Study on the Effects of Main Ions on Aerobic Granular Sludge and the Mechanisms Involved

（好気性グラニュール汚泥への主なイオンの影響とそのメカニズムに関する研究）

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Abstract

Under the demand of the reduction on the site footprint and energy usage, aerobic granular sludge (AGS), including bacterial AGS (BAGS) and algal-bacterial AGS (A-BAGS), has been developed from activated sludge (AS) in recent years. Many studies indicated that BAGS can significantly reduce space requirements and energy usage. Moreover, A-BAGS has the potentials to reduce CO_2 emission and further reduce electricity usage in comparison to BAGS. From AS to BAGS, the biological phosphorus removal (BPR) from wastewater is mainly dependent on polyphosphate accumulating organisms (PAOs) that can excessively uptake phosphorus (P) from both wastewater and anaerobically released P under aerobic conditions. As known, many ions like K^+, Mg^{2+}, Ca^{2+}, etc., as main ionic components of domestic wastewater, are involved in BPR process. And their effects on BPR have been widely studied in AS and BAGS systems. However, the P removal by algae is mainly based on its growth requirement, possibly leading to the combined P removal mechanisms in A-BASG. Algae co-existence in A-BAGS makes what is already known on the effect of main ions in wastewater become unclear. Up to now, little information is available on the roles of main ions during BPR process in A-BAGS, the next generation of the wastewater treatment system. Furthermore, effective P removal from wastewater is of great concern due to eutrophication concern and water environment deterioration. Highly effective P removal generally can be achieved through the enhanced biological phosphorus removal (EBPR) process in which PAOs are the dominant species. However, the growth of PAOs requires enough short-chain volatile fatty acids (VFAs) like acetate (Ac^-) and is sensitive to environmental variations.

Therefore, in this study, the response of main ions and mechanisms involved during BPR were compared and investigated in A-BAGS and BAGS (control). In addition, a novel EBPR

was proposed according to the main ionic behaviors in A-BAGS and BAGS-based sequencing batch reactors (SBRs), namely, P-rich liquid separation system during the non-aeration phase. The main results can be summarized as follows,

(1) Ac^-, K^+, Mg^{2+}, Ca^{2+} rather than Cl^-, SO_4^{2-}, NH_4^+ and Na^+ were mainly involved in the BPR process, with constant molar ratios of ΔP/ΔAc, ΔK/ΔP and ΔMg/ΔP in both A-BAGS and BAGS systems. In the batch anaerobic/aerobic tests, the ΔP/ΔAc in A-BAGS under the absence of illumination was about 0.33 during the non-aeration phase lower than 0.39 in BAGS, and negatively influenced by the light density. It was estimated that about 62% of acetate was not utilized for P release at the high illuminance of 81k lux with a low ΔP/ΔAc of 0.15, indicating inhibition of P release from PAOs. On the contrary, the ΔK/ΔP and ΔMg/ΔP molar ratios were positively correlated with light density and increased from 0.43 and 0.34 under the absence of illumination to 0.63 and 0.39 under the light density of 81k lux, respectively, which indicated that PO_4^{3-}, K^+ and Mg^{2+} were utilized by algae at different levels for its growth. In the typical SBR operated with a non-aeration/aeration model, partial K^+ and Mg^{2+} released with PO_4^{3-}-P were found to retain inside granules at the bottom part of the test SBR.

(2) Among all the tested ions, the release and uptake of Ca^{2+} were detected during the non-aeration and aeration cycle but did not participate in the biological reaction of P removal. The molar ratios of ΔCa/ΔP in P-rich liquids were about 0.12 in BAGS and 0.13 in A-BAGS, which led to the charge balances of +1.08 in BAGS and +1.13 in A-BAGS among K^+, Mg^{2+}, Ca^{2+} and PO_4^{3-}. The release of Ca^{2+} was contributed by the following two aspects. The first one is that a larger amount of Mg^{2+} from hydrolysis of polyphosphate may replace Ca^{2+} inside the granules based on ion exchange during the non-aeration phase and the released Ca^{2+} would return to the granules during the subsequent aeration phase because of the decrease of Mg^{2+} concentration. Secondly, $CaCO_3$ precipitates might be dissolved with Ca^{2+} released in the bulk liquid due to the decrease of pH resulted from wastewater feeding and no aeration during the non-aeration phase, while re-formation of $CaCO_3$ was possible with the increase of pH during the aeration phase.

(3) EBPR can be achieved in both A-BAGS and BAGS systems through the P-rich liquid collection from the bottom of SBRs during the non-aeration phase, in which both systems produced low effluent PO_4^{3-}-P of < 0.05 mg/L after 3 days' operation. Besides, this separation had little impact on the simultaneously high-efficiency removals of chemical oxygen demand (COD) and nitrogen (N). According to P balance analysis, the total influent P was found to

contribute 95% and 97% of P in P-rich liquids from A-BAGS and BAGS systems, respectively. The net P release from granules during the whole test period was detected to be about 5.23 ± 0.81 mg for BAGS and 9.11 ± 1.22 mg for A-BAGS in experimental groups, which partly contributed to the P-rich liquid. It has been estimated by using Visual MINTEQ that the P-rich liquid has great potential for P recovery as Ca-P precipitates (especially in hydroxyapatite).

Results from this study are expected to provide a more in-depth and scientific understanding of the roles played by ions during P removal by A-BAGS, targeting the development of a novel EBPR system by using BAGS and/or A-BAGS process.

Keywords: Bacterial aerobic granular sludge; Algal-bacterial aerobic granular sludge; Ionic response; Enhanced phosphorus removal; Phosphorus recovery