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Evaluating the performance of nitritation-denitritation process for sludge liquors treatment

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Abstract. Treatment and handling of sewage sludge (anaerobic digestion, thickening, dewatering, etc) results in the production of sludge liquors with a high ammonium content and low COD:N ratio, which are recycled back to the main wastewater treatment line thus contributing about 15-20% of the total nitrogen load of the wastewater treatment plants. Nitritation- denitritation process is often used for ammonia removal from sludge liquors. This process is based on the prevalence of ammonia-oxidizing bacteria and the inhibition of nitrite-oxidizing bacteria. The objective of this study was to evaluate the effect of temperature and the type of external organic carbon source on the performance of the nitritation–denitritation process for the treatment of sludge liquors with a high ammonia content. The study was performed through the monitoring of the operation of a 5L lab-scale SBR for a period of 350 d under alternative conditions (two different external organic carbon types and three temperatures). Based on the results the process can be sustained even at low temperatures (15°C) with lower rates though. Furthermore, the use of a highly biodegradable organic carbon source can provide for the achievement of very satisfactory denitritation rates thus allowing for the increase of system’s overall treatment capacity.

Keywords: AOB; nitritation; denitritation; sludge liquors

1. Introduction

The stabilization and handling of sewage sludge is achieved in a wide range of wastewater treatment plants (WWTPs) through the use of anaerobic digestion, thickening, dewatering, drying etc. Through these processes sludge liquors are produced, with a high ammonium content and low COD:N ratio, which are recycled back to the main wastewater treatment line thus contributing about 15-20% of the total nitrogen load of the WWTPs (Gustavsson, 2010).

The most common biological processes for ammonium reduction in the reject water of dewatered sludge includes the use of conventional nitrification/denitrification, short-cut nitrification/denitrification and partial nitritation/autotrophic anaerobic ammonium oxidation processes (anammox) (Fux and Siegrist, 2004).

Short-cut nitrification/denitrification (SCND) is based on the prevalence of ammonia-oxidizing bacteria (AOB) and the inhibition of nitrite oxidizing bacteria (NOB). This process offers about 25% less aeration requirements and saves up to 40% of the required external carbon source for the denitritation stage compared to conventional denitrification (Guo *et al*., 2010). In order to attain the short-cut nitrification process the different characteristics of AOB and NOB bacteria should be taken into account. The selection of the appropriate operational parameters could favor the growth of the first ones and the inhibition of the second (Ge *et al*., 2015). According to literature, the basic parameters which can enhance the partial nitrification is the temperature, the free ammonia (FA) and the free nitrous acid (FNA) concentration, the SRT, the available dissolved oxygen and pH (Zeng *et al*., 2014; Ruiz *et al*., 2003). The treatment of sludge reject water with the nitritation/denitritation process is usually applied in sequencing batch reactors (SBRs) that offers operation flexibility (Katsou *et al*., 2015). The phase alternations on SBR provide the ideal conditions for the aerobic ammonia oxidation to nitrite and anoxic denitritation which usually requires the addition of external carbon source due to the low COD:N ratio of reject water (Gustavsson, 2010).

Dosta *et al*. (2007), used an SBR to treat reject water with high ammonia nitrogen concentration (800-900 mg L^{-1} NH_4-N). Using three cycles per day with alternation of aerobic/anoxic phases , an HRT of 1 d and SRT of 11 d they achieved about 0.87 Kg N m^{-3} d^{-1} removal. Fux *et al*. (2006), examined the operation of a novel SBR with continuous reject water feed. With an HRT equal to 1 d and a nitrogen loading rate up to 1.2 KgNH_4-N $m^{-3}d^{-1}$ their reactor achieved nitritation rates of 3-3.6 KgN $m^{-3}d^{-1}$. Using ethanol as external carbon source the denitritation rates ranged to 3.2-4.3 KgNO_2-N $m^{-3}d^{-1}$.

