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Activated Sludge Model 1 (ASM 1)

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Abstract
The most simulation models of wastewater treatment have been based on ASM1that developed about a main model of activated sludge by International Research Institute for Water Pollution Control. It can be use to explain the rate of cell mass growth resulting in degradable Chemical Oxygen Demand (COD) and Nitrogen (N) (Particulate and soluble) in systems contain the both aerobic and anoxic zones of treatment. In municipal wastewater treatment using activated sludge process, the whole process continuously to ensure continuity and compliance with legal requirements and minimize costs, especially energy must be controlled. Organic matter, dissolved molecules, colloids and solids, minerals, soluble forms of nitrogen (ammonium, nitrite and nitrate) and phosphorus discharges and concentrations will change with time. In current research the relatively complex models of processes of remove the anoxic and aerobic nitrogen and carbon (C) considering the assumptions and mathematical equations and kinetics were followed in municipal wastewater treatment. In order to provide a model, in the form of a matrix, there are a range of reactions. According to the obtained results ASM1 was formed of a matrix 13×8.

Keyword: Activated sludge, Model, ASM 1, Activated sludge model 1

Introduction

In recent years, the complexity of the models has increased considerably with the discovery of new processes and as a result the modelling task became more time consuming with calibration of the model parameters. In this context, a compromise should be found between the difficulties in parameter estimation with large models and the characterization of important processes taking place in the reactors [1,2]. The model selection task is based on the target of the model use. Cost reduction and the search for process operating conditions that allow achievement of appropriate effluent quality criteria are the most common targets to be achieved with the model studies. After the model selection task, the most important issue is using this model to characterize the overall activated sludge plant behavior including the biological and physico-chemical phenomena, the so-called model 'calibration'. After a successful validation of the model, it can serve for its purpose [3,4].

The protocol for the calibration of activated sludge models is composed of four main stages and 12 modules. The first stage is the definition of the target(s) of the modelling exercise followed by decision making on the necessary information to be obtained from the activated sludge plant such that the target of the modelling study can be reached. Some of the modules can be skipped depending on the general evaluation whether the targets are reached. The second stage is the collection of detailed information on the activated sludge plant. The mass transfer (hydraulic and oxygen transfer), biological, settling and the influent characterizations are included in this step. In addition, the experimental or lab-scale work is incorporated with usage of the Optimal Experimental Design methodology [5,6]. By averaging the influent and operational characteristics, steady state modelling is performed for the mass transfer, settler and the biological model. The third step includes the complete calibration of the activated sludge model using the dynamic influent data, and incorporating the parameter values obtained from lab scale experiments or full-scale data. At the last stage, decisions will be made upon eventual re-iteration of a number of the modules. The proposed protocol for the modelling of the treatment plant is refined on the basis of a previous protocol developed by Petersen (2000) [7,8].

Activated Sludge Models (ASM1, ASM2-ASM2d, ASM3) proposed by the IWA (formerly IAWPRC,

then IAWQ) task group on Mathematical Modeling for Design and Operation of Biological Wastewater Treatment are the most commonly applied mathematical models for the modelling of the biological compartments of wastewater treatment plants. The ASM family models has been successfully applied to full-scale treatment plants and shown to be a good compromise between the complexity of the activated sludge processes and prediction of the plant behavior under dynamic conditions. The ASM1 introduced by Henze et al. (1987) essentially describes a single-stage activated sludge system performing simultaneous COD oxidation, nitrification and denitrification processes.

In this study, a comprehensive procedure for the activated sludge model is explained which accounts for the physical and biological processes. The methodology works for different activated sludge models, depending on the targets and the available engineering knowledge [8,9]. The main objective of present study was the explaining the ASM1.

