

DEVELOPMENT OF A SBR BENCH-SCALE TO OPTIMIZE THE PARTIAL NITRIFICATION PROCESS IN LANDFILL LEACHATE TREATMENT AND ITS POSSIBLE APPLICATION IN VIETNAM.

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ABSTRACT

Landfill leachate treatment is a major issue in many developing countries including Vietnam. Leachates are characterised by very high nitrogen concentrations, especially ammonium, needing an appropriate treatment technology. Conventional treatment technology has some drawbacks: mostly its high costs and problems to meet discharged standards requirements. This study applies a more recent approach for nitrogen removal, which is known as partial nitrification, by using a sequencing batch reactor (Bernet *et al.*, 2005) technique. For the first step, the experiments were done with Belgian leachates. Based on mathematical models derived from generally accepted ASM Model, specific growth rates of biomass ($\mu(T)$) found is 0.48 (d^{-1}), 0.39 (d^{-1}), 1.56 (d^{-1}) and 0.82 (d^{-1}) for ammonium nitrifiers, nitrite nitrifiers, nitrite denitrifiers and nitrate denitrifiers respectively. Concentration of the active part of these four kinds of bacteria is estimated of 22.3 mg/L, 12.4 mg/L, 464 mg/L and 12.3 mg/L. Maintaining dissolved Oxygen concentrations in the range 0.8 to 2.1 mgO₂/L, with typical value around 1.5 mg/L, the system yields nitrite accumulation (preliminary step of partial nitrification/denitrification). SBR cycle was changed from 4 hours/4 hours of aeration/mixing in turn to 5 hours/3 hours and then 6 hours/2 hours. The last cycle has shown the best partial nitrification capacity of the SBR (a nitrite accumulation of 89 %) but not yet yielding a 50/50 ratio of ammonium/nitrite at the end of nitrification process. However, a well managed SHARON process will be processed in the next step of the study to obtain higher nitrogen removal efficiency and the expected ammonium/nitrite ratio. It has also been shown that free ammoniac concentration affects the nitrite/(nitrite + nitrate) ratio at the end of aeration phase.

Keywords: Leachate, partial nitrification/denitrification, SHARON, SBR, model.

1. INTRODUCTION

In Vietnam, the rate of urbanisation is increasing rapidly generating larger amounts of municipal solid wastes with an average amount of solid waste around 0.8 kg/person/day. Unlike developed countries, solid waste disposal technology is mostly done in sanitary landfills without segregation. On the other hand, in Vietnam, the climate is hot and wet (tropical climate) with a very high rainfall (up to 1600 – 2200 mm per year), generating large amount of landfill leachates, characterised by high organic and nitrogen (15 – 2000 mg N-NH₄⁺/l) concentrations (HIMS, 2005). The recent Vietnamese discharge standard for leachate (TCVN 5945-2005 (B)) requires very strict values : less than 10 mg NH₄⁺-N/l. Existing conventional biological treatments have high operation costs, mostly due to oxygen requirement for NH₄⁺-N

nitrification, and meet existing discharge standards for COD and NH₄⁺-N with difficulties. Therefore, it is necessary to develop new treatment approaches at least for NH₄⁺-N aiming at cost reduction. In this case, partial N – removal process is promising, as it is expected to save both reaction volume as well as carbon and oxygen requirements. Besides, reaction and/or reactor design is also important. Sequencing Batch Reactor (SBR) technique due to its versatility can be operated with less skilled local workers. It is the technology that was selected for this study.

2. HYPOTHESIS

Partial nitrification is the oxidation of ammonium into nitrite, but not to nitrate (Schmidt *et al.*, 2003), which is based on the fact that nitrite is an intermediary compound in both nitrification and denitrification steps.

Nitrification up to nitrite is followed by nitrite denitrification (Ciudad *et al.*, 2005).

SHARON (Single reactor High activity Ammonia Removal Over Nitrite) process involves partial nitrification of ammonium to nitrite to get a given ratio of ammonium/nitrite (e.g. 50/50). In this case products of the SHARON process should be good candidates for the ANAMMOX process (which is the denitrification of nitrite into dinitrogen gas with ammonium as electron donor under anoxic or oxygen-limited conditions by autotrophic micro-organisms without external carbon source)

The process would be cost-effective since it needs less aeration : about 25 % (for nitrification) and less external carbon source, such as methanol, as electron donor, about 40 % (for denitrification) in case of a low C/N ratio in the wastewater (Jianlong and Ning, 2004; Schmidt *et al.*, 2003) and 100 % in case of the ANAMMOX process. In addition, this process could save 30 – 40 % reactor volume (Peng *et al.*, 2004). It is also noticed that the denitrification of nitrite is 1.5 to 2 times faster than that carried out starting from nitrate (Abeling and Seyfried, 1992).

3. OBJECTIVES

The main objective of this study is to optimize the partial nitrification process (SHARON) in a SBR bench-scale under controlled conditions for landfill leachate treatment aiming at its possible application in Vietnam.

