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A new configuration of sequencing batch reactor operated as a modified aerobic/extended-idle regime for simultaneously saving reactor volume and enhancing biological phosphorus removal

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ABSTRACT

Recently, it has been reported that the aerobic/extended-idle (AEI) regime can achieve a satisfied biological phosphorus removal (BPR). Although the AEI regime has exhibited some merits, its main drawback that the extended-idle phase (e.g., 210–450 min) is much longer than the anaerobic phase (e.g., 60–120 min) performed in the aerobic/oxic (A/O) regime requires to be addressed. In this study, a new configuration of sequencing batch reactor (SBR) with sludge tank halved (STH-SBR) was therefore designed. After stable operation, 96.9 ± 0.5% of total phosphorus was removed in the STH-SBR, which was higher than that in the AEI-SBR (86.9 ± 0.8%) and A/O-SBR (84.7 ± 1.3%). Further investigations showed that the biomass cultured in the STH-SBR contained more polyphosphate accumulating organisms but less glycogen accumulating organisms than that in the AEI-SBR and A/O-SBR. In the STH-SBR, the aerobic glycogen accumulation was lower than that in the A/O-SBR while the average idle phosphorus release was greater than that in the AEI-SBR. Finally, the key enzyme activities in the AEI and A/O regimes were compared for the first time, and the reasons for the AEI regime showing lower exopolyphosphatase and polyphosphate kinase activities were also discussed.

1. Introduction

Excessive phosphorus discharged from municipal sewages and industrial wastewaters affects water quality and ecosystem balance through a process known as eutrophication, thus phosphorus in wastewaters needs to be removed efficiently. Biological phosphorus removal (BPR) is a widely used method for wastewater phosphorus removal, because it is cost-effective in the long term and has a low environmental impact [1]. BPR technology exploits the ability of some microbes (e.g., *Candidatus Accumulibacter phosphatis*) to uptake phosphorus in excess of normal metabolic requirement and to store it as the intracellular polyphosphate (poly-P). This metabolic behavior can be achieved by alternating anaerobic and oxic (A/O) phases [2], low pH-inducible [3], or other environmental conditions [4–6]. Of these, the A/O regime drew the most attentions in the past and was proven to be the preferred approach for phosphorus removal since it could provide a more selective advantage to poly-P accumulating organisms (PAO) over other populations [7]. Despite that the A/O wastewater BPR regime is extensively investigated and applied, some external disturbances, such as high rainfall, low volatile fatty acid (VFA) presence, and excessive nitrate introducing to the anaerobic reactor, have been reported to easily deteriorate the BPR performance [3,8,9]. Due to the massive amount of wastewater treated daily, any enhancement in current phosphorus removal techniques should have substantially economic consequence and ecological significance.

Recently, it has been reported that a novel wastewater treatment regime, i.e., the aerobic/extended-idle (AEI) regime, can readily enrich PAO, which thereby achieves an excellent phosphorus removal performance [10–14]. Compared with the A/O regime, an anaerobic stage is not operated after wastewaters are influent,

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whereas an extended-idle phase (e.g., 210–450 min) is carried out instead between the decanting phase and the next aerobic phase. Though the extended-idle phase is also not aerated, the biochemical transformations involved in this phase are indeed different from those in the anaerobic phase performed in the A/O regime [12]. Apart from a substantial phosphorus release, external substrate consumption and polyhydroxyalkanoates (PHA) accumulation as well as glycogen degradation were not observed in this idle period obviously [11–14]. Surprisingly, a substantial phosphate release coupled with a low/negligible PHA synthesis in the extended-idle phase of AEI regime has been also verified to provide a selective advantage to PAO over other populations. The extended-idle phase requires extra energy for bacterial maintenance, and poly-P cleavage can nicely fulfill this energy requirement which thereby enhances the role of poly-P in PAO metabolisms [12].

The AEI regime has been demonstrated to have some merits, such as tolerance of higher nitrate level [11], simpler operation control, and reduced dependence upon wastewater VFA content [10], as compared with the A/O regime. However, one concern about the AEI regime, which should be noted, is that the extended-idle phase (usually operated for 210–450 min) is much longer than the anaerobic phase (e.g., 1–2 h) conducted in the A/O regime. This characteristic suggests that the AEI regime needs a greater reactor volume when treating the same quantity of wastewater, which increases the construction cost. Thus, if the reactor volume can be reduced and meanwhile the BPR performance is unaffected largely, the AEI regime will have a more promising future in application. Moreover, with the changes of reactor volume the hydraulic retention time will change as well, which is considered as one important parameter affecting BPR. For example, Wareham and Lee [15] found that the reduced retention time in anaerobic reactor deteriorated phosphorus removal, but Song et al. [16] observed that decreasing hydraulic retention time increased both nitrogen and phosphorus removal efficiency. To date, however, the effect of reactor volume on BPR induced by the AEI regime has never been addressed. In addition, it is well known that BPR consists of two biochemical reactions (i.e., phosphorus release and phosphorus uptake), which is directly related to the key enzyme activities of exopolyphosphatase (PPX) and polyphosphate kinase (PPK) [1]. According to the previous investigations, it was found that the AEI regime exhibited different inducing mechanisms from the A/O regime [11,12]. This different inducing mechanism in the AEI regime may affect the transformations of metabolic intermediates and biochemical processes of phosphorus release and phosphorus uptake, which may further influence the activities of PPX and PPK. Accordingly, it is very interesting to compare the activities of PPX and PPK involved in the AEI and A/O regimes. However, comparison of these key enzyme activities between the AEI and A/O regimes has also never been investigated before.

