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Biological Short-Cut Nitrogen Removal from Anaerobic Digestate in a Demonstration Sequencing Batch Reactor

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The paper deals with a demonstration study where the nitrogen biological removal from anaerobic supernatants of sewage sludge and organic fraction of the municipal solid waste (OFMSW) was carried out by short-cut nitrification denitrification. The anaerobic supernatant was fed to the demonstration sequencing batch reactor (SBR) directly from the belt press of the full scale municipal WWTP. The SBR had reaction volume of 2.7 m^3 and was engineered on the basis of control algorithms designed by the authors. It was equipped with in-situ probes for the direct ((N-NH4, N-NOx) and indirect (DO, ORP, pH, conductivity) control of biological nitrogen removal. The SBR, inoculated with activated sludge coming from the Treviso municipal wastewater treatment plant (WWTP), treated up to 1.1 kgN/m^3 d and removed more than 90% of the influent total nitrogen, when the oxygen transfer efficiency was not drastically influenced by the liquor's salinity. In spite of the different operating and environmental conditions, the effluent showed stable $N\text{-}NO_2/N\text{-}NOx$ ratio higher than 0.9.

1. Introduction

Conventional microbial nitrogen removal is carried out by autotrophic nitrification and heterotrophic denitrification via-nitrate and has been already optimized by automatic control systems (Fatone et al., 2008). Complete nitrification includes nitritation (from ammonia to nitrite) and nitratation (from nitrite to nitrate), which is catalyzed by two groups of autotrophic bacteria: ammonia oxidizing bacteria (AOB) and nitrite oxidizing bacteria (NOB), respectively. Partial nitrification and denitrification process is based on the partial nitrification up to nitrite followed by the nitrite denitrification. Compared with conventional nitrification and denitrification via nitrate, nitrogen removal via nitrite not only reduces the aeration consumption in nitrification stage by 25% but also saves the carbon-source requirement in the denitrification stage by 40% (Cervantes, 2009) Higher denitrification rate and lower wasted sludge production can also be obtained by partial nitrification and denitrification via nitrite. Based on these advantages, the short-cut nitrification-denitrification has attracted the most research interest and attention in recent years, particularly in treating low C/N ratio and strong nitrogenous wastewater (Gujer, 2010). These features are typical of liquid effluents from anaerobic digestion of biowaste (i.e. sewage sludge, Organic Fraction of

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Municipal Solid Waste (OFMSW), agro-industry and livestock waste, manure). In particular, the digestate of sewage sludge and OFMSW may have contents of 1-2 g/L and 0.1-0.3 g/L of ammonia nitrogen and total phosphorus, respectively. This paper deals with the results of a demonstration study carried out by a SBR operating for the treatment of real anaerobic supernatant coming from the full scale anaerobic codigestion of sewage sludge and OFMSW. The general objective of the paper is to demonstrate the stability and reliability of the process, taking into account one year operation of the demonstration plant. Moreover, the mechanisms observed for the accumulation of AOB were demonstrated by respirometry batch tests and are hereby discussed.

2. Materials and Methods

The demonstration SBR (Figure 1) had a reaction volume of 2.7 m^3 and was fed with anaerobic supernatant taken directly from the full scale belt press. Here the anaerobic digestate is dewatered from dry matter of 4-6% to 20-25%, the liquid passed through a 10 m^3 accumulation tank, where a volumetric pump of 0.8-2 m^3/h installed to feed the SBR. Dosages of external carbon and/or base and acid chemicals are provided by peristaltic pumps and industrial solutions. The mixing is realized by a Rushton turbine, while the aeration counts on three blowers, which progressive ON-OFF is automatically controlled on the basis of the DO and/or pH signals.

The plant is equipped with on-line submerged probes of dissolved oxygen (DO - LDO Hach-Lange), redox potential (ORP - Chemitec and Hach-Lange), pH (Hach-lange), conductivity (Hach-lange), N-NOx (Nitratax plus Hach-Lange coupled with Filtrax module), N-NH4 (NH4D sc Hach-Lange), mixed liquor suspended solids (Solitax Hach-lange) and temperature. No heating system was installed and the reaction temperature was consequence of the environmental conditions.

