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Article abstract

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INFLUENT FRACTIONATION FOR THE USE OF ASM1 TO OPTIMIZE URBAN WASTEWATER TREATMENT: APPLICATION TO THE REMOVAL OF C AND N IN A SBR

Fractionnement de l'eau usée pour l'utilisation du modèle ASM1 en vue de l'optimisation du traitement des eaux usées : application à l'élimination du carbone et de l'azote dans un SBR

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ABSTRACT

A simulation of a SBR using Benchmark procedure was done prior to field operation in order to optimize the cycle and phases lengths. The accurate identification of ASM1 variables is a prerequisite to achieve a good prediction. A fractionation procedure was applied to samples, corresponding to dry and rainy weather conditions, for taking into account the ASM1 state variable characteristics of specific wastewater (mixture of domestic and industrial wastewater), which differ largely from the default ones used in ASM1. The choice of the ASM1 state variables identification methodology is very important as it influences the results. Two methods were carried out: a batch test in closed reactors, and a coagulation/flocculation procedure. An optimal 12-hour cycle length was determined, in terms of discharged water quality and reactor productivity. The described methodology led to valuable results in terms of carbon and nitrogen removal: respectively more than 90% of COD removal and more than 80% on total nitrogen removal.

Keywords: SBR, ASM1, fractionation, wastewater, optimization, modelling.

RÉSUMÉ

Une méthodologie d'optimisation des durées du cycle et des phases d'un procédé SBR avant une mise en œuvre réelle a été développée grâce à l'utilisation de la modélisation mathématique (utilisation du modèle ASM1). Les valeurs par défaut du modèle ASM1 ne permettent pas toujours de tenir compte de la variabilité de la qualité des eaux usées, notamment dans le cas d'eaux usées particulières (cas d'un mélange d'eaux usées industrielles et domestiques). Afin de tenir de tenir

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compte de cette variabilité et dans le but de déterminer plus précisément les valeurs des variables du modèle ASM1, une procédure de fractionnement a été appliquée à des échantillons d'eaux usées urbaines, par temps de pluie et par temps sec. Le choix de la méthode d'identification des variables du modèle ASM1 est très important car il conditionne en partie le résultat. Deux méthodes ont été mises en œuvre : des tests de biodégradation en réacteurs fermés, et des tests de coagulation floculation. L'utilisation des variables définies notamment par les tests de biodégradation a permis de définir un cycle de 12 heures permettant d'allier une bonne qualité de l'eau de sortie à une productivité optimale. La méthodologie décrite permet d'obtenir de très bons taux d'abattement du carbone et de l'azote pour une eau usée urbaine, respectivement supérieurs à 90 % et 80 %.

Mots clés : SBR, ASM1, fractionnement, eaux usées, optimisation, modélisation.

NOMENCLATURE

S_I: soluble inert substrate concentration ($mgO_2 \bullet L^{-1}$)

S_s: readily biodegradable soluble substrate concentration ($mgO_2 \bullet L^{-1}$)

X_I: inert-particulate substrate concentration ($mgO_2 \bullet L^{-1}$)

X_s: particulate slowly biodegradable substrate concentration ($mgO_2 \bullet L^{-1}$)

S_{ND}: soluble biodegradable organic nitrogen concentration ($mgN \bullet L^{-1}$)

S_{NH}: ammonium concentration ($mgN \bullet L^{-1}$)

S_{NO}: nitrate and nitrite nitrogen concentration ($mgN \bullet L^{-1}$)

So: dissolved oxygen concentration ($mgO_2 \bullet L^{-1}$)

$X_{B,A}$: active autotrophic biomass concentration ($mgO_2 \bullet L^{-1}$)

$X_{B,H}$: active heterotrophic biomass concentration ($mgO_2 \bullet L^{-1}$)

X_{ND}: particulate biodegradable organic nitrogen concentration ($mgN \bullet L^{-1}$)

Xp: particulate product from biomass decay concentration ($mgO_2 \bullet L^{-1}$)

S_{ALK}: alkalinity

TSS: total suspended solids ($mg \bullet L^{-1}$)

VSS: volatile suspended solids ($mg \bullet L^{-1}$)

MSS : mineral suspended solids ($mg \bullet L^{-1}$)

Index i: values of ASM1 variables at t0 in the sludge

Index 0: values of ASM1 variables in the incoming wastewater

1. INTRODUCTION

Activated sludge processes are widespread for the biological treatment of domestic and industrial wastewater. Continuous systems are recommended when large amounts of water have to be treated. On the contrary, Sequencing Batch Reactors (SBRs) have been proposed for small communities and industries discharging very specific wastewaters (KARGI *et al.*, 2005; KIM *et al.*, 2004) because they have a higher degree of flexibility than continuous systems. According to the incoming pollutant concentration and to the specifications of the discharged water, the operating mode of Sequencing Batch Reactor (SBR) is based on a series of aerated and non-aerated reaction phases of variable duration (KARGI et UYGUR, 2003).

