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Jean-Marc CHOUBERT[1], Yvan RACAULT[1], Alain GRASMICK[2], Christian BECK[3], Alain HEDUIT[4]

Maximum nitrification rate in activated sludge processes at low temperature: key parameters, optimal value

ABSTRACT

The present work aims at identifying and analyzing the main parameters governing the value of the maximum nitrification rate in the extended aeration activated sludge process. An experimental monitoring of an activated sludge pilot plant operated under controlled conditions, a series of dynamic simulations achieved with the Activated Sludge Model n°1 (ASM1), and a theoretical approach based on the equations of growth and decay of nitrifying biomass have been undertaken to reach this objective.

At a given temperature, a minimum duration per day of oxygen presence is required to prevent the nitrifying micro-organisms from being washed out. Beyond this limit, the maximum nitrification rate is proportional to the nitrogen volumetric loading rate. It also depends on other operating parameters such as the COD/TKN ratio of the influent, the sludge retention time, the fraction of the total sludge contained in the intermittently aerated tank.

Keywords: Activated sludge ; Nitrification ; Reaction rates ; Nitrogen volumetric load; Duration of oxygen presence; Simulations ; Model ASM1

INTRODUCTION

In France, nitrogen of urban wastewater is mainly removed by activated sludge systems with an intermittent aeration to nitrify and denitrify in a same tank. The size of the aeration tank necessary to remove nitrogen is based on the minimum sludge retention time which depends on the minimum temperature reached during winter. A high nitrogen removal efficiency is expected down to a temperature of the mixed liquor of 10°C. This is generally achieved by applying a F/M ratio lower than 0.10 kg BOD_5.$(kgMLVSS.day)^{-1}$.

The maximum nitrogen removal capacity of a wastewater treatment plant can be assessed by multiplying two parameters relatively easy to measure: the duration of oxygen presence by the

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[1] *CEMAGREF, Water Quality Research Unit, 50 avenue de Verdun, 33612 CESTAS, FRANCE,* jean-marc.choubert@cemagref.fr

[2] *Laboratoire de Génie des Procédés et Sciences des Aliments, Université de Montpellier II, CC024, Place Eugène Bataillon, 34095 MONTPELLIER Cedex 05, FRANCE*

[3] *ENGEES, Laboratoire d'hydraulique urbaine, BP 1039-F, 67070 STRASBOURG Cedex, France*

[4] *CEMAGREF, Water Quality and Hydrology Research Unit, Parc de Tourvoie, BP 44, 92163 ANTONY Cedex, FRANCE*

value of the maximum nitrification rate. However, the values of the maximum nitrification rate reported in the literature at 10°C are in a very wide range: 1.0 to 4.5 $mgN_{nit}.(gMLVSS.h)^{-1}$ (Burica *et al.*, 1996; McCartney et Oleszkiewicz, 1990; Oleszkiewicz et Berquist, 1988; Palis et Irvine, 1985). The differences can be explained by various operating conditions (Al-Sa'ed, 1988; Thiem et Alkhatib, 1988): loading rate and characteristics of the influent (COD/TKN or COD/TSS ratios).

The present work aims at analyzing the main parameters governing the value of the maximum nitrification rate ($r_{V,\ max\ nit}$) in activated sludge processes. Three approaches have been followed:

- A 5 month comprehensive experimental monitoring of an activated sludge pilot plant fed with an urban wastewater under controlled conditions: temperature, F/M ratio, nitrogen volumetric load ($B_v(N)$), duration of oxygen presence (D_{prox}). The maximum nitrification rate of the sludge ($r_{V,\ max\ nit}$) was measured every week in a separate batch reactor. Moreover, intensive sampling campaigns in the continuous flow reactor were achieved to calibrate the Activated Sludge Model n°1 (ASM1);
- A series of dynamic simulations achieved with GPS-X® 3.0 numerical software, from Hydromantis, Inc., to further investigate the effects of the sludge retention time (SRT), the duration of oxygen presence (D_{prox}), and the nitrogen volumetric load ($B_v(N)$);
- A theoretical approach based on the equations of growth ($\mu_{A,\ maxi}$) and decay (b_A) of the autotrophic biomass responsible for nitrification.

