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Fast mass transfer processes of interfering trapped CO_2-clusters at reservoir conditions: Experiment and Theory

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The gas-to-oil ratio (GOR) of a reservoir fluid plays a critical role in optimizing oil recovery and oil production strategies, improving oil recovery efficiency, and predicting reservoir behavior. Understanding the complicated kinetics of multicomponent mass transfer at the pore scale after gas injection into petroleum reservoirs is of great importance for estimating GOR and enhanced oil recovery (EOR). However, to date, there is a significant gap in the fundamental process understanding of the complex mass transfer process at reservoir conditions. Using micro-CT technology, we investigate the time dependence of CO_2 mass transfer and cluster growth after high pressure CO_2 injection into sedimented porous media (sintered 0.2 mm glass beads). Surprisingly, the CO_2 partitioning equilibrium is already reached after 2 hours. To the best of our knowledge, such a fast CO_2 transport through water-saturated porous media, which cannot be explained by linear diffusion models (time scale 100 days for a diffusion length of 10 cm), has not been reported in the literature before. We proposed a conceptual model that assumes CO_2 inflation of interfering gas clusters drives cascading CO_2 transport. We verified this conceptual model through a time series of experiments at different initial gas saturation, analyzing in each case the spatial cluster distribution, cluster size distribution, and pore occupancy frequency.
Whether CO_2 inflation of the gas clusters occurs depends on the critical initial gas saturation, which is about 10%. Our main conclusion is that CO_2 migration should be considered as gas phase diffusion cascading along a quasi-percolating cluster, since CO_2 inflation leads to a high gas saturation of about 26%, which is close to the percolation threshold. Our experimental results support this physical hypothesis. We show for the first time that CO_2 clusters can expand over large pore spaces and thus are close to the critical percolation threshold (mobility threshold). The cluster size distribution can be described by a power distribution with the critical exponent 2.19, i.e., it shows *universal scaling*.
We model the interfering mass transfer processes of neighboring gas clusters with a multi-sphere model. Exploring different scenarios for the dissolution kinetics of an ensemble of interfering gas clusters allow a deeper understanding of the complicated mass transfer kinetics and agree well with experimental cluster analyses at specific times.