Many technical possibilities are available for SBR management and optimization but they are expensive and time-consuming to test experimentally. Models which are dedicated to describe the system performances in a SBR are available in the literature (ARTAN *et al.*, 2006; BOAVENTURA *et al.*, 2001; CARVALHO *et al.*, 2004; COELHO *et al.*, 2000; HVALA *et al.*, 2001; MOUSSA *et al.*, 2005; WU *et al.*, 2001). Therefore, modelling and simulation offer interesting alternatives (ARTAN *et al.*, 2006; HVALA *et al.*, 2001).The models used are mostly the ASM1 or ASM2d or an adaptation of the ASM. Models are used to validate experimental data and more rarely to design SBR systems except in the data provided by ARTAN *et al.* (2006) who describe the use of the ASM model to optimize the filling in batch reactors for nitrogen removal, but without lab or pilot scale validation.

Many strategies are proposed for the setting-up of wastewater treatment plants, but their evaluation and comparison are difficult. This is partly due to the variability of the influent, to the complexity of the physical and biochemical phenomena and to the large range of time constants (from a few minutes to several days), inherent to the activated sludge process. One of the difficulties for the application of modelling to a specific site lies in the wastewater fractionation corresponding to the local wastewater. The quality and the validity of the simulations depend on the quality of the initial variables. Efforts to identify ASM state variables in SBR systems are rarely reported, most authors preferring to use literature data (COELHO *et al.*, 2000) or online calibration of ASM parameters (ANDREOTTOLA *et al.*, 1997; DOSTA *et al.*, 2007).

Different methods of identifying or calibrating ASM1 state variables and parameters can be found in the literature. Most of them are collected by SIN *et al.* (2005) and a complete review of ASM variables and parameters identification is reported by PERTERSEN (2000). Many of them are based on respirometric methods (BROUWER *et al.*, 1998; CHECCHI et MARSILI-LIBELLI, 2005]) defined as the measurement and interpretation of the oxygen uptake rate of activated sludge

(EKAMA *et al.*, 1986; SPANJERS *et al.*, 1999). Interpretation of respirometric data can be achieved, for example, by fitting a model to the measured data (COEN *et al.*, 1998; SPANJERS et VANROLLEGHEM, 1995). S_S, parts of X_S, S_{NH}, parts of S_{ND} and X_{ND} can be determined through respirometric techniques; nevertheless, it is not possible to identify all ASM1 variables such as S_I and X_I. The respirometric techniques cannot be easily applied. It is necessary to conduct a thorough analysis of the respirograms, and to manage properly the nutrients to biomass ratio (SPERANDIO, 2007). Physico-chemical methods can also be used to identify some ASM1 variables and especially S_S (MAMAIS *et al.*, 1993; NAIDOO *et al.*, 1998). The main failure of these methods is the lack of distinction between non-biodegradable and biodegradable matter. That is why it is necessary to combine these methods with biodegradation tests. STRICKER (2000) described biodegradation tests which led to more complete identification.

This work presents the coupling of a mathematical model and wastewater fractionation to define an optimal sequence of a SBR, with the aim of treating carbon and nitrogen from domestic wastewater (Figure 1). In this paper, two kinds of wastewater fractionation were compared: the fractionation given by the Benchmark (BSM1) and a specific one for Limoges (France) wastewater that remained to be established more accurately. Modelling and fractionation were used to compare two kinds of setting up of a SBR: 12-hour cycles and 24-hour cycles. The interest of a specific identification for the choice of the cycle duration between 12-hour and 24-hour cycles is demonstrated during dry and rainy weathers. The cycle defined using the low cost strategy was tested in lab-scale and pilot-scale reactors.

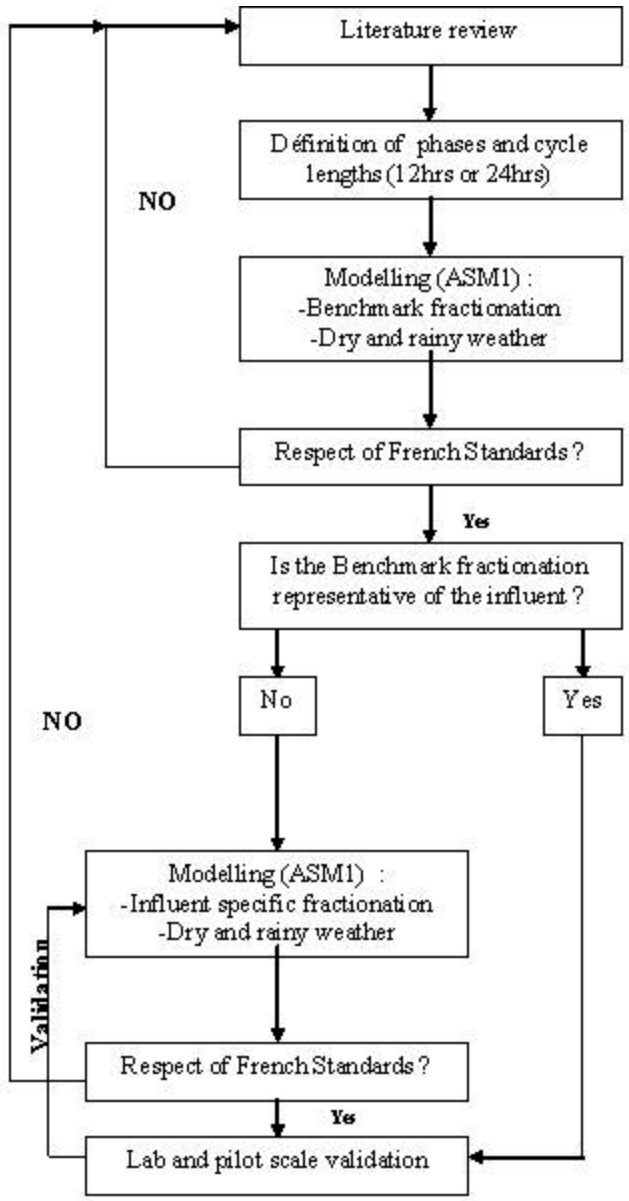

Figure 1. Methodology used for the optimization of wastewater treatment (C and N removal) in a SBR.
Méthodologie utilisée pour l'optimisation du traitement d'une eau usée (élimination de C et N) dans un SBR.

