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TREATMENT OF A MIXED INDUSTRIAL-DOMESTIC WASTEWATER WITH BIOLOGICAL NITROGEN REMOVAL

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ABSTRACT

Application of mathematical models in design and operation of biological nutrient removal systems is becoming more important with the legislations getting stricter. Recent developments in computer technology enabled development of computer programs that are able to solve complex models required to describe the processes taking place in activated sludge plants. In this study, methods for determining COD and nitrogen fractions and kinetic and stoichiometric parameters for domestic and industrial wastewaters are evaluated, and wastewater is fractionated using actual plant measurements and results of previous studies in literature. In addition, IWAQ Activated Sludge Model Number 1 (ASM1) is applied to Comodepur Wastewater Treatment Plant Italy using ASM 1 run-time simulation environment. Due to limitations of the software for simulating the behavior of Comodepur WWTP, benchmark configuration of the model had been used and Post Denitrification has not been included in the study. Mostly default kinetic and stoichiometric parameters offered by IWAQ Task Group are used in simulations some of them had been calibrated to get closer values to the measured ones. Since the simulation study lacked the study of Post Denitrification of the plant because of the incompatibility of the software, true capacity and shortcomings of Comodepur Waste water treatment plant cannot be determined. Therefore further study is proposed for determination of the Organic capacity and Nitrogen Removal efficiency. Therefore it is shown that the fate of carbonaceous and nitrogenous components of wastewater and MLSS concentration in aeration tanks requires sensitivity analysis for model calibration so that plant's response to various conditions can be estimated using ASM1. For WWTPs with complex design lay out and high influent volumes use of ASM 1 is not recommended and instead newer and latest versions of JASS Activated Sludge Models are recommended for future studies.

Keywords: Modeling, ASM1, Activated Sludge Process, Nitrogen Removal, Waste water treatment plant, COD Removal.

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INTRODUCTION

One of the most widespread biological wastewater treatment techniques is the activated sludge process. In this process, a bacterial biomass suspension is responsible for the removal of pollutants. Depending on the design and the specific application, an activated sludge wastewater treatment plant can achieve biological nitrogen removal and biological phosphorus removal, besides removal of organic carbon substances.

As the environmental legislations imposing stricter effluent standards, more complicated methods for design, operation and control of wastewater treatment plants are needed. As a result, mathematical models have been developed and widely used to assist design and operation of wastewater plants. Advances in computer science have also enabled complicated mathematical models developed for the design of such complex systems. Computer simulations have been shown to mimic the behavior and predict the performance of full-scale plants with reasonable accuracy. With computer simulations, it is now possible to test alternative operational strategies for full-scale plants without going through laboratory studies on pilot plants. Moreover, computer simulations have also been widely used in optimization studies that lead to cost-effective operational strategies, for trouble-shooting and upgrading of existing biological treatment plants (Tchobanoglous & Burton, 2003; Xu & Hultman, 1996). The increased knowledge about the mechanisms of different biological processes taking place in an activated sludge plant was translated into dynamic models that were developed to describe the degradation processes in the activated sludge plant.

Over the past two decades significant advances have been made in the areas of engineering design, implementation and operation of the activated sludge system (Cronje et aI., 2002). The progressively biological removal of carbon (C), nitrogen (N) and phosphorus (P) by the activated sludge systems have been successfully designed and implemented at full-scale. A suite of steady state design models (WRC, 1984; Wentz el et al.. 1990 and Maurer & Gujer, 1994) and kinetic simulation models (Old et aI., 1980; Oold et aI., 1991; Henze et aI., 1987; Henze et aI., 1995; van Haandel et aI., 1981 & Wentzel et aI., 1992) had been developed (Charles, 2009).

This study focuses on Biological Nitrogen Removal at Comodepur Waste Water Treatment Plant which treats a mixed urban and industrial waste water of the city of Como using Activated Sludge Model No. 1 (ASM1) (Henze et al., 1987), which through the years has been the state-of-the-art model for activated sludge plants with biological nitrogen removal.

Calibration of ASM1 is a must step as it is for all mathematical models. Behavior of an activated sludge plant depends upon a large number of kinetic and stoichiometric parameters. In addition to kinetic and stoichiometric parameters, there are a number of parameters that specify influent characteristics of wastewater.

Fortunately most of these parameters are not very sensitive and do not change appreciably for systems treating different municipal wastewaters (Henze et al., 1987; Kappeler & Gujer, 1992; Xu & Hultman, 1996; Sin, 2000). Default values for majority of these parameters are derived from earlier studies. Influent wastewater fractions also change significantly from wastewater to wastewater and it is often necessary to characterize wastewater on a case basis.

General aim of this study is to determine Biological Nitrogen Removal Efficiency and the Shortcomings in the performance of Comodepur Wastewater Treatment Plant and to calibrate, test and apply ASM1 model for the plant.

CHAPTER ONE

STATE OF THE ART

1.1 Theoretical Background

The activated sludge process was developed in 1914 by Arden and Lockett. It was so called because it involved the production of an activated mass of micro-organisms capable of aerobically stabilizing the organic content of a waste. Though many configurations of this process now exist, the basic units (Figure1) have remained the same (EPA, Ireland 1997).

Activated sludge process is a typical aerobic suspended growth system for biological wastewater treatment, and has been used extensively in its original form as well as in many modified forms (Kose,2006).

Operationally, wastewater treatment with the activated sludge process is typically accomplished using a flow diagram similar to the one shown in Figure 1.

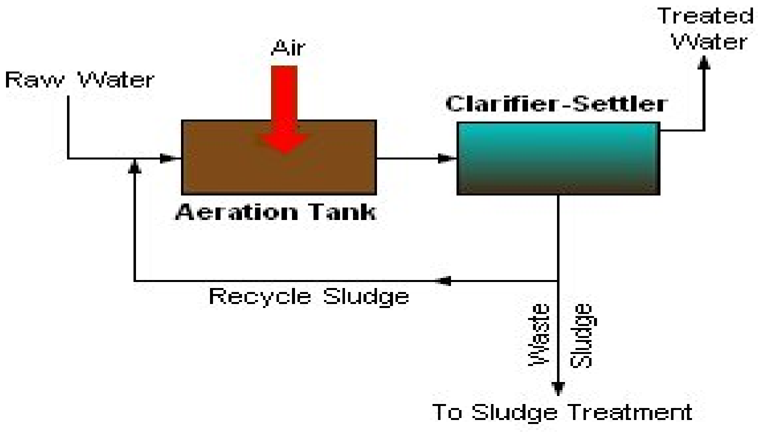


Fig 1.1: Schematic Representation of Activated Sludge Process.

Organic waste is introduced into a reactor where an aerobic bacterial culture is maintained in suspension. The reactor contents are referred to as the "mixed liquor". In reactor, mixed liquor suspended solids (bacterial culture) decomposes and converts the biodegradable fractions of organic waste in generalized stoichiometric equation indicated below (Kose, 2006).

$$\mathrm{COHNS} + \mathrm{O_2} + \text{nutrients} \xrightarrow{\text{biomass}} \mathrm{CO_2} + \mathrm{NH_3} + \mathrm{C_5H_7NO_2} + \text{end products} \qquad \text{(Eq: 1.1)}$$

Stoichiometry indicated in equation 1 represents the general oxidation and synthesis of bacterial culture. Where COHNS refers to organic matter in wastewater and $C_5H_7NO_2$ represents cells produced in the reactor.

Generalized endogenous respiration reaction is written as follows:

$$\mathrm{C_5H_7NO_2} + \mathrm{O_2} \xrightarrow{\text{biomass}} 5\mathrm{CO_2} + 2\mathrm{H_2O} + \mathrm{NH_3} + \text{energy} \qquad \text{(Eq: 1.2)}$$

Although the endogenous respiration reaction results in relatively simple end products and energy, stable organic end products are also formed.

1.2 Denitrification Processes

The process of denitrification

1.2.1 General

The denitrification process is the biological reduction of nitric / nitrous acid in nitrogen gas by facultative heterotrophic bacteria. This process is the result of a series of biochemical transformations.

$$\mathrm{NO_3}^- \rightarrow \mathrm{NO_2}^- \rightarrow \mathrm{NO} \rightarrow \mathrm{N_2O} \rightarrow \mathrm{N} \qquad \text{(Eq: 1.3)}$$

The final products in the denitrification are therefore constituted by a gaseous mixture composed of molecular nitrogen N_2, nitric oxide NO and nitrous oxide N_2O, depending on the type of microorganisms responsible and the environmental conditions. However, particularly when the biomass uses the oxygen of the nitrates for cellular respiration, a significant accumulation of NO and N_2O is not observed .The rate of formation of the latter is negligible compared to the rate of production of nitrogen.

The denitrification process is also referred to as dissimilative reduction of nitrates, distinguishing it from a reduction assimilative in which the nitrates are used as substrate for the cellular synthesis nitrogen (after reduction with ammonia nitrogen). The latter process occurs only in the absence of ammonia nitrogen.

In denitrification, in the absence of dissolved oxygen, the bacterial species are involved, using nitrate and nitrite as the final electron acceptor, while use the organic substance as an electron donor, from whose oxidation, they draw the energy necessary for their metabolism.

Depending on the process schemes employed, the carbon substrate substances or chemicals that can be used as an electron donor are added externally or organic substances contained in urban waste or residual cell mass resulting from endogenous respiration of sludge are used.

1.2.2 Microbiology

The process is done by heterotrophic organisms. These are characterized by a metabolism that involves the use of a carbon source and the use of an electron acceptor which can be dissolved oxygen in the sewage or the nitric / nitrous if oxygen is deficient.

The bacterial respiration has, in fact, identical characteristics in the presence of oxygen or nitric nitrogen (anoxic conditions) to be reduced by a final enzyme called nitro-reductase that in the absence of oxygen, allows the transport of electrons from the reducing substance to the oxidant. In case of simultaneous presence of oxygen and nitrate, there is a preferential consumption of oxygen because it is energetically more favorable to bacterial metabolism, but the similarity between the two processes, however, explains the relative ease with which the heterotrophic bacteria in the optional processes to integrated schemes alternatively can reduce molecular oxygen and nitrate.

In the effluents of domestic origin there are several bacterial species capable of carrying out a full or partial denitrification. You can then distinguish between two types:

- Facultative bacteria able to reduce nitrates to nitrites (Aerobacter, Proteus, Flavobacterium)
- Facultative bacteria capable of reducing nitrates and nitrites (Pseudomonas, Micrococcus, Alcaligenis, Achromobacter)

In the latter type bacteria that during the reduction do not provide accumulation of nitrite can be distinguished from those that produce it. The latter, while being able to complete the denitrification process are more sensitive to environmental conditions or power.

1.2.3 Stoichiometry

In heterotrophic denitrification, where nitrate is used as electron acceptors, the main objective is to produce energy by reducing the nitrate nitrogen (NO_3-N to nitrogen gas (N_2) and oxidizing the organic matter (electron donor):

$$S.org_{\text{reduced}} + NO_3^-(NO_2^-) \rightarrow S.org_{\text{oxidized}} + N_2 + \text{energy} \qquad \text{(Eq: 1.4)}$$

The compound electron acceptor then undergoes a reduction:

$$NO_3^- + 6H^+ + 5e^- \rightarrow \tfrac{1}{2} N_2 + 3H_2O \qquad \text{(Eq: 1.5)}$$

While the electron donor compound (organic substance) is oxidized:

Example methanol:

$$\tfrac{5}{6} CH_3OH + H_2O \rightarrow \tfrac{5}{6} CO_2 + 5H^+ + 5e^- \qquad \text{(Eq: 1.6)}$$

The denitrification process is typical of sewage treatment plant can be considered a process in two stages: the first is the conversion of nitrate to nitrite, while in the second case the conversion of nitrite into nitrogen gas.

This type of reactions can be expressed in a form based on the stoichiometry of electron donor. In the case of methanol, for example:

$$6NO_3^- + 2CH_3OH \rightarrow 6NO_2^- + 2CO_2^- + 4H_2O$$

$$6NO_2^- + 6H^+ + 3CH_3OH \rightarrow 3N_2 + 3CO_2 + 9H_2O$$

(Eq: 1.7)

If the denitrification is carried out in the presence of a sufficient amount of organic substrate and in strict anoxic conditions, nitrite formation is not much.
Depending on the type of substrate used, electron donor can have different reactions:

In the case of *methanol*, for example:

$$6NO_3^- + 5CH_3OH + 6H^+ \rightarrow 3N_2 + 5CO_2 + 13H_2O$$

(Eq: 1.8)

Ethanol:

$$12NO_3^- + 5C_2H_5OH + 12H^+ \rightarrow 10CO_2 + 21H_2O + 6N_2$$

(Eq: 1.9)

Acetic Acid:

$$8NO_3^- + 5CH_3COOH + 8H^+ \rightarrow 10CO_2 + 14H_2O + 4N_2$$

(Eq: 1.10)

Generic Organic Substance:

$$5C_xH_yO_z + (4x + y - z)NO_3^- \rightarrow 5xCO_2 + (2y - 2x + z)H_2O +$$

$$(4x + y - 2z)OH^- + (2x + \frac{1}{2}y - z)N_2$$

(Eq: 1.11)

These can be added in the case of denitrification resulting from the residue of cell mass in endogenous respiration. Using this formulation the residual reaction will be:

$$4NO_3^- + C_5H_7NO_2 \rightarrow 5CO_2 + 4OH^- + 2N_2 + NH_3 \qquad \text{(Eq: 1.12)}$$

1.2.4 Reaction Kinetics

On a modeling basis, reaction kinetics involves two basic processes; microbial growth and decay (Orhon & Artan, 1994). As process Stoichiometry inter-relates substrate utilization with microbial growth, these two processes are studied together. Although microbial decay is defined as the decrement in biomass, in latter approaches it’s understood that other effects of microbial decay such as degradation of biomass into substrate, must be taken into consideration (Henze et. al., 1987). In Figure 1.2, combined effect of these two processes is shown in a closed system with no initial substrate limitation. As seen on Figure 1.2, adaptation phase, followed by rapid growth phase is observed in a biological reactor under aerobic conditions. Third growth phase is the stationary phase in which microorganisms reach the maximum growth rate. Finally, as a result of decreasing substrate concentration and inhibitory effect of accumulating metabolic products, growth rate of microorganisms decreases.

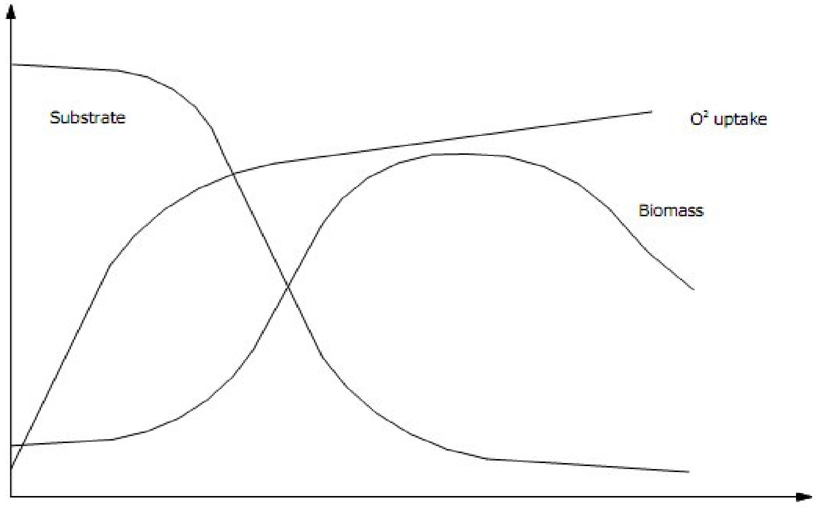


Fig 1.2: Reaction Kinetics

Subsequently, a stationary phase comes, where the endogenous metabolism is under equilibrium with synthesis of new cells. Reactions end with an endogenous phase where endogenous metabolism dominates because of substrate limitations (Orhon & Artan, 1994).

1.2.5 Microbial Growth

Microbial growth is usually defined with the following expression (Kose, 2006)

$$\frac{dX}{dt} = \mu X$$

(Eq: 1.13)

where; X= biomass concentration $[M(\text{biomass})/L^3]$

μ= specific growth rate $[T^{-1}]$

Growth can also be defined in terms of substrate removal with a yield term:

$$\frac{dX}{dt} = -Y\frac{dS}{dt}$$

(Eq: 1.14)

Hence, the relationship between substrate removal and microbial growth is:

$$\frac{dS}{dt} = -\frac{\mu}{Y}X$$

(Eq: 1.15)

Specific substrate removal rate, q, is related to substrate removal in the following expression:

$$\frac{dS}{dt} = -qX$$

(Eq: 1.16)

Thus, in terms of specific growth rate, q equals to:

$$q = \frac{\mu}{Y}$$

(Eq: 1.17)

The relationship between maximum specific growth rate and growth-limiting substrate concentration is usually explained using the Monod equation, which named after Jacques Monod, who first demonstrated the fit of P to S in accord with the rectangular hyperbola (Tchobanoglous & Burton, 2003)

$$\mu = \hat{\mu}\frac{S}{K_S + S}$$

(Eq: 1.18)

where; S= rate-limiting substrate concentration [M(substrate)/L^3]
μ= maximum specific growth rate [T^{-1}]
K_S= half-saturation constant [M(substrate)/L^3]

Substituting μ in equation (1.18) in equations (1.17) and (1.13), expressions describing microbial growth and substrate removal are:

$$\frac{dX}{dt} = \hat{\mu}\frac{SX}{K_S + S}$$

(Eq: 1.19)

And

$$\frac{dS}{dt} = -k_m\frac{SX}{K_S + S}$$

(Eq: 1.20)

k_m in equation (1.20) can also be written in terms of maximum specific sub removal rate as follows:

$$k_m = \frac{\hat{\mu}}{Y}$$

(Eq: 1.21)

Combining equations (1.19) and (1.21), specific substrate removal rate can be described with the following Monod-like expression:

$$q = k_m\frac{S}{K_S + S}$$

(Eq: 1.22)

1.2.6 Interpretation of Monod Equation

Values μ̂ and K_S determine the relationship between substrate concentration, S and specific growth rate, E. The four curves given in Figure1.2 cover majority of domestic wastewaters (Kose, 2006).

