UNIVERSITAT DE BARCELONA
FACULTAT DE QUÍMICA
DEPARTAMENT D'ENGINYERIA QUÍMICA

OPTIMISATION OF BIOLOGICAL NITROGEN REMOVAL PROCESSES TO TREAT REJECT WATER FROM ANAEROBIC DIGESTION OF SEWAGE SLUDGE

Doctoral Thesis directed by Joan Mata Álvarez

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ANNEXES

Annexe I.1: Wastewater respirogram performance

Time (h)	**OUR** (mg O_2 (L min)$^{-1}$)	**pH** (-)	**R^2 of OUR** (-)	**Initial DO** (mg O_2 L^{-1})
0.01	0.16	7.99	0.965	5.13
0.18	0.18	8.09	0.980	5.19
0.35	0.19	8.11	0.977	5.16
0.51	0.17	8.11	0.973	5.16
0.68	0.19	8.13	0.970	5.16
0.85	0.18	8.11	0.976	5.12
0.93	0.18	8.11	0.976	5.16
1.01	0.18	8.11	0.980	5.15
1.10	0.18	8.10	0.981	5.12
1.18	0.18	8.11	0.982	5.12
1.26	0.18	8.12	0.972	5.18
1.35	0.17	8.08	0.971	5.12
1.43	1.42	8.09	0.993	5.15
1.51	0.96	8.07	0.997	5.02
1.68	0.89	8.07	0.997	4.95
1.85	0.92	8.06	0.997	4.92
2.01	0.94	8.03	0.997	4.85
2.26	0.94	7.93	0.997	4.79
2.43	0.96	7.90	0.994	4.95
2.68	0.96	7.78	0.996	4.94
2.85	0.95	7.96	0.995	4.85
3.02	0.95	7.94	0.993	4.81
3.18	0.95	7.96	0.995	4.71
3.35	0.90	7.91	0.990	5.09
3.43	0.90	7.99	0.991	4.72
3.77	0.84	7.94	0.992	5.09
4.10	0.77	7.95	0.991	4.85
4.27	0.73	8.01	0.991	4.86
-	-	-	-	-
20.07	0.19	8.04	0.966	5.43

Annexe I.2: Wastewater respirogram performance with ATU

Time (h)	**OUR** (mg O_2 (L min)$^{-1}$)	**pH** (-)	**R^2 of OUR** (-)	**Initial DO** (mg O_2 L^{-1})
0.0	0.08	7.92	0.757	5.49
0.2	0.09	7.92	0.522	5.46
0.4	0.08	7.92	0.274	5.47
0.6	0.08	7.93	0.266	5.62
0.8	0.08	7.92	0.774	5.43
1.0	0.09	7.92	0.827	5.43
1.2	0.07	7.93	0.682	5.43
1.4	0.08	7.91	0.754	5.36
1.6	0.07	7.97	0.738	5.43
1.8	0.83	8.02	0.995	5.45
2.0	0.24	8.11	0.962	5.45
2.2	0.18	8.10	0.949	5.46
2.4	0.16	8.09	0.946	5.47
2.6	0.16	8.10	0.936	5.53
2.8	0.15	8.09	0.927	5.50
3.0	0.14	8.10	0.914	5.49
3.2	0.13	8.10	0.914	5.53
3.4	0.13	8.09	0.907	5.49
3.6	0.13	8.09	0.898	5.49
3.8	0.13	8.08	0.901	5.43
4.0	0.12	8.09	0.893	5.43
4.2	0.12	8.08	0.887	5.47
4.4	0.12	8.08	0.895	5.46
4.6	0.11	8.08	0.877	5.46
4.8	0.11	8.08	0.871	5.49
5.2	0.11	8.07	0.836	5.49
5.4	0.10	8.06	0.750	5.47
-	-	-	-	-
20.0	0.08	7.84	1.223	5.36

Annexe I.3: Activity of autotrophic biomass with pH

pH (-)	**AUR** (mg NH_4^+-N (L h)$^{-1}$)	**VSS** (mg VSS L^{-1})	**sAUR** (mg NH_4^+-N (g VSS h)$^{-1}$)
6	3.5	4460 ± 50	0.78
6.5	4.5	4460 ± 50	1.01
7	5.4	4470 ± 50	1.21
7.5	6.2	4470 ± 50	1.39
8	6.5	4260 ± 50	1.53
8.5	6.2	4260 ± 50	1.46
9	5.7	5400 ± 50	1.05
9.5	4.3	5400 ± 50	0.79

Annexe I.4: Nitrification acclimation

Day	**AUR** (mg NH_4^+-N (L h)$^{-1}$)	**VSS** (mg VSS L^{-1})	**sAUR** (mg NH_4^+-N (g VSS h)$^{-1}$)	**V30** (mL)
1	1.1	970 ± 50	1.1	450
2	1.2	950 ± 50	1.3	400
3	1.5	810 ± 50	1.9	400
6	3.0	590 ± 20	5.1	200
7	3.0	420 ± 20	7.2	190
8	3.4	380 ± 20	9.0	150
9	4.1	360 ± 20	11.3	90
11	5.0	360 ± 20	13.9	-
12	6.0	360 ± 20	16.7	50
13	7.0	360 ± 20	19.4	-
14	10.1	360 ± 20	27.9	20
15	10.4	350 ± 20	29.6	20
16	10.6	330 ± 20	32.0	35
17	10.9	300 ± 20	36.4	30
20	11.3	300 ± 20	37.5	20
21	11.0	320 ± 20	34.3	20
22	11.0	290 ± 20	37.9	20
23	9.8	290 ± 20	33.7	20
24	10.0	300 ± 20	33.2	20
27	10.4	320 ± 20	32.5	20
28	10.4	320 ± 20	32.6	20

Annexe I.5: Denitrification acclimation

Nitrites

Day	**NUR** (mg NO_2^--N (L h)$^{-1}$)	**VSS** (mg VSS L^{-1})	**sNUR** (mg NO_2^--N (g VSS h)$^{-1}$)	**V30** (mL)
1	3.3	1530 ± 50	2.1	575
2	7.7	1440 ± 50	5.3	500
3	8.2	1130 ± 50	7.3	400
4	11.0	1080 ± 50	10.2	325
5	15.7	1050 ± 50	14.9	325
8	18.1	990 ± 50	18.3	
10	18.5	970 ± 50	19.1	325
11	19.0	910 ± 50	20.9	325
12	18.5	940 ± 50	19.7	325

Nitrates

Day	**NUR** (mg NO_3^--N (L h)$^{-1}$)	**VSS** (mg VSS L^{-1})	**sNUR** (mg NO_3^--N (g VSS h)$^{-1}$)	**V30** (mL)
1	6.0	1750 ± 50	3.4	800
2	7.5	1500 ± 50	5.0	800
3	7.8	1300 ± 50	6.0	767
4	9.1	1280 ± 50	7.1	600
5	11.1	1290 ± 50	8.6	533
8	16.0	1310 ± 50	12.2	567
10	16.5	1300 ± 50	12.7	533
11	16.5	1250 ± 50	13.2	567
12	16.6	1250 ± 50	13.3	525
13	16.2	1200 ± 50	13.5	525

Annexe II.1: Relative activity with pH (Dosta et al., 2005)

Heterotrophic biomass (T = 32 ºC)

pH (-)	**OUR_{EX}** (mg O_2 (L min)$^{-1}$)	**Relative activity** (-)
8.25	0.35	0.98
9.00	0.35	0.99
8.50	0.32	0.90
9.50	0.35	1.00
10.00	0.34	0.97
10.50	0.30	0.86
11.00	0.26	0.75
12.00	0.01	0.01
8.00	**0.35**	1.00
5.50	0.02	0.04
6.00	0.06	0.18
6.50	0.15	0.43
7.00	0.26	0.72
11.50	0.06	0.17

Autotrophic biomass (T = 32 ºC)

pH (-)	**OUR_{EX}** (mg O_2 (L min)$^{-1}$)	**Relative activity** (-)
4.5	0.01	0.01
6.07	0.05	0.11
6.65	0.19	0.44
7.03	0.26	0.60
6.91	0.26	0.59
7.5	0.37	0.84
7.75	0.43	0.99
8	**0.44**	1.00
8.25	0.35	0.79
8.5	0.33	0.75
8.75	0.28	0.64
9	0.29	0.66
9.98	0.09	0.21
9.36	0.19	0.42
11.05	0.02	0.05
12.25	0.00	0.00

Annexe II.2: Relative activity with temperature (Dosta et al., 2005)

