Polyhydroxyalkanoates and phosphorus recovery at pilot scale through the SCEPPHAR system

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Keywords
Short-Cut Enhanced Phosphorus and PHA Recovery (SCEPPHAR), PHA, biological nitrogen removal; external carbon source; Horizon 2020 – Smart-Plant

INTRODUCTION

During the last decades, high attention has been given to the treatment of municipal wastewater, especially to which concern resource recovery and carbon footprint. Within the WWTPs, when the anaerobic digestion is accomplished, the usual practice is to return back in the main wastewater treatment line the anaerobic supernatant after the dewatering of the digestate. Although this liquid stream represents a small percentage of influent flow, it may increase significantly (15-25%) the nitrogen (N) and phosphorus (P) load (Cervantes et al. 2009, Malamis et al., 2013). Recently, several short-cut processes have been developed for the via-nitrite nitrogen removal from sludge reject water, including the complete autotrophic nitrogen removal which represents certainly an attractive alternative for both process performance and low energy requirements (Malamis et al., 2013). However, the very stringent operative conditions (i.e. temperature, DO concentration and COD fluctuations) make the technology very sensitive to environmental changes. A valid alternative is represented by the Short-Cut Enhanced Nutrient Abatement (S.C.E.N.A., Renzi et al., 2015) which represents an integrated process for resource recovery, where phosphorus is accumulated in P-rich sludge suitable as fertilizer.

A further development of S.C.E.N.A. has been implemented by Frison et al. (2015) which studied the feasibility of an integrated process for simultaneous nitrogen removal via-nitrite and polyhydroxyalkanoates (PHAs) production. PHAs are a class of biodegradable polymers produced by bacteria from volatile fatty acids (VFAs) under unfavourable growth conditions (i.e. low nitrogen and phosphorus concentrations). Frison et al. (2015) accomplished the ammonia oxidation to nitrite followed by the selection of PHAs-storing bacteria through aerobic-feast and anoxic-famine conditions in two Sequencing Batch Reactors (SBRs). This process scheme included also the production of VFAs by the acidogenic fermentation of primary and secondary sludge. The aim of the current study is to validate at pilot scale the above-mentioned system, with the implementation of phosphorus recovery by struvite precipitation, which has been named Short-Cut Enhanced Phosphorus and PHA Recovery (S.C.E.P.P.H.A.R.). The process sustainability is improved by organic matter recovery through wastewater sieving and subsequent fermentation of the cellulosic primary sludge for high rate VFAs production.

MATERIAL AND METHODS

The SCEPPHAR system (Figure 1) was installed at pilot scale within the WWTP of Carbonera (Treviso, North of Italy). The latter, serves 40,000 person equivalents (PE), and treats up to 15,000 m^3/d of municipal wastewater derived from a combined sewer system.

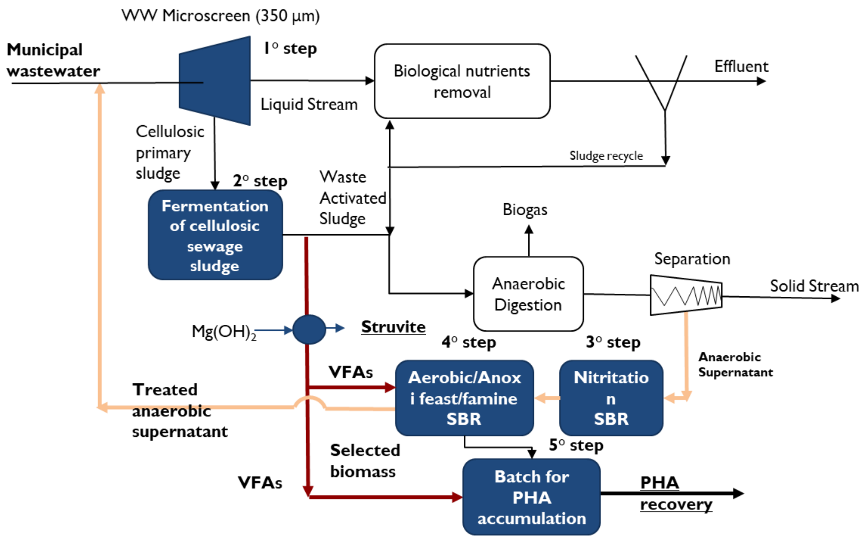

Figure 1 Schematic representation of the SCEPPHAR system integrated in Carbonera WWTPs

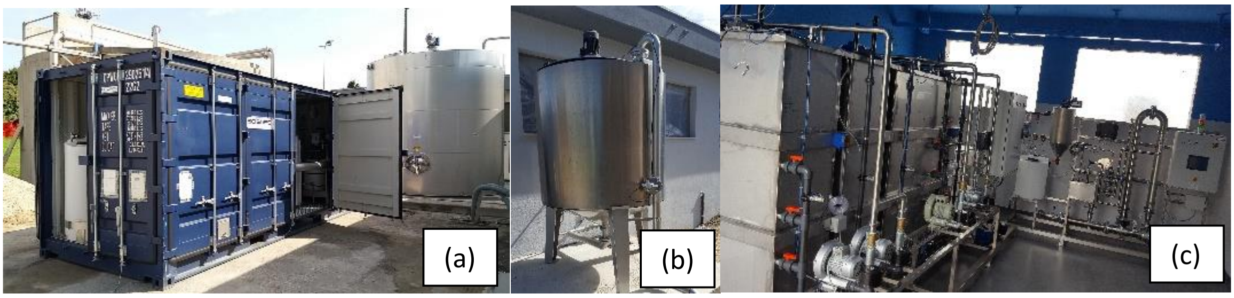

Figure 2a) SF1000 Salsnes Filter; b) Fermentation unit; c) Membrane, crystallizer, Nitritation SBR, Selection SBR, Accumulation SBR)

