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Optimization of Treatment Techniques for Up-scaling of Stimulated Ureolytic Microbially-Induced Calcite Precipitation

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Bio-mediated ground improvement technologies harness subsurface biological and chemical reactions to improve the engineering properties of soils with reductions in detrimental environmental impacts when compared to conventional methods (Seagren and Aydilek 2010; DeJong et al. 2013). One such technology, Microbially Induced Calcite Precipitation (MICP) or bio-cementation, has received significant recent attention and leverages the biologically-mediated hydrolysis of urea by soil microorganisms to enable the precipitation of calcium carbonate (Ferris et al. 1996). The process can bind soil particles at particle contacts and coat particle surfaces resulting in large increases in soil shear strength and stiffness with simultaneous reductions in hydraulic conductivity and porosity (DeJong et al. 2006; Phillips et al. 2016).

Although MICP has been most commonly performed using the injection of non-native bacteria containing urease enzymes, such as Sporosarcina pasteurii, more recently researchers have shown that bio-stimulation, or the enrichment of native ureolytic microorganisms in-situ, can achieve comparable microbial ureolysis rates and successful completion of the MICP process (Fujita et al. 2000). For example, Gomez et al. (2016) demonstrated that similar improvements in calcite contents and engineering properties could be achieved using either stimulated indigenous or S. pasteurii microorganisms to complete bio-cementation in meter-scale experiments. More recently, Gomez et al. (2018) showed that native ureolytic microorganisms capable of completing the MICP process could be successfully enriched at treatment depths near 12 meters in gravelly sands.

Despite significant advances in stimulated ureolytic MICP, treatment techniques have not rigorously attempted to minimize reagent consumption. Instead, stimulation techniques have targeted fast ureolysis rates indicative of successful enrichment and cementation techniques have largely provided urea in excess of calcium to complete precipitation under calcium-limited conditions. While perhaps effective from an engineering performance standpoint, reductions in process reagent consumption and related environmental impacts are critical if the technology is to become environmentally and financially feasible for field-scale applications.

In this study, a series of soil column experiments were completed to explore the effectiveness of treatment techniques involving significant reductions in urea and calcium consumption. PHREEQC geochemical modelling was used to identify chemically feasible treatment strategies to be investigated experimentally. First, a soil column experiment was completed to explore large reductions in urea concentrations during cementation. Tests considered urea-to-calcium ratios ranging from 1.4, used in previous tests, to 1.0, believed to offer the theoretical best chemical efficiency. Following this investigation, a second column experiment was performed to examine the effect of urea concentrations on microbial enrichment during stimulation. Although previous experiments identified the importance of solution pH, yeast extract, and ammonium on ureolytic enrichment, it was not clear if reductions in urea during stimulation would influence obtained ureolysis rates. Columns were monitored in time using aqueous chemical and non-destructive geophysical measurements, and geotechnical and calcite content measurements were obtained following all treatments. The effect of reagent reductions on obtained engineering properties, microbial ureolytic enrichment, chemical reaction kinetics, and process environmental impacts was evaluated. The results provide critical information needed to optimize treatment techniques and reduce process environmental impacts for future upscaling of stimulated ureolytic MICP.

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Primary authors: Ms SAN PABLO, Alexandra C.M. (Department of Civil and Environmental Engineering, University of California, Davis); Mr GRADDY, Charles M.R. (Department of Microbiology and Molecular Genetics, University of California, Davis); Dr GOMEZ, Michael G. (Department of Civil and Environmental Engineering, University of Washington, Seattle); Prof. DEJONG, Jason T. (Department of Civil and Environmental Engineering, University of California, Davis); Prof. NELSON, Douglas C. (Department of Microbiology and Molecular Genetics, University of California, Davis)

Presenter: Ms SAN PABLO, Alexandra C.M. (Department of Civil and Environmental Engineering, University of California, Davis)

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