SWINE WASTEWATER NITROGEN REMOVAL AT DIFFERENT C/N RATIOS USING THE MODIFIED LUDZACK-ETTINGER PROCESS

Adelcio Giongo[1*], Marcelo Bortoli[2], Marina Celant De Prá[3], Marcos Veruck[4], Airton Kunz[5]

[1*]Corresponding author. State University of Paraná, University Garden - Development Prototypes Building/ Cascavel - PR, Brazil.
E-mail: giongoadelcio@gmail.com

ABSTRACT

The swine industry has been presented strong growth and thus is producing large volumes of effluents that must be correctly management. Nitritation/denitritation process can be used to improve system performance, saving the energy cost with aeration and with the external source of carbon due to the lower C/N requirement. The aim of this study was to evaluate swine wastewater Nitrification/Denitrification (NDF) and Nitritation/denitritation (NDT) processes at different C/N ratios, using the Modified Ludzack-Ettinger (MLE) process, in order to obtain a system with efficient nitrogen removal and low oxygen and carbon consumption. Four phases were conducted during the experiment: Phase I) DO between 2.0-3.0 mg L^{-1} of O_2 and C/N 1.5 (NDF); Phase II) DO between 0.6-0.7 mg L^{-1} of O_2 and C/N 1.5 (NDT); Phase III) DO between 0.6-0.7 mg L^{-1} of O_2, C / N ratios of 1.5, 0.9, 0.75 and 0.6 (NDT); Phase IV) DO between 2.0-3.0 mg L^{-1} of O_2, C/N ratios of 1.5, 0.9, 0.75, and 0.6 (NDF). The best operational condition was found in the C / N ratio of 0.9 (Phase III) obtaining an optimum N removal of 86.3%. In this condition, the system saved around 26.8% in total organic carbon consumption and operated at conditions of 74% lower dissolved oxygen when compared to conventional process for N-removal. This strategy can be very useful for nitrogen removal for low carbon swine wastewater as digestate from anaerobic processes.

INTRODUCTION

Worldwide increasing demand for meat has caused the establishment of large concentrated animal feeding operations (CAFOs) for livestock production in order to reduce animal production costs and soil demanded for effluent disposal. Usually intensive breeding farms confine large numbers of animals in an area of land proportionally small, breaking the relationship between crops and animal production. Thus, large amounts of manure are applied to the soil without undergoing any kind of treatment or stabilization, and without considering agronomic and legal criteria (Kunz et al., 2005). According to Williams (2008), much of the environmental impact generated by swine farming is a result of the lack of adequate management of solid and liquid waste. The waste produced in CAFOs often exceeds the amount that can be used as biofertilizer due to land requirement limitations (Kinyua et al., 2014). Nutrient removal, mainly nitrogen and phosphorus from different wastewaters, has become the most important concern for the wastewater treatment plants in the past three decades. Nitrogen can be removed from wastewater by biological and physical chemical processes (Kunz & Mukhtar, 2016).

The biological Nitrification/Denitrification (NDF) process (Equation 1 and 2) is worldwide used for effluent nitrogen removal when an available carbon source is not a problem. In this process, during the aerobic and autotrophic step (nitrification) NH_4^+ is oxidized to NO_3^- followed by the anoxic and heterotrophic step (denitrification) where NO_3^- is converted to gaseous

nitrogen (N_2) (Lan et al., 2011). Nitrogen removal via nitrite Nitritation/denitritation (NDT) (Eq. 3 and 4) was reported to be technically feasible and economically favorable, especially when treating wastewater with high nitrogen concentrations and low C/N ratios (Yang et al., 2007). According to Peng & Zhu (2006), the methods used to accumulate nitrite are based on the appropriate regulation of temperature, pH, dissolved oxygen, cell retention time and initial nitrogen concentration.

$$NH_4^+ + 1.5O_2 \xrightarrow{\text{Nitrosomonas}} NO_2^- + H_2O + H^+ \rightarrow$$
$$NO_2^- + 0.5O_2 \xrightarrow{\text{Nitrobacter}} NO_3^- \qquad (1)$$

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2 \qquad (2)$$

$$NH_4^+ + 1.5O_2 \xrightarrow{\text{Nitrosomonas}} NO_2^- + H_2O + H^+ \qquad (3)$$

$$NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2 \qquad (4)$$
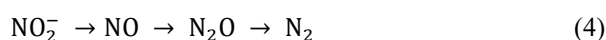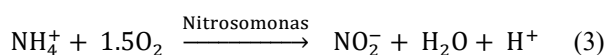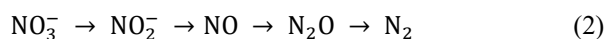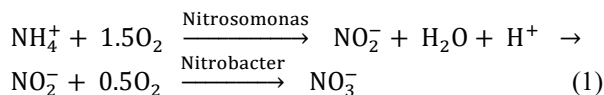
Nitrogen removal via NDT can be achieved by Nitrite Oxidizing Bacteria (NOB) inhibition (*e.g.*. DO restriction, sludge wash out), due to different physiological characteristics and responses to operating conditions in order to restrict nitrite oxidation to nitrate (Ge et al., 2015). For anoxic phase (denitrification or denitritation) the availability of biodegradable organic carbon becomes critical in wastewater with high ammonia concentration and low C/N ratio. An alternative to solve this problem is the use of NDT process saving carbon during denitritation step. For this, a possible alternative is the DO reduction, for NOB activity restriction. This process has attracted attention in recent years, especially for treatment of wastewater with low C/N ratio (Gujer, 2010; Ge et al., 2015). In this way, nitritation can be obtained and maintained at low DO concentration.

The present study aims the NDT establishment by DO restriction evaluating the influence of different C/N ratios on TOC (Total Organic Carbon) consumption and N removal efficiency comparing NDF and NDT for swine wastewater nitrogen removal.