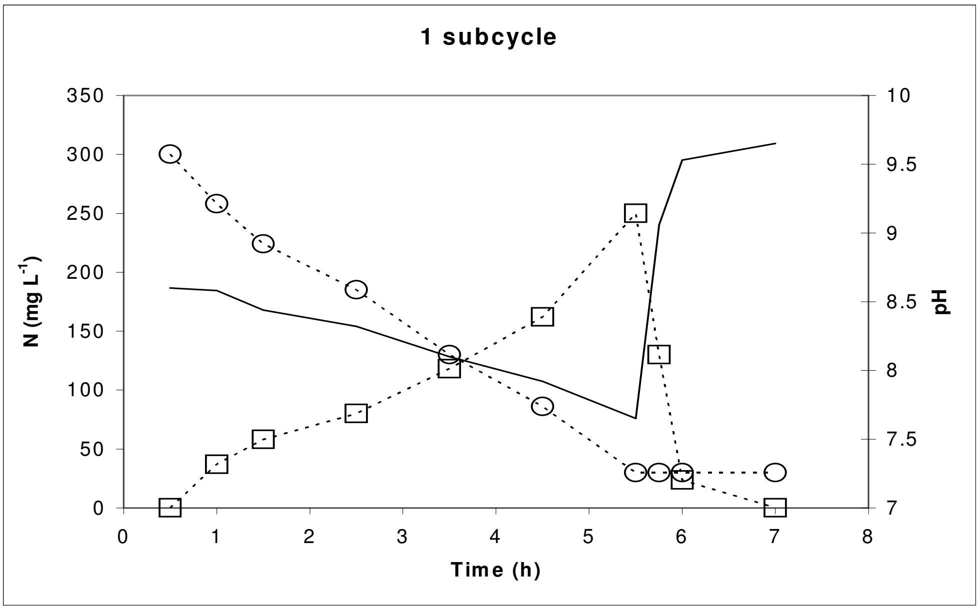
Heterotrophic biomass (pH = 8)

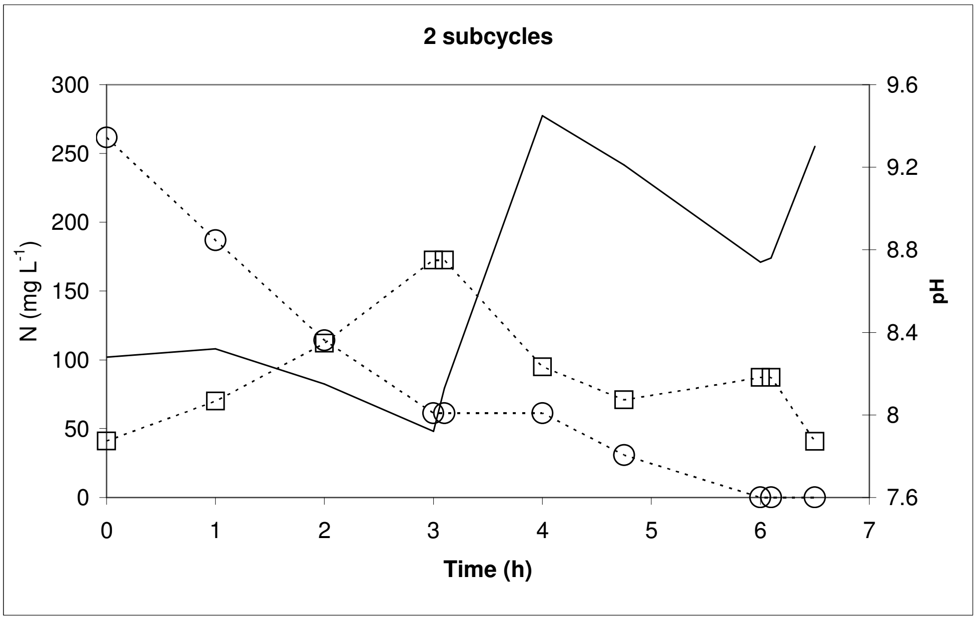
T (ºC)	**OUR_{EX}** (mg O_2 (L min)$^{-1}$)	**Relative activity** (-)
29.5	0.59	0.63
44.0	**0.93**	1.00
40.0	0.77	0.83
35.0	0.70	0.75
50.0	0.29	0.32
30.0	0.59	0.64
18.0	0.26	0.28
10.0	0.13	0.14
20.0	0.31	0.33
22.0	0.35	0.38
53.0	0.16	0.17
25.0	0.53	0.57

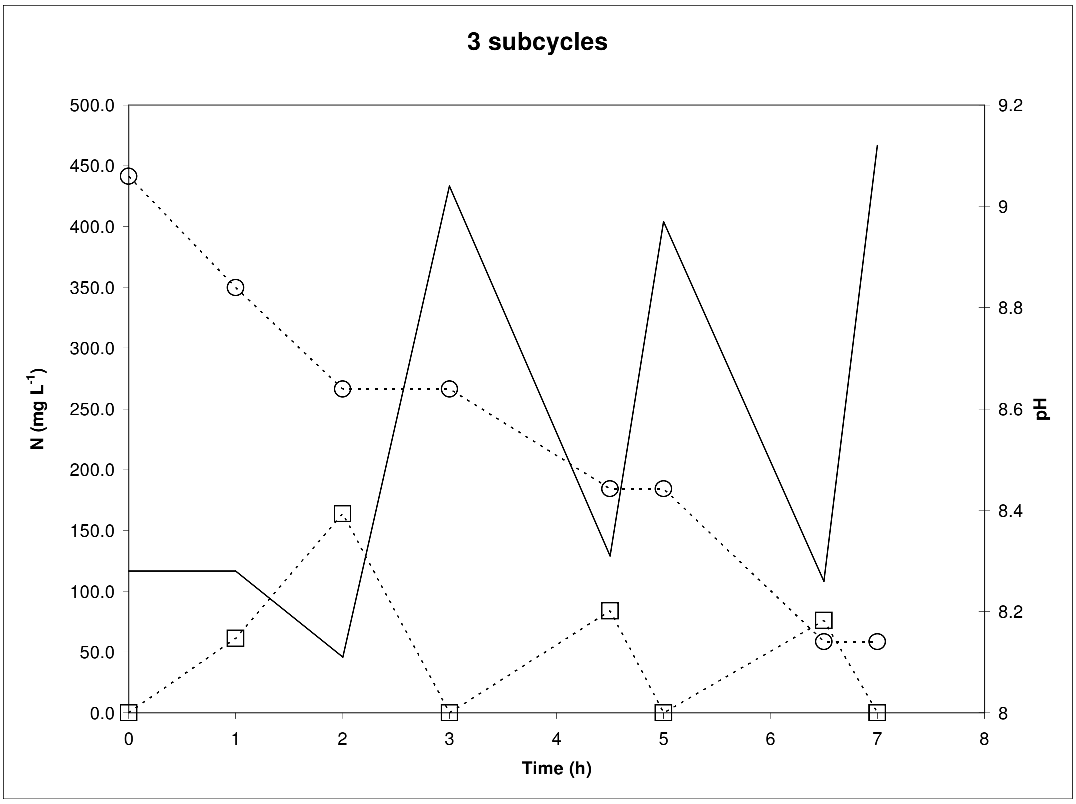
Autotrophic biomass (pH = 8)

T (ºC)	**OUR_{EX}** (mg O_2 (L min)$^{-1}$)	**Relative activity** (-)
10	0.08	0.05
15	0.16	0.08
21	0.46	0.25
26	0.84	0.46
30	1.27	0.69
33	1.45	0.79
35	1.58	0.86
37	1.60	0.86
41	**1.85**	1.00
42	1.84	0.99
45	0.59	0.32
50	0.01	0.01

Annexe II.3: Experiments with **1** (3500 mg VSS L^{-1}), **2** (3300 mg VSS L^{-1}) and **3** (4000 mg VSS L^{-1}) subcycles strategy (--○-- NH_4^+-N, --□-- NO_2^--N, ─ pH)






3 subcycles
N (mg L-1)
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
pH
9.2
9
8.8
8.6
8.4
8.2
8
Time (h)
0
1
2
3
4
5
6
7
8

Annexe III.1: Primary hidrolysate respirogram performance

Time (h)	**OUR** (mg O_2 (L min)$^{-1}$)	**pH** (-)	**R^2 of OUR** (-)	**Initial DO** (mg O_2 L^{-1})
0.0	0.09	8.23	0.973	8.53
0.2	0.09	8.15	0.964	7.70
0.4	0.07	8.11	0.965	7.34
0.6	0.08	8.08	0.980	7.22
0.8	0.08	8.07	0.980	7.16
1.0	0.08	8.07	0.984	7.13
1.2	0.08	8.04	0.982	7.12
1.4	0.08	8.05	0.982	7.11
1.6	0.81	8.14	0.998	6.43
1.8	0.56	8.09	0.998	6.24
2.0	0.55	8.09	0.999	6.48
2.2	0.55	8.05	0.999	6.51
2.4	0.56	8.08	0.999	6.51
2.6	0.56	8.09	0.999	6.51
2.8	0.57	8.02	0.999	6.53
3.0	0.59	8.03	0.999	6.51
3.2	0.60	8.06	0.999	6.51
3.4	0.61	7.94	0.999	6.50
3.6	0.63	8.07	0.999	6.48
3.8	0.64	8.06	0.999	6.48
4.0	0.65	8.08	0.999	6.46
4.2	0.65	7.92	0.999	6.44
4.4	0.65	8.09	0.999	6.44
4.6	0.64	8.07	0.999	6.47
4.8	0.62	8.05	0.999	6.50
5.0	0.59	8.03	0.999	6.55
-	-	-	-	-
10	0.24	7.99	0.997	6.98
20	0.16	8.08	0.994	7.11
30	0.14	8.03	0.994	7.07

Annexe IV.1: Kinetic and stoichiometric parameters calculations (For more detail the SBR constants can be found in Dosta et al., 2006a)