The on-line signals are processed by a program line controller (PLC - Schneider Electric) programmed according to control algorithms designed by the authors. The real-time control system allows the plant to operate according to five alternative algorithms, so as to adequate and optimize the treatment performances in different situations.

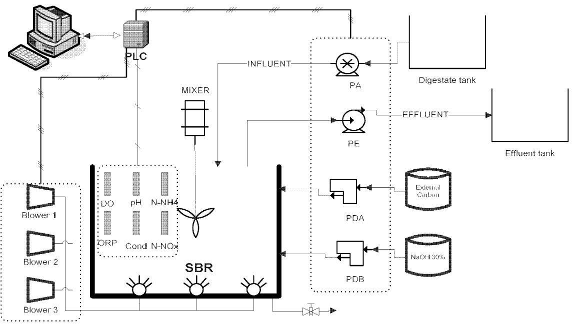


Figure 1: Schematic of the demonstration SBR

3. Results and Discussion

3.1 Influent characteristics, process conditions and efficiencies

The SBR was inoculated with activated sludge taken from the full scale WWTP of Treviso, and fed with the anaerobic supernatant (Table 1) according to the scheme of Figure 2.

The CVs of Table 1 clearly show the stability of the chemical-physical characteristics of the digestate, in spite of the high variability of the OFMSW collected to the Treviso treatment plant (5.1 ton/d ± 95%). The start-up lasted 14 days and the nitrogen removal rates increased from 3 to 30 mgN/L*h (Figure 3a). In the same time, the N-NO_2/N-NO_x ratio increased from 30 to 99% (Figure 3b).

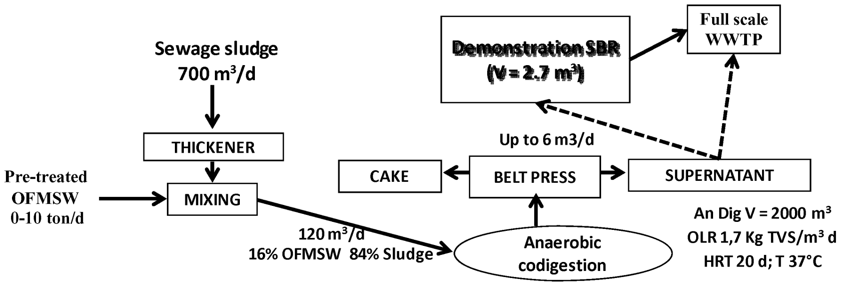


Figure 2: Scheme of the full scale co-digestion and the demonstration SBR

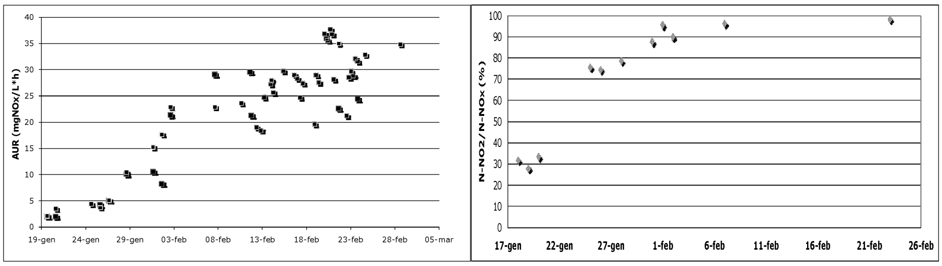


Figure 3a-b Nitrification rates and N-NO_2/N-NO_x ratio over the start-up

After the start-up, four experimental runs were carried out with increasing NLRs, up to 1.1 kgN/m3*d, corresponding to 0.53 kgN/kgVSS*d, as consequence of the biomass growth and speciation.