NOTATIONS

Table 1: Abbreviations and symbols

Symbols		**Unit**
b_A	Decay rate of nitrifiers	d^{-1}
$B_v(N)$	Nitrogen volumetric loading rate	$g\ N.(m^3.d)^{-1}$
D_{nitrif}	Duration for nitrification	h/d
D_{prox}	Daily duration of oxygen presence	h/d
$D_{prox\ mini}$	Minimum daily duration of oxygen presence	h/d
f_{AT}	Fraction of the total sludge contained in the intermittently aerated tank	%
F/M ratio	Food to micro-organisms ratio	$kg\ BOD_5.(kgMLVSS.d)^{-1}$
K_{OA}	Oxygen half-saturation coefficient for autotrophic biomass	$mg\ O_2/L$
K_{OH}	Oxygen half-saturation coefficient for heterotrophic biomass	$mg\ O_2/L$
K_{NH}	Ammonia half-saturation coefficient for autotrophic biomass	$mg\ NH_4\text{-}N/L$

Symbols		**Unit**
K_S	Readily biodegradable carbon half-saturation coefficient	mg COD/L
$MX_{B,A}$	Mass of nitrifying bacteria	g COD
P.E.	Population Equivalents	inhabitants
$r_{v,\ max\ nit}$	Maximum nitrification rate	mg N_{nit}.(L.h)$^{-1}$
SRT	Sludge retention time	d
Y_A	Yied of nitrifying bacteria	g $COD_{produced}$/g $N_{nitrified}$
$\mu_{A,\ maxi}$	Maximum growth rate of nitrifiers	d^{-1}
φ_{Nnit}	Nitrified nitrogen mass per day	g N/d
η_{BOD5}	Efficiency of BOD_5 removal	%
η_{TKN}	Efficiency of TKN removal	%

MATERIALS & METHODS

Continuous flow reactor

The pilot plant combined a 115-liter contact tank equipped with a stirrer and an intermittent aeration system (9 cycles per day), connected to a 45-liter clarifier with scraper, and a sludge recycling loop (**Figure 1**). This equipment was controlled by a timer switch. The system was operated for five months in a temperature-controlled room (11 ± 1°C).

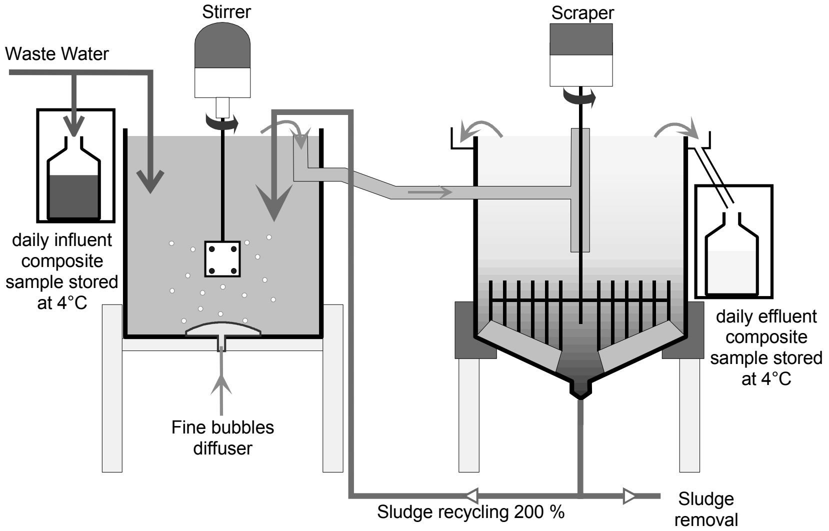

Figure 1: Diagram of the experimental plant

The system was fed with a domestic influent from a municipal plant (16,000 P.E.) sampled two or three times per week, screened at 1.3 mm and kept in a refrigerated container at 4°C. The influent characteristics (concentrations and ratio) are presented in **Table 2**. As it was sampled at 10:00am, which corresponded to the daily nitrogen peak load of the full scale WWTP, the COD/TKN ratio equaled 6.5 whereas, for a daily influent composite sample, the COD/TKN ratio is closer to 10 (Pons *et al.*, 2004).