In this study, a new configuration of sequencing batch reactor (SBR) with sludge tank halved (STH-SBR, i.e., dividing equally the conventional sludge tank into two tanks and alternating the activated sludge in the two tanks to mix with wastewater) was designed to save the reactor volume of the AEI regime, and the key enzyme activities in the AEI and A/O regimes were compared. First, the phosphorus removal in the STH-SBR was assessed in detail, and the reactor performance and metabolic transformation among the STH-SBR, conventional A/O-SBR, and AEI-SBR were compared. As the STH-SBR exhibited a better BPR performance than both the A/O-SBR and AEI-SBR, the reasons for the increased phosphorus removal in the STH-SBR were then explored from the aspects of microbiology and metabolic intermediate transformations. Finally, the activities of PPX and PPK involved in the three reactors were analyzed, and the reasons for the AEI regime showing much lower activities of PPX and PPK than the A/O regime were also discussed.

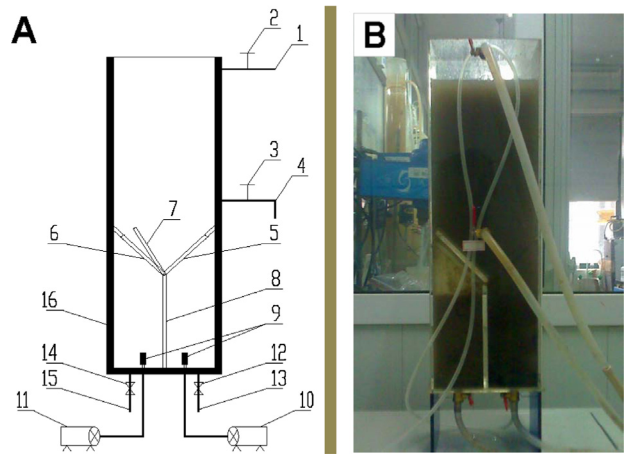

Fig. 1. The schematic diagram (A) and photograph (B) of STH-SBR.

2. Materials and methods

2.1. Wastewater

The wastewater used in this study was collected from a municipal wastewater treatment plant in Shanghai, China, and was prepared daily. Its characteristics were as follows: total phosphate (TP) 7.42–9.67 mg/L, NH_4^+–N 25.14–32.47 mg/L, chemical oxygen demand (COD) 106–154 mg/L. Due to the low influent COD concentration in wastewater, additional acetate was added into the wastewater, yielding an approximately influent COD:PO_4^{3-}–P ratio of 20 mg COD/mg PO_4^{3-}–P, which was considered as being favorable for PAO [7,17].

2.2. The configuration of STH-SBR and the operation of the STH-SBR and A/O-SBR and AEI-SBR

Fig. 1 shows the schematic diagram and photograph of STH-SBR (with a working volume of 7 L) designed and tested in this study. The main difference between the STH-SBR and conventional SBR is the configuration of sludge tank. The sludge tank of STH-SBR is divided equally into two tanks (each contains a sole air diffuser) by a vertical plank, and a rolling plank is connecting with the top of vertical plank (Fig. 1). By rotating the rolling plank, activated sludge in the two tanks can easily alternate to mix with wastewaters. The A/O-SBR and AEI-SBR are two identical conventional SBRs with working volumes of 7 L and set as controls.

Seed sludge was inoculated into three SBRs simultaneously, and all the reactors were maintained at 20 ± 1 °C in a temperature controlled room. The STH-SBR was operated with four cycles per day (6 h each). Each STH-SBR cycle consisted of approximately a 210 min aerobic period, 55 min settling, 5 min decanting, and 90 min idle periods. In the initial two cycles per day, the rolling plank (7 in Fig. 1A) was turned to the supporting incline II (6 in Fig. 1A). The activated sludge in the right sludge tank was mixed with the wastewater, whereas the activated sludge in the left sludge tank was in the status of "idle rest". During the idle phase of second cycle, the rolling plank (7 in Fig. 1A) was turned to the supporting incline I (5 in Fig. 1A) manually. On the contrary, the activated sludge in the left sludge tank was mixed with the wastewater, whereas the activated sludge in the right sludge tank was in the status of "idle rest" during the latter two cycles. Seemingly, the whole operation of the STH-SBR looks like the conventional activated sludge wastewater treatment regime. However, it can be found that activated sludge in each tank actually operated two cycles per day, and the actual operational regime for