MATERIAL AND METHODS

Wastewater Sampling and Characterization

The wastewater samples were collected from a swine manure treatment system (SMTS) at Embrapa Swine and Poultry, located in Concordia, Santa Catarina, Brazil. For the experiments, were used the primary settling tank effluent (STE), and the UASB reactor effluent (URE), in order to have samples at different C/N ratios (Table1).

Experimental design

A schematic representation of the experimental MLE (modified Ludzak-Etinger) process configuration, that was under operation at laboratory scale in Embrapa Swine and Poultry, is presented in Figure 1. The aeration was provided using an air pump (Big Air, A420) and controlled by a dissolved oxygen controller (Hach, SC200). The anoxic reactor was continuously fed (Q_{in} = 1.5 mL min^{-1}) for a nitrogen loading rate of 0.35±0.07 kg m^{-3}d^{-1} of N), the recirculation rate was equivalent to 5.5*Q_{in} and the sludge recirculation rate was 1*Q_{in} using peristaltic pumps (Masterflex, 7518-60). The anoxic and oxic reactors were maintained under continuous stirring (IKA-RW90) at 15 rpm and 200 rpm, respectively.

TABLE 1. Characterization of swine wastewater samples collected at a swine manure treatment process used to feed the MLE process configuration.

	STE	URE
NH$_3$ - N (mg L^{-1})	770 ± 99.3	767 ± 47.3
TOC (mg L^{-1})	1200 ± 380	235 ± 111
Alkalinity (mg L^{-1})	4000 ± 536	4000 ± 541
C/N Ratio	1.5	0.3

Where: STE: settling tank effluent, URE: UASB reactor effluent and TOC: Total Organic carbon

The study was conducted in four different phases:

Phase I (presence of AOB and NOB at high DO concentration, NDF process), between days 1 - 37, DO concentration in the oxic reactor between 2.0 - 3.0 mg L^{-1} of O$_2$. The system influent was composed by the STE presenting a TOC and NH$_3$–N concentration of 1,100 mg L^{-1} of N and 719 mg L^{-1} of N respectively, C/N ratio of 1.5.

Phase II (DO concentration reduction favoring inhibition of NOB, NDT process) was conducted between days 38-101. At the first 20 days (38-53) the DO concentration in oxic tank was kept between 0.5 to 0.6 mg L^{-1} of O$_2$, from day 54 to 67, the DO concentrations ranged from 0.4 to 0.5 mg L^{-1} of O$_2$, and between days 68-101 with DO concentration between 0.6 to 0.7 mg L^{-1} of O$_2$. The system influent was fed with SMTS STE with TOC and NH$_3$-N concentration of 1,097 mg L^{-1} and 734 mg L^{-1} of N respectively, resulting in a C/N ratio of 1.5.

Phase III (reduction of DO concentration favoring inhibition of NOB, NDT process), days 139 - 170, DO concentration in the nitrifying reactor between 0.6 - 0.7 mg L^{-1} of O$_2$. The system influent was fed with the SMTS URE and STE mixture. The mixtures were prepared to provide different C/N ratios, 1.5 (101 - 115 days), 0.9 (116 - 135 days), 0.75 (136 - 149 days), and 0.6 (150 - 170 days).

Phase IV (presence of AOB and NOB at high DO concentration, NDF process) was conducted between days 171 - 226 with oxic reactor DO concentration setted between 2.0 - 3.0 mg L^{-1} of O$_2$. The oxic reactor was fed with an URE and STE mixture to reach a C/N ratios of 1.5 (171 - 180 days), 0.9 (183 - 194 days), 0.75 (197 - 211 days), and 0.6 (212 - 226 days).
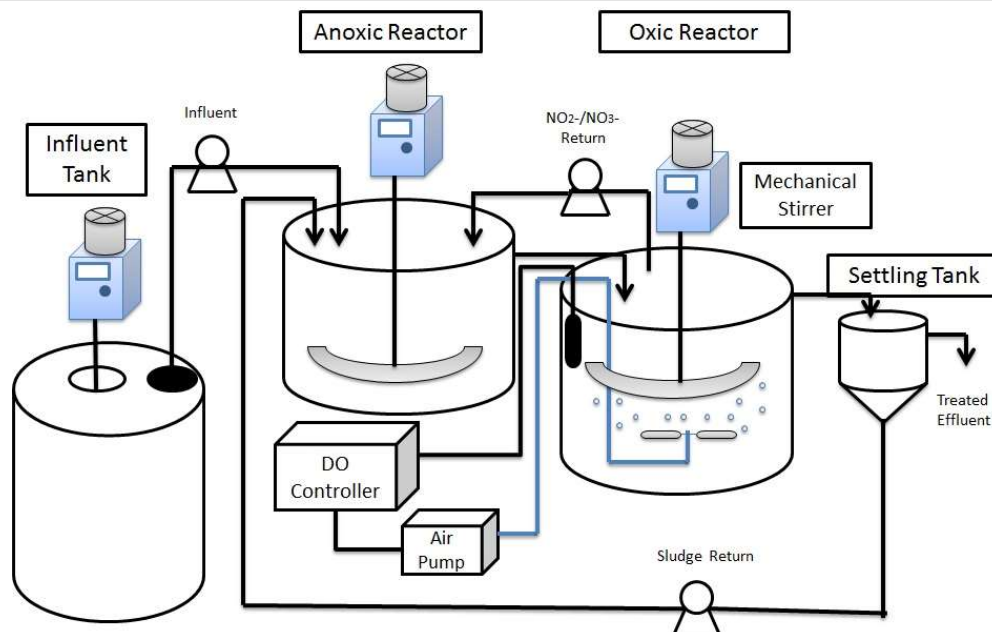
FIGURE 1. Schematic representation of the modified Ludzak-Etinger (MLE) process configuration for swine wastewater treatment. Oxic reactor =Nitritation or Nitrification, anoxic = denitritation or denitrification.

