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A Novel Microfluidic Approach to Quantify Pore-Scale Mineral Dissolution in Porous Media

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Mineral dissolution in porous media coupled with single- or multi-phase flows is pervasive in natural and engineering systems. In subsurface environments, the solid porous matrix is composed of various types of minerals, through which subsurface water flows. Dissolution of minerals occurs as chemicals in the solid phase are transformed into ions in the aqueous phase, effectively modifying the physical, hydrological, and geochemical properties of the solid matrix as well as the chemistry in the aqueous phase. These processes play a defining role in a broad range of applications such as carbon capture and sequestration (CCS), underground contaminant transport and vadose zone sciences. For instance, CCS is considered as a viable technology to reduce carbon emissions to the atmosphere, thus effectively mitigating global climate change. However, injection of CO₂ into geologic formations leads to dissolution of minerals, potentially comprising reservoirs rocks, and creating leakage pathways that threaten the safety and security of CO₂ storage. Therefore, to successfully model, predict, control, and optimize these many processes, a comprehensive understanding of mineral dissolution is crucial.

Mineral dissolution in porous media and pore flow are strongly coupled. On the one hand, pore flow plays a defining role in mixing and transporting the reactants to the reaction sites as well as transporting reaction products away. On the other hand, mineral dissolution modifies the porous media both structurally and chemically, in turn reshaping the pore flow. However, our fundamental understanding of this coupling effect at the pore level is still limited, leading to strong challenges in the effort of predicting mineral dissolution at much larger scales. To this end, mineral dissolution is studied in novel calcite-based porous micromodels under single- and multiphase conditions, with a focus on the interactions of mineral dissolution with pore flow. The microfluidic devices used in the experiments were fabricated in calcite using photolithography and wet etching. These surrogate porous media offer precise control over the structures and chemical properties and facilitate unobstructed and unaberrated optical access to the pore flow with μ PIV methods.

The preliminary results provide a unique view of the flow dynamics during mineral dissolution. It is observed that the local dissolution rate is strongly affected by the local pore flow, with much higher dissolution rate in fast flow regions and lower dissolution rate in slow flow regions. This process significantly reshapes the geometry of individual calcite grain, in turn posing feedback to the flow. Additionally, when HCl concentration is sufficiently high, the produced CO₂ emerges as a separate phase, leading to a multiphase flow. The separate CO₂ phase not only divert the HCl flow, but also shield the solid surfaces from further reaction, thus significantly modifying the local dissolution pattern and rate.

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References

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