Specific objectives is (1) to study and set up working mechanism for an SBR bench-scale to conduct the nitrogen removal process and (2) to study kinetics of the

partial nitrification process (SHARON) from ammonium (NH₄⁺) to nitrite (NO₂⁻), including (2.1) the effect of factors such as: DO, pH, temperature, SRT, HRT, input C/N, F/M, influent concentration of NH₄⁺-N, alkalinity and (2.2) to determine the optimum conditions for an ammonium/nitrite ratio of 50/50.

4. MATERIALS AND METHODS

Leachate and activated sludge (biomass)

Leachate used for the study is collected from a landfill site in Montzen, Belgium. This leachate has been selected after a comparison with leachates from some landfill sites in the Nord of Vietnam (especially Nam Son landfill site in Hanoi whose leachates will be used in Vietnam in a further step). Concentrations of the main parameters (COD, NO₂⁻, NO₃⁻, NH₄⁺, TKN, PO₄³⁻, Alkalinity, pH) of the leachates in Montzen, Belgium are shown in Table 4.1. This leachate is diluted to get NH₄⁺-N concentrations around 80 mg/L.cycle.. The COD load is 310 – 410 mgO₂/L.cycle (including inert COD in inlet wastewater and COD injected at the beginning of denitrification process), corresponding with C/N ratio of 3.6 – 4.8.

Biomass was collected from the MBR treating leachates from the Montzen sanitary landfill. The sludge was known for its good nitrifying and denitrifying activities. After some weeks in SBR, it has shown its suitability for the SBR system. Concentration of biomass in the pilot is kept around 1.6 - 2.1 gVSS/L.

Table 4.1. The characteristic of leachate in Nam Son and in Montzen

Parameter	Unit	Concentration	
		Nam Son (Vietnam) (Variation)	Montzen, Belgium (11 Jan 2008)
pH		8.43	8.3
COD	mgO ₂ /l	250 - 2800	2005
NO ₃ ⁻	mgN/l	1.6	< 0.01
NO ₂ ⁻	mgN/l	< 0.01	< 0.01
NH ₄ ⁺	mgN/l	15 - 2000	825
TKN	mgN/l	18-2500	982
Alkalinity	mgHCO ₃ ⁻ /l	740-6900	6560
PO ₄ ³⁻	mgP/l	3.4	11.2

Carbon source for denitrification

Potassium acetate as external carbon source is added 15 minutes after the beginning of anoxic phase. According to the reaction stoichiometry of denitrification, the quantity (expressed as COD) of acetate used in the denitrifying process is estimated by the following equation:

$$C_{COD} = 2.86[NO_3^-] + 1.71[NO_2^-] + 1.07[DO]$$

where C_{COD} is the [CH₃COO⁻] quantity added, mgCOD/L; [NO₃⁻] the nitrate concentration, mg NO₃-N /L; [NO₂⁻] the nitrite concentration, mg NO₂-N/L; DO is the dissolved oxygen concentration, mg/L.

The DO concentration during anoxic phase is very low (<0.05 mg/L) compared with the concentration of [NO₂⁻] + [NO₃⁻], so the part of 1.07[DO] in the equation can be ignored. [NO₂⁻] and [NO₃⁻]

concentrations produced in a cycle are used to calculate the next one.

SBR bench-scale

The SBR bench-scale is a set of experimental equipments including the following components:

- Tank: (20 cm x 15 cm x 40 cm), volume of 12 liters, maximum working volume of 8.6 litres, air diffusion device at the bottom of the tank.
- Electronic controller (Logo 230RC – Siemens) controls automatically water and/or sludge pumping in and out of the whole cycle through water level controlling devices.
- Pump and pipes: the pump (TOTTON Pumps (AD 550) is used to pump wastewater into the tank and

treated water and extra sludge from the tank; it is also used to mix liquor by circulation during the anoxic mixing phase.

A complete working cycle of the SBR includes 5 phases: filling, reaction (aeration, mixing), settling, wasting (with/without sludge wasting) and idle, which are shown in Figure 4.1. Total time of the cycle is 12 hours. At the first stage, time for both oxic reaction and anoxic reaction were set at 4 hours, but in the second stage, the duration for each has been changed into 5 hours and 3 hours, then into 6 hours and 2 hours respectively. Hydraulic Residence Time (HRT) during those three different working cycles is always set at 0.77 (d), Solid Retention Time (SRT) is kept around 21 (d).