Table 2: Average concentrations and ratios of wastewater vs usual French values

concentrations and ratios		Wastewater used for experiments	French typical values (Pons *et al.* , 2004)
COD	*mg / L*	300 - 450	634 ± 315
SS	*mg / L*	150 - 190	302 ± 170
TKN	*mg N/L*	50 - 85	52 ± 23
COD / BOD_5	-	2.7	2.1
COD / TKN	-	6.5	10.6
TKN / NH_4-N	-	1.5	-

The system was subjected to inflow rate variations, simulating the situation in full-scale wastewater treatment plants located in rural areas (high morning and evening peaks and very low inflow at night). Daily flow composite samples were collected in the influent and in the treated water. Standardized analysis techniques were used to measure the following parameters: TKN, N-NH_4, N-NO_3, COD, BOD_5, TSS, VSS.

Following a three-week start-up period, the system was run for three successive six-week experimental periods (Periods 1, 2, 3) in order to obtain steady-state conditions. Predefined organic and nitrogen loads were applied in each period (**Table 3**). Organic load was low during the first period, 0.09 kg BOD_5.(kg MLVSS.d)$^{-1}$, i.e. an SRT of 15 days, rising 0.115 (SRT = 12 days) in periods 2 and 3. Three levels of nitrogen volumetric loading rate (B_v(N)) were tested: 130 mgN.(L.d)$^{-1}$ in period 1, 160 in period 2, and 185 in period 3. Values were increased by adding ammoniacal nitrogen to influent. The aeration time was set to apply given durations of oxygen presence per day (D_{prox}): 13.5 h/d for 40 days, 10.5 for 10 days and 13.5 h/d for 10 days in period 1; 15 h/d for 40 days in period 2; and 15 h/d for 40 days in period 3.

Table 3: Successive steady state conditions in the pilot plant

Period	days	F/M ratio	SRT	D_{prox}	B_v(N)
	d	*kg BOD_5 . (kgMLVSS.d)$^{-1}$*	*d*	*h/d*	*mgN.(L.d)$^{-1}$*
1	0 - 40	0.09	15	13.5	130
	41 - 50	0.09	15	10.5	130
	51 - 60	0.09	15	13.5	130
2	61 - 100	0.115	12	15	160
3	101 - 140	0.115	12	15	185

Batch test reactor

The maximum nitrification rate ($r_{v,\ max\ nit}$) has been weekly measured in a batch test reactor with activated sludge from the continuous flow reactor operated at 11 ± 1°C. Non-limiting oxygen and ammonia concentrations conditions ($[O_2] > 5$ mg/L and initial $[NH_4\text{-}N] = 15$ mgN/L) were supplied to reach a zero order nitrification kinetics conditions (Harremoës *et al.*, 1998).

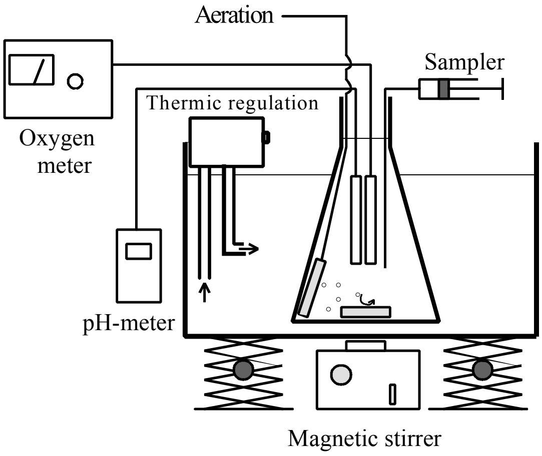

Figure 2: Diagram of the batch test for the measurement of the maximum nitrification rate ($r_{v,\ max\ nit}$)

The ammonium and nitrate concentrations were monitored every 10 minutes for one hour. The maximum nitrification rate ($r_{v,\ max\ nit}$) was calculated as the slope of the increase of the nitrate concentration.

Simulation tool

The Activated Sludge Model n°1 (ASM1) has been in a widespread use for about twenty years incorporating the coefficients proposed by Henze (1986), used as default values. Some of them, and particularly kinetics coefficients, need to be modified for more accurate predictions (Gujer et Henze, 1991). For that purpose, six intensive sampling campaigns were carried out at the half and at the end of each period. Samples were taken from the aeration tank every 10 minutes for 8 hours (i.e. 3 aeration + non-aeration cycles), and the nitrogen concentrations were analyzed. The results were used to calibrate the ASM1 parameters (Choubert, 2002). Changing the maximum nitrifiers growth rate and three half saturation constants, controlling the access to substrates at low concentrations, has resulted in a much better fit between the simulated and experimental values than the one obtained with default values. A unique set of parameters has been obtained for the six campaigns (see Table 4).

