

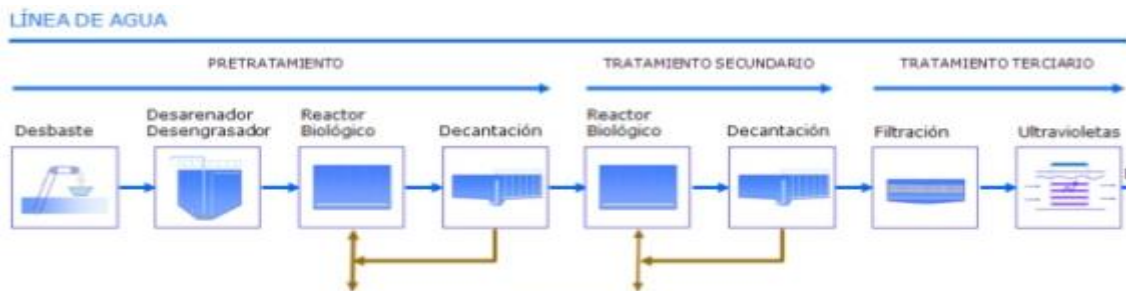
**BM Respirometry study about  
low nitrification in one activated sludge process**

***SURCIS***

## Activated Sludge Process - Technical data

Parameter	Value (average) / Comment	Parameter	Value (average) / Coment
Process type	Activated sludge double stage process	DO (ppm)	2.6
Nitrification / Denitrification	Yes	Total N influent (ppm)	73.4
pH in Ntrificación zone	7.10	P total influent (ppm)	9.1
Temperature average	18 °C	N total effluent (ppm)	26.3
COD influent to biological reactor (mg/l)	500	P total effluent efluent (ppm)	4.2
Amomnium influent / effluent (mg/l)	70/23 (N-NH4+)		
Volume of biological reactor (m <sup>3</sup> )	7920		
Volume for Nitrification (%)	75 (of the total volume of the reactor)		
MLSS / MLVSS (mg/l)	3700/2880		
MLSS / MLVSS (mg/l) in the reference sludge	4300/2750		
HRT (h)	15.4		
SRT (d)	17		
F/M (DBO)	0.16		

**PROBLEM:** Low nitrification performance: too high Ammonium in effluent



## BM Respirometer

The respirometer utilized for the study was a BM-T, provided with external thermostatic unit (bath)

This "batch system" respirometer consists of a single reactor vessel, divided into two interconnected compartments with closed recirculation loop between the two. Both compartments are kept completely mixed by means of paddle stirrers and a peristaltic recirculation. A constant air flow is supplied via a ceramic diffuser in the conditioning compartment, and a combined oxygen/temperature sensor in the reaction compartment controls the DO and monitors temperature. The temperature is controlled by means an external thermostatic unit (bath) connected to the reactor vessel.



The BM-T is noted by three different operation modes (Static, Cyclic and Dynamic).

In this study we are only making use of the dynamic R mode for toxicity, biomass yield, rbCOD fraction and nitrification rate.

The R mode is based on the addition of one or several small sample doses in the activated sludge previously aerated in the reactor vessel.

For R mode the measuring system was previously calibrated to get the corresponding offsets and factors with the purpose to determine the corresponding CO and bCOD results in mg/l units.

Data capture & handling together with respirometer control is performed by the powerful BM software loaded onto a permanently connected PC. The automatically derived parameters generated by that BM-T include:

<b>OUR</b> (mgO <sub>2</sub> /l.h)	Oxygen Uptake Rate.
<b>SOUR</b> (mgO <sub>2</sub> /gVSS.h)	Specific OUR - by introducing the MLVSS concentration -
<b>Rs</b> (mgO <sub>2</sub> /l.h)	Dynamic Respiration Rate.
<b>Rsp</b> (mgO <sub>2</sub> /gVSS.h)	Specific Rs - by introducing the MLVSS concentration -
<b>CO</b> (mg/L)	Consumed Oxygen
<b>bCOD &amp; rbCOD</b> (mg/L)	Biodegradable & Readily biodegradable COD - by introducing Y <sub>H</sub> -

## Study

This study was carried out with the aim to find out what is the actual reason for the low nitrification performance. For that purpose it was conducted on two main ways: possible nitrification toxicity already in the activated sludge and analysis of the nitrification rate and autotrophic biomass concentration.

