel. This method facilitates the evaluation of the effectiveness of counter-current imbibition in reservoirs, enabling the implementation of appropriate improvement measures. Furthermore, a comparison between counter-current and co-current imbibition indicates that the water phase in counter-current imbibition only affects the oil phase near the fracture, without reaching the interior of the matrix. Nevertheless, the imbibition front of counter-current imbibition remains relatively stable, without significant fingering.

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