Table 4: Kinetics parameters calibrated at 11°C (Choubert, 2002)

Parameter	Default value at 10°C	Calibrated value at 11°C	Biological meaning
$\mu_{A,.maxi}$ *(d^{-1})*	0.30	0.22 ($b_A = 0.02\ d^{-1}$)	nitrification growth more sensitive to SRT
K_{OH} *(mg O_2/L)*	0.20	0.05	easier access to oxygen for heterotrophic bacteria
K_{NH} *(mg NH_4-N/L)*	1.00	0.05	easier access to NH_4-N for heterotrophic bacteria
K_s *(mg COD/L)*	20.0	30.0	more difficult access to organic fraction for heterotrophic bacteria in anoxic conditions

To deepen the experimental results observed, the ASM1 was used with the calibrated kinetics parameters. The effects of the operating conditions (SRT, D_{prox}, $B_V(N)$) on the maximum nitrification rate ($r_{V,\ max\ nit}$) were assessed. The aeration sequences and the inflow rate variations applied were similar to those generally measured on full scale plants located in rural areas.

Theoretical approach

The amount of autotrophic biomass kept in an activated sludge system results from their net growth ($dMX_{B,A}/MX_{B,A}$) during the duration "dt". Equation 1 (Nowak, 1994) expresses the difference between the mass of bacteria produced by nitrification ($Y_A.\varphi_{Nnit}$) minus the mass lost by decay (b_A.dt) and by sludge wastage (dt/SRT):

$$\frac{dMX_{B,A}}{MX_{B,A}}(t) = Y_A.\varphi_{Nnit} - \left(b_A + \frac{1}{SRT}\right).dt \qquad \text{(Equation 1)}$$

When there is no nitrogen and no oxygen limitation, the daily nitrified mass ($Y_A.\varphi_{Nnit}$) of Equation 1 can be expressed as a function of the duration of nitrification (D_{nitrif}), the fraction of the total sludge contained in the intermittently aerated tank (f_{AT}), and the mass of nitrifiers ($MX_{B,A}$):

$$\mu_{A,\ maxi}.\frac{D_{nitrif}}{24}.f_{AT}..MX_{B,\ A} \qquad \text{(Equation 2)}$$

When nitrification is not complete (ammonium remains in treated water), it can be assumed that the duration of nitrification (D_{nitrif}) equals the duration of oxygen presence (D_{prox});

In steady-state conditions (i.e. constant mass of nitrifiers, so $dMX_{B,A}=0$), Equation 1 gives the mass of nitrifiers contained in a wastewater treatment plant (Equation 3):

$$MX_{B,A} = \frac{Y_A}{b_A + \frac{1}{SRT}} . \varphi N_{nit} \qquad [\text{g COD}] \qquad \text{(Equation 3)}$$

Using the fraction of the total sludge contained in the intermittently aerated tank (f_{AT}), and the volumetric nitrogen load nitrified ($B_v(N_{nitrified})$), the mass of nitrifiers ($MX_{B,A}$) has been converted into the concentration of nitrifiers ($X_{B,A}$) of the aerated/non-aerated biological reactor (Equation 4).

$$X_{B,A} = f_{AT} . \frac{Y_A}{b_A + \frac{1}{SRT}} . B_v(N_{nitrified}) \qquad [\text{mg COD/L}] \qquad \text{(Equation 4)}$$

RESULTS & DISCUSSION

The results of the long-term experiments, the additional simulation results and the theoretical approach lead to the study of the impact on the maximum nitrification rate of the following parameters:

1. the duration per day of oxygen presence (D_{prox});
2. the nitrogen volumetric load ($B_v(N)$);
3. the F/M ratio and the COD/TKN ratio in the influent.