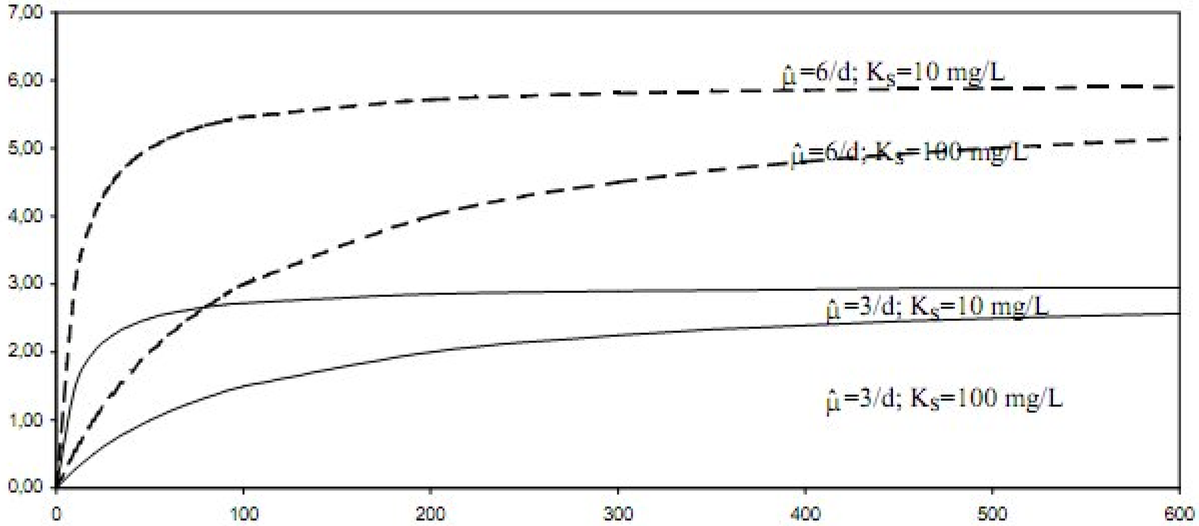


Fig 1.3 Effect of μ̂and KS over Monod equation

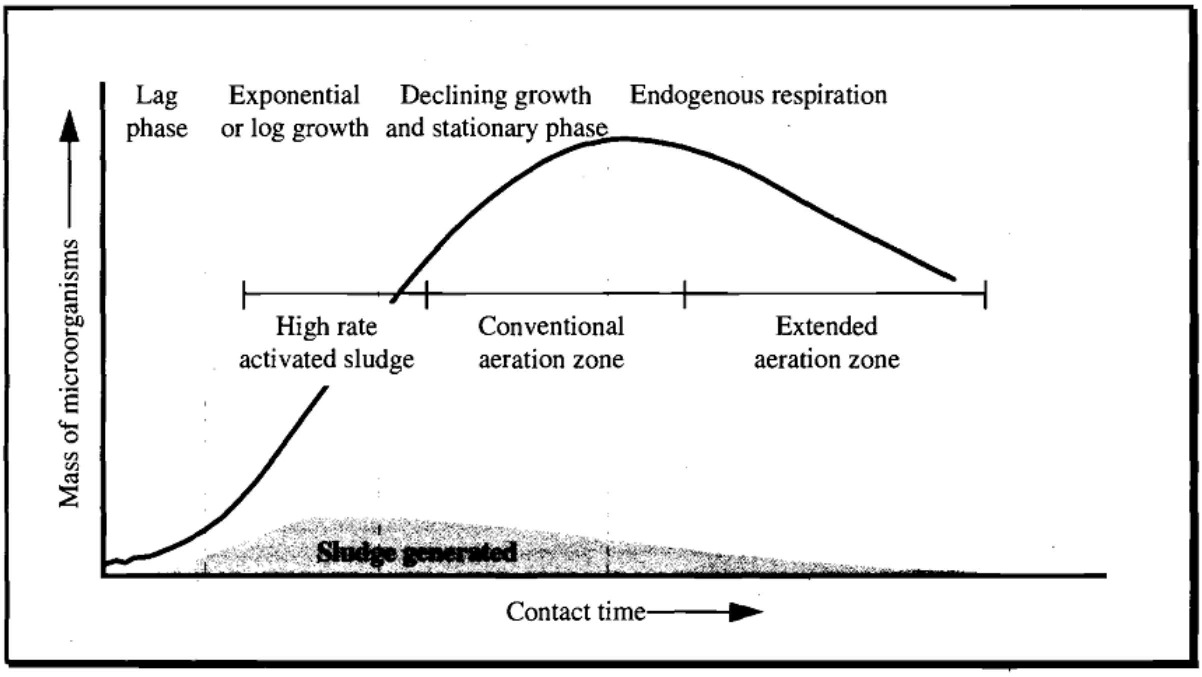


Fig: 1.4: Bacterial Growth Rate Curve

1.3 Method of Model Presentation

The mathematical models proposed to simulate the activated sludge system behavior involve a large number of reactions between a great number of components under various processes that occur in the system boundary. For a clear and definite representation of the systems and understanding of the models, the matrix format for the presentation of the activated sludge bio-kinetic model developed by Grady et al (1986) is used.

To illustrate the procedure for using the matrix format and notation, carbon removal by heterotrophic biomass under aerobic conditions is considered. In this situation, being general in activated sludge systems, the biomass increase and decay is the two fundamental processes that govern this system behavior. An example matrix describing this system, representing two fundamental processes is shown in Table 1.1.

Table 1.1: Matrix representation for biomass growth and decay

Components →	i	1	2	3	Process Rate, ρ_j
j	Processes ↓	X_H	S	S_O	$[ML^{-3}T^{-1}]$
1	Growth	1	$-\frac{1}{Y_H}$	$-\left(\frac{1-Y_H}{Y_H}\right)$	$\hat{\mu}_H \frac{S}{K_S+S} X_H$
2	Decay	-1		-1	$k_d X_H$
Observed conversion rates $[ML^{-3}T^{-1}]$		$r_j = \sum_j r_{ij} = \sum_j \nu_{ij} \rho_j$			
Parameters $[ML^{-3}]$		Cell COD	COD	O_2 (-COD)	

It's required to identify the relevant system components in order to develop a matrix representation of the model. In this case, as mentioned above, three components are considered; biomass, substrate and dissolved oxygen, which are listed at the first row of the Table 2.1.

The notation attributing system components is formed as follows:

The insoluble constituents are given the symbol X and the soluble components S. Corresponding subscripts are attached to differentiate each component as follows:

H for heterotrophic biomass, S for substrate and S_o for oxygen. The index i ranging from 1 to 3 is assigned to each different component (Henze at al., 1987). The next step is to define the biological processes occurring in the system. In this case, the biomass growth and decay are assumed to affect the concentration of the components in the system. These processes are listed in the first column of the Table 1.1. The index j, ranging from 1 to 2, refers to each process. The kinetic expressions associated with the reactions occurring within system are placed at the last column of the Table 1.1. Here, process rates are denoted by ρ and the subscript, j in ρ_j is to indicate the j^{th} process in the matrix. The stoichiometric coefficients are referred by the ν_{ij} notation to relate the action of j^{th} process upon the i^{th} components in the matrix. These coefficients are determined from mass balance relationships between components in each process. To illustrate, growth of biomass (+1) occurs at the expense of soluble substrate (-1/Y). In order to be consistent in terms of units, all coefficients and parameters are expressed in chemical oxygen demand (COD). The negative sign used in the matrix is to mean consumption and positive sign is to refer to production (Henze at al., 1987).

The system reaction rate is the sum of all reaction rates corresponding to different processes occurring in the system.

$$r_{ij} = \nu_{ij}\rho_j$$

(Eq: 1.22)

For example, the reaction rate regarding biomass, XB, for growth and decay, as it is read from the matrix, would be:

$$r_j = \sum_j r_{ij} = \sum_j \nu_{ij}\rho_j$$

(Eq: 1.23)

For soluble substrate, S, considering substrate utilization for biomass growth in the system, would be:

$$r_1 = r_{X_H} = \hat{\mu}_H \frac{S}{K_S + S} X_H - k_d X_H$$

(Eq: 1.24)

$$r_2 = r_S = -\frac{1}{Y_H} \hat{\mu}_H \frac{S}{K_S + S} X_H$$

(Eq: 1.25)

$$r_3 = r_{SO} = -\frac{(1 - Y_H)}{Y_H} \hat{\mu}_H \frac{S}{K_S + S} X_H - k_d X_H$$

(Eq: 1.26)

CHAPTER TWO

CASE STUDY: COMODEPUR WWTP

2.1 Description of the Plant

The consortium Comodepur spa, which includes the neighboring city of Como, and a hundred companies, mostly textiles, which operate in the district Como, has a treatment plant located in Viale Innocenzo XI, to the south-west of the city of Como.

The activities of the consortium began in the mid-seventies and the system under study finally becomes operational from 1980.The limited available area has influenced the design choices of the system, for which compact systems have been focused for treatments such as, for example, the adoption of lamella settlers for the primary sedimentation and tertiary sedimentation. This also makes it difficult, creating new spaces for the expansion of existing facilities or new process units.

The plant of Comodepur serves a population equivalent of a population of 212,000 and is able to treat a daily average flow of 55000 m^3/ d. The wastewater entering the plant is about 84% of civilian origin; the rest is of industrial type, especially textiles.

To carry out this study only a few parts of the plant were considered. The processes of pre denitrification and aeration-nitrification have been analyzed through the Modeling and Simulation.

The effluent exiting the primary treatments is sent to the phase of pre denitrification, consisting of from a tank equipped with submerged mixers, in which the aerated mixture of sludge circulation and recirculation extracted from the secondary clarifiers also flows. The effluent then passes to the two oxidation tanks nitrification-operating in parallel. The air required for the process is compressed by means of centrifugal blowers and placed in the tanks with the aid of microperforated membrane. Following the sewage passes into the tank post denitrification which has a flow meter for a hydroalcohol solution as external source of carbon for the process where the mixing is ensured by two submerged mixers.

In the block diagram shown in Figure 2.1 and Table 2.1 summarizes the main treatments and material flows involved in the process of purification plant.

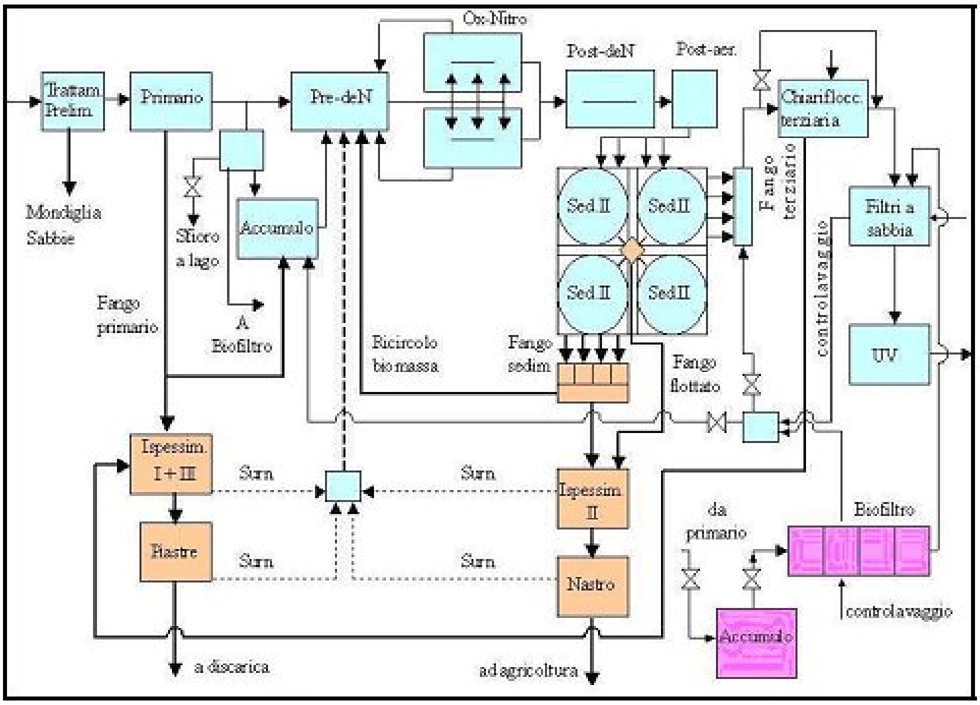


Fig 2.1: Schematic Block Diagram of Comodepur WWTP

Table 2.1 Description of the Treatment Lay out

Preliminary Treatment	**Primary Treatment**	**Biological Treatment**	**Tertiary Treament**	**Sludge Treatment**
Fine Screening	Coagulation/Flocculation Tank	Pre-denitrification	Vasche di coagulazione/ flocculazione	Thickening
Pumping		Oxidation Nitrification	Sedimentation through Lamella Settlers	
Grit Removal	Sedimentation through Lamella Settlers	Post-denitrificazione	Sand Filtration	Dewatering
		Sedimentation	Fabric Filtration	
		Biofiltration	UV Disinfection	

In figure 2.2 a planimetry of the treatment plant along with the all the treatment sections is shown:

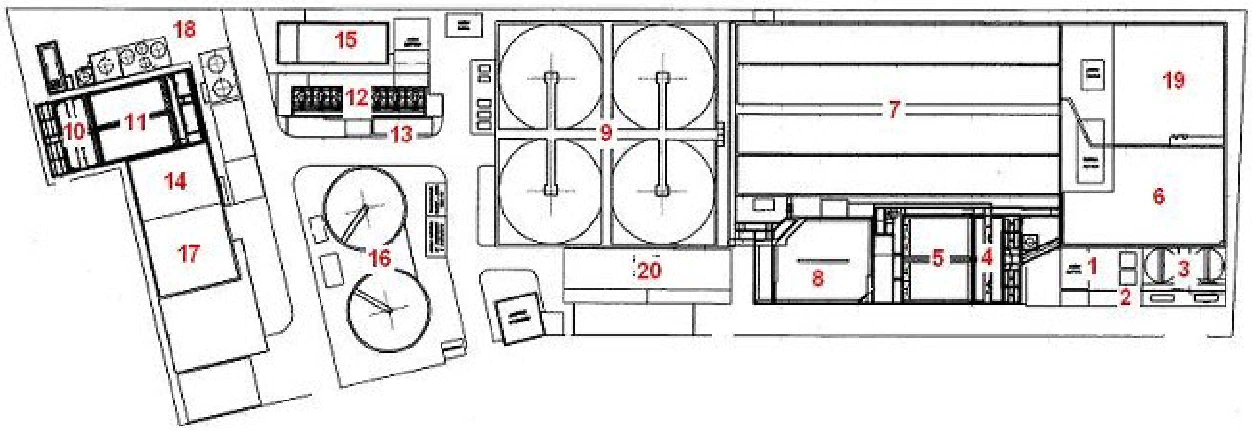


Fig 2.2: General Planimetry of the Plant

1. Fine Screening
2. Principal Pumping
3. Grit Removal
4. Primary Coagulation-Flocculation Tanks
5. Sedimentation through Lamella Settlers
6. Pre Denitrification
7. Nitrification
8. Post Denitrification
9. Secondary Sedimentation
10. Tertiary Coagulation-Flocculation Tanks

11. Tertiary Sedimentation through Lamella Settlers
12. Sand Filtration
13. Disinfection with UV Rays
14. Biofiltration accumulation
15. Biofiltration
16. Thickeners
17. Dewatering through Belt Pressing
18. Reagent Storage
19. Equalization Basin
20. Offices

2.1.1 Phases of treatment

The purification of the sewage mixture takes place through the following steps:

2.1.1.1 Preliminary treatment

- Fine screening
- Lifting
- Grit removal

2.1.1.2 Primary treatment

- Coagulation / flocculation
- Clarification on Lamella Settlers

2.1.1.3 Biological treatments

- Accumulation
- Pre denitrification
- Oxidation-Nitrification
- Post denitrification with dosage of external carbon source (hydroalcohol mixture)
- Post aeration
- Secondary sedimentation

2.1.1.4 Tertiary treatment

- Coagulation / flocculation
- Clarification to lamella
- Sand filtration
- UV disinfection

Part of the range (about 4,000 m^3/d) bypasses the biological treatment section and is treated by two lines of Biofilters consisting of the following units:

- Biofor C (removal of Carbon);
- Biofor N + C (oxidation of Nitrogen + Carbon);
- Biofor DN (nitrate removal with dosage hydroalcoholic solution);
- Clariflocculation (Chiariflocculazione) for chemical removal of phosphorus.

The sludge produced in the primary and tertiary treatments are subjected to:

- Thickening
- Conditioning with lime and iron salt

2.1.1.5 Dewatering with centrifuges

The sludge produced in the secondary treatments is subjected to:

- Thickening
- Air conditioning with polyelectrolytes
- Dehydration with centrifuges

2.1.2 Primary treatment

The water effluent from the grit chambers, previously pumped by the pumping station equipped with four pumps, are fed, via channel, to the two lines of clariflocculation caused by injection of ferric chloride and polyelectrolyte. From these channels, water can be sent directly to the section of pre-denitrification by a manually operated mechanical gate.

Before entering the in-line pH meter-transmitter has been installed that sends the signal to framework for this indication. It describes the operation of a line.

The line is intercepted by a gate. The water is fed to two tanks for rapid mixing and then moved to the flocculation tank. The water is then conveyed to the primary sedimentation tank, equipped with lamella settlers.

The clarified water from the two clarifying tanks is initiated through the channel to the next phase of pre-denitrification. The flow rate is regulated by a ring consisting of a weir adjustable and controlled by a motorized regulator which is fed the signal flow (the denitrification) coming from a transmitter that detects any change. An excess flow of 3,000 m^3 h^{-1} is sent to the storage tank by pumps. The spillway feeds a pond supplying water to the biological filtration plant from where the overflow is discharged into the lake basin as excess water.

This channel is also intercepted by a gate that once closed allows the whole bypassed water from the biological treatment to flow through the weir which are regulated by a motor which controls the flow rate.

The settled sludge is extracted by means of timed valves and discharged into a sump which has horizontal pumps. Piping through separate manual shutoff valve, they send, alternatively, to nitrification, denitrification, or the thickening.

The accumulation tank of flow rates in excess of 3000 m^3h^{-1} is equipped with two agitators submerged. In the tank is placed, via a system of fine bubble membrane diffusers, air compressed by blowers lobe, whose operation is controlled by a level measurement ultrasound. Two pumps to send water denitrification previously accumulated.

2.1.3 Biological Treatment

The clarified water is conveyed to the denitrification tank where mixed liquor suspended solids are also recycled along with the sludge from the final clarifiers. In this tank five submersible mixers are mounted.

The effluent from the pre-denitrification is conveyed to the two nitrification tanks, arranged in parallel, by means of two channels. Each channel opens into the relative tank, taking a "U" shaped path, by means of three inputs (arranged on the first stretch of the "U"), each equipped with floodgate interception.

The air is compressed by three centrifugal blowers and introduced into the nitrification tank through layer of micro perforated membrane. On each line that feeds the two basins flow meters are mounted. The tanks are of the channel type and each of the two, from the point of view of the process, is in fact constituted by two tanks to channel placed in series.

It describes the operation of a line.

Four probes regulate the flow meters controlling the dissolved oxygen in the air flow to the nitrification tank by a motorized valve.