Method
The work started with a literature review of available literature related to the research. Figure 1 shows a flow chart of the procedure followed in this research [10].
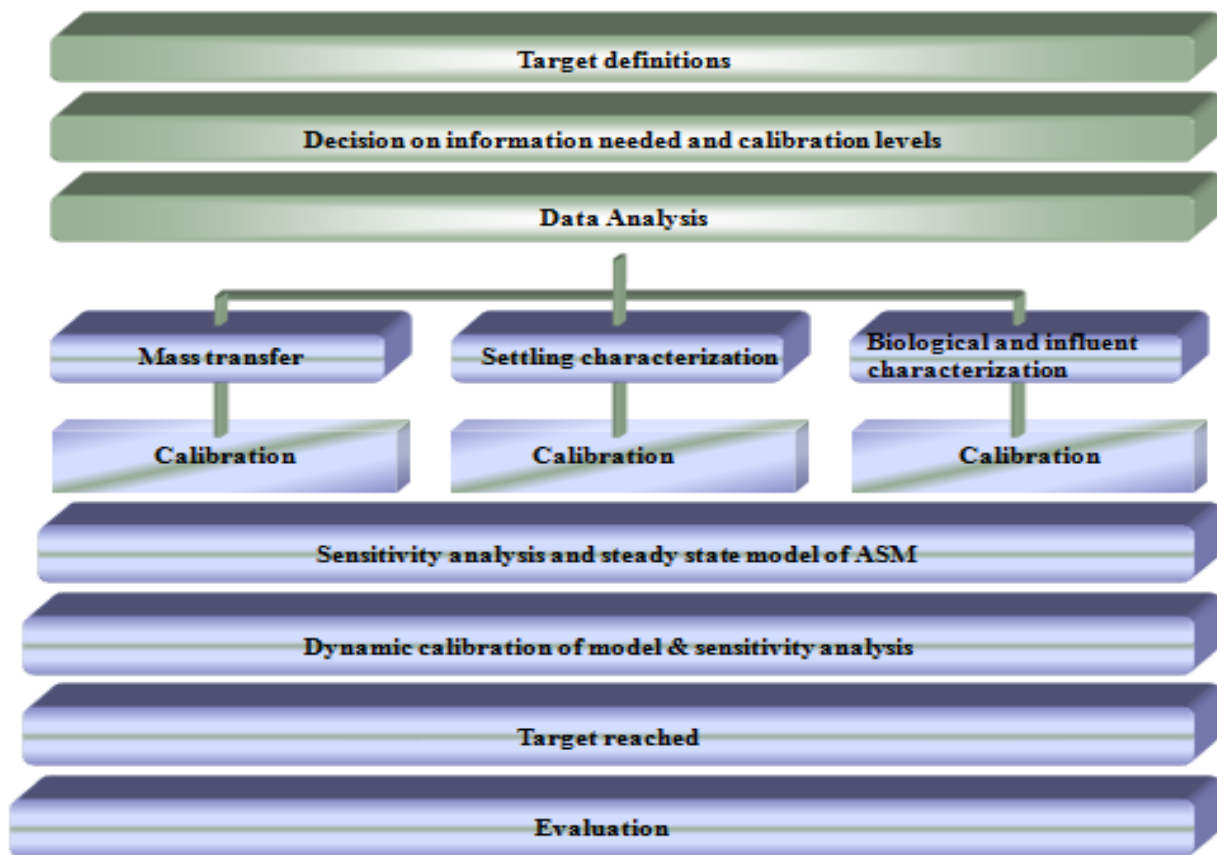

Figure 1 Flow chart of the followed work

Results and discussion
Mathematical models were developed to study of treatment processes in biological wastewater technology [11]. The main removable compounds in during treatment include organics, dissolved molecules, colloids and solid particles. Flow rates and concentrations change over time. Therefore, all processes online have to be checked to ensure

adherence with legal regulations and to decline costs and requirement energy. Based on the post-doctoral work of Gujer (1985) and the work of Henze et al. (1987and 2000) this model describes the relatively complex process of aerobic and anoxic C and N removal from municipal wastewater. In order to present the model in its fundamental form, it is shown as a matrix. ASM 1 consists of 13 different

substances and eight different processes. Table 1 shows substance concentrations of ASM 1 and the eight processes are summarized [12,13]. The reaction terms should be discussed in some detail. In present study we began with the reaction terms for soluble inert organic matter. Table 2 shows process kinetics and stoichiometric parameters of the activated sludge model ASM1 (Plotted in a matrix form (13 parameters, 8 processes) [13,14,15]. Wiesmann et al. (2007) to explain this model tried to gave an introduction to provide a better understanding. In current study has been used from all equations and factors to explain.