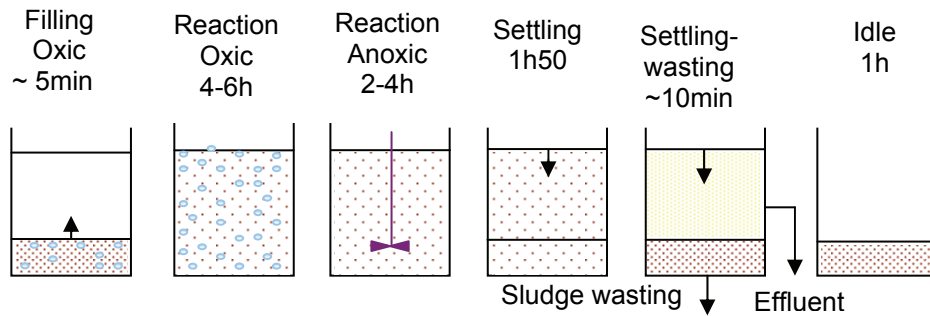


Figure: 4.1. Working cycle of SBR bench - scale

Online control strategy

DO (+ T^o) probe (Oxi 197i – WTW), pH probe (pH 537 - WTW) are installed in the tank to measure and control the nitrification and somehow denitrification processes.

Determination of the hydrodynamic and biological processes of SBR

- (1) Measurement of gas-liquid mass transfer coefficients Kla in the media with and without biomass according to the American Society of Civil Engineering (ASCE, 1992).
- (2) Determination of the mixing time
 - Principle: record the time for the system to reach 95 % of final conductivity after a salt (tracer) addition.
- (3) Respiration and biomass activity tests in the reactor with steady state biomass to set mixing time and aeration periods in the SBR reactor (flowing gas, static liquid respirometer)
 - Formula: $Ro = Kla (S^*o - So) - dSo/dt$
- (4) Determination of settling properties of the sludge when aeration is stopped.
 - SVI (sludge volume index) and settling velocity.

Mathematical model of the process for the whole study will be applied with a *Peterson Matrix* derived from accepted *ASM3 Model* (Henze *et al.*, 2000). At the first step, few formula of the model were used to estimate some kinetic parameters (e.g. μ_{max} , μ) and to evaluate the active proportion of nitrifying and denitrifying bacteria.

Model-based optimization

Observation of the best operating conditions will be carried out through an optimization algorithm to obtain a nitrite/ammonium ratio near 50:50 in the SBR bench-scale. Optimal values of conditional parameters includes DO, pH, free NH_3 , temperature, SRT, input C/N, F/M, influent concentration of NH_4^+-N , alkalinity and are studied using the *WEST Manager 3.7.2* and its Optimization Toolbox. At the first step, the conditions for nitrite accumulation are observed with influences of factors such as DO and free NH_3 .

Experimental approach

All off-line measurements followed Standard Methods for the Examination of Water and Wastewater (APHA, 1992).

5. RESULTS AND DISCUSSION

Tracer tests to determine mixing capacity

The tests were carried out in the liquid medium during filling process with aeration and during the mixing process. In both cases, the liquid temperature is 20°C. For each test 60 ml of a saturated sodium chloride (NaCl, 350 g.l⁻¹) solution is injected and mixed in the reactor. Conductivity was recorded and the time needed to get 95 % of the final conductivity was obtained after data processing.

During the filling phase with aeration, time needed for the system to get the well-mixed state is 10 seconds, which is very small compared to the duration of the filling + aeration phase (e.g. 4-5 hours). In the mixing phase with no aeration, this value reached 52 seconds, which is also much smaller than the 2-3 hours duration of the mixing phase. This means that the system can be considered as well-mixed.

Gas-liquid mass transfer coefficients *K_{la}*

The gas-liquid mass transfer coefficient, indicated by the *K_{la}* term, was estimated in the SBR pilot at

different settings (from 2 to 7) of the aeration system. Measurements are taken in clean water and then repeated with biomass. With the value of *K_{la}* determined in the system with (*K_{la}'*) and without biomass (*K_{la}*), we can calculate the α factor which is used to correct parameters of the aeration device. This value varies with type of aeration device, tank geometry, degree of mixing and characteristic of wastewaters. The average value of α factor of the SBR bench-scale is found to be 0.73 (Table 5.1), which is in the range of 0.4-0.8 for diffused aeration equipment reported by Metcalf&Eddy (1991).

The *K_{la}* is estimated according to the standard method of measurement of the transfer of oxygen in clean water published by the American Society of Civil Engineering (ASCE, 1992) during the phase of reaeration where the concentration of DO increases gradually in the reactor (positive level). Based on the value of *K_{la}*, it is possible to calculate the oxygenation capacity (OC') or the standard oxygen transfer rate (SOTR'). The values obtained are presented in Table 5.1, in which, with air flow rate from 6.1 to 10.2 lN/h, concentration of dissolved oxygen is controlled for partial nitrification.