## General Procedure

The following important parameters and procedures were carried out:

1. Readily biodegradable COD (rbCOD)
2. Analysis of the possible specific toxicity to nitrification by means a reference activated sludge from another plant
3. Autotrophic yield coefficient ( $Y_A$ )
4. Maximum nitrification rate ( $AUR_{max}$ )
5. Actual autotrophic biomass concentration ( $X_A$ )
6. Hydraulic residence time for a complete nitrification ( $HRT_N$ )
7. Estimated maximum nitrification rate ( $AUR_{max,t}$ ) for a complete nitrification
8. Estimated autotrophic biomass concentration (from rbCOD/N ratio) for efficient nitrification
9. Estimated minimum solids retention time ( $SRT_{N,t}$ ) for efficient nitrification
10. Conclusions
11. Probable causes of the problem
12. Proposed plan to solve the problem

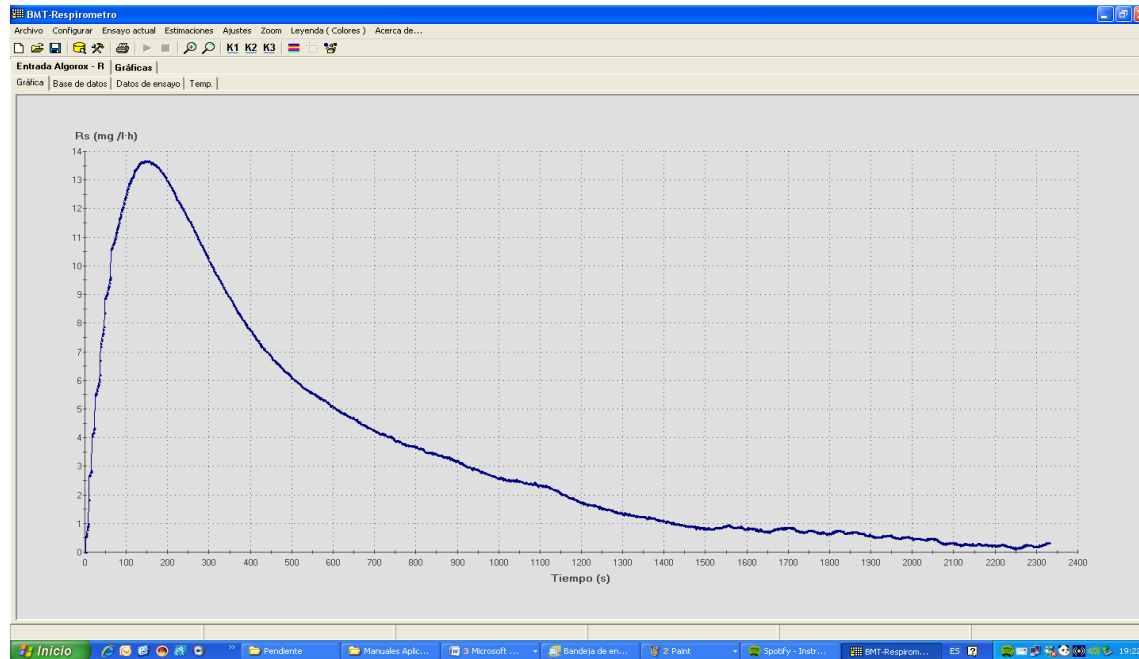
## Summary of results

Parameter	Application	Result	Normal range	Coment
<b>rbCOD</b> (mg/l)	Coherence with total COD rbCOD/N ratio	103 20% of total COD	15 – 30% of total COD	NORMAL
<b>rbCOD / N</b>	Nitrifier biomass assessment	1.4	0.5 - 8	NORMAL for a 2 stages process
<b>Toxicity</b> (%)	Specific inhibition to nitrification activity	0	-	<b>There is not any toxicity</b>
<b>Y<sub>A</sub></b> (1) (OC/N-NH <sub>4</sub> ) (2) (VSS <sub>A</sub> /N-NH <sub>4</sub> )	Autotrophic yield coefficient	(1) 0,2 (2) <b>0,14</b>	0,1 – 0,4	NORMAL
<b>AUR<sub>max</sub></b> [mg N-NH <sub>4</sub> /(l.h)]	Actual maximum nitrification rate	<b>2,46</b>	2 - 8	<b>Too low</b> for the current ammonium concentration in the influent
<b>X<sub>A</sub></b> (mg/l)	Autotrophic biomass concentration	<b>143</b> 5 % VSS	≈ 17 % VSS	<b>Too low</b> According to rbCOD/N ratio