A suspension of activated charcoal, prepared in special section, through a timed electro valve can also be introduced to the nitrification tank The mixed liquor is recycled to the pre-denitrification tanks by means of two horizontal pumps.

The aerated mixture then passes to the post-denitrification tank, equipped with two submersible mixers, and then to that of post-aeration. The post-denitrification tank is dosed with a hydro-alcohol mixture as a carbon source. The power supply is controlled by a dissolved oxygen probe NITRATAX plus DrLange connected to UV placed in the channel of the outlet flow from the post-aeration and that provides the value of nitrate in the effluent (functions with retro-active or logical-feedback).

Below the threshold (3 mgN-NO_3 l-1) the feed pump of the hydro-alcoholic solution works to 5% of the maximum value of flow rate. Upon exceeding the threshold pump comes into operation at full speed until the value of nitrates detected by the probe does not drop below the preset limit.

The mixture then passes to the phase of sedimentation. The organic phase of sedimentation is carried out by four units of square type with round bottom. For recycling of sludge settled in pre-denitrification three horizontal centrifugal pumps are installed; for lifting the excess sludge to the thickeners two other horizontal centrifugal pumps are installed .For the lifting of the supernatant the sump is equipped with two submersible pumps (one of which is installed).

The settled sludge is collected in a pond from where it is recycled to the pre-denitrification tank by means of horizontal pumps.

The excess sludge is sent to the thickening by means of timed pumps.

The sludge floating on the surface of the sedimentation tanks, are conveyed by the skimmer blades in the foaming ponds and with two submersible pumps it is sent to the thickeners.

The antifoam is stored in a special tank and from there metered into the feed channel of the nitrification by two metering pumps.

2.1.4 Biofiltration

From the motorized tank, adjustment of the flow is located downstream of the weir from where two primary pumps exiting from the flocculation feed the biological filtration plant during the day. The regulation of the flow to be sent to the biofiltration is carried out by two electro-valves subservient to a flow meter.

In the storage tank, a mixing system consisting of two mixers and a system injecting air consisting of two hydro-ejectors air-flow-type jet "to prevent phenomena of anaerobiosis is installed.

Achieving the maximum allowable level of the storage tank, closes the valve when if, during the day, is reached, the quantity of water reaches sufficient storage for the night. Reaching the maximum level blocks the entire plant. After filtration on filter static table, the effluent reaches, to the pond exit such that it goes to stabilizing flow of recirculating water from the ex-chlorination tank by two pumps.

With gravity water flows into the two lines of biofilters operating in parallel, each consisted of three filters: Biofor C, Biofor C + N and Biofor DN whose filter bed consists of inert material. A series of automatic on-off valves control the process. For Biofor C (carbon treatment) and C + N (ammonia oxidation) oxygen needed for biomass is provided by an injection system consisting of three compressors. Biofor DN (reduction of nitrate to molecular nitrogen) is dosed by an external carbon source through two pumps from a station storing and dosing hydro alcoholic solution.

In order to prevent the filter beds from clogging by the solid impurities in the suspension from excess biological sludge, biofilters are backwashed with a predetermined frequency or according to the clogging rate of the filter bed

The washing of the biofilter consists of a sequence of phases with release of air through the compressors already mentioned, and using water drawn by the three pumps from the pool of ex-chlorination.

The washing water and sludge from the channels that, during filtration, receive the treated water, end up in the tank with ex-washes water which comprises also the waters of Backwash of sand filters. When the biological filtration plant is not in the wash, the water (from Backwashing of sand filters) flow out through the overflow to pumping tank to tertiary treatment; during the washing of biofilters two pumps to transfer the water storage tank flow rates exceeding 3,000 $m^3 h^{-1}$.

The water exiting from the biofilters are conveyed by gravity to a Clariflocculator for the abatement of phosphorus. In the supply pipe Clariflocculator is dosed with ferric chloride by metered pumps. The polyelectrolyte is dosed at the entrance of the first segment of Clariflocculator (mixing). The second compartment constitutes an area of clarification with lamella settlers and of a zone below for the collection and thickening of the sludge. The water clarified ends in the last compartment of the Clariflocculator from where, by means of two pumps, it is raised to the sand filters.

The sludge collected in the hopper will be recycled to the head Clariflocculator through timed pump and the excess sludge is sent to Sludge thickener.

2.1.5 Tertiary Treatment

The clarified water is conveyed to the pumping station in which three vertical pumps are housed that send the tertiary Clariflocculation and the filtered sand. An electromagnetic flow meter is installed, through conveying pipes of the pump and manual adjustment valves against the flocculation and against tertiary sand filters before flow meter determining the bleaching dosage.

In the lifting station backwashing of sand filters, bypass of the biofiltration system and part of the backwash water of the same plant are also conveyed. The overflow of the pump station is discharged to lake as excess water.

The water pumped from the pumping station, are fed to the two lines of tertiary Clariflocculation, with introduction of aluminum chloride along the length of feeding pipes and to the polyelectrolyte, and after allocating the two lines.

Before the entrance lines a pH measuring transmitter is installed, this sends the signal to framework as an indication. According to the signal alarms of high / low pH are set. It describes the operation of one line.

The line is intercepted by a gate. The water is fed to two rapid mixing tanks and then moved to the flocculation tank. The waters are conveyed to tertiary sedimentation, with Lamella Settlers and scraper. The clarified water from the two settlers then goes to the pumping station where four submersible centrifugal pumps regulated by level switches are installed. The pumps send the wastewater to sand filtration. The overflow of the pump station is discharge as excess to the water lake.

The settled sludge are extracted by means of the opening of two timed valves and discharged into one well from where two submersible centrifugal pumps suck them up through pipes interceptible with manual valves, send them for sludge thickening.

It can also recycle and sludge in the feeding flocculators.

After the tertiary flocculation and after flocculation of the system of the biofiltration, feeding channels of sand filters are sent from the water stations pumping and waste directly lifted from the pumping station located after the sedimentation organic, depending on the adjustment of manual valves, placed on the line discharge. The overflow is discharged to the lake as excess flow.

Each of the seven filters installed is fed through pipe with pneumatic valve that connects the feed channel with the channel of distribution. The water passing through the filter medium up to the chamber plate and from here, through a valve, is conveyed through pipe to disinfection.

Backwashing of the filters are performed sequentially regardless of the degree of clogging of the filter bed. The backwash comprises a first step of emptying the filter by the pneumatic valve output and, in order to facilitate emptying; through a pneumatic valve mail above the bed of sand at a level conductivity indicates the completion of the drainage and gives consent for the initiation of the backwash air. The blower sends air to the chamber back plate through a valve. After reaching equilibrium, the phase of backwash air-water starts, the pump installed in the tank before the end of chlorination, sends the water to the back-plate room via a pneumatic valve, the liquid level in the filter sub channels up to meet the quota in the gutters overflow, hence the backwash water is conveyed to storage tank backwash system of biofiltration. At the end of the backwash valves of backwashing close and then open only at the start of the process again.

From sand filters the water is conveyed to the UV disinfection consists of 20 modules with 40 lamps each, placed in two parallel channels. Each channel is intercepted by gate, and at the outlet is equipped with a counterweight to maintain constant the free surface in the radiation area. The number of lamps in function is directly proportional to the input flow rate to the channels of disinfection by the signal of the ultrasonic flow meter located on the spillway outlet from the plant.

From the UV disinfection with the wastewater is conveyed to the tank originally used for the disinfection with hypochlorite (now no longer practiced), which takes the pumps:

- Recycling plant for biological filtration during periods when the flow rate after primary sedimentation does not reach the threshold for food relief
- washing of biofilters,
- For the feeding of the network of service water,
- For contract washing of sand filters.

From this tank, the purified wastewater is discharged into the Cosia stream.

2.1.6 Thickening and dewatering

The step of thickening is by means of two units of the circular type and with the bridge in traction, one used for the biological sludge and mud for the primary and tertiary sectors. To send the mud thickened to dehydration are installed three pumps monolith eccentric (-mono "); for lifting of the supernatant, the sump is equipped with three centrifugal pumps vertical. The supernatants of both thickeners are sent to a collection sump from which pick the pump that will recirculate in pre denitrification. Sludge thickeners of biological sludge is also dealt with the sludge floated in secondary clarifiers, and sludge to thickeners primary and tertiary are also sent the water from the backwash of biofilter.

The biological sludge extracted from thickener is then conditioned with polyelectrolyte and sent to dehydration, obtained by centrifugation. The dewatered sludge is then stored awaiting vehicles be removed from the plant to be reused in agriculture.

The primary and tertiary sludge after thickening are instead packed with ferric chloride and lime and fed to a centrifuge for dewatering.

The dewatered sludge is then disposed of in landfills.

The main technical data of the individual unit operations are summarized below:

2.2 Comodepur Waste Water Treatment Plant

2.2.1 Plant Specifications

Initial Pumping: the operation is performed using three pumps (+ a spare installed) at the vertical axis, controlled by an inverter and a subservient level measurement, having the following characteristics:

Maximum flow rate	1,670 m^3/hours
Prevalence	18.2 m

Overall, the pumping station has a variable flow rate between 200 and 4,800 m^3/h.

Primary Clariflocculation: each of the two primary lines of clarification has the characteristics listed below:

Rapid mixing (coagulation)

No. tanks per channel	N° 2
Tank width	3,000 mm
Length	3,000 mm
Liquid height	5,000 mm
Liquid volume	45 m^3

Slow mixing (flocculation)

No. tanks per channel	N° 1
Tank width	5,000 mm
Length	8,000 mm
Liquid height	5,000 mm
Liquid volume,	200 m^3

Sedimentation at the Lamella Settlers

Tank width	8,350 mm
Length	14,000 mm
Liquid height	5,000 mm
Liquid volume,	584 m^3
Equivalent surface Lamella plates	1,500 square meters

Excess sludge raising pumps

Number of units	N° 2
Flow rate	50 m^3/hours
Prevalence	22 m

Foam raising pump

Number of units	N° 1
Flow rate	50 m^3/h
Prevalence	7.2 m

Sump for raising Sludge pump

Surface	6.25 m^2 (triangular)
Liquid height	7,800 mm
Maximum liquid volume	48.8 m^3

Raising of Excess flow

The water exiting the flocculation is sent with a fixed rate to the pre-denitrification, the rest is sent through the motorized weir motorized raising. The characteristics of the system are the following:

Motorized overflow

Motorized weir length	5,000 mm blade skimming

Storage for flow exceeding 3000 m3/h

Surface area	20.9 m^2 (L-shaped)
Maximum liquid height	5,300 mm
Maximum liquid volume	111 m^3

Pump for lifting flow exceeding 3000m3/h

No. of units	N° 2
Flow rate	700 m^3/h
Prevalence	4 m

Pump for lifting to Biofiltration Plant

No. of units	N° 2
Flow rate functional	600(400) m^3/h
Prevalence	13 m

Excess Flow Storage

The water exiting the flocculation is sent with a fixed rate to the pre-denitrification, the rest is sent through the motorized weir sump. The characteristics of the system are the following:

Storage Tank

Width	22500/12630 mm
Length	32500 mm
Surface	680.9 m^2
Motorized weir length	5,000 mm blade skimming
Maximum liquid height	7500 mm
Minimum liquid height	1100mm
Max. Liquid volume	5107 m^3
Volume of water at minimum level	749 m^3
Max. Storage capacity	4,358 m^3

Blowers

No. of units	Nº 1 +1
Suction flow rate	1,700 m^3/h
Prevalence	9 m

Submersible mixers

Number of units	N° 2
Diameter of propeller	766 mm
Power consumption	15.25 kW
Rated motor power	25 kW

Biofiltration Storage

The storage tank is equipped with two submersible mixers, and two flow-jet to the air insufflations.

The characteristics are the following:

Storage tank

Width	16,100 mm
Length	29,500 mm
Surface area	475 m^2
Maximum liquid height	5,000 mm
Minimum liquid height	1,000 mm
Maximum liquid volume,	2,375 m^3
Volume of water at a minimum level	475 m^3
Max storage capacity	1,900 cubic meters

Flow-jet

No. of units	N° 2
Water flow	107 m^3/h
Air flow	44 m^3/h
Rated power of motor	3.1 kW

Submersible mixers

Number of unit	N° 2
Diameter of propeller	580 mm
Power consumption	4.5 kW
Rated motor power	5 kW

Pre-denitrification

The pre-denitrification tank is equipped with five submersible mixers and has the following geometric characteristics:

Length	32,500 mm
Width	21.100/30.970 mm
Surface area	701.2 m^2
Liquid height	7,500 mm
Liquid volume	5,260 m

Biological aeration

The characteristics are the following:

No. of tanks	N° 2
Width	16,700 mm
Length	65,800 mm
Liquid height	6,950 mm
Volume of the tank	7,500 m^3
Total liquid volume	15,000 m^3

Aeration system

No. of sets per tank	N° 8
No. of diffusers per set	Nº 288
No. of diffusers per tank	N° 2,304
Total No. of diffusers	Nº 4,608

Blowers

No. of Unit	No. 1
Minimum flow	13,600 m^3/h
Maximum capacity	34,000 m^3/h

Surface Area

No. of Unit	Nº 1
Minimum flow	13,500 m^3/h
Maximum capacity	30,000 m^3/h
Number of Unit	Nº 1
Minimum flow	8,200 m^3/h
Maximum capacity	20,500 m^3/h

Recirculation pumps for aerated mixture

- The station is equipped with four pumps which two of the reserve.

Number of unit	N° 2
Flow rate	850 m^3/h
Prevalence	3.5 m
Number of unit	n ° 2
Flow rate	800 m^3/h
Prevalence	3.5 m

CHAPTER THREE

MATERIALS AND METHODS

3.1 Tool used in this study

An activated sludge process is a complex system in which a range of bacterial conversion and transport processes occur. Kinetics, stoichiometry and transport processes play an important role in the conversion of contaminants. Models are needed for a quantitative evaluation of the processes. These models can become quite complex due to the wide variety of biological processes. Especially organisms responsible for biological phosphorus removal processes have a complicated cellular physiology (Mino et al., 1996) which is not easily understood from external measurements (*Veldhuizen.V et al ,1999).*

Therefore Modelling and Simulation of the activated sludge process under study was carried out using a practical model called Activated Sludge Model 1 (ASM 1) to be implemented on the Comodepur WWTP.

What is a Model?

A model can be defined as a purposeful representation or description of a system of interest (Ekama, 2008).

One never develops a model that describes every single detail of the process and models are just used as simplification of reality in such a way that they describe that they describe that part of reality that is relevant to understand and to deal with (Henze et al, 2008).

Why Use Modelling in Waste Water Treatment?

The most important advantages of the use of models in waste water treatment are:

- Getting insight into plant performance
- Evaluating possible scenarios for upgrading
- Evaluating new plant design (Henze et al, 2008).

3.2 The model ASM 1

3.2.1 Introduction to the Model

In 1983, the International Association on Water Quality (IAWQ, formerly IAWPRC) formed a task group, which was to promote development, and facilitate the application of, practical models for design and operation of biological wastewater treatment systems. The first goal was to review existing models and the second goal was to reach a consensus concerning the simplest mathematical model having the capability of realistically predicting the performance of single-sludge systems carrying out carbon oxidation, nitrification and denitrification (Jeppsson, 1996). The final result was presented in 1987 (Henze et al., 1987) as the IAWQ Activated Sludge Model No.1.

3.2.2 Description of the model

The Activated Sludge Model No. 1, commonly known as ASM1 (Henze et al., 1987),is the result of work of an international research team IWA and is commonly used, with all its subsequent changes and updates in design and operation of facilities for biological treatment of wastewater. During the years, the original model was expanded to include the removal process of phosphorus. The main novelty of the model ASM2 (Henze et al., 1995), is to facilitate implementation with data commonly available plants, or at least that was the stated purpose with the model ASM3 (Gujer et al., 1999).

The ASM1 is structured as a system of 8 processes that act on 13 components; the purpose is to describe the performance of the components over time.

Although the model has been extended since then, for example to incorporate more fractions of COD to accommodate new experimental observations , for the description of growth and population dynamics of floc forming and filamentous bacteria and to include new processes for describing enhanced biological phosphorus removal (Henze et al., 1995), the original model is probably still the most widely used for describing WWT processes all over the world.

Task group also introduced the concept of switching functions to gradually turn process rate equations on and off as the environmental conditions were changed. The switching functions are 'Monod-like' expressions that are mathematically continuous. and thereby reduce the problems of numerical instability during simulations (Jeppsson, 1996). The task group also presented the structure of biokinetic models in a matrix format described in previous chapter, which was easy to read and understand.

The model doesn't takes into consideration purely physical-chemical phenomena such as sedimentation or chemical precipitation, phenomena already widely described in literature.

The effluent fed to the biological process is characterized according to the different components as reported in Table 3.1.

Table 3.1- Components of the ASM1 model

COMPONENT	DEFINITION	UNIT OF MEASUREMENT
S_1	Soluble Inert COD	gCOD
S_s	Readily biodegradable COD	gCOD
S_o	Dissolved Oxygen Concentration	gO_2
S_{NO}	NO_3-N and NO_2-N	gN
S_{NH}	Free and Saline Ammonia	gN
S_{ND}	Organic Souble and biodegradable Nitrogen	gN
S_{ALK}	Alkalinity	$gCaCO_3$
X_I	Inert Particulate COD	gCOD
X_S	Slowly Biodegradable Particulate COD	gCOD
X_{BH}	Heterotrophic Biomass	gCOD
X_{BA}	Autotrophic Biomass	gCOD
X_{ND}	Particulate and Biodegradable Organic Nitrogen	gN
X_P	Inert Particulate Products arising from biomass	gCOD

From 13 members, a first distinction can be based on the nature, soluble (S) or particulate (X), with which they are present in the wastewater. With the exception of dissolved oxygen (S_O) and alkalinity (S_{alk}), the various components are grouped according to 2 main groups: organic matter (expressed as COD) and nitrogenous compounds.

3.2.3 ASM1 Model Components

COD and nitrogen fractions are called as model components in the ASM1 model. COD and nitrogen fractions incorporated in ASM1 are discussed in following two sections.

3.2.3.1 Carbonaceous Components

COD is selected as the most suitable parameter for defining the carbon substrates as it provides a link between electron equivalents in the organic substrate, the biomass and oxygen utilized. In ASM1 the COD is subdivided based on solubility, biodegradability, biodegradation rate (Jeppsson, 1996):

The total COD is divided into soluble (S) and particulate (X) components.