2. MATERIALS AND METHODS

2.1 Models description

Modelling the biodegradation phases. The Activated Sludge Model N°. 1 (ASM1) (HENZE *et al.*, 1987) was chosen to simulate the biological process. Thirteen state variables described the fate of biodegradable and non-biodegradable, soluble and insoluble, carbon and nitrogen-based pollution as well as bacteria (heterotrophs and autotrophs): the biological processes are described by 19 kinetic and stoechiometric parameters. The values of the kinetic and stoechiometric parameters were the default values proposed by HENZE *et al.* (1987) at 20°C.

Except for oxygen, the general mass balance during non-settling phases was:

$$q_{in}Z_{in} + r(Z)V = q_{out}Z + \frac{d(VZ)}{dt} \qquad (1)$$

where Z was a state variable, V the working volume, r the reaction rate, t the time and q_{in} and q_{out} the feed and discharge rate respectively. During feeding:

$$q_{in}Z_{in} + r(Z)V = q_{in}Z + V\frac{d(Z)}{dt} \qquad (2)$$

$$\text{as } dV/dt = q_{in} \qquad (3)$$

During the discharge and wastage phases, which were assumed to be non-reactive:

$$\frac{d(Z)}{dt} = 0 \qquad (4)$$

and

$$dV/dt = -q_{out} \quad (5)$$

Dissolved oxygen during aerated phases was controlled by a discrete PI controller by manipulation of the oxygen transfer coefficient.

For dissolved oxygen (S_O):

$$K_L a \cdot V \cdot \left(S_O^* - S_O\right) + r\left(S_O\right)V = \frac{d\left[V \cdot S_O\right]}{dt} \quad 6)$$

where S_O^* was the dissolved oxygen concentration at saturation and $K_L a$ the oxygen transfer coefficient.

During aerobic phases of the simulations, the oxygen concentration S_0 was maintained at 2 mg $O_2 \bullet L^{-1}$ and S_O^* was equal to 8 mg $O_2 \bullet L^{-1}$. The oxygen transfer coefficient ($K_L a$) was constant during aerobic phases and equal to 16 h^{-1} and was reduced to 0 during anoxic and anaerobic phases.

Modelling the settling phase: The double-exponential settling velocity model proposed by TAKACS *et al.* (1991) was selected to describe the behaviour of the sludge during the settling phase, which was not supposed to be reacting. The number of layers has been set to m and their thickness is adjusted for each cycle, with respect to the actual working volume. The first layer was at the bottom of the tank, where wastage was taking place. The partial discharge of a layer was taken into account to calculate the amount of sludge remaining in the reactor. Wastage and discharge were not supposed to disturb the layers.

Initialisation of the mathematical program: sludge and wastewater characteristics: The kinetic and settling parameters used to simulate the SBR behaviour were those given in the COST BSM1 (COPP, 2002; HENZE *et al.*, 1987).

2.1.1 Sludges ASM1 variables

The values of ASM1 variables in the sludge at t0 were the same whatever the kind of fractionation used for the incoming wastewater (Benchmark values or specific identification for the incoming wastewater (Limoges WWTP)). The values of sludge ASM1 state variables at t0 in the SBR (X_{Ii} , $X_{B,Hi}$, $X_{B,Ai}$, X_{Pi}) have been fixed according to theoretical calculation (equations 7 to 10) based on the knowledge of TSS and VSS concentrations of the sludge (expressed in mg $O_2 \bullet L^{-1}$). The variable Xp was calculated according to the concept of endogenous respiration.

$$X_{Ii} = COD_{MSS}/0.7 \quad (7)$$

$$X_{B,Hi} = COD_{VSS} * 0.95 \quad (8)$$

$$X_{B,Ai} = COD_{VSS} * 0.05 \quad (9)$$

$$X_{Pi} = COD_{VSS} * f'p \quad (10)$$

f'p is a factor representing the part of biomass lost in the endogenous respiration concept. Its value was taken as equal to 0.208. The TSS was considered equal to 5 g$\bullet L^{-1}$ that is to say 6499, 4 mg $O_2 \bullet L^{-1}$. The COD values for VSS and MSS were respectively equal to 5000 and 1499.4 mg $O_2 \bullet L^{-1}$. The values for the different state variables expressed inmg $O_2 \bullet L^{-1}$ are respectively: S_{Ii} = 60, S_{Si} = 0, X_{Ii} = 2142, X_{Si} = 0, $X_{B,Hi}$ = 4750, $X_{B,Ai}$ = 250, X_{Pi} = 1040, S_{Oi} = 0, S_{NOi} = 10, S_{NHi} = 0, S_{NDi} = 1, X_{NDi} = 5, S_{alki} = 7.