<b>HRT<sub>N,t</sub></b> (h)	Estimated hydraulic residence time for a complete nitrification process	<b>23</b>	-	NORMAL
<b>AUR<sub>max,t</sub></b> [mg N-NH <sub>4</sub> /(l.h)]	Estimated maximum nitrification rate for a complete nitrification process	<b>6.06</b>	2 - 8	NORMAL
<b>X<sub>A,t</sub></b> (mg/l)	Estimated autotrophic biomass concentration for efficient nitrification process	<b>489</b> 17 % VSS	15 - 20 % VSS	NORMAL
<b>SRT<sub>N,t</sub></b> (d)	Estimated sludge age for efficient nitrification process	<b>23</b>	5 - 30	Necessary to increase the biomass and nitrification rate

# 1. Readily biodegradable COD (rbCOD)

We are going to determine the actual rbCOD in order to calculate the ratio actual rbCOD/N ratio to be applied on the biomass concentration assessment.

For that purpose we carried out one dynamic R test by making use soluble wastewater sample (filtered at 0.45 micron)



Ensayo		Estimaciones	
Nombre:	Entrada Algorox	S:	0 mg/l
Operario:		Resultados	
Temp.:	20	R <sub>s</sub> Max:	13,681 mg/l-h
Fecha:	28/05/2009	R <sub>sp</sub> Max:	4,75 mg/g-h
Línea de base:	9,3552	OC:	47,616 mg/l
Sólidos:	2,88 g/l	DQOb:	103,512 mg/l
V <sub>f</sub> :	1000 ml	Duración:	00:38:51
V <sub>m</sub> :	50 ml		
s:	2		
Y:	0,54		

**rbCOD = 103 mg/l**

## Result analysis

The value of 103 mg/l represents about 20% of total COD (500 mg/l), what is a coherent level for the readily biodegradable COD. The corresponding rbCOD/N will be  $103/73 = 1.4$

## 2. Analysis of the possible specific toxicity to nitrification by means a reference activated sludge from another plant