Table 5.1: *K_{la}* of the SBR

Air flow rate (lN/h)	<i>K_{la}</i>	<i>K_{la}'</i>	α	<i>C_s'</i>	OC'	SOTR'
	<i>h⁻¹</i>	<i>h⁻¹</i>	= <i>K_{la}'</i> / <i>K_{la}</i>	mgO ₂ /L	mgO ₂ /Lh	mgO ₂ /h
45.2	13.75	9.35	0.68	6.93	64.8	557
40.6	12.35	8.96	0.73	6.23	55.8	480
31.7	8.176	6.12	0.75	5.74	35.1	302
10.2	2.997	2.13	0.71	4.99	10.6	91
6.1	2.73	2.09	0.77	4.2	8.8	75

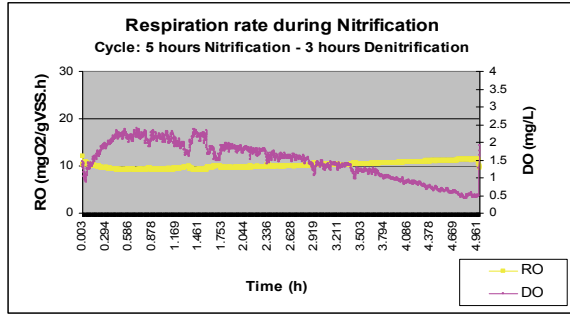
Respiration and biomass activity

Taking into account the value *K_{la}'*, we can calculate respiration rate (Ro) or oxygen uptake rate (OUR) of biomass in the system through the formula:

$$Ro = K_{la}' (S^*o - So) - dSo/dt \quad (\text{Spanjers and Vanrolleghem, 1995}).$$

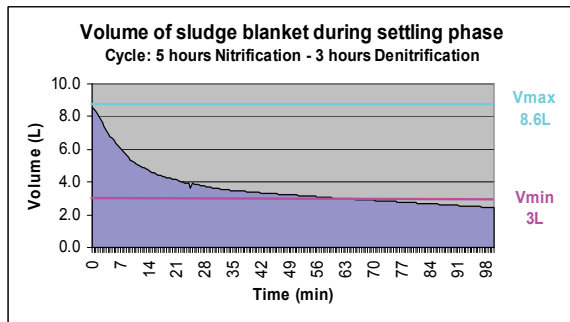
Where *S*o* and *So* are concentrations of saturated dissolved oxygen (DO) (according to temperature and atmospheric pressure in experimental conditions) and DO in the liquid phase respectively. At steady state for biomass, with DO controlled for partial nitrification (0.8-2.2 mg/L), the average value of Ro was found around 10.06 mgO₂/gVSS.h or 17.1 mgO₂/L.h with VSS at 1.7 g/L (Graph 5.1).

Comparing with the value of oxygen capacity (OC') (concentration of dissolved oxygen presents in the liquid media) shown above (10.6 mgO₂/L.h), the speed of aeration for partial nitrification is not high enough. The decrease of DO concentration during nitrification process (and to 0.5 mg/L) at the end of process could be a good explanation. This also explains why Simultaneous Nitrification Denitrification (SND) phenomena could take place during Nitrification process.. Therefore, the speed of aeration or *K_{la}* should be increased to provide enough oxygen for the process.

Graph 5.1. Respirometry during partial nitrification


Settling capacity of sludge in the system

At steady state, SVI (sludge volume index) of the system is 250 (mL/g). This value is still high for a system known for the good settling properties of the sludge. However, the measured settling velocity of sludge at the beginning of the settling phase is 12.2 cm/h. 1.5 hours of settling is just enough for the sludge blanket layer to get below the minimum water level at which the supernatant is discharged. The value of SVI, however, needs to improve or the minimum volume needs to be increased so that the system starts the wasting phase without risk of sludge wastage.

Graph 5.2. Sludge blanket level of SBR


Mathematical model

A mathematical model of the process is derived based on generally accepted ASM Model (Henze *et al.*, 2000). Simplifications adopted in the original model formulation were maintained: constant temperature and pH, lack of inhibitory effects and nutritional limitations, and homogeneous biomass. It was assumed that the reactor was completely stirred and kinetic parameters were kept constant along batch cycle. In this study, at the first step, the model includes fundamental phenomena which were modified from ASM3 as follows:

a/ Growth of autotrophic microorganisms:

- Maximum specific growth rate of autotrophic biomass

$$\hat{\mu}_A(T, \text{pH}) = \hat{\mu}_A(20^\circ \text{C}) \cdot \exp(\kappa(T - 20)) \quad (\text{Eq. 5.1})$$

κ : Temperature constant for μ_A and b_A

$$f_{\text{pH}} = \frac{1}{1 + 0.04 * (10^{8-\text{pH}} - 1)}$$

- Aerobic growth of nitrosomonas-like bacteria:

$$r_{G,NS} = \hat{\mu}_{NS} \cdot \frac{S_{-O}}{K_{-A_{-O}} + S_{-O}} \cdot \frac{S_{-NH}}{K_{-A_{-NH}} + S_{-NH}} \cdot \frac{S_{-AKL}}{K_{-A_{-AKL}} + S_{-AKL}} \cdot f_{\text{pH}} \cdot X_{-A_{-NS}} \quad (\text{E.q. 5.2})$$

