Bacterially mediated morphogenesis of struvite and its implication for phosphorus recovery

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ABSTRACT

Bacterially mediated struvite usually crystallizes as unusual morphologies. To better understand the relationship between growth habit of struvite and bacterial activity in struvite biomimetic mineralization process, Shewanella oneidensis MR-1 was selected as a model microbe to induce struvite mineralization in the synthetic sludge liquor. A combination of bacterial and biomimetic mineralization strategies was adopted. Different bacterial components were isolated from the cultures by a set of separation techniques, and used to influence struvite crystallization and growth. The identification and characterization of the mineralized products were done using XRD, FTIR, FESEM, TG-DTA, XPS, and elemental analysis. Bacterial mineralization experiments demonstrated that S. oneidensis MR-1 cannot only trigger mineralization and growth of struvite, but also mediate the specific morphogenesis of struvite. Biomimetic mineralization experiments revealed that different bacterial components had different effects on struvite morphology, and low molecular-weight peptides secreted by the bacteria played a dominant role. Current results can provide a deeper insight into bacterially mediated struvite morphogenesis, and be potentially applied to phosphorus and nitrogen recovery from various eutrophic wastewaters.

Keywords: Struvite, biomimeticization, morphogenesis, bacteria, extracellular polymeric substances (EPS), low molecular-weight organics

INTRODUCTION

Struvite, known as magnesium ammonium phosphate hexahydrate (MgNH$_4$PO$_4$·6H$_2$O), crystallizes in the orthorhombic system and adopts a series of abiotic morphologies including equant, short prismatic, wedge-shaped, and tabular shapes (Abbona and Boistelle 1979). Although struvite is not widely found in nature, it has still been discovered in some peculiar environments associated with organic matter decomposition, such as guano deposits, basaltic caves, marshlands, manures, and sediments rich in organic remains (Ben Omar et al. 1998; Sánchez-Román et al. 2007). In recent years, struvite has received increasing attention. On the one hand, struvite is the main component of infectious urinary stones resulting from urinary tract infection by urease-producing bacteria such as Proteus mirabilis (e.g., Prywer and Torzewska 2009, 2010; Prywer et al. 2012; Li et al. 2015). On the other hand, struvite can be potentially used as a fertilizer (Doyle and Parsons 2002; Le Corre et al. 2009). This makes struvite crystallization and precipitation a new route to phosphorus and nitrogen recovery from wastewater. As such, numerous efforts have been carried out at laboratory, pilot, and full-scale to increase yield and lower production costs of struvite (Stratful et al. 2001; Jaffer et al. 2002; de-Bashan and Bashan 2004; Le Corre et al. 2007; Mehta and Batstone 2013; Birnack et al. 2015). Nevertheless, these studies mostly focused on the effects of physicochemical parameters (e.g., pH, mixing energy, temperature, supersaturation level, and foreign ions) on struvite precipitation but not the microbial action (Le Corre et al. 2009; Soares et al. 2014).

In fact, there is a close relationship between struvite mineralization and microbial activity. It has been found that many bacterial strains, such as Proteus mirabilis, Myxococcus xanthus, Actinetobacter calcoaceticus, Bacillus pumilus, and Brevibacterium antipum, are able to produce struvite crystals in different natural habitats (Rivadeneyra et al. 1992, 1999; Da Silva et al. 2000; Prywer and Torzewska 2009; Soares et al. 2014; Han et al. 2015). Bacteria isolated from the wastewater treatment plants (WWTPs) can also precipitate struvite (Rivadeneyra et al. 2014; Gonzalez-Martinez et al. 2015). Bacterial production of struvite results from their metabolism of nitrogenous compounds accompanied with ammonium release and the consequent pH increase (Sánchez-Román et al. 2007; Sinha et al. 2014). The presence of bacterial cells or certain parts of the cell is also necessary to act as heterogeneous nuclei for struvite crystallization (González-Muñoz et al. 1996; Ben Omar et al. 1998; Sinha et al. 2014). Meanwhile, bacteria are able to effect and modify struvite morphology, and a series of different morphologies of struvite were observed in the bacterial mineralization experiments (Prywer and Torzewska 2009, 2010; Prywer et al. 2012; Sadowski et al. 2014; Sinha et al. 2014). For example, the coffin-like, X-shaped, and dendritic struvite crystals were obtained in the presence of Proteus bac-