DOCTORAL DISSERATATION

DESIGNING BIOLOGICAL WASTEWATER TREATMENT PROCESSES BASED ON ACTIVATED SLUDGE MODEL CONCEPT

NGUYEN DUONG QUANG CHANH

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DESIGNING BIOLOGICAL WASTEWATER TREATMENT PROCESSES BASED ON ACTIVATED SLUDGE MODEL CONCEPT

By

NGUYEN DUONG QUANG CHANH

Thesis submitted to the Graduate School of Environmental Engineering, The University of Kitakyushu in fulfillment of the requirement for the Degree of DOCTOR OF ENGINEERING

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Declaration

I hereby declare that this thesis has not been previously submitted to any other university or institution for obtaining any academic degree. Accept quotation and data which are properly cited, this thesis contains my original works. The thesis is only submitted to The University of Kitakyushu in fulfillment of the requirement for a Degree of Doctor of Engineering.

Kitakyushu, Japan

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Nguyen Duong Quang Chanh

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Abbreviations

Ammonium-N	Ammonium nitrogen
ASMs	Activated Sludge Models
BOD	Biochemical oxygen demand
BOD_n	Biochemical oxygen demand in n days
CBOD	Carbonaceous biochemical oxygen demand
COD	Chemical oxygen demand
C/N	Carbon/nitrogen
CSTR	Continuous stirred-tank reactor
IWA	International Water Association
HRT	Hydraulic Retention Time
MLSS	Mixed liquor suspended solids
MLVSS	Mixed liquor volatile suspended solids
NaClO	Sodium hypochlorite
Nitrate-N	Nitrate nitrogen
NOUR	Nitrogenous oxygen uptake rate
OUR	Oxygen uptake rate
PAC	Poly Aluminium Chloride
TKN	Total Kjeldahl nitrogen
TN	Total nitrogen
TOC	Total organic carbon

Total P	Total phosphorus
TSS	Total suspended solids
SBR	Sequencing batch reactors
SS	Suspended solids
SRT	Solids Retention Time
VSS	Volatile suspended solids
WB	World Bank
WWTP	Wastewater treatment plant

Abstract of the Dissertation

In developing countries like Vietnam, the combined drainage system with septic tank placed prior to the sewer leads to the wide variation composition of domestic wastewater. In order to catch the influent concentration besides wastewater flow, on-site water sampling is widely used and analyzed in laboratories. On the other hand, since the composition of the municipal wastewater is highly fluctuated and inconsistent along with time, a considerable number of water samples must be analyzed. This fact leads a challenge for planning and designing wastewater treatment plants (WWTPs) since default influent concentrations could not be applied unlike other countries having no septic tank process. In Vietnam, most WWTPs use aeration process and they have big challenges to ensure the effluent quality standard despite the wide range input composition.

Activated Sludge Models (ASMs) developed by IWA Task groups have been widely used for simulating various kind of biological reaction. They include mathematic equations of process rates and inner reaction of reactor. The mathematical approach was evaluated based on sensitivities of the WWTP model to kinetics and stoichiometry in relation to the influent composition and control parameters (flow rates, etc.).

In that way, a back-calculation method could be developed to identify the unrealistically influent concentrations. As the composition of activated sludge is a consequence of the influent and the operating condition, a lab-scale activated sludge reactor was set up in Vietnam and operated for a year. From the field experiment, the municipal wastewater constituents and concentrations were calculated to demonstrate the back-calculation approach. Also, the labor intensity of the analysis was also comparatively discussed to that of the conventional wastewater sampling/ analysis method.

On the other hand, ASM-based models can simulate and calculate biological reactors well. Low-cost biological treatment like bio-filter/ trickling filer reactor can be modelled and optimized with a novel design. Hence, to use the model for designing trickling filter process, mechanistic correlations must be developed between the operational conditions and the physical/ kinetic parameters of the model. The process responses of a pilot-scale trickling filter reactor were investigated by changing the hydraulic loadings and analyzed in laboratory. In this research, the liquid hold-up in the reactor, which was thought to be correlated with the

wetted surface area was especially focused on. A dynamic simulation was also performed to discuss influential kinetic parameters on the calculation.

Through these application of ASM, an alternative energy-saving approach for combined sewerage wastewater in comparison to conventional systems has illustrated.

Chapter 1: Historical Review for the Sanitation Development in Vietnam

1.1 Urban sanitation development in Vietnam

Vietnam has achieved noteworthy progress in economic development since its successful transition from a centrally planned economy to a market economy. Total domestic product (GDP) grew on average 7.5% per year over 2000–2009. GDP per capita increased from 700 USD in 2005 to 1,749 USD in 2012, primarily generated in urban areas (*VGP, 2013*). The proportion of urban population has increased dramatically over recent years.

The process of rapid urbanization and population growth has created huge pressures on infrastructure systems which were built decades ago, especially urban drainage and sewerage systems. Results of water quality monitoring of major canals, lakes and rivers in Vietnam showed that concentrations of organic pollutants are much higher than the permitted standard in some areas as shown in Figure 1.1 (*VEA, 2010*) . This situation has existed for many years, and has led to serious consequences for local populations and their immediate environment.

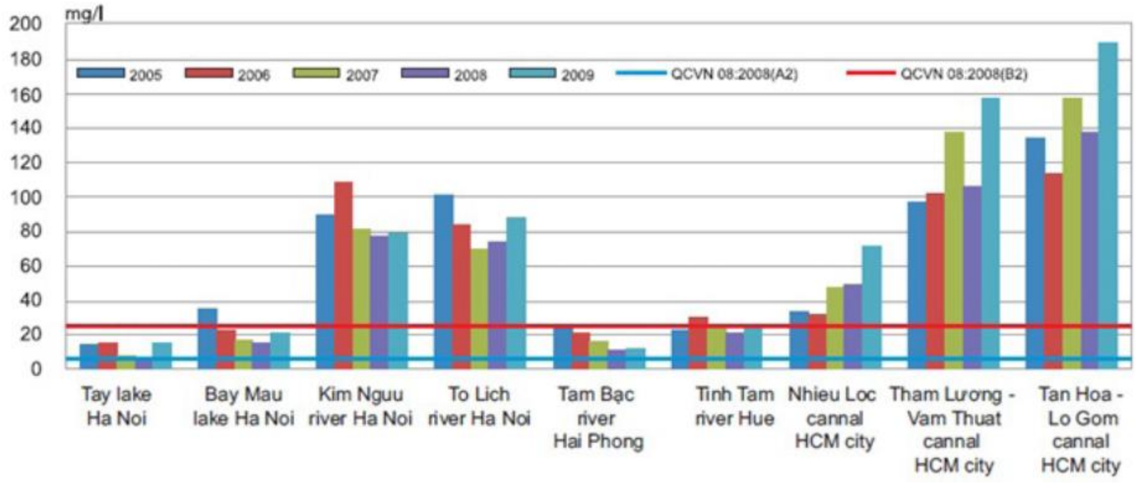


Figure 1.1 BOD5 loads in major selected canals and river in Vietnam

QCVN: Applied standard for surface water quality

(Source: Vietnam Environment Report., VEA 2010)

So far, the high densities population in cities (Hanoi, Ho Chi Minh, Danang, etc.) may up to 40,000 cap/km^2 (*Vietnam Environment Report 2015*) has lead to many social-environmental issues in Vietnam recently. It was the fastest and rapid growing for a long time and recently led to many consequences when the old infrastructure does not meet the development leads to increased environmental pollution in general, water urban particular is one of the prominent environmental problems in many cities of Vietnam. Over the past 20 years, the Government of Vietnam has made considerable effort to develop urban sanitation policies, legislations and regulations and to invest in urban sanitation including wastewater treatment systems.

Since 1998, the Government of Vietnam has initiated policies and provided investment to improve urban sanitation resulting in significant progress in development of the wastewater sector. There are significant achievements are as follows (World Bank 2013):

- Provision of wastewater services to the urban poor has been impressive with open defecation now eliminated.

- Access to toilets is now 94 percent with 90 percent of households using septic tanks as a means of on-site treatment.

- 60% of households dispose of wastewater to a public sewerage system, primarily comprising combined systems.

- By 2012, 17 urban wastewater systems had been constructed in Hanoi, Ho Chi Minh City and Danang city and another five systems in provincial towns and cities with a total capacity of 530,000 cubic meters per day (m3/day).

- Currently some 32 new wastewater systems, primarily comprising combined systems, are in the design/construction phase.

- During the past decade annual sanitation sector investment has been USD 150 million or USD 2.1 billion for drainage and wastewater during the period 1995-2009. This represents 0.45 percent of GDP annually.

1.2 Current status of wastewater management in Vietnam

1.2.1 Drainage and sewerage system management

Most cities in Vietnam have a drainage collection system, designed initially to collect rainwater runoff and reduce flooding/ inundation. As population densities increased in the urban areas, it became necessary to dispose of sewage generated by households. This need was largely met by the existing drainage systems which then began to function as combined sewers, collecting both rainwater runoff and sewage in the same drain/pipeline.

However, most drainage and sewerage systems in large cities of Vietnam were constructed over three decades ago and more than 90% of wastewater is conveyed by use of combined sewer systems, primarily serving as storm-water drainage, and “taking away” domestic wastewater to prevent flooding in the streets. Some newly developed urban areas introduce separate sewer and drainage systems; however, as most urban wastewater is untreated, thus both storm-water and domestic wastewater are finally discharged together into nearby water environments such as rivers, lakes and canals. Meanwhile, service coverage of sewerage and wastewater treatment is still rather low compared to the drinking water supply service coverage. The coverage of sewer networks average just 40–50%, with 70% in large urban areas and only 1–2% in sub-urban areas.

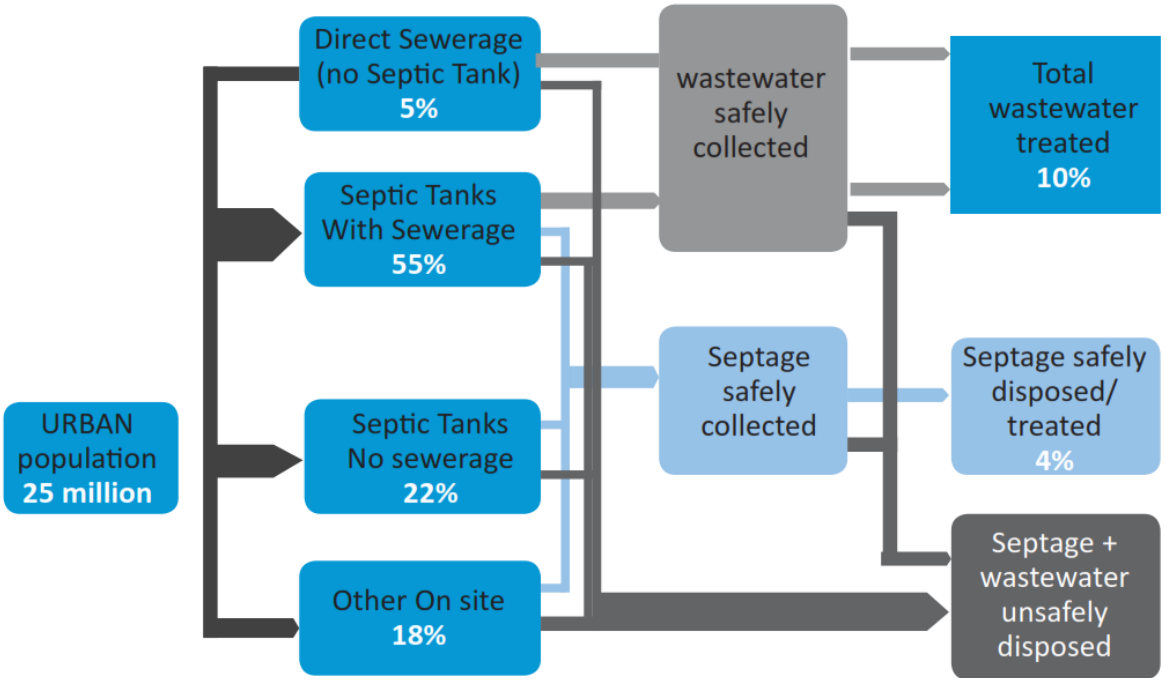


Figure 1.2 Status of Urban wastewater management in Vietnam

(*World Bank 2013*)

Currently, Vietnam urban wastewater management system is implemented as shown in Figure 1.2. Although there are 60 percent of households dispose of wastewater to a public system, much of this is directed informally to the drainage system and only 10 percent is treated. While 90 percent of households dispose wastewater to septic tanks, only 4 percent of septage is treated. Fecal sludge management is generally poor in most cities (*World Bank 2013*).

Domestic wastewater from households is mainly treated in household's septic tank before being discharging into combined sewer systems, then into rivers, lakes, and canals without any further treatment, except in some big cities such as Hanoi and Ho Chi Minh City (Fig. 1.3). Nearly 90% of households in urban areas have septic tanks. The remaining households are either equipped with other type of onsite sanitation such as double vault composting toilet, pit latrines or directly discharge their wastewater into combined sewers without any treatment.