SBR

1. μ_{mH}

	S_S	S_O	S_{NH}	X_{BH}	
Aerobic growth	$-\left(\frac{1}{Y_H}\right)$	$-\left(\frac{1-Y_H}{Y_H}\right)$	$-i_{XB}$	1	$\mu_{mH}\frac{S_S}{K_S+S_S}\frac{S_O}{K_{OH}+S_O}$
Decay rate		1		-1	$b_H\ X_{BH}$

$$OUR=-\frac{d\,S_O}{d\,t}=\frac{1-Y_H}{Y_H}\mu_{mH}\frac{S_S}{K_S+S_S}\frac{S_O}{K_{OH}+S_O}X_{BH}+b_H X_{BH} \qquad \text{(IV.1)}$$

$$If\ S_S>>K_S\rightarrow\frac{S_S}{K_S+S_S}=1 \qquad \text{(IV.2)}$$

$$If\ S_O>>K_{OH}\rightarrow\frac{S_O}{K_{OH}+S_O}=1 \qquad \text{(IV.3)}$$

$$OUR=\frac{1-Y_H}{Y_H}\mu_{mH}\ X_{BH}+b_H X_{BH} \qquad \text{(IV.4)}$$

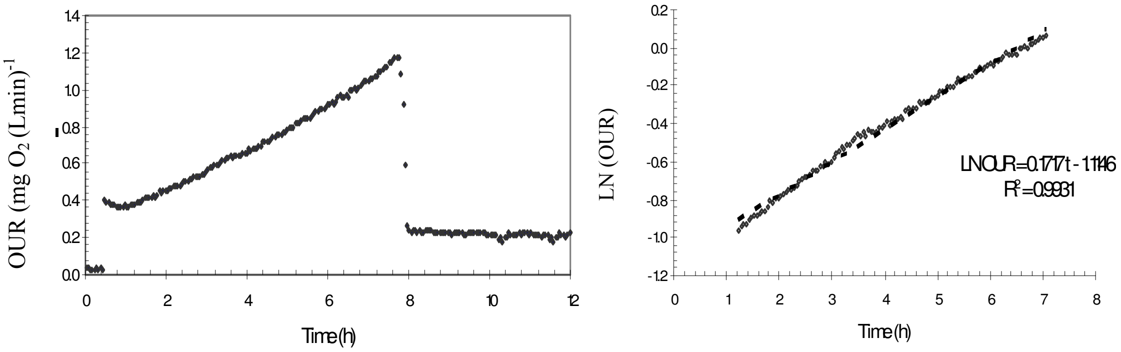
$$\frac{d\,X_{BH}}{d\,t}=\mu_{mH}\frac{S_S}{K_S+S_S}\frac{S_O}{K_{OH}+S_O}X_{BH}-b_H X_{BH} \qquad \text{(IV.5)}$$

$$\frac{d\,X_{BH}}{d\,t}=\left(\mu_{mH}-b_H\right)X_{BH} \qquad \text{(IV.6)}$$

$$X_{BH}=X_{BH,INITIAL}\ e^{\left(\mu_{mH}-b_H\right)t} \qquad \text{(IV.7)}$$

$$OUR=\frac{1-Y_H}{Y_H}\left(\mu_{mH}+b_H\right)X_{BH,INITIAL}\ e^{\left(\mu_{mH}-b_H\right)t} \qquad \text{(IV.8)}$$

$$Ln\ OUR = Ln\left(\frac{1-Y_H}{Y_H} \left(\mu_{mH} + b_H \right) X_{BH,INITIAL} \right) + \left(\mu_{mH} - b_H \right) t \qquad \text{(IV.9)}$$



(a) Respirogram (b) $\mu_{m,H}$ Calculation

Figure IV.1– Experimental μ_{mH} determination (Kappeler and Gujer, 1992); Respirogram (a) OUR vs. time (b) LN(OUR); Adjust (---)

2. $\mu_{m,AOB}$

	S_O	S_{NH}	S_{NO_2}	X_{BH}	$X_{BA,I}$	
AOB aerobic growth	$-\left(\frac{3.43-Y_{AOB}}{Y_{AOB}}\right)$	$-\left(\frac{1}{Y_{AOB}}\right)$	$\left(\frac{1}{Y_{AOB}}\right)$		1	$\mu_{mAOB}\frac{S_{NH}}{K_{NH}+S_{NH}}\frac{S_O}{K_{OA}+S_O}X_{BA}$
AOB decay rate	1			-1		$b_A\ X_{BA}$

$$OUR = -\frac{d\,S_O}{d\,t} = \frac{3.43 - Y_{AOB}}{Y_{AOB}} \mu_{mAOB} \frac{S_{NH}}{K_{NH} + S_{NH}} \frac{S_O}{K_{OA} + S_O} X_{BA} + b_A X_{BA} \qquad \text{(IV.10)}$$

$$If\ S_{NH} >> K_{NH} \rightarrow \frac{S_{NH}}{K_{NH} + S_{NH}} = 1 \qquad \text{(IV.11)}$$

$$If\ S_O >> K_{OA} \rightarrow \frac{S_O}{K_{OA}+S_O}=1 \qquad (IV.12)$$

$$OUR=\frac{3.43-Y_{AOB}}{Y_{AOB}}\mu_{mAOB}\,X_{BA}+b_A X_{BA} \qquad (IV.13)$$

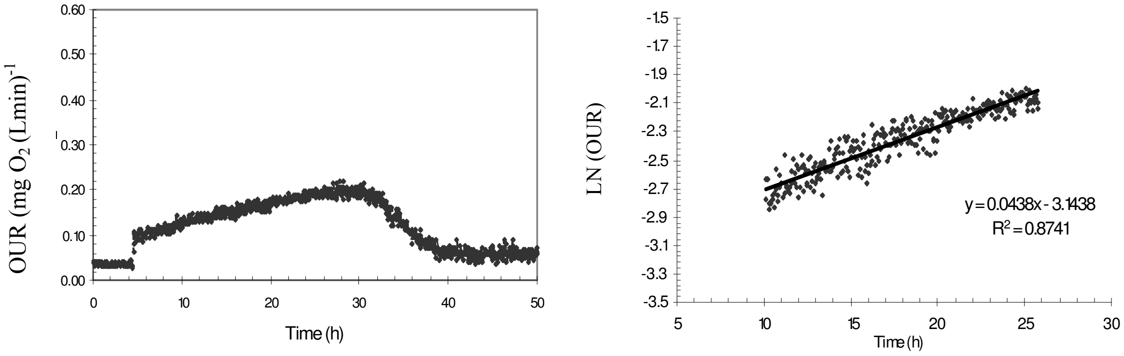
$$\frac{d\,X_{BA}}{d\,t}=\mu_{mAOB}\frac{S_{NH}}{K_{NH}+S_{NH}}\frac{S_O}{K_{OA}+S_O}X_{BA}-b_A X_{BA} \qquad (IV.14)$$

$$\frac{d\,X_{BA}}{d\,t}=\left(\mu_{mAOB}-b_A\right)X_{BA} \qquad (IV.15)$$

$$X_{BA}=X_{BA,INITIAL}\;e^{\left(\mu_{mAOB}-b_A\right)t} \qquad (IV.16)$$

$$OUR=\frac{3.43-Y_{AOB}}{Y_{AOB}}\left(\mu_{mAOB}+b_A\right)X_{BA,INITIAL}\;e^{\left(\mu_{mAOB}-b_A\right)t} \qquad (IV.17)$$

$$Ln\,OUR=Ln\left(\frac{3.43-Y_{AOB}}{Y_{AOB}}\left(\mu_{mAOB}+b_A\right)X_{BA,INITIAL}\right)+\left(\mu_{mAOB}-b_A\right)t \qquad (IV.18)$$