2.1.2 Wastewater ASM1 variables

For predictive simulations, two kinds of influent fractionation were considered to feed the SBR. The influent composition was considered to remain unchanged during the complete simulation period.

- An influent of constant composition determined by the average of the values given by the benchmark program (BSM1) (dry and rainy weathers) (see Table 1).

- An influent of constant composition determined after an influent fractionation (see 2.2) for the wastewater used (dry and rainy weathers) (see Table 1).

  For the pilot scale validation, the ASM1 state variables were calculated according to real values of wastewater composition.

- Simulation conditions: the SBR results discussed thereafter have been obtained using a FORTRAN code and the set of differential equations was integrated using a 4th-order Runge-Kutta algorithm and a constant integration step size (0.002 hr). A stabilization time of 100 days was used. This time was tested in an open loop (no control of dissolved oxygen) and the oxygen transfer coefficient set to its maximal value.

2.2 Experimental methods

Reactor characteristics: The working volume of the lab scale reactor used for the simulations was 2 L. The incoming wastewater volume was equal to 0.9 L per cycle. The length of the phases, the control of dissolved oxygen concentration (2 mg/L) and the feeding and discharge of the reactor were controlled and monitored through the Bioexpert© software.

Table 1. **Values of ASM1 state variables: Benchmark (BSM1) values, and results of the incoming wastewater identification.**

Tableau 1. ***Valeurs des variables d'état du modèle ASM1 : Valeurs issues de la base de données (Benchmark, BSM1), valeurs issues de l'identification spécifique pour l'eau d'entrée.***

ASM1 State variables	S_{I0}	S_{S0}	X_{I0}	X_{S0}	$X_{B,H0}$	S_{NH0}	S_{ND0}	X_{ND0}
Unit	$mgO_2 \bullet L^{-1}$					$mgN \bullet L^{-1}$		
	Benchmark fractionation							
Dry weather	30	65.2	45.6	192,7	26.5	30.1	6.5	9.95
Rainy weather	27.8	60.5	42	178	24.5	27.9	6	9.2
	Incoming wastewater specific fractionation							
Dry weather	34	131	51	352	26.5	16	17	19
Rainy weather	26	219	114	294	24.5	14	15	11

Feeding and discharge of the reactor were achieved using peristaltic pumps. The agitation rate was regulated at 80 rpm.

The working volume of the pilot scale SBR was 1320 litres. It was stirred at 40 rpm during the aerobic phase and at 30 rpm during the anoxic phase. The volume of incoming wastewater represented 50% of the working volume of the reactor. The reactor was monitored and controlled through the TSX Premium© (Télémécanique) software.

Fractionation of the incoming wastewater: The incoming wastewater was a mixture of domestic (85% v/v) and industrial wastewater (15% v/v).

The ASM1 state variables for the incoming wastewater have been identified by different methods: a) coagulation-floculation followed by 0.45 µm pore size membrane filtration and b) biodegradation tests in closed reactors.

The fractionations were achieved under dry and rainy conditions.

a) The soluble fraction of COD (S_{s0}) was also identified by physico-chemical methods described by (MAMAIS *et al.*, 1993; NAIDOO *et al.*, 1998).The first step consisted in the elimination of suspended solids by using a coagulant flocculant. The supernatant was then filtered at 0.45 µm. S_{s0} corresponds to the COD measured in the filtrate. Two coagulant flocculants were evaluated $FeCl_3$ (1 $g \bullet L^{-1}$) and $ZnSO_4$ (3 $g \bullet L^{-1}$).

b) The state variables of ASM1 (S_{I0}, S_{S0}, X_{S0}, X_{I0}, S_{NI0}, S_{ND0}, X_{NI0}, X_{ND0}) were measured by a method inspired by STRICKER (2000): two reactors were filled with wastewater: the first one (working volume of 4 L) was filled with untreated wastewater (collected after pre-treatment in the WWTP of Limoges) and the second was filled with 4 L of filtered wastewater (1.2 µm). According to STRICKER (2000) recommendations, the reactors were inoculated with activated sludge (1/1000 v/v). The biodegradation tests lasted 30 days and were conducted twice for rainy weather and three times during the dry weather period of time, in order to have an accurate identification. Soluble and insoluble COD and nitrogen species were monitored every day.

Performance criteria, removal efficiency, analytical methods: The exit concentration of soluble carbon and nitrogen was compared to French standards. The removal efficiency (RE) was calculated according to equation 11:

$$RE = \left(\text{Input value} - \text{Output value}\right) / \text{Input value}) * 100 \quad (11)$$

Input value corresponded to the values reported in table 1 and output values were given by the simulator after ten SBR cycles.

French standards methods were used to determine pollution parameters: chemical oxygen demand (COD) (NFT 90-101), total Kjeldhal nitrogen (TKN) (ISO 5663-1984(F)), total suspended solids (TSS, VSS, MSS) (NFT 90-105-1), nitrate, nitrite and orthophosphate ions (NF EN 10304-2). Ammonium ions concentrations were measured by ionic chromatography (Dionex DX 100).

3. RESULTS AND DISCUSSIONS

According to the bibliographic study, two kinds of overall lengths were chosen for the treatment of urban wastewater in a SBR: 12 hours and 24 hours. The sequence and duration of the different phases are reported in table 2.

