Formation of Granules with High Phosphorus Content to Realize Efficient Phosphorus Recovery from Waste Activated Sludge by Using Anaerobic Digestion Followed by Aerobic Granulation Technology

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研究課題名（英文）Formation of Granules with High Phosphorus Content to Realize Efficient Phosphorus Recovery from Waste Activated Sludge by Using Anaerobic Digestion Followed by Aerobic Granulation Technology

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研究成果の概要（和文）：リンは多く分野に重要な役割を果たし、再生できない資源の一つである。日本は世界の８番目のリンの消費国であり、すべてのリンを海外から輸入に依存している。本研究は熱水前処理と嫌気性消化と好気性グラニュール化のコンビ―ネーションによって廃棄活性汚泥からリンの高含有グラニュール生産を実現する可能性等を検討した。熱水処理条件の最適化により、汚泥からのメタンガス生産性が改善された結果、エネルギー収支の面からも、前処理法は効率的な方法であると明らかになった。また、合成した消化液或いは廃水を用いてグラニュール化した結果、6-10%のリンを含有し、そのうちリンの生物学的利用性は９５%に高いグラニュールを得ました。

研究成果の概要（英文）：Phosphorus (P) as a non-renewable resource plays important roles in agricultural and industrial activities. Japan is the 8th largest P consumption nation with all the P resources being imported from other countries. This project investigated the feasibility of P-rich granules production from waste activated sludge by combining hydrothermal pretreatment, anaerobic digestion and aerobic granulation. Results show that hydrothermal treatment can be a cost-effective process when the treatment temperature and duration are optimized according to the energy balance of enhanced methane production from the pretreated waste activated sludge. P-rich granules (6-10%) with P bioavailability up to 95% could be successfully cultivated using synthetic digestate or wastewater.

研究分野：　持続環境学

キーワード：　リン回収　好気性グラニュール化　廃棄活性汚泥　熱水前処理　嫌気性消化

１．研究開始当初の背景

(1) Wastewater treatment plants (WWTPs) contribute a lot to the sustainable utilization of water in our society, in which activated sludge process is applied worldwide. Waste activated sludge (WAS), a major by-product from WWTPs, is difficult and costly to handle with mainly due to its huge production amount. In Japan, WAS production is about one-fourth of the total waste biomass, 79 million tones wet and 2 million tones dried mass, respectively. After being thickened, anaerobically digested, chemically adjusted, and then mechanically dewatered, the treated WAS can be incinerated and the resultant ash is always landfilled. The treatment cost of these processes amounts to 40-60% of the total operation and maintenance costs of the WWTP. In fact, because of being rich in organics and mineral nutrients, WAS can be recycled and reused after being appropriately treated. The main bottlenecks are associated with how to quickly separate the treated WAS from the mainstream treatment units and keep the bioavailability of the nutrients in the WAS after being treated.

(2) Phosphorus (P) is a non-renewable resource and plays a major role in agricultural and industrial activities. The reserve of P mineral is estimated to deplete within 50-100 years. More importantly, Japan is the 8th largest P consumption nation in the world and all the P resources are imported from other countries. Meanwhile, our preliminary results of WAS samples from several WWTPs nearby indicate that the P content in WAS is about 2-5% of the total solids (dry weight). The successful recovery of P from WAS can greatly ameliorate the pending crisis of P resource, thus reducing the dependence on P import from other countries.

２．研究の目的

(1) The major objective of this project was to cultivate P-rich aerobic granules by using the liquid digestate of WAS. To achieve this target, the operation strategies, characterization of WAS digestate and additional additives were considered to make clear which factor impacts greatly on the effective P accumulation into the granules, and which factor could largely enhance P bioavailability.

(2) The aerobic granulation conditions would be optimized to achieve high bioavailability (≥ 80%) of P in the granules, efficient removal of pollutants, easy control of the operation and less addition of additives. The mechanisms involved in the granulation with enhanced P recovery and P bioavailability would be further elucidated in the context of P recovery from the liquid WAS digestate.

３．研究の方法

Three sets of experiments were carefully designed and conducted to fulfill the targets of this research.

(1) Enhanced anaerobic digestion of waste activated sludge (WAS) was realized by using hydrothermal (HT) pretreatment and the optimal conditions were finalized according to the performance of methane production and P release.

(2) N recovery as ammonia was achieved from liquid WAS digestate by using air stripping.

(3) P-rich granules with high bioavailability were then cultivated by using aerobic granulation through treating liquid WAS digestate, which provides a new promising process for fast P recovery and easy post-treatment of WAS digestate.

In the above three sets of experiments, the crucial influencing factors were also determined and optimized, and the mechanisms involved were explored.

４．研究成果

(1) Results show that hydrothermal treatment can be a cost-effective process when HT temperature and duration are optimized according to the energy balance of enhanced methane production from the pretreated WAS. P-rich granules (6-10%) with P bioavailability up to 95% could be successfully cultivated by using synthetic digestate or wastewater. Through the proposed processes, the released ammonia can also be recovered simultaneously with P when coupling with magnesium ammonium phosphate (MAP) precipitation after WAS being HT pretreated. Besides excellent organics and N removal, a constant 5 mg/L Fe^{2+} addition to the influent of aerobic granulation system can achieve stably

efficient P removal (92%) and recovery from wastewater to produce P-rich granules with high P bioavailability. In addition, a comparative study has been conducted between the lab-scale aerobic granular sludge system and Johkasou system with respect to their pollutants removal, energy consumption, and investment and operation costs, indicating the greater application potential of the aerobic granular sludge process.

(2) The results from this project suggest that the combination of HT pretreatment, anaerobic digestion and aerobic granulation processes might be the most prospective solution to manage organic solid wastes or high-strength organic wastewater, targeting efficient pollutants removal and energy/resources recovery. In the case of P recovery from WAS, not only organics can be decomposed and recovered as biogas (mainly methane) but also P-rich granules are produced, which can be easily re-utilized for multipurpose due to its high P bioavailability. Based on our experimental results, about 40,000 - 100, 000 tons of P could be annually recycled and reused in Japan if these processes could be applied.

(3) In addition to the pollutants removal and resources recovery efficiencies, the mechanisms involved have been explored, especially on P accumulation and its distribution in different kind of aerobic granules. The contributions of the main factors have been identified, including operation strategy, influent characteristics, additional additives, extracellular polymeric substances (EPS), etc. Furthermore, through this project we proposed some new and promising processes such as ammonia stripping and algal-bacterial granular sludge processes which possess great potentials for nutrients recovery from organic waste or wastewater.

(4) During the three years' investigation, the major results from this project have been published in 16 papers in international journals and 22 conference presentations as well, which provided good opportunities for us to communicate with the peer researchers in the similar research fields. Moreover, we extended the proposed processes to treat not only WAS but also other organic solid wastes like manure waste, reflecting their high efficiencies in simultaneous organics, N and P removal or recovery when their optimal conditions are applied.

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［その他］
ホームページ等
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