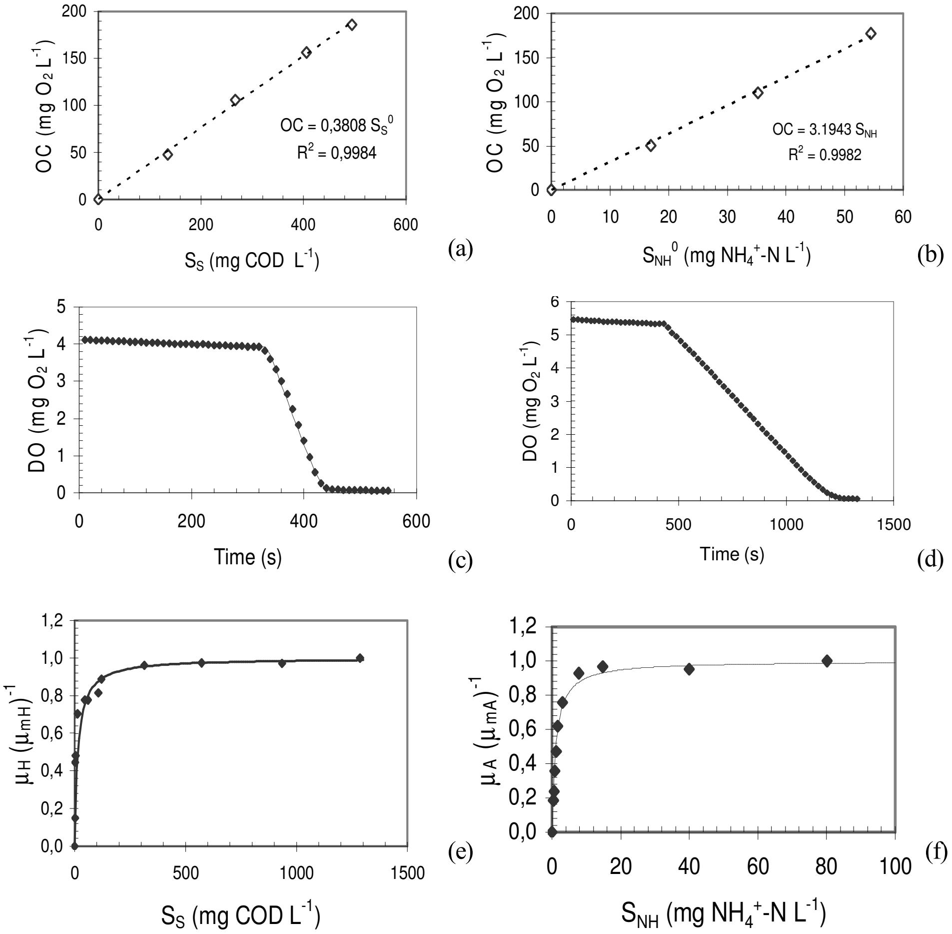


(a) Respirogram

(b) μ_{mAOB} calculation

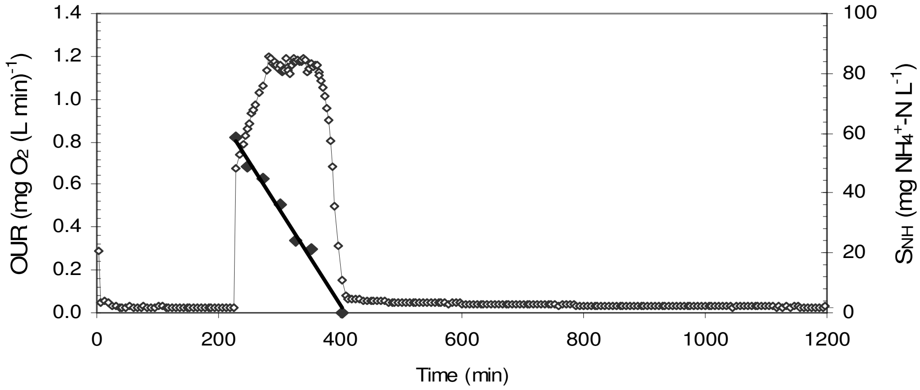
Figure IV.2– Experimental μ_{mAOB} determination (Kappeler and Gujer, 1992) Respirogram (a) OUR vs. time (b) LN(OUR); Adjust (—)

3. Y_H (a), $Y_{A,I}$ (b), K_{OH} (c), K_{OA} (d), K_S (e) and K_{NH} (f)

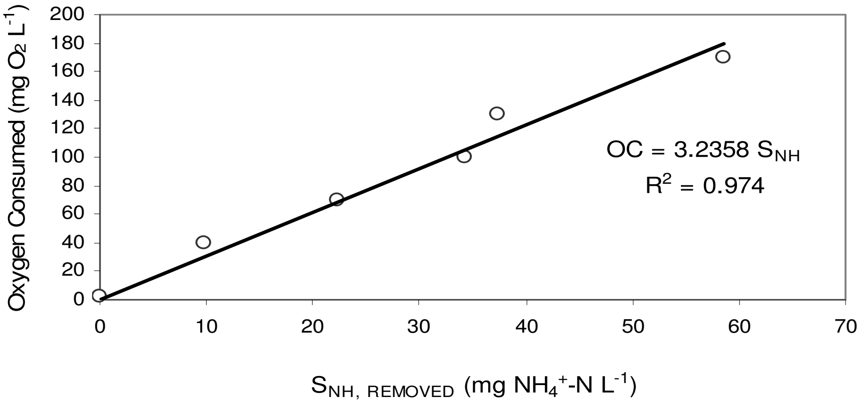


SHARON/DN

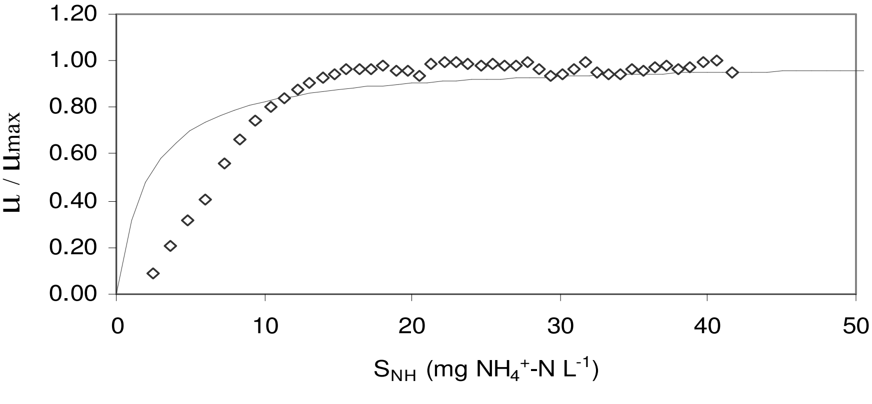
1. Y_{AOB} (a,b) and K_{NH} (c): ($Y_{AOB} = 3.43 - 3.2358 = 0.20$; $K_{NH} = 2.15$ mg NH_4^+-N L^{-1})



(a)

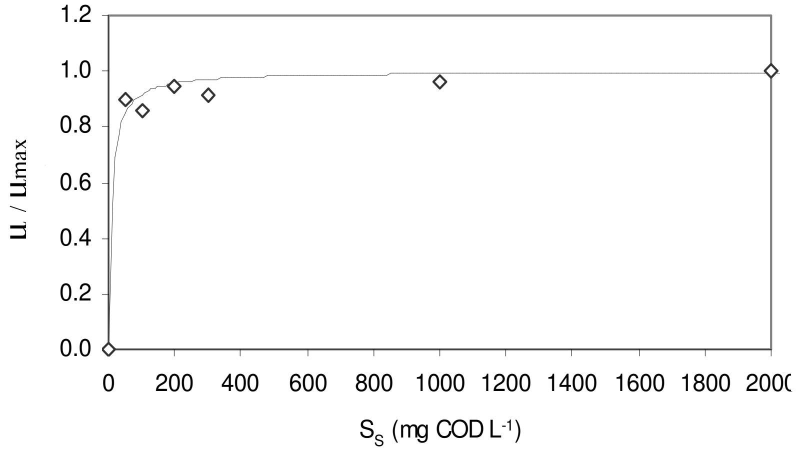


(b)

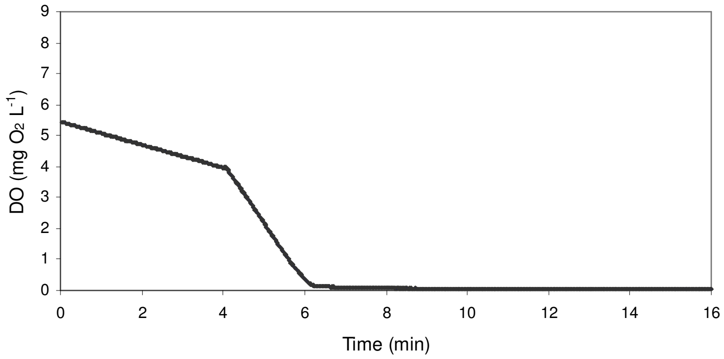


(c)

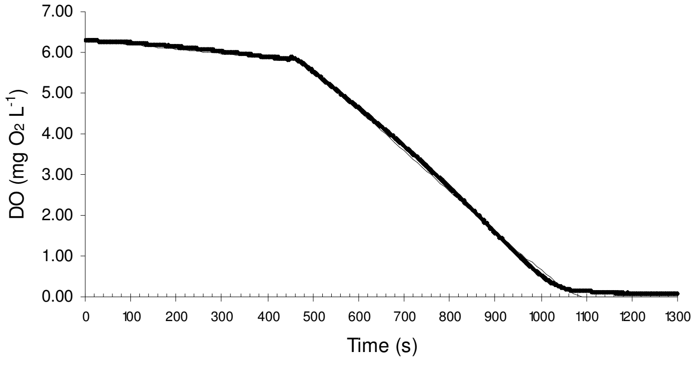
2. K_S (a), $K_{O,A}$ (b) , K_{OH} (c): *(K_S=9.01 mg COD L^{-1}; $K_{O,A}$ =0.46 mg O_2 L^{-1}; K_{OH} =0.14 mg O_2 L^{-1})*



(a)

