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学位の種類	博　士（環境学）
学位記番号	博　甲　第　9868　号
学位授与年月日	令和　3　年　3　月　25　日
学位授与の要件	学位規則第４条第１項該当
審査研究科	生命環境科学研究科
学位論文題目	Use of Chitosan-Fe for Phosphorus Recovery and Promoted Methane Production from Anaerobic Digestion of Waste Activated Sludge （キトサン鉄を用いた廃棄活性汚泥の嫌気性消化におけるリン酸塩回収及びメタン生成の促進）

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論　文　の　要　旨
Abstract of thesis

The increasing generation amount of waste activated sludge (WAS) from wastewater treatment plants (WWTPs) is becoming a major problem for the sustainable management of WWTPs. Anaerobic digestion (AD) has been successfully applied for WAS treatment in WWTPs, owing to its capability of simultaneous bioenergy production and resources recovery. However, low methane yield and sludge reduction rate to some extent limit the application of AD in WAS treatment. Besides, the posttreatment of liquid digestate containing high level of phosphate is also one of the main problems for AD systems, due to the massive phosphorus (P) released during AD process. Therefore, it is highly demanded to develop new methods for simultaneous P recovery and enhanced methane production from AD of WAS. Previous studies indicate that conductive carbon-based materials or Fe(III) might improve AD of WAS through the direct interspecies electron transfer (DIET). Chitosan-Fe(III) complex (CTS-Fe) as an inexpensive and environmentally friendly carbon-based material possesses excellent P adsorption capacity and has been successfully employed to adsorb phosphate. Therefore, it is speculated that CTS-Fe has great potential for methane production and P recovery from AD of WAS. This study for the first time attempted to simultaneously recover P and enhance methane production from WAS with the supplementation of CTS-Fe.

This dissertation is divided into 5 chapters. In Chapter 1, the author introduced the research background and literature review. In this chapter, the author introduced the existing problems of WAS treatment, including those from AD system, nutrients and energy recovery. Specifically, the author discussed the great potentials of AD system together with carbon-based material like CTS-Fe addition, and then arrived at the objectives and framework of this research. In Chapter 2, the author compared the effects of crosslinked/non-crosslinked CTS-Fe composites on P recovery from aqueous solution

and explored the mechanisms involved at different pH conditions. Results show that CTS-Fe had a better adsorption capacity than crosslinked-CTS-Fe in a wide pH range, mainly through electrostatic attraction and ligand exchange. In Chapter 3, the author attempted to simultaneously promote AD of WAS and recover P by CTS-Fe supplementation. Results show that partial Fe (III) on the CTS-Fe was reduced and effectively combined with P to form vivianite crystals on the CTS-Fe surface during AD process, with the mechanisms for P recovery dominated by ligand exchange and chemical precipitation. P fractionation results indicate that 2.4 times higher non-apatite inorganic phosphorus (NAIP) reduction occurred in the solid phase of sludge at 20.0 g/L of CTS-Fe (6.72 mg/g-SS) when compared to the control (no CTS-Fe addition,2.77 mg/g-SS). Notably, under the test conditions, P adsorption capacity of CST-Fe was about 36.15 - 91.43 mg/g at dosage of 5.0 – 20.0 g/L, much higher than its use for synthetic phosphate-containing wastewater treatment (15.70 mg/g). This observation is mainly due to the more complex composition of the liquid digestate involving more pathways to remove P. In Chapter 4, the author further investigated the potential mechanisms involved in the enhancement of methane production from AD of WAS by CTS-Fe supplementation. The cumulative methane yields at CTS-Fe dosage of 5.0, 10.0 and 20.0 g/L of were detected to be 209.9, 236.6 and 247.9 mL/g-VS, respectively, about 12% - 32% higher than the control (187.5 mL/g-VS). Moreover, the VS reductions in the CTS-Fe reactors were increased by about 1.04 - 1.22 times compared to the control (27.4%). Microbial community analysis confirmed that iron reducing bacteria (IRB) and acetoclastic methanogens were enriched in the CTS-Fe added reactors, most probably due to that CTS-Fe facilitated dissimilatory iron reduction (DIR) and direct interspecies electron transfer (DIET) during AD process. Finally, in Chapter 5, the author summarized the major conclusions, and proposed the future research directions.

審　査　の　要　旨
Abstract of assessment result

Anaerobic digestion has been commercialized for simultaneous bioenergy production and resource recovery from WAS worldwide. However, little information is available on simultaneous P recovery and enhanced methane production from WAS. This study attempted to realize simultaneously recover P and enhance methane production from WAS by adding CTS-Fe. Results show that CTS-Fe addition can significantly improve methane production from WAS by 11.9 - 32.2%. Microbial community analysis confirmed that IRB and acetoclastic methanogens were enriched in the CTS-Fe added reactors, beneficial for DIR process. P fractionation results suggest that enhance NAIP reduction occurred in the solid phase of sludge due to CTS-Fe addition. Besides, partial Fe(III) on the CTS-Fe could be reduced and effectively combined with P to form vivianite crystals on the CTS-Fe surface during the AD of WAS, in which ligand exchange and chemical precipitation were the dominant mechanisms. Efforts should be made on the comparison with other adsorbents and their efficiencies for P recovery and enhancement on methane production, in addition to the analysis of prolonged lag phase after CTS-Fe addition.

The final examination committee conducted a meeting as a final examination on 15 January, 2021. The applicant provided an overview of the dissertation, addressed questions and comments raised during Q & A session. All the committee members reached a final decision that the applicant has passed the final examination.

Therefore, the final examination committee approved that the applicant is qualified to be awarded the degree of Doctor of Philosophy in Environmental Studies.