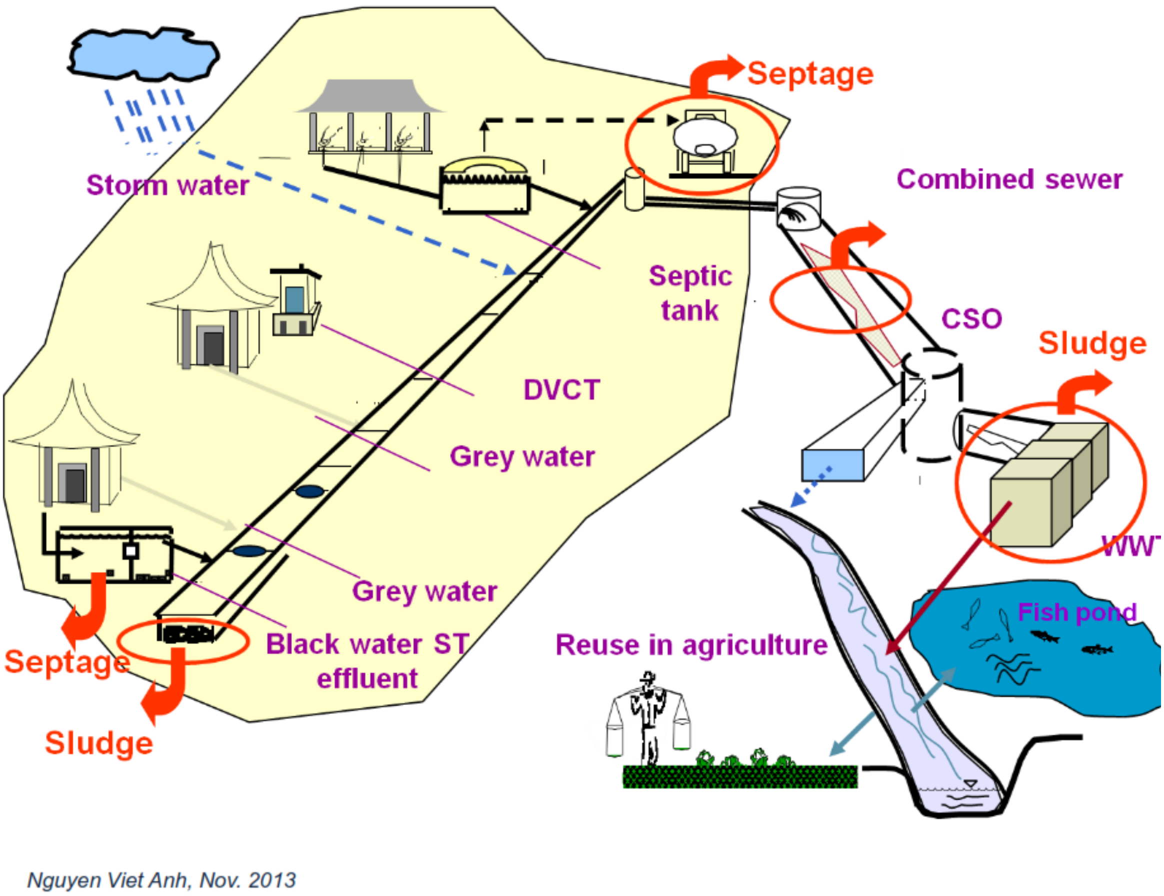


Figure 1.3. Typical combined drainage and sewerage system in Vietnamese cities (Nguyen Viet Anh, Nov. 2013)

According to the Ministry of Construction, before Nov. 2013 only 08 urban areas in Vietnam had centralized wastewater treatment plants, mainly in big cities including Hanoi, Ho Chi Minh City, Da Nang, Quang Ninh, Da Lat, Buon Ma Thuat, Bac Giang and Phan Rang. However, in recent years a large number of decentralized wastewater treatment plants have been constructed in both large and medium-sized urban areas such as Hanoi, Bac Ninh, Vinh and Can Tho under support from the Vietnam Government and a number of international organization (*WEPA 2013*).

On-site treatment system

On-site treatment systems such as septic tanks play a key role in wastewater treatment activities in Vietnam. Septic tanks are in fact “low-rate” anaerobic treatment units, and much evidence proves they are often of low performance and low efficiency, are under-maintained and cause groundwater pollution. Their actual BOD_5 removal efficiency is only about 20–30% (*Anh N.V 2002*). According to the authors’ observation, the majority of household septic tanks in Vietnam are only used to treat black water, while grey-water from bathrooms, kitchens, washing machines, for example, is not treated in septic tanks. This grey-water has often been discharged directly to canals or sewer system, especially in big cities like Hanoi and Ho Chi Minh. Most septic tanks in Vietnam are not properly maintained and not emptied frequently. Households only contact the urban environment company (URENCO) or a private enterprise (either state-owned, limited liability or private companies) when problems such as clogging or overflowing occur. Most septic tanks are built underground and indoors, making it is very difficult for de-sludging crews to actually find them to access the drain hole. Workers normally have to drill a hole through the floor just above the septic tank to insert a suction pipe and empty the sludge.

Wastewater collection system

Approximately 92% of urban wastewater collection is done via the combined system; a separate system is used for the remaining 8%. As most of the sewer systems were built or renovated two to three decades ago, many of them have deteriorated and do not function properly due to poor maintenance. New construction or renovation is often patchy and unplanned from the outset; further, this work has not been carried out in sync with the construction of wastewater treatment plants located along the network. Many sewage treatment plants have not realized their full capacity due to a lack of sewer networks. For example, Bac Thang Long-Van Tri WWTP was designed and constructed with a capacity of 42,000 m3/day but in reality the plant only operated at the capacity of 7,000 m3/day as the domestic wastewater from the surrounding residential areas have not yet been connected to the plant due to a reason that the sewer networks have not been fully covered in the area.

Centralized wastewater treatment system

Most sanitation projects tend to choose or adopt advanced and expensive wastewater treatment technologies, which are popular in developed countries, without considering local conditions such as financial recovery capacity and affordability for users. These technologies are often known as activated sludge treatment technologies. Of the 31 new centralized wastewater treatment plants planned for the near future, up to 28, or 90%, will use activated sludge-based treatment technologies (Table 1.1), which may negatively impact on sustainability and viability of the sanitation projects over the long term.

1.2.3 Wastewater treatment technologies

Despite the low concentration of influent BOD and other constituents measured in the flow to the 13 WWTPs currently being served by combined sewer systems, eight 5 of these are now operating based on conventional activated sludge treatment solutions (*World Bank 2013*). The lack of household septic tanks connections, partial treatment/decomposition of organic matter in septic tanks and the drainage canals, infiltration of groundwater and collection of rainwater runoff all contribute to the dilution of the collected sewage in these combined systems. Given the low organic loading at these treatment facilities, lower cost appropriate technologies could have been adopted which would allow for upgrading as the influent strength increases over time. However, a lack of understanding by decision makers of appropriate technical solutions and the limited land available for the WWTPs has resulted in a continuation of more expensive, advanced technology facilities. Facilities which emphasize low power consumption, resource recovery from sludge or reuse of treated wastewater are not currently given high priority by planners in Vietnam.

Regarding wastewater treatment technologies at centralized treatment plants, the most common technologies are based on activated sludge (AS) process, such as aeration tanks or sequencing batch reactors (SBR); for example, in Hanoi city: Kim Lien & Truc Bach wastewater treatment plant (WWTP), North Thang Long WWTP, Yen So WWTP and in Quang Ninh province: Bai Chay WWTP, Quang Ninh WWTP. In addition, there are a number of wastewater treatment plants utilizing low-cost and environmentally sound sanitation technologies, such as waste stabilization ponds or constructed wetlands. Examples of these are the WWTPs in Ho Chi Minh City (Binh Hung Hoa WWTP), in Danang city with anaerobic lagoon process and multi-lagoon process in Buon Ma Thuoc province.

Concerning on decentralized wastewater treatment technologies, basically, activated sludge based-treatment process and biological filtration are among the most commonly used. Recently, a new type of septic tank has been introduced, namely baffled septic tank, sometimes it has been used in combination with waste stabilization pond or constructed wetland system.

Table 1.1 shows the list of applied technology in WWTPs of Vietnamese cities

Table 1.1 Applied technology in Vietnam WWTPs

No.	**City**	**Plant**	**Technology**	**Capacity (m^3/day)**	**Note**
1	Hanoi	Kim Lien	Activated Sludge Process	3,700	
2		Truc Bach	Activated Sludge Process	2,500	
3		Bac Thang Long	Activated Sludge Process with Nitrification	7,000	
4		Yen So	Activated Sludge (SBR-Sequence Batch Reactor)	120,000	
5		Ho Tay	Activated Sludge (SBR-Sequence Batch Reactor)	33,000	
6		Bay Mau	Continuous Activated Sludge (CAS)	13,300	
7	Ho Chi Minh	Binh Hung	Continuous Activated Sludge (CAS)	141,000	
8		Binh Hung Hoa	Aeration Pond	30,000	
9		Canh Doi (Phu My Hung)	Oxidation ditch	10,000	
10		Nam Vien (Phu My Hung)	Activated Sludge	15,000	
11	Danang	Son Tra	Anaerobic lagoon	15,900	
12		Hoa Cuong	Anaerobic lagoon	36,000	
13		Phu Loc	Anaerobic lagoon	36,000	

No.	City	Plant	Technology	Capacity (m^3/day)	Note
14		Ngu Hanh Son	Anaerobic lagoon	11,600	
15		Hoa Xuan	Activated Sludge (SBR-Sequence Batch Reactor)	26,000	Operation from 2015
16	Quang Ninh	Bai Chay	Activated Sludge (SBR-Sequence Batch Reactor)	3,500	
17		Ha Khanh	Activated Sludge (SBR-Sequence Batch Reactor)	7,500	
18	Da Lat	Da Lat	Activated Sludge-Trickling Filter	7,400	Separated sewerage
19	Buon Me Thuoc	Buon Me Thuoc	Multi-ponds process	8,000	Separated sewerage
20	Bac Giang	Bac Giang city	Oxidation ditch	10,000	
21	Vinh Phuc	Vinh Yen	Oxidation ditch	5,000	
22	Binh Dinh	Quy Nhon	Activated Sludge Biofilm	14,000	
23		2A	Activated Sludge Oxidation ditch	2,350	
24	Quang Binh	Dong Hoi	Aeration Pond	19,000	
25	Nghe An	Vinh	Activated Sludge (SBR-Sequence Batch Reactor)	50,000	
26		Cua Lo	Activated Sludge (SBR-Sequence Batch Reactor)	6,000	

No.	City	Plant	Technology	Capacity (m^3/day)	Note
27	Bac Ninh	Bac Ninh	Activated Sludge (SBR-Sequence Batch Reactor)	28,000	
28	Hai Duong	Hai Duong	Activated Sludge (SBR-Sequence Batch Reactor)	13,500	
29	Ninh Thuan	Phan Rang	Aeration Pond	10,000	
30	Khanh Hoa	Nam Nha Trang	Activated Sludge Oxidation ditch	40,000	
31	Binh Duong	Thu Dau Mot	Activated Sludge (SBR-Sequence Batch Reactor)	35,000	

Data collected from *World Bank, 2013, NV Anh, 2016*

Chapter 2: Technical Review for Mechanistic Modelling Biological Wastewater Treatment Process

2.1 Unrealistic influent wastewater of combined system in Vietnam

Although the government and many environmental organization have work much and had significant achievement in wastewater treatment issues, there are still some big problems that Vietnam have to faced. They have to be solved in near future to ensure the living condition for communities' as well natural environment.

The wastewater sample for assessment is collected by two methods in Vietnam, including the collection (including drainage) in combined sewerage systems (CSS) and the collection (excluding drainage) in separate sewerage systems (SSS). The distinction between these two collection types is significant, as the inclusion of drainage with the CSS-based system results in a much more dilute influent flow when received at the downstream wastewater treatment plant. This is evidenced in the data collected from WWTPs, which illustrate that the influent flow organic loading (BOD) for CSS-based systems range on the average from 31-135mg/l, with an overall flow-weighted average of 67.5mg/l, shown in the Table 2.1 (World Bank, 2013).

Worldwide, CSS-based systems with underground sewers and interceptors have been shown to deliver more normal (higher) concentrations of influent organic matter loading than is being experienced in Vietnam. The different situation in Vietnam appears to be the result of the use of large drainage canals for CSS which allow sedimentation of solids, thus reducing the organic concentration. The consequent release of ammonia, due to the anaerobic digestion of the settled solids, results in elevated ammonia levels.

