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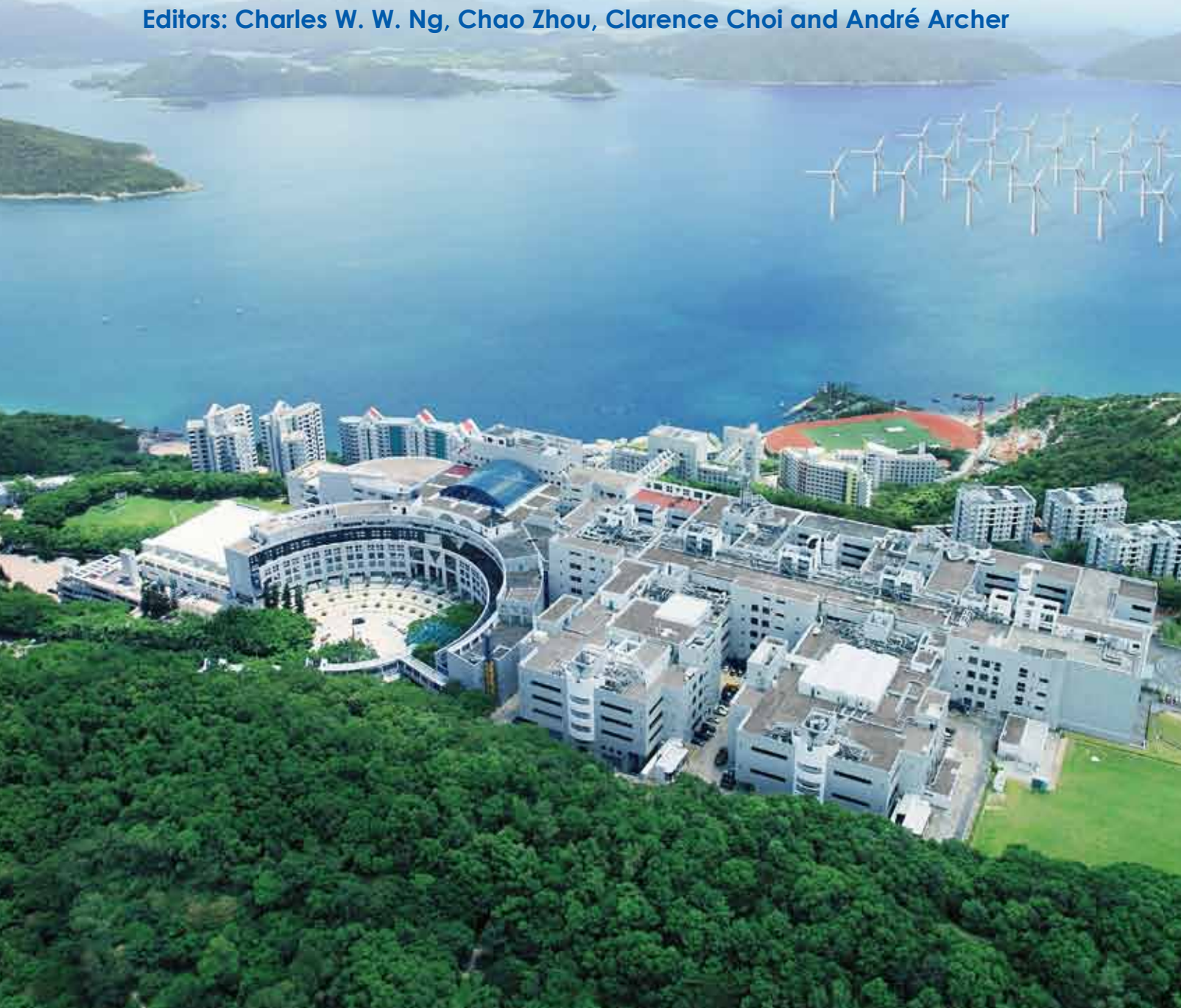

PORE-SCALE STUDY OF MICROBIAL-INDUCED CALCIUM CARBONATE PRECIPITATION

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BRIEF INTRODUCTION, METHODOLOGY AND KEY RESULTS

Microbial-induced calcium carbonate precipitation (MICP) is potentially a new innovative soil improvement technique. MICP is capable of increasing the shear strength and stiffness of soils, and decreasing the hydraulic conductivity of soils (Whiffin et al., 2007; Al Qabany et al., 2012; Montoya and DeJong, 2015). However, the precise roles of the microbes in the carbonate precipitation process and the mechanisms that are responsible for the observed deposition of carbonate in soil pores are still not clear (van Paassen et al., 2010). In this study, micromodel experiments were conducted to visualize small-scale physical, chemical and biological processes of MICP.

