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The metabolic versatility of PAOs as an opportunity to obtain a highly P-enriched stream for further P-recovery

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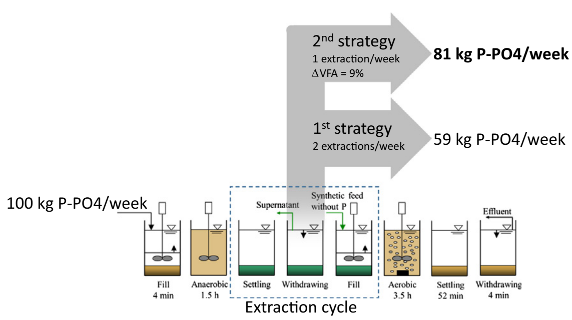
HIGHLIGHTS

- A simple process was proposed to recover P in a SBR operated for EBPR.
- The P recovery did not affect the biological P removal performance.
- This process enables to recover up to 81% of the incoming P per week.

GRAPHICAL ABSTRACT



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ABSTRACT

The effects of two sequencing batch reactor operation strategies for phosphorus stream enrichment over the biological phosphorus removal performance have been studied. The objective of both strategies is of performing an extraction cycle in order to obtain a new stream highly enriched with phosphorus. In the 1st strategy the amount of influent volatile fatty acids (VFAs) is the same in each cycle; while in the 2nd strategy the influent VFAs concentration is increased during phosphorus extraction experiments. Despite the strong decrease of the stored poly-P inside the cells in both strategies after the recovery cycles, the ability of the systems to remove phosphorus was not affected. The $P_{release}/HAc_{uptake}$ ratio (changing from 0.73 to 0.21 mmol P mmol C^{-1}) together with FISH analyses (around 85% of *Accumulibacter* through the experimental period) confirmed that a shift from PAM to GAM occurred after phosphorus enrichment in the 2nd strategy experiments. These results suggest that energy required for VFA uptake by polyphosphate-accumulating organisms (PAOs) was not only derived from polyphosphates degradation, but also from glycogen degradation. FISH also revealed that Type II *Accumulibacter* species are responsible of the metabolic shift. The strategy based on increasing influent VFAs concentration during phosphorus extraction experiments showed a higher extraction efficiency (from 46% to 76%), as higher phosphorus concentration within supernatant can be achieved (from 113.9 to 198.7 mg P l^{-1}). Following this strategy, it is possible to concentrate up to 81% of the incoming phosphorus in a single enriched stream. This suggests that, despite the extra addition of carbon source needed (9%), this strategy is more appropriate if phosphorus recovery for reuse purposes is required.

1. Introduction

Phosphorus (P) is essential for all life and is a key element in fertilizers to increase crop yields not existing any other component

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that can substitute P in food production. Yet the world's main source of P (phosphate rock) is non-renewable and is becoming increasingly scarce and expensive. Phosphorus peak was estimated to occur by 2035, after which its demand would outstrip supply [7].

Approximately 17% of the total P in phosphate rock mined specifically for food production is lost in human excreta via wastewater (approximately 3 million tonnes of elemental phosphorus per year), which should be removed before its final disposal in inland and coastal waters in order to prevent eutrophication [8]. The classical biological P removal technology [20] currently is presented as an opportunity not only for P removal but also for P recovery and therefore provides a possible solution for the phosphate rock scarcity in a near future. PAOs are the group of microorganisms primarily responsible for the P removal process. PAOs are equipped with a polyphosphate accumulating metabolism under alternating anaerobic–aerobic/anoxic conditions. Under these operational conditions PAOs are able to internally store the soluble P present in the raw wastewater as polyphosphate (poly-P). All the P-recovery technologies from PAOs pass through a previous P extraction before its final recovery mainly as struvite.

According to Yuan et al. [32] there are a number of ways to recover P from sludge including: (a) direct application of dewatered biosolids to the soil; (b) release of P from Enhanced Biological Phosphorus Removal (EBPR) sludge by biological methods followed by recovery through chemical methods; and (c) release of P from EBPR sludge by thermal-chemical methods, followed by either utilization of residue, or further processing for recovery. However, these methods are focused on recovering P in the sludge line of the wastewater treatment plants (WWTP) after the anaerobic digestion. This operation mode entails some disadvantages such as not being able to prevent an uncontrolled precipitation inside the digester and the downstream sludge management devices due to an important P release and pH increase during digestion [11]. Other processes based on P recovery in the water line are the Phostrip process [16] and the BCFS process [28]. The Phostrip and BCFS process are technologies that besides achieving the phosphate effluent standards also recovers P from wastewater in the water line. However, this technology requires a phosphate stripping and further separation in a specific settler. One of the bottlenecks of this technology is that the phosphate concentration achieved in the stripper stream is not high enough to assure a high P recovery efficiency in a later crystallization process (around 25 mg P l^{-1} in the anaerobic phase, see [4]. Other studies, recently published, studied the feasibility of the P recovery as P enriched stream in the water line using different configurations [14,26,30,31].