Table 2. **Basic phases sequencing for the 12 and 24 hour cycles.**
Tableau 2. ***Séquences de base pour les cycles de 12 heures et de 24 heures.***

Phase nb	24 h cycles length (%)	12 h cycles length (%)	Feeding	Aeration	Mixing	Discharge/Wastage
1	4.2	8.3	Yes	No	Yes	No
2	2.1	4.2	No	No	Yes	No
3	33.3	37.5	No	Yes	Yes	No
4	48.9	27.1	No	No	Yes	No
5	1	2.1	No	Yes	Yes	No
6	4.2	8.3	No	No	No	No
7	4.2	8.3	No	No	No	Yes
8	2.1	4.2	No	No	No	No

3.1 Use of ASM 1 for the prediction of the phases and cycle lengths of a SBR.

Modelling carbon and nitrogen removal during 12-hour and 24-hour cycles (Benchmark fractionation): In a first part the effectiveness of BSM1 fractionation for SBR sizing was assessed. The characterisation of the incoming wastewater was determined according to the fractionation given by the Benchmark (BSM1) (see in table 1). The results, in terms of removal efficiencies and composition of the treated wastewater, respectively for 12-hour and 24-hour cycles of a SBR are given in table 3.

Table 3 shows that it was possible with the 24-hour cycles to reach both the French standard and low level of exit concentration, especially for nitrogen (5.5 and 5.7 mg $N\bullet.L^{-1}$) - whatever the climatic conditions. On the contrary, the exit concentrations of the 12-hour SBR cycles reached the upper limit of the French standards especially for total nitrogen (15.3 and 12.7 mg $N\bullet.L^{-1}$). In a first approach, this result may lead to the rejection of 12-hour cycles because of a possible lack of reliability of 12-hour SBR cycles.

The distribution of ASM1 state variables given by the benchmark (BSM1) can be a useful tool at first, but it might prove to be incomplete if one considers the high variability of wastewater, according to the kind of effluent it contains (presence of industrial wastewater, separated or combined sewer system). It is then necessary to achieve a specific identification of ASM1 state variables for local wastewater later used in a lab scale or pilot scale reactor.

Specific fractionation of the influent: The incoming wastewater was a combination of industrial and domestic wastewater. The wastewater characterization might differ significantly from standard municipal wastewater used in the Benchmark (BSM1), but was a good example of the interest of using modelling and fractionation.

Table 3. **Removal efficiencies and outgoing concentrations of the 12-hr and 24-hr simulated cycles with the benchmark distribution (BSM1), compared to the incoming wastewater specific identification of ASM1 state variables during dry and rainy weathers.**
Tableau 3. ***Efficacités d'abattement et concentrations de sortie des cycles simulés de 12 heures et 24 heures avec la distribution de la base de données (Benchmark, BSM1), comparée à l'identification spécifique sur l'eau d'entrée des variables d'état du modèle ASM1 par temps sec et par temps de pluie.***

	Origin of ASM1 state variables fractionation	24-h cycles		12-h cycles		French standard
		Dry weather	Rainy weather	Dry weather	Rainy weather	
Average outgoing $COD_{soluble}$ ($mgO_2.L^{-1}$)	BSM1	35 ± 5.6	33.3 ± 6	32.4 ± 4	30.4 ± 4.4	125
	This study	35 ± 5.5	32.9 ± 6	**36.2 ± 3.5**	**28.7 ± 4.6**	
COD Removal Efficiency (%)	BSM1	90	90	91	91	70-90
	This Study	94	95	**94**	**96**	
Average outgoing $N_{soluble}$ ($mgN.L^{-1}$)	BSM1	5.7 ± 0,5	5.5 ± 0,5	15.3 ± 0,5	12.7 ± 0,5	10-15
	This study	5.7 ± 0.5	4.2 ± 0.2	**10.6 ± 0.5**	**4.8 ± 0.5**	
TN Removal Efficiency (%)	BSM1	88	87	67	71	70-80
	This study	90	92	**80**	**89**	

The results obtained for the variables in relation with carbon and nitrogen species are reported in tables 5 and 6. It is assumed in this study that S_{I0} and X_{I0} were not produced during aerobic batch tests from biomass decay, as the sludge inoculum was very low.

An accurate identification of S_{S0} is of interest, as the availability of readily biodegradable carbon substances is important for the successful achievement of denitrification. The results showed that the method of biodegradation tests in closed reactors led to an overestimation of the S_{s0} fraction, compared to physico-chemical methods (see in Table 4). The estimation of S_{S0} includes a part of colloidal matter. It is in agreement with LEVINE *et al.* (1985), who concluded that it was necessary to use a 1.0 µm pore-size membrane to separate correctly the true soluble and particulate forms. Nevertheless, 0.45 µm pore-size membranes are widely used.

The specific identification of carbon ASM1 state variables during rainy or dry weather presented good correlations with other results found in literature (Table 5). The largest part of COD is biodegradable (soluble or particulate). Especially during dry periods, the largest part of biodegradable COD is particulate.

The results of nitrogen ASM1 variables (Table 6) showed that the distribution for the incoming wastewater differs partly from literature data. The proportion of inert species was not negligible, hence the interest of a specific identification.

For carbonaceous species, it was possible to conclude to a good agreement with the literature values, but it was not the case for nitrogen variables, the distribution of which appearing to be really specific when compared to the references. These results might be due to the presence of industrial effluent in the wastewater.