- The COD is further divided into non-biodegradable and biodegradable organic matter. The non-biodegradable matter is biologically inert and passes through an activated sludge system without any changes. The inert soluble organic matter (S_I) leaves the system at the same concentration as it enters. Inert suspended organic matter in the wastewater influent (X_I) or produced via decay (X_P) becomes enmeshed in the activated sludge and is removed from the system via the sludge wastage.
- The biodegradable matter is divided into soluble readily biodegradable (S_S) and slowly biodegradable (X_S) substrate. The readily biodegradable substrate is assumed to consist of relatively simple molecules that may be consumed directly by heterotrophic organisms and used for growth of new biomass. On the contrary, the slowly biodegradable substrate consists of relatively complex molecules that require enzymatic breakdown prior to utilization. Finally, heterotrophic biomass (X_{BH}) and autotrophic biomass (X_{BA}) are generated by growth on the readily biodegradable substrate (SS) or by growth on ammonia nitrogen (S_{NH}). The biomass is lost via the decay process and converted to X_P and X_S.

Figure 3.1 summarizes carbonaceous components incorporated in ASM1.

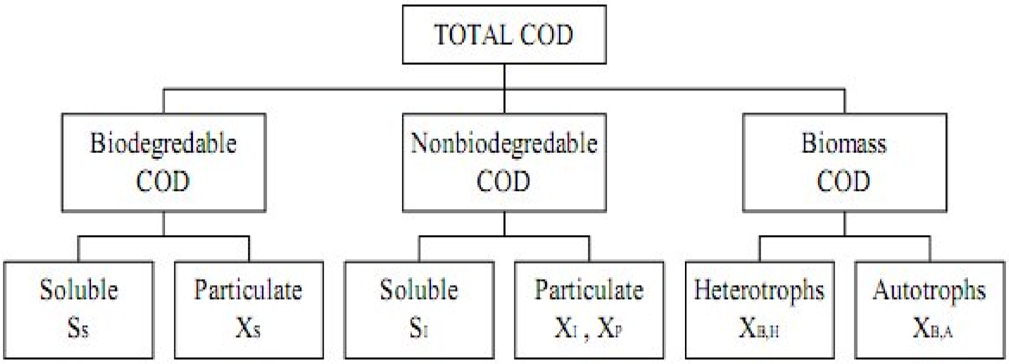


Fig 3.1 Carbonaceous components in ASM – 1

3.2.3.2 Nitrogenous Components

Similar to the organic matter, total nitrogen can be subdivided based on solubility, biodegradability and biodegradation rate (Jeppsson, 1997):

- Total nitrogen can be subdivided into soluble (S) and particulate (X) components.
- The nitrogen is divided into non-biodegradable matter and biodegradable matter. The non-biodegradable particulate organic nitrogen is associated with the non-biodegradable particulate COD (XI or XP), and the soluble non-biodegradable organic nitrogen is assumed to be negligible and not incorporated into the model.
- The biodegradable nitrogen is further divided into ammonia nitrogen (SNH) nitrate + nitrite nitrogen (SNO), soluble organic nitrogen (SND) and particulate organic nitrogen (XND). The particulate organic nitrogen is hydrolyzed soluble organic nitrogen in parallel with hydrolysis of the slowly biodegradable organic matter (XS). The soluble organic nitrogen is converting to ammonia nitrogen by ammonification. Ammonia nitrogen is the nitrogen source for biomass growth. Finally, the autotrophic conversion of ammonia results in nitrate nitrogen (SNO), which is considered to be a single step process in ASM1.

Nitrogenous components in ASM1 are summarized in Figure.

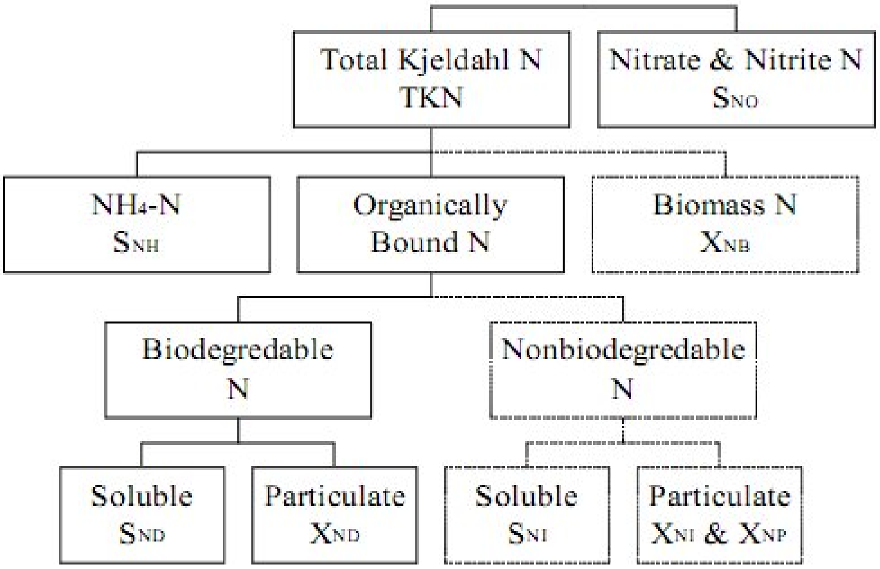


Fig 3.2 Nitrogenous components in ASM1.

Components shown in dotted frames are not included in the model although they can be calculated except S_{NI}.

3.2.3.3 Model Processes

- There are four different main processes defined in ASM1:
- Growth of biomass
- Decay of biomass
- Ammonification of organic nitrogen
- Hydrolysis of particulate organic matter

3.2.3.4 Aerobic Growth of Heterotrophic Biomass

Growth occurs by degradation of soluble readily biodegradable substrate (S_S) and consumption of oxygen (S_O). Ammonia nitrogen (S_{NH}) is also incorporated into cell mass. Both the concentrations of S_S and S_O are rate limiting for the growth process. The Monod relationship is used to describe the growth of heterotrophic and autotrophic organisms (Henze et al., 1987).

3.2.3.5 Anoxic Growth of Heterotrophic Biomass (Denitrification)

Heterotrophic organisms are capable of using nitrate as the terminal electron acceptor with S_S as substrate resulting in biomass growth and nitrogen gas in the absence of oxygen. Monod kinetics used for aerobic growth is applied except that the kinetic rate expression is multiplied by a correction factor □$_g$(<1). This factor is accounting for the fact that the anoxic substrate removal rate is slower compared to aerobic conditions. This can either be caused by a lower maximum growth rate or because only a fraction of the heterotrophic biomass is able to denitrify. Furthermore, anoxic growth is inhibited when oxygen is present which is described by the switching function.

$$\frac{K_{OH}}{K_{OH}+S_O}$$

(Eq: 3.1)

The coefficient K_{OH} has the same value as in the expression for aerobic growth. Thus, as aerobic growth declines, the capacity for anoxic growth increases (Henze et al., 1987).

3.2.3.6 Aerobic Growth of Autotrophic Biomass (Nitrification)

Ammonia nitrogen (S_{NH}) is oxidized to nitrate resulting in production of autotrophic biomass. A part of the S_{NH} is also incorporated in the autotrophic cell mass. As for heterotrophic growth the concentrations of S_{NH} and S_O can be rate limiting for the process. Nitrification has a considerable effect on the alkalinity (S_{ALK}) (Henze et al., 1987).

3.2.3.7 Decay of Heterotrophic Biomass

The death regeneration concept of Dold (1980) is applied to describe the different reactions that take place when organisms die. The traditional endogenous respiration concept describes how a fraction of the organism mass disappears to provide energy for maintenance. However, in the death regeneration concept oxygen is not directly associated with microbial decay. Decay is assumed to result in the release of slowly biodegradable substrate that is recycled back to soluble substrate and used for more cell growth. Thus, the oxygen utilization normally associated directly with decay is calculated as if it occurs indirectly from growth of new biomass on released endogenous respiration the loss of one unit of biomass COD leads to the utilization of one unit of oxygen minus the COD of the inert particulate products that are formed. However, in the death regeneration model the loss of one biomass COD unit results in the ultimate formation of one unit of COD due to the formed readily biodegradable substrate minus the formed inert particulate products. When the readily biodegradable COD is used for cell synthesis, only a fraction of a unit of oxygen (determined by the yield) will be required because of the energy incorporated into the cell mass. That cell mass undergoes in turn decay etc. before the unit of oxygen is finally removed (Petersen, 2000).

As a summary, to give the same amount of oxygen utilization per time due to the decay process, the decay rate coefficient must be larger for the death regeneration concept than if a more traditional endogenous decay process was adopted (Grady, et al., 1999).

3.2.3.8 Decay of Autotrophic Biomass

The decay of autotrophs is described similar to the heterotrophic decay process.

3.2.4 Ammonification of Soluble Organic Nitrogen (S_{ND})

Biodegradable soluble organic nitrogen (S_{ND}) is converted to ammonia nitrogen (S_{NH}) in a first order process.

3.2.4.1 Hydrolysis

Slowly biodegradable substrate (X_S) in the sludge is broken down producing readily biodegradable substrate (S_S). The degradation of slowly biodegradable matter has appeared rather important to realistic modeling of activated sludge systems because it is primarily responsible for realistic electron acceptor profiles (Dold 1980). This process is modeled on the basis of surface reaction kinetics and occurs only under aerobic and anoxic conditions. The hydrolysis rate is reduced under anoxic conditions in the same way as anoxic growth, by applying a correction factor $\square_h$ (<1) (Henze et al., 1987).

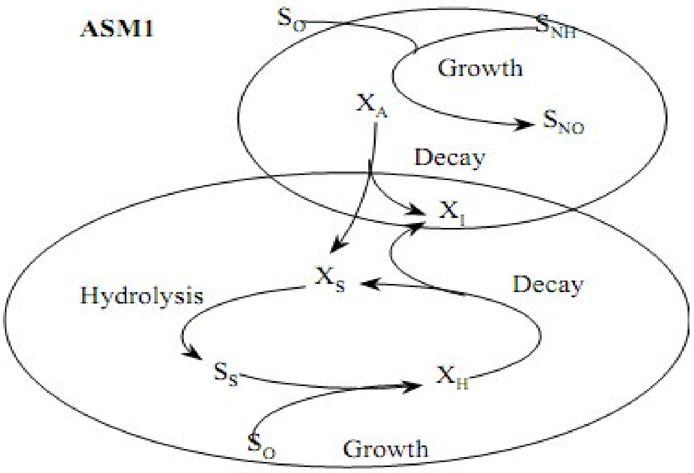
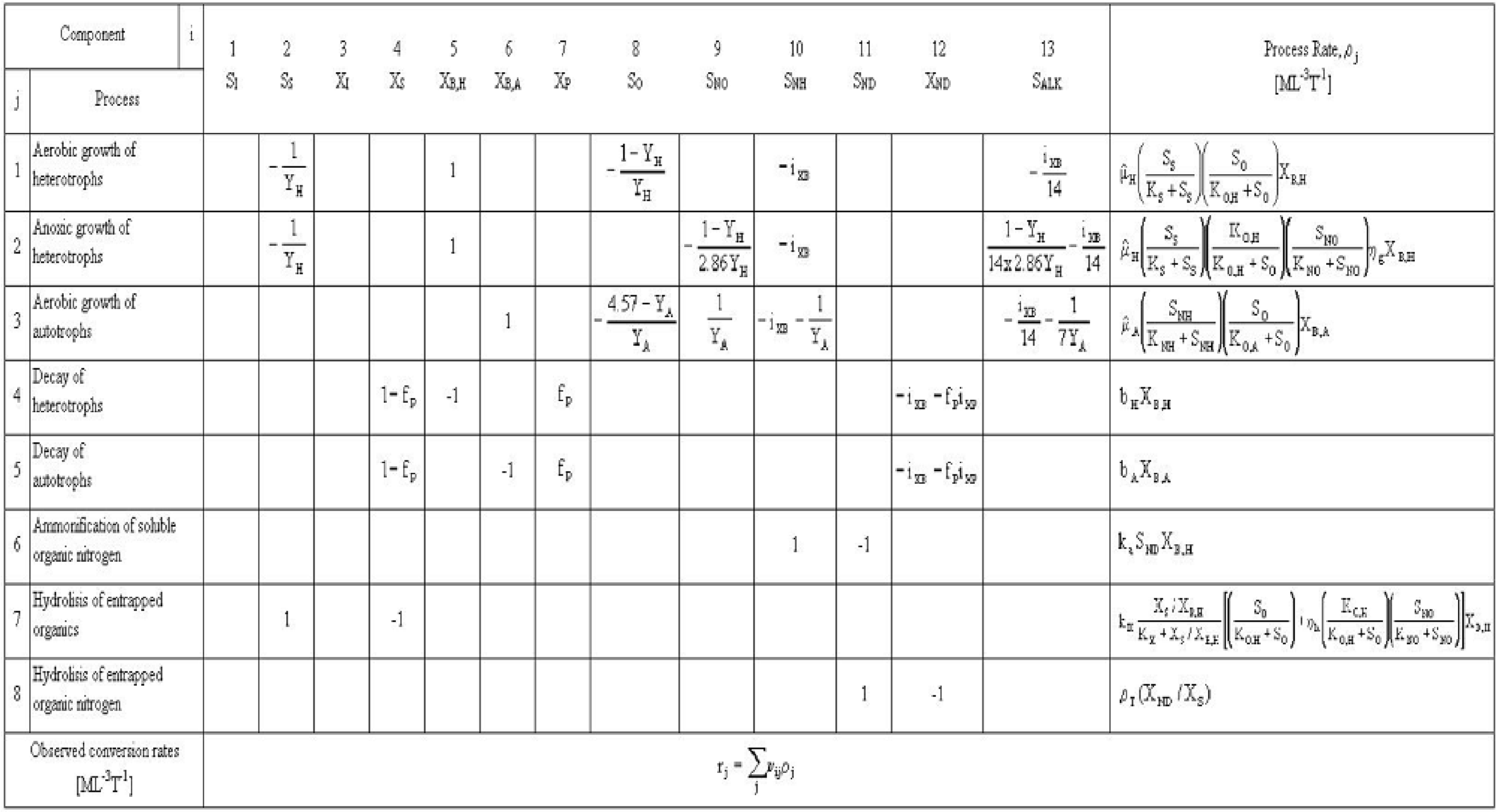


Fig 3.3: Substrate flows in ASM1

3.2.4.2 Model Formulation

Based on the component and processes described in previous two sections, ASM 1 model can be formulated as ordinary differential equations. The equations are arranged in the matrix format described in section two by the task group is given is Table

Table 3.2: ASM1 Model Matrix (Modified from Henze et al., 1987)



Component	i	1	2	3	4	5	6	7	8	9	10	11	12	13	Process Rate, ρ_j
j	Process	S_I	S_S	X_I	X_S	$X_{B,H}$	$X_{B,A}$	X_P	S_O	S_{NO}	S_{NH}	S_{ND}	X_{ND}	S_{ALK}	$[ML^{-3}T^{-1}]$
1	Aerobic growth of heterotrophs		$-\frac{1}{Y_H}$			1			$-\frac{1-Y_H}{Y_H}$		$-i_{XB}$			$-\frac{i_{XB}}{14}$	$\hat{\mu}_H\left(\frac{S_S}{K_S+S_S}\right)\left(\frac{S_O}{K_{OH}+S_O}\right)X_{B,H}$
2	Anoxic growth of heterotrophs		$-\frac{1}{Y_H}$			1				$-\frac{1-Y_H}{2.86Y_H}$	$-i_{XB}$			$\frac{1-Y_H}{14x2.86Y_H}-\frac{i_{XB}}{14}$	$\hat{\mu}_H\left(\frac{S_S}{K_S+S_S}\right)\left(\frac{K_{O,H}}{K_{O,H}+S_O}\right)\left(\frac{S_{NO}}{K_{NO}+S_{NO}}\right)\eta_g X_{B,H}$
3	Aerobic growth of autotrophs						1		$-\frac{4.57-Y_A}{Y_A}$	$\frac{1}{Y_A}$	$-i_{XB}-\frac{1}{Y_A}$			$-\frac{i_{XB}}{14}-\frac{1}{7Y_A}$	$\hat{\mu}_A\left(\frac{S_{NH}}{K_{NH}+S_{NH}}\right)\left(\frac{S_O}{K_{O,A}+S_O}\right)X_{B,A}$
4	Decay of heterotrophs				$1-f_p$	-1		f_p					$-i_{XB}-f_p i_{XP}$		$b_H X_{B,H}$
5	Decay of autotrophs				$1-f_p$		-1	f_p					$-i_{XB}-f_p i_{XP}$		$b_A X_{B,A}$
6	Ammonification of soluble organic nitrogen										1	-1			$k_a S_{ND} X_{B,H}$
7	Hydrolisis of entrapped organics		1		-1										$k_h \frac{X_S/X_{B,H}}{K_X+X_S/X_{B,H}}\left[\left(\frac{S_O}{K_{OH}+S_O}\right)+\eta_h\left(\frac{K_{O,H}}{K_{O,H}+S_O}\right)\left(\frac{S_{NO}}{K_{NO}+S_{NO}}\right)\right]X_{B,H}$
8	Hydrolisis of entrapped organic nitrogen											1	-1		$\rho_7(X_{ND}/X_S)$
Observed conversion rates $[ML^{-3}T^{-1}]$		$r_j=\sum_j \nu_{ij}\rho_j$													

Inert soluble organics (S_I) is not affected by any of eight processes included in ASM1 and therefore leaves the system at the same concentration as it enters. This component is included in the model only for simulation purposes. The concentration of readily biodegradable substrate (S_S) is reduced by the growth of heterotrophic bacteria in both aerobic and anoxic conditions and is increased by hydrolysis of slowly biodegradable substrate. The differential equation describing this is:

$$\frac{dS_S}{dt} = \left[-\frac{\hat{\mu}_H}{Y_H}\left(\frac{S_S}{K_S + S_S}\right)\left\{\left(\frac{S_O}{K_{O,H} + S_O}\right) + \right.\right.$$

$$\left.\eta_g\left(\frac{K_{O,H}}{K_{O,H} + S_O}\right)\left(\frac{S_{NO}}{K_{NO} + S_{NO}}\right)\right\} +$$

(Eq: 3.2)

$$k_h \frac{X_S / K_{B,H}}{K_X + (X_S / X_{B,H})}\left\{\left(\frac{S_O}{K_{O,H} + S_O}\right) + \right.$$

$$\left.\left.\eta_h\left(\frac{K_{O,H}}{K_{O,H} + S_O}\right)\left(\frac{S_{NO}}{K_{NO} + S_{NO}}\right)\right\}\right] X_{B,H}$$

(Eq: 3.3)

Inert suspended organic matter (X_I) becomes enmeshed in the activated sludge and is removed from the system via the sludge wastage. Like S_I, this component is also included in the model for simulation purposes. The concentration of slowly biodegradable substrate (X_S) is increased by recycling of dead biomass according to the death-regeneration hypothesis and decreased by the hydrolysis process according to:

$$\frac{dX_S}{dt} = (1 - f_P)(b_H X_{B,H} + b_A X_{B,A}) - k_h \frac{X_S / K_{B,H}}{K_X + (X_S / X_{B,H})}\left\{\left(\frac{S_O}{K_{O,H} + S_O}\right) + \eta_h\left(\frac{K_{O,H}}{K_{O,H} + S_O}\right)\left(\frac{S_{NO}}{K_{NO} + S_{NO}}\right)\right\} X_{B,H}$$