The objectives of this study was to evaluate the effect of temperature and the type of external organic carbon source on the performance of the short-cut nitrification/denitrification (SCND) process for the treatment of sludge reject water with a high NH_4-N content.

2. Materials and Methods

A 5L laboratory-scale SBR made of glass was operated for the treatment of dewatered sludge reject water using the short-cut nitrification/denitrification process (SCND). The

SBR worked, for a total period of 350 d, at 4 experimental periods in order to investigate the effect of temperature on nitritation/denitritation process and to compare two available external organic carbon sources required for the denitritation stage. Systems SCND-A2 and SCNDB operated at 25^0C with reject water of primary sludge thickening as external carbon source for SCND-A2 and hydrolyzed primary sludge liquor for SCND-B. Both systems SCND-A1 and SCND-A3 used reject water from primary sludge thickening as external carbon source and operated at 15^0C and 30^0C respectively. In each experimental period the SBR operated on one cycle per day that started with feeding, followed by aerobic phase, anoxic phase and an additional shorter aerobic phase before the settling and decanting. The solids retention time (SRT) was 12 d, while the hydraulic retention time (HRT) ranged between 1.92 and 2.15 d. The stirring was accomplished with magnetic stirrers at SCND-A2 and SCND-B systems and with mechanical stirrer at SCNDA1 and SCNDA3 systems that were submerged in thermal baths in order to keep temperature constant at 15^0C and 30^0C. Air blowers were used for the aeration of SBR and a peristaltic pump to provide the required external carbon source at the beginning of anoxic phase. The alternation of aerobic/anoxic phases and the on/off operation of the peristaltic pump were controlled with pre-programmed timers.

During all experimental periods the performance of the SBR units was assessed by routine measurements of temperature, pH, DO, ORP, TSS, VSS, MLSS, MLVSS, total and soluble COD, NH_4-N, NO_3-N and NO_2-N. In order to evaluate the effect of the operating conditions (type of substrate and temperature) to the nitritation and denitritation rate, a series of ex-situ batch experiments were also performed. All experiments were conducted in more than triplicates after steady state conditions were achieved in each system.

All analyses of SBR units and batch assays were performed in accordance with Standard Methods(APHA, 2012). DO and ORP were measured daily using portable equipment (HACH, HQ40d).

3. Results and Discussion

The SBR reactor was inoculated with a mixture of activated sludge from the aerobic reactor and diluted sludge liquors originating from the sludge dewatering unit (downstream of the anaerobic digestion unit)of Psyttalia Wastewater Treatment Plant (PWTP) at a ratio of 50%/50% on a volume basis.

The start-up of the reactor lasted for 38 d. During this period the reactor was operated at alternative aerobic and anoxic phases and was being fed with diluted dewatered sludge reject water. The objective of this period was to establish nitritation and at the same time to achieve the inhibition of NOBs. The nitrogen loading rate (NLR) was progressively increased during the start-up period from 0.2 – 0.35 kg N m^{-3} d^{-1}. During the first 20 d of operation, a build up of nitrates concentration to the order of 100-200 mg NO_3-N L^{-1} was recorded. However, upon increasing the NLR from 0.2 to 0.35 kg N m^{-3} d^{-1}, free nitrous acid concentrations of greater than 0.05 mg L^{-1} were established and NOB activity was totally suppressed (minimal nitrates concentrations). The results of the operation of the reactor for the four experimental periods are summarized in Table 1, while the results of the batch tests are reported in Figures 1-2.

