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Removal of ammonium by-products from the effluent of bio-cementation system through struvite precipitation

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ABSTRACT

Microbial induced carbonate precipitation (MICP) (also referred to as bio-cementation) is an innovative soil improvement technology, introduced through Bio-mediated Geotechnics. During the process, supplied microorganisms hydrolyze urea, resulting in the formation of calcium carbonate. The precipitates tend to cement the soil particles at particle contacts and enhance the strength of the matrix. Despite the considerable interests in MICP, one major hurdle that hinders the field-scale applications is related to the production of ammonium during the process. The objective of this study is to evaluate the feasibility of struvite ($NH_4MgPO_4{\cdot}6H_2O$) precipitation to eliminate the ammonium from the reaction effluent system. For this purpose, the study is considered in two stages: (i) rinsing the ammonium from the sand, and (ii) precipitating ammonium as struvite. In the first-stage, the conditions of rinsing are studied to optimize the removal of ammonium from the soil. In the second-stage, influences of pH conditions, molar ratio and calcium ions on the precipitation of struvite are evaluated. The study demonstrates, through the struvite precipitation technique, around 90% of ammonium could be removed from the effluent. Finding also suggests that the molar ratio (NH_4^+: Mg^{2+}: PO_4^{3-}) of 1: 1.2: 1 provides a desirable environment for appropriate removal.

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1. Introduction

Bio-mediated Geotechnical Engineering is an emerging research field that has high potential to solve several geotechnical problems. The bio-mediated techniques sustainably employ the use of biological substances such as microorganisms or their functional extracts (i.e., enzymes) for the improvement of mechanical properties of soil. Microbial induced carbonate precipitation (MICP) is the mostly investigated bio-cementation technique, which utilizes the energy-efficient ureolysis to precipitate the calcium carbonate bio-cement [1-4]. The process of carbonate precipitation occurs through a set of chain reactions given in Eqs. 1–3. At first, augmented or stimulated ureolytic bacteria catalyst the hydrolysis of urea and produces the carbonate, ammonium and hydroxide ions, which leads to the increase in the alkalinity of the pore fluid. When calcium ions are available from either treatment solutions or groundwater, the pore fluid is supersaturated with respect to calcium carbonate, and the precipitation is desirably induced within the embedded soil matrix.

$$H_2N - CO - NH_2 + 2H_2O \xrightarrow{\text{ureolyticbacteria}} H_2CO_3 + 2NH_3 \quad (1)$$

$$NH_3 + H_2O \leftrightarrow NH_4^+ + OH^- \quad (2)$$

$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3(\downarrow) \quad (3)$$

Precipitated calcium carbonate binds the soil particles at particle contact points and densifies the soil by reducing the void ratio [5,6]. Number of studies demonstrated that the MICP treated soils exhibit significant increase in shear strength, unconfined compressive strength (UCS), stiffness and dilative properties [7-9] and fractional decrease in permeability due to the reduction in pore throat size and voids space [10]. In fact, the MICP is often documented as environmentally superior to chemical grouting which are potentially hazardous [11]. For example, Portland cement, the typical

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