Table 1 Substance concentrations and processes of ASM 1

No.	Symbol	Substance	Processes
1	S_i	Soluble inert organic matter	Aerobic growth of heterotrophs
2	S_S	Readily biodegradable substrate	Anoxic growth of heterotrophs
3	X_i	Particulate inert organic matter	Aerobic growth of autotrophs
4	X_S	Slowly biodegradable substrate	Decay of heterotrophs
5	X_H	Active heterotrophic biomass	Decay of autotrophs
6	X_A	Active autotrophic biomass	Ammonification of soluble organic nitrogen
7	X_P	Particulate products from biomass decay	Hydrolysis of particulate organics
8	C'	Dissolved oxygen	Hydrolysis of particulate organic nitrogen
9	S_{NO}	Nitrate and nitrite nitrogen	
10	S_{NH4}	Ammonium and amonia nitrogen	
11	S_{NS}	Soluble degradable organic nitrogen	
12	X_{ND}	Particulate degradable organic nitrogen	
13	S_{AlK}	Alkalinity	

Units for symbols 1–7: mol L^{-1} COD; units for symbol 8: mol L^{-1} COD; units for symbols 9–12: mol L^{-1} N; units for symbol 13: mol L^{-1}.

Table 2 Process kinetics and stoichiometric parameters of the activated sludge model ASM 1

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	S_i $r_{Si} = \circ$	**process (1)**
	S_S	**process (2)**
$r_{SS} = \dfrac{1}{Y^\circ{}_{XH/SS}} \mu_{max,H} \dfrac{SS}{K_S + S_S} \left(\dfrac{C'}{K'_H + C'} + \eta \dfrac{K_{io}}{K_{io} + C'} \dfrac{S_{NO3}}{K_{NO} + S_{NO3}} \right) X_H$		
$S_{S\Sigma} = S_i + S_S$		equation (1)
	X_i $r_{xi} = \circ$	**process (3)**
$\dfrac{d_{xi}}{d_t} = \dfrac{Q_M}{V}(X_{im} - X_i)$		equation (2)
	X_S	**process (4)**
$r_{xs} = \underbrace{(1 - f_i)K_{dH}X_H}_{} + \underbrace{(1 - f_i)K_{dA}X_A}_{}$ Formation from decay of heterotrophs + Formation from decay of autotrophs		equation (3)
$-K_H \dfrac{X_S/X_H}{K_X + X_S/X_H} \left(\dfrac{C'}{K'_H + C'} + \eta \dfrac{K_{io}}{K_{io} + C'} \cdot \dfrac{S_{NO3}}{K_{NO} + S_{NO3}} \right) X_H$ Hydrolysis of entrapped organics by aerobic and anoxic bacteria		equation (4)
$f_i = \dfrac{X_i}{X_H + X_A + X_i + X_S}$		equation (5)
$1 - f_i = \dfrac{X_H + X_A + X_S}{X_H + X_A + X_i + X_S}$		equation (6)
$\eta = \dfrac{r_{H,Ax}}{r_{H,Ae}} =$ hydrolysis by anoxic bacteria /hydrolysis by aerobic bacteria		equation (7)
	X_H	**process (5)**
$r_{XH} = \underbrace{\mu_{max,H} \dfrac{S_S}{K_S + S_S} \left(\dfrac{C'}{K'_H + C'} + \eta \dfrac{K_{io}}{K_{io} + C'} \dfrac{S_{NO3}}{K_{NO} + S_{NO3}} \right) X_H}_{}$ Growth of aerobic and anoxic bacteria		equation (8)
$\underbrace{-K_{dH}X_H}_{}$ Decay of heterotrophs		equation (9)
	X_A	**process (6)**

