

Concept of a dynamic model of SMP and EPS formation based on the Activated Sludge Model No. 1

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ABSTRACT: The paper presents a dynamic mathematical model which is able to predict formation of soluble microbial products (SMP) and external polymer substrates (EPS) by introducing an extension to the Activated Sludge Model No. 1. ASM1 was originally made of 8 biological processes and 13 state variables representing DO and fractions of COD and N. The original model was expanded by adding 3 additional state variables – UAP, BAP and EPS and 5 additional reaction terms describing utilization and formation processes of the added variables. EPS is formed during biomass decay and is converted to BAP through biomass assisted hydrolysis. UAP and BAP are produced and consumed as a result of biomass activity and their concentrations add up to form SMP. Extra kinetic and stoichiometric parameters introduced to the model were estimated based on the experimental results from Lu et al. (2001). Simulations with the estimated parameter set gave a good approximation of the produced SMP and thus the model will be used in further research in an attempt to model a combined process of biological SMP formation and fouling in a membrane bioreactor.

1 INTRODUCTION

The number of full-scale applications of membrane bioreactors (MBR) has been increasing over the last few years and gained importance in industrial effluent but also in municipal waste water treatment. A major issue preventing an even wider popularity of membrane processes in wastewater treatment is reversible and irreversible membrane fouling. Membrane fouling is a complex process involving many different phenomena like pore constriction, pore blockage and cake filtration and is responsible for flux decline in time due to an increased TMP (transmembrane pressure). It is assumed that membrane fouling is mostly caused by the presence of protein-like soluble microbial products (SMP) which block the membrane pores (Carroll et al., 2000; Lee et al., 2004; Park et al. 2005; Meng et al., 2006, etc.) and lead to severe flux decline and alteration of membrane rejection properties.

It is therefore needed to construct a model capable of predicting the rates of EPS and SMP formation in order to be able to numerically calculate the formation of foulants and thus the rates of membrane fouling.

At the moment activated sludge models like ASM1, ASM2d or ASM3 are not capable of predicting SMP concentrations. ASM1 is the first activated sludge model which became widely used and was introduced in 1987 by Henze et al. (1987). It has

gained much popularity over the last 20 years and is still considered as 'state of the art' model for modelling municipal wastewater treatment with carbon and nitrogen removal. The model has been applied in hundreds if not thousands of research and practical simulation studies and therefore has been extensively tested and its parameters have been well calibrated. ASM1 is able to predict oxygen demand and sludge production in aerobic and anoxic systems and calculate effluent quality with regards to Nitrogen and Carbonaceous components (mainly N-NH_4^+ , N-NO_3^- , N_{org} , COD, BOD_5).

However, calculations of soluble effluent COD are done in a very simplified way by setting an average fraction of inlet COD which is soluble inert and which goes through the system untreated. In fully nitrifying system where complete biodegradable carbon removal takes place, it implies that the effluent soluble COD is equal to the influent inert soluble COD. In most cases this is not true as soluble COD (SMP) is also produced and consumed as a result of biomass activity. Therefore, inclusion of SMP in the ASM1 process may improve the model predictability of soluble COD concentrations. This can be of importance in long sludge age systems where elevated effluent COD concentrations are an issue, (Baskir and Hansford, 1980; Rittmann et al., 1987; Hao and Lao, 1988; Pribyl et al., 1997).

Many researchers have attempted to build a model capable of simulating SMP formation and

utilisation processes and this has been done in many different ways. Lu et al. (2001) created an ASM1 modification which included two additional states: S_{UAP} and S_{BAP} (Utilisation Associated Products and Biomass Associated Products). However, during the analysis of their paper, some defects of the model were found. One of the deficiencies was negative S_{BAP} concentrations produced during the simulation runs. Ahn et al. (2006) created an ASM1 extension with extracellular polymeric substances (EPS). Oliveira-Esquerre et al. (2006) produced a modified ASM3 model which included microbial products (MP) as an additional state. Jang et al. (2006) provided a steady state model including biomass associated product (BAP), utilization associated product (UAP) and EPS. Lapsidou and Rittmann (2002) produced a dynamic model which also included EPS, UAP and BAP, but which was not based on any Activated Sludge Model as described by IAWQ, (Henze et al., 1987).