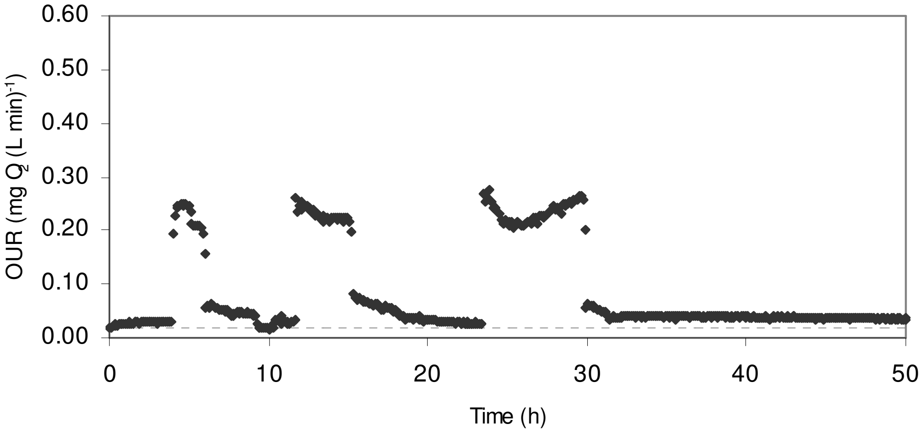


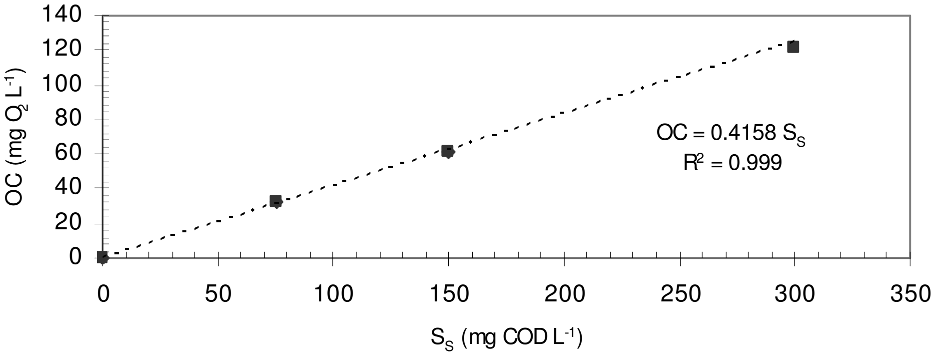
(b)



(c)

3. Y_H


0.60
0.50
0.40
0.30
0.20
0.10
0.00
OUR (mg O2 (L min)-1)
0
10
20
30
40
50
Time (h)


140
120
100
80
60
40
20
0
OC (mg O2 L-1)
OC = 0.4158 SS
R2 = 0.999
0
50
100
150
200
250
300
350
SS (mg COD L-1)

CORRECTION FACTOR AND DECAY RATE FOR BOTH REACTORS

1. Denitrification corrector factor

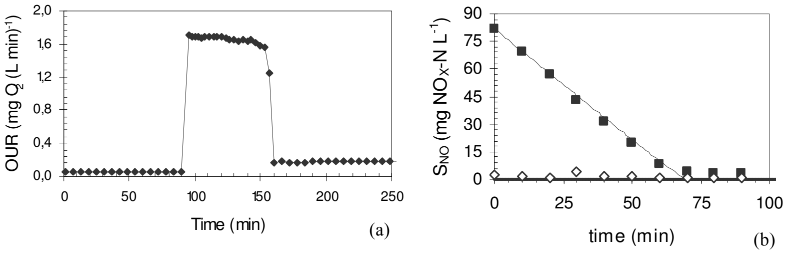
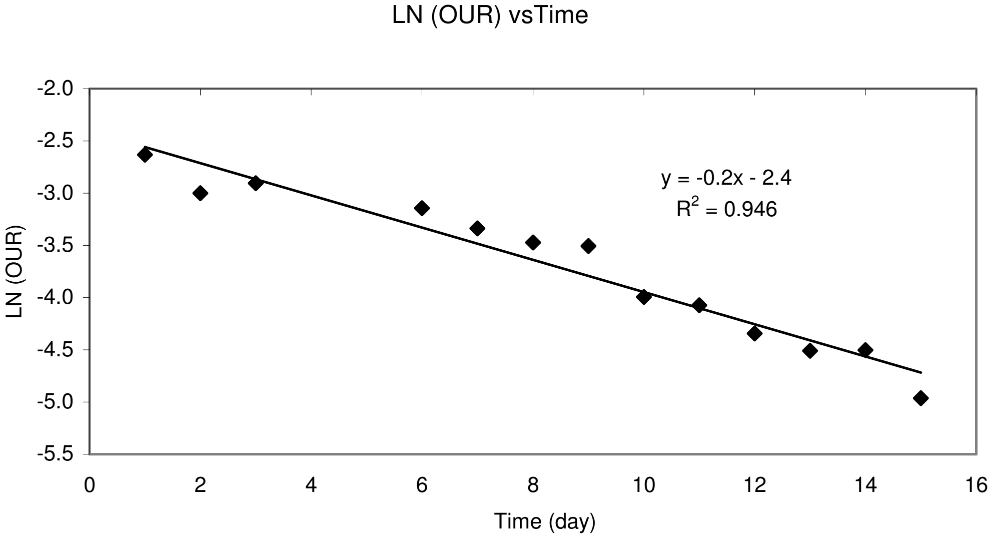


Figure IV.3: Experimental determination of anoxic correction factors for heterotrophic growth. Respirogram in (a) aerobic reactor and (b) N-NO$_X$ profiles inside anoxic reactors using nitrite (b) as final electron acceptor; OUR (●), NO_2^--N (■), NO_3^--N (○)

2. Lineal decay rate (kd)



Annexe IV.2: Oxygen mass balance performance

a) Calculate the oxygen transfer rate: **OTR (kg O_2 m^3 s^{-1})**

b) **$OTR = 0.0055\ V_{GS}{}^{C} \cdot (P_t\ 10^{-5} + 0.05H - 109C_{O2})\ (1+0.020H)^{-1}$** (IV. 19)

This equation comes from applying the mass balances between the liquid and the gas phase and using the gas phase side. With this equation and knowing the total pressure (P_t = 1 atm), the reactor height (H in Table 5) and the oxygen concentration (C_{O2}) inside the reactor (Table 7.2) it is possible to calculate gas superficial speed ($V_{GS}{}^{C}$).

c) **$V_{GS}{}^{C} = V_{GS}{}^{o}\ P^{o}\ (LN\ P_b/P_t) \cdot (P_b - P_t)^{-1}$** (IV. 20)

With equation IV.20 it is possible to calculate the gas superficial standard speed ($V_{GS}{}^{o}$) by knowing equation (IV.19), the standard pressure (P^o = 1 atm), the total pressure (P_t = 1 atm) and the pressure at the bottom of the reactor (P_b) that depends on the reactor height.

d) Calculate the air flow-rate (Q in m^3 h^{-1}) with the ($V_{GS}{}^{o}$) and the reactor area.

e) **O2-uptake (mol h^{-1}) = Volume · ORT · M^{-1}** (M = molecular weight) (IV. 21a)
O2-input (mol h^{-1}) = Q· 0.0224^{-1} · % O_2 in air (IV. 21b)

Equation (IV.21a) gives us the real oxygen consumption and equation (IV.21b) the quantity of oxygen that is present in the reactor.

f) **P/V = density · gravity · $V_{GS}{}^{C}$** (IV. 22)

g) **OTR / (P/V)** in kg O_2 $(kw\ h)^{-1}$ (IV. 23)

This last equation is used to calculate the cost of the oxygen by knowing the cost of the kw·h that is the unit of electricity consumption.
In the following table there are shown the air cost calculations for the SBR and the chemostat reactor:

	SBR	**SHARON/DN**
Conversion (%)	***1***	***1***
Water flow (m^3 day^{-1})	***300***	***300***
Water flow (m^3 h-1)	12.5	12.5
kgN day^{-1}	240	240
C_{O2} (kg m^{-3})	***0.001***	***0.003***
H (m)	***5***	***6***
D(m)	***9***	***12***
Area (m^2)	63.6	113.1
Volume (m^3)	318.1	678.6
Concentration of N (kg N m^{-3})	***0.8***	***0.8***
Stoichiometry (g O_2 g^{-1} N)	***3.23***	***3.23***
Reaction time (h)	***16.5***	***12***
P_b (atm)	1.5	1.6
P_t (atm)	***1***	***1***
P_o (atm)	***1***	***1***
MW O_2 (kg mol^{-1})	***0.032***	***0.032***
% O_2 in air (mol)	***0.2095***	***0.2095***
1mol= 22.4 L (m^3)	***0.0224***	***0.0224***
density liquid (kg m^{-3})	***1000***	***1000***
Gravity (m s^{-2})	***9.8***	***9.8***
OTR (kg O_2 m^{-3}d^{-1})	2.4371	1.1424
V_{gs} C (m s^{-1})	0.0049	0.0028
V_{gs} o (m s^{-1})	0.0061	0.0035
Q (m^{-3} day^{-1})	33512	34519
O_2- uptake (mol h^{-1})	1.0336	1.0336
O_2-input (mol h^{-1})	13060	13452
% consumption	0.0079	0.0077
P/V (kw m^{-3})	0.0485	0.0271
KgO_2/Kwh	2.0957	1.7552
Efficiency (%)	***0.7***	***0.7***
kgO_2/kwh real	1.4670	1.2287
g O_2 consumed/m^3 O_2 supply	11.3	11.0
Kg O_2 day^{-1}	775.2	775.2
Price kwh (euro)	***0.09***	***0.09***
Cost (euros day^{-1})	47.56	56.78
Cost (euro Kg^{-1} N)	**0.20**	**0.23**

