A pilot-scale SBR configuration for optimal biological nutrient removal

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INTRODUCTION

This work presents a novel pilot-scale configuration named as SCHEPPHAR (Short-Cut Enhanced Phosphorus and PHA Recovery) which is one of the novel technologies involved in the SMART-Plant project (Scale-up of low-carbon footprint Material Recovery Techniques, EUH2020, grant agreement 690323). The whole SMART-Plant project aims to prove the feasibility of novel wastewater treatment technologies at pilot-scale towards a circular economy scenario. Nutrient recovery is promoted together with a reduction of energy consumption and carbon footprint.

Thus, the technology presented in this work (SMARTech2b) aims not only to treat wastewater, but also to recover phosphorus and nitrogen as struvite (magnesium ammonium phosphate) and also to recover polyhydroxyalkanoates (PHA) from the mainstream. This configuration is based on a previous work of Marcelino et al. (2011) with some modifications to increase nutrient recovery efficiency while reducing carbon source and energy requirements. The system is based on two sequential biological reactors (SBR); the first one (HET-SBR) performs enhanced biological phosphorus removal (EBPR) by alternating anaerobic – anoxic – aerobic conditions while the second one (AUT-SBR) is in charge of nitrification (or partial nitrification process up to nitrite).

In the conventional EBPR process, phosphorus is removed by purging biomass at the end of aerobic phase because this is the moment when PAOs have the maximum amount of polyphosphate (Poly-P) accumulated. This fact usually may led to undesired and uncontrolled struvite) precipitation in the subsequent sludge digestion steps, increasing thus operational costs of the plant. Conversely to the conventional treatment strategy, SCEPPHAR proposes a purge at the end of the anaerobic phase, when biomass has released most of the Poly-P accumulated in the previous cycle limiting then undesired precipitation problems; in addition, the purge should have the highest PHA content of the whole operation. Sludge rich in PHA shows two potential advantages: i) if it is recovered from the sludge it can be used as a precursor for bioplastics production and ii) some authors reported higher potential methane production when sludge rich in PHA is anaerobically digested (Shamsul Huda et al. (2013), Wang et al., (2015)).

At the end of anaerobic step, after settling, part of the supernatant rich in phosphorus and ammonia is diverted to a precipitation reactor, where pH is increased and $MgCl_2$ is added in order to recover nutrients as struvite, which can be used as a crops fertilizer. With this strategy is expected to recover up to 50% of the incoming phosphorus. The fact that part of the ammonia is removed by precipitation, in addition to the nitrite short-cut implemented in AUT-SBR, allows the system to save up to 25% of aeration requirements. In addition, since denitrification process is performed by Denitrifying Polyphosphate-Accumulating Organisms (DPAO) using nitrite this step requires less organic matter (i.e., DPAOs uses PHA stored as carbon source for denitrification).

MATERIALS AND METHODS

Pilot-scale SCEPPHAR system

The system proposed consists of two 3 m^3 SBR reactors, an exchange vessel with the same volume and a precipitation reactor (200 L). Figure 1 shows a detailed block flow diagram of the pilot-plant. As can be seen, the process starts with an influent load of wastewater from the primary settler of the WWTP to the SBR-HET. Then, anaerobic phase takes place, where DPAOs release phosphorus and consume organic matter accumulating PHA. Also, anaerobic purge is performed and, after settling, supernatant of the reactor, which is rich in phosphates and ammonia, is sent to the buffer tank. From this vessel 150 L are sent to the precipitation vessel in order to recover nutrients as struvite. Then, 50% of the volume is transferred to SBR-AUT, where ammonia is oxidized to nitrite by Ammonia Oxidizing Bacteria (AOB). After this phase the supernatant is returned to SBR-HET and anoxic step occurs. During this period, DPAO take up phosphorus anoxically. Finally, an aerobic phase is required to take up the rest of phosphorus. After settling, part of the supernatant is discharged to the effluent and the cycle starts again. The cycle takes 8 hours but may be modified in the future in order to increase the treatment capability. The SCEPPHAR system is located in field (Manresa WWTP, Barcelona) and will be able to treat 10 $m^3 \cdot day^{-1}$ of primary effluent.

