(Initial page layout)

Short-cut enhanced nutrient abatement (SCENA) from anaerobic supernatant at pilot and full scale

F. Fatone*, N. Frison**, E. Katsou*, S. Longo*, S. Malamis*, A Piasentin***, D. Renzi***

*Department of Biotechnology, University of Verona, Strada Le Grazie 15, 37134, Verona, Italy (email: evangelia.katsou@univr.it; malamis.simos@gmail.com; francesco.fatone@univr.it)
**Department of Environmental Sciences, Informatics and Statistics, University Ca'Foscari of Venice, Dorsoduro 2137, 30121 Venice, Italy (E-mail: nicolafrison85@gmail.com)
***Alto Trevigiano Servizi srl, Via Schiavonesca Priula 86 - 31044 - Montebelluna, Italy (email: drenzi@altotrevigianoservizi.it; apiasentin@altotrevigianoservizi.it)

Abstract

Ammonium and phosphorus rich reject water from the dewatering of anaerobic digested sludge must be properly managed to recover resources and optimize the sustainability of biological nutrient removal in wastewater treatment plants. This work investigated the integrated scheme of nitritation/denitritation and via nitrite enhanced phosphorus removal coupled to alkaline fermentation liquid of sewage sludge as an in situ best available carbon source. Despite the problematic characteristics of the influent, the via nitrite bioprocesses were stable in the pilot scale plant. Using the alkaline silicate mineral of wollastonite to buffer pH in the fermenter, the conversion rates for external carbon source were 0.30±0.4 gSCVFA/gTVS, while the propionate and butyrate contents were optimized. The via nitrite nutrient removal rates were 15±2 mgN-$NH_{4oxidized}$/gMLVSS·h; 40±10 mgN-$NO_{2reduced}$/ gMLVSS·h; 10±3 mgP-$PO_{4bioaccumulated}$/gMLVSS·h. The cost comparison between conventional scheme and SCENA estimated a potential annual net income of approximately 35000 euros for a actual treatment potential of 50000 PE.

Keywords
Nitritation-denitritation; via nitrite enhanced phosphorus uptake, anaerobic supernatant

INTRODUCTION

Enhanced nutrient removal at municipal wastewater treatment plants (WWTPs) can be partly and efficiently carried out by treating the ammonium and phosphorus rich reject water produced from the dewatering of anaerobic digested sewage sludge. In conventional plants this flow constitutes 10-30% of the total nitrogen load (Gustavsson, 2010). Phosphorus concentration in reject water produced by the dewatering of anaerobically digested activated sludge, can be up to 130 mg/L (Oleszkiewicz and Barnard, 2006, Ivanov et al., 2009), while higher P concentrations may be reached when anaerobic co-digestion of sewage sludge and organic waste are applied (Malamis et al., 2014). Thus, reject water is returned to the activated sludge tank and contributes from 10 to 50% of the nutrients in the main stream of WWTPs. Furthermore, innovative schemes aiming at energy neutral or positive municipal WWTPs are considering anaerobic digestion as a core unit for energy recovery from enhanced removal of solids through primary sedimentation. Thus, the separate enhanced nutrients bioremoval from the anaerobic supernatant of sewage sludge is becoming a core process unit within the new conceived WWTPs. Among the different treatment technologies for sludge reject water, the innovative biological processes proved to be the most economically and environmentally sustainable in terms of nitrogen removal (STOWA, 2012). In fact, complete autotrophic nitrogen removal is widely considered the best sustainable and reliable solution for sludge reject water, which should be followed by phosphorus recovery processes to optimize the nutrients management. In fact, via nitrite autotrophic/heterotrophic processes (nitritation/denitritation) needs external carbon sources, which could negatively affect the