Oxygen Uptake Rates (OUR) on NDF and NDT Activity

The respirometer, consisted of a 400 mL glass conical flask with three exits at the top for an oxygen probe insertion (Hanna, HI 98186), a pH probe (Hanna, HI 98183) and the injection of the ammonium solution (NH4Cl) (De Prá et al., 2016). All nitrifying (Phase I: NDF and Phase II: NDT) respirometric tests were carried out at the same biomass concentration (0.47 g L^{-1} of VSS) with the biomass provided from the oxic reactor. A nutrient solution without total ammonia nitrogen (TAN), described by Campos et al. (1999), was prepared to carry out the washing of biomass between tests through suspension, centrifugation and discarding the supernatant. Once the mixed liquor reached DO saturation (9.0±0.5 mg L^{-1} of O$_2$), ammonia substrate (NH4Cl) was added to the flask at concentrations of 50, 100, 200, 400, 600 and 800 mg L^{-1} of NH$_3$-N. DO depletion was monitored until the concentration decreased to 15% of the DO saturation. The specific oxygen uptake rate (SOUR) was determined by [eq. (5)].

$$SOUR\ (mgO_2 \cdot gSSV^{-1} \cdot min^{-1} = \frac{OUR\ (mgO_2.min^{-1})}{X\ (gSSV)} - ER\ (mgO_2 \cdot gSSV^{-1} \cdot min^{-1}) \tag{5}$$

Where:

SOUR: Specific Oxygen Uptake Rate (mgO$_2$. gSSV^{-1}. min^{-1});

OUR: Oxygen Uptake Rate (mg. min^{-1} of O$_2$);

X : biomass concentration (g of SSV),

ER: endogenous respiration (mgO$_2$. gSSV^{-1}. min^{-1}).

Analytical Methods

Alkalinity, TOC, NO$_2^-$-N, NO$_3^-$-N and NH$_3$-N was determined according to APHA, AWWA, WEF (2012). TOC analyzes were performed using a TOC analyzer (Analytik Jena, Multi C/N 2100). While NO$_2^-$-N, NO$_3^-$-N and NH$_3$-N were determined based on a colorimetric method using a flow injection analysis system (FIAlab – 2500). Alkalinity was determined using the titrimetric method (Titronic T-200semiautomatic). DO concentrations in oxic reactor were measured and controlled using a DO controller (Hach, SC200).

RESULTS AND DISCUSSION

DO restriction effect on NDF process

At the beginning of phase I the main objective was to keep the conventional NDF process. Throughout this stage, between day 1 - 37, the system presented an N removal efficiency of 82.3%, with 70% of TOC consumption (Figure 2). During this phase NDF process has been successfully established and kept during the 37 days.
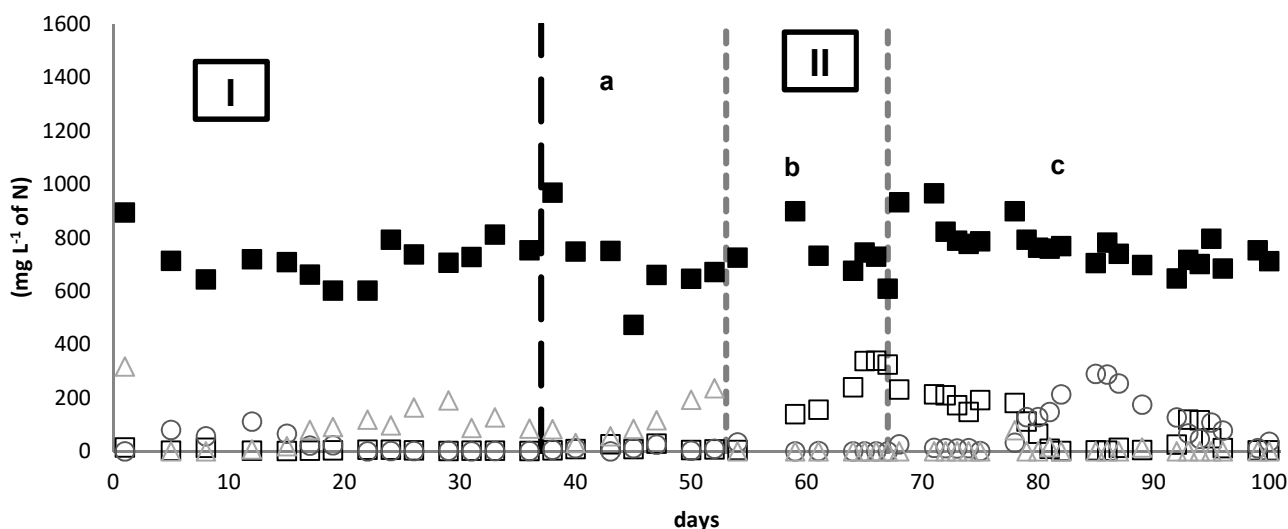
FIGURE 2. Nitrogen species concentrations (NH$_3$-N$_{in}$ ■, NH$_3$-N$_{out}$ □, NO$_2$-N$_{out}$ ○, NO$_3$-N$_{out}$ △) in the MLE process configuration treating swine wastewater. Phase I: NDF C/N 1.5, DO 2.0 - 3.0 mg L^{-1} of O$_2$. Phase II: NDT C/N 1.5, (a) DO 0.5 - 0.6 mg L^{-1} of O$_2$, (b) DO 0.4 - 0.5 mg L^{-1} of O$_2$, (c) DO 0.6 - 0.7 mg L^{-1} of O$_2$.