It appeared from these experimental data that:

- The reliability of Ss determination depended on the applied pore-size of the membrane, which confirms the work of LEVINE *et al.* (1985);
- Parts of the soluble and settleable fraction might belong to Xs (SOLLFRANK et GUJER, 1991);
- It was not possible to identify the variable $X_{B,H}$. In her important work on calibration, identifiability and optimal experimental design of activated sludge models, PETERSEN (2000) reported that this variable was not negligible. SPERANDIO (1998) evaluated this fraction at 10% of the global COD, and HENZE (1992) at 15-20%.

Modelling carbon and nitrogen removal during 12-hours and 24-hour cycles with a specific influent fractionation: The modelling of the 12-hour and 24-hour cycles, using the specific distribution of ASM1 state variables of incoming wastewater, is presented at figure 2. The average values of COD and TN were measured during rainy and dry weathers over three months, in the Wastewater Treatment Plant of Limoges (see Table 7).

Table 4. **Identification of S_{S0} expressed as a percentage of the total COD of the incoming wastewater.**
Tableau 4. ***Identification de S_{s0} exprimé en pourcentage de la DCO totale de l'eau d'entrée.***

Climatic conditions	S_{S0} (%) Biodegration tests in closed reactors	S_{S0} (%) Coagulation floculation + 0.45 µm filtration $FeCl_3$	S_{S0} (%) Coagulation floculation + 0.45 µm filtration $ZnSO_4$
Rainy	27.46	16	16
Dry	17	13	20
Dry	25	18	19

Table 5. **Comparison between the average values of ASM1 carbon variables (percentage of the total COD) of the incoming wastewater and the most frequent values of the bibliography for urban wastewater.**
Tableau 5. ***Comparaison entre les valeurs moyennes des variables carbonées d'ASM1 (pourcentage de la DCO totale) de l'eau d'entrée et des valeurs les plus fréquentes de la bibliographie pour des eaux usées urbaines.***

Reference	Climatic conditions	S_{I0} (%)	X_{I0} (%)	S_{S0} (%)	X_{S0} (%)	$X_{B,H0}$ (%)
This study	Dry	6	9	23	62	/
This study	Rainy	4	17.5	33.5	45	/
STRICKER (2000)	Dry	4	15	31	50	/
STRICKER (2000)	Rainy	6	11	28	55	/
Most frequent values		6-13	8-13	7-30	40-60	15-20
Extreme values		3-20	4-26	1-54	15-80	3-20
HENZE *et al.* (1987)		8-11	11-20	4-32	43-49	/
Benchmark (BSM1)		8.3	12.7	18.1	53.5	7.3

Table 6. **Comparison between the average values of ASM1 nitrogen variables (percentage of the total Nitrogen) of the incoming wastewater and the most frequent values of the bibliography for urban wastewater.**

Tableau 6. ***Comparaison entre les valeurs moyennes des variables azotées d'ASM1 (pourcentage de l'azote total) de l'eau d'entrée et des valeurs les plus fréquentes de la bibliographie pour des eaux usées urbaines.***

Reference	Climatic conditions	S_{NH0} (%)	S_{ND0} (%)	X_{ND0} (%)	S_{NI0} (%)	X_{NI0} (%)
This study	Dry	27.7	29	32.7	7.9	2.7
This study	Rainy	26	28.75	21.25	16.75	7.25
HENZE *et al.* (1987)	Default values		29 to 40	50 to 59	10 to 12	neglected
HENZE (1992)						4
HENZE *et al.* (1993)			45	55	neglected	neglected
STRICKER (2000)	Dry		33	45	10	12
STRICKER (2000)	Rainy		/	/	5	6
Benchmark (BSM1)		64.7	14	21.3	/	/