Table 1: Main chemical characteristics of the anaerobic supernatant (n.50 samples analyzed over one year)

		Average	*Coefficient of variation (CV) (%)*	*Range*
COD	mg/L	109	30	49-170
Soluble COD	mg/L	93	30	51-136
TKN	mg/L	491	14	355-535
N-NO3	mg/L	<0.5		
N-NO2	mg/L	<0.5		
N-NH4	mg/L	446	17	355-535
TS	mg/L	33	27	22-47
Partial alkalinity	mgHCO3-/L	969	20	665-1269
Total alkalinity	mgCaCO3/L	1850	16	1380-2270
Conductivity	mS/cm	4.2	12	3-6
pH		7.7	3	7.5-7.85
Ptot	mg/L	90	36	29-120
P-PO4	mg/L	95	27	33-117
Cl-	mg/L	6	31	39-98
SO4--	mg/L	4	75	2-8
Mg+	mg/L	40	5	36-41
Ca++	mg/L	124	3	119-131
K+	mg/L	30	6	28-33

The accumulation of AOB and limitation-inhibition-washout of NOB is the critical point for maintaining stable partial nitrification (Cervantes, 2009). Several process parameters, including dissolved oxygen (DO) concentration, temperature, sludge retention time (SRT), substrate concentration, aeration pattern, and inhibitors, have been found to inhibit or washout NOB selectively. In this study the stable AOB accumulation was obtained by a 15-day-long ammonia concentration in the range 1-3 mgN/L. From that point on the process conditions were typical of common activated sludge systems (Table 2).

Table 2: Process operating conditions

	DAYS	*T*	*HRT*	*SRT*	*MLSS*	*MLVSS*	*DO*	*pH*
		°C	d	d	g/L	g/L	mg/L	
START UP	15	13	-	-	2-3	2.3-2.7	1.5	7.5
RUN 0	0-50	13	3.2	30	2.89	2	1.5	7.5
RUN 1	50-107	14	3.2	15	2.4	1.9	1.5	7.5
RUN 2	108-140	17	1.9	13	3	2.5	1.5	7.5
RUN 3	228-293	28	0.9	11	2.5	1.6	1.5	7.5
RUN 4	294-365	25	0.52	15	3.8	2	0.4-0.7	7.5

From Table 2 one should consider that the DO of the Run 4 depended on the effect of the liquors salinity on the oxygen transfer, which must be taken into account to design and operate the aeration systems. In fact, increasing the nitrogen loading rate from 0.15 to 1.1 kgN/m3*d, the beta factor linearly passed from 0.8 to 0.4.

Except for nitrogen, the specific loadings applied to the SBR were as high as showed in Table 3. In particular, the acetate dosage was in the range 1.5-2.2 g COD/gN$_{\text{denitrified}}$, as high as from the stoichiometric requirements for the heterotrophic denitritation.

Table 3: Specific loadings to the demonstration SBR

	DAYS	*NLRv*	*NLRs*	*F:M$_{acetate}$*	*OLR*
		kgN/m3*d	gN/gVSS*d	gCOD/gVSS*d	gCOD/m3*d
START-UP	15	-	-	-	-
RUN 0	0-50	0.15	0.08	0.17	0.35
RUN 1	50-107	0.12	0.085	0.17	0.36
RUN 2	108-140	0.28	0.14	0.23	0.52
RUN 3	228-293	0.4	0.25	0.45	0.72
RUN 4	294-365	1.05	0.53	0.5	1.05

Under the conditions of Tables 2 and 3, almost total nitrogen removal was achieved up to NLR of 0.7-0.8 kgN/m^3*d, while DO concentration probably limited the complete nitritation in Run 4. However, the effluent showed stable N-NO$_2$/N-NOx ratio of 0.8-0.9. As from Table 4, owing to the increase of the available internal alkalinity, the specific consumption of external NaOH was obviously lower at higher NLR.