Simulation

Fine process design was performed based on simulations with a model developed. The International Water Association ASM2d model was extended to include nitrite as state variable was used for the modelling studies. The kinetic model used was an extension of the International Water Association model ASM2d with nitrite included as another state variable (Henze et al., 2000). DO concentration dynamics was also modelled including its control using a proportional controller during the aerobic phases. All the simulations were performed with Matlab® and the differential equations of the system balances were solved with ode15s function, a variable order method recommended for stiff systems.

RESULTS

The pilot-scale SBR is currently running and the details of the performance will be presented in the full presentation. Figure 2 and Table 1 show, as an example, the results obtained from the design simulation under steady state when this is operated with 8 hours cycles, SRT of 15 days and complete nitrification. Under these conditions, ammonia is totally oxidized in SBR-AUT while phosphate is completely removed in SBR-HET. The high phosphate concentration reached in this reactor at the end of the anaerobic phase (60.7 $mgP \cdot L^{-1}$) allows the generation of an enriched stream that increases the possibilities to recover P as struvite in the precipitation vessel. Table 2 presents the loads and main inputs and outputs of the system. As can be seen, the predicted nitrogen and phosphorus removal are very high (98 and 99% correspondingly), and more than 50% of the incoming phosphorus is sent to the precipitation reactor. COD removal is high too (89%) and around 9% of the influent COD can be recovered as PHA.

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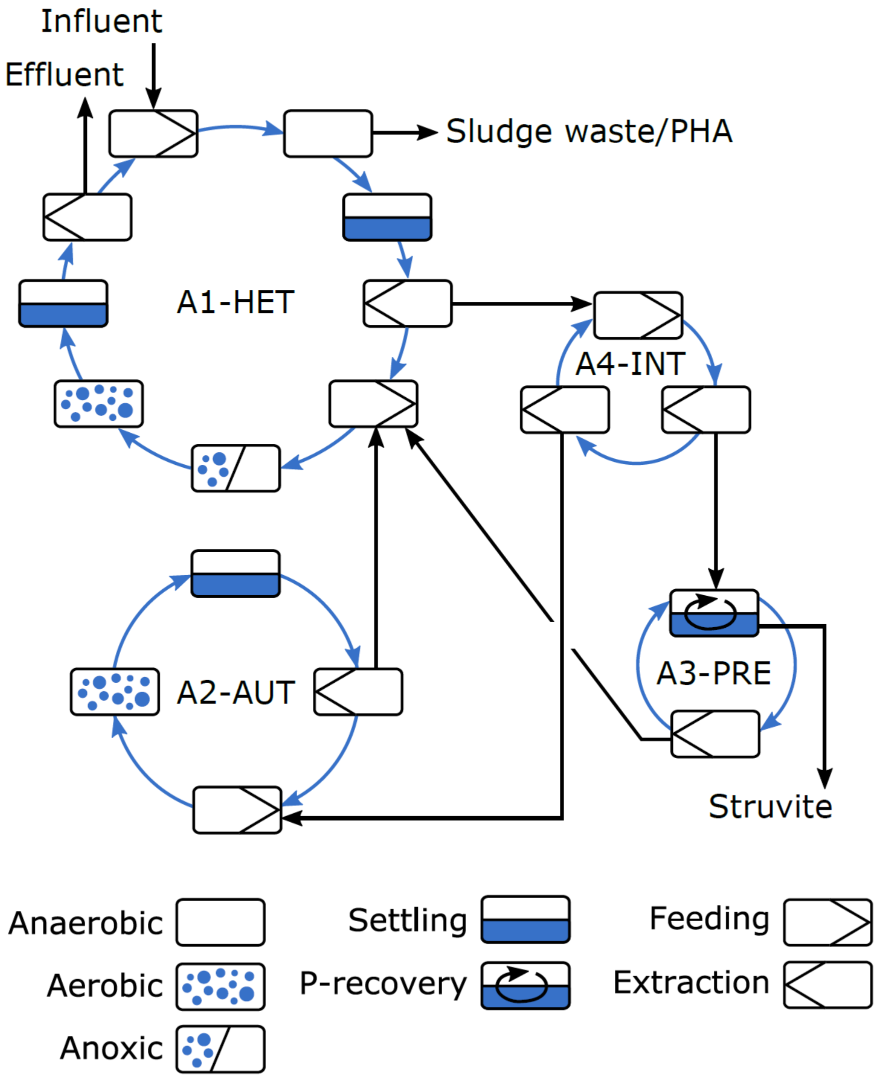