Table 2.1 Influent wastewater characteristics of Vietnam cities

No.	City	Plant	BOD_5 *(mg/L)*	TSS *(mg/L)*	T-N *(mgN/L)*
1	Hanoi	Kim Lien	115	85	40
2		Truc Bach	135	85	34
3		Bac Thang Long	85	65	38
4		Yen So	45	51	34
5	HCM city	Binh Hung	42	103	11
6		Binh Hung Hoa	78	49	-
7	Danang	Son Tra	37	38	18
8		Hoa Cuong	63	59	23.6
9		Phu Loc	96	71	28.3
10		Ngu Hanh Son	31	27	15.6
11	Quang Ninh	Bai Chay	36	196	-
12		Ha Khanh	45	41	-

Source: World Bank, 2013

Household connections to public piped sewerage systems are an essential component for any sewerage system, whether it is based on combined or separate flows. These connections allow the household's wastewater to be conveyed offsite, precluding the need for on-site disposal, which is often difficult due to limited land area and poor underlying soil conditions

The majority of households located in urban areas of Vietnam utilize septic tanks for on-site treatment of wastewater prior to discharge of the treated effluent off-site. This on-site treatment provides for basic sedimentation of the wastewater, removing those solids that could otherwise cause operational problems if allowed to enter the downstream combined sewerage systems. The sludge settled in the septic tank is anaerobically digested and must be periodically removed to ensure functionality of the septic tank system and to prevent overload. An overloaded septic tank greatly reduces the effectiveness of treatment and can contribute to solids deposition in downstream sewers and odor generation.

For household connections to separate collection systems, the household can eliminate the septic tank, as was done in the Buon Ma Thuoc wastewater system. This is made possible due to the hydraulic conditions in the pipeline which keep the solids suspended in the pipe, thus minimizing the effects of solids deposition. Additionally, separate systems are constructed to be totally enclosed piped systems, with little opportunity for odor generation.

The low influent quality for wastewater collected by combined sewerage systems (CSS) presents unique problems for the operators of the downstream wastewater treatment plants, particularly those based on biological treatment systems. These problems can be no better highlighted than at the Yen So WWTP in Hanoi. The catchment area tributary to the Yen So WWTP generates combined sewerage flow that then discharges to the Kim Nguu canal and onto the WWTP, where a portion of the canal flow is withdrawn for treatment. As the Kim Nguu canal flows through the City, CSS drainage channels and pipelines discharge collected flow into the canal. As the canal velocity is slow, solids contained in the combined sewerage settle to the bottom of the canal and are anaerobically digested. This has two effects, first, to reduce the organic loading in terms of BOD to the WWTP and second, to increase the ammonia content as a result of the fermentation process in the canal bottom.

Besides, the monitor results of wastewater sampling during pre-consulting for WWTPs always implement in the “short term” and limited monitoring such as “one shot sample) so that the input information for consulting work might be unreliable. This problem would lead to many later troubles not only in designing but also operating the WWTPs. The lack of influent characteristics that varies in very long range and depends much on the season in the tropical countries like Vietnam bring the many negative consequences to environmental management. The maintenance staffs cannot get the right implementation with “unknown wastewater” appear in specific time. For examples, from August to September, the change of weather in Vietnam from rainy to dry season lead to the dilution of wastewater in sewerage as well as influent of WWTPs. Almost WWTPs use the activated sludge processes so that it becomes the big hit to reactor in these days.

Current wastewater sampling

One of the most important tasks of WWTP implementation is identification of data sets measured at the influent of the WWTP. The determination of wastewater characteristics always has a fundamental role for designing, optimizing operation, management and upgrading of any wastewater treatment plant. The high cost (both in terms of workload and financial resources) related to experimental collection of an extended dynamic influent dataset is one of the main reasons. Traditionally, manual sampling is widely used to catch up the characteristics of wastewater before WWTP can be designed and built.

According to US EPA (2003), the objective of sampling is to collect representative sample. Representative sample by means a sample in which relative proportions or concentration of all pertinent components will be the same as in the material being sampled. Moreover, the same sample will be handled in such a way that no significant changes in composition occur before the tests are made. The sample volume shall optimal small enough that it can be transported and large enough for analytical purposes. Because of the increasing placed on verifying the accuracy and representatives of data, greater emphasis is placed on proper sample collection, tracking, and preservation techniques. Often laboratory personnel help in planning a sampling program, in consultation with the user of the test results. Such consultation is essential to ensure selecting samples and analytical methods that provide a sound and valid basis for answering the questions that prompted the sampling and that will meet regulatory and/or project-specific requirements.

However, the current process of consulting and designing cannot satisfy well for above requirement. In traditional way, the sampling and monitoring data are almost conducted in “one-shot” or short-term with limited analyzed parameters as well as sample quantities. In addition, the fractionation of the wastewater (particle/ soluble, biodegradable/ un-degradable) is known to be highly variable with time and sampling point. In that way, the survey cannot guarantee the reliability of sewage characteristics that always vary along time.

Besides, the use of on-line sensors still remains complicated, since the sticky materials of raw wastewater and the heavy deposit of pollutants make their maintenance cost considerable. Moreover, in view of risk analysis, models are generally used ton predict the behavior of the system under some hypothetical conditions (population growth; strong rain events; uncontrolled spills, etc.) for which real data might not exist. Influent data for municipal

WWTP modelling consist of time series data of the flow and concentrations of the water quality parameters (COD, TKN, TSS, BOD, NH_4, NO_3, T-P, PO_4, etc.). These profiles depend on many factors: size of the catchment, type of the sewer system, number of person equivalents, industrial discharges, soil type, rainfall patterns, temperature, etc. (Butler et al., 1995; Bott and Parker, 2010; Schilperoort, 2011). The complexity of the wastewater generation is so big that there is still no clear relationship between the generating mechanisms and the expected water quality profiles.

2.2 Activated Sludge Model No.1 (ASM 1)

Activated Sludge Model 1 (ASM1) is a theoretical mathematical model depicting the biological processes occurring in the activated sludge section of a wastewater treatment plant. It represents an useful tool for the design and operation of a plant. It was developed in 1986 (Henze et al., 1986) by the task group formed from the International Association on Water Quality (IAWQ, formerly IAWPRC). The primary aim was to set out a standardization of biological WWTP design by building a mathematical model able to realistically describe carbon oxidation, nitrification and denitrification.

The first model developed for municipal activated sludge ASM1 describes the removal of organic carbon compounds and ammonia-nitrogen, with facultative consumption of oxygen or nitrate as the electron acceptor, depending on the conditions in the activated sludge system. Other models, ASM2 and ASM2d, which include chemical precipitation processes and phosphorus removal, have also been developed. To correct a number of shortcomings of the ASM1 model, the ASM3 model was developed based on the ASM1 model.

Table 2.2 show the matrix format of ASM1 (Henze et al. 1987)

Table 2.2 The ASM1 process matrix

No	Description Process	Units	XC_B	S_B	X_{OHO}	X_{ANO}	S_{O2}	S_{NHx}	S_{B_orgN}	XC_{B_orgN}	X_U	X_I	X_{Ig}
1	Hydrolysis of particulate biodegradable COD material	$gCOD/m^3/d$	-1	1									
2	Aerobic growth of heterotrophs	$gCOD/m^3/d$		$-1/Y_{OHO}$	1		$-(1-Y_{OHO})/Y_{OHO}$	$-f_N$					
3	Aerobic growth of autotrophs	$gCOD/m^3/d$				1	$-(4.57-Y_{ANO})/Y_{ANO}$	$-f_N-1/Y_{ANO}$					
4	Decay of heterotrophs	$gCOD/m^3/d$			-1					$f_N(1-f_U)$	f_U		
5	Decay of autotrophs	$gCOD/m^3/d$				-1				$f_N(1-f_U)$	f_U		
6	Hydrolysis of particulate biodegradable nitrogen	$gN/m^3/d$							1	-1			
7	Ammonification of soluble organic nitrogen	$gN/m^3/d$						1	-1				

Organic components in ASM1

In ASM1, the total COD represent the organic matter in a wastewater, which is divided into three main fractions, non-biodegradable, biodegradable and active biomass. The non-biodegradable COD has two fractions, non-biodegradable particulate also known as particulate inert, X_I and non-biodegradable soluble also known as soluble inert, S_I. The biodegradable COD also has two fractions, the slowly biodegradable, X_S and readily biodegradable COD, S_S, while the active biomass consists of heterotrophic biomass, X_{BH} and autotrophic biomass $X_{B,A}$. Particulate products arising from biomass decay X also contribute to the total COD. Figure 1.3 shows the COD fraction up to total COD in ASM1.

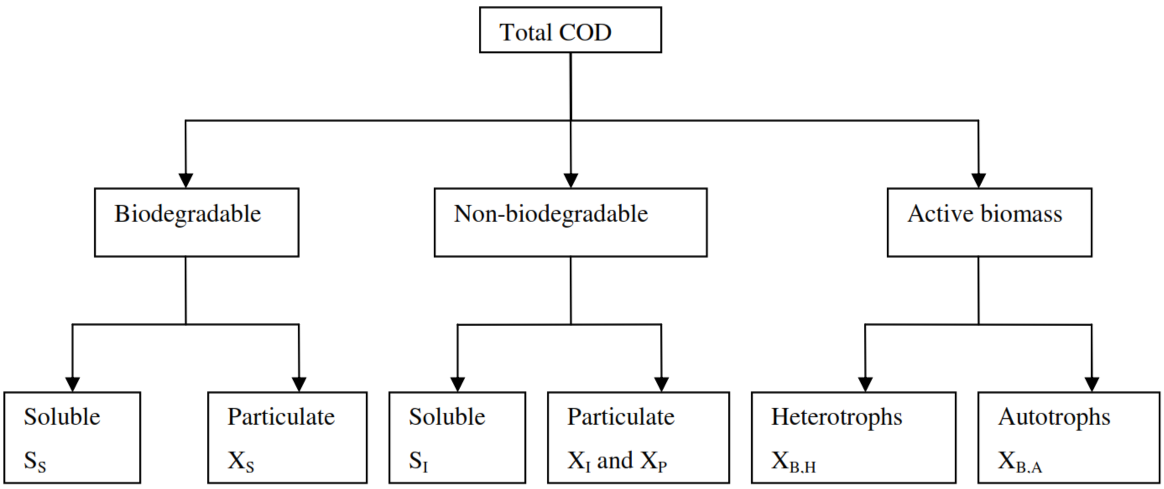


Figure 1.4 COD fraction in ASM1

Nitrogen components in ASM1

The Total Kjeldahl Nitrogen in ASM1 is then subdivided in a similar way as the COD, into three categories, the biodegradable, non-biodegradable and the active biomass. The biodegradable component consists of soluble ammonia nitrogen, S_{NH} and two organic nitrogen fraction, soluble organic nitrogen S_{ND} and particulate organic nitrogen, X_{ND}. The non-biodegradable components are not included as separate components in the ASM1 model. The particulate non-biodegradable organic nitrogen, X_{NI} is linked to non-biodegradable particulate components of COD and the soluble non-biodegradable organic nitrogen, S_{NI} occurs in negligible amounts. The active biomass is also associated with a nitrogen fraction, X_{NB} which is split between heterotrophic and autotrophic biomass $i_{XB}.X_{BH}$ and $i_{XA}.X_{BH}$ respectively. The particulate products, X_P and inert particulate, X_I are also associated with nitrogen fractions, X_{NP} and X_{NI} respectively. The Figure 1.4 gives the total nitrogen fraction in the influent wastewater of ASM1