1. Impact of the duration of the oxygen presence per day on N-removal

Because of the particularly low COD/TKN ratio of the influent (**Table 2**), the average nitrate concentration in the treated water was around 20 mgNO$_3$-N/L. In order to reduce this value, 20 days before the end of Period 1, the duration of oxygen presence per day was decreased from 13.5 h/d to 10.5 h/d (Table 3). The ammonium concentration immediately increased from 5 to 16 mg NH$_4$-N/L, and the nitrate concentration decreases from 20 to 10 mg NO$_3$-N/L. In 10 days, the maximum nitrification rate decreased to 6.2 mgN$_{nit}$.(L.h)$^{-1}$. To face this decrease, the duration of oxygen presence was increased to 13.5 h/day inducing the decrease of the ammonium concentration lower than 5 mg NH$_4$-N/L, and resulting in a maximum nitrification rate of 8 mgN$_{nit}$.(L.h)$^{-1}$.

These observations point out that for a SRT of 15 days and a temperature of 11°C, a duration of oxygen presence per day around 13.5 h/day is required to maintain an average ammonium concentration in the treated water lower than 5 mgNH$_4$-N/L. These results confirm the previous on-site observations on extended aeration activated sludge process (Heduit, 1990).

To illustrate the impact of the duration of the oxygen presence (D_{prox}) on the maximum nitrification capacity ($r_{V,\ max\ nit}$), steady-state simulations were performed at 11°C for a F/M ratio of 0.09 $kgBOD_5.(kgMLVSS.d)^{-1}$ (SRT = 15 days). D_{prox} was set in the range 9.75 - 15 hour/day. The results of simulations are shown in **Figure 3**.

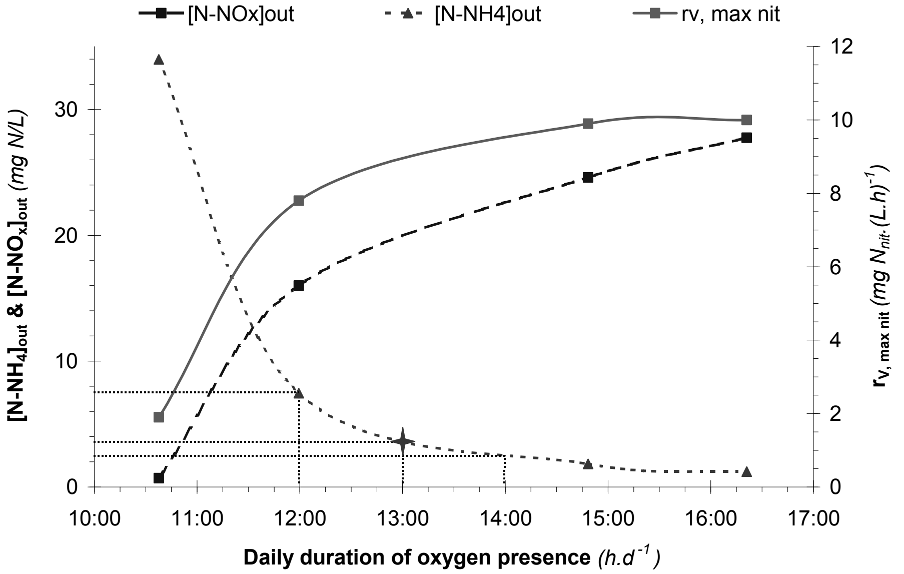

Figure 3: maximum nitrification rate and nitrogen concentrations in the treated water versus the duration of oxygen presence per day (simulations)

When SRT = 15 days, a mean ammonium concentration in the treated water lower than 5 mgN/L is reached when the duration of oxygen presence per day is higher than 13 hours a day. A lower duration induces a decrease of the maximum nitrification rate (corresponding to decrease of the mass of nitrifiers) and an increase of the ammonium nitrogen concentration in treated water: 8 mg NH_4-N/L with 12 hours a day, 22 mg NH_4-N/L with 11 hours a day. Above 13 hours a day, the increase of the duration of oxygen presence needs to be much more important to decrease the ammonium concentration in the treated water: 15 hours a day of oxygen presence are necessary to reach an ammonium concentration lower than 2 mg NH_4-N/L.

Considering the theoretical approach based on Equation 1 and Equation 2, and expressing that the nitrifiers can be kept in a biological system only if the net growth has a positive value: $dMX_{B,A}(t) \geq 0$, then a minimum duration of oxygen presence per day can be deduced (Equation 5) as a function of f_{AT}, SRT, $\mu_{A,\ maxi}$, b_A.

$$D_{prox\ mini} = \left(b_A + \frac{1}{SRT}\right) . \frac{24}{\mu_{A,\ maxi} . f_{AT}} \qquad \text{(Equation 5)}$$

$D_{prox\ mini}$ corresponds to the minimum duration of oxygen presence not to wash-out nitrifiers. Its numerical values are calculated at 11°C with the values of b_A and $\mu_{A,\ maxi}$ presented in Table 4.