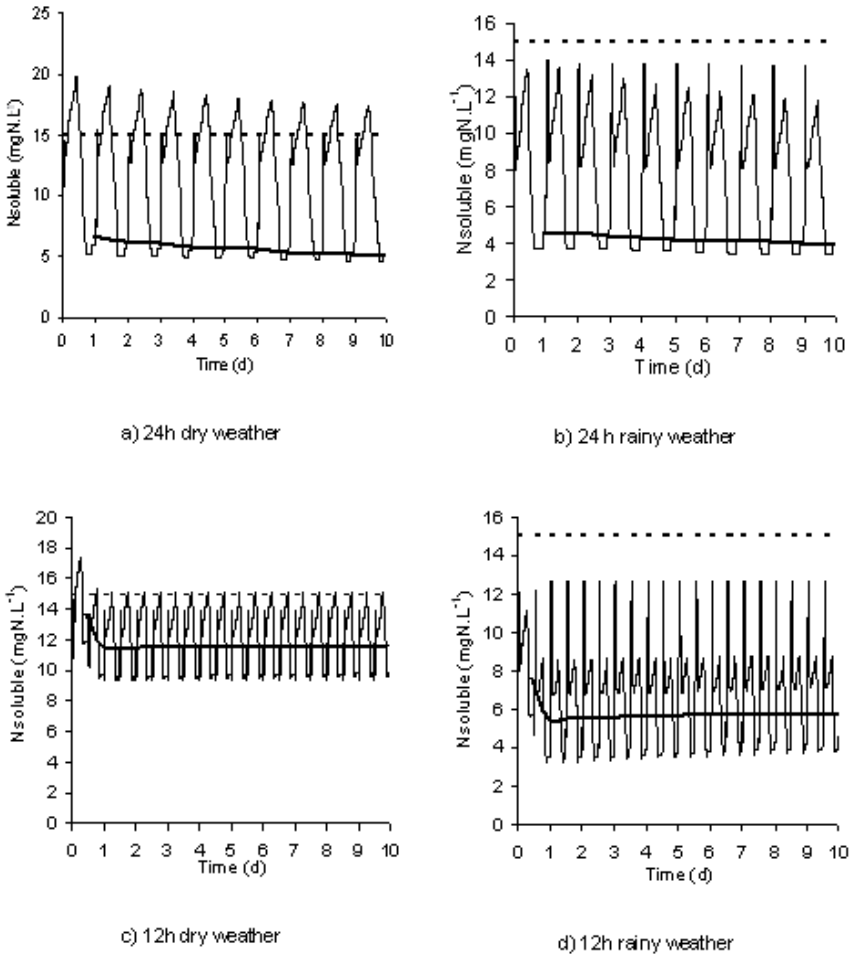

Figure 2. **Evolution of the soluble Nitrogen concentrations during the simulations over ten days for the 24-h and the 12-h cycles (dry and rainy weathers). The continuous lines represent the exit concentration evolutions of soluble nitrogen at the end of the cycle, just before the discharge; the broken line represents the French standards required for the exit water.**

Évolution de la concentration en azote soluble au cours des simulations sur dix jours pour les cycles de 24 heures et de 12 heures (temps sec et temps de pluie). Les lignes continues représentent la concentration de sortie de l'azote soluble à la fin du cycle, juste avant la vidange, les traits pointillés correspondent à la norme française exigée en sortie.

Table 7. **Average values of total COD, TN, ammonium ion, and organic nitrogen concentrations in the incoming wastewater during dry or rainy weather. The results are given for several months of measurement.**
Tableau 7. ***Valeurs moyennes des concentrations en DCO, azote total, ions ammonium, azote organique dans l'eau d'entrée par temps sec et par temps de pluie. Les résultats sont donnés après plusieurs mois de mesures.***

	Global COD ($mgO_2 \bullet L^{-1}$)	TN ($mgN \bullet L^{-1}$)	NH_4^+ ($mgN \bullet L^{-1}$)	Norganic ($mgN \bullet L^{-1}$)
Rainy weather	653 ± 326	52 ± 18,6	13.1 ± 4.2	38.8 ± 16.3
Dry weather	568 ± 237	58 ± 20	15.6 ± 5.2	41 ± 18.8

The exit concentrations taken into account for the carbon forms are Ss and S_I (soluble forms of COD) and the ones for nitrogen are S_{NH}, S_{ND} (soluble forms of nitrogen) as we assumed that particular species concentration were negligible in the effluent.

The results of the simulations for 12-hour and 24-hour cycles with incoming wastewater specific identification of ASM1 state variables are collected in table 3. The exit concentrations and removal efficiency of nitrogen and carbon of the simulations show that it was now possible to treat the incoming wastewater with 12-hour cycles in a SBR (Figure 2). It was, especially during dry weather, possible to reach exit concentrations of the treated wastewater below the French standards (Figure 2).

3.2 Lab scale and pilot scale validation of cycles determined thanks to modelling

In order to test the validity of the above strategy (fractionation and modelling), 12-hour cycles have been carried out at lab scale and then at pilot scale for several months. The incoming organic loading rate had an average value of 0.05 kg $BOD_5 \bullet$kg $TSS \bullet cycle^{-1}$. The sludge retention time was equal to ten days. The results are presented in table 8.

The different tests completed for the 12-hour cycles defined above, both at a lab scale or pilot scale, led to satisfactory results, in terms of carbon (> 90%) and nitrogen (> 80%) removal. The model validation was then controlled during one cycle for carbon and nitrogen removal. The results are presented for the pilot scale validation (Figures 3 and 4).

The specific identification of ASM1 state variables for the incoming wastewater during rainy or dry weather makes it possible to describe the experimental data with sufficient accuracy:

- Soluble carbon removal was very well described by ASM1, as well as the nitrification process, the increase of the soluble COD between 10 h and 11 h was linked to the withdrawal of the reactor (increase of the relative concentration);
- It was considered in this study that the effluent was only made of soluble forms of carbon. Possible underestimation of soluble carbon and especially S_I by ASM1 could be possible as it was a part of biomass decay (PETERSEN, 2000). This phenomenon was observed for the lab scale simulation but not for the pilot scale. Some authors mentioned that for long solid and hydraulic retention times, ASM1 did not give a good description of carbon consumption (SPERANDIO, 2006).
- The modelling of nitrogen removal with ASM1 has been largely discussed in the literature. Some authors mentioned difficulties for ASM1 to correctly describe the nitrification and denitrification processes, especially when the nitrogen content of the influent was important. On the other hand, COELHO *et al.* (2000), SMETS *et al.* (2003) showed that it was possible, in the context of domestic wastewater, to describe correctly N removal through a simplification of ASM1. BOAVENTURA *et al.* (2001) stated that for better

Table 8. **Removal efficiencies of 12-hour cycles, lab scale and pilot scale.**
Tableau 8. ***Taux d'abattement obtenus pour les cycles de 12 heures à l'échelle du laboratoire et à l'échelle pilote.***