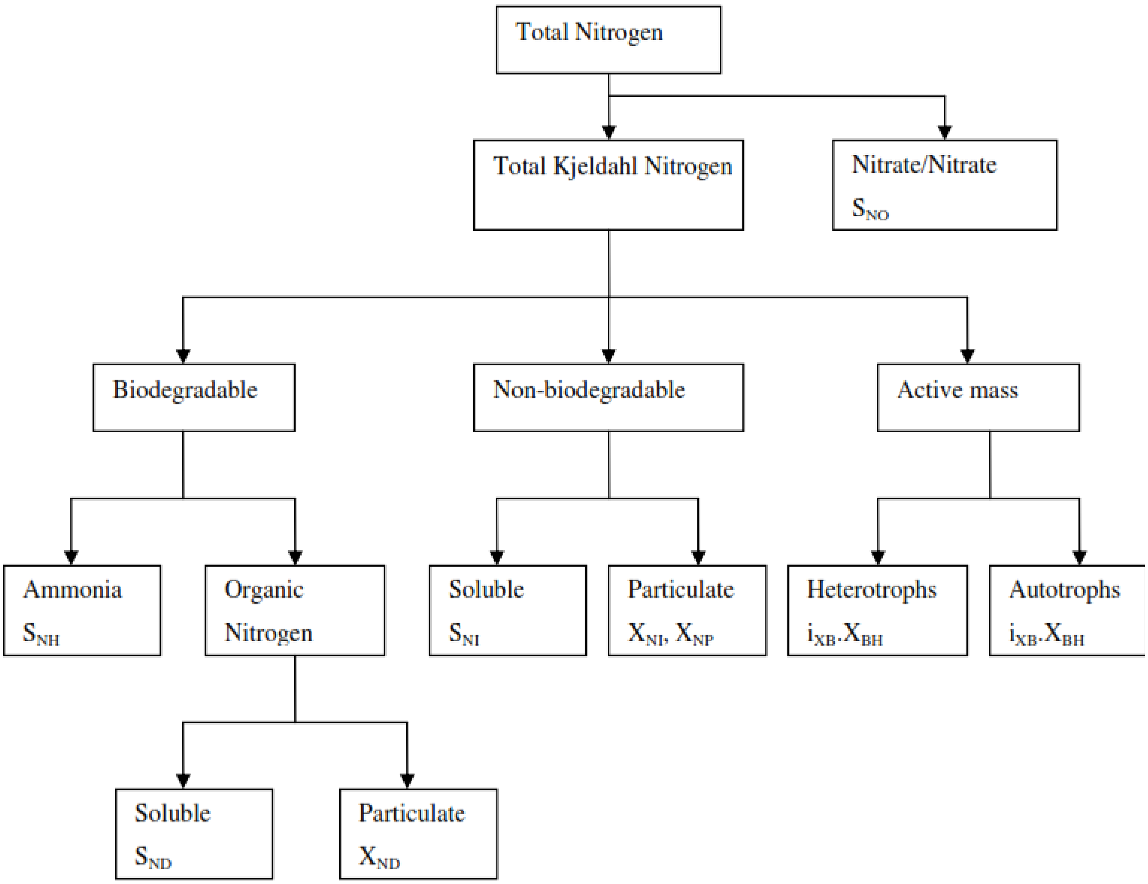


Figure 1.5 Nitrogenous fraction in the influent wastewater of ASM1

Process in ASM1

Four processes are considered in ASM1, the growth of biomass, decay of biomass, ammonification of organic nitrogen and the hydrolysis of particulate organics which are entrapped in the bio-flocculation. The growth of the biomass is represented by three processes; aerobic growth of heterotrophs, anoxic growth of heterotrophs and aerobic growth of autotrophs.

Aerobic growth of heterotrophs

Aerobic growth of heterotrophic biomass occurs at the expense of soluble substrate, S_S, and results in the production of heterotrophic biomass. It is associated with the utilization of oxygen, which is represented by the negative COD in the process model matrix. Ammonia nitrogen is removed from solution and incorporated into cell mass. Monod kinetics is used to describe the process in the model matrix.

Anoxic growth of heterotrophs

Anoxic growth of heterotrophs is the de-nitrification process which occurs at the expense of readily biodegradable substrate and results in heterotrophic biomass while nitrate nitrogen serves as the terminal electron acceptor. As in aerobic growth, ammonia nitrogen is converted to organic nitrogen in the biomass. The same Monod kinetics as the aerobic process is used to represent the process, but a correction factor, η_g is included to account for the anoxic process rates being slower than the aerobic process rates.

Aerobic growth of autotrophs

Aerobic growth of autotrophs, results in autotrophic cell mass and nitrate nitrogen as end products. This is the nitrification process where ammonia nitrogen SgNH is oxidized to nitrate S. Soluble ammonia nitrogen serves as the energy source for the growth of the nitrifiers. Oxygen is used in proportion to the amount of ammonia nitrogen oxidized.

The decay of biomass is represented by two processes; decay of heterotrophs and decay of autotrophs.

Decay of heterotrophs

In the decay process, the biomass is converted to a combination of particulate products and slowly biodegradable substrate. The slowly biodegradable substrate is hydrolyzed in the hydrolysis process. No loss of COD is involved in the split and no electron acceptor is utilized.

Decay of autotrophs

The decay of autotrophs is modelled in a similar manner to that of heterotrophs as seen in the model matrix shown in Table 2.1.

Ammonification of organic nitrogen

In this process, organic ammonia, S_{ND} is converted to ammonia nitrogen, S_{NH} through a first order reaction accompanied by alkalinity changes.

Hydrolysis of particulate organics is represented by two processes; the hydrolysis of entrapped organics and the hydrolysis of entrapped organic nitrogen.

Hydrolysis of entrapped organics

In this process slowly biodegradable substrate, X_S is broken down into readily biodegradable substrate, S_S. A correction factor, η_h is included to account for the reduced hydrolysis rate under anoxic conditions.

Hydrolysis of entrapped organic nitrogen

The hydrolysis of entrapped organic nitrogen is modelled in a similar way to the hydrolysis of entrapped organics.

Summary, Table 2.3 show the list of state variables use in ASM1

Table 2.3 State variable

State variables	Description	Units
Inorganic Suspended Solids		
xii	inert inorganic suspended solids	g/m3
Organic Variables		
si	soluble inert organic material	gCOD/m3
ss	readily biodegradable substrate	gCOD/m3
xi	particulate inert organic material	gCOD/m3
xs	slowly biodegradable substrate	gCOD/m3
xbh	active heterotrophic biomass	gCOD/m3
xba	active autotrophic biomass	gCOD/m3
xu	unbiodegradable particulates from cell decay	gCOD/m3
xsto	internal cell storage product	gCOD/m3
Dissolved Oxygen		
so	dissolved oxygen	gO2/m3
Nitrogen Compounds		
snh	free and ionized ammonia	gN/m3
snd	soluble biodegradable organic nitrogen	gN/m3
xnd	particulate biodegradable organic nitrogen	gN/m3
sno	nitrate and nitrite	gN/m3
snn	dinitrogen	gN/m3
Alkalinity		
salk	alkalinity	mole/m3

2.3 Trickling Filter

2.3.1 Introduction

Trickling filters (TFs) are the method used to remove organic matter from wastewater. The TF is an aerobic treatment system that utilizes microorganisms attached to a medium to remove organic matter from wastewater. This type of system is common to a number of technologies such as rotating biological contactors and packed bed reactors (biological towers). These systems are known as attached-growth processes with the carrier inside. In contrast, systems in which microorganisms are sustained in a liquid are known as suspended-growth processes.

The trickling filter consists of a cylindrical tank and is filled with a high specific surface area material, such as rocks, gravel, shredded PVC bottles, or special pre-formed plastic filter media (Figure 1.4). A high specific surface provides a large area for biofilm formation. Organisms that grow in the thin biofilm over the surface of the media oxidize the organic load in the wastewater to carbon dioxide and water, while generating new biomass. This happens mainly in the outer part of the slime layer, which is generally of 0.1 to 0.2 mm thickness. As the wastewater flows over the medium, microorganisms already in the water gradually attach themselves to the rock, slag, or plastic surface and form a film. The organic material is then degraded by the aerobic microorganisms in the outer part of the slime layer.

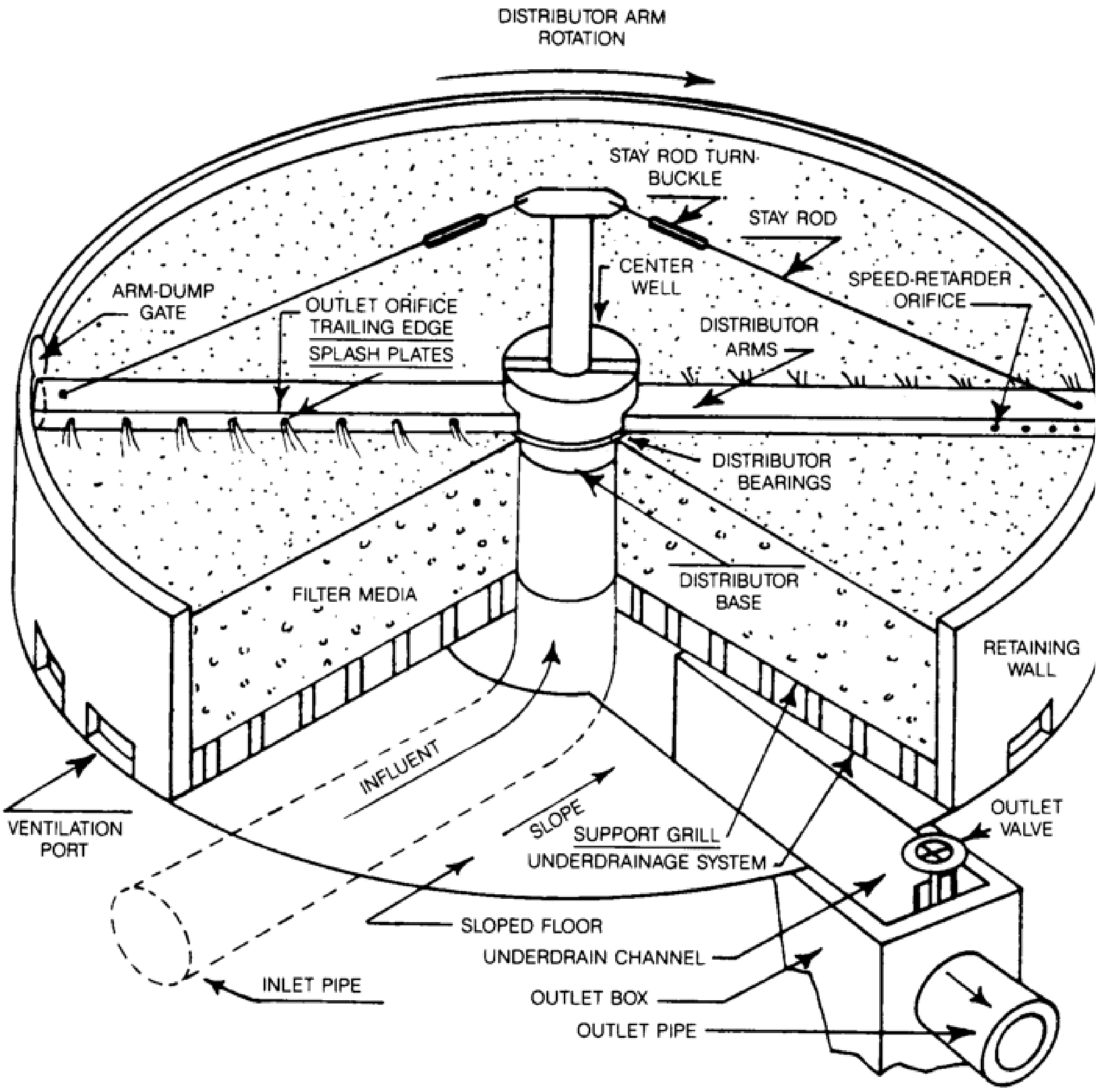


Figure 1.6 Trickling Filter construction

Source: Metcalf & Eddy, 1998

The design of a TF system for wastewater also includes a distribution system for distributing the influent onto the reactor. A rotary hydraulic distribution is usually standard for this process, but fixed nozzle distributors are also being used in square or rectangular reactors.

Overall, fixed nozzle distributors are being limited to small facilities and package plants. Recently some distributors have been equipped with motorized units to control their speed. Distributors can be set up to be mechanically driven at all times or during stalled conditions.

In addition, a TF has an underdrain system that collects the filtrate and solids, and also serves as a source of air for the microorganisms on the filter. The treated wastewater and solids are piped to a settling tank where the solids are separated. Usually, part of the liquid from the settling chamber is recirculated to improve wetting and flushing of the filter medium, optimizing the process and increasing the removal rate.

Operation and Application

TFs enable organic material in the wastewater to be adsorbed by a population of microorganisms (aerobic, anaerobic, and facultative bacteria; fungi; algae; and protozoa) attached to the medium as a biological film or slime layer (approximately 0.1 to 0.2 mm thick). As the wastewater flows over the medium, microorganisms already in the water gradually attach themselves to the rock, slag, or plastic surface and form a film. The organic material is then degraded by the aerobic microorganisms in the outer part of the slime layer.

As the layer thickens through microbial growth, oxygen cannot penetrate the medium face, and anaerobic organisms develop. As the biological film continues to grow, the microorganisms near the surface lose their ability to cling to the medium, and a portion of the slime layer falls off the filter. This process is known as sloughing. The sloughed solids are picked up by the underdrain system and transported to a clarifier for removal from the wastewater

The incoming pre-treated wastewater is ‘trickled’ over the filter, e.g., with the use of a rotating sprinkler. In this way, the filter media goes through cycles of being dosed and exposed to air. However, oxygen is depleted within the biomass and the inner layers may be anoxic or anaerobic. As the layer thickens through microbial growth, oxygen cannot penetrate the medium face, and anaerobic organisms develop.