economical and environmental sustainability. On the other hand, the autotrophic nitrogen removal process is much more sensitive to environmental and operational parameters. In contrast to nitrogen, phosphorus is a limited resource, which must be recovered from wastewaters and reused (Gilbert, 2009). Struvite is generally considered as the optimal phosphate mineral for recovery and could potentially be used as a slow-release fertilizer. However, if the economic and life cycle costs are taken into account, phosphate recovery as struvite was not considered the best approach, and efforts were addressed also to the use of (composted) P-rich sludge for effective fertilization (Hao et al., 2013). Therefore, the via nitrite enhanced phosphorus removal associated with nitritation-denitritation (SCENA - Short-cut enhanced nutrients abatement) can realize the optimal side stream nutrients management in WWTPs. The SCENA system demonstrated its feasibility for the treatment of digester supernatant produced from the co-digestion of waste activated sludge (WAS) and the organic fraction of municipal solid waste (OFMSW), when the best available carbon source was recovered from OFMSW alkaline fermentation (Frison et al., 2013).
This paper deals with the pilot-scale operation of the SCENA system and the forthcoming full scale development in the municipal WWTP of Carbonera (Veneto Region, Northern Italy). It presents and discusses the integration of a conventional municipal WWTP, where the in situ best available carbon source for denitritation and via-nitrite enhanced P uptake is recovered from alkaline fermentation of sewage sludge.

MATERIAL AND METHODS

The SCENA pilot scheme consists of a sludge alkaline fermentation (SAF) unit coupled to a short-cut sequencing batch reactor (scSBR). The integrated SAF-scSBR has been set up within the conventional, municipal WWTP of Carbonera (Veneto, Italy). The system is applied to treat the real anaerobic supernatant for the short-cut N removal and via nitrite enhanced P bioaccumulation. It is composed of three main units: the sewage sludge alkaline fermentation unit (reaction volume 500 L, preceded by a coarse screen to prevent retain gross material present in the primary sludge), a tubular membrane (UF) filtration skid for the solid/liquid separation of the fermentation effluent, an SBR (3 m^3) for the treatment of the anaerobic supernatant to remove nutrients via nitrite pathway. The system is treating up to 6 m^3/d of anaerobic supernatant that is generated from the full-scale anaerobic digester of sewage sludge in Carbonera. The main processes involved are:

- ✓ Nitritation/denitritation coupled with the best available mix of short chain fatty acids (SCFAs) to enhance the denitrifying via nitrite biological phosphorus removal (DNBPR).
- ✓ Sludge alkaline fermentation to recover the best available mix of SCFAs for P removal and/or PHA production (which is not presented and discussed in this paper)
- ✓ Membrane filtration for the solid/liquid separation of the fermentation.

In addition, cheap and reliable system-wide process control may be realized by indirect parameters, namely: pH, conductivity, oxidation-reduction potential (ORP).

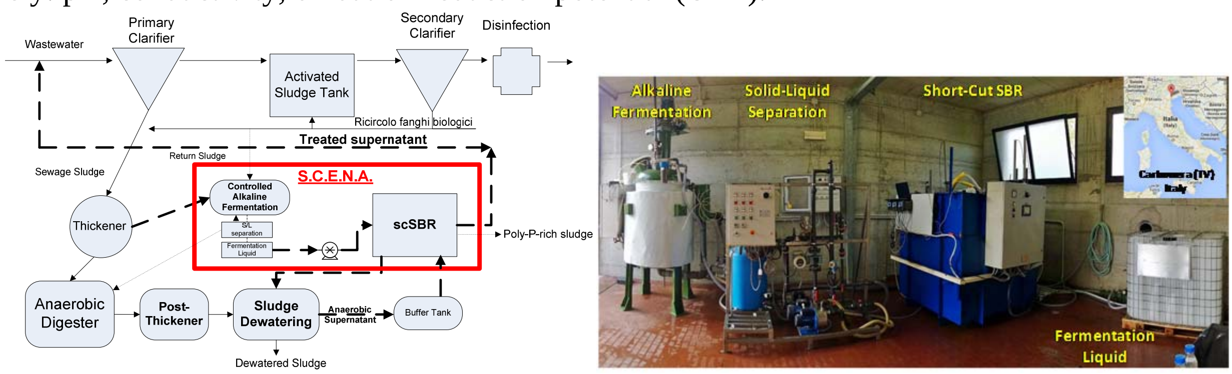

Figure 1. a) Integration of SCENA system in the conventional WWTP; b) SCENA pilot scale plant

According to the overview recently published by Desloover et al. (2012), the N_2O mitigation strategies were implemented according to Table 1. In addition, promotion of the mineral CO_2

sequestration is achieved by the use of alkaline silicates for pH buffering in the acidogenic fermentation (Salek et al., 2013).