(The know data is presented in bold and italic characters)

Annexe V.1: Specific activity depending on pH (DO max = 6.9 mg L^{-1})

Experiment 1

Time (h)	**pH** (-)	**DO** (mg L^{-1})	**ΔDO** (DO max- DO)	**Relative activity** (ΔDO/3.43)
0.73	7.6	3.93	2.97	0.87
0.87	8	3.65	3.25	0.95
1.00	8.1	3.64	3.26	0.95
1.13	8.2	3.63	3.27	0.95
1.27	8.2	3.69	3.21	0.94
1.40	8.3	3.66	3.24	0.94
1.53	8.3	3.63	3.27	0.95
1.67	8.3	3.6	3.3	0.96
1.80	8.3	3.55	3.35	0.98
1.93	8.2	3.52	3.38	0.99
2.07	8.2	3.53	3.37	0.98
2.20	8.1	3.52	3.38	0.99
2.33	8.1	3.52	3.38	0.99
2.47	8	3.47	**3.43**	1.00
2.60	8	3.51	3.39	0.99
2.73	7.9	3.56	3.34	0.97
2.87	7.8	3.63	3.27	0.95
3.00	7.7	3.75	3.15	0.92
3.13	7.6	3.92	2.98	0.87
3.27	7.5	4.11	2.79	0.81
3.33	7.4	4.26	2.64	0.77
3.47	7.3	4.6	2.3	0.67
3.53	7.2	4.83	2.07	0.60
3.67	7	5.58	1.32	0.38
3.73	6.9	5.75	1.15	0.34
3.80	6.8	6	0.9	0.26
3.93	6.6	6.43	0.47	0.14
4.00	6.5	6.54	0.36	0.10

Experiment 2

Time (h)	**pH** (-)	**DO** (mg L^{-1})	**ΔDO** (DO max- DO)	**Relative activity** (ΔDO/3.56)
4.67	6.5	6.54	0.36	0.10
4.87	7.6	3.63	3.27	0.92
5.00	8	3.57	3.33	0.94
5.13	8.1	3.53	3.37	0.95
5.27	8.1	3.6	3.3	0.93
5.40	8.2	3.65	3.25	0.92
5.53	8.2	3.58	3.32	0.94
5.67	8.2	3.49	3.41	0.96
5.80	8.1	3.5	3.4	0.96
5.93	8.1	3.44	3.46	0.98
6.07	8.1	3.36	3.54	1.00
6.13	8.1	3.34	**3.56**	1.00
6.20	8	3.33	3.57	1.00
6.33	8	3.4	3.5	0.99
6.47	7.9	3.38	3.52	0.99
6.60	7.9	3.5	3.4	0.96
6.73	7.8	3.58	3.32	0.94
6.87	7.7	3.67	3.23	0.91
7.00	7.6	3.84	3.06	0.86
7.13	7.4	4.18	2.72	0.77
7.27	7.3	4.61	2.29	0.65
7.40	7.1	5.22	1.68	0.47
7.53	6.9	5.8	1.1	0.31
7.67	6.7	6.3	0.6	0.17
7.80	6.5	6.6	0.3	0.08
7.93	6.4	6.77	0.13	0.04
8.07	6.3	6.71	0.19	0.05

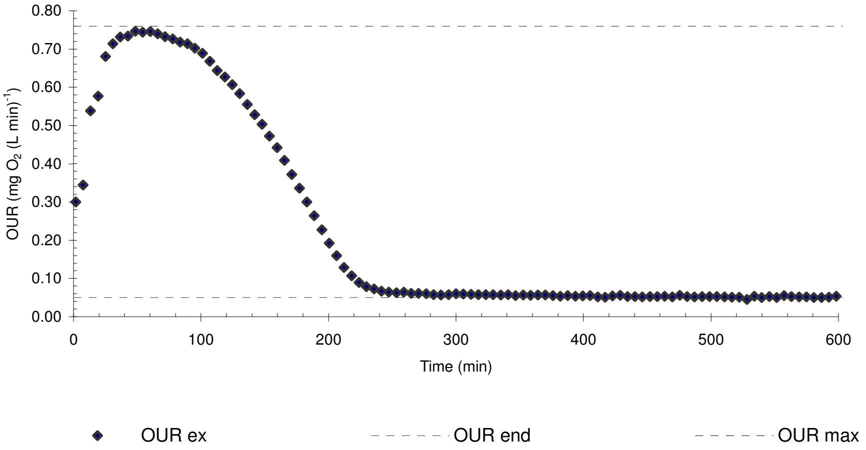
Experiment 3

Time (h)	**pH** (-)	**DO** (mg L^{-1})	**ΔDO** (DO max- DO)	**Relative activity** (ΔDO/3.82)
8.87	7.8	3.33	3.57	0.93
9.00	8	3.24	3.66	0.96
9.13	8.1	3.3	3.6	0.94
9.27	8.2	3.3	3.6	0.94
9.40	8.2	3.24	3.66	0.96
9.53	8.2	3.17	3.73	0.98
9.67	8.2	3.13	3.77	0.99
9.73	8.2	3.19	3.71	0.97
9.87	8.1	3.14	3.76	0.98
10.00	8.1	3.12	3.78	0.99
10.13	8.1	3.08	3.82	1.00
10.27	8	3.12	3.78	0.99
10.40	8	3.08	**3.82**	1.00
10.53	7.9	3.13	3.77	0.99
10.67	7.8	3.2	3.7	0.97
10.87	7.7	3.32	3.58	0.94
11.00	7.6	3.53	3.37	0.88
11.20	7.4	4.04	2.86	0.75
11.33	7.2	4.6	2.3	0.60
11.47	7	5.3	1.6	0.42
11.60	6.8	5.98	0.92	0.24
11.73	6.6	6.4	0.5	0.13
11.87	6.5	6.66	0.24	0.06
12.00	6.4	6.79	0.11	0.03

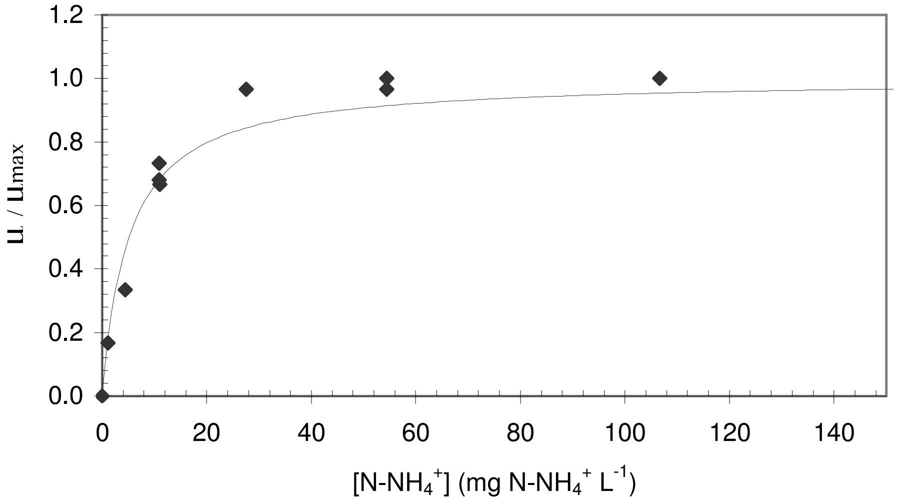
Annexe V.2: Kinetic and stoichiometric parameters

Partial Nitrification in SBR (More information in Dosta et al., 2006b)

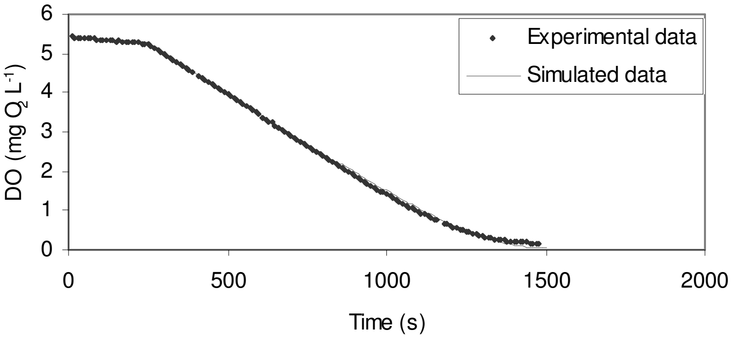
1. **μ_{mA} X_{BA} and Y_{AOB}** (T=30ºC; VSS= 285 mg VSS/L; pH=8.0)



2. K_{NH} (T=30ºC; pH=8.0)

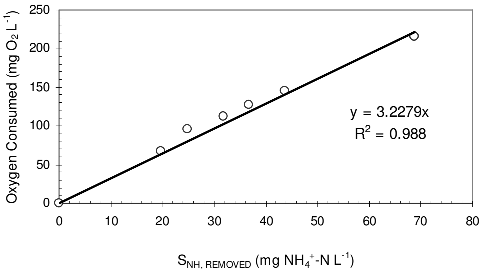


3. K_{OA} (T=30ºC; pH 8.0)

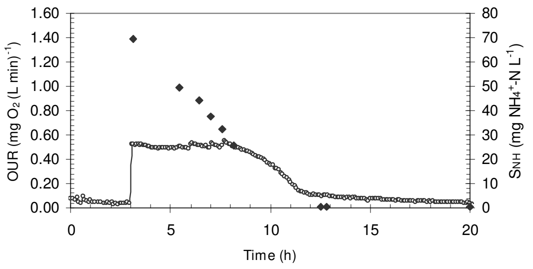


Partial Nitrification in a SHARON reactor (More information in Dosta et al., 2006b)