Based on the results it is exhibited that moderate TN removal were achieved for systems SCND-A1, SCND-A2 and SCND-A3 which were operated with the addition of primary sludge reject water as carbon source. In all systems a 48.7±4.1% total nitrogen removal was recorded, although with appreciable differences in the processes' rates. As illustrated in Figures 1(a) and 2(a), nitritation and denitritation rates differed markedly for the three systems. More specifically nitritation and denitritation rates at 15^oC, accounted for the 47% and 43% of the respective rates at 30^oC. The temperature dependency of both nitritation and denitritation rates (K) was evaluated using Arrhenius relationship (Figures 1(b), 2(b)) as follows:

$$K = A \times \exp[-Ea/(R \times T)]$$

where K is the nitritation or the dentritation rate (mgN $gVSS^{-1}$ h^{-1}), A is a frequency factor (mgN $gVSS^{-1}$ h^{-1}), Ea is the activation energy of the process (J mol^{-1}), R is the ideal gas constant (8.314 J mol^{-1} K^{-1}) and T is the temperature (K). In Figures 1-2 the line has been fitted to the experimental data points obtained in this study. Since the coefficient of the determination (R^2) of the linear regression in the Arrhenius plot is greater than 0.9% (0.96-0.97) it is suggested that the effect of temperature on nitritation and denitritation rates can be described by a single activated energy (Ea). From the slope of the straight line the activation energy was calculated equal to 37.6 KJ mol^{-1} for the nitritation and 39.6 KJ mol^{-1} for the denitritation. These values are close although somewhat lower than the reported ones for nitritation (Guo *et al.*, 2010) and denitrification (Foglar *et al.*, 2004).

Systems SCND-A2 and SCND-B were operated at the same temperature (25^oC) while being fed with reject water of different composition as external carbon source. System SCND-A2 was supplied with reject water from primary sludge thickening whereas system SCND-B was fed by hydrolyzed primary sludge liquor.

The different composition of the two external carbon sources was markedly, as in the first case 12% of the total organic carbon was readily biodegradable and 58% slowly biodegradable (approximately 70% of the organic carbon was biodegradable), while in the latter case more than 90% of the total COD was biodegradable, thus presenting an easily biodegradable portion of 52%. Furthermore, the organic loading rate of system SCND-B was more than 50% higher than that of system's SCND-A2 (1.65 KgCOD m^{-3} d^{-1} versus 1.1KgCOD m^{-3} d^{-1}). As a result, system SCND-B exhibited higher nitritation rates (on average 20% greater than that of system's SCND-A2) while its denitritation rates were almost doubled than that of system's SCND-A2 (10.1 versus 5.2 mgNO_2-N g VSS^{-1} h^{-1}). In view of the above system SCND-B achieved satisfactory nitrogen removal (to the order of 60%) at increased NLRs (0.49 versus 0.39 Kg N m^{-3} d^{-1}).

Table 1: SBR operating conditions and effluent values (average values ±standard deviation).

Parameter	SCND-A1	SCND-A2	SCND-A3	SCND-B
pH	8.52±0.33	7.47±0.68	7.93±1.14	7.87±0.3
MLSS (mg L^{-1})	3986±632	3437±385	3496±934	3749±1390
MLVSS (mg L^{-1})	2786±405	2686±284	2781±737	2990±281
NLR (Kg N m^{-3} d^{-1})	0.24±0.09	0.39±0.07	0.41±0.03	0.49±0.05
NH$_4$-Nef (mg L^{-1})	343±174	314±72	356±195	357±58
NO$_2$-Nef (mg L^{-1})	48±46	262±97	239±153	58±26
OLR (Kg COD m^{-3} d^{-1})	1.01±0.46	1.07±0.37	1.28±0.35	1.68±0.42
tCODef (mg L^{-1})	1523±903	1049±129	1093±347	1020±115
sCODef (mg L^{-1})	920±389	731±177	725±305	666±115
AUR (mgNO$_2$-N g VSS^{-1} h^{-1})[1]	3.46±0.3	6.2±1.1	6.97±0.9	7.58±0.9
NUR (mgNO$_2$-N/g VSS^{-1} h^{-1})[1]	3.23±0.7	5.2±1.0	7.47±2.7	10.1±2.7
TN removal (%)	50±15	44.1±8.2	52±11.9	59.7±4.2
NH$_4$-N removal (%)	57±21.6	62.1±8.7	73±22.1	65.8±4

