Recycle and reuse of dewatered alum sludge in green bio-sorption reactor (GBR) for wastewater treatment: Roles and concerns

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Introduction

Alum sludge refers to the inescapable by-product from the coagulation process in water treatment works. Such sludge typically contains humic matters and minerals removed and precipitated from the raw water, together with the residues of any treatment chemicals used as coagulant (aluminium salts). In Europe, several million tons of water sludge is produced every year and this has doubled compared with last decade (Basibuyuk and Kalat, 2004 too old ref.). Such a large volume raised considerable concerns associated with their disposal and costs. Actually, alum sludge had been explored and stated as robust adsorbent for phosphorus (P) (Yang et al., 2006). Moreover, it has been successfully studied and employed as substrate in constructed wetland (CW) by University College Dublin, Ireland (Zhao et al., 2010).

Recently, a novel biofilm-alike system named green bio-sorption reactor (GBR) was firstly proposed and studied in University College Dublin. GBR integrates the alum sludge-based CW into conventional activated sludge (CAS) system. Alum sludge in the reactor served as biofilm carriers and adsorbent concurrently, which is in line with the theory of “recycle, reuse and reduce”. GBR inherits the pleasing appearance of CW and the high treatment capacity of CAS. Based on previous work, the GBR could achieve 96%, 99% and 90% removal efficiency for BOD, TP and TN respectively. Compared with CAS or other biofilm reactor (MBBR and IFAS), GBR possesses high aesthetic value, reliable performance and potential carbon sink.

As stated, the key component of GBR is the carrier of alum sludge which is also a robust adsorbent for P. Obviously, the initial roles of alum sludge are, on the one hand, to accommodate a large quantity of biomass and, on the other hand, to adsorb P. However, the roles of alum sludge in the reactor are far more these two. According to the composition of alum sludge (Yang et al., 2006), aluminum (Al^{3+}) and natural organic matter (NOM) could be released into bulk liquid during the operation. Although the release of Al^{3+} and NOM are within the safe level, they undoubtedly induced influence to the system. In the operation of the GBR, significant change of the suspended sludge was observed after the addition of alum sludge particles. The size of floccule increased significantly and the TN removal efficiency improved considerably as well. Therefore, the present study aimed to explore the insight of the alum sludge into the reactor reflection after adding alum sludge in terms of the sludge properties, contributions to pollutants removal and the biomass revolution.

Methods

A lab-scale sequencing batch reactor (SBR) was operated stably for 5 months with anaerobic, aerobic and anoxic stages for nitrogen and P removal. This SBR could achieve 95%, 93% and 96% removal efficiencies for COD, TN and TP under influent of 400 mg COD/L, 70 mg NH_4^+-N/L and 10 mg P/L. Then, alum sludge based CW was embedded into this SBR to become a GBR. The sludge properties and pollutants removal schemes before and after adding alum sludge were monitored and compared.

In terms of the suspended sludge properties, the settling and dewatering properties were comparatively evaluated based on the standard methods (van Loosdrecht, et al., 2016). The contribution of alum sludge addition to pollutants removal was monitored in a lab-scale GBR. Moreover, the influence of alum sludge on the bacteria in the reactor was observed and compared.

Results and discussion

Impact on the organisms in the reactor

The impact of alum sludge on the activities of various bacteria was monitored in terms of nitrification rate and P adsorption rate (R_{-N} AND R_{-P}). The results are illustrated in Fig. 1. The point of adding alum sludge was set as 0 point. The activities of P accumulating organisms (PAOs) and nitrification in SBR and GBR were displayed on each side. Obviously, the introduction of alum sludge into activated sludge system did not induce adverse impact on nitrogen removal but detrimental effect on PAOs. For PAOs, the P release rate after alum sludge addition declined sharply. At the 45th day after adding alum sludge, the P release rate in anaerobic condition decreased to 0.1 mg/(L·min) which was only one-sixth of that before adding alum sludge. It is noteworthy that at the 60th day the activity of PAOs seemed to recover. Exactly, around 60th day, the alum sludge particles were trapped by a layer of thick activated sludge due to the mild agitation. By removing the thick sludge on the surface of alum sludge, the activity of PAOs decreased gradually to insignificance. Based on these results, the reasons of inactivity of PAOs could be due to competition with alum sludge for P and the inhibition effect of Al^{3+} released from alum sludge.