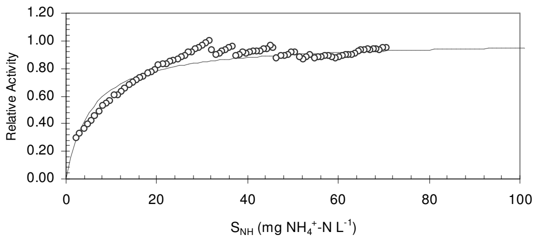
1. **μ_{mA} X_{BA}, Y_{AOB} (a, b) and K_{NH} (c)** (T=35ºC; pH 8.0)



(a)

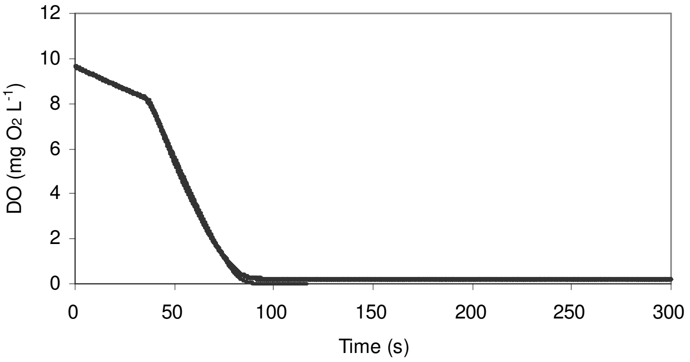


(b)

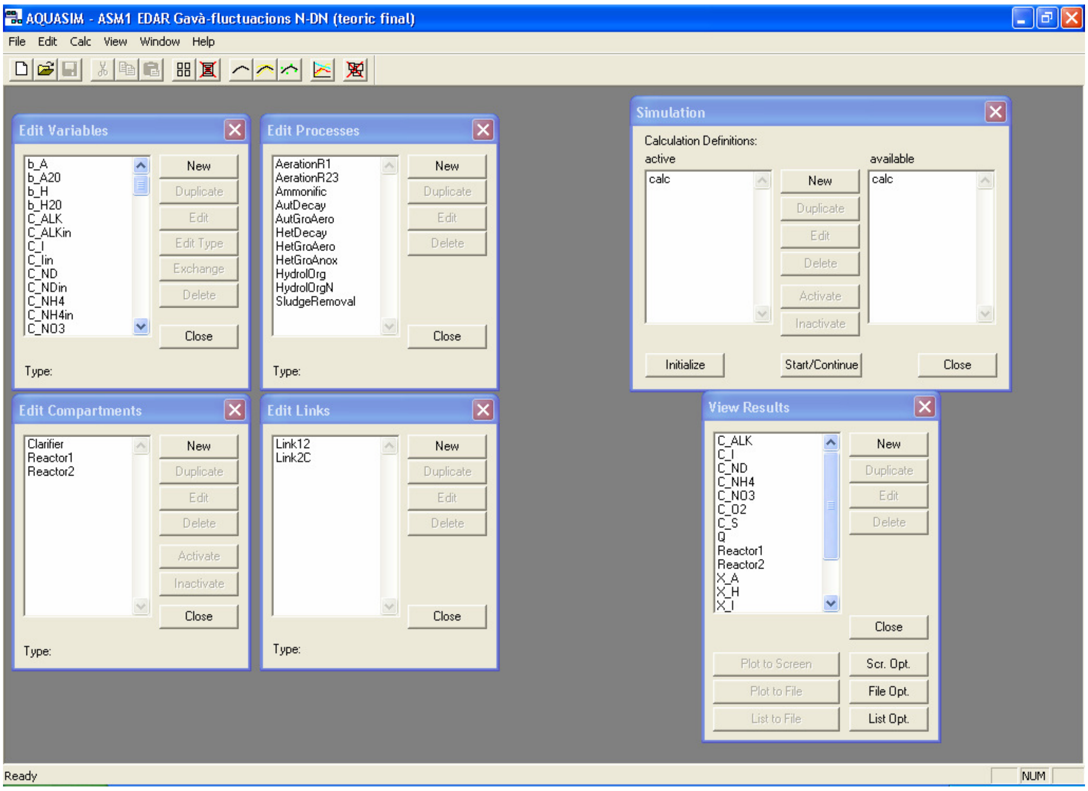


(c)

2. **$K_{O,AOB}$** (T=35ºC; pH 8.0)



Annexe VI.1: AQUASIM 2.0 Software



Annexe VI.2: Simulated data in winter conditions

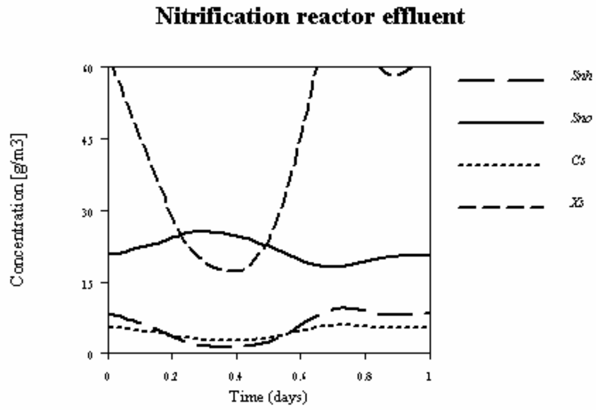
Time day	**S_{NH}** g Nm^{-3}	**Ss** g $CODm^{-3}$	**Xs** g $CODm^{-3}$	**X_I** g $CODm^{-3}$	**Xp** g $CODm^{-3}$	**X_{BH}** g $CODm^{-3}$	**X_{TSS}** g $SSTm^{-3}$
0	44.13	6.819	49.61	651.5	80.03	1011	1500
0.04	44.24	6.537	44.88	652.1	80.04	1016	1500
0.08	44.26	6.161	37.76	651.5	80.06	1019	1496
0.12	44.27	5.716	30.53	650.3	80.08	1021	1491
0.16	44.29	5.124	23.3	648.4	80.1	1022	1484
0.2	44.37	4.328	16.3	645.5	80.12	1021	1475
0.24	44.44	3.505	11.29	641.9	80.14	1017	1465
0.28	44.4	2.986	8.943	638.1	80.15	1011	1454
0.32	44.25	2.765	8.063	634.3	80.16	1003	1444
0.36	44.04	2.678	7.724	630.5	80.16	995	1434
0.4	43.74	2.766	8.105	627	80.15	987.1	1425
0.44	43.33	3.125	9.671	624.4	80.14	980	1418
0.48	42.89	3.742	12.75	623.1	80.13	974.9	1415
0.52	42.57	4.552	17.81	623.6	80.11	972.3	1417
0.56	42.42	5.436	25.28	626.2	80.09	972.5	1426
0.6	42.42	6.244	35.02	630.6	80.07	975.2	1440
0.64	42.57	6.851	45.66	636.1	80.06	979.8	1457
0.68	42.86	7.189	54.67	641.6	80.04	985.5	1474
0.72	43.18	7.258	59.49	645.9	80.04	991.6	1487
0.76	43.36	7.123	58.94	648.4	80.04	997.4	1493
0.8	43.39	6.911	54.47	649.4	80.04	1003	1495
0.84	43.45	6.747	49.53	650.1	80.05	1008	1495
0.88	43.62	6.684	46.71	651.4	80.06	1012	1498
0.92	43.89	6.719	46.51	653.4	80.07	1017	1503
0.96	44.18	6.793	47.9	656.1	80.09	1021	1511
1	44.43	6.838	49.32	658.8	80.1	1026	1518