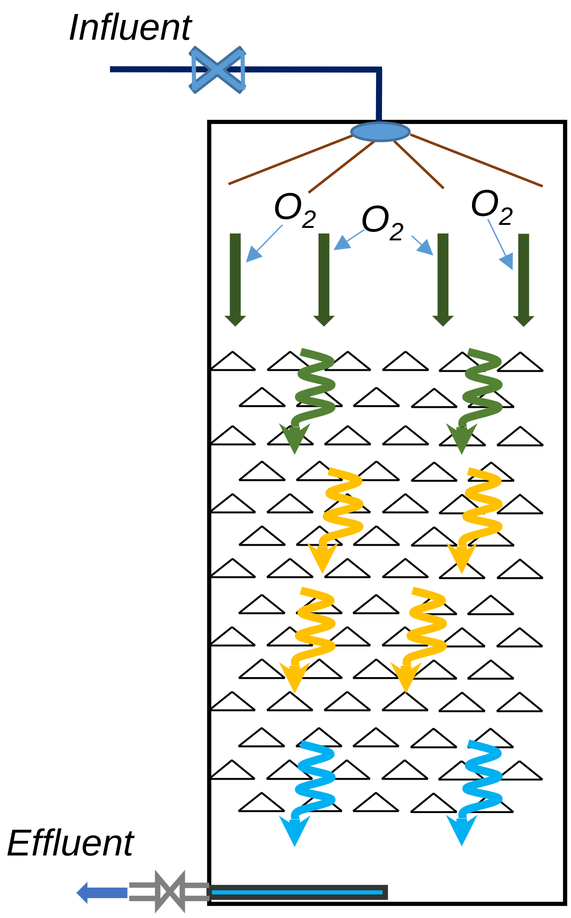


Figure 1.7 Trickling Filter operation description

The removal of pollutants from the waste water stream involves both absorption and adsorption of organic compounds and some inorganic species such as nitrite and nitrate ions by the layer of microbial bio film. The filter media is typically chosen to provide a very high surface area to volume. Typical materials are often porous and have considerable internal surface area in addition to the external surface of the medium. Passage of the waste water over the media provides dissolved oxygen which the bio-film layer requires for the biochemical oxidation of the organic compounds and releases carbon dioxide gas, water and other oxidized end products. As the bio film layer thickens, it eventually sloughs off into the liquid flow and subsequently forms part of the secondary sludge. Typically, a trickling filter is followed by a clarifier or sedimentation tank for the separation and removal of the sloughed film. Other filters utilizing higher-density media such as sand, foam and peat moss do not produce a sludge that must be removed, but require forced air blowers and backwashing or an enclosed anaerobic environment.

Application

Low Rate Trickling Filter

The standard rate or Low rate trickling filters (LRTF) are relatively simple treatment units that normally produce a consistent effluent quality even with varying influent strength. They are generally not provided with recirculation of effluent. Depending upon the dosing system, wastewater is applied intermittently with rest periods which generally do not exceed five minutes at the designed rate of waste flow. With proper loadings the LRTF, including primary and secondary sedimentation units, should remove from 80 to 85 percent of the applied BOD.

The sloughed solids from a low-rate filter are generally well-digested and as a result these filters yield less solids than higher rate filters. Secondary quality effluent is readily achievable if the low-rate trickling filter design incorporates filter media with bio-flocculation capabilities or good secondary clarification.

High Rate Trickling Filter

The High Rate Trickling Filters (HRTF), have the same construction details, but the recirculation of effluent is provided. Part of the settled treated effluent is pumped to the PST or to the filter. Recirculation of effluent is an essential and important feature of the HRTF. Thus the incoming wastewater is diluted and TSS concentrations are reduced. High-rate filters are usually characterized by higher hydraulic and organic loadings than low-rate filters. The higher BOD loading is accomplished by applying a larger volume of waste per unit surface area of the filter. One method of increasing the efficiency of a trickling filter is to incorporate recirculation. When recirculation is used, the hydraulic loading per unit area of filter media is increased. As a result, higher flow velocities will usually occur causing a more continuous and uniform sloughing of excess growths. High-rate trickling filters, including primary and secondary sedimentation, should, under normal operation, remove from 65 to 85 percent of the BOD of the wastewater

High-rate filters are generally loaded at the maximum organic loading capabilities of the filter and receive total BOD loading ranging from 64 to 160 kg $BOD_5/100m^3d$ (40 to 100 lb. BOD/1000cuft/day). Achieving a secondary quality effluent is less likely for a high-rate filter without a second stage process. As a result, high-rate filters are often used with combined processes.

Roughing Filter

Roughing filters are high rate type filters designed with plastic packing. In most cases roughing filters are used to treat wastewater prior to secondary treatment. One of the advantages of roughing filter is low energy requirement for BOD removal of high strength wastewaters as compared to activated sludge process because the energy required is only for pumping the influent wastewater and recirculation flows.

Advantages and Disadvantages of Trickling Filter

Advantages

- Simple biological process.

- Suitable in areas where large tracts of land are not available for land intensive treatment systems.

- May qualify for equivalent secondary discharge standards.

- Effective in treating high concentrations of organics depending on the type of medium used.

- Appropriate for small- to medium-sized communities.

- Rapidly reduce soluble organic matter in applied wastewater.

- Efficient nitrification process

- Low power requirements.

- Moderate level of skill and technical expertise needed to manage and operate the system.

Disadvantages

- Additional treatment may be needed to meet more stringent discharge standards.

- Possible accumulation of excess biomass that cannot retain an aerobic condition and can impair TF performance (maximum biomass thickness is controlled by hydraulic dosage rate, type of media, type of organic matter, temperature and nature of the biological growth).

- Requires regular operator attention.

- Incidence of clogging is relatively high.

- Requires low loadings depending on the medium.

- Flexibility and control are limited in comparison with activated-sludge processes.

- Snail, fly appearance and odor problems

2.3.2 Design method for trickling filter

The purpose of design trickling filter formulation is to obtain a relationship among organic matter removal, depth of filter, hydraulic loading and media characteristics. The following formulation are developed and used popular by many consultants in designing the trickling filter for wastewater treatment (*Adam, 1997*).

Velz equation

The following equation is used for a single-stage system and in the 1st stage of a 2-stage system:

$$S_{e1} = \left(\frac{S_i + r_i S_{e1}}{1 + r_i} \right) \exp \left[\left(\frac{-kDA^n}{Q^n} \right) \left(1.035^{(T-20)} \right) \right] \quad (2.1)$$

Equation 2.2 is used for the 2nd stage of a 2-stage system

$$S_{e2} = \left(\frac{S_{e1} + r_2 S_{e2}}{1 + r_2} \right) \exp \left[\left(\frac{-kDA^n S_{e1}}{Q^n S_i} \right) \left(1.035^{(T-20)} \right) \right] \quad (2.2)$$

Where: S_e: Effluent BOD from the filter (mg/L)

S_i: Influent BOD (mg/L)

r: Ratio of recirculated flow to wastewater flow

D: filter depth (m)

A: filter area (m^2)

Q: wastewater flow (m^3/min)

T: wastewater temperature (^oC)

k, n : empirical coefficients (for municipal wastewater: k=0.02 and n=0.5)

Subscript i: stage number

NRC (National Research Council, US) equation:

The following equation is used for a single-stage and the 1st of 2-stage system, for the 2nd or later the similar equations are used

$$1-\left(\frac{S_{e1}}{S_i}\right)=\frac{1}{1+0.532\left(\frac{QS_i}{V_1F_1}\right)^{0.5}} \tag{2.3}$$

$$F_1=\frac{1+r_1}{(1+0.1r_1)^2} \tag{2.4}$$

Where, *V*: filter volume

F: recirculation factor

Eckenfelder equation

Eckenfelder has developed performance equation based on the specific rate of substrate removal for a pseudo-first-order reaction

$$\frac{S_e}{S_i}=\exp\left[-\frac{-KD}{L^n}\right]$$
$$K=kC'C''A_V^{(m+1)} \tag{2.5}$$

Where: *K* (for specific packed media): function of rate constant *k* for the substrate

L: hydraulic loading (m/d)

A_V: specific surface area of media (m^2/m^3)

D: filter depth (m)

C', C'': proportionality constants

m, n: empirical coefficient

Germain/ Schultz equation

$$\frac{S_e}{S_i} = \exp\left[-K_{20,\mathrm{i}} D_i \left(\frac{Q}{A}\right)^{-n}\right] \tag{2.6}$$

Trickling filter are bed with packing such as broken rock, clinkers, or synthetic media (that become more popular today). Influent wastewater percolates through the packing, coming in contact with the biological slime layer. The different between media characteristics brings the various efficiencies of trickling filters. On the other word, the features of packed media would define the the types of a bio-filter through its loading rate and shape. The two most important properties of trickling filter media are the specific surface area and the void space. The specific surface is defined as m^2 (ft^2) of packing surface per volume. The larger the specific surface area the greater is the amount of biological slime per unit volume. Greater percentage of the void volume space, on the other hand, allows higher hydraulic loading without the risk of flooding. However, in practical, the real activated area of media depend on the characteristics of media styles. The study on relation between wetted surface area (of media) and flow rate are still limited in wastewater treatment area because the trickling filters are usually packed with conventional media such as soil, sand, plastic pieces. However, the develop of material field brings many kinds of media that has large specific areas than before so that they require the study of above relation.

2.3.3 Wetted surface area of media

Most current trickling biological filter designs are based on an empirical loading criteria or design formulas; however, successful modeling requires accurate estimates of solute diffusion into and out of the biofilm. Several attempts have been made to model biofilm reactors more analytically, but such factors as mass transfer and fluid shear are often difficult to predict under trickling flow. Both of these parameters are affected by the fluid velocity over the biofilm surface. While it is impossible to predict analytically the flow at a given point, the probability distribution of flow rates (Reynolds numbers) inside a random-packed trickling filter can be determined (Krumin et al. 2000).

In principle, mass transfer of biological trickling filters can be expressed as an analogy of counter-flow packed tower processes where the target materials in the sprayed liquid adsorb the gas fed from the bottom of the reactor. Since these reactions proceed at the wetted surface area of the packed media in the reactor, the wetted area dominates the process performance.

Studies to estimate the wetted area of packed tower processes were extensively carried out in the fields of chemical engineering in 1960s. Onda *et al.* (1967) developed an empirical equation (Equation 2.7) composed of three kinds of bed-scale engineering parameters (bed-scale Reynolds number ($Re_{,b}$), bed-scale Froude number ($Fr_{,b}$) and bed-scale Weber number ($We_{,b}$)) and the ratio of surface tension of the packing media to that of liquid (Equation 2.8-2.10)

$$\frac{a_w}{a_t} = 1 - \exp\left(-A\left(\sigma_C / \sigma_{LV} \right)^B \cdot Re_{,b}{}^C \cdot Fr_{,b}{}^D \cdot We_{,b}{}^E \right) \qquad \text{Eq.(2.7)}$$

Where; a_w/a_t = the ratio of wetted specific surface area (a_w, m^2/m^3) to the total specific area of the packing media (a_t, m^2/m^3) in the reactor,

σ_c/σ_{LV}: the ratio of the surface tension of the packing media to the fluid

A-E: regression coefficients.

$$Re_{,b} = \frac{1}{a_t} \frac{Q_b}{A_b} \cdot \frac{\rho_L}{\eta_L}. \qquad \text{Eq.(2.8)}$$

$$Fr_{,b} = \left(\frac{Q_b}{A_b}\right)^2 \cdot \frac{a_t}{g} \qquad \text{Eq.(2.9)}$$

$$We_{,b} = \frac{\rho_L}{\sigma_{LV}} \cdot \frac{1}{a_t} \cdot \left(\frac{Q_b}{A_b}\right)^2 \qquad \text{Eq.(2.10)}$$

Where Q_b: Volumetric flow rate applied to the bed (m^3/h),

A_b: bed cross-sectional area (m^2), a_t: specific surface area of the packing media (m^2/m^3),

ρ_L: liquid density (kg/m^3), σ_c: critical liquid surface tension of the media (kg/hr^2),

η_L: viscosity of the liquid (kg/m/hr) (H_2O = 3.62),

g: acceleration of gravity (1.27E+08 m/hr^2),

σ_{LV}: liquid/vapor interfacial energy (surface tension) kg/hr^2 (H_2O=942,840)

The relation between a_w/a_t & linear velocity (LV) varied considerably depending on the equations applied, all these equations yielded high LV at high a_w/a_t conditions. Hence the optimization of LV can be pointed out to be one of the most essential research items for the reactor development.

For mathematical modelling the trickling filter processes, a set of mass transfer equations on/in the biofilm are formulated defining relevant state variables. In this case, determination of the parameter of the model through calibration and verification- upon collecting the series of data with difference loading would be carried out.