The main task of this study was to develop an SMP and EPS formation model which would combine all concepts and ideas of the above mentioned models and thus could model the SMP formation processes in the most complete manner.

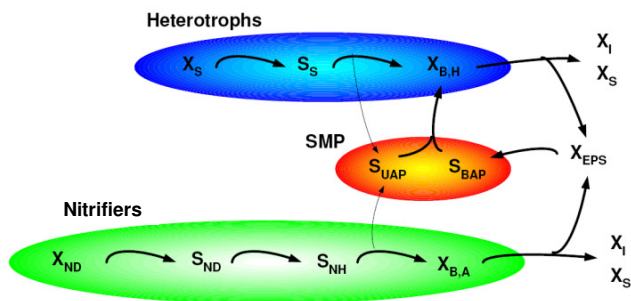


Figure 1: Schematic layout of the new modified Activated Sludge Model No. 1 with SMP (UAP and BAP) and EPS.

2 MODEL DEVELOPMENT

The model that was developed is based on IAWQ ASM1 activated sludge model. A schematic layout showing EPS, UAP and BAP formation and utilisation process paths is shown in Figure 1 above. The model is based on the following hypotheses:

- X_{EPS} is a particulate component which is produced as one of the products of biomass decay and undergoes hydrolysis to form a soluble component S_{BAP} .
- A soluble component S_{UAP} is created as a product of autotrophic and heterotrophic biomass activity and is used as a substrate by heterotrophic biomass (together with S_S and S_{BAP}).
- A soluble component S_{BAP} is produced from EPS hydrolysis and is taken up by heterotrophic biomass (together with S_S and S_{BAP}).
- SMP concentration is calculated as a sum of S_{UAP} and S_{BAP} .

The new model is an extension of ASM1 which means that the original processes of ASM1 were not changed. As mentioned earlier the new model introduces three new state variables (S_{UAP} , S_{BAP} and X_{EPS}) and five new processes: aerobic and anoxic growth of heterotrophs on S_{UAP} , aerobic and anoxic growth of heterotrophs on S_{BAP} and hydrolysis of X_{EPS} . These new processes are based on Monod kinetics and will be described in more detail in the latter paragraphs.

Model stoichiometry and mass conservation are presented in the form of Petersen Matrices and shown in Tables 4 and 5. Some of the stoichiometric coefficients in the original ASM1 model had to be modified in order to satisfy COD, N and charge balances in each process. This creates coupling between old and new transformation reactions and means that some of the original default stoichiometric parameter set will need to be altered in order to create a model which is equivalent to the original ASM1 with its default parameters. Degrees to which new parameters influence the original ASM1 processes are explained later on during the sensitivity analysis.

The model introduces seven new stoichiometric and kinetic parameters associated with SMP and EPS. These are listed in Table 3 below. All other stoichiometric and kinetic parameters in the model follow the naming conventions introduced in ASM1.

Table 3. Newly introduced stoichiometric and kinetic parameters

Parameter	Unit	Description
Y_{SMP}	--	Yield coefficient for SMP
γ_H	--	UAP formation constant for heterotrophs
γ_A	--	UAP formation constant for autotrophs
μ_{SMP}	d^{-1}	Max. specific growth rate on SMP
K_{SMP}	$gCOD/m^3$	Half-saturation constant for SMP
f_{EPS}	--	Fraction of EPS produced through decay
f_M^*	--	Fraction of SMP going through the membrane
i_{XBAP}	$gN/gCOD$	mass N / mass COD in S_{BAP}
i_{XUAP}	$gN/gCOD$	mass N / mass COD in S_{UAP}

* SMP is not truly soluble and therefore some fraction of its mass does not pass through the membrane and is retained in the reactor

2.1 Decay of heterotrophic and autotrophic biomass

This is an original ASM1 process and follows a death/regeneration concept. Stoichiometry of this process has however been modified in such a way that that the biomass no longer produces X_P and X_S only, but also X_{EPS} is produced through biomass decay. The amount of X_{EPS} produced during the decay processes depends on the new stoichiometric parameter f_{EPS} (see Table 3). The larger the parameter is the more X_{EPS} and the less X_S is produced from the biomass decay.