Equation 5 leads to the following conclusions:

1. The lower the SRT (*i.e.* the F/M ratio is high), the higher the minimum duration of oxygen presence per day. Considering that 15% of sludge lies in the clarifier (i.e. f_{AT}=0.85), the minimum theoretical duration of oxygen presence per day to prevent the washing-out of nitrifiers is 11.1 h/d if SRT=15 days (15.4 h/d, if SRT=10 days). The difference between the experimental/simulated values (13 to 13.5 h/d) and the theoretical value (11.1 h/d) can be explained by the assumption we did in Equation 5. No limitation by oxygen concentration on the maximum nitrification rate was considered, whereas the Monod function defined as $O_2/(K_{O,A}+O_2)$ equals 0.90 at 4 mgO_2/L with $K_{O,A} = 0.4\ mgO_2/L$;
2. The minimum value for the aeration duration depends on the aerated fraction of the biological tank. For a plant with an anaerobic and/or anoxic tank of 30% of the biological tank volume (f_{AT} = 0.55 instead of 0.85 with a single tank), $D_{prox\ mini}$ would be 0.85/0.55-1=54% higher than for a single aerobic tank operated at the same SRT;
3. The minimum value of the oxygen presence duration ($D_{prox\ mini}$) does not depend on the nitrogen volumetric loading rate applied (B_v(N)). Therefore, the maximum nitrification rate ($r_{v,\ max\ nit}$) changes when the nitrogen volumetric loading rate is modified.

2. Influence of the N volumetric loading rate on the maximum nitrification rate

A 25% increase of the nitrogen volumetric load (**Table 3**), from 160 to 185 $gN.(m^3.d)^{-1}$ (others parameters unchanged), has induced an increase of the maximum nitrification rate in 3 days by +15%: from 8.0 to 9.2 $mgN_{nit}.(L.h)^{-1}$. This increase results from the production of autotrophic biomass concentration with the additional load of nitrogen available (25 $gN.(m^3.d)^{-1}$).

To assess the impact of B_v(N) on the nitrification capacity, simulations (ASM1) were performed at 11°C with a constant carbon loading rate: F/M ratio = 0.09 $kgBOD_5.(kgMLVSS.d)^{-1}$ (i.e. SRT = 15 days). B_v(N) was changed in the range 95 - 195 $mgN.(L.d)^{-1}$ by increasing the TKN concentration in the influent (COD/TKN decreasing from 10 to 5). In order to meet a low NH_4-N concentration in treated water, the duration of oxygen presence per day was set to 15 hours/day which is 2 hours higher than the duration necessary not to wash-out the nitrifiers at a SRT of 15 days. All the results of simulations are shown in Figure 4.

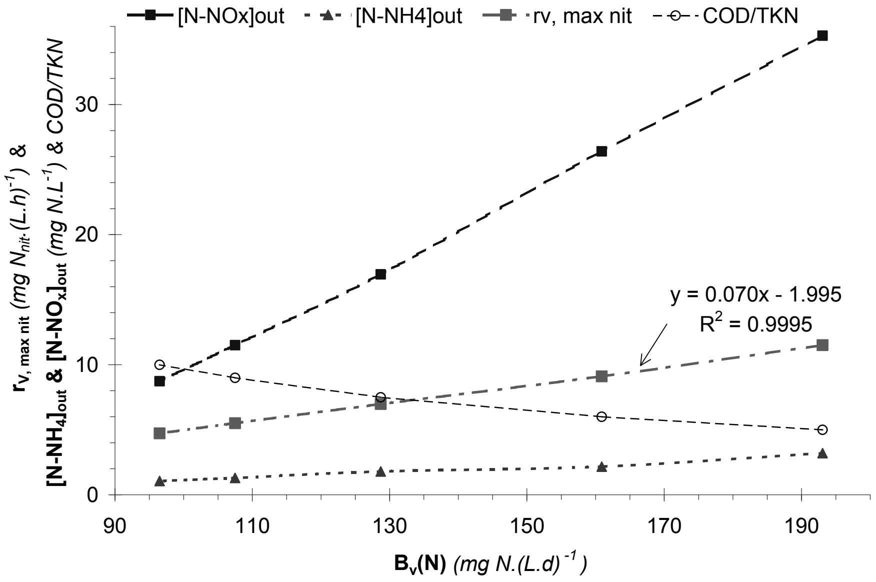

Figure 4: Maximum nitrification rate and nitrogen concentrations in the treated water VS the daily nitrogen volumetric loading rate (simulations, 11°C, SRT=15 days)