- Aerobic growth of nitrobacter-like bacteria:

$$r_{G,NB} = \hat{\mu}_{NB} \cdot \frac{S_{-O}}{K_{-A_{-O}} + S_{-O}} \cdot \frac{S_{-NO2}}{K_{-A_{-NO2}} + S_{-NH}} \cdot \frac{S_{-AKL}}{K_{-A_{-AKL}} + S_{-AKL}} \cdot f_{\text{pH}} \cdot X_{-A_{-NB}} \quad (\text{E.q. 5.3})$$

b/ Growth of heterotrophic microorganisms:

- Maximum specific growth rate heterotrophic biomass

$$\hat{\mu}_H(T, \text{pH}) = \hat{\mu}_H(20^\circ \text{C}) \cdot \exp(\kappa(T - 20)) \cdot [1 - 0.083(7.2 - \text{pH})] \quad (\text{E.q. 5.4})$$

κ : Temperature constant for μ_H and b_H

- Anoxic growth rate of nitrite denitrifiers:

$$r_{G,H_{-NO2}} = \hat{\mu}_{H_{-NO2}} \cdot \eta_{NOx} \cdot \frac{K_{-O}}{K_{-O} + S_{-O}} \cdot \frac{S_{-NO2}}{K_{-NO2} + S_{-NO2}} \cdot \frac{S_{-NH}}{K_{-NH} + S_{-NH}} \cdot \frac{S_{-COD}}{K_{-COD} + S_{-COD}} \cdot \frac{X_{-STO} / X_{-H}}{K_{-STO} + X_{-STO} / X_{-H}} \cdot f_{\text{pH}} \cdot X_{-H_{-NO2}} \quad (\text{E.q. 5.5})$$

- Anoxic growth rate of nitrate denitrifiers:

$$r_{G,H_{-NO3}} = \hat{\mu}_{H_{-NO3}} \cdot \eta_{NOx} \cdot \frac{K_{-O}}{K_{-O} + S_{-O}} \cdot \frac{S_{-NO3}}{K_{-NO3} + S_{-NO3}} \cdot \frac{S_{-NH}}{K_{-NH} + S_{-NH}} \cdot \frac{S_{-COD}}{K_{-COD} + S_{-COD}} \cdot \frac{X_{-STO} / X_{-H}}{K_{-STO} + X_{-STO} / X_{-H}} \cdot f_{\text{pH}} \cdot X_{-H_{-NO3}} \quad (\text{E.q. 5.6})$$

c/ Decay rate of autotrophs and heterotrophs:

- Decay rate of autotrophic microorganisms

$$r_{D,A} = b_A X_A \quad (\text{E.q. 5.7})$$

- Decay rate of heterotrophic microorganisms

$$r_{D,H} = b_H X_H \quad (\text{E.q. 5.8})$$

d/Organic nitrogen mineralization (ammonification)
soluble organic nitrogen is converted to ammonium):

$$r_{\text{ammonification}} = k_a \cdot S_{\text{ND}} \cdot X_{\text{H}} \cdot \frac{S_{\text{O}}}{K_{\text{O}} + S_{\text{O}}} \quad (\text{E.q. 5.9})$$

From the defined rates, it is possible to propose a respiration rate for substrate utilization processes in SBR:

e) Nitrification rate (aerobic condition)

- Oxidation of ammonium to nitrite:

$$r_{\text{NH-NO}_2} = - \left(i_{\text{XB}} + \frac{1}{Y_{\text{NS}}} \right) \cdot (r_{\text{G,NS}} - r_{\text{D,A}}) \quad (\text{E.q. 5.10})$$

- Oxidation of nitrite to nitrate:

$$r_{\text{NO}_2\text{-NO}_3} = - \left(i_{\text{XB}} + \frac{1}{Y_{\text{NB}}} \right) \cdot (r_{\text{G,NB}} - r_{\text{D,A}}) \quad (\text{E.q. 5.11})$$

f) Denitrification rate (anoxic condition)

- Nitrate denitrification

$$r_{\text{NO}_3} = \frac{d\text{NO}_3}{dt} = \frac{-(1 - Y_{\text{H-NO}_3})}{2.86 \cdot Y_{\text{H-NO}_3}} \cdot \eta_g \cdot (r_{\text{G,H-NO}_3} - r_{\text{D,H}}) \quad (\text{E.q. 5.12})$$

- Nitrite denitrification

$$r_{\text{NO}_2} = \frac{d\text{NO}_2}{dt} = \frac{-(1 - Y_{\text{H-NO}_2})}{1.71 \cdot Y_{\text{H-NO}_2}} \cdot \eta_g \cdot (r_{\text{G,H-NO}_2} - r_{\text{D,H}}) \quad (\text{E.q. 5.13})$$

The experimental variables (temperature, DO, Alkalinity, pH, COD, NH_4^+ , NO_3^- , NO_2^- , TKN, VSS) were measured and analyzed during experiment, kinetic and stoichiometric parameters are taken from literature (Table 5.2). The unit of biomass (VSS) was converted to mg of COD. $X_{\text{STO}}/X_{\text{H}}$ ratio (with X_{STO} is cell internal storage product of heterotrophic organisms) is assumed to be equal to $X_{\text{PHA}}/X_{\text{H}}$ ratio. This value for SBR system reported in (Hanada et al., 2002) is 2.2.