Annexe VI.3: Simulated data in summer conditions

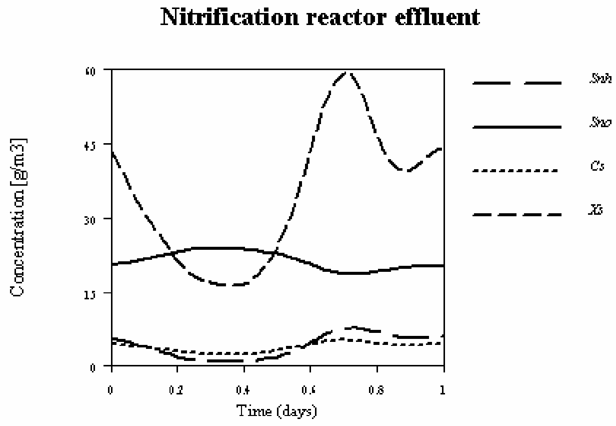
Time day	**S_{NH}** gNm^{-3}	**S_{NO}** gNm^{-3}	**Ss** $gCODm^{-3}$	**Xs** $gCODm^{-3}$	**X_I** $gCODm^{-3}$	**Xp** $gCODm^{-3}$	**X_{BH}** $gCODm^{-3}$	**X_{BA}** $gCODm^{-3}$	**X_{TSS}** $gSSTm^{-3}$
0	11.4	30.28	4.84	26.85	492.5	92.93	47.51	641.7	1085
0.04	11.06	30.66	4.431	23.08	493	92.99	47.58	645.3	1085
0.08	10.42	31.29	3.948	19.04	492.3	93.05	47.65	646.6	1082
0.12	9.615	32.04	3.581	16.33	491.1	93.12	47.71	645.6	1078
0.16	8.592	33	3.237	14	489.1	93.18	47.76	642.8	1072
0.2	7.267	34.31	2.848	11.63	486.2	93.23	47.8	637.9	1064
0.24	5.725	35.85	2.555	10	482.6	93.27	47.81	631.1	1054
0.28	4.19	37.33	2.44	9.335	478.8	93.29	47.78	623.2	1044
0.32	2.86	38.58	2.408	9.052	475	93.3	47.7	615	1033
0.36	1.883	39.47	2.404	8.896	471.2	93.29	47.53	606.8	1023
0.4	1.425	39.77	2.511	9.28	467.7	93.26	47.28	598.9	1014
0.44	1.507	39.43	2.812	10.66	465.1	93.22	47	592.2	1007
0.48	2.03	38.6	3.305	13.25	463.9	93.17	46.77	587.7	1004
0.52	2.973	37.42	3.954	17.27	464.5	93.12	46.63	586.2	1006
0.56	4.354	35.93	4.674	22.86	467.1	93.06	46.57	587.9	1015
0.6	6.102	34.2	5.341	29.57	471.5	93.02	46.57	593	1028
0.64	7.966	32.47	5.822	36.01	477	92.98	46.61	600.6	1044
0.68	9.584	31.13	6.028	40	482.5	92.97	46.68	609.8	1060
0.72	10.68	30.33	5.93	39.74	486.7	92.97	46.75	619.3	1071
0.76	11.17	30	5.554	35.16	489.2	92.99	46.83	627.9	1077
0.8	11.23	29.99	5.029	28.87	490.2	93.02	46.9	634.5	1078
0.84	11.14	30.13	4.62	24.6	490.9	93.07	46.98	638.8	1079
0.88	11.11	30.27	4.516	23.63	492.1	93.12	47.05	641.9	1081
0.92	11.22	30.31	4.644	24.9	494.1	93.18	47.13	645.1	1087
0.96	11.45	30.24	4.814	26.73	496.7	93.24	47.21	649.2	1094
1	11.69	30.16	4.899	27.86	499.4	93.31	47.3	654	1102

Annexe VI.4: Simulated profile values operating with the different denitrification/nitrification conditions

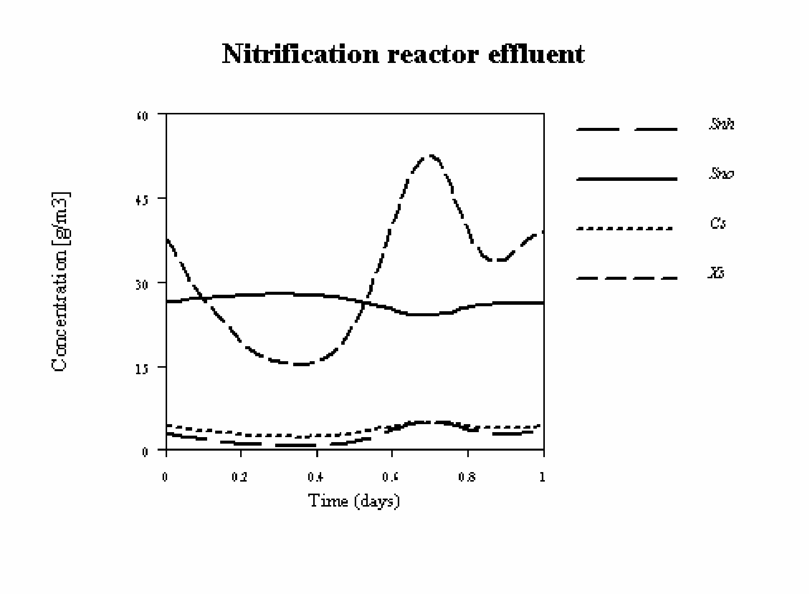
A). Denitrification reactor (7000 m^3); nitrification reactor (17000 m^3); % recirculation = 100



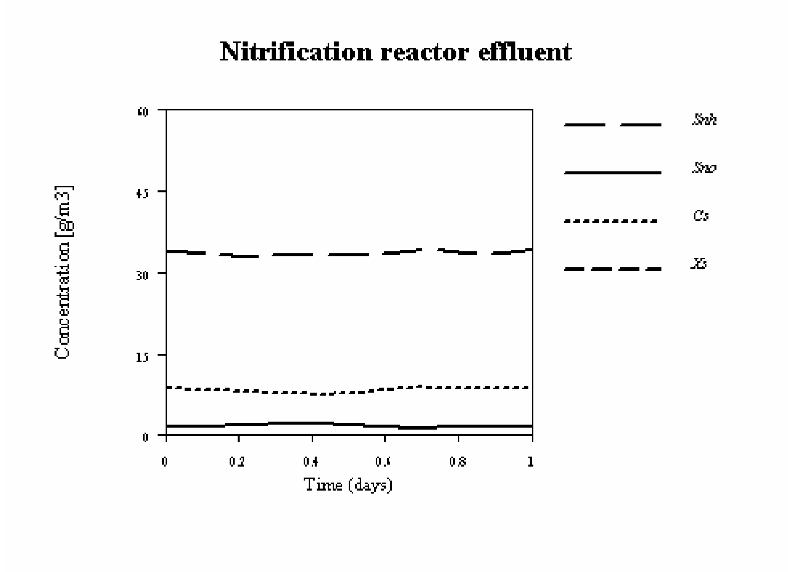
B). Denitrification reactor (7000 m^3); nitrification reactor (17000 m^3); % recirculation = 500



C). Denitrification reactor (4000 m^3); nitrification reactor (20000 m^3); % recirculation = 200



D). Denitrification reactor (12000 m^3); nitrification reactor (12000 m^3); % recirculation = 200 (250 mg L^{-1} < Xs < 350 mg L^{-1})



Annexe VI.5: Optimised simulated profile values operating with denitrification/nitrification

	DENITRIFICATION REACTOR				NITRIFICATION REACTOR			
Time day	S_{NH} gNm^{-3}	S_{NO} gNm^{-3}	**Ss** gCODm^{-3}	**Xs** gCODm^{-3}	S_{NH} gNm^{-3}	S_{NO} gNm^{-3}	**Ss** gCODm^{-3}	**Xs** gCODm^{-3}
0	18.2	2.73	3.251	132.3	6.659	18.74	4.477	45.19
0.04	17.48	3.023	3.092	122.7	6.085	19.18	4.199	40.65
0.08	16.48	3.531	2.94	109.2	5.249	19.78	3.842	34.96
0.12	15.49	4.142	2.799	96.77	4.395	20.37	3.517	30.28
0.16	14.4	4.892	2.63	84.73	3.464	21.03	3.179	25.96
0.2	13.05	5.896	2.44	72.12	2.421	21.8	2.804	21.69
0.24	11.63	7.067	2.275	61.24	1.576	22.37	2.501	18.54
0.28	10.46	8.121	2.164	54.13	1.155	22.53	2.335	16.87
0.32	9.609	8.906	2.093	50.01	0.9767	22.46	2.251	16.01
0.36	9.021	9.437	2.055	47.64	0.8937	22.32	2.209	15.55
0.4	8.814	9.621	2.083	47.76	0.9307	22.09	2.256	15.84
0.44	9.218	9.28	2.209	51.99	1.147	21.72	2.446	17.38
0.48	10.29	8.39	2.43	61.12	1.592	21.25	2.79	20.47
0.52	11.92	7.1	2.719	75.41	2.341	20.66	3.272	25.42
0.56	13.92	5.598	3.028	94.39	3.477	19.86	3.845	32.45
0.6	16.03	4.088	3.306	116.3	4.976	18.84	4.419	41.24
0.64	17.9	2.825	3.513	138	6.55	17.8	4.881	50.29
0.68	19.2	2.037	3.617	154.6	7.743	17.12	5.142	57.07
0.72	19.69	1.755	3.588	161.7	8.27	16.95	5.172	59.29
0.76	19.39	1.829	3.449	156.9	8.132	17.18	4.996	56.26
0.8	18.67	2.094	3.302	144.4	7.593	17.63	4.701	50.13
0.84	18.07	2.4	3.227	132.6	7.035	18.08	4.445	44.83
0.88	17.87	2.623	3.225	127.1	6.707	18.42	4.34	42.63
0.92	18.01	2.703	3.269	127.8	6.655	18.57	4.379	43.18
0.96	18.29	2.667	3.312	131.6	6.781	18.58	4.473	44.97
1	18.49	2.606	3.33	135	6.913	18.57	4.535	46.39

Annexe VI.6: Simulated profile values operating with different volume and recirculation rates

Clarifier WWTP profiles working with denitrification reactor of 15000 m^3, nitrification reactor of 30000 m^3 and a recirculation rate of 500%