Table 1 N_2O mitigation strategies implemented within the SCENA system

Objective	Required approach	SCENA approach
Minimize aerobic N_2O production	- Ensure high DO and adapted aeration regime; - Ensure constant DO (no repeated changes from anoxic to oxic)	DO during nitritation was always in the range 1.5-2 mg/L Only one aerobic/anoxic change is done
Maximize anoxic N_2O consumption	- Careful choice of the external carbon source	The alkaline fermentation liquid is rich of SCFA (i.e. propionate and butyrate) which minimize N_2O emissions (Zhu and Chen, 2011)

RESULTS AND DISCUSSION

Characteristics of the supernatant and start-up

The SCENA system was inoculated with conventional activated sludge coming from the full scale municipal WWTP of Carbonera. The start-up was carried out in two stages according to Frison et al. (2013). Due to extraordinary operation of the full scale wastewater treatment plant (i.e. low temperature), low performance and transient anaerobic digestion conditions were observed during the 150 operation days (Table 2). In spite of these problematic conditions (i.e. sCOD:N ~ 2) for autotrophic growth and nitrite oxidizing bacteria (NOB) suppression in the scSBR, the complete via nitrite pathway was achieved in around 30 days.

Table 2 Characteristics of digester liquor from the Carbonera WWTP

	Days 1-60	Days 61-150
pH	7,5±0,1	7,3±0,2
sCOD	520±30	155±38
$N\text{-}NH_4$	270±24	439±19
$P\text{-}PO_4$	25±3	43±3
Alkalinity ($mgCaCO_3/L$)	1065±170	1735±100

Alkaline fermentation and impact on denitritation and DNBPR

In WWTP required to meeting increasingly stringent nutrient requirement, the pre-fermentation of primary sludge to recover SCFA for BNR systems is a almost spread alternative to purchased carbon. Acid fermentation and its dosing to the main treatment line for the conventional BNR is a known practice (WERF, 2011). The innovation of SCENA system consists of: (1) the alkaline fermentation of sewage sludge; (2) the use of wollastonite for pH buffering; (3) the addition of sewage fermentation liquid in the anoxic phase of the nitritation-denitritation for the separate via nitrite enhanced nitrogen and phosphorus removal.

During the pilot scale trials the fermentation rate was as high as 0.30±0.4 gSCVFA/gTVS, while the average composition of the fermentation liquid optimized the contents of propionate and butyrate (Table 3), so as to enhance the via nitrite phosphorus removal (Ji and Chen, 2010). Optimal fermentation HRT was in the range 5-7 days according to the content of primary and waste activated sludge, while semi-batch conditions were considered to obtain a stable production of SCFAs.

Table 3 Characteristics of alkaline fermentation liquid

Acetate	Propionate	Butyrate	Valerate
32 %	30 %	21 %	17 %
sAUR	sNUR	sPUR	
$mgN\text{-}NH_{4oxidized}/gMLVSS\cdot h$	$mgN\text{-}NO_{2reduced}/ gMLVSS\cdot h$	$mgP\text{-}PO_{4bioaccumulated}/ gMLVSS\cdot h$	
15±2	40±10	10±3	

Full scale development and economic impact

The CAPEX and OPEX conventional activated sludge (modified Ludzack-Ettinger (MLE) + chemical P removal by alum) and SCENA systems were preliminary compared for the treatment of the nutrient loadings associated with digester supernatant (Table 4).