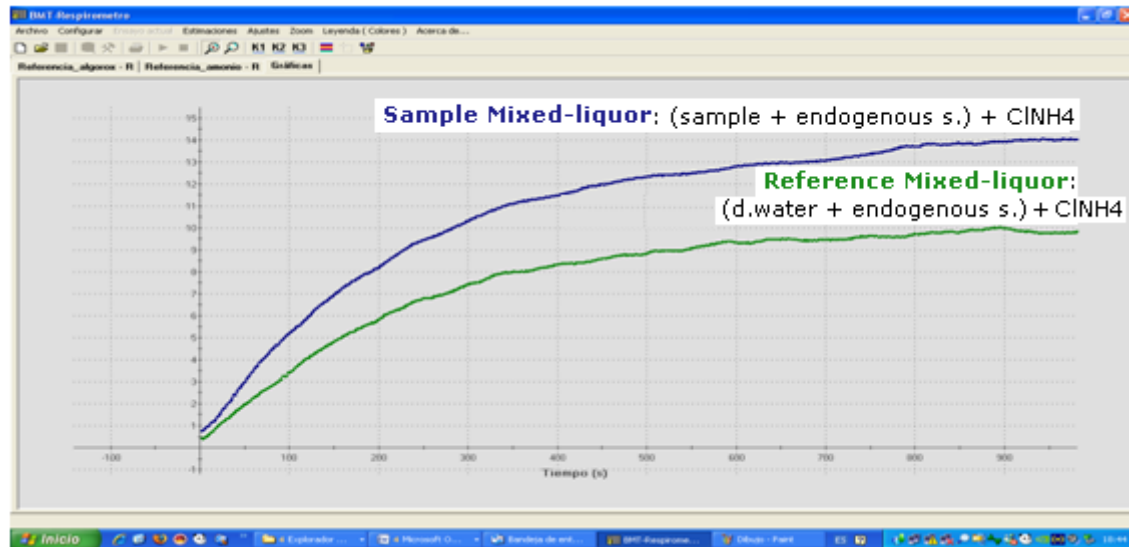
For this analysis we have made up two different mixed-liquors in equivalent proportion to the actual biological process:

Mixed-liquor reference: 800 ml a. sludge + 200 ml distilled water solution with ammonium chloride (in equivalent proportion to the actual ammonium in the influent wastewater)

Mixed-liquor sample: 800 ml sludge + 200 ml wastewater.

The mixed-liquors were leaved under permanent aeration during a sufficient periode ( $> TRH$ ) to reach their endogenous respiration phase.

From those mixed-liquors under endogenous level, we have carried out two R dynamic respirometry tests by adding identical amount of ammonium chloride to one litre of endogenous sludge in each of them.



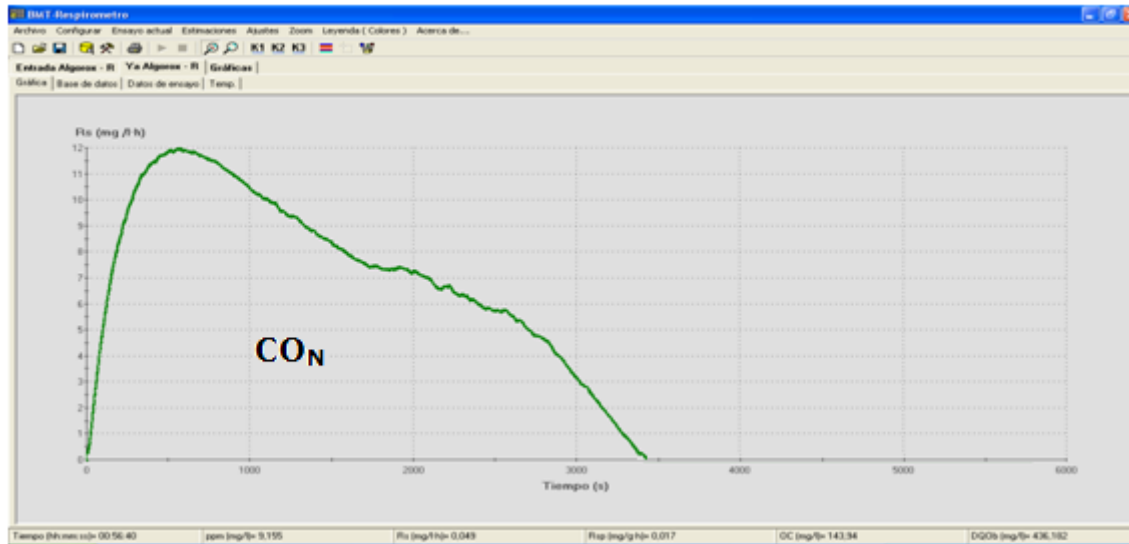
### Result analysis

We can observe that the [Reference Mixed-liquor] is taking a trajectory below the [Sample Mixed-liquor]. That means: There is not any inhibitory effect that the simple of wastewater could provoke in the activated sludge.