The main steps involved in the SCEPPHAR system involved the following units:

1) Pre-concentration of municipal wastewater through the sieving at 350 μm and recovery of cellulosic primary sludge (CPS) accomplished by a rotating belt dynamic filter (RBDF) (type SF1000 Salsnes Filter, Norway);

2) Controlled fermentation of CPS at 37°C in a sequencing batch fermentation reactor (SBFR) with a working volume 2.6 m^3 for the production of VFAs. The fermentation liquid containing VFAs was recovered by a solid/liquid separation using a ceramic membrane;

3) Struvite crystallizer with a working volume of 50 liters where $Mg(OH)_2$ is added to favor the crystallization;

4) Ammonia oxidation via-nitrite from the anaerobic supernatant in sequencing batch reactor (N-SBR) with 1.5 m^3 of working volume. The SRT was maintained at 15-20 days;

5) Selection of PHA storing biomass by feast/famine regime in a Sequencing Batch Reactor (S-SBR) under aerobic/anoxic conditions in a 2.9 m^3 of working volume. The applied SRT was maintained at around 5 days;

6) PHA accumulation in the biomass-cells was carried out in a SBR with a 1 m^3 of working volume, where up to 5-8 pulse-addition of VFAs were accomplished in 5-6 hours.

Table 1. Operating conditions of the SBRs for the nitritation, selection and accumulation

Parameter	**Nitritation SBR**	**Selection SBR**	**Accumulation SBR**
Type of Carbon source	-	Liquid fraction of fermented CPS	Liquid fraction of fermented CPS
Electron acceptor	Oxygen	Oxygen (feast)/Nitrite(famine)	Oxygen
Applied vNLR (kgN/m^3 d)	1.5-1.7	0.55-0.65	-
tOLR(kgCOD/m^3d)	-	1.2-1.4	5-8 spikes of 1 gCOD/L of VFAs from fermentation liquid

Food/Microorganism (gCOD-VFA/gMLVSS)	-	1.16 ± 0.25	-
Slugde Retention Time (d)	15-18	5-8	-

RESULTS AND DISCUSSION

Production of carbon source from cellulosic primary sludge (CPS)

Preliminary results shows that RBDF produced 650-720 liters in 9 hours of cellulosic primary sludge (CPS) with a total solid content of 5% by the sieving of 40 m^3/h of raw wastewater.
Around 95-100 mgTSS/L were removed from the wastewater without the addition of polyelectrolyte, which corresponded at around 50% of the suspended solids and 30% of COD influent.
Every day, the cellulosic primary sludge was fed into the fermentation unit. The mesophilic fermenting conditions lead to VFAs concentration of 10-15 gCOD/L with a specific yield of 0.3 $gVFA/gVSS_{fed.}$

Ammonia and phosphate were released during the acidogenic fermentation at concentrations of around 400 mgN/L and 50-60 mgP/L respectively. The low concentration of phosphate is due to the low content of phosphorus in the cellulosic material. However, the co-fermentation of CPS and secondary sludge may increase the concentration of phosphate in the fermentation liquid up to 100 mgP/L, which potentially increase the recovery of struvite precipitation by the addition of $Mg(OH)_2$ in the dedicated crystallizer after the solid/liquid separation.

Nitritation and selection of PHA storing biomass

Meanwhile the 1.5 m^3 SBR was fed with anaerobic supernatant with ammonium concentration of 800-1,000 mgN/L. The applied vNLR was increased up to around 1.7 kgN/ m^3 d of which 85% of the ammonium is oxydised to nitrite by ammonium oxidizing bacteria.

During the aerobic phase of the selection SBR, the fermentation liquid after the struvite crystallization was used as source of VFAs. During the operations, the observed VFAs uptake rate increased up to 280 mgCOD/gMLVSS h at 20°C in 10 days, which was in agreement with the decrease of the feast/famine ratio from 0.45 to less than 0.15 min/min. The observed PHA production yield was around 0.42 g of COD_{PHA} g^{-1} COD_{VFA}, which was comparable with the one reported by previous study (Frison et al., 2015). At the beginning of famine phase the effluent of nitritation reactor was fed to the selection reactor and anoxic conditions were established. In this phase the sole electron acceptor is the nitrite that is denitrified using stored PHA as carbon source. Currently, the combination of the nitritation reactor with the selection SBR allows the removal of around 1.0-1.2 kgN/d via nitrite.

PHA accumulation

Around selected biomass from the selection SBR is moved into 1 m^3 SBR where PHA accumulation is performed using CPS fermentation liquid fraction under 6-8 spikes of 1 gCOD/L as carbon source. The mixture of VFAs in the carbon source allows to accumulate polymers composed by both polyhydroxybutyrate and polyhydroxyvalerate which improve the final polymer properties. The expected yield is 0.42 g COD_{PHA} $gCOD_{VFA}$ and the final content of PHA in the microbial cell is higher than 25%. The potential PHA production is 0.7 kgPHA per accumulation batch.

CONCLUSIONS

The pilot SCEPPHAR process was applied and started-up at Carbonera WWTP. The system integrates the short-cut nitrogen removal with the production of PHAs and the recovery of struvite from cellulosic primary sludge. The performances of the system in terms of PHA production and struvite recovery yield will be evaluated during the next months Horizon 2020 - Smart-Plant Project.

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