

Surfactant-enhanced carbon storage: Pore-scale insights from micro-CT imaging

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The large-scale implementation of carbon capture and storage (CCS) is essential for mitigating anthropogenic CO₂ emissions and achieving net-zero targets. While depleted hydrocarbon reservoirs offer promising storage solutions due to their proven containment integrity, maximizing storage efficiency through enhanced pore space utilization remains challenging. This study investigates the effect of surfactant-assisted CO₂ injection on storage efficiency at the pore scale using high-resolution synchrotron-based 3D microcomputed tomography. Experiments were conducted on sandstone from a depleted gas field under reservoir-relevant conditions (6–16 MPa, 80°C), spanning both gaseous and supercritical CO₂ phases. A nonionic surfactant at 0.05 wt% concentration was employed to reduce CO₂-brine interfacial tension (IFT) while maintaining reservoir compatibility. High-resolution 3D imaging enabled direct visualization of CO₂ distribution and displacement dynamics in the pore network. Results demonstrate that surfactant addition significantly enhanced storage performance by lowering CO₂-brine IFT and promoting CO₂ entry into smaller pore throats. At 6 MPa, CO₂ saturation increased by 30%, while at higher pressures (8–16 MPa), improvements of 12–17% were observed. The treatment also led to reduced capillary pressure and increased relative permeability (up to 25% enhancement). Gaussian curvature analysis revealed more uniform CO₂ distribution, minimizing capillary barriers and enhancing pore connectivity. These findings highlight the potential of surfactant-assisted CO₂ sequestration for improving injection efficiency and maximizing storage capacity in depleted reservoirs.