Mathematical modeling of MICP in meter-scale 2D-D transient reactive transport experiments

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Data from meter scale laboratory experiments on microbially-induced calcite precipitation (MICP) were simulated by mathematical modeling of transient nonuniform multicomponent bioreactive transport in natural soil used in laboratory experiments. Flow in the cookie-shaped domain (“Tub”) was induced by pairwise injection-withdrawal periods that iterated among sequential pairings of two of the three wells used to control the hydraulics, and occurred in daily sets of high-Peclet ~1hr 3/4PV injections each followed by a 23hr reaction period of zero flow for 14 days. Two separate tubs were used in the experiment, one relying on biostimulation of native ureolytic bacteria and the other relying on bio augmentation with injected isolates. Both clubs were subject to the same hydraulic controls and aqueous chemistry boundary conditions that involved a mix designed to induce a moderated ureolysis rate which, in conjunction with the 14d injection-reaction sequence, was a strategy targeting uniform calcite precipitation within the domain over the 14d period. Internal and effluent sampling allowed for detailed data on aqueous chemistry, ureolysis, and calcite molar volume at different locations in space and in time. These data were modeled using PHT 3-D and COMSOL-iCP in parallel for cross-validation, and involved simulation of transient pressure boundary conditions inducing transient and nonuniform flow, alternatingly high- and low-Peclet transports with correspeondingly high- and low-Damkohler reactive transport. A parsimonious approach was taken in order to limit the number of fitted parameters to zero. Independent column experiments were used to ascertain an effective rate of ureolysis represented with single-Monod kinetics. All other reactions including precipitation were assumed at equilibrium. The assumption that all microbial growth partitioned into the aqueous phase with little subsequent filtration, which results in a solid phase-associated biocatalyst at effective steady-state, in conjunction with the foregoing treatment of the reaction network, provided for efficient and accurate modeling of the entire process leading to nonuniform calcite precipitation. This analysis suggests that microbial transport in natural ecosystem is not governed by filtration kinetics but is controlled largely by growth.