2.2 Hydrolysis of EPS

This new process is based on the structure of the ASM1 process describing hydrolysis of entrapped organics and is modelled on the basis of surface reaction kinetics ($X_{EPS}/X_H / (K_X + X_{EPS}/X_H)$). The rate of hydrolysis is reduced under anoxic conditions compared with aerobic conditions by a factor η_g as described in the original ASM1 model. X_{EPS} is hydrolysed by heterotrophic microorganisms and as a result of this reaction S_{BAP} is produced. The process rate describing hydrolysis of EPS is presented in the Equation 1 below.

$$\rho_{04} = k_H \cdot \frac{X_{EPS} / X_H}{K_X + X_{EPS} / X_H} \cdot \left(\frac{S_O}{K_{O,H} + S_O} + \eta_g \cdot \frac{K_{O,H}}{K_{O,H} + S_O} \cdot \frac{S_{NO}}{K_{NO} + S_{NO}} \right) \cdot X_H \quad (1)$$

2.3 Aerobic growth of heterotrophs on S_{BAP} and S_{UAP}

S_{BAP} and S_{UAP} are utilised by heterotrophic biomass in a similar way as S_S and are used for biomass growth. Heterotrophic biomass growth processes on S_{BAP} and S_{UAP} are governed by Equations 2 and 3 respectively.

$$\rho_{06} = \mu_{SMP} \cdot \frac{S_{BAP}}{K_{SMP} + S_{BAP}} \cdot \frac{S_O}{K_{O,H} + S_O} \cdot X_H \quad (2)$$

$$\rho_{07} = \mu_{SMP} \cdot \frac{S_{UAP}}{K_{SMP} + S_{UAP}} \cdot \frac{S_O}{K_{O,H} + S_O} \cdot X_H \quad (3)$$

Both rates are limited by low oxygen and S_{BAP} and S_{UAP} concentrations in the bulk liquid. These parameters affect heterotrophic growth rates on SMP (ρ_{06} & ρ_{07}) by reducing the maximum growth rate on SMP (μ_{SMP} , d^{-1}).

2.4 Anoxic growth of heterotrophs on S_{BAP} and S_{UAP}

Under anoxic conditions S_{BAP} and S_{UAP} are utilised by heterotrophic biomass along with S_S as electron donor for denitrification process. The equations modelling heterotrophic biomass growth on S_{BAP} and S_{UAP} under anoxic conditions (Equation 4 and 5) are based on the model of anoxic heterotrophic growth rate on S_S .

$$\rho_{09} = \mu_{SMP} \cdot \eta_g \cdot \frac{S_{BAP}}{K_{SMP} + S_{BAP}} \cdot \frac{K_{O,H}}{K_{O,H} + S_O} \cdot \frac{S_{NO}}{K_{NO} + S_{NO}} \cdot X_H \quad (4)$$

$$\rho_{10} = \mu_{SMP} \cdot \eta_g \cdot \frac{S_{UAP}}{K_{SMP} + S_{UAP}} \cdot \frac{K_{O,H}}{K_{O,H} + S_O} \cdot \frac{S_{NO}}{K_{NO} + S_{NO}} \cdot X_H \quad (5)$$

Both rates are limited by low S_{NO} , S_{BAP} and S_{UAP} and high S_O concentrations in the bulk liquid. The heterotrophic growth rate on SMP at anoxic conditions is reduced comparing to aerobic conditions by the anoxic growth factor η_g ($\eta_g < 1$).

3 MODEL CALIBRATION

The new model introduces 7 new stoichiometric and kinetic parameters (Table 3), which need to be determined based on real measurements. It was decided that the original parameters published in the ASM1 model will be left default during the model calibration, except the anoxic reduction coefficient which has been raised to 0.9. This might not be true as, as mentioned earlier, new reactions affect the old processes and therefore the original stoichiometric parameters would need to be altered in order to have a model which would be equivalent to the original ASM1 with its default parameter set. It is however justified to use default original parameters as a starting point as new parameters are not known a priori and therefore the impact which new processes will have on original reaction terms is unknown.

At the time of writing this paper no own measurements had been obtained from either a pilot plant or a full scale works as the pilot plant is going to be commissioned and be in operation in a few months time. In order to obtain the first (initial) set of new parameters, SMP measurements and operational data was taken from Lu et al. (2001). This information was then used in the model calibration exercise.