We also observe however that the nitrification activity is rather low.

The reason of why the  $R_s$  of Sample liquor goes over Reference liquor is mainly because the effect of difference between the MLVSS concentration ( $VSS_{sample\ mix-liq.} > VSS_{ref. Mix-liq.}$ )

### 3. Autotrophic yield coefficient ( $Y_A$ )



Ensayo		Estimaciones	
Nombre:	Ya Algorox	S:	0 mg/l
Operario:		Resultados	
Temp.:	20	RsMax:	11,995 mg/l/h
Fecha:	28/05/2009	RspMax:	4,165 mg/g-h
Línea de base:	9,1572	OC:	165,94 mg/l
Sólidos:	2,88 g/l	DQOb:	436,183 mg/l
Vf:	1000 ml	Duración:	01:36:29
Vm:	50 ml		
s:	2		

$$Y_{A.COD} = Y_{A1.COD} + Y_{A2.COD}$$

$Y_{A1.COD}$  = Yield coefficient to pass from ammonium into nitrite.

$Y_{A2.COD}$  = Yield coefficient to pass from nitrite into nitrate = 0,08 (assumed, by default)

$$Y_{A1.COD} \text{ (mg O}_2\text{/mg N-NH}_4\text{)} = 3,43 - CO_N / S_{N[CINH_4]} = 3,43 - 166 / 50 = 0,12$$

$$S_{N [CINH_4]} = 50 \text{ mg/L}$$

$$Y_{A.COD} \text{ (mg O}_2\text{/mg N-NH}_4\text{)} = Y_{A1.COD} + Y_{A2.COD} = 0,12 + 0,08 = 0,2$$

$$Y_{A.VSSA} \text{ (mg VSS}_A\text{/mg N-NH}_4\text{)} = 0,2 / 1,42 = \mathbf{0,14}$$

#### Result analysis

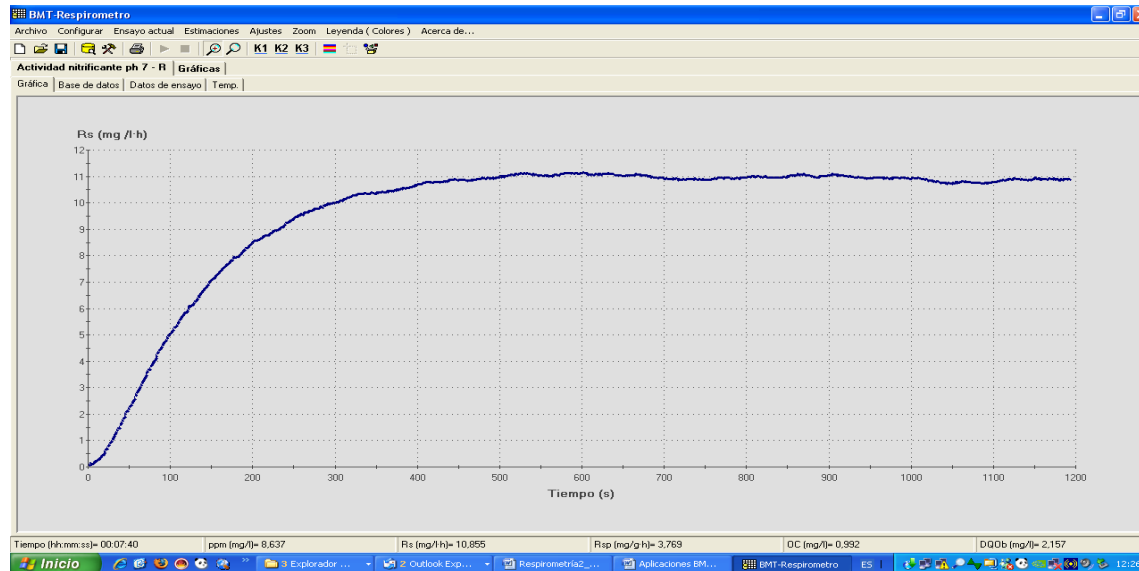
The value of 0.2 and 0.14 are very coherent values for  $Y_A$ .