Sporosarcina pasteurii (ATCC 11859), a ureolytic bacteria strain for MICP, was cultivated in the ATCC1376 NH_4-YE medium at 30 °C (Mortensen et al. 2011) and stained by a nucleic acid stain SYTO-9 to be fluorescent and still alive after staining (Schultz et al.,2009). The optical density (OD) of 600 nm (OD_{600}) was measured by a spectrophotometer to quantify cell density. A 2-D porous Polydimethylsiloxane (PDMS) micromodel was manufactured as a representative of the porous soil matrix (e.g. Karadimitriou and Hassanizadeh, 2012). Cementation solution consisting of 0.1 M $CaCl_2$, 0.1 M urea and 0.3 mg/mL nutrition bust were prepared. In order to observe the transport of bacteria in the micromodel and to study the effects of injection of a later phase on the previous phase, a multiple-phase injection was conducted. First bacteria were injected into the PDMS micromodel at the injection rate of 0.5 mL/h. Then the cementation solution was injected into the micromodel, followed by another injection of bacteria suspension. The time interval between each injection phase is 30 mins.

Figure 1 is an image after the first time of injection of bacteria suspension and cementation solution. It can be seen that there were interfaces between these two phases of liquid. The injection of cementation solution pushed the bacteria suspension forward towards the outlet zone of the microfluidic chip. In the interface of bacteria suspension and cementation solution, calcium carbonate precipitated. Figure 2 is an image after the second time of injection of bacteria suspension. The cementation process had already begun during the injection phase in the inlet zone of the microchip. As the calcium carbonate was in a non-stable stage, it was flushed and it transported in the porous media. It can also be seen from Figure 2 that less calcium carbonates were produced on the top of the chip, as there was a gas bubble on the top left corner of the microchip, which stopped the transport of either bacteria suspension or cementation solution there. This means gas bubbles, which commonly present in natural soils, may have effects on the uniformity of the

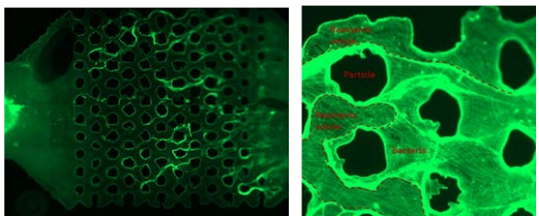

Figure 1: Imaging after the first time injection of S. pasteurii suspension and cementation solution

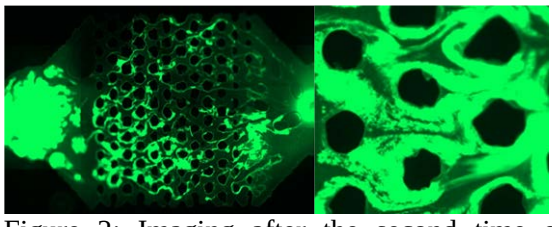

Figure 2: Imaging after the second time of cementation solution injection

distribution of calcium carbonate in the porous media. The work is currently extended to find an optimum injection process of bacteria and cementation solution in order to maximise the efficiency of MICP.

CONCLUSIONS

1. A 2-D porous PDMS transparent micromodel and bacteria florescent staining were used in this study. These two techniques together offer a good way for microscale study of MICP in the porous medium.
2. The bacteria suspension, cementation solution and gas bubbles compose the multiple phases in the porous medium. The injection of cementation solution pushed the bacteria suspension forward to the outlet of the chip and on the interface of these two liquid phases calcium carbonate precipitated. The precipitated calcium carbonate within the first a few minutes are in an unstable phase, which can transport through the pore throats in the porous micromodel. Gas bubbles stopped the transport of bacteria suspension or cementation solution, influencing the uniformity of the distribution of precipitated calcium carbonate. The next phase of injection of cementation suspension pushed the unstable phase of calcium carbonate, which may be good for increasing the injection depth of carbonate cementation.
3. In this paper, the injection intervals were not long enough for $CaCO_3$ to become the stable phase. Experiments of longer time will be conducted to analyse the effects of injection intervals on MICP efficiency. Also, other factors such as concentration of cementation solution and flow rates will be considered in future work to optimise the MICP process.

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