Data presented in Lu et al. (2001) was obtained in an experiment carried out in a single completely stirred membrane bioreactor with the working volume of 40 litres and fed with artificial wastewater based on peptone. The reactor was fed continuously but the aeration was cyclic with 30 min and 60 min aerated/non-aerated phases. Hydraulic retention time (HRT) of the system was 2.67 days and the Sludge Retention Time (SRT) was maintained at 50 days. Average temperature inside the reactor was about 25°C, average MLSS of about 13.5 mg SS/l and DO was kept constant in the aerated phases at the level of 5.0 mgO₂/l. For more information about the experimental setup used by Lu et al. (2001), the reader is asked to refer to the original paper.

Seven new parameter values were determined using model fitting to experimental data with genetic algorithms implemented in the genetic algorithm toolbox in the MATLAB® environment. As an objective function the sum of least squares of deviations between the measured and the modelled data was used. The genetic algorithm was started with an initial population of 90. Values of the estimated parameters are presented in Table 6.

Table 4. Stoichiometric matrix of the modified ASM1 model

Processes	S_I	S_S	X_I	X_S	X_H	X_A	X_{EPS}	S_{UAP}	S_{BAP}	X_P	S_O	S_{NO}	S_{NH}	S_{N_2}	S_{ND}	X_{ND}
1 Hydrolysis of entrapped organics		1		-1												
2 Hydrolysis of entrapped organic nitrogen															1	-1
3 Ammonification of soluble organic nitrogen													1		-1	
4 Hydrolysis of EPS							-1		1							
5 Aerobic growth of heterotrophs by soluble biodegradable substrate		$-\frac{1}{Y_H}$			$1-\gamma_H$			γ_H			$-\frac{1-Y_H}{Y_H}$		$-(1-\gamma_H) \cdot i_{XB}$			
6 Aerobic growth of heterotrophs by biomass associated product					$1-\gamma_H$			γ_H	$-\frac{1}{Y_{SMP}}$		$-\frac{1-Y_{SMP}}{Y_{SMP}}$		$-(1-\gamma_H) \cdot i_{XB} + \frac{1}{Y_{SMP}} \cdot i_{XBAP}$			
7 Aerobic growth of heterotrophs by utilization associated product					1			$-\frac{1}{Y_{SMP}}$			$-\frac{1-Y_{SMP}}{Y_{SMP}}$		$-i_{XB}$			
8 Anoxic growth of heterotrophs by soluble biodegradable substrate		$-\frac{1}{Y_H}$			$1-\gamma_H$			γ_H			$-\frac{1-Y_H}{2.86 \cdot Y_H}$		$-(1-\gamma_H) \cdot i_{XB}$		$\frac{1-Y_H}{2.86 \cdot Y_H}$	
9 Anoxic growth of heterotrophs by biomass associated product					$1-\gamma_H$			γ_H	$-\frac{1}{Y_{SMP}}$		$-\frac{1-Y_{SMP}}{2.86 \cdot Y_{SMP}}$		$-(1-\gamma_H) \cdot i_{XB} + \frac{1}{Y_{SMP}} \cdot i_{XBAP}$		$\frac{1-Y_{SMP}}{2.86 \cdot Y_{SMP}}$	
10 Anoxic growth of heterotrophs by utilization associated product					1			$-\frac{1}{Y_{SMP}}$			$-\frac{1-Y_{SMP}}{2.86 \cdot Y_{SMP}}$		$-i_{XB}$		$\frac{1-Y_{SMP}}{2.86 \cdot Y_{SMP}}$	
11 Aerobic growth of autotrophs						$1-\gamma_A$		γ_A			$-\frac{4.57-Y_A}{Y_A}$	$\frac{1}{Y_A}$	$-(1-\gamma_A) \cdot i_{XB} - \frac{1}{Y_A}$			
12 Decay of heterotrophs				$1-f_P - f_{EPS}$	-1		f_{EPS}			f_P						$i_{XB} - f_P \cdot i_{XP} - f_{EPS} \cdot i_{XEPS}$
13 Decay of autotrophs				$1-f_P - f_{EPS}$		-1	f_{EPS}			f_P						$i_{XB} - f_P \cdot i_{XP} - f_{EPS} \cdot i_{XEPS}$

Table 5. Composition matrix used for determining the unknown stoichiometric parameters

