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A quantitative study of the effect of pore-scale heterogeneity on MICP in meter-long microfluidic porous media analogues

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Microbially-Induced Calcium Carbonate (CaCO3) precipitation (MICP) has a great potential for soil improvement of granular soils as a more environmentally friendly alternative to traditional grouting technologies. The application of MICP in real geotechnical problems requires better engineering control of the spatiotemporal evolution of MICP. Moreover, the optimization of chemical reaction efficiency, which is defined as the percentage of injected calcium and urea that convert to calcite is necessary to avoid the waste of raw materials. In this study, we developed a setup to investigate the effect of pore-scale heterogeneity on the spatiotemporal evolution of MICP and the chemical reaction efficiency along distance from the injection point. Our novel setup combines meter long microfluidic devices of homogenous and heterogenous porous networks of same initial porosity, real-time video microscopy monitoring and pressure monitoring at the inlet and outlet. We applied the same MICP injection strategy to the two chips in triplicates; firstly, we introduced 6.7 pore volumes (PVs) of bacterial solution in the fully saturated chip with MilliQ water to achieve a uniform distribution in the whole chip. Subsequently, we introduced 6 PVs of calcifying solutions and monitored the evolution of bacterial concentration and crystal growth during the flow of the solution and 17h of no-flow conditions. A comprehensive algorithm was developed in Matlab to detect bacteria and crystals from time-lapse microscopy data at multiple positions along the meter-long trajectory. Thereby, we estimated crystal numbers and diameters and calculated the chemical reaction efficiency. We demonstrate that although the initial bacterial distribution was identical in the two chips prior to the injection of the calcium rich solutions, the average CaCO3 mass growth rate was overall higher in the heterogeneous porous medium. We observed that the peak of the average chemical reaction efficiency over the three replicates of the heterogeneous porous medium was in the middle of the reactive trajectory. Moreover, the efficiency remained higher in the heterogeneous than the homogeneous pore network at the second half of the meter-long path. This can be attributed to the intrinsic property of the heterogeneous microfluidic to consist of zones of higher and lower velocity, with the zones of higher velocity directing the reactants further downstream in the reactive path, leading to the nucleation of higher number of crystals that created larger crystal aggregates. This trend was different in the homogeneous microfluidic, where predominantly small single crystals were created which were not able to clog pore throats and attract more reactants, thus resulting in a lower efficiency. At the end of the injection of the calcification solution the permeability of the heterogeneous porous medium was decreased by 21.7%, while the reduction in the homogeneous porous medium was 5.7% lower.

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Participation

In person

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