For mathematical modelling of the trickling filter process, a empirical equations (Equation 2.11) was utilized to calculate the wetted area for trickling filter system. This empirical equation with three kinds of bed-scale engineering parameters that includes: Reynolds number (Re), bed-scale Froude number (Fr) and bed-scale Weber number (We). These parameter are functions depending on loading velocity (LV) and the ratio of surface tension of the packing media to the liquid. They were developed to calculate the wetted area of packed tower processes by Onda et al (1968) and Krumin et al (2000).

$$\frac{a_w}{a_t} = 1 - \exp\left(-A\left(\sigma_C / \sigma_{LV} \right)^B \cdot Re_{,b}{}^C \cdot Fr_{,b}{}^D \cdot We_{,b}{}^E \right) \qquad \text{Eq.(2.11)}$$

For the set of the regression coefficients (*A*-*E*), Onda *et al.* (1968) identified as A = 1.45, B = 0.32, C = 0.1, D = -0.05, E = 0.2, from their counter-flow packed tower experiments. The empirical equation could predict a_w/a_t with an accuracy of ±20% when $A{\cdot}Re_{,b}{}^C Fr_{,b}{}^D We_{,b}{}^E$ was in the range between 0.05 and 1.2. On the other hand, Krumin *et al.* (2000) assumed that σ_c/σ_{LV} = 1.0 for their nitrifying trickling filter since the biofilm was hydrophilic. Consequently they slightly modified A to be 3.85 and E to be 0.4 respectively in order to meet their experimental results.

It should be noted that these bed-scale engineering parameters have an operational variable for the liquid flow (Q_b) per the cross sectional area of the reactor (A_b). Therefore the linear velocity of the sprayed liquid ($LV = Q_b/A_b$) is a highly influential factor on a_w/a_t. Besides LV, the impact of other parameters (*i.e.* viscosity of liquid (η_L), liquid density (ρ_L), and surface tension (σ_{LV})) are limited. Because the three parameters are inherent physical properties of the liquid (e.g water), and hence almost constant in practice whilst a_t may vary between 200-400 m^2/m^3 in typical commercial plastic media.

As Equation 2.12 does not take into account the shape of packing media (e.g. sphere, ring, saddle…), distinct a_w might be given if distinct packing media is used from the above investigated. In such case, a calibration of the coefficients and/or modification of the equation itself is required to retain the prediction accuracy. In this regard, Hikita *et al.* (1960) developed another empirical equation applying two kinds of packing media-dependent coefficients (Equation 3.8).

$$\frac{a_w}{a_t} = F \cdot LV_{weight}{}^G \cdot (1000\sigma)^H \qquad \text{Eq.(2.12)}$$

Where:

F: packing media-dependent coefficient (e.g. 2.26 for Raschig ring), LV_{weight}: mass flow of the liquid per cross sectional area of the reactor ($kg/m^2/sec$),

G: coefficient (fixed at 0.455),

σ: liquid/vapour interfacial energy (surface tension, H_2O/air = 0.072 N/m^2),

H: packing media-dependent coefficient (e.g. -0.091*(D_P, packing-media diameter)$^{-0.08}$ for Raschig ring).

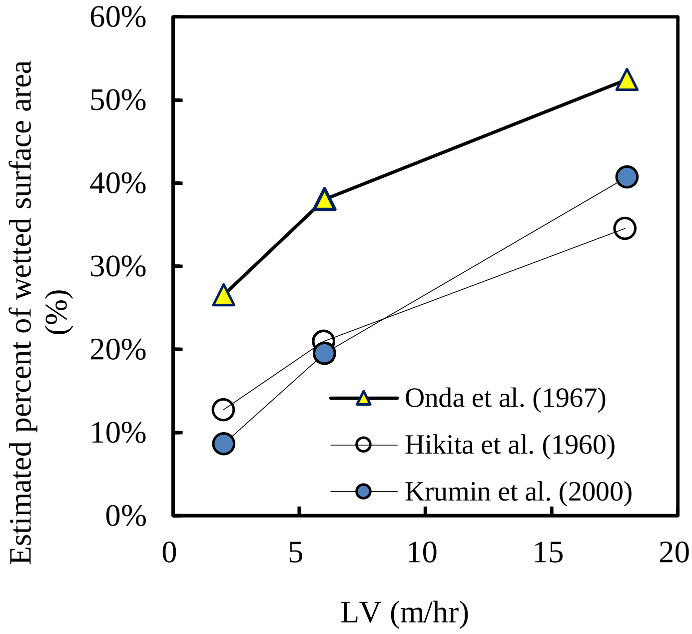


Figure 3.1 Estimated percent of the wetted surface area of the packing media

Using the above three empirical equations, a_w/a_t vs. LV for a plastic packing media used in a pilot-scale reactor can be calculated through experimental pilot. As shown in Figure 3.1, although the calculated a_w/a_t vs. LV varied considerably depending on the equations applied, all these equations yielded high LV at high a_w/a_t conditions. For LV at 18 m/hr, a_w/a_t increased as much as 200-400% of those at 2 m/hr. This suggested that operations under high LV could improve the volumetric reaction rate of the trickling filter. Since the capital cost of the packing media significantly affects the investment cost of the trickling filter process, high LV operation allowing to reduce the reactor volume would lead to the saving of the investment cost. Hence the optimization of LV can be pointed out to be one of the most essential research items for the reactor development.

2.4 Problem formulation

2.4.1 Existing hindrances

Through existing problems present above, there were some hindrances in wastewater treatment management in Vietnam as well as developing countries. Therefor, the thesis content suggesting solutions for these matters from influent determination to applied modelling trickling filter process.

The direct on-site sampling is very popular way to determine the wastewater concentration. To the combined sewage system, this method requires the high cost, man-power as well as a number of samples to get the tendency of municipal wastewater characteristics. Due to the fluctuation of wastewater by day, by seasons and even by hours in a day, it requires the reliable and reasonable approach to catch the compositions. In this regard, considering that the composition of activated sludge is the consequence of the influent and the operating condition, back-calculation of the influent material concentrations from the activated sludge constituents might be an attractive option.

Besides, the use of bio-filter in wastewater treatment plant and wastewater process is a novel and low-cost method in compare with the conventional way such as aeration tanks. So, it need to be clarified the trickling filter operation parameter and design data for consulting task. The insight of trickling filter as well as dynamics simulation ability can provide the suitable approach of WWTP design in developing countries.

On the other hand, a mathematical model for a trickling filter process can be set up by using ASM concepts with two-step Mantis model. Although biological kinetic /stoichiometric coefficients could be mostly adopted from literatures, some engineering coefficients for the empirical equation to estimate reactive wet surface area. So, the study of intensive test (high loading in influent) can provide the data of the maximum nitrification efficiency of the reactor as well as calibrate the wetted surface area and essential kinetic parameters. Then, the fairly good simulations of nitrification showed that it can be applied further with various process in trickling filter

2.4.2 Research Topics

The determination of kinetic and stoichiometric parameters, as well as sewage sludge and water inflow characterization has assumed a fundamental role in the last decade for optimized planning, modelling, design, management and upgrading of the biological stage in a wastewater treatment plant. However, in wastewater research field the respirometry method has been developed for a long time in the parallel with the development of process modeling. In this regard, considering that the composition of activated sludge is the consequence of the influent and the operating condition.

From that attractive approach, a new approach in order to catch up the fluctuating influent concentrations in Vietnam was used and presented in **Chapter 3**. In addition, another approach by using the GPS-X software also was introduced and compared in **Chapter 4**.

On the other hand, the use of trickling filter is advantageous as no aeration and suitable solution for combined municipal wastewater with high ammonia contain. Since its application can be good approach for sewerage in developing countries that require the stable and low-cost treatment process, the insight of TF for design and development have to carried out in order to bring the most suitable method. The study on this topic was carried out and present in **Chapter 5**.

From the achieved results in above chapters, **Chapter 6** present the case study and application for combined sewerage wastewater in Hue city, Vietnam

The objective of this study are as follows:

1. Develop the theoretical method to build up the back-calculation for influent characteristics determination.

2. Apply the back-calculation with case studies in Vietnamese city (Danang city and Hue city) and compare to the results from optimized tool.

3. To estimate and develop empirical equation of wetted area and linear velocity of trickling filter.

4. To evaluate the trickling filter process with the response of the nitrification.

5. To layout the suggestion of wastewater treatment plant through research results

In general, the thesis content was composed by 7 chapters:

In the chapter 1, the research background is introduced to situation of Vietnam wastewater treatment management. The existing work about ASM1 model and trickling filter process are also mentioned. In Chapter 2, the hindrances in Vietnam wastewater treatment as the unrealistic influent characteristics and limitation in determining the engineering parameter of trickling filter process are provided. Next, the application for identifying the influent characteristics is implemented and present in Chapter 3 and in Chapter 4, the estimation by optimizer tool and its comparison was carried out. In the Chapter 5, the relation between liquid hold-up and wetted surface area in trickling reactor as well as dynamic simulation are shown. Chapter 6 present the suggestion of treatment process for combined sewerage wastewater with case study in Hue city, Vietnam. Finally, the research is summarized in Chapter 7.

Chapter 3: Back Calculation of Influent Wastewater Constituents from Activated Sludge Reactors

3.1 Introduction

Due to rapid growth of population and economy in developing countries, a number of governmental projects to build new municipal wastewater treatment plants (WWTPs) is initiated especially in Vietnam. According to a consulting report published by World Bank in 2013, the household connection to wastewater service in urban areas in Vietnam is ranged from 40 to 90% depending on cities whereas only 20% of the municipal wastewater is transferred to WWTPs. To cope with the pollution of water bodies, more than 30 projects are implemented over Vietnam as of 2013.

The report revealed that the constituents and concentrations of the municipal wastewater were not comparable to those in Japan, Europe and USA because of compulsory installation of septic tank placed prior to the sewer. As the septic tank is a sort of decentralized module to reduce the pollutant load, a part of readily biodegradable materials in the wastewater is decomposed in a certain extent during the storage in the tank (Harada et al. 2008). However, in reality the performance of the septic tank process is recognized to be considerably scattered over the areas and the households due to no concrete design guideline and lack of regular maintenance (Harada 2010 & Anh TNQ 2016). According to Nguyen (2013), the effluent of the septic tank to the sewer noticeably varied, *e.g.* BOD_5: 30-140 mg/L, SS: 27-200 mg/L and Total nitrogen: 11-40 mg-N/L. This fact lead a challenge for planning and designing WWTPs since default influent concentrations could not be applied unlike other countries having no septic tank process. When unrealistically too high or too low influent concentrations were chosen in the projects, the WWTPs might become undercapacity/ overcapacity systems.

In order to catch the influent concentration besides wastewater flow, on-site water sampling is widely used. The collected water samples are then analyzed in laboratories and the constituents and concentrations are listed accordingly. On the other hand, since the composition of the municipal wastewater is highly fluctuated and inconsistent along with time, considerable number of water samples must be analyzed. As the procedure is highly cumbersome, developments of simple and reliable methods are desired.

In this regard, considering that the composition of activated sludge is the consequence of the influent and the operating condition, back-calculation of the influent material concentrations from the activated sludge constituents might be an attractive option. For the purpose, IWA Activated Sludge Models (ASMs) can be used in mathematical way (Henze 2000). Once such is built, the new technique can be incorporated to WWTP planning in the countries. Based on the background, lab-scale activated sludge reactors were set up in Vietnam and operated for a couple of months. From the field experiment, the municipal wastewater constituents and concentrations were calculated to demonstrate the back-calculation approach. In this study, the labour intensity of the analysis was also comparatively discussed with that of the conventional wastewater sampling/ analysis method.

3.2 Material and Methods

3.2.1 Field Experimental Module

Reactor installation

Two sets of lab-scale activated sludge reactors (ASRs) were installed at Phu Loc wastewater treatment plant, Da Nang, Vietnam. As illustrated in **Figure 3.1**, one of the two ASRs was composed of a primary settling tank, an aeration tank and a secondary settling tank (ASR#1) whilst the other was identical to ASR#1 except that no primary settling tank was equipped (ASR#2). All tanks had 22-litre of working volume with a conical cylinder shape. Each settling tank had a sludge scraper rotating at 1 rpm whilst each aeration tank had an air diffuser made of porous ceramic and a small blower (OP-N026D, Iwaki pumps co. ltd., Japan). Sludge return from the secondary settling tank to the aeration tank was controlled using an air-lift pump with a 0.5-inch PVC tube where a small amount of air was injected at the bottom of the tube from a blower (APN-057R, Iwaki pumps co. ltd., Japan).