	S_I	S_S	X_I	X_S	X_H	X_A	X_{EPS}	S_{UAP}	S_{BAP}	X_P	S_O	S_{NO}	S_{NH}	S_{N_2}	S_{ND}	X_{ND}
COD	1	1	1	1	1	1	1	1	1	1	-1	-4.57			-1.71	
N					i_{XB}	i_{XB}	i_{XEPS}			i_{XBAP}		1	1	1	1	1
Charge												$-\frac{1}{14}$	$\frac{1}{14}$			-1

The quality of model fitting is reasonably good and will be discussed in the next section. It was however observed that different parameter sets can produce similar results. The model, like all ASM models suffers from an identifiability problem. If too many parameters are selected for calibration, there is no unique combination of parameters which describe the system behaviour. The number of data points for parameter fitting was also not sufficient which in combination with such a small plant scale introduces a lot of uncertainty in the measured data. We are not sure whether the information on the pilot-plant operational conditions provided in Lu et al. (2001) is complete or whether there is some information missing. Therefore we could not trust the results as much as we would our own data. We are hoping to carry out our own measurements on an industrial pilot

plant in the near future. It is hoped that the data provided from the pilot plant will be sufficient to perform more comprehensive model calibration and then the obtained model parameters will be less uncertain.

Table 6. Parameter values obtained during the parameter calibration with a genetic algorithm

Parameter	Unit	Value
Y_{SMP}	--	0.9
γ_H	--	0.318
γ_A	--	0.5
μ_{SMP}	d ⁻¹	1.31
K_{SMP}	gCOD/m ³	53.4
f_{EPS}	--	0.91
f_M	--	0.36
i_{XBAP}	gN/gCOD	0.093

4 SENSITIVITY ANALYSIS

As mentioned earlier, the newly introduced stoichiometric parameters affect the stoichiometric parameters of the original ASM1 model. In order to investigate what impact the newly introduced processes have on the original reaction rates as well as how sensitive the SMP and EPS formation/ degradation reactions are to the new stoichiometric/kinetic parameters, several sensitivity analyses were carried out.

In this analysis, sensitivity to Y_{SMP} , γ_H , γ_A , μ_{SMP} , K_{SMP} and f_{EPS} was analysed. γ_H , γ_A , Y_{SMP} and f_{EPS} were varied between 0.1 and 1.0. μ_{SMP} was changed between 0.1 and 1.9 and K_{SMP} was varied between 10 and 100. The following variables were monitored during the analysis: X_I , X_S , X_H , X_A , X_{EPS} , S_{UAP} , S_{BAP} and X_P . Some of the most important results are presented underneath and supported by graphical representations (Figures 2 to 8). In each sensitivity analysis only one parameter out of 5 investigated parameters was varied. Other parameters were left constant and equal to the values obtained in the model calibration exercise.

Concentration of X_I in the bulk liquid was found to be independent on all investigated parameters. Formation/degradation of X_S is strongly dependent on f_{EPS} and Y_{SMP} and slightly dependent on μ_{SMP} . X_S concentration strongly decreases with increasing f_{EPS} and Y_{SMP} and slightly increases at μ_{SMP} below 0.5 d^{-1} .

X_H increases with increasing f_{EPS} , Y_{SMP} and μ_{SMP} , decreases with increasing γ_H and is independent on K_{SMP} and γ_A . Population of X_A was found to be rather independent on all new kinetic and stoichiometric parameters. X_P was found to be independent on K_{SMP} and only slightly dependent on γ_A . Its concentration increased with f_{EPS} , Y_{SMP} and μ_{SMP} and was found to decrease with increasing γ_H . X_{EPS} was found not to be influenced by K_{SMP} and γ_A . It increased with increasing μ_{SMP} and f_{EPS} and decreased with increasing γ_H . X_{EPS} increased with Y_{SMP} for Y_{SMP} between 0.1 and 0.4 and then decreased sharply at Y_{SMP} above 0.4. S_{BAP} and S_{UAP} concentrations in the bulk liquid were found to be dependent on all new stoichiometric and kinetic parameters. The observations are presented underneath in Figures 2 to 7.