Table 4 Preliminary cost comparison for management of nutrients associated with digester supernatant (interest rate 4% was used for CAPEX)

Costs		MLE	SCENA
CAPEX: for MLE [a]	€/year	1277	0
CAPEX: for SBR [a]	€/year	0	389
CAPEX: for sludge fermenter [a]	€/year	0	449
OPEX: EE for aeration [b]	€/year	72060	54084
OPEX: Sludge disposal [c]	€/year	13607	7884
OPEX: Aluminium Polychloride (PAC)[d]	€/year	10439	0

[a] Payback time = 25 years; [b] 4 kWh/kgO_2, 0.2 €/kWh; [c] 400 €/kg$TS_{disposed}$; [d] €/tonAl 5500

In the specific case of Carbonera, even major net incomes are expected because the SCENA system will be realized by revamping the existing structures. The full scale plant is under construction and will be fully operating by the end of 2014. Future evaluations will incorporate sustainability considerations (i.e. LCA, usability of the removed phosphorus).

CONCLUSIONS

Nitritation/denitritation and via nitrite enhanced phosphorus removal from anaerobic digested supernatant were obtained in pilot scale by the in situ recovering of best available carbon source. Removal rates of 15±2 mgN-$NH_{4oxidized}$/gMLVSS·h; 40±10 mgN-$NO_{2reduced}$/ gMLVSS·h; 10±3 mgP-$PO_{4bioaccumulated}$/ gMLVSS·h were observed and annual net income of 30-40 k€/year were estimated for a municipal WWTP with actual treatment capacity of 50 000 PE.

ACKOWLEDMENTS

The authors thank Alto Trevigiano Servizi Srl for funding and technical assistance.

REFERENCES

Desloover, J., Vlaeminck, S.E., Clauwaert, P., Verstraete, W., Boon, N. 2012 Strategies to mitigate N2O emissions from biological nitrogen removal systems. Current Opinion in Biotechnology 23, 1-9.

Frison, N., Di Fabio, S., Cavinato, C., Pavan, P., Fatone, F. 2013 Best available carbon sources to enhance the via-nitrite biological nutrients removal from supernatants of anaerobic co-digestion, Chem. Eng. J. 230, 595-604.

Gilbert, N. 2009 The disappearing nutrient. Nature, 461 (8), 716-718

Gustavsson DJI. 2010 Biological sludge liquor treatment at municipal wastewater treatment plants - a review. Vatten, 66, 179–92

Ivanov V., Kuang S., Stabnikov V., Guo C. 2009 The removal of phosphorus from reject water in a municipal wastewater treatment plant using iron ore J. of Chem. Tech. and Biotech. 84, 1, 78–82

Malamis S., Katsou E., Di Fabio S., Bolzonella D., Fatone F. 2014 Biological nutrients removal from the supernatant originating from the anaerobic digestion of the organic fraction of municipal solid waste. Crit. Rev. Biotech.. In press

Hao, X., Wang, C., van Loosdrecht, M.C.M., Hu, Y. 2013 Looking Beyond Struvite for P-Recovery Environ. Sci. Technol. 47, 4965-4966

Ji Z., Chen Y. 2010 Using sludge fermentation liquid to improve wastewater shortcut nitrification-denitrification and denitrifying phosphorus removal via nitrite, Environ. Sci. Technol. 44 8957–8963

Oleszkiewicz, J.A., Barnard, J.L. 2006 Nutrient Removal Technology in North America and the European Union: A Review Water Qual. Res. J. Canada, 41, 4, 449–462

Salek, S. S., Kleerebezem R., Jonkers H.M., Witkamp G., van Loosdrecht M.C.M. (2013) Mineral CO2 sequestration by environmental biotechnological processes. Trends in Biotechnology, 31 (3) 139-146

STOWA 2012 Explorative research on innovative nitrogen recovery - Report 51

WERF 2011 Fermenters for Biological Phosphorus Removal Carbon Augmentation - Compendium

Zhu, X., Chen, Y. 2011. Reduction of N2O and NO generation in anaerobic-aerobic (low dissolved oxygen) biological wastewater treatment process by using sludge alkaline fermentation liquid, Env. Sci. and Tech., 45 2137–2143