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Monitoring bacterially induced calcite precipitation in porous media using MRI and NMR flow measurements

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Fractures in rocks originate when external forces such as thermal stresses and high fluid pressures place strains on weakened areas. The size of these fractures can vary enormously; they are important to various geotechnical and hydro-geological engineering processes due to their ability to affect fluid flow via creation of what are effectively local high permeability regions. In this study we consider using calcium precipitation to plug such fractures and natural pores such that the rock provides impermeable containment of injected fluids.

Traditionally such porous media hydrodynamics are monitored using tracer tests and the resultant breakthrough curves following tracer injection. Here we apply various Nuclear Magnetic Resonance (NMR) techniques to provide both non-invasive and non-intrusive measurements of flow and transport in various porous media with and without fractures. This is predominately achieved using NMR *propagator measurements*, which are probability distributions of fluid displacement. The non-fractured porous media considered were (i) a 100 μm borosilicate ballotini packing, (ii) Bentheimer sandstone and (iii) Portland carbonate rock. Cylindrical rock cores or bead packings of diameter 37 mm and length 60-105 mm were used. All measurements were performed on a horizontal-bore Bruker AV 85 magnet with a magnetic field strength of 2 T. Displacement propagator measurements were performed using the alternating pulsed gradient stimulated echo (APGSTE) [1] pulse sequence as a function of both observation time (0.1 to 2 s) and flowrate using deionised water (7 - 45 ml/min). These measurements also featured the use of slice selection to avoid contributions from entry effects. It was shown through modification and variations of the calcite precipitation treatment that differences in the calcite fill would occur but all methods were successful in blocking the different porous media. Precipitation was seen to occur predominantly at the inlet of the bead pack, whereas precipitation occurred almost uniformly along the sandstone core. The evolution in propagator shape as a function of either an increasing fluid flowrate or observation time was shown to be sensitive to porous media, quantifying the local effect of calcite formation on system hydrodynamics and the extent of stagnant region formation and supplementing conventional permeability measurements.

Collectively, the combination of NMR measurements utilised here provides a toolkit for determining the efficacy of a biological-precipitation reaction for blocking porous materials.

[1] R.M. Cotts, M.J.R. Hoch, T. Sun, and J.T. Markert, Pulsed field gradient stimulated echo methods for improved NMR diffusion measurements in heterogeneous systems. **83** (1989) 252-266.