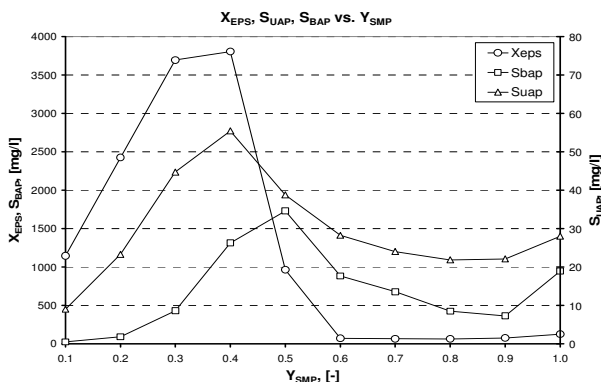


Figure 2 X_{EPS} , S_{UAP} and S_{BAP} concentrations in the bulk liquid versus Y_{SMP} .

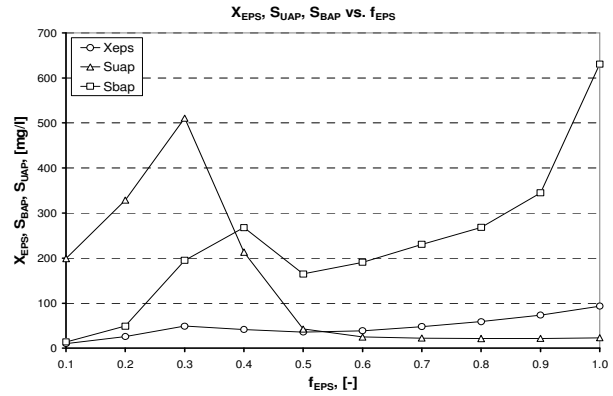


Figure 3: X_{EPS} , S_{UAP} and S_{BAP} concentrations in the bulk liquid versus f_{EPS} .

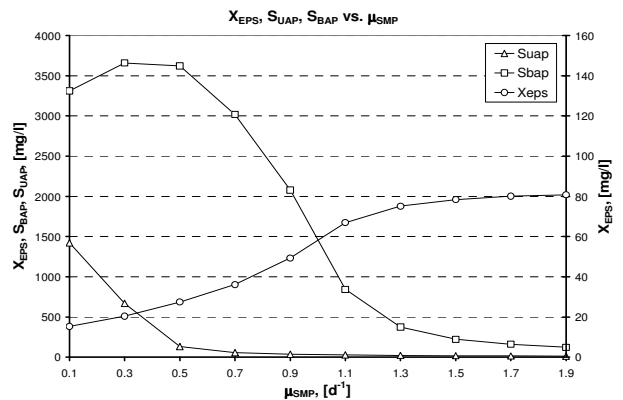


Figure 4: X_{EPS} , S_{UAP} and S_{BAP} concentrations in the bulk liquid versus μ_{SMP} .

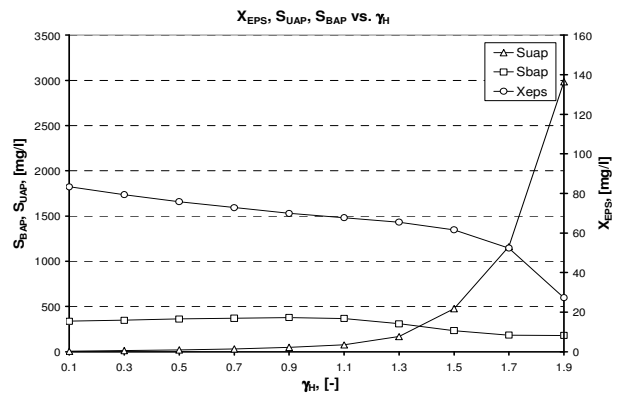


Figure 5: X_{EPS} , S_{UAP} and S_{BAP} concentrations in the bulk liquid versus γ_H .

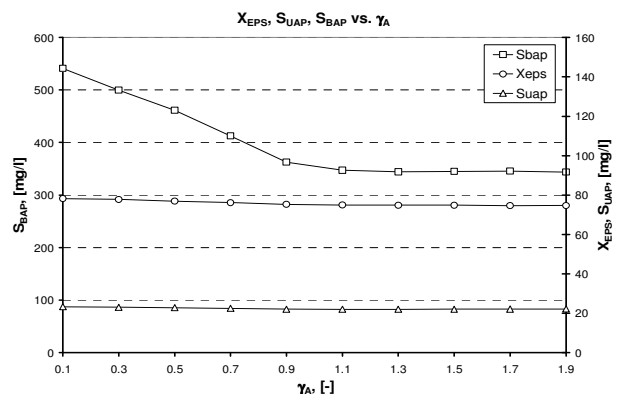


Figure 6: X_{EPS} , S_{UAP} and S_{BAP} concentrations in the bulk liquid versus γ_A .