On the other hand, different studies [1,33] showed that the stripping of P in a Sequencing Batch Reactor (SBR) operated for EBPR could provide a highly enriched stream with soluble P after a decanting period and withdrawal at the end of the anaerobic stage. As the key point of these operation mode consists in achieving a very high P extraction during the SBR operation cycle, polyphosphate (poly-P) was expected to reach low level concentrations and therefore to reduce considerably the main PAOs energy source. Under these conditions, traditionally deterioration of P removal process was expected to occur due to the upgrowth of GAOs which use glycogen as energy source instead of poly-P [22]. While GAO metabolism is based on the use of glycolysis to produce ATP for HAc consumption under anaerobic conditions, PAOs use the hydrolysis of intracellular poly-P and the consequent release of phosphate for the same purpose. However, the same studies [1,33] demonstrated the versatility of PAOs metabolism when these bacteria are starved for poly-P due to the P extraction. These authors observed that PAOs are able to resist under extreme conditions without poly-P during short periods when this component is removed from the bacteria.

Therefore, a new SBR-EBPR operation performance, consisting on the stripping of P in a SBR operated for EBPR, would provide a P recovery stream with low cost and high potential P recovery.

However, it is necessary to experimentally evaluate this potential P recovery and the effect of this new operation mode over the biological P removal process over time. Therefore, the aim of this paper is to carry out P extraction cycles following two different strategies (keeping influent VFAs concentrations constant or increasing them) with a SBR operated for EBPR, in order to: know the potential P recovery of the proposed new SBR operation mode and to study its effect over the biological P removal performance: process efficiency and microbial population dynamics.

2. Materials and methods

2.1. Experimental device

A laboratory scale SBR (total volume (V_T) of 7 l) was operated under anaerobic-aerobic conditions for biological phosphorus removal. The SBR was operated with four 6-h cycle per day: filling period 4 min; anaerobic phase 1.5 h; aerobic phase 3.5 h; settling phase 52 min and withdrawing period 4 min. The phase length during some extraction cycles was modified as will be shown later.

The SBR was equipped with conductivity, ORP, pH, temperature and dissolved oxygen electrodes. The temperature was maintained at 20 °C. Dissolved oxygen (DO) concentration in the aerobic phase was controlled between 1.5 and 2.5 mg O_2 l^{-1}. Initial pH of the cycle was kept around 7.5 and it was not controlled but did vary from 7 to 8.5 during the different phases of the cycle. Synthetic wastewater was used during the experimental period with a COD/P ratio of 13.3 COD mg P mg^{-1} (100 mg COD l^{-1} and 7.5 mg P l^{-1}). Synthetic wastewater used consisted of two solutions: the first one contained mineral compounds including K_2HPO_4 whilst the other one contained acetate and NH_4Cl (for detailed description of the SBR configuration and wastewater see [5]. Allyl-thiourea was added in a concentration of 2 mg l^{-1} in order to inhibit nitrification. The Solid Retention Time (SRT) and Hydraulic Retention Time (HRT) were kept constant around 10 d and 12 h, respectively.

In both strategies, the reactor was seeded with sludge from a real WWTP with biological phosphorus removal by means of an A/O scheme located in Valencia (Spain). The WWTP treated 33,785 m^3 per day, and it was operated at a SRT of 10 days. The SBR was operated for approximately two months for each strategy of the study to obtain a sludge enriched in PAO bacteria. Operational conditions during the first strategy were maintained with no change. During some experiments of the second strategy, however, increases in length of anaerobic and aerobic phases were implemented aiming to achieve either complete VFAs uptake and glycogen regeneration.

2.2. Experimental design

During the experiments, an extraction cycle (hereafter known as recovery cycle) was made in order to obtain a new stream highly enriched with P. The different stages of this cycle are shown in Fig. 1. The SBR was filled with synthetic wastewater and operated under anaerobic conditions. The sludge was settled in order to obtain an effluent highly enriched in phosphate after achieving complete VFAs uptake and consequently an increase in the amount of soluble phosphate. Then, the maximum volume of the effluent was extracted and replaced with synthetic wastewater without acetate, following with aerobic conditions. Finally, the sludge was settled and the effluent was discharged.

The study was performed in two periods following different operation strategies: