



ACTIVATED SLUDGE MODEL NO. 3

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ABSTRACT

The Activated Sludge Model No. 3 (ASM3) can predict oxygen consumption, sludge production, nitrification and denitrification of activated sludge systems. It relates to the Activated Sludge Model No. 1 (ASM1) and corrects for some defects of ASM1. In addition to ASM1, ASM3 includes storage of organic substrates as a new process. The lysis (decay) process is exchanged for an endogenous respiration process. ASM3 is provided as a reference in a form which can be implemented in a computer code without further adjustments. Typical kinetic and stoichiometric parameters are provided for 10°C and 20°C together with the composition of a typical primary effluent in terms of the model components. © 1999 IAWQ Published by Elsevier Science Ltd. All rights reserved

KEYWORDS

Activated Sludge Model No. 1; Activated Sludge Model No. 3; ASM1; ASM3; nitrification; denitrification; oxygen consumption; sludge production; storage of organic substrates; kinetics; stoichiometry; mathematical modeling.

INTRODUCTION

With the introduction of the Activated Sludge Model No. 1 (ASM1) the IAWQ Task Group on Mathematical Modeling for Design and Operation of Biological Wastewater Treatment Processes introduced a new paradigm for the mathematical modeling of activated sludge systems. ASM1 as it was introduced in 1987 (Henze *et al.*, 1987) has become a major reference for many scientific and practical projects. Today mathematical models related to ASM1 are implemented in various computer codes for the simulation of the behavior of activated sludge systems treating domestic wastewater.

With over ten years of experience with the application of ASM1 some defects of this model have become apparent:

- ASM1 does not include kinetic expressions which can deal with nitrogen and alkalinity limitations of heterotrophic organisms. This results in the fact that computer code cannot be based on the original form of ASM1, which allows under some circumstances for negative concentrations of e.g. ammonium. This led to the creation of different versions of ASM1, which can hardly be differentiated any more.
- ASM1 includes biodegradable soluble and particulate organic nitrogen as model components. These cannot easily be measured and have in the meantime been eliminated in many versions of ASM 1.
- The kinetics of ammonification in ASM1 cannot really be quantified. Again in many versions of ASM1 this process has been eliminated by assuming a constant composition of all organic components (constant N to COD ratio).
- ASM1 differentiates inert particulate organic material depending on its origin, influent or biomass decay. It is impossible however to differentiate these two fractions in reality.
- The process of hydrolysis has a dominating effect upon the predictions of oxygen consumption and denitrification by heterotrophic organisms. At the same time the quantification of the kinetic parameters for this process is difficult.
- Lysis combined with hydrolysis and growth is used to describe the lumped effects of endogenous respiration of e.g. storage compounds, death, predation, lysis, etc. of the biomass. This leads to difficulties in the evaluation of kinetic parameters.
- Storage of poly-hydroxy-alkanoates and sometimes glycogen is observed under aerobic and anoxic conditions in activated sludge plants, provided that elevated concentrations of readily biodegradable organic substrates are available. This process is not included in ASM1.
- ASM1 does not include the possibility to differentiate decay rates of nitrifiers under aerobic and anoxic conditions. At high solids retention times (SRT) and high fractions of anoxic reactor volumes this leads to problems with the prediction of maximum nitrification rates.
- ASM 1 does not allow for the prediction of directly observable mixed liquor suspended solids.

Considering all these defects, the Task Group has decided to propose the Activated Sludge Model No. 3 (ASM3) which should correct for all these defects and which could become a standard again. ASM3 relates to the same dominating phenomena as does ASM1: Oxygen consumption, sludge production, nitrification and denitrification in activated sludge systems treating primarily domestic wastewater. Biological phosphorus removal is contained in the Activated Sludge Model No. 2 (Henze *et al.*, 1995) and will not be considered in ASM3.

ASM3: DEFINITION OF COMPONENTS IN THE MODEL

The following components are used in ASM3. Concentrations of soluble components are characterized by S_i and particulate components by X_i . Within the activated sludge systems the particulate components are assumed to be associated with the activated sludge (flocculated onto the activated sludge or contained within the active biomass). Particulate components can be concentrated by sedimentation/thickening in clarifiers whereas soluble components can only be transported with the water. Only soluble components may carry ionic charge. One important difference relative to ASM1 and ASM2 is that in ASM3 soluble and particulate components can better be differentiated with filtration over 0.45 μm membrane filters whereas a significant fraction of slowly biodegradable organic substrates X_s in ASM1 and ASM2 would be contained in the filtrate of the inflowing wastewater.

Definition of soluble components, S_i

1. S_O [$M(O_2) L^{-3}$]: Dissolved oxygen, O_2 . Dissolved oxygen can directly be measured and is subject to gas exchange.
2. S_I [$M(COD) L^{-3}$]: Inert soluble organic material. The prime characteristic of S_I is that these organics cannot be further degraded in the treatment plants dealt with in this paper. This material is assumed to be part of the influent and may be produced in the context of hydrolysis of particulate substrates X_s .
3. S_s [$M(COD) L^{-3}$]: Readily biodegradable organic substrates (COD). This fraction of the soluble COD is directly available for biodegradation by heterotrophic organisms. In ASM3 it is assumed that all these substrates are first taken up by heterotrophic organisms and stored in the form of X_{STO} . $S_I + S_s$ are approximately equal to the total soluble COD as determined with $0.45 \mu m$ membrane filtration.
4. S_{NH} [$M(N) L^{-3}$]: Ammonium plus ammonia nitrogen ($NH_4^{+}-N + NH_3-N$). For the balance of the ionic charges, S_{NH} is assumed to be all NH_4^{+} .
5. SN_2 [$M(N) L^{-3}$]: Dinitrogen (N_2). SN_2 is assumed to be the only product of denitrification. SN_2 may be subject to gas exchange, parallel with oxygen, S_O . It can then be used to predict problems due to supersaturation with N_2 in secondary clarifiers. Alternatively the N_2 contained in the influent and gas exchange are neglected. SN_2 may then be used to add up any fixed nitrogen lost due to denitrification.
6. S_{NO} [$M(N) L^{-3}$]: Nitrate plus nitrite nitrogen ($NO_3^{-}-N + NO_2^{-}-N$). S_{NO} is assumed to include nitrate as well as nitrite nitrogen, since nitrite is not included as a separate model component. For all stoichiometric computations (COD conservation), S_{NO} is considered to be $NO_3^{-}-N$ only.
7. S_{ALK} [mole(HCO_3^{-}) L^{-3}]: Alkalinity of the wastewater (HCO_3^{-}). Alkalinity is used to approximate the conservation of ionic charge in biological reactions. Alkalinity is introduced in order to obtain an early indication of possible low pH conditions, which might inhibit some biological processes. For all stoichiometric computations, S_{ALK} is assumed to be bicarbonate, HCO_3^{-} , only.

Definition of particulate components, X_i

8. X_I [$M(COD) L^{-3}$]: Inert particulate organic material (COD). This material is not degraded within the systems of interest. It is flocculated onto the activated sludge. X_I may be a fraction of the influent or may be produced in the context of biomass decay.
9. X_s [$M(COD) L^{-3}$]: Slowly biodegradable substrates (COD). Slowly biodegradable substrates are high molecular weight, colloidal and particulate organic substrates which must undergo cell external hydrolysis before they are available for degradation. It is assumed that the products of hydrolysis are either readily biodegradable (S_s) or inert (S_I) soluble organics. As compared to ASM1 this fraction is different. All X_s is contained in the influent and it is generally assumed that X_s is retained on a $0.45 \mu m$ membrane filter.
10. X_H [$M(COD) L^{-3}$]: Heterotrophic organisms (COD). These organisms are assumed to be the 'allrounder' heterotrophic organisms, they may grow aerobically and most of them also anoxically (denitrification). These organisms are responsible for hydrolysis of particulate substrates X_s and can use all degradable organic substrates under all relevant environmental conditions. They can form organic storage products in the form of poly-hydroxy-alkanoates or glycogen. No anaerobic activity is included in ASM3 with the exception of cell external hydrolysis.
11. X_{STO} [$M(COD) L^{-3}$]: A cell internal storage product of heterotrophic organisms (COD). It includes polyhydroxy-alkanoates (PHA), glycogen, etc. It occurs only associated with X_H ; it is, however, not included in the mass of X_H . X_{STO} cannot be directly compared with analytically measured PHA or glycogen concentrations; X_{STO} is only a functional component required for modeling but not directly identifiable

chemically. X_{STO} may, however, be recovered in COD analysis, where it must satisfy COD conservation. For stoichiometric considerations, X_{STO} is assumed to have the chemical composition of poly-hydroxybutyrate ($C_4H_6O_2$)_n.

12. X_A [M(COD) L⁻³]: Nitrifying organisms (COD). Nitrifying organisms are responsible for nitrification; they are obligate aerobic, chemo-litho-autotrophic. It is assumed that nitrifiers oxidize ammonium S_{NH} directly to nitrate S_{NO} . Nitrite as an intermediate component of nitrification is not considered in ASM3.

13. X_{TS} [M(TSS) L⁻³]: Total suspended solids (TSS). Total suspended solids are introduced into the biokinetic models in order to compute their concentration via stoichiometry. TSS is typically followed by treatment plant operators in day-to-day analysis. If the influent TSS ($X_{TS,O}$) include an inorganic fraction of TSS, the TSS predicted from ASM3 should also be observed in the activated sludge reactors. If chemicals are added in order to precipitate phosphorus, the precipitates formed must be added to the concentration of TSS measured in the influent. Alternatively X_{TS} may be used to model volatile suspended Solids (VSS). This requires the relevant choice of absolute numbers for the composition parameters for TSS (i_{TS} in Table 4).

ASM3: DEFINITION OF PROCESSES IN THE MODEL

ASM3 includes only the microbiological transformation processes. Chemical precipitation processes are not included, but may easily be added based on the information provided for ASM2 (Henze *et al.*, 1995). ASM3 considers the following transformation processes:

1. *Hydrolysis*: This process makes available all slowly biodegradable substrates X_s contained in the influent to an activated sludge system. It is assumed to be active independent of the electron donor. This process is different from the hydrolysis process in ASM1: It is of less dominating importance for the rates of oxygen consumption and denitrification.

2. *Aerobic storage of readily biodegradable substrate*: This process describes the storage of readily biodegradable substrate S_s in the form of cell internal storage products X_{STO} . This process requires energy in the form of ATP which is obtained from aerobic respiration. It is assumed that all substrates first become stored material and then are later assimilated to biomass. This is definitely not observed in reality however at this moment no reliable model is available which can predict the substrate flux into storage, assimilation and dissimilation respectively. Therefore the Task Group suggests for the time being this simplest assumption.

3. *Anoxic storage of readily biodegradable substrate*: This process is identical to aerobic storage but denitrification rather than aerobic respiration provides the energy required. It is unclear whether only a fraction of the heterotrophic organisms X_H in activated sludge is capable of denitrification or whether all heterotrophs may denitrify at a reduced rate as compared to aerobic respiration. ASM3 considers this by reducing the anoxic heterotrophic storage rate as compared to the aerobic rate but does not distinguish two groups of heterotrophic organisms.

4. *Aerobic growth of heterotrophs*: The substrate for the growth of heterotrophic organisms is assumed to consist entirely of stored organics X_{STO} . This assumption simplifies ASM3 considerably.

5. *Anoxic growth of heterotrophs*: This process is similar to aerobic growth but respiration is based on denitrification. Again it is not clear whether all heterotrophic organisms X_H are capable of denitrification. Experimentally we observe a reduced denitrification rate as compared with aerobic respiration.

6. *Aerobic endogenous respiration*: This process describes all forms of biomass loss and energy requirements not associated with growth by considering related respiration under aerobic conditions: Decay, (maintenance), endogenous respiration, lysis, predation, motility, death,... The model of this process is significantly different from the decay (lysis) process introduced in ASM1.

7. *Anoxic endogenous respiration*: This process is similar to aerobic endogenous respiration but typically slower. Especially protozoa (predation) are considerably less active under denitrifying than under aerobic conditions.

8. *Aerobic respiration of storage products*: This process is analogous to endogenous respiration. It ensures that storage products decay together with biomass.

9. *Anoxic respiration of storage products*: This process is analogous to the aerobic process but under denitrifying conditions.

As compared with ASM1, ASM3 includes a more detailed description of cell internal processes (storage) and allows for better adjustment of decay processes to environmental conditions. The importance of hydrolysis has been reduced and degradation of soluble and particulate organic nitrogen has been integrated into the hydrolysis, decay and growth process.

ASM3: STOICHIOMETRY

Table 1 introduces the stoichiometric matrix $v_{j,i}$ of ASM3 together with the composition matrix $\iota_{k,i}$ as proposed by Gujer and Larsen (1995). Whereas the stoichiometric matrix $v_{j,i}$ is known since the introduction of ASM1, the composition matrix is less well known. Relating to Table 1 the composition matrix may be read as follows: $\iota_{2,3}$ is filled with the symbol iNS_s and indicates that any g COD in the form of S_s contains i_{NS} g of N. The index $k = 2$ relates to the second conservative which is nitrogen, the index $i = 3$ relates to the third component which is S_s . S_s is measured in terms of g COD (as indicated below the Symbol S_s) and the conservative Nitrogen is measured in g N (as indicated to the right of Nitrogen in the composition matrix). i_{NS} therefore indicates the composition of S_s relative to nitrogen, hence $\iota_{k,i}$ is called the composition matrix.

All empty elements of $\omega_{j,i}$ or $\iota_{k,i}$ indicate values of 0. All values of x_j , y_j and z_j can be obtained from the conservation Equation 1 for the three conservatives k : COD, Nitrogen and ionic charge:

$$\sum_i v_{j,i} \cdot \iota_{k,i} = 0 \text{ for } i = 1 \text{ to } 12 \quad (1)$$

It is emphasized here that the stoichiometric coefficient for S_{N2} in any denitrification process is the negative of the coefficient for S_{NO} . The composition coefficients for the conservative COD for S_{N2} ($-1.71 \text{ g COD g}^{-1} \text{ N}_2$) and S_{NO} ($-4.57 \text{ g COD g}^{-1} \text{ NO}_3^{-}\text{-N}$) as well as S_O ($-1 \text{ g COD g}^{-1} \text{ O}_2$) are negative for electron donors relative to the redox reference which is NH_4 , CO_2 and H_2O .

The stoichiometric coefficients for the observable X_{TS} can be obtained from the composition Equation 2:

$$v_{j,13} = \sum_i v_{j,i} \cdot \iota_{4,i} \text{ for } i = 8 \text{ to } 12 \quad (2)$$

It is known that the biochemical energy (ATP) yield of anoxic respiration is smaller than in aerobic respiration. This leads to the fact that aerobic yield coefficients (Y_{STO, O_2} and Y_{HO_2}) exceed the anoxic yield coefficients ($Y_{STO, NO}$ and Y_{HNO}). Assuming the anoxic energy yield to be $\eta_{\text{anoxic}} = 0.70$ of the aerobic energy yield the following energy relationship (Equation 3) applies:

$$\frac{1 - Y_{STO, O_2}}{Y_{STO, O_2}} = \frac{\eta_{\text{anoxic}} \cdot (1 - Y_{STO, NO})}{Y_{STO, NO}} \quad \text{and} \quad \frac{1 - Y_{H, O_2}}{Y_{H, O_2}} = \frac{\eta_{\text{anoxic}} \cdot (1 - Y_{H, NO})}{Y_{H, NO}} \quad (3)$$

It is suggested that Equation 3 is used to relate anoxic and aerobic yields in ASM3.

The net (true) yield of heterotrophic biomass X_H produced per unit of substrate S_s removed in ASM3 is obtained from Equation 4:

$$Y_{\text{net},O_2} = Y_{\text{STO},O_2} \cdot Y_{H,O_2} \quad \text{and} \quad Y_{\text{net},NO} = Y_{\text{STO},NO} \cdot Y_{H,NO} \quad (4)$$

All stoichiometric parameters are defined together with their units and a typical value in Table 4. A numeric example of all stoichiometric coefficients is given in Table 6.

Table 1. Stoichiometric matrix $\omega_{j,i}$ and composition matrix $\iota_{k,i}$ of ASM3. The values of x_j , y_j , z_j , and t_j can be obtained in this sequence from mass and charge conservation (Equation 1) and composition (Equation 2)

j	Process	Component i >	1	2	3	4	5	6	7	8	9	10	11	12	13
v		expressed as >	S_O	S_I	S_S	S_{NH}	S_{N2}	S_{NO}	S_{HCO}	X_I	X_S	X_H	X_{STO}	X_A	X_{TS}
			O_2	COD	COD	N	N	N	Mole	COD	COD	COD	COD	COD	TSS
1	Hydrolysis			f_{SI}	x_1	y_1			z_1		-1				$-i_{XS}$
Heterotrophic organisms, denitrification															
2	Aerobic storage of COD		x_2		-1	y_2			z_2				Y_{STO,O_2}		t_2
3	Anoxic storage of COD				-1	y_3	$-x_3$	x_3	z_3				$Y_{\text{STO},NO}$		t_3
4	Aerobic growth		x_4			y_4			z_4			1	$-1/Y_{H,O_2}$		t_4
5	Anoxic growth (denitrification)					y_4	$-x_5$	x_5	z_5			1	$-1/Y_{H,NO}$		t_5
6	Aerobic endog. respiration		x_6			y_6			z_6	f_I		-1			t_6
7	Anoxic endog. respiration					y_7	$-x_7$	x_7	z_7	f_I		-1			t_7
8	Aerobic respiration of X_{STO}		x_8										-1		t_8
9	Anoxic respiration of X_{STO}						$-x_9$	x_9	z_9				-1		t_9
Autotrophic organisms, nitrification															
10	Nitrification		x_{10}			y_{10}		$1/Y_A$	z_{10}					1	t_{10}
11	Aerobic endog. respiration		x_{11}			y_{11}			z_{11}	f_I				-1	t_{11}
12	Anoxic endog. respiration					y_{12}	$-x_{12}$	x_{12}	z_{12}	f_I				-1	t_{12}
Composition matrix $\iota_{k,i}$															
k	Conservatives														
1	COD	g COD	-1	1	1		-1.71	-4.57		1	1	1	1	1	
2	Nitrogen	g N		i_{NSI}	i_{NSS}	1	1	1		i_{NXI}	i_{NXS}	i_{NXH}		i_{NXA}	
3	Ionic charge	Mole +				1/14		-1/14	-1						
Observables															
4	TSS	g TSS								i_{TSXI}	i_{TSXS}	i_{TSBH}	0.60	i_{TSA}	

ASM3: KINETICS

The kinetic expressions of ASM3 are based on switching functions (hyperbolic or saturation terms, Monod equations, $S/(K+S)$) for all soluble components consumed. This form of kinetic expression is chosen not because of experimental evidence but rather for mathematical convenience. These switching functions stop all biological activity as educts of a process approach zero concentrations, an important difference between ASM1 and ASM3. Similarly for particulate educts the switching functions relate to the ratio of X_{STO}/X_H respectively X_S/X_H .

Table 2 is a summary of all kinetic expressions of ASM3. The parameters are defined in Table 3 together with their units and a typical value at 10 and 20°C. It is recommended to interpolate kinetic parameters k to different temperatures T (in °C) with the following temperature Equation 5:

$$k(T) = k(20^\circ\text{C}) \cdot \exp(\theta_T \cdot (T - 20^\circ\text{C})) \quad (5)$$

where θ_T (in $^{\circ}\text{C}^{-1}$) may be obtained from

$$\theta_T = \frac{\ln(k(T_1)/k(T_2))}{T_1 - T_2} \quad (6)$$

Table 2. Kinetic rate expressions p_j for ASM3. All $p_j \geq 0$

j	Process	Process rate equation p_j , all $p_j \geq 0$
1	Hydrolysis	$k_H \cdot \frac{X_S / X_H}{K_X + X_S / X_H} \cdot X_H$
Heterotrophic organisms, denitrification		
2	Aerobic storage of COD	$k_{STO} \cdot \frac{S_O}{K_O + S_O} \cdot \frac{S_S}{K_S + S_S} \cdot X_H$
3	Anoxic storage of COD	$k_{STO} \cdot \eta_{NO} \cdot \frac{K_O}{K_O + S_O} \cdot \frac{S_{NO}}{K_{NO} + S_{NO}} \cdot \frac{S_S}{K_S + S_S} \cdot X_H$
4	Aerobic growth	$\mu_H \cdot \frac{S_O}{K_O + S_O} \cdot \frac{S_{NH}}{K_{NH} + S_{NH}} \cdot \frac{S_{HCO}}{K_{HCO} + S_{HCO}} \cdot \frac{X_{STO} / X_H}{K_{STO} + X_{STO} / X_H} \cdot X_H$
5	Anoxic growth (denitrification)	$\mu_H \cdot \eta_{NO} \cdot \frac{K_O}{K_O + S_O} \cdot \frac{S_{NO}}{K_{NO} + S_{NO}} \cdot \frac{S_{NH}}{K_{NH} + S_{NH}} \cdot \frac{S_{HCO}}{K_{HCO} + S_{HCO}} \cdot \frac{X_{STO} / X_H}{K_{STO} + X_{STO} / X_H} \cdot X_H$
6	Aerobic endogenous respiration	$b_{H,O2} \cdot \frac{S_O}{K_O + S_O} \cdot X_H$
7	Anoxic endogenous respiration	$b_{H,NO} \cdot \frac{K_O}{K_O + S_O} \cdot \frac{S_{NO}}{K_{NO} + S_{NO}} \cdot X_H$
8	Aerobic respiration of X_{STO}	$b_{STO,O2} \cdot \frac{S_O}{K_O + S_O} \cdot X_{STO}$ $b_{STO,O2} \geq b_{H,O2}$
9	Anoxic respiration of X_{STO}	$b_{STO,NO} \cdot \frac{K_O}{K_O + S_O} \cdot \frac{S_{NO}}{K_{NO} + S_{NO}} \cdot X_{STO}$ $b_{STO,NO} \geq b_{H,NO}$
Autotrophic organisms, nitrification		
10	Nitrification	$\mu_A \cdot \frac{S_O}{K_{A,O} + S_O} \cdot \frac{S_{NH}}{K_{A,NH} + S_{NH}} \cdot \frac{S_{HCO}}{K_{A,HCO} + S_{HCO}} \cdot X_A$
11	Aerobic endogenous respiration	$b_{A,O2} \cdot \frac{S_O}{K_O + S_O} \cdot X_A$
12	Anoxic endogenous respiration	$b_{A,NO} \cdot \frac{K_O}{K_O + S_O} \cdot \frac{S_{NO}}{K_{NO} + S_{NO}} \cdot X_A$

ASM3: TYPICAL WASTEWATER CHARACTERISTICS, KINETIC AND STOICHIOMETRIC PARAMETERS

It is the responsibility of the user of ASM3 to determine the concentrations of relevant components in the wastewater, as well as the stoichiometric and kinetic parameters which apply to the specific case to be dealt with. *Absolute numbers of these parameters are not part of ASM3!* They are necessary however if ASM3 is to be applied to any specific case.

In Tables 3 to 6 a set of typical model parameters and concentrations of model components in a primary effluent is provided for convenience. This neither indicates that ASM3 is meant to be reliable with these parameters in any case, nor that these parameters are the state of the art. They are merely presented here as a reference for testing computer code and as a first estimate for the design of possible experiments which may be used to identify these parameters more accurately.

Table 3. Typical values of kinetic parameters for ASM3. These values are provided as examples and *are not part of ASM3!*

Symbol	Characterization	Temperature		Units
		10°C	20°C	
k_H	Hydrolysis rate constant	2	3	$\text{g } X_S \text{ g}^{-1} X_H \text{ d}^{-1}$
K_X	Hydrolysis saturation constant	1	1	$\text{g } X_S \text{ g}^{-1} X_H$
Heterotrophic organisms, denitrification, X_H				
k_{STO}	Storage rate constant	2.5	5	$\text{g } S_S \text{ g}^{-1} X_H \text{ d}^{-1}$
η_{NO}	Anoxic reduction factor	0.6	0.6	-
K_O	Saturation constant for S_O	0.2	0.2	$\text{g } O_2 \text{ m}^{-3}$
K_{NO}	Saturation constant for S_{NO}	0.5	0.5	$\text{g } NO_3^- - N \text{ m}^{-3}$
K_S	Saturation constant for substrate S_S	2	2	$\text{g } COD \text{ m}^{-3}$
K_{STO}	Saturation constant for X_{STO}	1	1	$\text{g } X_{STO} \text{ g}^{-1} X_H$
μ_H	Heterotrophic max. growth rate	1	2	d^{-1}
K_{NH}	Saturation constant for ammonium, S_{NH}	0.01	0.01	$\text{g } N \text{ m}^{-3}$
K_{HCO}	Bicarbonate saturation constant of X_H	0.1	0.1	$\text{mole } HCO_3^- \text{ m}^{-3}$
b_{H,O_2}	Aerobic endogenous respiration rate of X_H	0.1	0.2	d^{-1}
$b_{H,NO}$	Anoxic endogenous respiration rate of X_H	0.05	0.1	d^{-1}
b_{STO,O_2}	Aerobic respiration rate for X_{STO}	0.1	0.2	d^{-1}
$b_{STO,NO}$	Anoxic respiration rate for X_{STO}	0.05	0.1	d^{-1}
Autotrophic organisms, nitrification, X_A				
μ_A	Autotrophic max. growth rate of X_A	0.35	1.0	d^{-1}
$K_{A,NH}$	Ammonium substrate saturation for X_A	1	1	$\text{g } N \text{ m}^{-3}$
$K_{A,O}$	Oxygen saturation for nitrifiers	0.5	0.5	$\text{g } O_2 \text{ m}^{-3}$
$K_{A,HCO}$	Bicarbonate saturation for nitrifiers	0.5	0.5	$\text{mole } HCO_3^- \text{ m}^{-3}$
b_{A,O_2}	Aerobic endogenous respiration rate of X_A	0.05	0.15	d^{-1}
$b_{A,NO}$	Anoxic endogenous respiration rate of X_A	0.02	0.05	d^{-1}

Table 4. Typical stoichiometric and composition parameters for ASM3. These values are given as examples and *are not part of ASM3!*

Symbol	Characterization	Value	Units	
f_{SI}	Production of S_I in hydrolysis	0	$\text{g } S_I \text{ g}^{-1} X_S$	
Y_{STO,O_2}	Aerobic yield of stored product per S_S	0.85	$\text{g } X_{STO} \text{ g}^{-1} S_S$	
$Y_{STO,NO}$	Anoxic yield of stored product per S_S	0.80	$\text{g } X_{STO} \text{ g}^{-1} S_S$	
Y_{H,O_2}	Aerobic yield of heterotrophic biomass	0.63	$\text{g } X_H \text{ g}^{-1} X_{STO}$	
$Y_{H,NO}$	Anoxic yield of heterotrophic biomass	0.54	$\text{g } X_H \text{ g}^{-1} X_{STO}$	
Y_A	Yield of autotrophic biomass per $NO_3^- - N$	0.24	$\text{g } X_A \text{ g}^{-1} S_{NO}$	
i_{NSI}	N content of S_I	0.01	$\text{g } N \text{ g}^{-1} S_I$	
i_{NSS}	N content of S_S	0.03	$\text{g } N \text{ g}^{-1} S_S$	
i_{NXI}	N content of X_I	0.02	$\text{g } N \text{ g}^{-1} X_I$	
i_{NXS}	N content of X_S	0.04	$\text{g } N \text{ g}^{-1} X_S$	
i_{NBM}	N content of biomass, X_H , X_A	0.07	$\text{g } N \text{ g}^{-1} X_{H \text{ or } A}$	The values below are suggested if X_{TS} is used to model VSS rather than TSS
i_{TSXI}	TSS to COD ratio for X_I	0.75	$\text{g } TS \text{ g}^{-1} X_I$	
i_{TSXS}	TSS to COD ratio for X_S	0.75	$\text{g } TS \text{ g}^{-1} X_S$	
i_{TSBM}	TSS to COD ratio for biomass, X_H , X_A	0.90	$\text{g } TS \text{ g}^{-1} X_{H \text{ or } A}$	
i_{TSSTO}	TSS to COD ratio for X_{STO} based on PHB	0.60	$\text{g } TS \text{ g}^{-1} X_{STO}$	

Table 3 contains a list of typical kinetic parameters, Table 4 suggests some typical stoichiometric parameters, Table 5 indicates the composition of a typical primary effluent and finally Table 6 is a stoichiometric matrix, based on Table 1 and the specific values introduced in Table 4.

Table 5. Short definition of model components and typical wastewater composition (primary effluent) for ASM3. The value of TKN considers the composition of the different model components as indicated in

Table 4: $\text{TKN} = \sum S_i \text{ } t_{2,i}$ over all components i - $S_{\text{NO}} S_{\text{N2}}$

$\text{COD}_{\text{tot}} = 260 \text{ g COD m}^{-3}$, $\text{TKN} = 25 \text{ g N m}^{-3}$		
Dissolved components		Concentration Units
S_{O}	Dissolved Oxygen	$0 \text{ g O}_2 \text{ m}^{-3}$
S_{I}	Soluble inert organics	30 g COD m^{-3}
S_{S}	Readily biodegradable substrates	100 g COD m^{-3}
S_{NH}	Ammonium	16 g N m^{-3}
S_{N2}	Dinitrogen, released by denitrification	0 g N m^{-3}
S_{NO}	Nitrite plus Nitrate	0 g N m^{-3}
S_{HCO}	Alkalinity, Bicarbonate	$5 \text{ mole HCO}_3^- \text{ m}^{-3}$
Particulate components		
X_{I}	Inert particulate organics	25 g COD m^{-3}
X_{S}	Slowly biodegradable substrates	75 g COD m^{-3}
X_{H}	Heterotrophic biomass	30 g COD m^{-3}
X_{STO}	Organics stored by heterotrophs	0 g COD m^{-3}
X_{A}	Autotrophic, nitrifying biomass	0 g COD m^{-3}
X_{TS}	Total suspended solids	125 g TSS m^{-3}

The value below is suggested if X_{TS} is used to model VSS rather than TSS
100 g VSS m^{-3}

Table 6. Stoichiometric matrix of ASM3 based on the stoichiometric parameters in Table 4. This Matrix is a typical application of ASM3 but it is not suggested as a reliable form of ASM3

j	Process	component i >	1	2	3	4	5	6	7	8	9	10	11	12	13
v		expressed as >	S_{O} O_2	S_{I} COD	S_{S} COD	S_{NH} N	S_{N2} N	S_{NO} N	S_{HCO} Mole	X_{I} COD	X_{S} COD	X_{H} COD	X_{STO} COD	X_{A} COD	X_{TS} TSS
1	Hydrolysis			0	1	0.01			0.001		-1				-0.75
Heterotrophic organisms, denitrification															
2	Aerobic storage of COD		-0.15		-1	0.03			0.002				0.85		0.51
3	Anoxic storage of COD				-1	0.03	0.07	-0.07	0.007				0.80		0.48
4	Aerobic growth		-0.60			-0.07			-0.005			1	-1.60		-0.06
5	Anoxic growth (denitrification)					-0.07	0.30	-0.30	0.016			1	-1.85		-0.21
6	Aerobic endog. Respiration		-0.80			0.066			0.005	0.20		-1			-0.75
7	Anoxic endog. Respiration					0.066	0.28	-0.28	0.025	0.20		-1			-0.75
8	Aerobic respiration of X_{STO}		-1										-1		-0.60
9	Anoxic respiration of X_{STO}						0.35	-0.35	0.025				-1		-0.60
Autotrophic organisms, nitrification															
10	Nitrification		-18.04			-4.24		4.17	-0.600					1	0.90
11	Aerobic endog. respiration		-0.80			0.066			0.005	0.20				-1	-0.75
12	Anoxic endog. respiration					0.066	0.28	-0.28	0.025	0.20				-1	-0.75

DISCUSSION AND CONCLUSION

The complexity of ASM3 is comparable to ASM1. With the shift of emphasis from hydrolysis to storage of organic substrates one important aspect of wastewater characterization is changed: readily biodegradable COD in ASM1 has to be estimated from a respiration test and the interpretation of this test depends on the value of Y_{H} . In ASM3 soluble COD is composed of S_{I} + S_{S} only. This is seen in Table 5 where S_{S} is now about 40% of total COD rather than only about 10% as used in ASM1. This adjustment became possible with the introduction of stored substrates which have been postulated and observed by many researchers. Nevertheless correct characterisation of wastewater for the use of ASM3 will still rely on bioassays which relate respiration in order to identify readily biodegradable substrate S_{S} .