Phase II, between days 38 - 53 (Figures 2 and 3, II-a) DO concentration was restricted from 2.5 ± 0.5 mg L^{-1} of O$_2$ to 0.55 ± 0.05 mg L^{-1} of O$_2$, to reduce nitrite oxidation bacteria (NOB) activity (Hanaki & Wantawin, 1990). However, even after severe reduction of DO concentration, N removal efficiency via nitrate presented a low decrease when compared to phase I (Table 2). The literature reports that complete nitrification is kept with higher values of DO concentration of 1.5 mg L^{-1} of O$_2$ (Yang et al., 2012), while at lower DO levels 0.3–0.7 mg L^{-1} of O$_2$ nitrite is accumulated by the nitration process prevalence (Ma et al., 2009; Zeng et al., 2013).
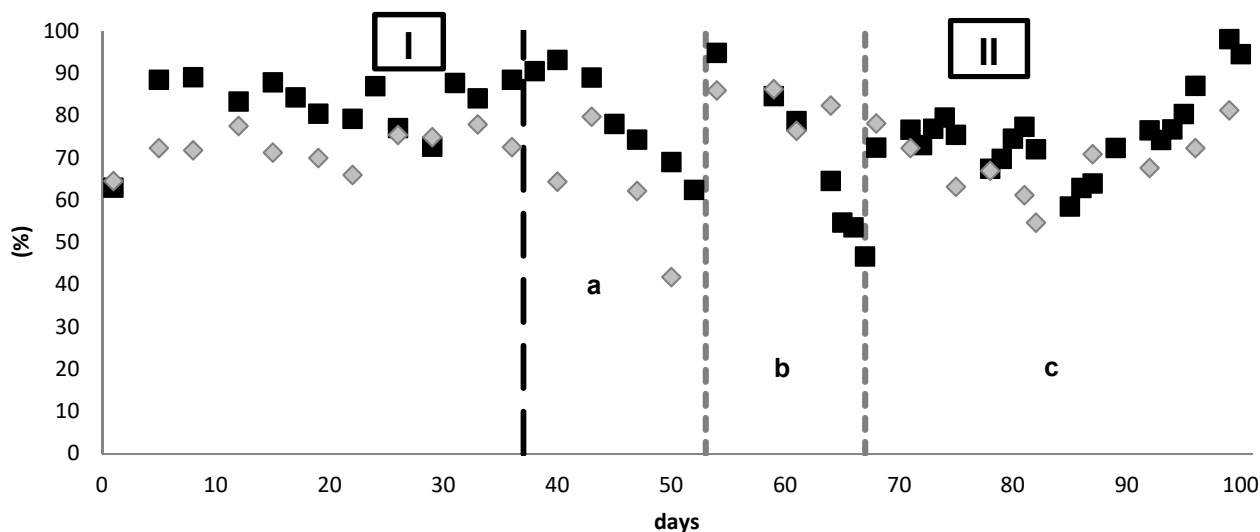

FIGURE 3. N removal ■) and TOC consumption ◇) TOC in MLE process configuration treating swine wastewater. Phase I: NDF C/N 1.5, DO 2.0-3.0 mg L^{-1} of O$_2$. Phase II: NDT C/N 1.5, (a) DO 0.5-0.6 mg L^{-1} of O$_2$, (b) DO 0.4-0.5 mg L^{-1} of O$_2$, (c) DO 0.6-0.7 mg L^{-1} of O$_2$.

As nitritation was not stablished in Phase II-a, DO concentration was restricted again in the oxic reactor between days 54-67 (Phase II-b, Figures 2 and 3). The DO concentration was decreased from 0.55 ± 0.05 mg L^{-1} of O_2 to 0.45 ± 0.05 mg L^{-1} of O_2. At this condition, it was observed a NH_3-N accumulation (220.02 ± 117.4 mg L^{-1} of N) in oxic reactor, caused by the reduction of AOB (Ammonia oxidizing bacteria) activity.

On phase II-c, DO concentration was again increased in the oxic reactor from 0.45 ± 0.05 mg L^{-1} of O_2 to 0.65 ± 0.05 mg L^{-1} of O_2 (between days 68-101) in order to recover the AOB efficiency to completely remove NH_3-N from the MLE process. During this phase (Figures 2 and 3) NH_3-N removal was increased about 61%, compared to phase II-b with a slight improvement in N removal process (Table 2).

Effect of DO concentration and different C/N ratios in N removal process via NDF and NDT

Initially the system was operated at C/N ratio of 1.5 (phase III-a, Figures 4 and 5) and DO 0.65 ± 0.05 mg L^{-1} of O_2, under the same operating conditions of phase II-c, reaching a similar N removal efficiency that was also quite similar to phase I when NDF was established (Table 2).

At this phase III-b (between days 116 - 135) NH_3-N removal was around 90 % (Table 2). However, even with the reduction of C/N ratio at this stage to 0.9, TOC consumption was reduced 23% when compared to Phase III-a, without significant impact on the N removal efficiency (Table 2). According to Yang & Yang (2011), a reduction in the consumption of organic matter switching NDF to NDT can reach in 40% of carbon economy for heterotrophic process.