Table 4: Specific NaOH consumption and N removal efficiency

Specific NaOH 30% consumed (gNaOH /m$^3_{treated}$)	*433*	*350*	*230*	*140*
TN removal Efficency (%)	89	88	89	49

We considered and investigated the recovery of ordinary partial nitrification after extra-ordinary temporary conditions such as: (1) low temperature (<12 °C); (2) sludge escape due to the presence of cationic polyelectrolyte residuals in the anaerobic supernatant.

The effect of the temperature was as relevant as expected from the Arrhenius plot. However, the system continued to perform short-cut nitrification within 14 days after 5 days under 12°C.

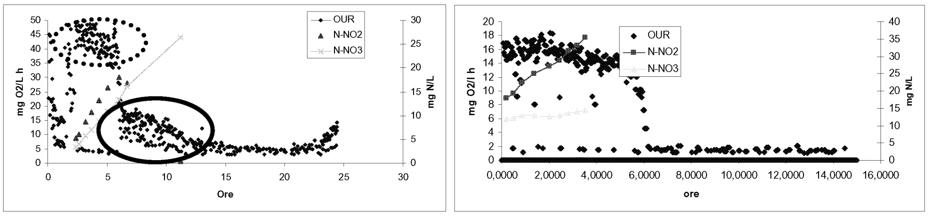
The specific polyelectrolyte use in the full scale dewatering station was as high as 4 grams per kilogram of dry matter. However, this quantity was often and uncarefully increased by the operators, as soon as the TS contents of the cake decreased. As a result, significant polyelectrolyte residuals were present in the anaerobic supernatant and entered the SBR, causing flocculation of the activated sludge.

The residuals of the cationic polymer caused sludge flocculation, flotation and escape, leading to the 30% decrease of the biomass concentration. However, the partial nitritation capability was not lost and soon recovered, so as to demonstrate the process stability and robustness for the industrial application.

3.2 Mechanism for NOB stable wash-out: respirometry investigation on pH effect

In order to investigate the stable effect of a free ammonia on the selection and accumulation of AOB, a respirometry batch test was carried out. The activated sludge was taken from the Treviso full scale WWTP, continuously aerated for 14 days at pH 8, mainatining the free ammonia higher than 2.5 mg NH_3/L. Respirometry plots are showed in Figure 4 (a-b) were the activity of the biomass AOB and NOB are visible. In particular, Figure 4a shows the sum of the activity AOB and NOB in the part at OUR 40-45 mg O_2/l h (dotted circle - Figure 4a), while the NOB activity is visible at OUR 15-18 mg O_2/l h (continuous circle - Figure 4b). After 8 days, Figure 4b shows that the NOB activity is almost disappeared due to the free ammonia inhibition (> 2.5 mg NH_3/L a pH 8).

Figure 4 a-b: Nitrification respirometry: activated sludge under pH8 on day 1 (a) and day 8 (b)



Conclusions

The short-cut of biological nitrogen removal was stably achieved in a demonstration SBR treating supernatant from anaerobic codigestion of sewage sludge and OFMSW. The stable NOB wash-out was achieved in 14 days. From that point on, the process was reliable and resistant to extra-ordinary environmental and field conditions (i.e. reaction temperature. sludge wash-out due to polyelectrolyte residuals). The maximal nitrogen loading rate was 0.7-0.8 kgN/m3*d, while the system was limited by reduced oxygen transfer at 1.1 kgN/m3*d. Currently further investigation are ongoing adopting an improved aeration system.

References

Cervantes F.J., Editor, 2009, Environmental technologies to treat nitrogen pollution, IWA Publishing, London

Fatone F., Battistoni P., Bolzonella D., Pavan P., Cecchi F., 2008, Long term experience with an automatic process control for nitrogen removal in membrane bioreactors, Desalination, 227 72-84

Gujer W., 2010, Nitrification and me – A subjective review, Water Research, 44, 11-19

Jubany I., Carrera J., Lafuente J., Baeza JA., 2008, Start-up of a nitrification system with automatic control to treat highly concentrated ammonium wastewater: experimental results and modelling, Chemical Engineering Journal, 144 407–19