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Microbially driven fracture sealing for inhibiting contaminant transport at the field scale

Lindsay McMillan (1), Mark Cuthbert (1), Michael Riley (1), Stephanie Handley-Sidhu (1), Dominique Tobler (2), and Vernon Phoenix (2)

(1) Water Sciences (Hydrogeology), School of Geography, Earth and Environmental Sciences, University of Birmingham, Birmingham, B15 2TT, UK., (2) School of Geographical and Earth Sciences, University of Glasgow, Glasgow, G12 8QQ, UK.

Successful implementation of subsurface carbon storage and nuclear waste containment schemes relies on transmissivity reduction through the sealing of fractures in the surrounding rocks. Effective transmissivity reduction in fine scale features is difficult to achieve using traditional high viscosity cement grouts injected at high pressures. However, laboratory scale studies suggest microbially induced calcite precipitation (MICP) can provide a low-viscosity alternative.

The first field trials of MICP in fractured hard rock were carried out in a multiple borehole array by using the ureolytic bacterium Sporosarcina pasteurii. Flow at depth at the experimental site is dominated by a single fracture. Injection of the bacteria in parallel with a 'cementing fluid' of urea and calcium chloride was used to fix the bacteria in the subsurface. Subsequent flushing with the cementing fluid alone drove further ureolysis and calcite precipitation. Calcite precipitation is eventually limited by crystal growth preventing interaction of the accumulated bacteria with the cementing fluid; repeated bacteria injections are necessary. Coupled equations for bacterial and urea transport, bacterial accumulation, and calcite production were used to model the field trial numerically and gave excellent agreement with field data. While a significant reduction in the transmissivity of the fracture was achieved over several m2 the modelling results suggest challenges remain in encouraging aperture reduction at a distance from the injection borehole due primarily to cementation and clogging around the bacteria injection hole.

A further borehole array at the same site provides the opportunity for additional experiments informed by the promising initial results. Models of a number of alternative bacteria and cementing fluid injection schemes have been created using the geometry of the new borehole array. These models have been parameterised using the calibrated model from the initial field trial. Scenario testing suggests that using separate boreholes for bacteria injection and the subsequent cementing fluid flush can help prevent injection hole clogging. Flushing the injection hole with fresh water during the cementing stage may also help to reduce clogging by acting as a hydraulic barrier to the cementing fluid.

While scenario testing has provided some alternative strategies, uncertainty surrounds particularly the relationship between urea concentration and bacterial accumulation and the rate limiting effect of calcite crystal growth. Short duration field trials are planned to reduce this uncertainty and improve the injection scheme design for a subsequent full-scale field trial. The lessons learned from these short trials will also be presented.