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Dissolution enhancement of injected CO_2 into entrapped brine in porous media

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Geological storage of CO_2 via injection into porous sub-surface formations is considered a promising solution for reducing carbon emissions into the atmosphere. Injected CO_2 in the pore space between rock grains can be trapped via several mechanisms, including structural and stratigraphic trapping, capillary trapping, mineral precipitation, and dissolution. Understanding the multiphase flow behavior and interaction between CO_2 and brine in porous media is of great importance to improve both storage capacity and accurate prediction of CO_2 fate over time.

In this study, we use microfluidic devices and a dual-camera microscopic particle image velocimetry (micro-PIV) setup to quantitatively observe the dynamic flow interaction between CO_2 and water within a 2D porous micro-model. A drainage experiment, wherein a water-saturated micro-model was infiltrated with liquid/supercritical CO_2, was performed at reservoir conditions. The velocity field of the water phase revealed the existence of flow circulation within otherwise static, trapped water ganglia. This motion is induced by shear from CO_2 flow at the CO_2-trapped water interfaces, and could have strong implications for dissolution and transport in CO_2 sequestration processes. Solubility trapping is typically treated as a process having its rate limited by molecular diffusion of dissolved CO_2 away from the CO_2-water interface. However, the observed pore-scale shear-induced circulation in trapped water ganglia and the concomitant advective transport will certainly enhance the dissolution rate beyond that simply associated with molecular diffusion; therefore these processes must be accounted for in pore-scale models relevant to geologic CO_2 sequestration. To quantitatively evaluate the impact of this flow-circulation effect on dissolution processes, we developed a numerical model by solving an advection-diffusion equation with a dynamic dissolution source term. In this model, the CO_2-water interface is treated as the fixed diffusion surface. The concentration of the dissolved CO_2 is then advected using the water velocity field measured directly from the micro-PIV experiment. The dissolution rate of CO_2 is described using a mass transfer coefficient, which is related to the Schmidt (Sc) number and Reynolds (Re) number of the flow circulation. The impact of flow circulation in the water ganglia on the dissolution process and transport of the dissolved CO_2 is assessed. In addition, the relationship between the intensity of this flow circulation (which is a function of the shear at the CO_2-water interface due to CO_2 flow) and the CO_2 dissolution rate is quantified. In this regard, the time scales associated with different trapping mechanisms, particularly solubility and mineral trapping, are expected to be affected substantially owing to the identified pore-scale flow dynamics.