$r_{XA} = \underbrace{\mu_{\max,A} \dfrac{S_{NH4}}{K_{SA} + S_{NH4}} \dfrac{C'}{K'_A + C'} X_A}_{} - \underbrace{K_{dA} X_A}_{}$ Decay of autotrophs - Growth of autotrophs		equation (10)
	X_P	**process (7)**
$r_{XP} = \underbrace{f_P K_{dH} X_H + f_P K_{dA} X_A}_{}$ Production rate by decay		equation (11)
$f_P = \dfrac{X_P}{X_H + X_A}$		equation (12)
	C'	**process (8)**
$r_{O2} = -Y^{\circ}_{O2/XH} \mu_{\max,H} \dfrac{S_S}{K_S + S_S} \dfrac{C'}{K'_H + C'} X_H$ $\quad - Y^{\circ}_{O2/XA} \mu_{\max,A} \dfrac{S_{NH4}}{K_{SA} + S_{NH4}} \dfrac{C'}{K'_A + C'} X_A$		equation (13)
$\underbrace{Y^{\circ}_{XH/SS}}_{} + \underbrace{Y^{\circ}_{O2/SS}}_{} = 1$ Anabolism + Catabolism		equation (14)
$Y^{\circ}_{O2/XH} = \dfrac{Y^{\circ}_{O2/SS}}{Y^{\circ}_{XH/SS}} = \dfrac{1 - Y^{\circ}_{XH/SS}}{Y^{\circ}_{XH/SS}}$		equation (15)
$Y^{\circ}_{O2/XA} = \dfrac{Y^{\circ}_{O2/NH4}}{Y^{\circ}_{XA/NH4}}$		equation (16)
$\underbrace{Y^{\circ}_{O2/NH4}}_{} = Y^{\circ}_{O2/NH4-N,\Sigma} - \underbrace{Y^{\circ}_{XA/NH4}}_{}$ Anabolism $\qquad\qquad$ Catabolism		equation (17)
$Y^{\circ}_{O2/NH4-N,\Sigma} = \dfrac{r_{O2}}{r_{NH4-N,\Sigma}} = \dfrac{64}{14} = 4.57 \dfrac{g\ O_2}{g\ NH_4 - N}$		equation (18)
$Y^{\circ}_{O2/XA} = \dfrac{4.57 - Y^{\circ}_{XA/NH4}}{Y^{\circ}_{XA/NH4}}$		equation (19)
	SNO_3	**process (9)**
$r_{NO3} = \underbrace{-Y^{\circ}_{NO3/XH} \mu_{\max,H} \eta \dfrac{S_S}{K_S + S_S} \dfrac{K_{io}}{K_{io} + C'} \dfrac{S_{NO3}}{K_{NO} + S_{NO3}} X_H}_{}$ Reduction of NO3 by denitrification		equation (20)
$\underbrace{+ Y^{\circ}_{NO3/XA} \mu_{\max,A} \dfrac{S_{NH4}}{K_{SA} + S_{NH4}} \dfrac{C'}{K'_A + C'} X_A}_{}$ Formation of NO3 by nitrification		equation (21)