Among other things, this coherent value might be a confirmation of the current absence of any toxic or inhibitor in the process.



## 4. Maximum nitrification rate ( $AUR_{max}$ )

To get the nitrification rate, we carry out a dynamic R test from endogenous sludge, with equivalent temperature and pH of the process, by adding a dose of ammonium chloride equivalent to the ammonium in the influent to biological reactor until reaching its maximum respiration rate



Ensayo		Estimaciones	
Nombre:	Actividad nitrificante	S:	0 mg/l
Operario:		Resultados	
Temp.:	20	RsMax:	11,17 mg/l.h
Fecha:	28/05/2009	RspMax:	3,878 mg/g.h
Línea de base:	9,174	OC:	3,225 mg/l
Sólidos:	2,88 g/l	DQOb:	7,011 mg/l
Vf:	1000 ml	Duración:	00:19:52
Vm	1 ml		
s:	2		
Y:	0,54		

$$AUR \text{ (mg N-NH}_4\text{/l.h)} = R_{s,max} / 4.57; \quad R_N = 11.17 / 4.57 = 2.44 \text{ [mg N-Nh}_4\text{/(l.h)]}$$

$$AUR_{max} \text{ (mg N-NH}_4\text{ /l.h)} = AUR / [S_N / (K_N + S_N)]$$

$S_N$ : Normal ammonium concentration = 70 (mg N-NH<sub>4</sub>/l)

$K_N$ : Monod constant  $K_N$  at 18°C = 0.75

Note: We do not apply any DO correction factor because of the relatively normal-high DO level in the ASP (>2.5 ppm)

$$AUR_{max} = 2.44 / [70 / (0.75 + 70)] = 2.46$$

$$AUR_{max} = 2.46 \text{ (mg N-NH}_4\text{ /l.h)}$$

Temp	$K_N$ (mg/l as NH <sub>4</sub> <sup>+</sup> -N)
10°C	0.45
15°C	0.59
20°C	0.77
25°C	1.0

## 5. Actual autotrophic biomass concentration ( $X_A$ )

$$X_A = Y_{A,vss} * SRT * S_{Ne} / [(1 + b_A * SRT) * HRT_N]$$

Sources: Marais and Ekama (1976) - Handbook Biological Wastewater Treatment. Adrianus van Haandel (2009)

$$Y_{A,vss} = 0.14$$

SRT (d): Current actual sludge age = 17

$S_{Ne}$  (mg/L): Average concentration of eliminated ammonium-nitrogen in the nitrification process = 70 - 23 = 47

$b_A$  ( $d^{-1}$ ): Autotrophic decay rate = 0,037

Temp	Death & Decay Rate $b_A$ (days <sup>-1</sup> )
10°C	0.02
15°C	0.03
20°C	0.04
25°C	0.05

$$X_A = 0.14 * 17 * 47 / [(1 + 0,037 * 17) * 0,48] = 143 \text{ mg/l}$$

$$X_A = 143 \text{ (mg/l)}$$

### Result analysis

The value of 143 mg/l represents a biomass nitrifying fraction of 5 % ( $F_N = 0.05$ ) of the total volatile biomass. If we compare the  $F_N$  value with a reference table, we will realize that it is too low value for the current rbCOD/N (1.4)

Reference table

Influence of rbCOD/N ratio on Nitrification							
rbCOD/N	0,5	1	2	3	4	6	8
$F_N$	0,35	0,21	0,12	0,083	0,064	0,043	0,033

This low nitrifier biomass is the reason of the low nitrification rate and also the cause to get not enough hydraulic residence time to remove the ammonium of the influent.