(Eq: 3.4)

The dynamic behavior of the heterotrophic biomass (X_{BH}) concentration is affected by aerobic and anoxic growth and decay of heterotrophs according to the following equation:

$$\frac{dX_{B,H}}{dt} = \left[- \hat{\mu}_{\mathrm{H}}\left(\frac{S_S}{K_S + S_S}\right)\left\{\left(\frac{S_O}{K_{O,H} + S_O}\right) + \eta_g\left(\frac{K_{O,H}}{K_{O,H} + S_O}\right)\left(\frac{S_{NO}}{K_{NO} + S_{NO}}\right)\right\} - b_H \right] X_{B,H}$$

(Eq: 3.5)

For autotrophic biomass, the differential equation is simpler since autotrophs do not grow in anoxic environment. Concentration of autotrophic biomass is affected by anoxic growth and decay processes as follows:

$$\frac{dX_{B,A}}{dt} = \left[\hat{\mu}_{\mathrm{A}}\left(\frac{S_{NH}}{K_{NH} + S_{NH}}\right)\left(\frac{S_O}{K_{O,A} + S_O}\right) - b_A \right] X_{B,A}$$

(Eq: 3.6)

Like X_I, particulate inert organic products (X_P) arising from biomass decay also becomes enmeshed in the activated sludge and is removed from the system via the sludge wastage. The model equation describing X_P production is:

$$\frac{dX_P}{dt} = f_P(b_H X_{B,H} + b_A X_{B,A})$$

(Eq: 3.7)

The concentration of nitrate is affected by two processes. It's increased by nitrification and decreased by denitrification. Equation describing this is formulated below:

$$\frac{dS_{NO}}{dt} = -\hat{\mu}_H \eta_g \left(\frac{1-Y_H}{2.86Y_H}\right)\left(\frac{S_S}{K_S+S_S}\right)\left(\frac{K_{O,H}}{K_{O,H}+S_O}\right)\left(\frac{S_{NO}}{K_{NO}+S_{NO}}\right)X_{B,H} +$$

$$\frac{\hat{\mu}_A}{Y_A}\left(\frac{S_{NH}}{K_{NH}+S_{NH}}\right)\left(\frac{S_O}{K_{O,A}+S_O}\right)X_{B,A}$$

(Eq: 3.8)

The ammonia concentration is decreased by growth of all microorganisms ammonia is used as the nitrogen source for incorporation into the biomass. The concentration is also decreased by the nitrification process and increased as a result of soluble organic nitrogen. The differential equation describing this is:

$$\frac{dS_{NH}}{dt} = \left[-i_{XB}\hat{\mu}_H\left(\frac{S_S}{K_S+S_S}\right)\left\{\left(\frac{S_O}{K_{O,H}+S_O}\right)+\right.\right.$$

$$\left.\left.\eta_g\left(\frac{K_{O,H}}{K_{O,H}+S_O}\right)\left(\frac{S_{NO}}{K_{NO}+S_{NO}}\right)\right\} + k_a S_{ND}\right]X_{B,H} -$$

$$\hat{\mu}_A\left(i_{XB}+\frac{1}{Y_A}\right)\left(\frac{S_{NH}}{K_{NH}+S_{NH}}\right)\left(\frac{S_O}{K_{O,A}+S_O}\right)X_{B,A}$$

(Eq: 3.9)

The concentration of soluble organic nitrogen is increased by hydrolysis process and decreased by ammonification process according to:

$$\frac{dS_{ND}}{dt} = \left[-k_a S_{ND} + k_h \frac{X_{ND} / X_{B,H}}{K_X + (X_S / X_{B,H})} \left\{ \left(\frac{S_O}{K_{O,H} + S_O} \right) + \eta_h \left(\frac{K_{O,H}}{K_{O,H} + S_O} \right) \left(\frac{S_{NO}}{K_{NO} + S_{NO}} \right) \right\} \right] X_{B,H}$$

(Eq: 3.10)

The concentration of particulate organic nitrogen (X_{ND}) is increased by biomass decay and decreased by the hydrolysis process similar to the concentration of X_S. The differential equation describing this is:

$$\frac{dX_{ND}}{dt} = (i_{XB} - f_P i_{XP})(b_H X_{B,H} + b_A X_{B,A}) - k_h \frac{X_S / K_{B,H}}{K_X + (X_S / X_{B,H})} \left\{ \left(\frac{S_O}{K_{O,H} + S_O} \right) + \eta_h \left(\frac{K_{O,H}}{K_{O,H} + S_O} \right) \left(\frac{S_{NO}}{K_{NO} + S_{NO}} \right) \right\} X_{B,H}$$

(Eq: 3.11)

The oxygen concentration in wastewater (S_O) is reduced by aerobic growth of heterotrophic and autotrophic microorganisms according to:

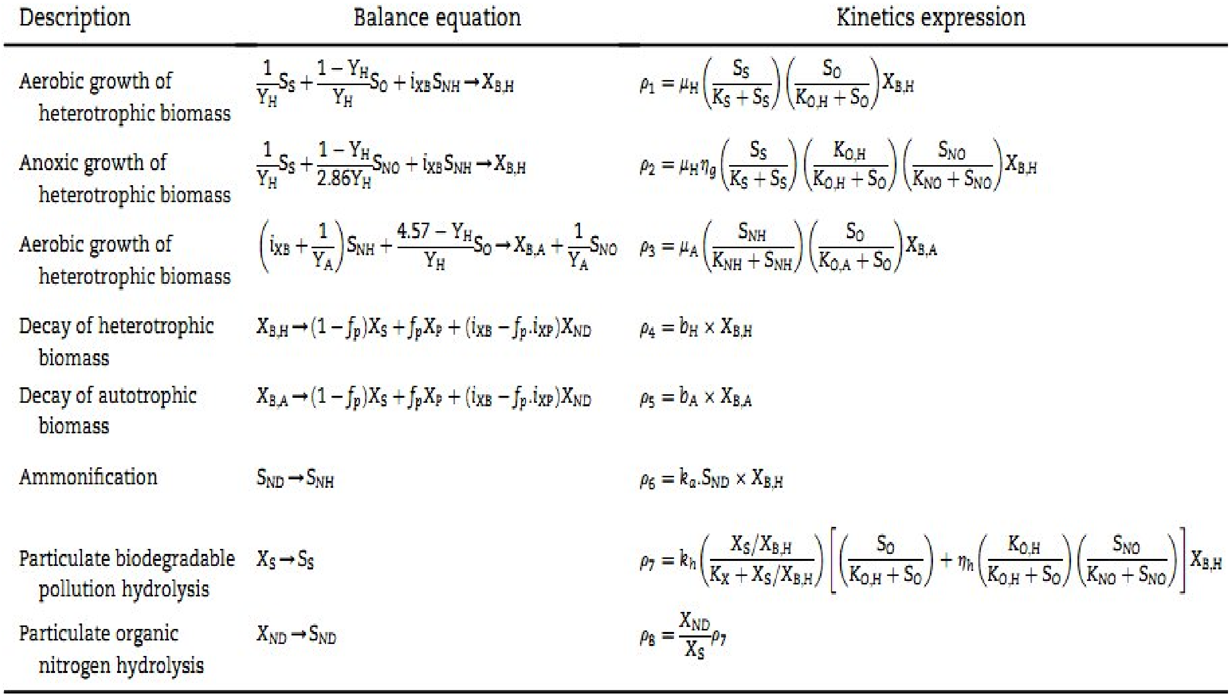
$$\frac{dS_O}{dt} = -\hat{\mu}_H \left(\frac{1 - Y_H}{Y_H} \right) \left(\frac{S_S}{K_S + S_S} \right) \left(\frac{S_O}{K_{O,H} + S_O} \right) X_{B,H} - \hat{\mu}_A \left(\frac{4.57 - Y_A}{Y_A} \right) \left(\frac{S_{NH}}{K_{NH} + S_{NH}} \right) \left(\frac{S_O}{K_{O,A} + S_O} \right) X_{B,A}$$

(Eq: 3.12)

Finally, alkalinity (S_{ALK}) is increased by anoxic growth of heterotrophs (denitrification) and ammonification processes, and decreased by aerobic growth of both heterotrophs and autotrophs according to:

$$\frac{dS_{ALK}}{dt} = \left[\hat{\mu}_H \left(\frac{S_S}{K_S + S_S} \right) \left\{ -\frac{i_{XB}}{14} \left(\frac{S_O}{K_{O,H} + S_O} \right) + \eta_g \left(\frac{1-Y_H}{14x2.86Y_H} - \frac{i_{XB}}{14} \right) \left(\frac{K_{O,H}}{K_{O,H} + S_O} \right) \left(\frac{S_{NO}}{K_{NO} + S_{NO}} \right) \right\} + \frac{1}{14} k_a S_{ND} \right] X_{B,H} - \hat{\mu}_A \left(\frac{i_{XB}}{14} + \frac{1}{7Y_A} \right) \left(\frac{S_{NH}}{K_{NH} + S_{NH}} \right) \left(\frac{S_O}{K_{O,A} + S_O} \right) X_{B,A} \quad \text{(Eq: 3.2)}$$

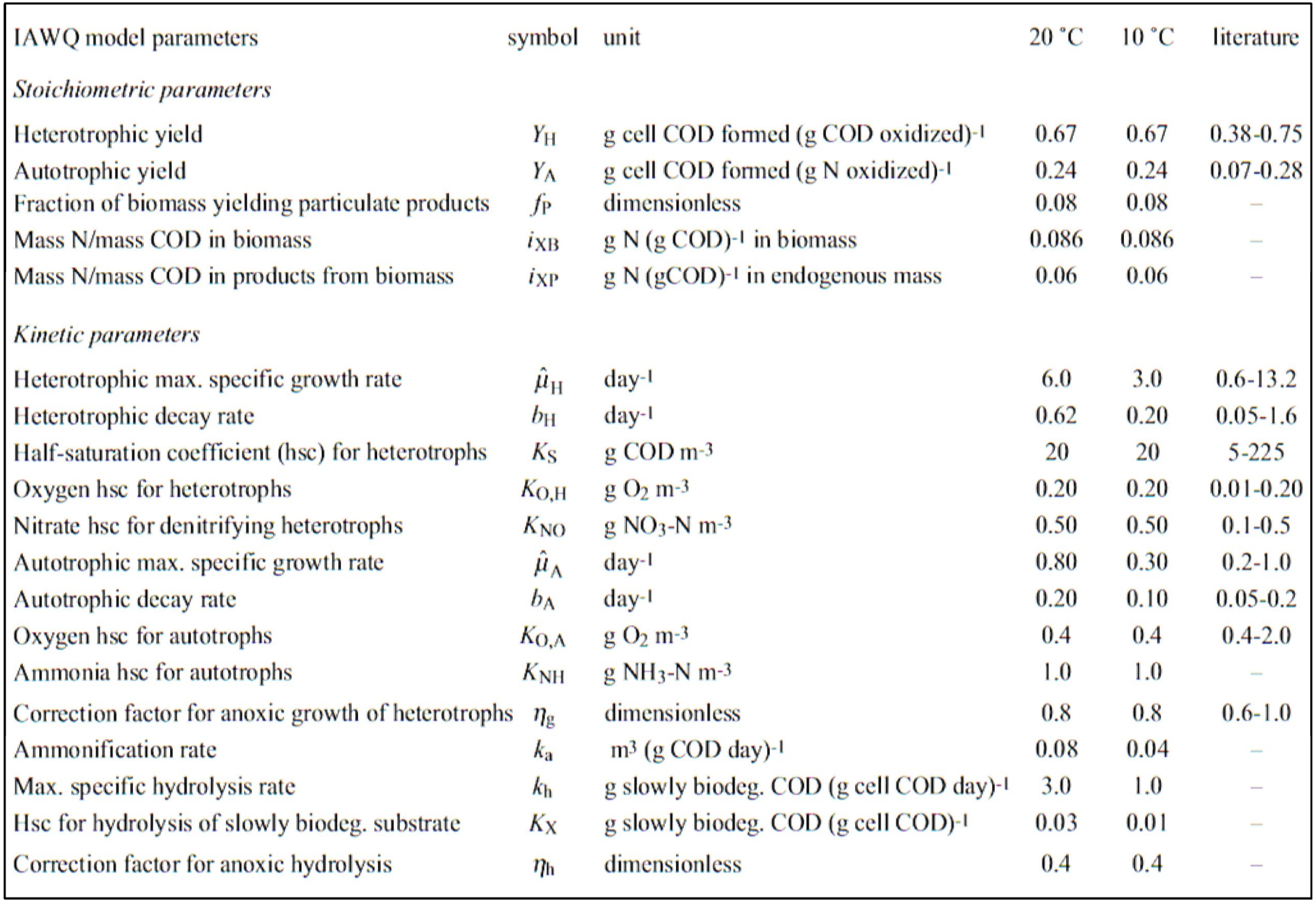
Table 3.4: Brief description of the processes of ASM-1 model.



Description	Balance equation	Kinetics expression
Aerobic growth of heterotrophic biomass	$\frac{1}{Y_H}S_S + \frac{1-Y_H}{Y_H}S_O + i_{XB}S_{NH} \rightarrow X_{B,H}$	$\rho_1 = \mu_H \left(\frac{S_S}{K_S + S_S}\right)\left(\frac{S_O}{K_{O,H} + S_O}\right)X_{B,H}$
Anoxic growth of heterotrophic biomass	$\frac{1}{Y_H}S_S + \frac{1-Y_H}{2.86Y_H}S_{NO} + i_{XB}S_{NH} \rightarrow X_{B,H}$	$\rho_2 = \mu_H \eta_g \left(\frac{S_S}{K_S + S_S}\right)\left(\frac{K_{O,H}}{K_{O,H} + S_O}\right)\left(\frac{S_{NO}}{K_{NO} + S_{NO}}\right)X_{B,H}$
Aerobic growth of heterotrophic biomass	$\left(i_{XB} + \frac{1}{Y_A}\right)S_{NH} + \frac{4.57 - Y_H}{Y_H}S_O \rightarrow X_{B,A} + \frac{1}{Y_A}S_{NO}$	$\rho_3 = \mu_A \left(\frac{S_{NH}}{K_{NH} + S_{NH}}\right)\left(\frac{S_O}{K_{O,A} + S_O}\right)X_{B,A}$
Decay of heterotrophic biomass	$X_{B,H} \rightarrow (1 - f_p)X_S + f_pX_P + (i_{XB} - f_p.i_{XP})X_{ND}$	$\rho_4 = b_H \times X_{B,H}$
Decay of autotrophic biomass	$X_{B,A} \rightarrow (1 - f_p)X_S + f_pX_P + (i_{XB} - f_p.i_{XP})X_{ND}$	$\rho_5 = b_A \times X_{B,A}$
Ammonification	$S_{ND} \rightarrow S_{NH}$	$\rho_6 = k_a.S_{ND} \times X_{B,H}$
Particulate biodegradable pollution hydrolysis	$X_S \rightarrow S_S$	$\rho_7 = k_h \left(\frac{X_S/X_{B,H}}{K_X + X_S/X_{B,H}}\right)\left[\left(\frac{S_O}{K_{O,H} + S_O}\right) + \eta_h \left(\frac{K_{O,H}}{K_{O,H} + S_O}\right)\left(\frac{S_{NO}}{K_{NO} + S_{NO}}\right)\right]X_{B,H}$
Particulate organic nitrogen hydrolysis	$X_{ND} \rightarrow S_{ND}$	$\rho_8 = \frac{X_{ND}}{X_S}\rho_7$

As an example, values for the Model parameters suggested by the IAWQ task group are presented in table 3.5.

Table 3.5: Typical model parameter values at neutral pH



IAWQ model parameters	symbol	unit	20 °C	10 °C	literature
Stoichiometric parameters					
Heterotrophic yield	Y_H	g cell COD formed (g COD oxidized)$^{-1}$	0.67	0.67	0.38-0.75
Autotrophic yield	Y_A	g cell COD formed (g N oxidized)$^{-1}$	0.24	0.24	0.07-0.28
Fraction of biomass yielding particulate products	f_P	dimensionless	0.08	0.08	–
Mass N/mass COD in biomass	i_{XB}	g N (g COD)$^{-1}$ in biomass	0.086	0.086	–
Mass N/mass COD in products from biomass	i_{XP}	g N (gCOD)$^{-1}$ in endogenous mass	0.06	0.06	–
Kinetic parameters					
Heterotrophic max. specific growth rate	$\hat{\mu}_H$	day^{-1}	6.0	3.0	0.6-13.2
Heterotrophic decay rate	b_H	day^{-1}	0.62	0.20	0.05-1.6
Half-saturation coefficient (hsc) for heterotrophs	K_S	g COD m^{-3}	20	20	5-225
Oxygen hsc for heterotrophs	$K_{O,H}$	g O_2 m^{-3}	0.20	0.20	0.01-0.20
Nitrate hsc for denitrifying heterotrophs	K_{NO}	g NO_3-N m^{-3}	0.50	0.50	0.1-0.5
Autotrophic max. specific growth rate	$\hat{\mu}_A$	day^{-1}	0.80	0.30	0.2-1.0
Autotrophic decay rate	b_A	day^{-1}	0.20	0.10	0.05-0.2
Oxygen hsc for autotrophs	$K_{O,A}$	g O_2 m^{-3}	0.4	0.4	0.4-2.0
Ammonia hsc for autotrophs	K_{NH}	g NH_3-N m^{-3}	1.0	1.0	–
Correction factor for anoxic growth of heterotrophs	η_g	dimensionless	0.8	0.8	0.6-1.0
Ammonification rate	k_a	m^3 (g COD day)$^{-1}$	0.08	0.04	–
Max. specific hydrolysis rate	k_h	g slowly biodeg. COD (g cell COD day)$^{-1}$	3.0	1.0	–
Hsc for hydrolysis of slowly biodeg. substrate	K_X	g slowly biodeg. COD (g cell COD)$^{-1}$	0.03	0.01	–
Correction factor for anoxic hydrolysis	η_h	dimensionless	0.4	0.4	–

3.3 Restrictions of ASM1

A number of restrictions concerning ASM1 are summarized below (Henze et al., 1987):

- The system must operate at constant temperature.
- The pH is constant and near neutrality. It is known that the pH has an influence on many of the parameters, however only limited knowledge is available to be able to express these possible influences. Consequently, a constant pH has been assumed. The inclusion of alkalinity in the model, however, does allow for detection of pH problems.
- No considerations have been given to changes in the nature of the organic matter within any given wastewater fractions (e.g. the readily biodegradable substrate). Therefore, the parameters in the rate expressions have been assumed to have constant values. This means that only concentration changes of the wastewater components can be handled whereas changes in the wastewater character cannot.
- The effects of nutrient limitations (e.g. N and P) on the cell growth have not been considered. It is, however, easy to add limitation terms in the model if needed. The correction factors for denitrification (η_g and η_h) are fixed and constant for a given wastewater, even though it is possible that their values are depending on the system configuration. The parameters for nitrification are assumed to be constant and to incorporate any inhibitory effects that wastewater constituents may have on them.
- The heterotrophic biomass is homogeneous and does not undergo changes in species diversity with time. This assumption is inherent to the assumption of constant kinetic parameters. This means that any changes in substrate concentration gradients, reactor configuration, etc. on sludge settleability are not considered.
- The entrapment of particulate organic matter in the biomass is assumed to be instantaneous.