Table 5.2. Kinetic parameters for nitrification and denitrification (Henze et al., 2000; Henze et al., 2002)

Parameters	Definition	Unit	Value (at 20°C)			
			AOB	NOB	NO_2^- Denitrifier	NO_3^- Denitrifier
κ	Temperature constant for μ_{max} b	$^{\circ}\text{C}^{-1}$	0.1	0.085	0.08	0.08
$\hat{\mu}$	Maximum specific growth rate of nitrifying biomass at 20 oC	d^{-1}	0.6	0.7	4.5	4.5
b	Decay constant	d^{-1}	0.06	0.06	0.075	0.075
D_g	Fraction heterotrops using nitrate as electron acceptor	-			0.8	0.8
k_a	Maximum specific ammonification rate	l/mgCOD.d	0.06	0.06		
i_{XB}	Mass of nitrogen per mass of COD in biomass	mgN/mgCOD	0.086	0.086		
D_{NOX}	Anoxic reduction factor	-			0.6	0.6
Y_A	Maximum yield coefficient	mgCOD/mgNO_3^- produced	0.11	0.06		
Y_H	Maximum yield coefficient	mgCOD/mgNO_3^-			1.7	1.7
K_N	Saturation constant for ammonium or nitrite	mgN/L	0.5	1		
K_{NO}	Saturation constant for nitrite or nitrate	mgN/L			0.35	0.35
K_{DO}	Saturation constant for oxygen	mgO_2/L	0.75	1	0.3	0.3
K_{AKL}	Saturation constant for alkalinity	$\text{mgHCO}_3^-/\text{L}$	30.5	30.5		
K_{COD}	Saturation constant for COD	mgO_2/L			15	15
K_{STO}	Saturation constant for X_{STO}	$\text{mgCOD}(X_{\text{STO}})/\text{mgCOD}(X_{\text{H}})$			1	1

Specific growth rates of ammonium and nitrite nitrifying bacteria at given temperature (21.2 °C) are 0.42 and 0.39 (d^{-1}) respectively. Average nitrification rates (mgN/L.h) in the total experimental time are compared to nitrification rates calculated with Monod equations E.q.5.1-5.3; E.q.5.7, E.q.5.10 and E.q.5.11

(using parameters mentioned in Table 5.2). By fitting value of concentration of Ammonium oxidizing bacteria (AOB) and Nitrite oxidizing bacteria (NOB) to fit the two values of nitrification rate, we can estimate the proportion of (AOB) and (NOB). Estimated proportion of active AOB and NOB is about 1.13% and 0.63% of VSS (22 and 12.4 mg/L), respectively,

corresponding to an activity of biomass (around 1.54 mgN/gVSS.h). The concentration of NOB is smaller compared to AOB due to limitation of oxygen during partial nitrification. The proportion of active biomass for ammonification during nitrification process was estimated about 0.79% of VSS by the same way (by fitting two values of experimental and theoretical ammonification rate (E.q. 5.9)). Minimum SRT (calculated by $\theta_{min} = 1/(\mu-b)$) should be kept around 2.8 (d) for AOB and 3.0 d for NOB so that the system does not lose biomass.

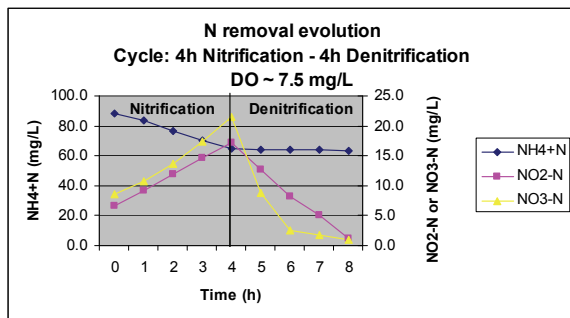
For the denitrification process, specific growth rates at given temperature of nitrite and nitrate denitrifying bacteria are 1.56 and 0.82 (d⁻¹) respectively. Average denitrification rates (mgN/L.h) during denitrification time are compared to denitrification rates calculated with E.q.5.4-5.6; E.q.5.8, E.5.12 and E.q.5.13 (using parameters mentioned in Table 5.2). Proportion of active Nitrite denitrifying bacteria and Nitrate denitrifying bacteria is evaluated around 23.8% and 2.17 % of VSS (461 and 42.3 mg/L), respectively. However, the concentration of the later could be higher if more nitrates were produced during the nitrification process. Minimum SRT should be kept at least 1.77 d for denitrifiant and 2.30 (d) for denitratant. However, when the ANAMMOX process is considered, this SRT will have to be increased.

