Start-up, performances and preliminary economics of the first full scale Short Cut Enhanced Nutrients Abatement (S.C.E.N.A.) system

Daniele Renzi[1], Nicola Frison[2], Aleksandra Jelic[2], Francesco Fatone[2]

[1]Alto Trevigiano Servizi srl, via Schiavonesca Priula 86, 31044, Montebelluna (Treviso, Italy)
[2]University of Verona, Department of Biotechnology, Strada Le Grazie 15, 37134, Verona (Italy)

Abstract: The first full-scale Short-Cut Enhanced Nutrients Removal (S.C.E.N.A.) system was realized and started up in Carbonera WWTP for denitrifying biological phosphorus removal via-nitrite (DBPRN) which integrates phosphorus and nitrogen removal in a robust process in which ammonium is oxidised to nitrite under aerobic conditions, while under anoxic conditions the denitrification via nitrite and enhanced biological phosphorus uptake occur simultaneously. After 16 days to achieve a complete via-nitrite pathway, the system operated at 0.55 kgN/m^3 d during the working days and 0.12 kgN/m^3 d during the week end, according with the working hours of the anaerobic digestate dewatering. However, the maximal sAUR and sNUR increase constantly after 40 days, achieving 14-15 and 35-40 mgN/gVSS h respectively. As far as the environmental impacts are concerned, S.C.E.N.A. system led to a reduction of the overall electrical energy consumptions from 117 to 100 Wh/m^3 of treated wastewater in the main bioreactor. Moreover, the calculated O&M costs were 1.60 € / kgN removed which are promising for further replications in others WWTPs adopting the primary and secondary sludge anaerobic digestion.

Keywords: anaerobic supernatant, short-cut nitrogen and phosphorus removal, carbon source, operating costs.

Introduction

Sludge reject water is a nutrient-rich flux which should be properly managed to optimise the nitrogen removal and phosphorus recovery in wastewater treatment plants (WWTPs). Completely autotrophic nitrogen removal is becoming the most attractive biological process for the treatment of sludge reject waters in municipal WWTPs with several full-scale applications (Lackner et al, 2014). This process cannot enhance the phosphorus bioaccumulation and should be followed by struvite crystallisation for sustainable phosphorus recovery. However, if the economic and life cycle costs are taken into account, phosphate recovery as struvite was not considered the only sustainable alternative, and the use of composted sludge was considered another efficient phosphate based compounds for fertilisation (Hao et al., 2013). In consolidated schemes for EBPR, PAOs take up excess phosphorus and store it as polyphosphate in the cell mass using the energy from the aerobic heterotrophic oxidation of organic materials. If PAOs are exposed to anaerobic conditions, they obtain energy from the hydrolysis of the accumulated polyphosphate to take up volatile fatty acids (VFAs) as poly-hydroxyalkanoates (PHAs). On the other hand, the novel denitrifying biological phosphorus removal via nitrite (DBPRN) offers the potential to integrate phosphorus and nitrogen removal in a robust process in which ammonium is oxidised to nitrite under aerobic conditions, while under anoxic conditions the denitrification via nitrite and enhanced biological phosphorus uptake occur simultaneously by the DPAOs. The DPRN process is enhanced when high percentages of propionic and butyric acids are used as carbon source (Frison et al., 2013), which can be obtained in-situ by alkaline fermentation of sewage sludge (Longo et al., 2015). These concepts are included in the S.C.E.N.A. system which first full scale plant for the treatment of reject water was started up in September 2015 in Carbonera (Northern Italy). This paper reports the start-up, performances, O&M peculiarities and preliminary economics.

Material and Methods

- *The Carbonera WWTP*

The Carbonera WWTP (Veneto Region, North of Italy) treats around 15.000 m^3/d of municipal wastewater (Table 1). In the mainline the WWTP accomplish the nitrification and denitrification with a time-based intermitted aeration by a Schreiber bioreactor, while the phosphorus is removed mainly by chemical precipitation using PAC. The final effluent from the WWTP is discharged in a sensitive water body. The sewage sludge is treated in thickening, anaerobic digestion and the dewatering which is operated 5 days per week and produces around 60-80 m^3/d supernatant is recycled into the mainstream in 8 working hours per day (Figure 1). Between September and November 2015, the concentration of NH_4-N and PO_4-P in the anaerobic supernatant were respectively 591±60 mgN/L and 32±14 mgP/L, with a COD/TN around 1 gCOD/gN.