$Y^{\circ}{}_{NO3/XH} = \dfrac{Y^{\circ}{}_{O2/XH}}{\Delta Y^{\circ}{}_{O2/NO3}}$		equation (22)
$\Delta Y^{\circ}{}_{O2/NO3} = Y^{\circ}{}_{O2/NH4} - Y^{\circ}{}_{O2/NO3}$		equation (23)
$Y^{\circ}{}_{O2/NH4-N,\Sigma} = 4.57 \; g \; O_2 \; (g \; NH_4 - N)^{-1}$		equation (24)
$6NH_4^+ + 12O_2 \rightarrow 6NO_3^- + 6H_2O + 12H^+$		equation (25)
$6NO_3^- + 5CH_3OH \rightarrow 3N_2 + 5Co_2 + 7H_2O + 6OH^-$		equation (26)
$7.5O_2 + 5CH_3OH \rightarrow 5Co_2 + 10H_2O$		equation (27)
$Y^{\circ}{}_{O2/NO3} = \dfrac{24-15}{6} = 1.5 \dfrac{gO}{gNO_3^-} = 1.5 \dfrac{16}{14} \dfrac{O}{mol \; N} = 1.71 \; \dfrac{O}{N}$		equation (28)
$\Delta Y^{\circ}{}_{O2/NO3} = Y^{\circ}{}_{O2/NH4} - Y^{\circ}{}_{O2/NO3} = 4.57 - 1.71 = 2.86 gO_2 (gNO3-N)^{-1}$		equation (29)
$Y^{\circ}{}_{NO3/XH} = \dfrac{1 - Y^{\circ}{}_{XH/SS}}{2/86 Y^{\circ}{}_{XH/SS}}$		equation (30)
	S_{NH4}	**Process (10)**
$r_{NH4} = \underbrace{-i_{XB}\mu_{max,H} \dfrac{S_S}{K_S + S_S} \dfrac{C'}{K'_H + C'} X_H}$ NH4 uptake by aerobic heterotrophs		equation (31)
$\underbrace{-i_{XB}.\eta\mu_{max,H} \dfrac{S_S}{K_S + S_S} \dfrac{K_{io}}{K_{io} + C'} \dfrac{S_{NO3}}{K_{NO} + S_{NH3}} X_H}$ NH4 uptake by anoxic heterotrophs		equation (32)
$\underbrace{-\left(i_{XB} + \dfrac{1}{Y^{\circ}{}_{NA/NH4}} \right) \mu_{max,A} \dfrac{S_{NH4}}{K_{SA} + S_{NH4}} \dfrac{C'}{K'_A + C'} X_A}$ NH4 uptake and NH4 oxidation by autotrophs		equation (33)
$\underbrace{+ K_a S_{ND} X_H}$ NH4 formation by anoxic hydrolysis of heterotrophs		equation (34)
	S_{ND}	**Process (11)**
$r_{ND} = \underbrace{- K_a S_{ND} X_H} + \underbrace{K_{en} X_{ND}/X_S}$ NH4 + NH3 uptake by heterotrophs + Formation of organic nitrogen by hydrolysis		equation (35)
	X_{ND}	**Process (12)**
$r_{ND} = \underbrace{i_{XB} - f_P i_{XP})k_{dH} X_H} + \underbrace{(i_{XB} - f_P i_{XP}) K_{dA} X_A} - \underbrace{K_{en} X_{ND/X_S}}$ Formation from decay of heterotrophs + Formation from decay of autotrophs- Hydrolysis		equation (36)
Nitrogen in bacteria/ particulate inert organic matter in bacteria + Slowly biodegradable substrate		equation (37)