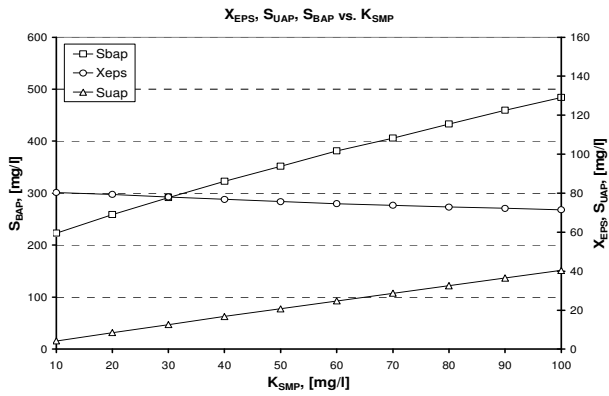


Figure 7: X_{EPS} , S_{UAP} and S_{BAP} concentrations in the bulk liquid versus K_{SMP} .

In order to graphically show how original ASM1 processes like X_A , X_H or X_P production are affected by new processes an exemplary graph describing dependency of X_S , X_H and X_P on Y_{SMP} is presented in Figure 8 below.

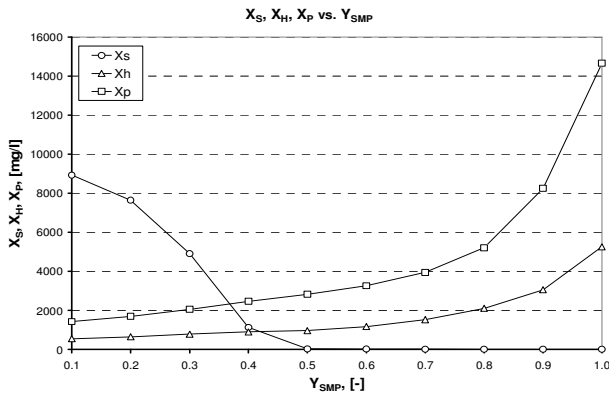


Figure 8: X_S , X_H and X_P concentrations in the bulk liquid versus Y_{SMP} .

What has been shown in here is that new SMP and EPS formation/consumption processes are all dependent on the new parameters, which means that all new processes play noticeable role in the SMP and EPS kinetics. New parameters are also affecting the old processes, which means that in order to make the new model equivalent to the original ASM1, some default stoichiometric parameters in ASM1 will need to be modified. In order to minimise the degree of interaction between the new stoichiometric parameters and the old processes, these parameters will need to be kept as small as possible. To prevent obtaining high values of the new kinetic and stoichiometric parameters either constraints or penalty functions penalising large parameter values should be put during the model calibration exercise. Parameter values obtained during our model calibration but also the ones published in the papers by Lu and Oliveira (Lu et al. 2001; Oliveira-Esquerre et al. 2006) produce strong coupling between the new parameters and the original process rates. As an effect of such a strong coupling, wrong predictions of biomass concentrations in the reactor (see the results in

Oliveira-Esquerre et al. 2006) and most probably also the oxygen requirements are observed.

5 SIMULATION RESULTS WITH A CALIBRATED PARAMETER SET

Results obtained from the simulation with calibrated parameter set are shown in Figures 9 and 10 below. Figure 9 shows the effluent soluble COD and its fractions and Figure 10 deals with Ammonia, Nitrates and Total Nitrogen. The simulation was done for a 2-hr cycle (1hr aerated phase/ 1hr non-aerated phase) and the simulation results were compared against the measurements taken from Lu et. al. (2001).