Thereafter a new reduction of C/N ratio from 0.9 to 0.75 (Phase III-c, Figures 4 and 5) between days 136-149 was performed. This strategy affected the N removal efficiency in almost 30 % comparing phases III-c with III-b (Table 2). However, with the reduction of C/N ratio, there were accumulation of NO_2^--N (60.11 ± 21.9 mg L^{-1} of N) and NO_3^--N (138.2 ± 123.5 mg L^{-1} of N). The accumulation of NO_X-N (NO_2^--N + NO_3^--N) occurs when there is absence of TOC in the denitrifying reactor because the TOC is the donor source of electrons, and nitrite and nitrate, are the electrons acceptors. Associated to NO_X-N accumulation, and alkalinity consumption, pH will decrease favoring the generation of Free Nitrous Acid (FNA) that can also cause inhibition on nitrification process (Mohan et al., 2016; Hou et al., 2014).
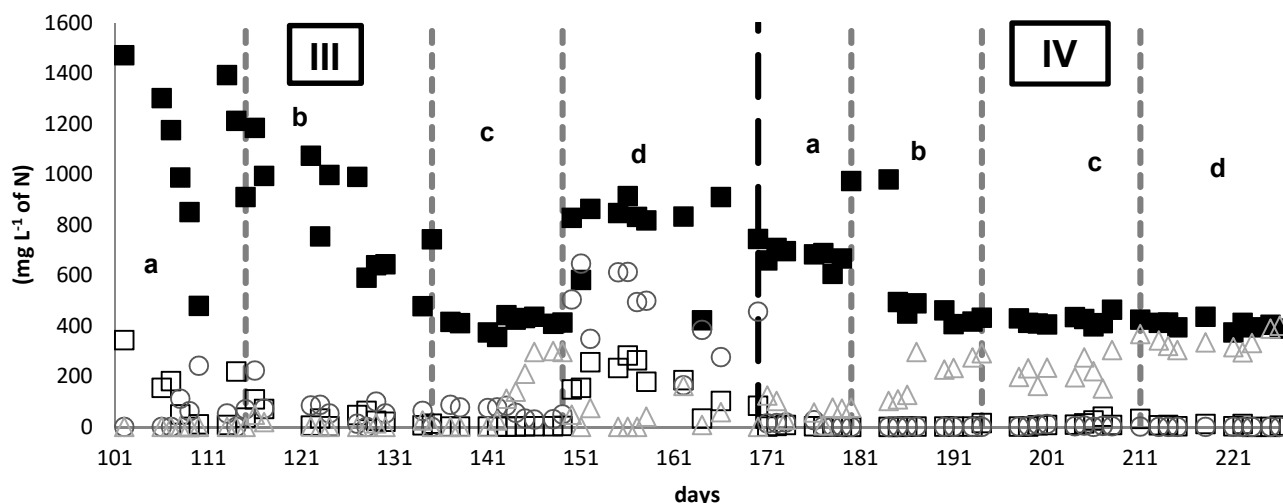

FIGURE 4. Nitrogen species concentrations (NH_3-N_{in} ■, NH_3-N_{out} □, NO_2-N_{out} ○, NO_3-N_{out} △) in MLE configuration process treating swine wastewater. Phase III: DO 0.6 - 0.7 mg L^{-1} of O_2 and NDF (a) C/N 1.5; (b) C/N 0.9; (c) C/N 0.75; (d) C/N 0.6. Phase IV: DO 2.0 - 3.0 mg L^{-1} of O_2 and NDT (a) C/N 1.5; (b) C/N 0.9; (c) C/N 0.75; (d) C/N 0.6.

In Phase III-d, C/N ratio was decreased to 0.6 (Phase III-d, Figures 4 and 5), between days 150 - 170. During this phase, N removal efficiency was drastically reduced from 51.93% (Phase III-c) to 16.10% (Phase III-d). AOB was probably inhibited by the accumulation of NO_2^--N (454.8 ± 143.1 mg L^{-1} of N) in the system, which

occurred by limiting TOC biodegradable. With the absence of TOC heterotrophic bacteria are not capable of converting NO_2^--N. At this high NO_2-N concentration, for the reactor conditions the FNA concentration was 1.19 mg L^{-1} of N that act negatively on the AOB activity (De Prá et al., 2012).
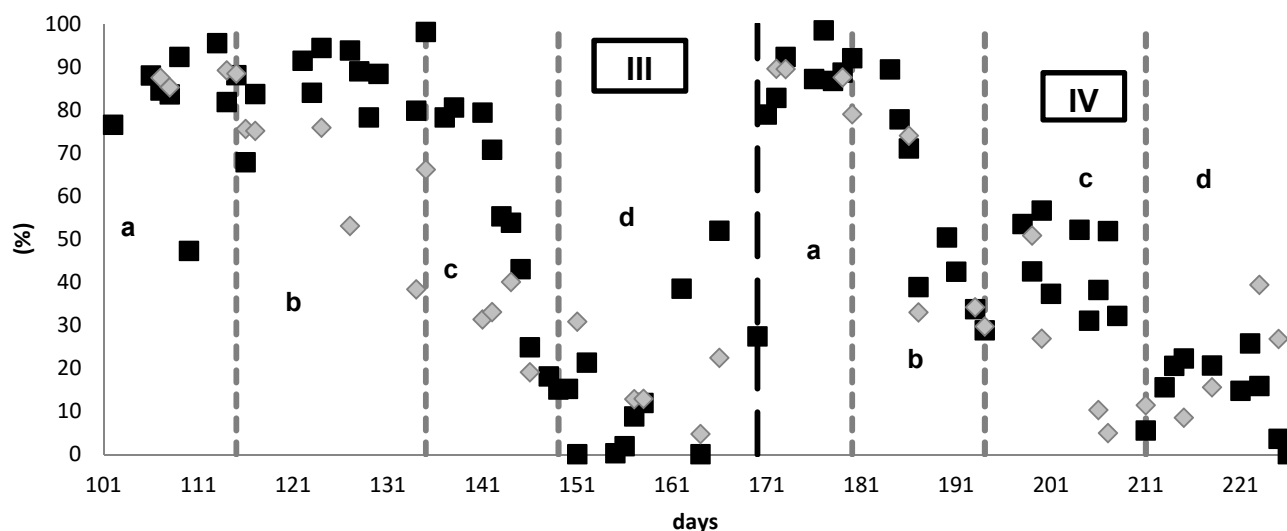
FIGURE 5. N removal (■) and TOC consumption (◇) in MLE configuration process treating swine wastewater. Phase III: DO 0.6 - 0.7 mg L^{-1} of O_2 and NDF (a) C/N 1.5; (b) C/N 0.9; (c) C/N 0.75; (d) C/N 0.6. Phase IV: DO 2.0 - 3.0 mg L^{-1} of O_2 and NDT (a) C/N 1.5; (b) C/N 0.9; (c) C/N 0.75; (d) C/N 0.6.