In ASM1 one decay process (lysis) has been introduced to describe the sum of all decay processes. This was due to the fact that in 1985, when ASM1 was first published, computing power was still scarce. The simplest description possible saved computation time. Today, as computation is not limiting simulation to the same extent, a more realistic description of decay processes is introduced: endogenous respiration is close to the phenomena observed (we typically measure a respiration rate) and the relevant rate constants can be obtained directly and independently of stoichiometric parameters (from the slope of $\ln(r_{O_2, \text{endog}})$ versus time).

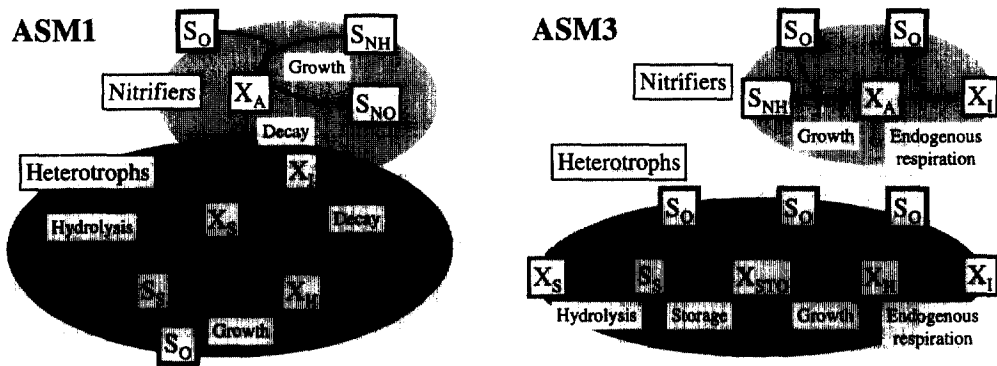


Figure 1. Flow of COD in ASM1 and ASM3. In ASM1 (left) heterotrophic organisms use COD in a cyclic reaction scheme: Decay feeds into hydrolysis and triggers additional growth. Nitrifiers decay and thereby enhance heterotrophic growth. Autotrophic and heterotrophic organisms cannot be entirely separated. Only two entry points for oxygen exist. In ASM3 (right) nitrifiers and heterotrophs are clearly separated, no COD flows from one group to the other. Many entry points for oxygen exist.

The flow of COD in ASM1 is rather complex. The death (decay) regeneration cycle of the heterotrophs and the decay process of nitrifiers are strongly interrelated (Figure 1). The two decay processes differ significantly in their details. This results in differing and confusing meanings of the two decay rates in ASM1. In ASM3 all the conversion processes of the two groups of organisms are clearly separated and decay processes are described with identical models (Figure 1).

Similar to ASM2 (Henze *et al.*, 1995) ASM3 includes cell internal storage compounds. This requires the biomass to be modelled with cell internal structure. Decay processes must include both fractions of the biomass, hence four decay processes are required (aerobic and anoxic loss of X_H as well as X_{STO}) and the kinetics of the growth processes (aerobic and anoxic) must relate to the ratio of X_{STO}/X_H .

ASM3 has not yet been tested against a large variety of experimental data. It is expected that future improvements of model structure may still be required, especially for the description of the storage phenomena. It is obvious that in the beginning experience with ASM3 might be inferior to experience with ASM1. But as our experience will improve the two models might well prove to be equivalent. ASM3 has the advantage that its structure does not have to be adjusted in order to be applicable even if ammonium or bicarbonate limit microbial activity. Therefore if we report that a simulation was performed with ASM3 we can assume the structure proposed in this report.

It is good practice to indicate if model structure has been changed: this would then be a dialect of ASM3 but not ASM3 itself.

LITERATURE

The following limited citations relate to the topic discussed in this report and may be useful to understand the background and the presentation of ASM3. The Task Group would like to apologize for not following

the standard rules of citation of scientific work and acknowledges that a vast literature has stimulated its work. It appears impossible to explicitly identify the specific source of the elements of ASM3.

Henze, M., Grady, C. P. L., Jr, Gujer, W., Marais, G. v. R. and Matsuo, T. (1987). *Activated Sludge Model No. 1*. IAWPRC Scientific and Technical Report No. 1, IAWPRC, London.

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