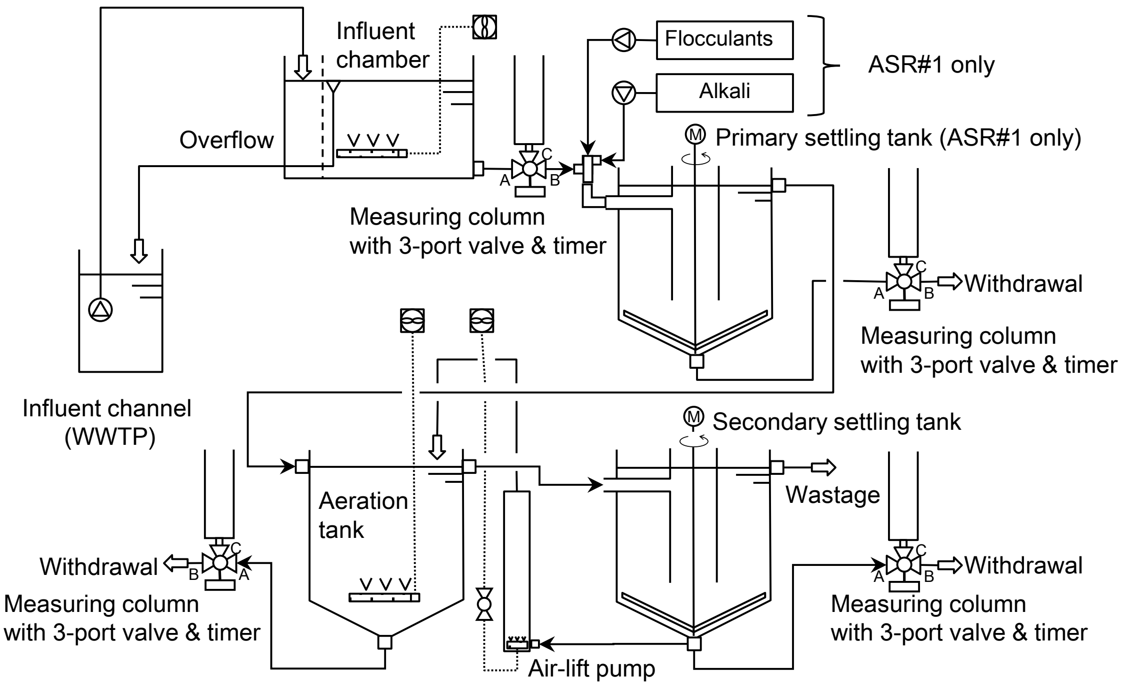


Figure 3.1 Schematic diagram of activated sludge reactors

The wastewater at Phu Loc WWTP was pumped with a submerged bilge pump (S-500LN, Terada pump co. ltd., Japan) at the downstream of the channel where the wastewater passed a course screen. The wastewater at about 30 L/min of flow rate was continuously transferred to a 50-L influent chamber positioned beyond the top of ASRs. The influent chamber was equipped with a fine screen followed by an aeration zone for mixing the liquid. The excess wastewater was overflown from a weir at the top of the influent chamber, and returned to the WWTP.

The bottom of the influent chamber was connected with a 2.5-L PVC measuring column via a 3-port motor valve (common-port, port-A (*normal close*) and port-B (*normal open*)) (EALB100-UTNE15A, Kitz co. ltd, Japan) which was intermittently activated by an on-off periodic timer (H3CA-A, OMRON co, ltd., Japan). During '*on*' event, the common-port was connected with the port-A, and the wastewater in the influent chamber was automatically filled in the measuring column until the wastewater reached the same water level as that of the influent chamber. Subsequently, during the '*off*', the common-port was rotated to connect with the port-B, and the wastewater in the measuring column was discharged to the ASRs and emptied by gravity. This set was periodically operated with a fixed interval at 10 min for '*on*' and 2 min for '*off*'. In similar manner, the primary sludge and excess activated sludge were withdrawn with corresponding measuring columns positioned at the side of reactor.

Operating conditions

The hydraulic loadings of the influent to both the ASRs were set at 134 L/d (hydraulic retention time of the aeration tank = 3.9 hrs) using the above mentioned apparatus. The sludge retention times of the ASRs were also identically controlled to be about 10 days. Inoculum activated sludge was obtained from a food processing factory nearby the WWTP.

For ASR#1, about 10 mg-Al/L of poly-aluminium chloride and 1 mg/L of anion coagulant (Organo corp., Japan) were dosed on the basis of influent flow to maximise the clarification of primary settling tank using an electro-magnet metering pump (EHN-B11, Iwaki pumps co. ltd., Japan) whilst small amount of NaOH solution was also added to neutralise the pH in the primary settling tank to be about 7.0. In this way the suspended solid (SS) concentration at the primary settling tank could be kept below 3-8 mg/L (data not shown). The dissolved oxygen (DO) concentration was also maintained between 5.5-7.0 mg-O_2/L in both the ASRs. The water temperature in the aeration tanks was ranged between 26 °C and 31.5 °C during the experimental period of 85 days. Although the pH in the aeration tank at ASR #2 was not controlled, it was kept between 6.9 and 7.2 throughout the experiment.

After about 1 month of a preliminary continuous operation, sampling of the activated sludge from the ASRs was initiated at about 7-10 day interval between September and December 2016. The effluent SS concentrations at the secondary settler of the ASRs were also regularly measured to catch the exact sludge retention time. Nevertheless, as the SS concentration for the both secondary settlers was acceptably low at the most of sampling events, this impact on the mass balance calculation was limited to be less than 10%.

Laboratory Analysis

About 1,000 mL of activated sludge samples was regularly collected from the ASRs at about 7-day interval. Using the samples, endogenous oxygen uptake rates (OUR_{e_OHO}) of ordinary heterotrophic organism (X_{OHO}) were measured. Each sample was placed in a flask and was kept aerated for a week in a batch mode at room temperature which was comparable to those of wastewater in ASRs. During the batch test, the pH of the samples was manually adjusted to about 7.0 using NaOH every day.

From the flasks, about 100 mL of the activated sludge was transferred daily to a Winkler bottle after adding 20 mg/L of allyl-thiourea to inhibit possible oxygen uptake by nitrification (*Friedrich 2017)*. In the air-tight condition and constant temperature at 26 °C with water bath, the reaction period to reach DO concentration from 7.0 mg-O_2/L to 1.0 mg-O_2/L was measured with a DO meter (TPX-1000, Toko chemicals, Japan). From the reaction period and the decrement of DO, a dataset of OUR_{e_OHO} for 6-8 days was obtained. Based on the decline of OUR_{e_OHO} along with the batch incubation time (6–8 OUR_{e_OHO} plots per batch test), specific decay rate of X_{OHO} (b_{OHO}) and the X_{OHO} concentration in the activated sludge were calculated according to the decay concept of ASM3 with **Eq. 3.1** (*Kappeler 1992 & Ramdani 2010*). Total 12 activated sludge samples of each ASR were examined during the field experiment.

$$\mathrm{OUR}_{\mathrm{e\_OHO}(t)} = (1 - f_U)\,\mathrm{b}_{\mathrm{OHO}} \cdot \mathrm{X}_{\mathrm{OHO}(0)} \cdot \exp(-\mathrm{b}_{\mathrm{OHO}} \cdot t) \qquad \textbf{Eq. 3.1}$$

Where, $OUR_{e\_OHO(t)}$: endogenous oxygen uptake rate of X_{HO} at the batch incubation time = t, f_U: production of unbiodegradable inert organic particulate (0.20 g-COD/g-COD, *Henze 2000*), b_{OHO}: specific endogenous decay rate of X_{OHO} (day^{-1}), $X_{OHO(0)}$: X_{OHO} concentration present in the ASR (mg-COD/L), t: batch incubation time (day)

To estimate autotrophic nitrifying organism concentration (X_{ANO}) from **Eq. 3.2** (*Makinia 2010*), nitrifier's maximum oxygen uptake rates (OUR_{max_ANO}) in ASRs were also regularly monitored with addition of ammonium nitrogen to be 50 mg-N/L. As X_{ANO} could not be separated from $\mu_{max\_ANO} \cdot X_{ANO}/Y_{ANO}$ unless μ_{max_ANO}/Y_{ANO} was determined, the kinetic parameter was adopted to be 4.17 mg-N/g-COD/day in 20 °C with a temperature coefficient θ= 1.07 according to Henze *et al.* (2000).

$$OUR_{max\_ANO} = \frac{\left(\frac{2 \times 32}{14}\right) - Y_{ANO}}{Y_{ANO}} \mu_{max\_ANO} \cdot X_{ANO} + (1 - f_U) b_{ANO} \cdot X_{ANO} \qquad \textbf{Eq.3.2}$$

Where, OUR_{max_ANO}: maximum oxygen uptake rate of X_{ANO}, μ_{max_ANO}: maximum specific growth rate of X_{ANO} (1.0 day^{-1} at 20 °C), Y_{ANO}: biomass yield coefficient for X_{ANO} (0.24 g-COD/g-N), b_{ANO}: endogenous oxygen uptake rate of X_{ANO} (0.15 day^{-1} at 20 °C), X_{ANO}: autotrophic nitrifying organism concentration (mg-COD/L).

3.2.2 Estimation of Constituents for Influent from Activated Sludge Biomass

Apart from X_{OHO} and X_{ANO}, 4 kinds of carbonaceous state variables (soluble biodegradable COD material (S_B), particulate hydrolysable biodegradable COD material (XC_B), biologically inert COD particulate material in the influent (X_I), and unbiodegradable COD particulate material built from biomass decay (X_U)), 2 kinds of nitrogenous state variables (particulate biodegradable nitrogen ($XC_{B\_org\ N}$) and soluble biodegradable nitrogen including ammonium-N (S_{B_N})) and inorganic particulate (X_{Ig})) were defined respectively in **Table 3.1** (*Corominas 2010*).

As illustrated in **Fig 3.2**, S_B concentration was estimated from the analysis of X_{OHO} collected from ASR#1 (with primary settling tank) based on the system condition (b_{OHO}, hydraulic retention time and sludge retention time). X_U concentrations were also determined from X_{OHO} and X_{ANO} and the system condition (b_{OHO}, b_{ANO}, hydraulic retention time and sludge retention time). X_I concentration was calculated from the COD-based activated sludge concentration (X_{total}) ($X_{total} = X_{OHO} + X_{ANO} + X_U + X_I$). XC_B was obtained from the increment of X_{OHO} between ASR#1 and ASR#2 (without primary settling tank). In similar manner, concentrations for $XC_{B\_org\ N}$, S_{B_N} and X_{Ig} were estimated respectively.

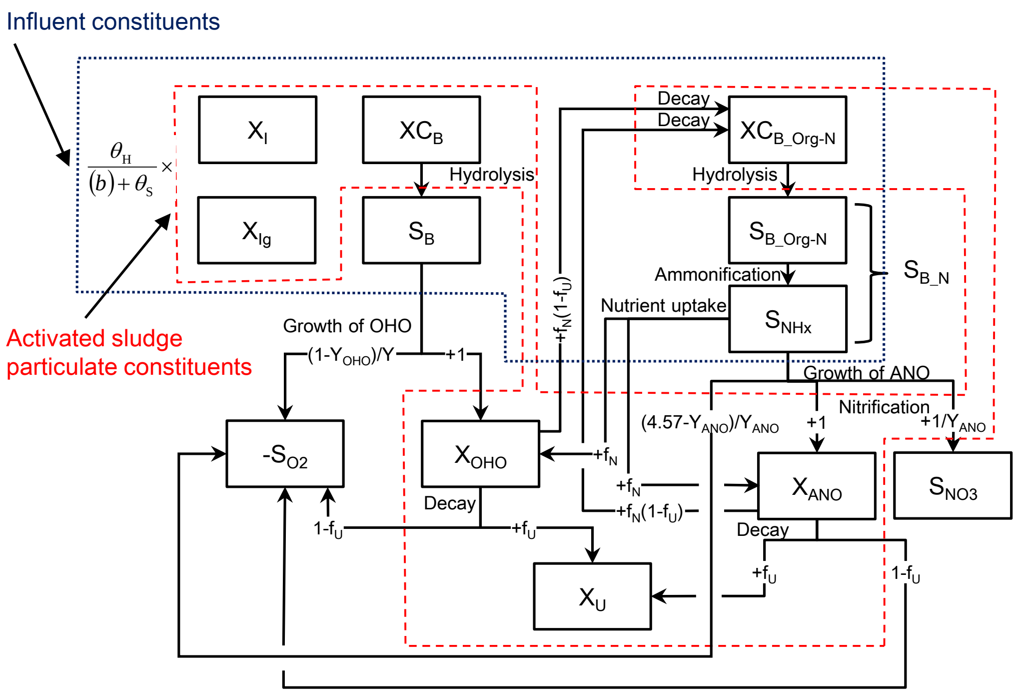


Figure 3.2 Fate of influent materials in the activated sludge process

Concentrations of MLSS, MLVSS and sludge COD were measured according to Standard method [11]. The dynamic simulation for MLSS and MLVSS concentrations was performed using the estimated influent concentration using a process simulator (GPS-X ver. 6.4, Hydromatis Inc., Canada).