When we compare phase III-d (low C/N ratio), with phase II-b (high C/N ratio), it can be seen that in both stages the AOB bacteria were affected, with reduced conversion capacity of NH_3-N to NO_2^--N. By the O_2 restriction (Phase II-b), it was observed an accumulation of NH_3-N, at pH 8.26. At this condition, the generation of FA (Free ammonia) is favored reaching of 41.53 mg L^{-1} of N, with sufficient concentration to inhibit the AOB activity (De Prá et al., 2012; Kunz & Mukhtar, 2016).

The main objective of this phase IV, was to compare the behavior of the NDF (Phase IV) with NDT (Phase III), comparing TOC consumption and N removing.

Initially at phase IV, DO concentration in the oxic reactor was increased from 0.65 ± 0.05 mg L^{-1} of O_2 to 2.5 ± 0.5 mg L^{-1} of O_2, and C/N ratio adjusted to 1.5. At these conditions the N and TOC removal reached 88.45% and 86.45% respectively. Comparing Phase IV-a with Phase III-a (C/N 1.5 and DO 0.65 ± 0.05 mg L^{-1} of O_2) (Table 2) was observed a similar N removal and TOC consumption in both phases, around 80% and 87% respectively.

In order to prove that oxygen was not the limiting agent in the process, C/N ratio was successively reduced as performed in phase III. At phase IV-b, C/N ratio was reduced from 1.5 to 0.9 (Figures 4 and 5), between days 183 - 194. At this phase, N removal of 54.07% showing an

efficiency decreasing of 34.38% compared to phase IV-a. Comparing with Phase III-b (Table 2), it is observed that besides of O_2 economy (about 74 %). Meng et al. (2015) obtained N removal of 87% using nitritation/denitritation in an upflow microaerobic sludge reactor (UMSR), operating with swine influent at C/N ratio of 0.84.

In phase IV-c, C/N ratio was reduced from 0.9 to 0.75 (Figures 4 and 5) between days 197-211. Compared to Phase IV-b was observed a decrease in the N removal reaching 40.11% (Table 2).

C/N ratio was reduced from 0.75 to 0.6 (phase IV-d, Figures 4 and 5) between days 212-226. Comparing phase IV-d, (high DO and low C/N) to Phase III- d (low DO and low C/N) it was observed that both processes showed N removal efficiency around 15% associated to low TOC consumption.

At Figure 6 is presented the nitrogen removal rate (NRR) comparing nitritation/denitritation (Phase III) and nitrification/denitrification (Phase IV). For C/N ratio of 1.5; the NRR was maintained similar for both processes (about 0.27 kg m^{-3} d^{-1} of N). However, at the C/N ratio of 0.9 was observed an NRR for NDT of about 57% higher when compared to NDF. However at C/N ratios of 0.75 and 0.6 low values of NRR were observed showing the effect of carbon restriction on both processes.
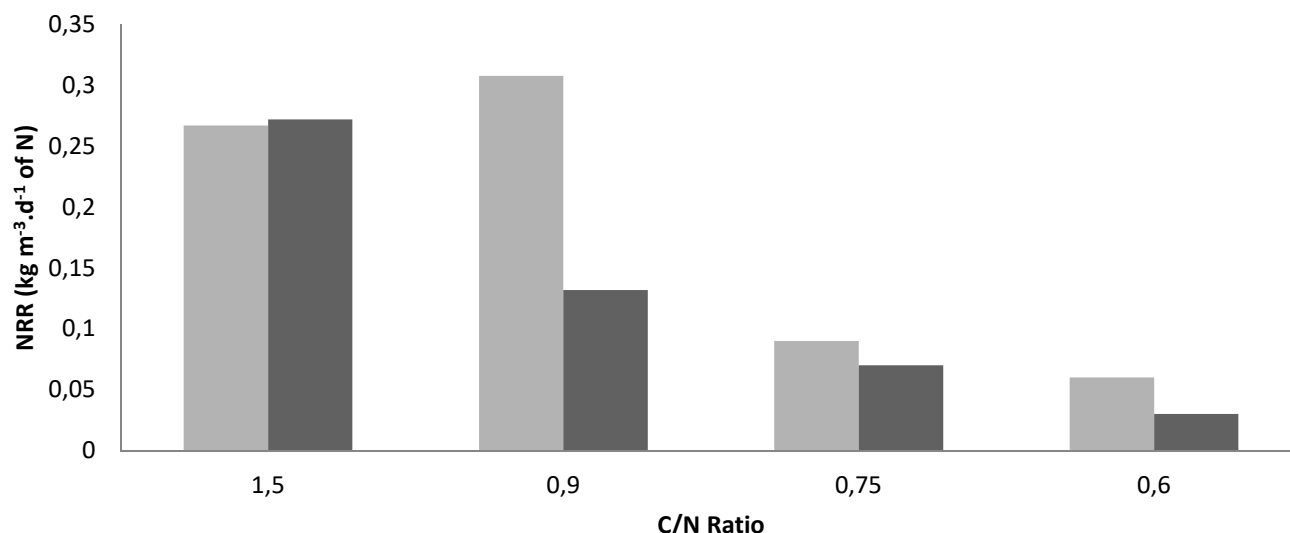
FIGURE 6. Nitrogen Removal Rates (NRR) at Phase III - NDT (☐) and Phase IV - NDF (■) C/N ratios in MLE configuration process treating swine wastewater. Phase III (NDT): DO 0.65±0.05 mg L^{-1} of O_2; Phase IV (NDF): DO 2.5±0.5 mg L^{-1} of O_2.