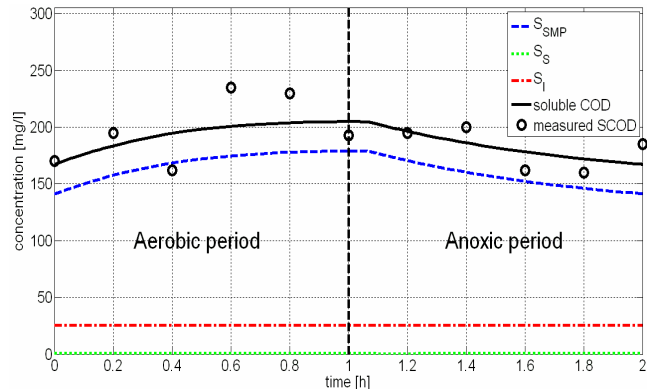


Figure 9: Simulation results and measured values for the soluble COD in the effluent

The model predicts effluent soluble COD pretty good, what implies that the model is capable to model SMP transformation processes quite well under certain conditions.

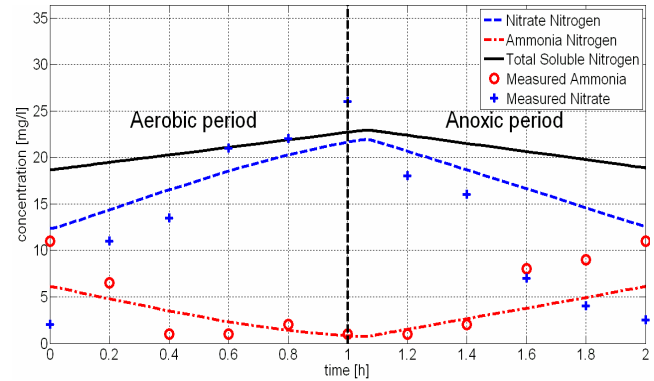


Figure 10: Simulation results and measured values for the nitrate/ammonia in the effluent

Nitrate and ammonia concentration changes however could not be well represented by the model. The model predicts lower denitrification and lower Nitrification reaction rates. This results in flatter Nitrification and Denitrification curves as shown in the Figure 10. It is assumed that this is a result of the changes that the new stoichiometric and kinetic parameters had on the old ASM1 processes. It is also

feared that the influent information presented in Lu et al. (2001) may be erroneous.

In order to obtain a more correct new kinetic and stoichiometric parameter set and validate the model structure it is therefore required to obtain new sets of experimental data. For the purpose of model calibration both SMP and EPS will need to be measured on top on other "conventional" parameter concentrations used for calibrating the original ASM1 model.

6 CONCLUSIONS

The paper presents a new possible model structure for predicting SMP concentrations in biological wastewater systems. The model development was based on several already published models and is intended to extract the most important features of each model and combine them all in a single complete activated sludge model based on ASM1.

The model introduced 3 new state variables, 5 processes and 9 new parameters which were determined by fitting the model to experimental results taken from the paper by Lu et al. (2001). During the model calibration, model identifiability problems were experienced and measurement uncertainty issues were addressed. Simulations with the calibrated parameter set gave good predictions of soluble COD but could not represent the Nitrogen transformation processes correctly.

Through sensitivity analysis it was found that the new stoichiometric and kinetic parameters governing the new SMP and EPS transformation processes also have an effect on the original ASM1 rates, which among others have an impact on heterotrophic and autotrophic growth processes and may skew sludge production, oxygen demand and biomass composition. In order to reduce the degree of interaction between the old and the new SMP and EPS transformation processes the newly obtained parameters need to be kept as small as possible. This can be obtained by penalising large values of the new parameters during the model calibration exercise. This shall be done once a larger and more certain data set is obtained from an MBR pilot plant which is intended to be commissioned in a couple months time. At present, the model calibration was based on small number of uncertain measurements and therefore values of the new stoichiometric and kinetic parameters cannot be trusted. In addition to that, current parameters provide high degree of coupling between the new and the original ASM1 processes.

In the scheduled parameter identification experiment based on the above mentioned MBR pilot plant some of the parameters will need to be measured separately, so the number of parameters taken for calibration can be smaller and thus the model identifiability problem can be mitigated. Parameters which

can be identified in separate experiments will need to be first identified.

It is intended to test the predictive power of this new model on the results obtained from the mentioned MBR pilot plant. Then the questions whether the model is of the right structure, whether a unique set of model parameters can be identified and whether the coupling between new and old processes can be kept so small that the practical application of the model is feasible will be answered.

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