$i_{XB} = \dfrac{X_N}{X_H + X_A + X_S}$		
$i_{XP} = \dfrac{X_N}{X_i}$ = Nitrogen in bacteria/ Particulate inert organic matter in bacteria		equation (38)
$i_{XB} - f_P i_{XP}$ = Biodegradable organic nitrogen/ Particulate organic matter		equation (39)
	S_{ALK}	**Process (13)**
$S_{ALK} = S_{HCO_3^-} + S_{CO_3^{-2}} + S_{NO3} + S_{OH^-}$		equation (40)
	S_{ALK}	equation (41)
$\dfrac{dS_{ALk}}{d_t} = \dfrac{Q_M}{V}(S_{ALK,O} - S_{ALK}) \pm r_{ALK}$		equation (42)
$r_{ALK} = \underbrace{-\dfrac{i_{XB}}{14} \mu_{\max,H} \dfrac{S_S}{K_S + S_S} \dfrac{C'}{K_H' + C'} X_H}$ Use of NO3⁻ for growth of aerobic heterotrophs		equation (43)
$\underbrace{-\left(\dfrac{i_{XB}}{14} - \dfrac{1 - Y°_{XH/SS}}{14.2.86 Y°_{XH/SS}}\right) \mu_{\max,H}.\eta \dfrac{S_S}{K_S + S_S} \dfrac{K_{io}}{K_{io} + C'} \dfrac{S_{NO3}}{K_{NO} + S_{NO3}} X_H}$ Use of NO3⁻ for growth of heterotrophs and production of HCO3⁻ by denitrification		equation (44)
$\underbrace{-\left(\dfrac{i_{XB}}{14} + \dfrac{1}{7Y°_{XA/NH4}}\right) \mu_{\max,A} \dfrac{S_{NH4}}{K_{SA} + S_{NH4}} \dfrac{C'}{K_A' + C'} X_A} + \underbrace{\dfrac{1}{14} K_{en} \dfrac{X_{ND}}{X_S}}$ Use of NO3⁻ for growth of autotrophs and use of HCO3⁻ for H+ uptake during Nitrification+ production of NO3 by hydrolysis of par ticular orgaic nitrogen		equation (45)
$NH_4^+ + 2o_2 \rightarrow NO_3^- + H_2O + 2H^+$		equation (46)
$2H^+ + 2HCO_3^- \rightarrow 2H_2CO_3$		equation (47)
$\dfrac{Y°_{HCO_3^-/NH_4^+}}{14Y°_{XA/SS}} r_{NH4} = \dfrac{1}{7Y°_{XA/SS}} r_{NH4}$		equation (48)

This assumption (rSi = 0) is a simplification made by ASM 1. In reality, such dissolved inert substances (non-biodegradable) can be formed by the hydrolysis of solid particles or other dissolved substances or they can be adsorbed on solid surfaces. rSS is the rate of COD removal by aerobic and anoxic bacteria (equation 1). SS can only be determined if Si is known. In equations of 8 process, equations 15 and 19 are introduced into the matrix of Table 3 (space i = 8 for j = 1, j = 3). As already assumed for nitrifier growth (i = 6), where nearly no NO₂ is produced, denitrification goes directly to nitrogen and the denitrification of NO₂ is not considered. The balance of anions is written in moles (equations 43, 44 and 45) to control PH. Table 3 represents the typical parameter values at neutral pH and 20 °C in domestic wastewater of USA [16 to 21].