- The hydrolysis of organic matter and organic nitrogen are coupled and occurs simultaneously with equal rates.
- The type of electron acceptor present does not affect loss of biomass by decay.
- The type of electron acceptor does not affect the heterotrophic yield coefficient.
- ASM1 is developed for simulation of treatment of municipal wastewater, and it is therefore not advised to apply the model to systems where industrial contributions dominate the characteristics of the wastewater.
- ASM1 cannot deal with elevated nitrite concentrations.
- ASM1 is not designed to deal with activated sludge systems with very high load or small sludge retention time (SRT<1 day).

3.4 Model Calibration

Model calibration is understood as the adaptation of a model to describe a certain amount of information obtained from a full-scale wastewater treatment plant (WWTP) under study. This task is often rather time-consuming, and typically the time needed for a model calibration is underestimated. Even though more than a decade has passed since the publication of the Activated Sludge Model No. 1 (ASM1) (Henze et al., 1987), a fully developed model calibration procedure has not been defined yet. The purpose of the calibrated model determines how to approach a model calibration, e.g. which information is needed and to which level of detail the model should be calibrated. A systematic model calibration procedure was therefore defined and evaluated for a municipal–industrial wastewater treatment plant. In the case that was studied it was important to have a detailed description of the process dynamics, since the model was to be used as the basis for optimization. COD and nitrogen fractions are called as model components in the ASM1 model COD and nitrogen fractions incorporated in ASM1 are discussed in following two sections. Due to the major impact of ASM1 on the WWT community it is considered as a 'state-of-the-art' model when biological phosphorus removal is not considered (Jeppsson, 1996). Monod relationship is used to describe the growth rate of both heterotrophic and autotrophic organisms. Unlike most of the previous models, COD was selected as the suitable parameter for defining the carbonaceous material, as it provides a link between electron equivalents in the organic substrate, the biomass and the oxygen utilized. Furthermore, mass balances can be made in terms of COD (Petersen et al, 2000).

There isn't a complete procedure for calibration of ASM1. There may be many reasons for this. Important to realize is that the purpose of a model being built is very much determining on how to approach the calibration, making it difficult to generalize (Henze et al., 1995). Usually model calibration procedures depend on the applications, e.g. for process scenarios and optimizations etc. To obtain information on model calibration procedures one often has to collect bits and pieces from various sources to obtain an overview (Petersen, 2000). Parameter estimation consists of determining the optimal values of the parameters of a given model with the aid of measured data. Initially, the model structures, of which selected parameters need to be estimated, and the experimental data need to be defined. Moreover, first guesses of the initial conditions, i.e. concentrations, and parameters, have to be given (Petersen, 2000). The parameter estimation routine then basically consists of minimizing an objective function, which for example can be defined as the weighted sum of squared errors between the model output and the data (Fikar et al., 2002). When the objective function reaches a minimum with a certain given accuracy the optimal parameter values are obtained. Thus, parameter estimation is carried out using specific mathematical search algorithms.

However, due to the high complexity caused by the numerous parameters and the unidentifiable nature of the ASM models, it will be hard to apply mathematical calibration techniques. A major problem encountered in calibration of ASM is the identifiability of the mode parameters (Petersen, 2000). Identifiability is the ability to obtain a unique combination of parameters describing system behavior. A distinction should be made between theoretical and practical identifiability. Theoretical identifiability is a property of the model structure, and relates to the question whether it is at all possible to obtain unique parameter values for a given model structure considering certain selected outputs, and assuming ideal measurements. Practical identifiability, on the other hand, includes the quality of the data. Thus, theoretically identifiable parameters may be practically unidentifiable if the data are too noise corrupted (Jeppsson, 1996).

When estimating model parameters, it must always be noted that a typical problem related to the model calibration of ASM is that more than one combination of influent characteristics and model parameters can give the same good description of the collected data (Kristensen et al., 1998). This indicates identifiability problems of either theoretical or practical origin. Regarding theoretical and practical identifiability problems of model parameters, model calibration of ASM is typically based on a step-wise procedure, and by changing just a few of the many parameters instead of applying an automatic mathematical optimization routine (Petersen, 2000).

3.4.1 Information set for Model Calibration

The set of information that should be collected for successful model calibration was extracted and combined from different sources (Henze et al., 1987; Henze, 1992; Lesouef et al., 1992; Xu & Hultman, 1996; Kristensen et al., 1998, Petersen, 2000), and is summarized below:

- Design data: reactor volumes pump flows and aeration capacities.
- Operational data:
- Flow rates, as averages or dynamic trajectories, of influent, effluent, recycle and waste flows.
- Aeration, pH and temperatures.
- Characterization for the hydraulic model, e.g. the results of tracer tests.
- Characterization for the settler model: e.g. zone settling velocities at different mixed liquor suspended solids concentrations.
- Characterization for the biological model, ASM, of:
- Wastewater concentrations of full-scale WWTP influent and effluent (as well as some intermediate streams between the WWTP's unit

processes), as averages or a dynamic trajectories: e.g. SS, COD, TKN, NH4-N, NO3-N, PO4-P etc.

- Sludge composition: e.g. SS, VSS, COD, N and/or P content.
- Reaction kinetics: e.g. growth and decay rates.
- Reaction Stoichiometry: e.g. biomass yields

The list does not describe how the particular information can be collected in practice. As mentioned above, the required quality and quantity of information will depend very much on the purpose of the modeling exercise. In case the model is to be used for educational purposes, for comparison of design alternatives for non existing plants or in other situations where qualitative comparisons are sufficient, the default parameter values defined by Henze et al. (1987) can be applied (Petersen2000). A reasonably good description can most often be obtained with this default parameter set for typical municipal cases without significant industrial influence (Henze et al., 1997). However, some processes may need a more adequate description than others depending on the purpose of the model calibration. This may especially apply for models that are supposed to describe the processes in an industrial or combined municipal and industrial treatment plant (Petersen, 2000). In such cases the wastewater characterization and the activated sludge may differ significantly from standard municipal wastewater. Also, the availability of readily biodegradable carbon substances is important for the successful achievement of both denitrification and biological P removal, and may need to be characterized in more detail (Petersen, 2000).

The information needed for the characterization of the biological model can basically be gathered from three sources (Petersen, 2000):

- Default values from literature (e.g. Henze et al., 1987).
- Full-scale plant data
- Average or dynamic data from grab or time/flow proportional samples.
- Conventional mass balances of the full-scale data.
- On-line data.

- Measurements in reactors to characterize process dynamics (mainly relevant for SBR’s and alternating systems).
- Information obtained from different kinds of lab-scale experiments with wastewater and activated sludge from the full-scale plant under study.

The intended use of the model will determine which information source to choose for the characterization of the different biological processes in the model. Furthermore, the purpose will decide to which level the model has to be calibrated, since the quality of the desired model predictions will depend strongly on the quality of the model calibration (Petersen, 2000).

3.4.2 Model Calibration Levels (Steady State Model Calibration)

In this step, assuming that the average represents a steady state, data obtained from the full-scale WWTP are averaged and a simple model not including hydraulic detail is calibrated to average effluent and sludge waste data. Typically, the calibrations of the ASM and the settler are linked together, since the aim is most often to describe the final effluent quality. The recycle from the settler also has an influence on the activated sludge system. Thus, there may be an interaction between the steady state calibration and the settler model calibration. Finally, the next step in the calibration procedure is a steady state model calibration that includes the hydraulic model. In general, with a steady state model calibration, only parameters responsible for long-term behavior of the WWTP can be determined, i.e. Y_H, f_p, b_H and X_I in the influent (Henze et al., 1999; Nowak et al., 1999). These parameters are correlated to a certain degree, meaning that a modification of one parameter value can be compensated by a modification of another parameter value. In the study of Nowak et al. (1999) on mass balances of full-scale data, it was therefore chosen to fix Y_H and f_p, leaving X_I in the influent and b_H to be determined from the steady state data. In the study of Lesouef et al. (1992), two WWTP models were calibrated via steady state calibration only, and this calibrated model was applied to simulate dynamic process scenarios. A steady state calibration is, very useful for the determination of initial conditions prior to a dynamic model calibration and for the initiation of first parameter iteration (Kristensen et al., 1998; Petersen, 2000).

3.4.3 Characterization of Wastewater

Different methods are proposed to structure the wealth of methods that have been developed and applied for the characterization of wastewater and reaction kinetics in relation to ASM1. Wastewater can be characterized either with physical-chemical methods or with biological methods. In practice one typically ends up with a combined approach to obtain an estimate of the concentrations of all components (Petersen et al., 2000). In ASM1 the COD_{tot} of the wastewater is considered to consist of inert soluble organic matter (S_i), readily and slowly biodegradable substrate (S_S and X_S respectively) and inert suspended organic matter (X_i), whereas biomass in the wastewater is considered to be insignificant.

A wastewater can be separated into different components in a relatively simple manner via physical-chemical separation methods. The difference in molecular size can give an indication on biodegradability because small molecules can be taken up directly over the cell membranes whereas bigger molecules need to be broken down prior to uptake. Enzymatic hydrolysis is primarily a surface phenomenon, which means that the hydrolysis rate is directly related to the surface area. Thus, smaller molecules are readily degraded whereas degradation of larger material can be kinetically limited (Grady et al., 1999).The ASM models do not differentiate between filtered, colloidal and settleable wastewater fractions. It is therefore necessary to convert the fractions resulting from a physical-chemical characterization to the ASM components. The possibilities and limitations of physical-chemical methods to accomplish this task are summarized below.

3.4.3.1 Inert Soluble Organic Matter

Soluble inert organic matter (S_I) is present in the influent, but also produced during the activated sludge process (Petersen et al., 2002). Most of the evidence for the production of soluble organics by microorganisms is collected from experiments with simple known substrates, e.g. glucose (Petersen et al., 2000). However, the production has also been proven to take place with wastewater (Petersen et al., 2002). A model has been proposed relating the S_I formation to the hydrolysis of non-viable cellular materials in the system, thereby linking the S_I production to the initial substrate concentration and the decay of the produced biomass (Petersen et al., 2002). This model was verified in a study with different industrial wastewaters and, although the data were not of very high quality, some evidence was given that the S_I production depends very much on the wastewater type (Petersen, 2000). Although the origin of the S_I production may remain unexplained, it seems clear that it does take place to various extents depending on different factors as mentioned above, resulting in a S_I concentration in the effluent that may be higher than the influent. Such S_I production is, however, not included in the ASM models, where S_I is considered a conservative component. To deal with this discrepancy between model concept and reality a simplified approach is typically applied by the definition of a fictive model influent concentration S_I that includes the produced SI together with the real S_I influent concentration (Henze, 1992).It is not possible to measure S_I directly and different approximations are therefore usually applied. Most often S_I is determined by the soluble effluent COD, which has appeared to be a good estimate for S_I in case of a low loaded activated sludge process (Ekama et al., 1986). On the other hand Siegrist and Tschui (1992) suggested that the influent S_I could be estimated as 90% of the effluent COD. These approximations may hold in most cases, but a more correct approach would be to consider it as the soluble effluent COD minus the soluble effluent Biochemical Oxygen Demand (BOD) multiplied with a BOD/COD conversion factor (Henze, 1992). Furthermore, S_I can be determined as the soluble COD remaining after a long-term BOD test with the influent (Henze et al., 1987). The latter approach is in fact a combination of physical-chemical and biological methods.

Summarizing, it will be case depending whether it is needed to characterize the produced S_I or whether the model component can be approximated as described above.

3.4.3.2 Readily Biodegradable Substrate

The soluble COD fraction excluding the soluble inert organic matter (S_I) is mostly considered to be the readily biodegradable substrate (S_s). The correctness of this approach does however evidently depend on the pore size of the filters used for the separation. It was confirmed biologically with respirometric methods, that the studied wastewater did not contain any particulate readily biodegradable matter (Petersen, 2002).

Finally, a method based on flocculation with $Zn(OH)_2$ has been developed to remove colloidal matter of 0.1-10 Pm that normally passes through 0.45 Pm filter membranes, and was successfully applied to a nitrifying (Sin, 2000) and phosphorus removal activated sludge system (Mamais et al.,1993, Petersen).

3.4.3.3 Inert Suspended Organic Matter

The test proposed for the determination of S_I, as the residual soluble COD remaining after a long-term BOD test, by Lesouef et al. (1992) can also be applied to determine X_I (Petersen et al., 2000). The X_I concentration is then determined as the residual particulate COD, assuming that X_I is not produced during the test. This assumption may, however, be questionable since X_I will be produced due to decay during the long-term BOD test and corrections for this will have to be considered. It is also proposed that X_I should be estimated by comparing the effective sludge production in the full-scale plant with simulation (Sin, 2000).

3.4.3.4 Slowly Biodegradable Substrate

A physical characterization based on different molecular sizes can be used to distinguish between readily biodegradable substrate S_S and slowly biodegradable substrate X_S (Petersen et al., 2000). If the components S_S, S_I and X_I are known and if it is assumed that the biomass concentration is negligible, X_S can be determined via a simple mass COD balance.

3.4.3.5 Biomass

It is not possible to determine biomass concentrations (X_{BH} and X_{BA}) with a physical-chemical method.

3.4.3.6 Nitrogen Components

The nitrogen components (S_{NH}, S_{ND}, S_{NO}, X_{ND}) can rather easily be detected by physical–chemical analysis via a combination of standard analyses of ammonium, nitrite and nitrate and Kjeldahl nitrogen (TKN) on filtered and non filtered samples (Henze et al., 1987).

CHAPTER FOUR

APPLICATION OF JAVA BASED ACTIVATED SLUDGE SIMULATOR-ACTIVATED SLUDGE MODEL 1

4.1 Introduction to JASS

JASS stands for Java Activated Sludge process Simulator and is a Java program that simulates activated sludge processes. In JASS the activated sludge process is simulated with the help of the International Water Association Activated Sludge Model no 1 (ASM 1).The equations in the model is solved with a fourth order Runge Kutta method. Different ASP plants can be simulated with JASS. The simulation results are presented dynamically in bar diagrams and a time plot in the graphical user interface (GUI). Changes to the process can be made during the simulation.

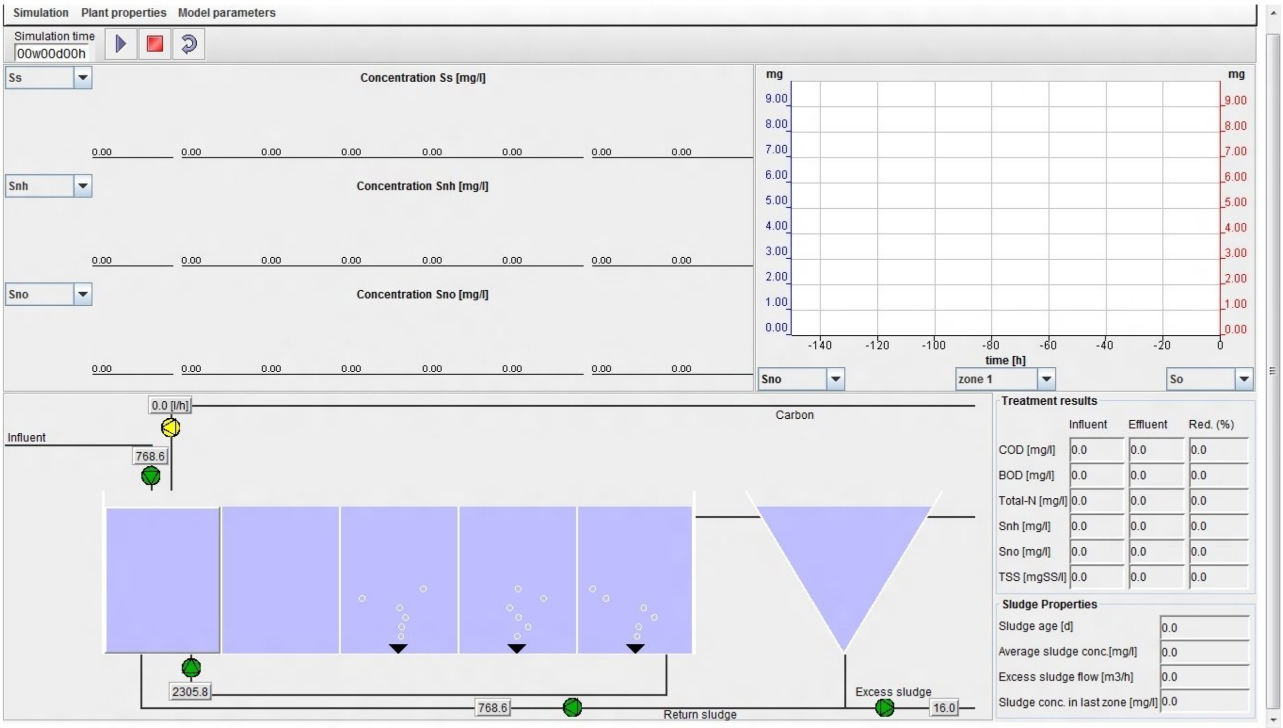
4.1.1 Starting the Simulator

The simulator can be run in any web browser that has the Java plug-in version 1.3 or later installed. The simulator is then loaded by opening the correct URL.

A user that has access to the Java class files and has the Java run time environment version 1.3 or later installed may also run the simulator as a standard Java application.

4.1.2 Plant configuration chosen for the simulation of the data

Comodepur is too huge of a Water Treatment Plant to be simulated in the ASM 1 software. The tank volumes given in the software for the data to be inserted are much smaller than the original plant has. This caused a large error in the comparison of measured and simulated values. Thus for simplicity's sake Benchmark Configuration of the Software were used for the simulation of the Plant Data.