Model-based optimization

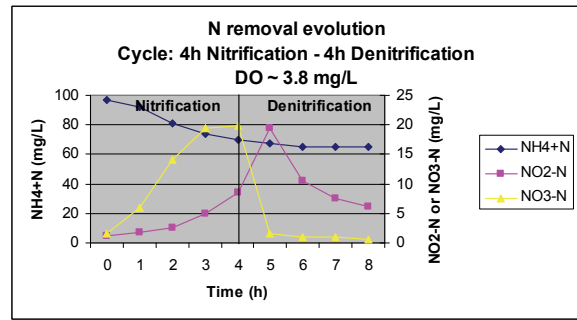
Observations of influence of working conditions on nitrite accumulation (necessary for partial nitrification) as well as nitrification and denitrification efficiency was done with concentration of dissolved oxygen (DO) and free ammoniac (free NH₃) in the first step of the study, which is presented in this paper.

The influence of DO on nitrite accumulation in nitrification process is significant. The nitrite accumulation increases when DO decreases, this shows capability to get partial nitrification in SBR. Graph 5.2, 5.3 and 5.4 present nitrogen removal evolution when average DO in the period of nitrification is controlled around 7.5, 3.8 and 1.5 mg/L.

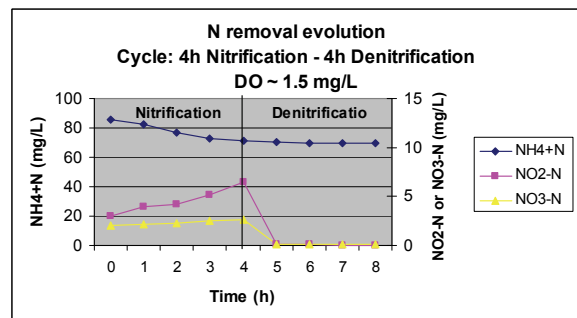
Graph 5.2. Nitrogen removal evolution 1



Graph 5.3. Nitrogen removal evolution 2

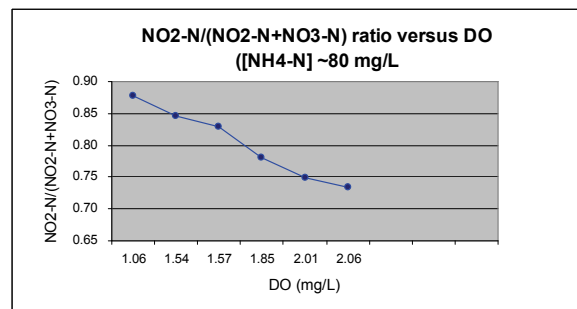


Graph 5.4. Nitrogen removal evolution 3



Concentration of DO that is suitable for the partial nitrification process is around 0.8-2.2 mg/L. Among the three values of DO used to control the process (1 mg/L, 1.5 mg/L and 2 mg/L) it is found that with DO ~ 1mg/L the system can get the best nitrite accumulation and not with DO ~ 2mg/L (Graph 5.5). But the result is opposite when N removal efficiency is concerned. With DO of 1.5 mg/L, the system obtains an intermediate result of the two DO of 1 and 2 mg/L.

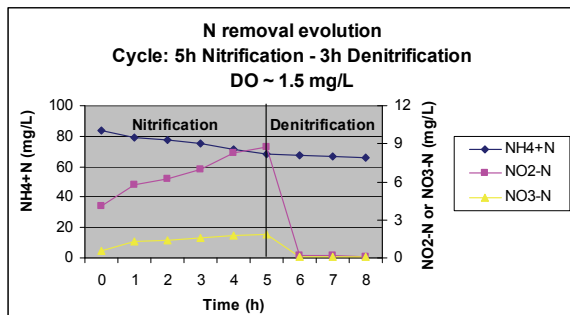
Graph 5.5. Influence of DO on nitrite accumulation



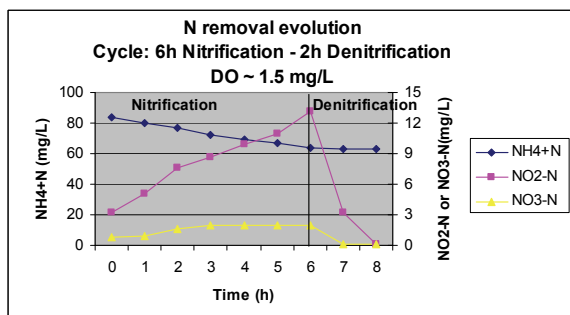
It is obvious that, with a DO of 1.5 mg/L, nitrate is almost not produced; there is a nitrite accumulation of 88%. However, ammonium removal efficiency in this case is limited (17 %), while nitrite produced is fully consumed before the end of denitrification. Working

