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Optimizing field-scale MICP with multi-scale micro-continuum OpenFOAM modeling

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Microbially Induced Carbonate Precipitation (MICP) through the urea hydrolysis reaction has been extensively studied in the lab and implemented at field-scale several times, most notably for fracture sealing (Cuthbert et al., 2013; Phillips et al., 2016), for erosion control (Gomez et al., 2015), and for ground improvement (van Paassen et al., 2010). Grouting strategies used in industry are commonly based on experience derived from the injection of Ordinary Portland Cement, (e.g. use of the split-spacing method). Field-scale injection strategies for MICP are likely to differ considerably from traditional cement grout injections as:

i. the low viscosity of the injection fluids allows near-surface grouting with minimal risk of ground heave and the potential for larger soil/rock volumes to be treated around each injection point,
ii. strength improvement occurs without complete permeability reduction and multiple injections are required to incrementally reach the desired strength and permeability,
iii. flow velocity (to control bacteria attachment), pH adjustment (to control CaCO3 saturation state), and temperature (to control the rate of ureolysis) may all be used to limit blocking of the injection points, and
iv. abstraction boreholes may be required for the removal of waste ammonium.

We present here a multi-scale micro-continuum MICP model implemented in OpenFOAM and solving fluid flow with the Navier-Stokes equations. The model is intended to inform the choice of injection strategy used in field-scale pilot projects and solves for 1) bacteria injection, velocity dependent attachment, and encapsulation within precipitating CaCO3; 2) re-agent transport, urea hydrolysis and CO3 production with Michaelis-Menten kinetics and 3) CaCO3 precipitation, porosity reduction, and subsequent flow path alteration.

In this model injections can be driven by a constant flow rate, constant pressure, or stepped flow rate and can be planar flow (e.g. for groundwater movement) as well as radial flow from/ to multiple injection/ abstraction wells. The model includes the ability to import 2D and 3D data from image analysis software ImageJ allowing X-ray micro-CT results from lab scale experiments to be modeled (at pore or micro-continuum scale) for validation purposes, and for heterogeneous site conditions to be modelled (at continuum-scale). A parametric sweep function is included to assess sensitivity to the choice of parameter values.

Results show that grouting with MICP is fundamentally different to grouting with cement. Operators may wish to replace sequential injection through a series of boreholes with simultaneous injection through multiple boreholes, or use abstraction boreholes to both collect waste ammonium and direct the transport of MICP re-agents.

References

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