Figure 4 shows a linear relationship: "$r_{v,\ \mathrm{max\ nit}} = 0.070\ B_v(N) - 1.995$" when all other parameters are unchanged. The slope is 10% higher than the experimental value obtained on pilot and full scale plants (FNDAE, 2002; Heduit, 1990).

Defining λ as:

$$\lambda = \frac{B_v(N_{\mathrm{nitrified}})}{B_v(N)} = \eta_{\mathrm{TKN}} - 5\% \, . \, \eta_{\mathrm{BOD}_5} \, . \, \frac{[\mathrm{COD}]_{\mathrm{influent}}}{[\mathrm{TKN}]_{\mathrm{influent}}} \, . \, \frac{[\mathrm{BOD}_5]_{\mathrm{influent}}}{[\mathrm{COD}]_{\mathrm{influent}}} \qquad \text{(Equation 6)}$$

Then, the theoretical approach leads to the Equation 7 expressing the maximum nitrification rate ($r_{V,\ \mathrm{max\ nit}}$) as a function of f_{AT}, SRT, $\mu_{A,\ \mathrm{maxi}}$, $b_{A,}$ $B_v(N)$:

$$r_{v,\,\mathrm{max\,nit}} = \frac{\mu_{A,\,\mathrm{maxi}} . X_{B,\,A}}{24 . Y_A} = \lambda . \frac{f_{AT}}{24} . \frac{\mu_{A,\,\mathrm{maxi}}}{b_A + \frac{1}{SRT}} . B_v(N) \qquad \text{(Equation 7)}$$

Equation 7 expresses a linear relationship between $r_{v,\ \mathrm{max\ nit}}$ and $B_v(N)$. It also demonstrates that SRT has an inverse non-proportional effect on $r_{v,\ \mathrm{max\ nit}}$.

3. Impact of the F/M ratio and the COD/TKN ratio in the influent on N-removal

Simulations were performed to investigate the impact of the F/M ratio (i.e. SRT) and of the COD/TKN ratio in the influent (i.e. $B_V(N)$) on nitrogen removal. In each case, the duration of oxygen presence per day was higher than the minimum value required ($D_{prox\ mini}$). The results of the simulation are shown in Figure 5.

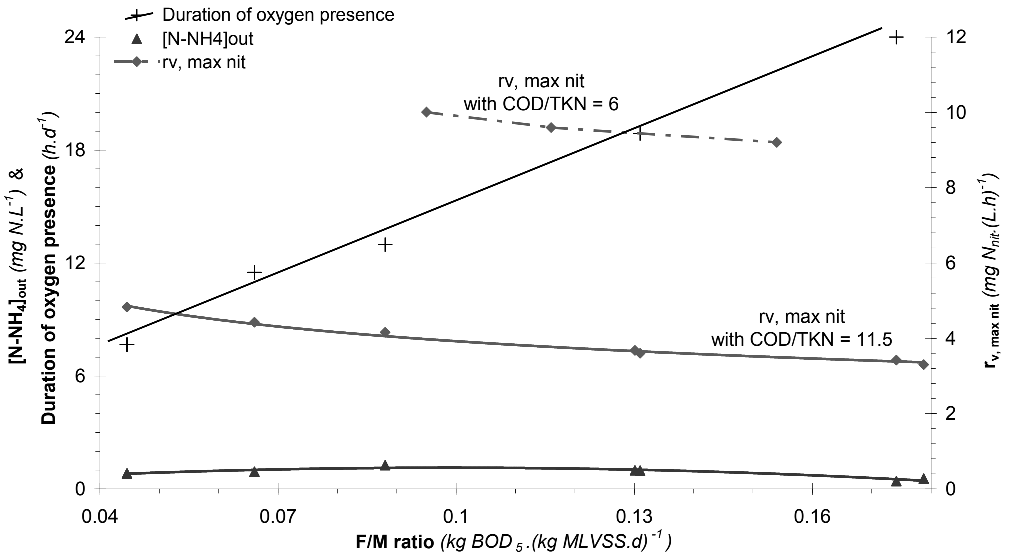

Figure 5: ammonium concentration and maximum nitrification rate VS the F/M ratio and the COD/TKN in the influent (simulations)