time therefore was changed to improve nitrification efficiency, to get a 50/50 ratio of ammonium (remaining)/nitrite (produced), meanwhile avoiding to waste time and energy in the denitrification process. Time of aeration phase (nitrification) was changed from 4 hours to 5 hours and then 6 hours. As a result, time of mixing phase (denitrification) was changed from 4 hours to 3 hours and then 2 hours, respectively. Graph 5.6 and 5.7 present nitrogen removal evolution of those time cycles. DO concentration is still controlled around 1.5 mg/L. It is found that, the cycle of 6 hours-nitrification and 2 hours – denitrification (Graph 5.7) got a best nitrite accumulation, which is up to 89% and an improved ammonium removal efficiency of 24 %. The nitrification process, however has not yet reached a 50/50 ammonium/nitrite ratio. Other factors such as temperature, HRT, SRT and also DO will be modified in the next step in SHARON process. Total ammonium oxidized is always higher than total nitrite and nitrate produced in nitrification (about 57%), suggesting that Simultaneous Nitrification Denitrification (SND) phenomena could take place. It is expected to get a higher value of nitrogen removal efficiency and an expected ratio of ammonium/nitrite when these working conditions (especially temperature and also dissolved oxygen) are controlled more strictly in the SHARON process.

Graph 5.6. Nitrogen removal evolution 4



Graph 5.7. Nitrogen removal evolution 5

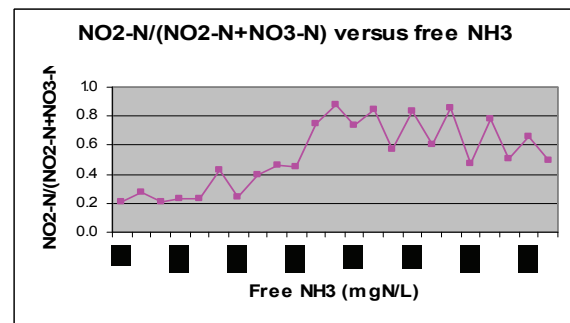


Free NH₃ was calculated according to the E.q. 5.14 (Verstraete and van Vaerenberg, 1985),

$$\frac{NH_3}{\sum(NH_3 + NH_4^+)} = \frac{10^{pH}}{10^{pH} - 3.398 * 10^9 \ln(0.0241T)} \quad (\text{E.q. 5.14})$$

Influence of free NH₃ on NO₂-N/(NO₂-N+NO₃-N) and NH₄⁺ removal efficiency is also obvious. With a free NH₃ concentration of 1.6 mgN/L, the system already obtains an accumulation of 75% of NO₂⁻ (Graph 5.8). But NH₄⁺ removal efficiency is lower when free NH₃ increases. According to the results presented by (Anthonisen et al., 1976), a partial inhibition of the ammonium nitrifiers is observed from 10 mgN-NH₃/L and the inhibition is complete at 150 mgN/L. For nitrite nitrifiers, the partial and total inhibition levels were estimated at 0.1 and 1 mgN/L, respectively. In contrast, the results obtained by (Beline et al., 2007) indicated no inhibition of ammonium nitrifiers or nitrite nitrifiers by free NH₃ up to 50 mgN/L. As mentioned by Villaverde et al. (2000), acclimatisation of the bacteria could explain the different inhibition levels reported in the literature (Tabares, 2006). However, the ammonium removal efficiency is lower when free NH₃ decreases (data not shown).

Graph 5.8. Influence of free NH₃ on nitrite accumulation



6. CONCLUSION

The system is well-mixed for both nitrification and denitrification processes.

It is necessary to increase the aeration rate (e.g. K_{la} value) to supply enough oxygen for the nitrification process and possibly to avoid Simultaneous Nitrification Denitrification (SND) phenomena in partial nitrification.

Although time for settling phase is just enough but the latest value of SVI measured is still high (250 mL/g). This value needs to be improved by eliminating suspended solid in inlet leachate or even increasing the minimum working volume of SBR.

Mathematical model based on modified ASM3 helped to determine some kinetic parameters of the process (e.g. special growth rate at given temperature μ(T)) of AOB, NOB, Nitrite denitrifiers and Nitrate denitrifiers.

The concentrations of those main micro-organisms were also estimated by fitting value of nitrification rate (mgN/L.h) obtained directly from experiment and calculation with Monod equations of the model. These values have to be confirmed by other testing methods (e.g. FISH) to estimate the accuracy of other kinetic or stoichiometric parameters.

The nitrite accumulation increases when DO decreases, confirming the SBR capability of partial nitrification. Concentration of DO that is suitable for this process is around 0.8-2.2 mg/L with the best value of 1.5mg/L. The working cycle of 6 hours Nitrification/2 hours Denitrification has shown the best nitrite accumulation of the SBR but not yet yielding a 50/50 ratio of ammonium/nitrite at the end of nitrification process. A well managed SHARON process will be processed in the next step of the study to obtain higher nitrogen removal efficiency and the expected ratio of ammonium/nitrite. Influence of free NH₃ on NO₂-N/(NO₂-N+NO₃-N) was also obvious. With concentration of free NH₃ around 1.6 mgN/L, the system already obtained an accumulation of 75% NO₂⁻-N.

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