Table 3 Typical parameter values at neutral pH and 20 °C for domestic wastewater

Symbol	Description	Units	Values
**Stoichiometric coefficients**			
r	Consumption rate	-	-
S	Substrate	$(mg\ L^{-1})$	-
V	volume	M^3	-
k_{io}	Factor of COD removal by aerobic and anoxic bacteria	-	-
f_i	Portion of inert biomass related to the total biomass	-	-
r_{o2}	Oxygen consumption	rate $(g\ m^{-3}\ h^{-1}\ COD)$	-
$-Y^\circ_{NO3/XH}$	Yield coefficient	-	-
$-Y^\circ_{NO3/XA}$	Yield coefficient	-	-
$Y^\circ_{XH/SS}$	Anabolism	Mg biomass COD formed per mg COD removed	0.60
F_P	Portion of particulate products related to biomass	Mg debris COD $(mg\ biomass\ COD)^{-1}$	0.08
i_{XB}	Nitrogen fraction in biomass	Mg N $(mg\ COD)^{-1}$ in active biomass	0.086
i_{XP}	Nitrogen fraction in endogenous mass	Mg N$(mg\ COD)^{-1}$ in biomass debris	0.06
$Y^\circ_{XA/NH4}$	Yield coefficient	Mg biomass COD formed per mg N oxidized	0.24
**Kinetic parameters**			
$\mu_{max,H}$	Heterotrophic max growth rate	h^{-1}	0.25
K_s	Substrate saturation constant	Mg L^{-1} COD	20
K'_H	Factor related to oxygen consumption of heterotrophs	Mg L^{-1} O2	0.10
K_{NO}	Nitrate saturation constant	Mg L^{-1} N	0.20
K_{dH}	Heterotrophic decay factor	h^{-1}	0.017
η	Anoxic growth correction factor	Dimensionless	0.8
η_h	Anoxic hydrolysis correction factor	Dimensionless	0.4
K_a	Ammonification rate constant	L $(mg\ biomass\ COD\ h)^{-1}$	0.0067
K_H	Hydrolysis rate constant	Mg COD $(mg\ biomass\ COD\ h)^{-1}$	0.092
K_x	Hydrolysis saturation constant	Mg COD $(mg\ biomass\ COD)^{-1}$	0.15
$\mu_{max,A}$	Autotrophic max growth rate	h^{-1}	0.032
K_{NO}	Saturation/inhibition constant for SNO	Mg L^{-1} N	1.0
K'_A	Factor related to oxygen consumption of autotrophs	Mg L^{-1} O2	0.75
K_{dA}	Autotrophic decay factor	h^{-1}	0.004
X_i	Inert particulate organic matter (COD)	After primary sedimentation $(mg\ L^{-1})$	35.0
X_S	Slowly biodegradable substrate (COD)	After primary sedimentation $(mg\ L^{-1})$	150.0
S_S	Readily biodegradable substrate (COD)	After primary sedimentation $(mg\ L^{-1})$	115.0

C'	Oxygen (O2)	After primary sedimentation (mg L^{-1})	0.0
S_{NO}	Soluble nitrate N	After primary sedimentation (mg L^{-1})	0.0
S_{NH}	Soluble ammonia N	After primary sedimentation (mg L^{-1})	25.0
S_{NS}	Soluble biodegradable organic N	After primary sedimentation (mg L^{-1})	6.5
X_{NO}	Particulate biodegradable organic N	After primary sedimentation (mg L^{-1})	8.5

The ASM 1 model makes it possible to simulate different loadings of municipal activated sludge plants in steady and non-steady state without biological phosphorous removal. It can be used as the basis for a training program for the staff of wastewater treatment plants and for design calculation of the plant and optimization of the processes [22,23].

Krist et al. (2004) focused on modelling of Wastewater Treatment Plants (WWTP) using White-box modeling. The IWA task group use to introduce the ASM model family [24]. In study of Yonghun et al. (2002), ASM1 and membrane fouling model have been developed for a submerged membrane bioreactor (SMBR). The ASM1 has been used to take account into biological characteristics of the SMBR and the resistance-in-series model was surveyed into the modified ASM1 to explain membrane fouling. The model reported as a suitable tool to optimizing operation conditions and design parameters of SMBR [25]. The study of Koch et al. (2000), showed that application from ASM3 against experimental data from aerobic, anoxic and full- scale experiments was successful to treating as well as the production and the denitrification capacity from various WWTPs in Swiss municipal wastewater [26]. Based on the research Iacopozzi et al. (2007), there are some Activated Sludge Models (ASM) such as ASM1, ASM2, ASM2d, and ASM3 [27]. Smets et al. (2003), have been developed a strategy to decline the complexity of ASM1. Therefore, this model is can be use as a valuable tool to study the risk assessment environment as well as in on-line control strategies [28].

Conclusion
ASM 1 does not describe biological or chemical phosphorus removal. The reaction terms include the some reactions of Monod parts. ASM 1 model is too simple to describe the activated sludge process. There is no single model which describes all the qualities and properties of a plant-scale activated sludge process. An activated sludge plant in non-steady operation is influenced by the complicated reaction terms, fluid dynamics, the mass transfer, the substrate removal, nitrification and the micro-kinetics.

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