Two main conclusions can be drawn from the simulations results obtained at 11°C and presented in Figure 5:

1. With a COD/TKN ratio of 11.5, the increase of the F/M ratio by 400% from 0.045 to 0.180 kg $BOD_5.(kgMLVSS.d)^{-1}$, induces a decrease of $r_{v,\ max\ nit}$ by 30% from 4.8 to 3.3 mg $N_{nit}.(L.h)^{-1}$. This difference results from the increase of the F/M ratio which increases the nitrified nitrogen amount and decreases SRT but not in the same proportion. Indeed, the predicted sludge production increases by 60% from 0.24 to 0.39 kg $MLVSS/kgCOD_{removed}$ (corresponding to 0.6 to 0.9 kg MLVSS/kg BOD_5) when F/M ratio is increased from 0.045 to 0.180 kg $BOD_5.(kgMLVSS.d)^{-1}$. To maintain a high nitrogen removal efficiency despite the decrease of $r_{v,\ max\ nit}$, the duration of oxygen presence should be increased;
2. When COD/TKN = 6 (experimental case), $r_{v,\ max\ nit}$ is around 9 mg $N_{nit}.(L.h)^{-1}$ (=2.8 mg $N_{nit}.(gMLVSS.h)^{-1}$), whereas when COD/TKN = 11.5 (close to common value for daily composite sample (Pons *et al.*, 2004)), $r_{v,\ max\ nit}$ is 4 mg $N_{nit}.(L.h)^{-1}$ (=1.3 mg $N_{nit}.(gMLVSS.h)^{-1}$). These values are in accordance to the range: 1 - 4.4 mg $N_{nit}.(gMLVSS.h)^{-1}$ obtained respectively with COD/TKN of 12 (Palis et Irvine, 1985) and 2 (McCartney et Oleszkiewicz, 1990).

Besides temperature, the COD/TKN ratio in the influent has the major effect on the value of the maximal nitrification rate. The influence of the F/M ratio (and also the effect of sludge retention time) is less significant.

CONCLUSION

The parameters which govern the nitrification capacity of an activated sludge plant have been investigated at 11°C from long-term experiments carried out on a continuous reactor and on batch testings. The main trends have been deepened with dynamic simulations (ASM1), and with a theoretical approach based on mass balances.

The main conclusions drawn are listed below:

- To be sure not to wash-out the nitrifiers, a minimum duration of oxygen presence per day is necessary. Its value depends on the temperature of the mixed liquor, on the sludge retention time, and on the distribution of sludge between the different tanks. It does not depends on the nitrogen volumetric loading rate. At 11°C, 13 to 13.5 hours of oxygen presence are required for a F/M ratio of 0.09 $kgBOD_5.(kgMLVSS.d)^{-1}$. 16 hours/d are necessary if the F/M ratio equals 0.14, but this setting induces a high nitrate concentration in the treated water due to a partial denitrification;
- The maximum nitrification rate is proportional to the nitrogen volumetric loading rate. This parameter is also influenced by the operating conditions such as the sludge retention time, and the distribution of sludge between the different tanks. The expression given can be used to predict the maximum nitrification rate which can be expected according to the operating conditions;
- The effect of the COD/TKN ratio of the influent on the maximum nitrification rate is also pointed out. With a usual influent (COD/TKN=11.5), the $r_{v,\ max\ nit}$ at 11°C is about 4 mg $N_{nit}.(L.h)^{-1}$ whereas for nitrogen enriched influent (COD/TKN=6), $r_{v,\ max\ nit} \approx 9$ mg $N_{nit}.(L.h)^{-1}$. The preventive addition of nitrogen compounds in the influent is a mean to enhance the nitrification capacity of wastewater treatment plants facing seasonal peak loads;
- The increase of the F/M ratio by 400% induces the decrease of the maximum nitrification rate by 30%.

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