Chen et al. (2015) showed N removal efficiency higher than 80% using an anaerobic/anoxic/aerobic (A^2/O)-biological aerated filter (BAF) system at C/N ratio of 5.5. Hu et al (2014), pointed out that a C/N ratio lower than 3.0 makes nitrogen removal from piggery wastewater difficult using NDF process. However, Lackner & Horn (2013) reached 80–85% N removal with an influent C/N ratio of 1, in a sequencing batch reactor treating industrial wastewater.

Critical Comparison of Specific Oxygen Uptake Rate in NDT e NDF processes

The concentration of dissolved oxygen during the respirometric tests to determine the endogenous respiration (ER) of NDT and NDF processes showed a linear behavior (R^2 = 0.951 and R^2 = 0.991, NDT and NDF respectively), showing a SOUR of 0.043 mgO_2 gSSV^{-1} min^{-1} and 0.084 mgO_2 gSSV^{-1} min^{-1}, respectively (Table 3). The results of o OUR for each test are presented in Table 3 (Phase I for NDF; Phase II for NDT), and were performed after the process stability to avoid fluctuations in the results. The highest SOURs were observed during the test 3 (Table 3) with a $(NH_4)_2SO_4$ concentration nearby 200 mg of NH_3-N, at this condition the oxygen consumption for NDT was around 25 % lower when compared to NDF process.

During the initial tests at NH_3-N low concentrations (Tests 1 to 3, Table 1), the $SOUR_{NDF}$ and $SOUR_{NDT}$ had an increasing rates, reaching the highest specific oxygen consumption rate in the test 4 ($SOUR_{NDF}$ = 0.323 mgO_2gVSS^{-1} min^{-1}) under an initial NH_3-N concentration of 393.3 mg L^{-1} and for test 3 ($SOUR_{NDT}$ = 0.255 mgO_2 gVSS^{-1} min^{-1}) under an initial NH_3-N concentration of 196.52 mg L^{-1}. After these S (substrate) concentrations in subsequent tests, the SOURs start to decrease, indicating that this process is more sensitive for concentrations above 200 mg L^{-1} of NH_3-N. De Prá et al. (2016) observed the beginning of inhibition of nitrifying bacteria after the concentration 200 mg L^{-1} of NH_3-N, with then downfall in the consumption of oxygen.

Although SOURs were the highest for test 3 (Figure 7), the oxygen consumption reduction between NDF and NDT was not the highest found during the respirometric tests. Figure 8 shows the performance between SOURs and S (($NH_4)_2SO_4$) concentrations for the two studied processes. Whilst for 50 mg L^{-1} of NH_3-N 11.5% oxygen saving is reached for a S concentration of 800 mg L^{-1} of NH_3-N was achieved around 37% in oxygen saving (Figure 8), that is higher than that is reported in the literature (Turk & Mavinic, 1986; Yang & Yang, 2011; Zhu et al. 2008; Fu & Zhao, 2015).
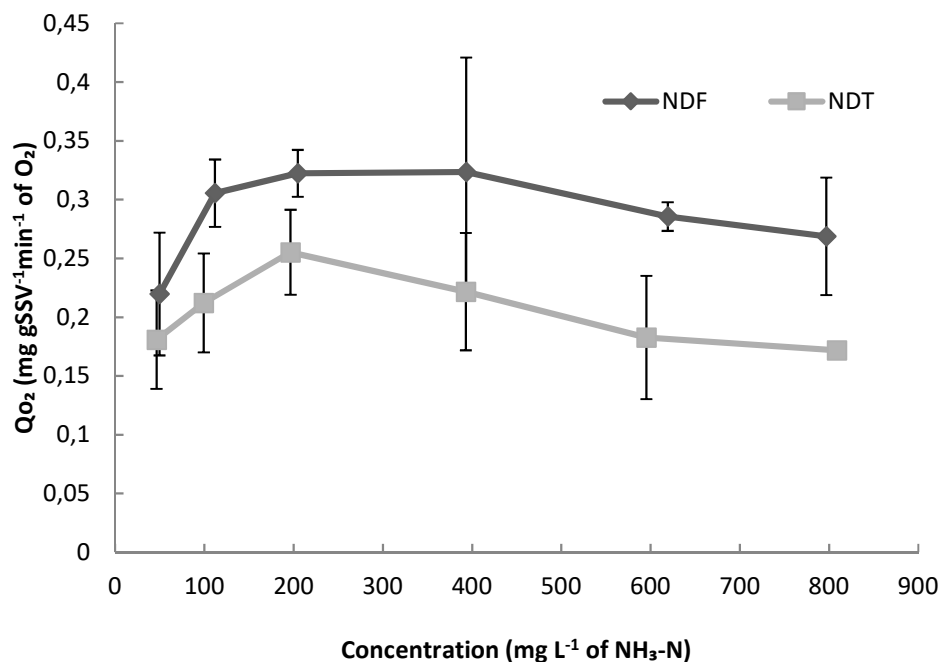
FIGURE 7. Performance of SOUR during the respirometric tests for NDT and NDF processes.
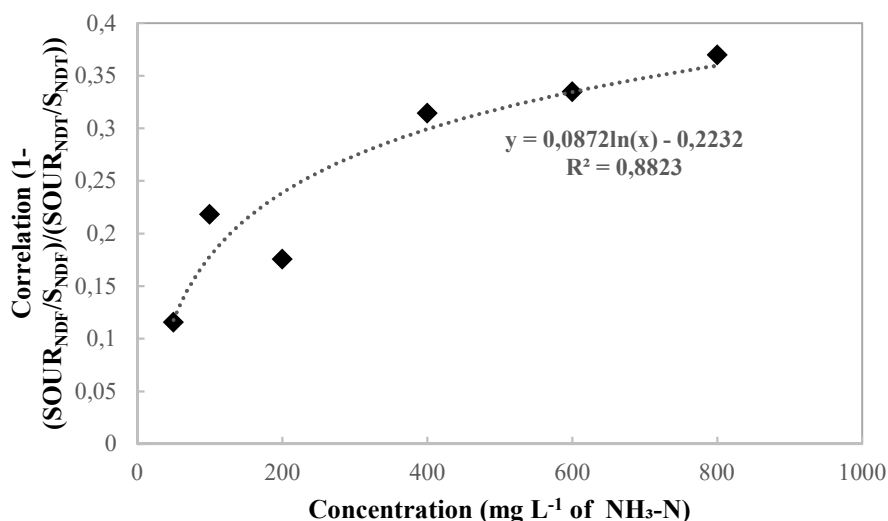

FIGURE 8. Correlation of SOUR and NH_3-N concentration between NDT and NDF processes.