Impact on the properties of activated sludge

In the operation of GBR, the sludge volume index (SVI) and VSS/SS ratio in the reactor were observed regularly as depicted in Fig. 2. The change of SVI was wild with increasing from 85 to 115 mL/g. The VSS/SS ratio, along with the change of SVI, increased as well. It is believed that the evolution of the sludge properties was related to the elimination of PAOs as VSS/SS could be an indicator of PAOs change. The activity decrease of PAOs favored the proliferation of glycogen accumulating organisms (GAOs) which could be the culprit of VSS/SS increase. In terms of the increase of SVI, it is believed to be related to the dissolved oxygen (DO) concentration. In the reactor, air flow rate was fixed along the operation period. The decrease of PAOs' activity cannot consume organic any more in anaerobic stage. Therefore, much more organic flowed into aerobic. Moreover, the increase activity of nitrifiers in the reactor increased the oxygen consumption. These two factors decreased the DO in the reactor, which favored the growth of filamentous bacteria.

Contribution to the nutrients removal

Given the robust P adsorption capacity of alum sludge, its contribution to P removal was significant. Despite P removal, alum sludge also did benefit to the nitrogen removal. As observed in the reactor, the introduction of alum sludge increased the floccular size of suspended sludge, which enhanced the tolerance of simultaneous nitrification and denitrification process to oxygen variation.

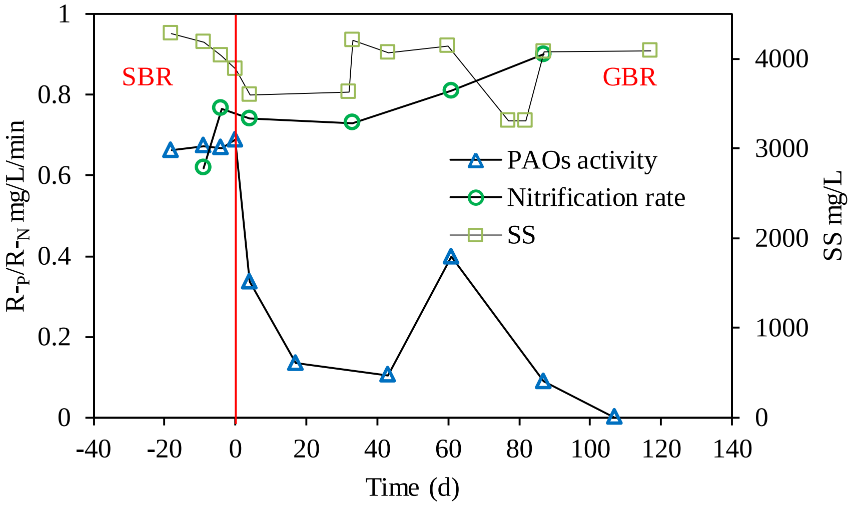

Fig. 1 Changes of organisms' activity induced by alum sludge

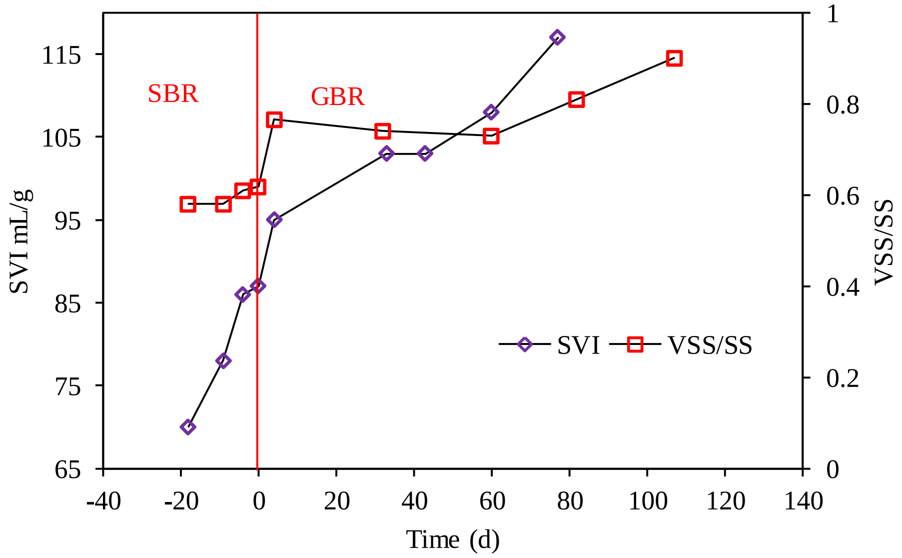

Fig. 2 Evolution of sludge properties in the reactor

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