Simulation time: 00w00d00h

Ss; Snh; Sno; zone 1; So

Treatment results

	Influent	Effluent	Red. (%)
COD [mg/l]	0.0	0.0	0.0
BOD [mg/l]	0.0	0.0	0.0
Total-N [mg/l]	0.0	0.0	0.0
Snh [mg/l]	0.0	0.0	0.0
Sno [mg/l]	0.0	0.0	0.0
TSS [mgSS/l]	0.0	0.0	0.0

Sludge Properties

Sludge age [d]	0.0
Average sludge conc.[mg/l]	0.0
Excess sludge flow [m3/h]	0.0
Sludge conc. in last zone [mg/l]	0.0

Fig 4.1 Screenshot of the benchmark configuration of ASM 1

4.1.3 Loading Plant Configuration

The *LOAD* item in the Simulation menu can be used to load different plant configurations. When this item is selected the available plant configurations are displayed in a menu. If JASS is run in a non-appalet environment, it is also possible to load a configuration from a file.

A major drawback of the non-appalet environment is that in the Simulation Menu the plant configuration cannot be saved to a file since appalets are not allowed to save files to disk.

In this study Benchmark configuration is used and Post Denitrification is not included. Hence there are only five tanks, two of which are anoxic tanks and the rest of three showing bubbles are the aeration tanks. Thus they show Pre-denitrification and Denitrification respectively.

In the lower left of the GUI a schematic picture of the process is displayed. Here the compartments, the settler and the flow-paths (internal recirculation, return sludge etc) are displayed. Some flow paths have a pump attached. If the pump is clicked, a dialogue is displayed where the flow rate can be set.

The composition of the influent water can be set by selecting *Influents* in the *Plant Properties* Menu. This displays a dialog where the concentration of the different components can be set.

The volumes of the compartments are set by selecting *Compartment volumes* in *the Plant properties* menu. This displays a dialog where the volumes can be set.

In the *Controllers sub menu* in the Plant Properties menu the configuration used in the plant are listed where the controller parameters are set.

In the *Flow rates* sub menu in the *Plant properties* menu different flows are listed. Selecting one of them brings up a dialog where the flow rates can be set, just as when the corresponding pump in the process is pressed.

Selecting *Miscellaneous properties* in the *Plant properties* menu displays a dialog box where the concentration of the external carbon is set which in our case is set to be zero because Post denitrification is not included in this study.

4.1.4 Changing Model Parameters

- Selecting ASM 1-parameters in the Model parameters menu brings up a dialog where the different parameters in the ASM 1 can be set. Some of the parameters are temperature dependent and will therefore change with temperature which can also be set.

In this study original temperatures of Comodepur plant in winter and summer had been used which are 15^0 C and 30^0 C respectively for both seasons.

- Selecting *Settler Model Parameters* in the *Model parameters* dialog brings up a dialog where the settler model parameters are set. The Volume of the settler tank had to be adjusted in the case of Comodepur since the original value of the Settler tank volume created sludge over flow during simulation since the Sludge flow rate is much higher as in accordance with the settler tank volume for the ASM 1 plant configuration.
- Selecting *Oxygen Transfer Parameters* in the *Model parameters* dialog brings up a dialog where the oxygen transfer is set. In this study the Air Carbon Zone value is set to be 4.5 which is in accordance with the flow rate of the air diffusers of the Comodepur Plant in the Aeration tanks.

Then the software is run for a period of seven days which is the usual simulation time used as proposed in the User Manual.

4.2 Calibration of ASM1

ASM1 model is calibrated with influent and effluent data obtained from plant for periods of data from January, 2009 to December, 2011. Months of January, February, March, and December were chosen for Winter Season, while June and July were selected for the summer season in each of the three years data. Data obtained from the plant is given in Table 4.4 with the influent water characterization into Carbonaceous and Nitrogenous Components. Removal efficiency of COD and Total Nitrogen are given in the Results and discussion chapter. COD and nitrogen is fractionated using the proposed percentages by IWA Task Group (Henze et al., 1987).

4.2.1 COD and Nitrogen Fractions

Literatures data on COD fractionation from different authors are collected from different authors are summarized in Table 4.1. As discussed in previous chapter, COD fractionation is determined on a long-term (average) basis. In absence of physical-chemical and respirometric tests, soluble inert organic matter concentration may be calculated by considering it as effluent COD minus the effluent Biochemical Oxygen Demand (BOD) multiplied with a BOD/COD conversion factor (Henze,1992). Inert suspended organic matter, on the other hand, should be evaluated by entering remaining parameters to the simulation (Henze, 1992; Sin, 2000). BOD has not been considered in this study.

The nitrogen components (S_{NH}, S_{ND}, S_{NO}, X_{ND}) can rather easily be detected by physical–chemical analysis via a combination of standard analyses of ammonium, nitrite and nitrate and Kjeldahl nitrogen (TKN) (Henze et al., 1987). Literature data on N Fractionation is summarized in Table 4.2.

However in this study no lab experiments and respirometric tests have been performed and literature of Henze with along with the Task Group has been followed for the characterization of the water into its Carbonaceous and Nitrogenous Fractions.

Table 4.1: Comparison of different literature data on COD fractions

	Henze et al (1987)	Kappeler & Gujer(1992)	Sollfrank (1988)	Park et al (1997)	Ekama et al (1986)
Ss	19.7%	9 %	10 %	7 %	5 – 20 %
SI	8.5%	11 %	40 %	48 %	-
XS	57.3%	58 %	25 %	-	-
XH	-	12 %	25 %	15 %	2 – 3 %
XI	14.5%	10 %	10 %	7 %	5 – 20 %

Table 4.2: Comparison of different literature data on N fractions

	Henze et al(1987)	Fikar et al (2000)
S_{NH}	64.3 %	66 %
S_{ND}	14.2 %	2 %
S_{NO}	0 %	0 %
X_{ND}	21.6%	32 %

Task group's proposed COD and N fractionation is widely used in recent studies in absence of experimental data. These data are used in model calibration except for S_I and results obtained are shown in Table 3.3.

Table 4.3: Default COD and N Fractionation used in ASM 1 software

Parameters	**Concentration mg/L**	**Percentage**
S_S	76.7	19.7 %
S_I	33.1	8.5 %
X_S	223.2	57.3 %
X_H	0.0	0 %
X_I	56.5	14.5 %
S_{NH}	21.7	64.3 %
S_{ND}	4.8	14.2 %
S_{NO}	0	0 %
X_{ND}	7.3	21.6 %

Influents of Comodepur and their COD and N fractions used in calibration study are summarized in table 4.4:

Table 4.4: Influents characterized into Carbonaceous and Nitrogenous Components

Time		**Carbonaceous Components**					**Nitrogenous Components**			
		Q in	**Xs**	**Xi**	**Ss**	**Si**	**Total N**	**Snh**	**Snd**	**Xnd**
2009	**January**	2028.4	223.2	56.5	76.7	33.1	33.7	21.7	4.8	7.3
	February	2250.9	246.3	62.3	84.7	36.5	32.5	20.9	4.6	7.0
	March	1908.4	256.4	64.9	88.2	38.0	39.8	25.6	5.7	8.6
	April	2299.5	212.4	53.7	73.0	31.5	35.3	22.7	5.0	7.6
	May	2186.8	215.3	54.5	74.0	31.9	37.4	24.1	5.3	8.1
	June	2057.2	211.8	53.6	72.8	31.4	36.1	23.2	5.1	7.8
	July	1981.5	219.7	55.6	75.5	32.6	37.7	24.2	5.4	8.1
	August	1360.0	203.8	51.6	70.1	30.2	28.6	18.4	4.1	6.2
	September	1810.1	265.9	67.3	91.4	39.4	43.2	27.8	6.1	9.3
	October	1673.8	246.7	62.4	84.8	36.6	48.9	31.4	6.9	10.6
	November	1854.6	234.4	59.3	80.6	34.8	44.2	28.4	6.3	9.6
	December	2027.8	197.7	50.0	68.0	29.3	36.6	23.5	5.2	7.9
2010	**January**	1843.8	215.3	54.5	74.0	31.9	36.4	23.4	5.2	7.9
	February	1966.6	219.3	55.5	75.4	32.5	40.0	25.7	5.7	8.6
	March	1846.4	199.3	50.4	68.5	29.6	37.4	24.0	5.3	8.1
	April	1968.6	198.1	50.1	68.1	29.4	37.4	24.0	5.3	8.1
	May	2902.0	121.2	30.7	41.7	18.0	26.0	16.7	3.7	5.6
	June	2111.7	154.7	39.2	53.2	23.0	32.1	20.6	4.6	6.9
	July	2041.1	125.0	31.6	43.0	18.5	30.1	19.3	4.3	6.5
	August	1889.3	93.2	23.6	32.0	13.8	21.2	13.6	3.0	4.6
	September	2104.6	180.3	45.6	62.0	26.8	31.5	20.3	4.5	6.8

	October	2026.7	225.0	56.9	77.4	33.4	39.6	25.5	5.6	8.6
	November	3188.4	140.3	35.5	48.2	20.8	27.6	17.8	3.9	6.0
	December	2478.3	143.9	36.4	49.5	21.3	28.6	18.4	4.1	6.2
2011	**January**	2078.1	167.6	42.4	57.6	24.9	31.2	20.1	4.4	6.7
	February	1833.1	206.6	52.3	71.0	30.6	38.6	24.8	5.5	8.3
	March	1993.5	206.4	52.2	71.0	30.6	37.4	24.1	5.3	8.1
	April	1858.3	226.7	57.4	77.9	33.6	40.2	25.9	5.7	8.7
	May	1857.3	201.5	51.0	69.3	29.9	37.0	23.8	5.3	8.0
	June	2353.3	155.5	39.4	53.5	23.1	27.2	17.5	3.9	5.9
	July	2174.5	214.7	54.3	73.8	31.9	34.7	22.3	4.9	7.5
	August	1568.6	130.7	33.1	44.9	19.4	24.4	15.7	3.5	5.3
	September	1864.7	206.8	52.3	71.1	30.7	39.1	25.1	5.5	8.4
	October	1850.8	200.3	50.7	68.8	29.7	36.4	23.4	5.2	7.9
	November	2101.3	197.1	49.9	67.8	29.2	35.7	23.0	5.1	7.7
	December	1591.6	231.3	58.5	79.5	34.3	41.7	26.8	5.9	9.0

4.2.1.1 Kinetic and Stoichiometric Coefficients

Default kinetic and stoichiometric parameters proposed the by task group are used in model calibration.

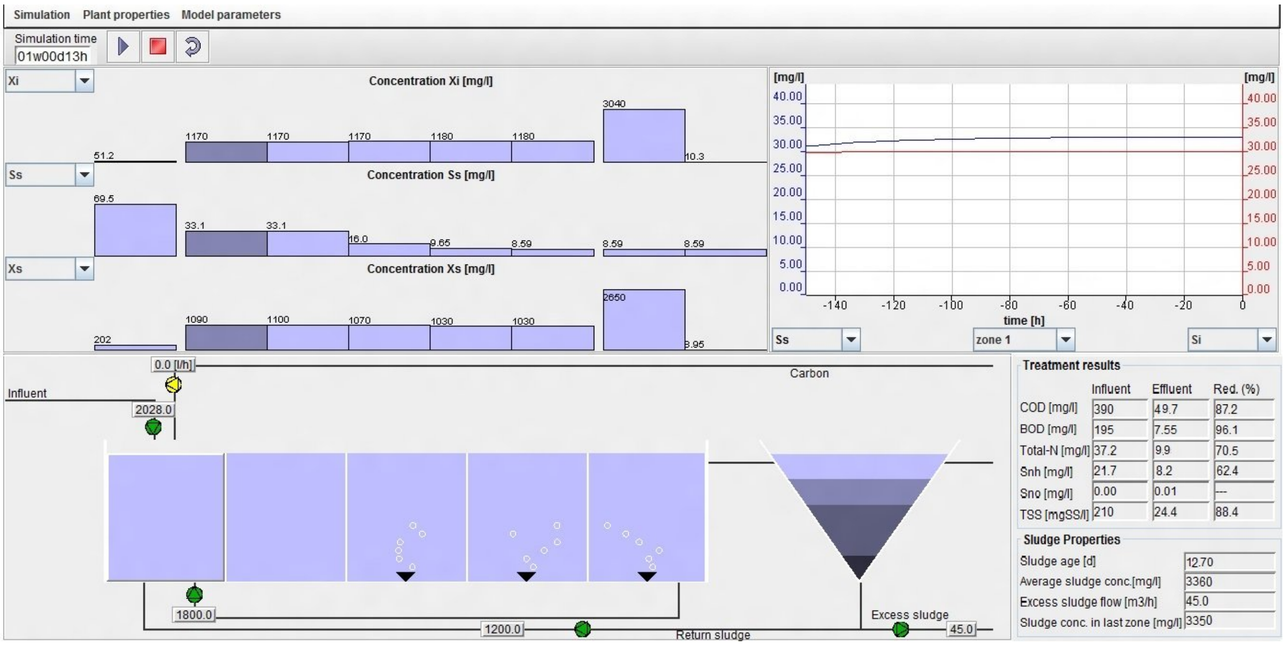
4.2.1.2 Parameters adjusted to obtain the simulation close to measured

The table below shows the values of parameters for ASM1 at 20 °C (the default values) and the calibrated values.

Table 4.5: Parameters adjusted to obtain the simulation close to measured

Parameters	Default (20°C)	Calibrated	Units
$\mathbf{Y_H}$	0.67	0.67	g cell COD formed/(g COD Oxidized)
$\mathbf{Y_A}$	0.24	0.24	g cell COD formed/(g N Oxidized)
μ_{maxH}	6.0	4.0	d^{-1}
μ_{maxA}	0.8	0.5	d^{-1}
$\mathbf{b_H}$	0.62	0.3	d^{-1}
$\mathbf{b_A}$	0.2	0.05	d^{-1}
$\mathbf{K_s}$	10	20	g O_2 /m^3
$\mathbf{K_{NH}}$	1	1	g NH_3-N/ m^3
$\mathbf{K_{NO}}$	0.5	0.5	g NO_3-N/ m^3
$\mathbf{K_{OH}}$	0.2	0.2	g O_2 /m^3
$\mathbf{K_{OA}}$	0.4	0.4	g O_2 /m^3
$\mathbf{k_h}$	3	3	g slowly biodegradable COD/(g cell COD day)
$\mathbf{K_X}$	0.03	0.03	g slowly biodegradable COD/(g cell COD day)
η_g	0.8	0.6	Dimensionless

The figure below is a screen shot of the simulation showing the results after calibration for the data of month of January 2009.



Treatment results

	Influent	Effluent	Red. (%)
COD [mg/l]	390	49.7	87.2
BOD [mg/l]	195	7.55	96.1
Total-N [mg/l]	37.2	9.9	70.5
Snh [mg/l]	21.7	8.2	62.4
Sno [mg/l]	0.00	0.01	---
TSS [mgSS/l]	210	24.4	88.4

Sludge Properties

Sludge age [d]	12.70
Average sludge conc.[mg/l]	3360
Excess sludge flow [m3/h]	45.0
Sludge conc. in last zone [mg/l]	3350

Fig 4.2: Screenshot with all inputs and the parameters calibrated

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Simulation Studies

A steady-state simulation application is performed on the basis of above data. Simulated result for effluent COD compared with measured actual plant data is presented in Figure 4.1. Simulation results for COD removal are presented in Table 4.1.

5.2 COD Removal

Table 5.1 shows the measured values of COD averaged for each month selected as data to be run in ASM 1 excluding the rainy days and keeping just the dry days. Actual values of COD entering and exiting the plant along with the COD removal efficiency of the WWTP have been compared with the ones obtained through simulation in the software.

Table 5.1: Actual COD Plant data compared with the Simulated Results

		COD Measured (Actual Plant Data)			**COD Simulated (ASM 1)**	
		CODin(mg/l)	**CODeff(mg/l)**	**Removal Efficiency %**	**mg/l**	**% Removal**
2009	January	389.5	35.0	91.0	49.7	87.24
	February	429.9	36.9	91.4	55.4	87.11
	March	447.5	44.9	90.0	61.4	86.28
	April	370.6	34.2	90.8	Data not Simulated	
	May	375.7	32.0	91.5		
	June	369.6	34.4	90.7	59	84.04
	July	383.4	36.5	90.5	59.9	84.37
	August	355.7	21.2	94.0	Data not Simulated	
	September	464.1	36.6	92.1		
	October	430.5	33.7	92.2		

	November	409.0	33.2	91.9		
	December	345.0	33.5	90.3	50.5	85.36
2010	January	375.7	33.2	91.2	51.9	86.19
	February	382.8	36.1	90.6	55.3	85.55
	March	347.9	33.8	90.3	50.1	85.60
	April	345.7	42.2	87.8	Data not Simulated	
	May	211.6	20.8	90.2		
	June	270.0	24.3	91.0	46.1	82.93
	July	218.2	24.6	88.7	38.9	82.17
	August	162.6	15.7	90.4	Data not Simulated	
	September	314.7	40.7	87.1		
	October	392.8	30.9	92.1		
	November	244.9	24.5	90.0		
	December	251.1	29.5	88.2	44.6	82.23
2011	January	292.5	25.8	91.2	45.4	84.48
	February	360.5	32.3	91.0	51.2	85.80
	March	360.3	45.4	87.4	53.3	85.21
	April	395.7	37.5	90.5	Data not Simulated	
	May	351.7	29.6	91.6		
	June	271.4	24.0	91.2	54.3	79.99
	July	374.7	25.4	93.2	61.8	83.51
	August	228.1	18.4	91.9	Data not Simulated	
	September	360.8	28.8	92.0		
	October	349.5	23.8	93.2		
	November	344.0	36.1	89.5		
	December	403.8	36.5	91.0	53.8	86.67

Following is the Graphical representation of the measured and simulated data for a period of three consecutive years for the months of January, February, March, June , July and December starting from 2009 to 2011.