TABLE 2. NH_3-N_{in}, TOC_{in} with the respective effluent nitrogen species, TOC and alkalinity consumption and removal efficiencies for swine effluent treatment. Mean values of the parameters in the four phases studied.

Phase		NH_3-N_{in} (mg L^{-1})	NH_3-N_{out} (mg L^{-1})	NO_2^--N_{out} (mg L^{-1})	NO_3^--N_{out} (mg L^{-1})	Alkalinity Comsuption (%)	TOC_{in} (mg L^{-1})	TOC Consumption (%)	N Removal (%)
I[a]		719.42±77.2	4.44±4.2	26.09±35.7	98.93±83.1	84.74	1110.2±41.32	72.18	82.28
II[b]	a	702.4±138.1	12.41±9.9	9.62±7.5	114.2±68.9	76.07	615.2±219.6	62.01	79.45
	b	730.7±81.5	220.0±117.4	4.83±11.5	0.00	40.38	1887.3±136.0	8.73	68.19
	c	772.2±76.9	85.70±82.6	100.3±91.8	4.96±16.8	63.60	789.3±219.7	68.83	75.42
III[c]	a	1087.0±294.0	111.7±113.1	60.14±74.9	0.28±0.8	52.12	1724.9±27.76	87.64	82.02
	b	826.2±219.6	36.00±32.1	68.38±59.0	9.97±15.0	64.23	814.2±61.96	64.06	86.3

c	411.4±26.0	2.10±0.7	60.11±21.9	138.2±123.5	92.78	269.6±16.96	30.87	51.93
d	781.3±142.7	175.1±76.5	454.8±143.1	35.64±48.1	41.16	418.7±105.13	16.75	16.1
IV[d] a	710.6±103.8	2.52±2.1	9.93±9.2	67.92±35.3	64.55	1170.5±88.55	86.45	88.45
b	516.5±177.6	2.77±5.1	0.56±0.4	208.0±77.4	72.66	424.1±72.96	42.75	54.07
c	422.0±17.8	14.52±12.8	4.29±3.5	234.4±62.6	73.09	310.8±43.29	20.87	40.11
d	403.5±16.9	5.29±4.2	0.09±0.2	337.3±34.1	79.59	254.0±28.80	22.59	15.44

Where:

in = affluent, out = effluent;

[a]Phase I: C/N ratio 1.5 and DO 2.0 - 3.0 mg L^{-1} of O_2 (oxic reactor)

[b]Phase II: C/N ratio 1.5 and (a) DO 0.5 - 0.6 mg L^{-1} of O_2; (b) DO 0.4 - 0.5 mg L^{-1} of O_2; (c) DO 0.6 - 0.7 mg L^{-1} of O_2; (oxic reactor)

[c]Phase III: DO 0.6 - 0.7 mg L^{-1} of O_2 (oxic reactor) and (a) C/N ratio 1.5; (b) C/N ratio 0.9; (c) C/N ratio 0.75; (d) C/N ratio 0.6

[d]Phase IV: DO 2.0 - 3.0 mg L^{-1} of O_2 (oxic reactor) and (a) C/N ratio 1.5; (b) C/N ratio 0.9; (c) C/N ratio 0.75; (d) C/N ratio 0.6

TABLE 3. OUR and SOUR for each substrate ($(NH_4)SO_4$) concentration (S) for NDT and NDF processes.

Tests	S_{NDF} (mg L^{-1} of NH_3-N)	S_{NDT} (mg L^{-1} of NH_3-N))	$SOUR_{NDF}$ (mgO_2 gVSS^{-1} min^{-1})	$SOUR_{NDT}$ (mgO_2 gVSS^{-1} min^{-1})
ER	-	-	0.046	0.084
1	49.71±0.05	46.27±0.04	0.219	0.180
2	111.8±0.03	99.33±0.04	0.305	0.212
3	204.6±0.02	196.5±0.04	0.322	0.255
4	393.3±0.09	393.0±0.05	0.323	0.222
5	619.2±0.01	595.4±0.05	0.285	0.183
6	796.8±0.05	808.6±0.01	0.268	0.172

ER = Endogenous respiration.

Figure 8 shows a logarithmic tendency curve indicating a possible stability at substrate concentrations above 800 mg L^{-1} of NH_3-N. However, a great advantage to operate the NDT process compared to NDF process, maintaining efficiency next to 80% in N removal (Table 2 and Figure 5) and parallel consuming less 36.8% of carbon for denitrification (Figure 6).

CONCLUSIONS

NDT was successfully stablished for swine wastewater nitrogen removal at DO of 0.6 - 0.7 mg L^{-1} of O_2, reaching N removal of 75%. At C/N ratio of 0.9 the nitrogen removal rate for NDT reached 0.31 kg m^{-3} d^{-1} of N that is 133% higher than the obtained for NDF at the same conditions with a reduction of TOC consumption of 27 %. The results show that it is possible to obtain efficient nitrogen removal efficiency for MLE configuration process for swine wastewater treatment operating the process at low DO and C/N ratios creating the possibility of application and operating with influent low carbon and high nitrogen, such as digestate from anaerobic processes.

ACKNOWLEDGEMENTS

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Adelcio Giongo, Marcelo Bortoli, Marina Celant De Prá, et al.

977

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