	Average outgoing concentration of the treated wastewater($mg \bullet L^{-1}$)			Average Removal Efficiency (%)		
	COD	BOD_5	TN	COD	BOD_5	TN
Lab scale	54 ± 37	5 ± 3	11 ± 6	92 ± 6	99 ± 1	85 ± 8
Pilot scale	26 ± 8	5 ± 5	11 ± 5	94 ± 3	97 ± 5	82 ±7
French standard	125	25	10-15	75	70-90	70-80

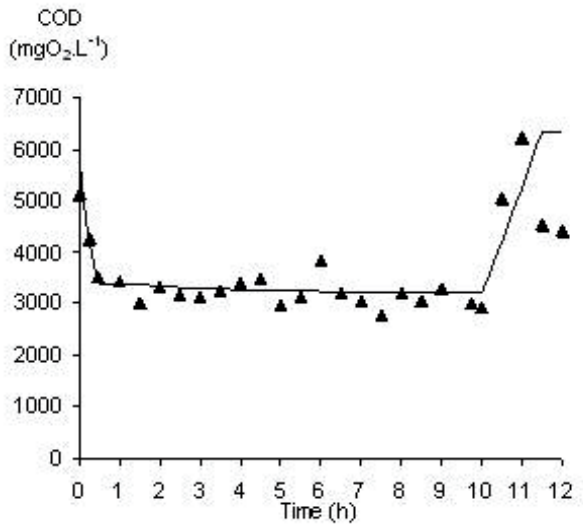

Figure 3. Correlation between model and experiment for COD during a pilot scale cycle.
Corrélation entre le modèle et l'expérience pour la DCO au cours d'un cycle de fonctionnement.

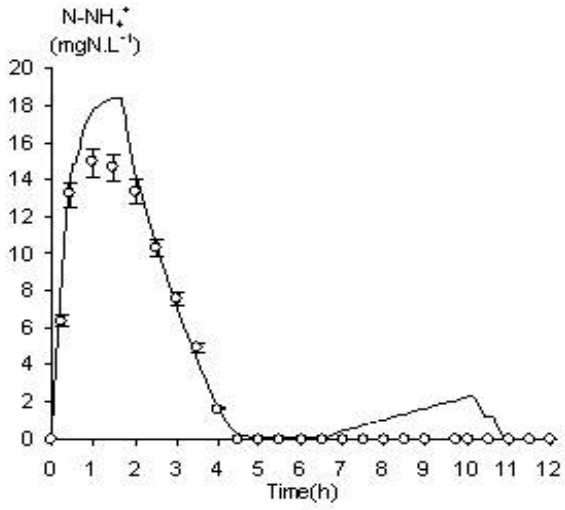

Figure 4. Correlation between model and experiment for N-NH_4^+ during a pilot scale cycle.
Corrélation entre le modèle et l'expérience pour l'azote ammoniacal au cours d'un cycle de fonctionnement.

accuracy of simplified ASM1 model, it was necessary to use robust mathematical filters.

- In this study, ASM1 was used without any simplification. An overestimation of ammonium concentration could be observed, probably due to the fact that biological reactions have not been considered during the modelling of the settling phase. KELLER et YUAN (2002) proposed to remedy this problem by using a combination of a hydraulic and a biological (ASM2d) model during the settling phase; in particular when the influent was fed in the bottom of the reactor during this phase.

4. CONCLUSION

There are many possibilities for the set up of an SBR; testing the different scenarios in the labscale is both costly and time-consuming. The ASM1 makes it possible to test different scenarios during rainy and dry weather, with different distributions for ASM1 state variables.

In a very reduced time (three months) and very reduced cost compared to the cost of labscale tests needed to test so many scenarios (2 global length*2 kind of weather = 4) we demonstrated that it was possible to define an accurate optimal SBR sequence for the treatment of carbon and nitrogen, with any kind of urban wastewater.

To initialize the mathematical model, it was possible to use predefined state variables (BSM1) or to achieve a specific fractionation for the wastewater of interest.

It was necessary to have an accurate description of ASM1 state variables especially when the model was supposed to describe the treatment of industrial or combined domestic and industrial wastewater (COEN *et al.*, 1997). The incoming wastewater entered in this field was a mixture of domestic and industrial effluent. This conclusion is important, for the transposition of this methodology to an industrial effluent.

The specific fractionation results showed that it was possible to treat the incoming wastewater correctly, with 12-hour cycles whereas the BSM1 distribution led to 24-hour cycles. This conclusion is of major interest, as it leads to doubling the effectiveness of the reactor in terms of the amount of treated nitrogen (CASELLAS, 2002).

The SBR cycle, defined thanks to the above strategy, was tested in a lab scale and pilot scale strategy. The experimental validation led to very good results, in terms of carbon and nitrogen removal: more than 90% of COD removal and more than 80% of total nitrogen removal. Moreover, specific fractionation for the incoming wastewater led to good adequacy between the experimental data and model prediction, even though better model adequacy could have been reached by completing the measurement of ASM kinetics and stoechiometric parameters.

ASM1 state variable identifications led to a more accurate definition of SBR phase lengths and species concentration

evolution during one cycle. This methodology can be easily used for sizing a SBR treating urban wastewater.

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