Figure 1. Detailed block diagram of the pilot SMARTech2b.

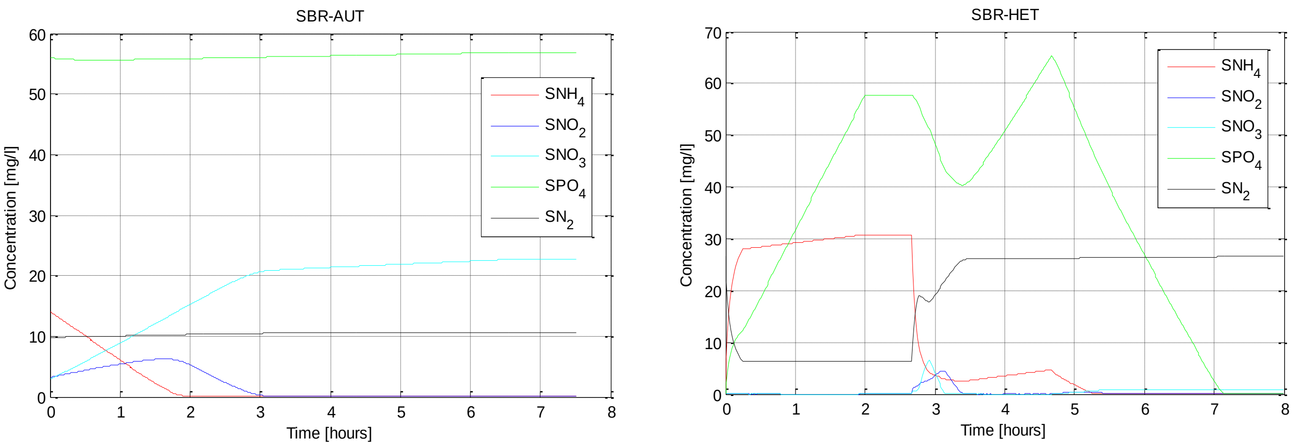

Figure 2. Steady state prediction for N and P soluble compounds in SBR-HET and SBR-AUT. Results obtained with the model developed for SMARTech2b design and optimization.

Table 1. Concentration of nutrients in SBR-Het and SBR-Aut.

	Influent	**SBR-HET End anaerobic phase**	**SBR-HET End aerobic phase**	**SBR-AUT End aerobic phase**
NH_4^+ [$gN\cdot m^{-3}$]	35	31.3	0	0
NO_2^- [$gN\cdot m^{-3}$]	0	0	0.1	0.1
NO_3^- [$gN\cdot m^{-3}$]	1	0	0.7	20.1
PO_4^{3-} [$gP\cdot m^{-3}$]	9	60.7	0.0	59.4

Table 2. Main inputs and outputs of the system.

Parameter	**System input/output (g/d)**
COD load	2972
COD in the effluent	320
COD recovered as PHA	257
NH_4^+-N load	202
NH_4^+-N in the effluent	0
NO_3^--N in the effluent	3.5
NO_2^--N in the effluent	0.3
PO_4^{3-} -P load	51.8
PO_4^{3-} -P in the effluent	0.2
PO_4^{3-} -P sent to P-recovery	26.2

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