[1] from the ex-situ batch experiments

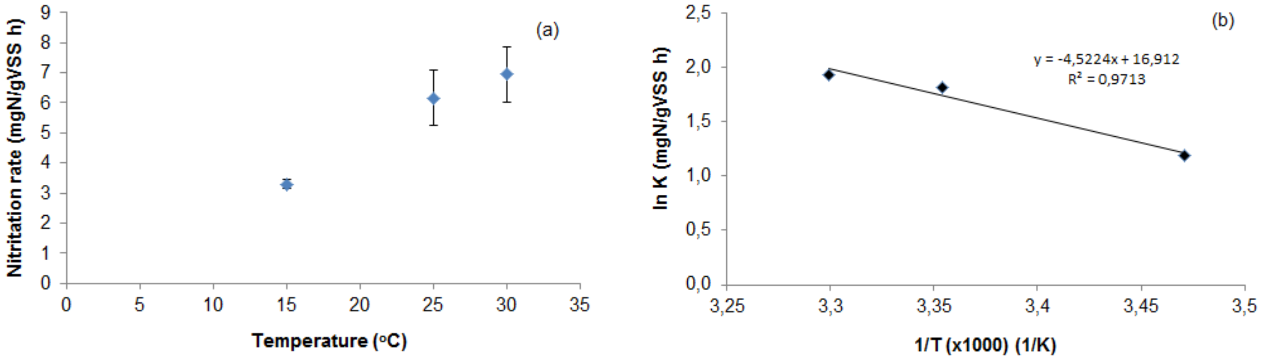

Figure 1: Effect of temperature on nitritation rate (a) and Arrhenius plot for nitritation rate with corresponding activation energy calculation (b).

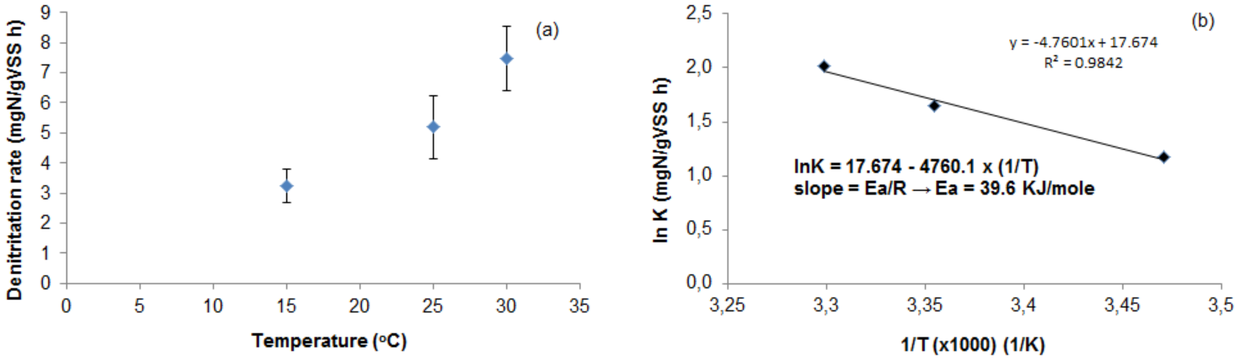

Figure 2: Effect of temperature on denitritation rate (a) and Arrhenius plot for denitritation rate with corresponding activation energy calculation (b).

4. Conclusions

In the present study the effect of temperature in the performance of the short-cut nitrification denitrification process for the treatment of reject water originating from anaerobic digestion units was assessed. Based on the results the process can be sustained even at low temperatures (to the order of 15^{o}C) with lower rates though. By taking into account that reject water temperature is higher than 20^{o}C for most of the time due to the preceding treatment (anaerobic digestion and in some cases thermal hydrolysis), it is anticipated that reject water treatment can reliably be sustained throughout the year with rather satisfactory nitritation and denitritation rates. The use of an on-site produced organic carbon source with a high readily biodegradable content, can provide for the achievement of an even higher denitritation rate thus contributing on treatment's performance.

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