## 6. Hydraulic residence time for nitrification ( $HRT_N$ ) for a complete nitrification

$$HRT_N (h) = S_N / AUR_{max}$$

$$HRT_N (h) = 70 / 2.46 = 28.45$$

$$HRT_N = 28.45 (h)$$

### Result analysis

The value of 28.45 h is much higher than the current available time for nitrification (75% of  $HRT_{N,act} = 0.75 * 15.4 = 11.55$  h)  
That means; with the current nitrification rate there is not time enough to remove the ammonium of the influent to the biological reactor.

## 7. Estimated nitrification rate ( $AUR_{max,t}$ ) for a complete nitrification

Here we calculate the theoretical necessary maximum nitrification rate to remove the actual ammonium of the influent to biological reactor.

$$AUR_{max,t} = S_N / HRT_{N,act}$$

$HRT_{N,act}$  (h): available hydraulic residence time for nitrification = 11.55 h

$$AUR_{max,t} [mg N-NH_4/(l.h)] = 70 / 11.55 = 6.06$$

$$AUR_{max,t} = 6.06 [mg N-NH_4/(l.h)]$$

## 8. Estimated autotrophic biomass concentration from rbCOD/N ratio for efficient nitrification

Reference table

Influence of rbCOD/N ratio on Nitrification							
rbCOD/N	0,5	1	2	3	4	6	8
$F_N$	0,35	0,21	0,12	0,083	0,064	0,043	0,033

rbCOD/N ratio = 1.4

$$F_N = 0.17$$

$$X_{A,t} (\text{mg/l}) = 0.17 * X_V = 0.17 * 2880 = 489$$

$X_V$  (mg/l): actual MLVSS

$$X_{A,t} = 489 \text{ (mg/l)}$$

### Result analysis

The current autotrophic biomass needs be increased in more than 3 times.

$$X_{A,t} / X_A = 489 / 143 = 3,42$$

## 9. Theoretical minimum solids retention time ( $SRT_{N,t}$ ) for efficient nitrification

$$SRT_N (\text{d}) = 1 / [24 * AUR_{\max} / (X_A / Y_{A,vss})]$$

Source: Based on Handbook Wastewater Treatment - Adrianus van Haandel and Jeroen van der Lubbe. 2007

$$SRT_N (\text{d}) = 1 / [24 * 6.06 / (489 / 0.14)] = 23$$

$$SRT_{N,t} = 23 \text{ (d)}$$

## 10. Conclusions

1. Currently there is not any toxicity symptom.
2. The nitrification rate is too low because of too low current autotrophic biomass concentration.
3. Actual autotrophic biomass needs to be increased in more that 3 times.

## 11. Probable causes of the problem

1. In the near past occurred an episode of toxicity that had eliminated part of the autotrophic biomass, and now the biomass is not yet recovered.
2. From time to time, there is hidden toxic spill in the influent that systematically is killing part of the autotrophic biomass.

## 12. Proposed plan to solve the problem

1. To raise the sludge age to the theoretical sludge retention time (23 days) or more.
2. To install in-situ a lab. BM respirometer in order to follow up the nitrification activity (respiration rate) and autotrophic biomass concentration.
3. During follow-up period, according to the current respirometry results, adapt the operative parameters (SRT & F/M) to the actual nitrification condition.
4. If along the time, activity and autotrophic biomass concentration are not improving, try to seed the process by activated sludge from another healthy plant with good nitrification performance.
5. If after all, the nitrification process is still going down, we can think about a specific online instrument to detect a possible toxicity that periodically is damaging the nitrifier biomass (consult SURCIS)

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