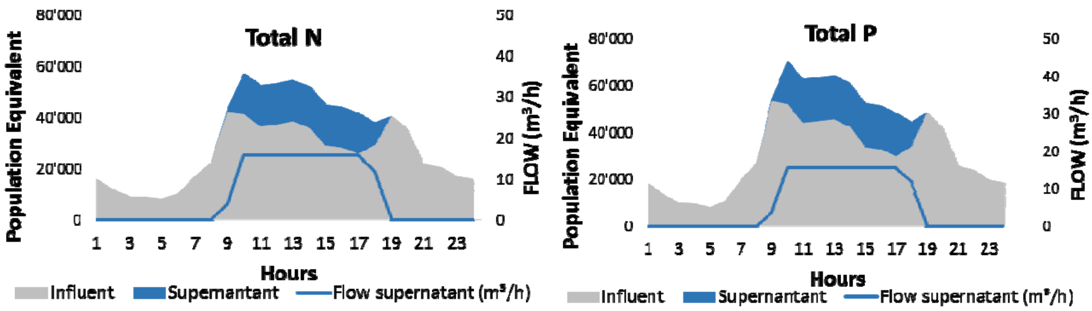

Figure 1. Effect of the anaerobic centrate on the nitrogen and phosphorus loading in the Carbonera's WWTP.

- *The S.C.E.N.A. system*

The first full scale S.C.E.N.A. system was designed and realized to revamp an existing and dismissed underground tank, which required very high flexibility of the system which has not optimal equalization volume for its stable operation as described below.

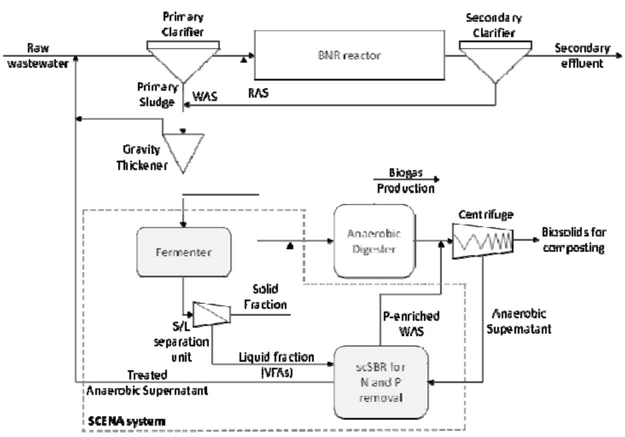

Figure 2. Schematic representation of the S.C.E.N.A. system integrated in the full scale WWTP

The S.C.E.N.A. system (Figure 2) combines the sewage sludge fermentation, coupled with a screw-press for separation of fermentation liquid, with a Short-Cut Sequencing Batch Reactor (scSBR) for nitritation-denitritation and DBPRN. After the dewatering, the anaerobic supernatant is equalized in a 40 m^3 tank, then fed to the scSBR (70 m^3 reaction volume). The anaerobic-aerobic-anoxic phases of the scSBR and the dosage of the carbon source are controlled by a programmable logic controller (PLC, Siemens) which uses indirect parametric signals, such us conductivity (3798 sc, Hach Lange) and pH (pHD, Hach Lange). Fermentation liquid is produced in the range of 10-12 m^3/d from Monday to Friday in a 50 m3 fermenter that can operate at different T, pH and conditions (batch, semi-batch). Solid-liquid separation by screw-press (SCAE, Vicenza, Italy).

Results and Conclusions

- *Performance of the SCENA system and impact on the total energy consumptions*

The complete start-up of the scSBR was carried out in less than 30 days to achieve the design vNLR of 0.55 kgN/m^3 d. After less than 20 days complete inhibition of the nitrite oxidizing bacteria was achieved thanks to the controlled concentration of free ammonia in the mixed liquor 1 mgFA/L.

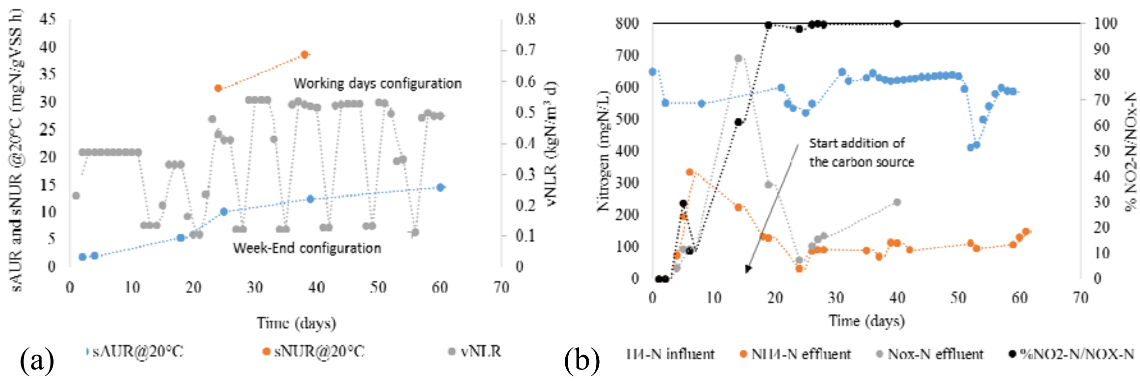

Figure 3 (a) vNLR variation during the week. (b) Profile of the nitrogen forms in the influent and effluent of the scSBR.