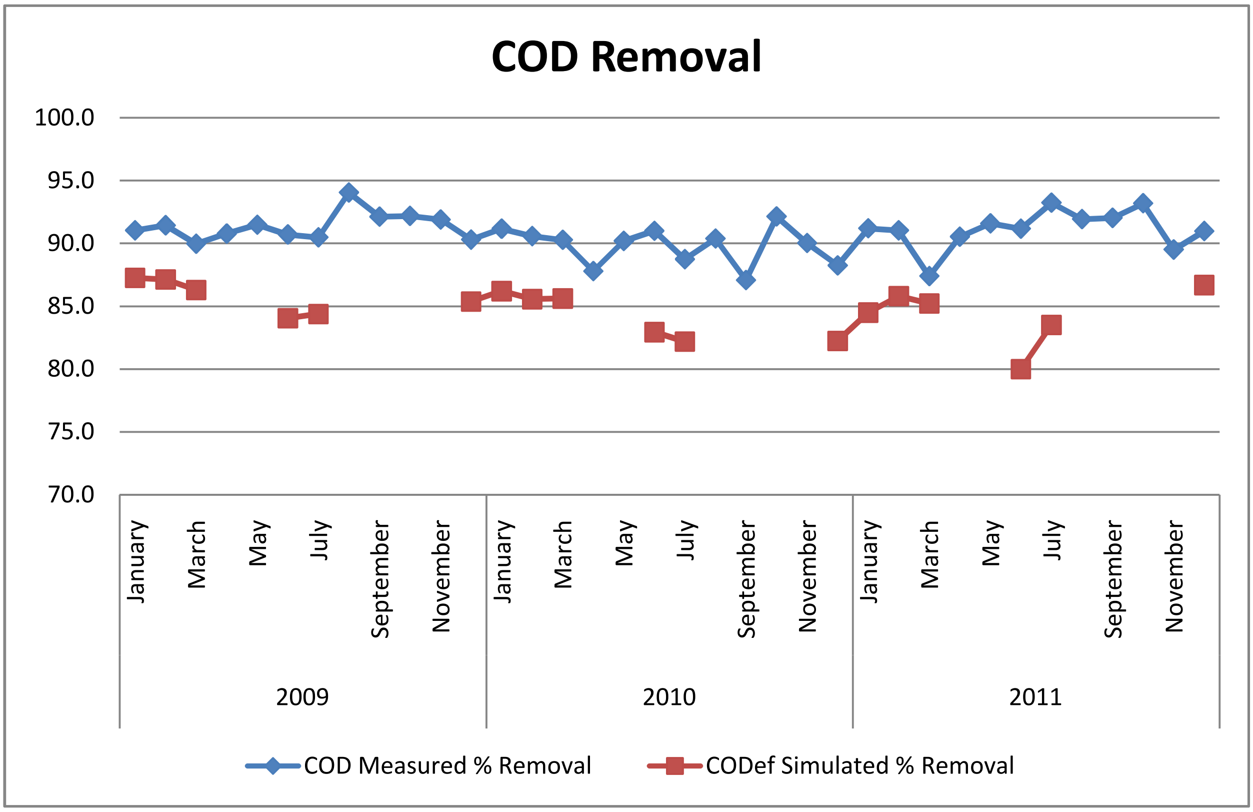


Fig 5.1: Graph showing COD removal trend over selected time period.

As observed in figure 5.1, the trend of COD removal changes its pattern with the change in season. COD removal rate is observed to be high in winter and is comparable to the actual data of the plant, while it differs considerably in summer. The difference between measured and the simulated values are found to be 2-4% in winter and 6-9% in summer.

Aeration was the main parameter needed to be adjusted according to the real plant aeration values in order to obtain simulated values comparable to the original Plant values. The Air Carbon Zone value in the Influent Menu of the software was adjusted to 4.5 according to the flow rate of the centrifugal blowers installed in the aeration tanks in Comodepur.

This can imply a fact that there could be improper mixing of oxygen with the water to be aerated which causes problems in both COD and Nitrogen removal efficiency.

5.3 Nitrogen Removal

The table 5.2 shows the measured and simulated values of Nitrogen Removal and its efficiency in percentage compared. This is dry, monthly data averaged and the period chosen is also the same as of COD.

Table 5.2: Measured and Simulated Data for Nitrogen Removal

		Total N (Actual Plant Data)			**Total N (Simulated ASM 1)**	
		$N_{influent}$ mg/l	$N_{effluent}$ mg/l	% Reduction	mg/l	% Reduction
2009	**January**	33.7	10.5	68.9	9.9	70.5
	February	32.5	9.0	72.3	9.9	69.7
	March	39.8	9.2	76.8	10.9	72.5
	April	35.3	8.5	75.9	Data not Simulated	
	May	37.4	8.8	76.4		
	June	36.1	8.6	76.1	7.5	79.3
	July	37.7	11.5	69.4	9.5	74.9
	August	28.6	7.1	75.2	Data not Simulated	
	September	43.2	10.9	74.8		
	October	48.9	9.7	80.2		
	November	44.2	9.4	78.6		
	December	36.6	9.3	74.7	11.8	67.8
2010	**January**	36.4	8.9	75.6	9.4	74.2
	February	40.0	8.1	79.7	11.3	71.6
	March	37.4	7.9	78.8	8.9	76.3
	April	37.4	7.3	80.4	Data not Simulated	
	May	26.0	7.3	72.0		
	June	32.1	7.7	76.0	6.8	78.9
	July	30.1	8.5	71.6	6.7	77.8
	August	21.2	7.8	63.1	Data not Simulated	
	September	31.5	8.6	72.9		
	October	39.6	9.1	77.1		
	November	27.6	8.7	68.7		
	December	28.6	8.7	69.7	8.8	69.1
2011	**January**	31.2	8.4	73.2	8.9	71.5
	February	38.6	8.6	77.8	9.3	75.8
	March	37.4	7.6	79.6	9.9	73.5
	April	40.2	6.9	82.9	Data not Simulated	
	May	37.0	6.4	82.6		
	June	27.2	6.5	76.1	6.0	78.0

	July	34.7	8.1	76.7	7.4	78.7
	August	24.4	7.3	70.1	Data not Simulated	
	September	39.1	8.6	78.0		
	October	36.4	8.5	76.7		
	November	35.7	8.5	76.3		
	December	41.7	7.7	81.5	8.0	80.7

Figure 5.2 shows graphically, the trend of Nitrogen Removal for the selected period of data for three years.

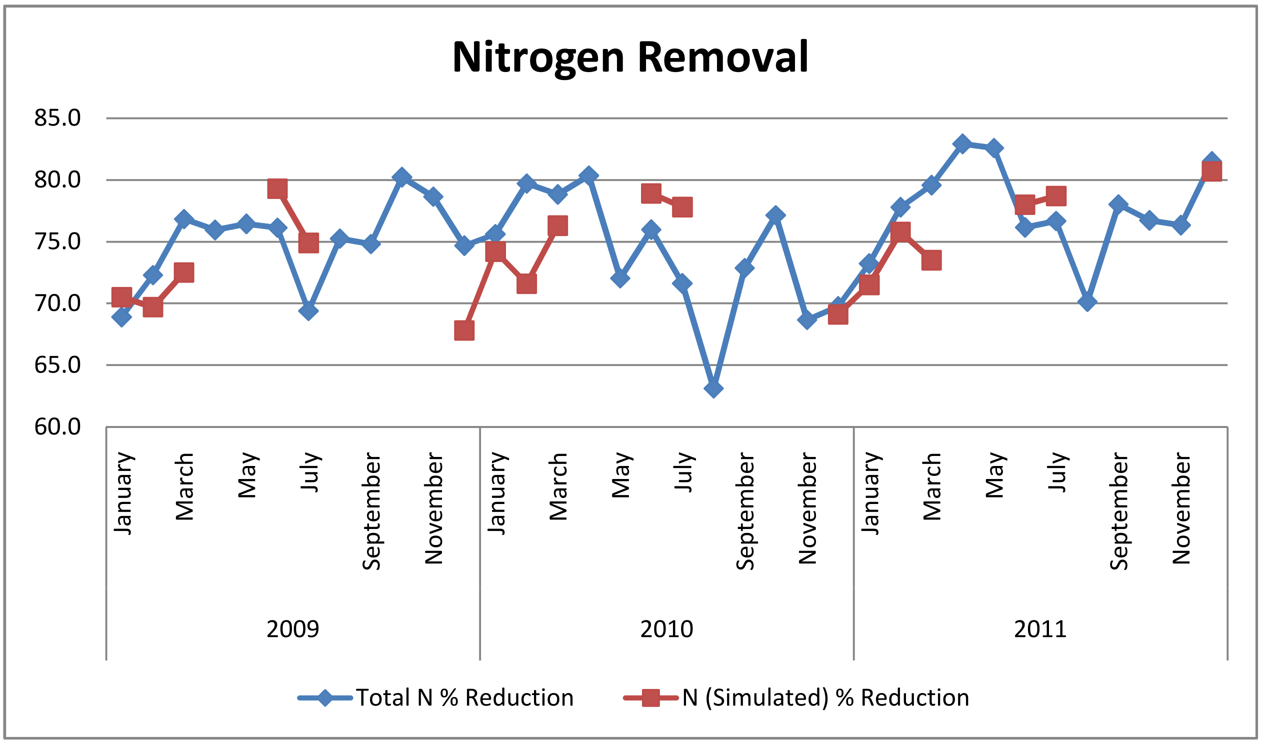


Fig 5.2: Trend of measured and simulated values of N Removal.

As shown in figure 5.2 it can be observed that according to the simulation, Nitrogen Removal rate is higher in summer and thus the simulated values are up to 6% higher than those measured. The trend in winter is opposite as the measured values are higher than simulated ones but still close to one another.

Temperature of water in Comodepur is changed from that of winter which is 15^{o}C and is increased to 30^{o}C instead. This plays a strong role in Nitrogen Removal efficiency of the plant.

In order to obtain correct values for simulation *Air Carbon Zone value* was adjusted to 4.5 while r_h value from the *Model Parameters* Menu and choosing Settler Model played a vital role. It's the Hindered Zone Settling Parameter which affects the Nitrate removal in the aeration tank where denitrification is taking place. This has to be decreased much lower than that of the default value of the model. Values of the parameters b_A and b_H which are the decay rates of autotrophic and heterotrophic nitrifying bacteria also needed to be adjusted along with the r_h value.

Flow rate of excess sludge also plays a very important role both for Nitrogen removal and the removal of suspended solids from the waste water. This is to give proper retention time to the nitrates in the Mixed Liquor suspended solids so that effective Nitrogen removal might take place.

Therefore Excess sludge flow rate had to be decreased for simulation than the original flow rate used at Comodepur.

5.4 SST Concentration

Table 5.3 is the comparison of Total suspended solids concentration in the MLSS for the measured and simulated values for the data of chosen period of this study.

Table 5.3: Measured and simulated data for SST concentration

		SST (Measured)	**SST (Simulated)**
		mg/l	**mg/l**
2009	**January**	3289.2	3360.00
	February	3040.0	3480.00
	March	3310.5	3270.00
	April	3245.7	
	May	3150.5	
	June	3446.4	3450.00
	July	3395.0	3320.00
	August	3085.7	
	September	3498.2	
	October	3625.5	
	November	3362.9	
	December	3633.3	3370.00

2010	**January**	3539.4	3490.00
	February	3690.7	3700.00
	March	3677.6	3500.00
	April	3660.6	
	May	3442.0	
	June	3765.3	3530.00
	July	3364.8	3250.00
	August	3075.5	
	September	3563.1	
	October	3687.9	
	November	3417.5	
	December	3585.7	3390.00
2011	**January**	3976.3	3470.00
	February	3893.1	3730.00
	March	3664.4	3750.00
	April	3848.4	
	May	3816.5	
	June	4025.0	3770.00
	July	3608.6	3430.00
	August	2925.6	
	September	3728.0	
	October	3711.6	
	November	3699.2	
	December	4009.4	3870.00

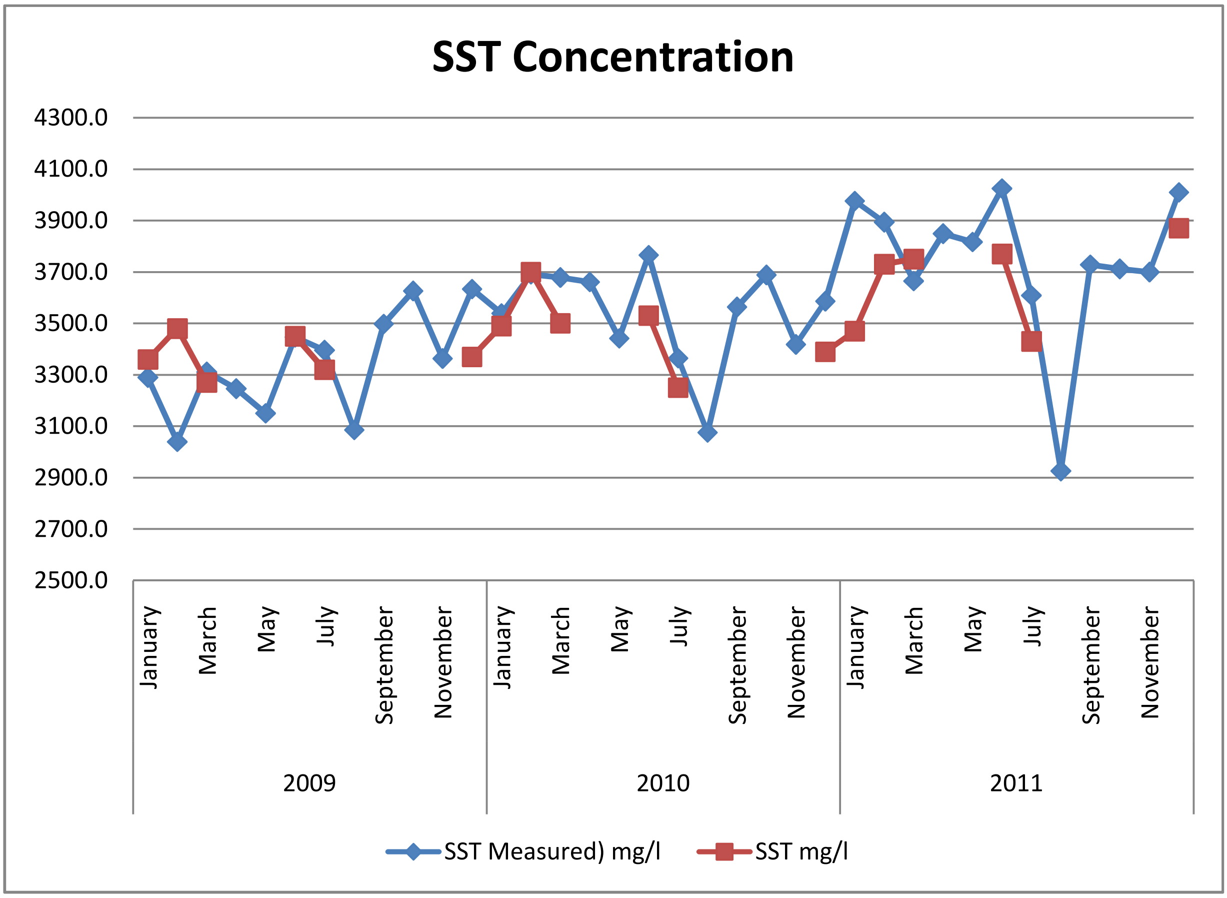


Fig 5.3: Trend of SST concentration

The above graph shows the trend of Total Suspended Solids Concentration in the MLSS over the three years of data. There is a large difference between the measured and simulated values in winter season as can be seen in January and February 2009 and 2010.The difference between actual and the simulated values is between 10-12 % for the month of February 2009 and January 2011. While in summer the measured and simulated values tend to be closer. The difference is 3-5 % in summer.

Excess Sludge flow rate was the most important parameter capable of modifying the value of SST concentration the most. The flow rate of excess sludge used at Comodepur is quite higher while for the simulation it had been decreased in order to get the correct results comparable to the measured ones.

The parameters affecting the Nitrogen Removal rate also affect the concentration of Total Suspended Solids as well. Therefore if they are adjusted for Nitrogen removal, SST concentration automatically lies within the range comparable to measured ones.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

- In this Simulation study, Activated Sludge Model 1 has been used as a Java Appalet over the Web and not as purchased software. This gave a lot of trouble in running the data since no data can be stored and the configuration and calibration of parameters cannot be saved which is a big nuisance for the user since each time all parameters have to be adjusted and influent values have to be given again for a new simulation. This makes it very time consuming.
- Benchmark Scheme of ASM 1 has been used in this study because of the limitations of the software. In this way Post denitrification of the plant could not be studied as the results obtained by using the "Pre Denit" configuration for the plant set up from the "Load" menu were not accurate. To calibrate the parameters to get the simulation close to the measured ones, the parameters calibration went out of their pre defined range. This makes ASM 1 not very suitable for the study of a WWTP with a large volume of influents like Comodepur which has influents of 55000 m^3 /day.
- The volumes of the tank in the model are much smaller than those of the actual plants which mean less holding capacity for the waste water influents and thus make the values Nitrogen removal, Sludge age and the sludge concentration totally deviated from the measured ones. The Model displays sludge overflow in this case and even the calibration falls out of range for adjusting the values according to the measured ones.

These were a few drawbacks of the software ASM 1. Now, concluding the study made with the benchmark configuration of the software for Comdepur WWTP following are the main observations for the behavior of the simulation:

- COD removal rate is observed to be high in winter and is comparable to the actual data of the plant, while it differs considerably in summer. The difference between measured and the simulated values are found to be 2-4% in winter and 6-9% in Summer.
- Aeration was the main parameter needed to be adjusted according to the real plant aeration values in order to obtain simulated values comparable to the original Plant values.
- This can imply a fact that there could be improper mixing of oxygen with the water to be aerated which causes problems in both COD and Nitrogen removal efficiency.
- According to the simulation, Nitrogen Removal rate is higher in summer and thus the simulated values are up to 6% higher than those measured. The trend in winter is opposite as the measured values are higher than simulated ones but still close to one another.
- Trend of Total Suspended Solids Concentration in the MLSS over the three years of data shows a large difference between the measured and simulated values in winter season. The difference between actual and the simulated values is between 10-12 % for the month of February 2009 and January 2011. While in summer the measured and simulated values tend to be closer. The difference is 3-5 % in summer.
- Excess Sludge flow rate was the most important parameter capable of modifying the value of TSS concentration the most. The flow rate of excess sludge used at Comodepur is quite higher while for the simulation it had been decreased in order to get the correct results comparable to the measured ones.
- The parameters affecting the Nitrogen Removal rate also affect the concentration of Total Suspended Solids as well. Therefore if they are adjusted for Nitrogen removal, TSS concentration automatically lies within the range comparable to measured ones.

- Overall conclusion of the Benchmark study shows that whatever simulations have been carried out; mimic the behavior of the original plant although Post Denitrification has not been included. Therefore it can be inferred that there is not deviation between the simulated and the measured values for Nitrogen Removal and for the Benchmark studies the calibration of parameters falls more or less within the range.

6.2 RECOMMENDATIONS

- Since the simulation study lacked the study of Post Denitrification of the plant because of the incompatibility of the software, true capacity and shortcomings of Comodepur WWTP cannot be determined. Therefore further study is proposed for determination of the Organic capacity and Nitrogen Removal efficiency
- This kind of WWTP needs detailed Respirometric Laboratory Analysis. For studying the simulation of Post denitrification process, a detailed sensitivity analysis for parameter calibration is also necessary and is recommended for further studies.
- Activated Sludge Model 1 run as an appalet in run-time environment is not recommended for future studies since it is not user friendly and cannot save any configurations while being used over web.
- For WWTPs with complex design lay out and high influent volumes use of ASM 1 is not recommended and instead newer and latest versions of JASS Activated Sludge Models are recommended for future studies.

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