In order to cope with lack of supernatant and carbon source of the week-end, the scSBR treats up to 55 m^3/d of anaerobic supernatant from Monday to Friday, while in the week-end the feeding is decreased at 15 m^3/d. Despite the high fluctuation of the applied vNLR (Figure 3a) and the fermentation liquid dosage in the scSBR, the maximal specific ammonium oxidation rate (sAUR) and the specific nitrite uptake rate (sNUR) increased during the start-up achieving 14-15 and 35-40 mgN/gVSS h respectively after 40 days (Figure 3b). Nitrite up to 425 mgNO_2-N/L accumulated in the reactor in the start-up (0-14 days) were gradually but partially denitrified afterwards by the addition of fermentation liquid. Due to operational problems of the primary clarifier, the sewage sludge was thickened only as much as 2-3 %TS and fermentation liquid reached only 2.5±0.5 gVFA/L in spite of the good conversion of 0.25-0.3 gVFA/gTVS. This resulted in a low COD/NO_2-N applied (1.53±0.5 gCOD/gNO_2-N) that was not sufficient for complete denitritation and enhanced phosphorus removal. In the coming future the dynamic thickening of the sewage sludge will drastically improve the VFA concentration of the carbon source and achieve the DBPRN observed at pilot scale (Frison et al., 2014). In spite of this initial non-optimized operation, relevant impact was observed on both the final effluent quality standard and on the overall energy consumption (Figure 4). By measuring the real-time energy consumptions, we observed 15% reduction of overall values in a trend that is still decreasing with the optimization of the processes.

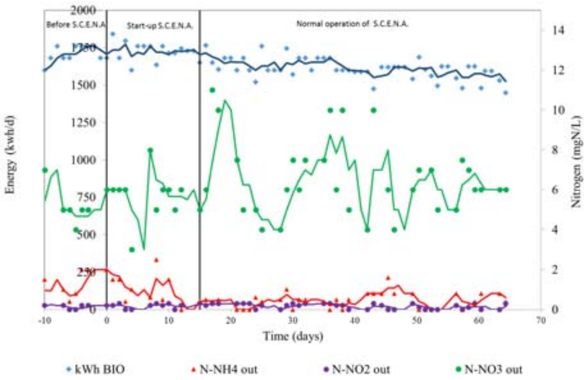

Figure 4. Energy consumption and nitrogen forms in the final effluent of the WWTP of Carbonera municipality.

- *O&M cost of S.C.E.N.A. system*

On the basis of conservative assumptions of average nitrogen removal of 30 kgN/d, the O&M costs were calculated and are reported in Table 2.

Table 2. Cost for the treatment of the anaerobic supernatant with S.C.E.N.A system.

Functional unit	Unit	Value	Percentage	Operating cost (€/kgN removed)
Storage supernatant	kwh/d	9	7%	0.05
Sequencing Batch Reactor	kwh/d	56	43%	0.31
Fermenter	kwh/d	48	37%	0.26
Solid/Liquid separation unit	kwh/d	17	13%	0.09
ENERGY CONSUMPTION	**kwh/d**	**130**	**100%**	**0.72**
POLYELECTROLITE	**kg/d**	**8.5**		**0.41**
SLUDGE PRODUCTION	**ton/d**	**0.07**		**0.16**
PERSONNEL				**0.21**
MAINTENANCE				**0.10**
O&M COST				**1.60**

The S.C.E.N.A. O&M cost of 1.6 €/kgN removed are much lower that the O&M cost of the mainline (3.5 €/kgN removed, Renzi at al., 2015) and will lead the water utility Alto Trevigiano Servizi to replicate the system in other WWTPs.

References

Cervantes, F.J. Environmental Technologies to Treat Nitrogen Pollution; IWA Publishing: London, 2009.

Frison, N., Di Fabio, S., Cavinato, C., Pavan, P., Fatone, F. Best available carbon sources to enhance the via-nitrite biological nutrients removal from supernatants of anaerobic co-digestion. Chemical Engineering Journal 2013, 15–22, 215–216.

Frison, N, Katsou, E., Malamis, S., Fatone, F. A novel scheme for denitrifying biological phosphorus removal via nitrite from nutrient-rich anaerobic effluents in a short-cut sequencing batch reactor. Journal of Chemical Technology and Biotechnology 2014, DOI: 10.1002/jctb.4561.

Hao X, van Loosdrecht MCM and Hu Y, Looking beyond Struvite for P recovery. Environ Sci Technol 2013, 47, 4965–4966.

Lackner, S., Gilbert E.M., Siegfried, E.V., Joss, A., Horn, H., Van Loosdrecht, M.C.M. Full-scale partial nitritation/anammox experiences - An application survey. Water Research 2014, 55, 292-303.

Longo, S.; Katsou, E.; Malamis, S.; Frison, N.; Renzi, D.; Fatone, F. Recovery of volatile fatty acids from fermentation of sewage sludge in municipal wastewater treatment plants. Bioresource. Technology 2015, 175, 436−444.

Renzi,D., Longo,S., Frison, N., Malamis, S., Katsou, E., Fatone, F. Short-Cut Enhanced Nutrients Removal from Anaerobic Supernatants: Pilot scale results and full scale development of the S.C.E.N.A. process. IWA Book. Sewage Treatment Plants: Economic Evaluation of Innovative Technologies for Energy Efficiency, April 2015.