Table 3.1 Gujer matrix for biological degradation of organics and nitrogenous compounds

Processes	Units	XC_B	S_B	X_{OHO}	X_{ANO}	S_{O2}	S_{NHx}	$S_{B\_org\ N}$	$XC_{B\_org\ N}$	X_U	X_I	X_{Ig}
Hydrolysis of particulate	g-COD/m³/d	-1	1									
Aerobic growth of heterotrophs	g-COD/m³/d		$-\frac{1}{Y_{OHO}}$	1		$-\frac{1-Y_{OHO}}{Y_{OHO}}$	$-f_N$					
Aerobic growth of autotrophs	g-COD/m³/d				1	$-\frac{4.57-Y_{ANO}}{Y_{ANO}}$	$-f_N-\frac{1}{Y_{ANO}}$					
Decay of heterotrophs	g-COD/m³/d			-1		$1-f_U$			$f_N(1-f_U)$	f_U		
Decay of nitrifiers	g-COD/m³/d				-1	$1-f_U$			$f_N(1-f_U)$	f_U		
Hydrolysis of particulate biodegradable nitrogen	g-N/m³/d							1	-1			
Ammonification of soluble organic nitrogen	g-N/m³/d						1	-1				
Stoichiometry [5, 12] Y_{OHO}: 0.66 g-COD/g-COD Y_{ANO}: 0.24 g-COD/g-N f_U: 0.20 g-COD/g-COD f_N: 0.086 g-N/g-COD		Particulate hydrolysable biodegradable COD material (mg-CO/L)	Soluble biodegradable COD material (mg-CO/L)	Ordinary heterotrophic microorganism (mg-COD/L)	Nitrifiers (mg-COD/L)	Dissolved oxygen (mg-O²/L)	Ammonium-nitrogen (mg-N/L)	Soluble biodegradable nitrogen (mg-N/L)	Particulate biodegradable nitrogen (mg-N/L)	Unbiodegradable COD particulate material built from biomass decay (mg-COD/L)	Biologically inert COD particulate material (mg-COD/L)	Inorganic particulate (mg/L)

3.3 Results and Discussion

3.3.1 Specific Decay Rate of Ordinary Heterotrophic Organisms

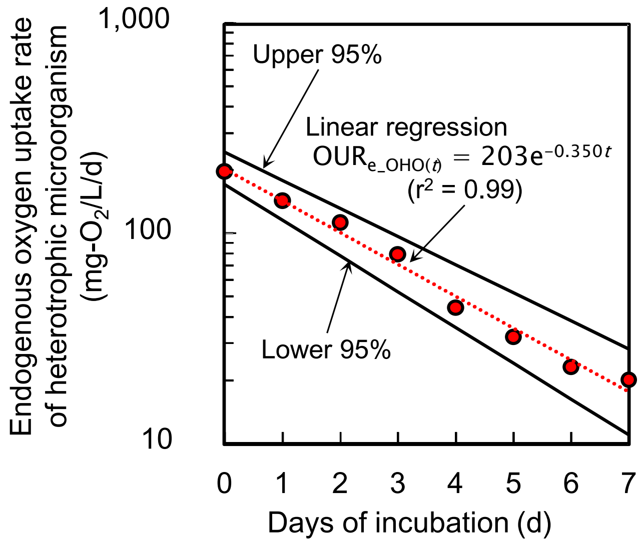


Figure 3.3 Example to estimate specific decay rate of ordinary heterotrophic organisms in the batch test (dataset #2_ASR#1, water temperature = 30.6 °C)

As shown in **Fig 3.3**, each $OUR_{e\_OHO(t)}$ at the daily measurement was almost lineally plotted with a reasonable correlation coefficient (r^2 = 0.99). However, the statistical analysis with 95% of confidence interval revealed that the probable slope and the probable intersection were present between 0.308-0.392 day^{-1} and 171-242 mg-O_2/L/day^{-1} respectively, which resulted in noticeable uncertainness to identify the parameters. Since appropriate b_{OHO} had to be selected in order to calculate $X_{OHO(0)}$ concentration, the 24 data sets for b_{OH} were plotted together with the range of the 95% of confidence interval after normalisation at 20 °C with a temperature coefficient θ= 1.07 (*Makinia 2010).*

As shown in **Figure 3.4**, b_{OHO} of both the ASRs seemed to be almost evenly scattered at around 0.13-0.21 day^{-1}. Based on this and assuming that b_{OHO} was a consistent kinetic parameter at the WWTP, the mean of the datasets, $b_{OHO(20°C)}$ = 0.171 day^{-1} was chosen for the analysis.

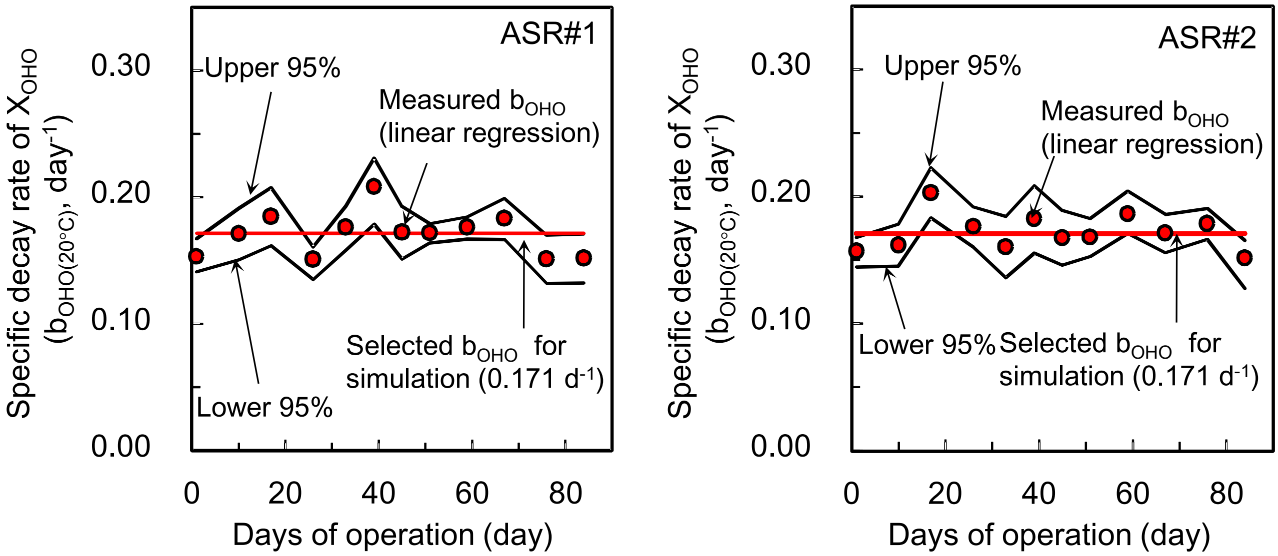


Figure 3.4 Specific decay rate of ordinary heterotrophic organism after normalisation into 20 °C (Left: ASR#1 (with primary settling tank), right: ASR#2 (without primary settling tank))

For further checking, a dimensionless $OUR_{e\_OHO(t)}$ (= $OUR_{e\_OHO(t)}/OUR_{e\_OHO(0)}$) was defined and compared to the calculated ones. As shown in **Figure 3.5**, the measured dimensionless $OUR_{e\_OHO(t)\_}$ plots of the 24 data sets were almost positioned on those calculated with the default b_{OHO} ($r^2 = 0.98$). Although plots within middle-low OUR_{e_OHO} were considerably scattered and the least-square regression gave slight mismatch ($Y = 1.03\ X$), this was attributed to the measurement error during the experiment caused by low oxygen uptake rate at the laboratory analysis.

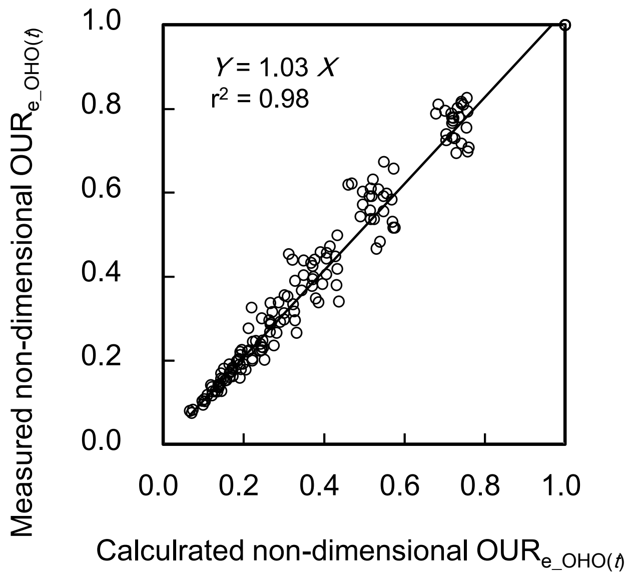


Figure 3.5 Plots of non-dimensional $OUR_{e\_OHO(t)}$

3.3.2 Ordinary Heterotrophic Organism Concentration in the Reactor

From the OUR_{e_OHO} and b_{OHO}, X_{OHO} concentrations in the activated sludge for ASR#1 and ASR#2 were obtained respectively. Due to the presence of particulate hydrolysable biodegradable COD materials (XC_B) in the influent of ASR#2 (without primary settling tank), slightly high X_{OHO} concentration was recognised in ASR#2 during the period comparing to that in ASR#1 (without primary settling tank). Both X_{OHO} concentrations in ASRs were slightly fluctuated along with time indicating that the influent biodegradable organic concentrations were also fluctuated.

Next, the process rate for X_{OHO} in the ASRs (dX_{OHO}/dt) was expressed by **Eq. 3.3**. For simplification, this was rewritten as **Eq. 3.4** by neglecting the effluent substrate concentrations. Here, as two X_{OHO} concentrations ($X_{OHO(m)}$ and $X_{OHO(l)}$) at different time (m and l) were measured from the OUR analysis, by inputting these state variables into the equation, XC_{B_inf} and S_{B_inf} at time = m could be estimated.

$$\frac{d\,X_{OHO}}{dt} = \theta_H\, Y_{OHO}\left(\left(XC_{B\_inf} - XC_{B\_eff}\right) + \left(S_{B\_inf} - S_{B\_eff}\right)\right) - \left(\theta_S + b_{OHO}\right) X_{OHO} \qquad \textbf{Eq. 3.3}$$

Where, θ_H: reciprocal hydraulic retention time (day^{-1}), θ_S: reciprocal sludge retention time (day^{-1}), Y_{OHO}: X_{OHO} yield coefficient (0.66 g-COD/g-COD), suffix inf: influent, suffix eff: effluent.

$$\begin{aligned} XC_{B\_inf(m)} + S_{inf(m)} &\cong \frac{\left(\theta_S + b_{OHO}\right)}{\theta_H}\frac{1}{Y_{OHO}} X_{OHO(m)} + \frac{1}{\theta_H}\frac{1}{Y_{OHO}}\frac{d\,X_{OHO}}{dt} \\ &\approx \frac{\left(\theta_S + b_{OHO}\right)}{\theta_H}\frac{1}{Y_{OHO}} X_{OHO(m)} + \frac{1}{\theta_H}\frac{1}{Y_{OHO}}\left(\frac{X_{OHO(m)} - X_{OHO(l)}}{m - l}\right) \end{aligned} \qquad \textbf{Eq. 3.4}$$

Where, $XC_{B\_inf(m)}$: Influent XC_B concentration at time = m (mg-COD/L), $S_{B\_inf(m)}$: Influent S_B concentration at time = m (mg-COD/L), $X_{OHO(m)}$: X_{OHO} concentration at time = m (mg-COD/L), m and l : time (day) ($m \geq l$).

However, when $X_{OHO(m)} \neq X_{OHO(n)}$, it was noted that the second term (dX_{OHO}/dt) of **Eq. 3.4** could not reach zero even at large time step ($m>>l$) . This would result in slight overestimation and/or underestimation of XC_{B_inf} and S_{B_inf} under steady-state condition. To damp the response, an additional switching function ($0 \leq f \leq 1$) was elaborated and applied as shown in **Eq. 3.5.** When the time step was large enough comparing to the sludge retention time, the switching function could almost eliminate the second term (*e.g.* if the time step (m-l) was as much as 3 times of the sludge retention time, $f = e^{-3} \approx 0.05$). In this way, the influent substrate concentrations were modelled to be changed in a step-wise manner at every time step (e.g. between day l and day m, $S_{inf} = S_{inf(m)}$, between day m and day n, $S_{inf} = S_{inf(n)}$…). This concept was also applied to the estimation of influent biodegradable nitrogen.

$$\begin{cases} XC_{B\_inf(m)} + S_{inf(m)} \cong \dfrac{(\theta_S + b_{OHO})}{\theta_H} \dfrac{1}{Y_{OHO}} X_{OHO(m)} + \dfrac{1}{\theta_H} \dfrac{1}{Y_{OHO}} \left(\dfrac{X_{OHO(m)} - X_{OHO(l)}}{m-l} \right) \times f \\ f = \exp(-\theta_S \times (m-l)) \end{cases} \quad \textbf{Eq. 3.5}$$

Based on the set of estimated influent substrates, concentrations of X_{OHO} in ASR#1 and those in ASR#2 were calculated under dynamic condition. As shown in **Fig. 3.6**, the estimated influent substrate concentrations could fairly reproduce the measured X_{OHO} concentrations obtained from OUR_{e_OHO}.

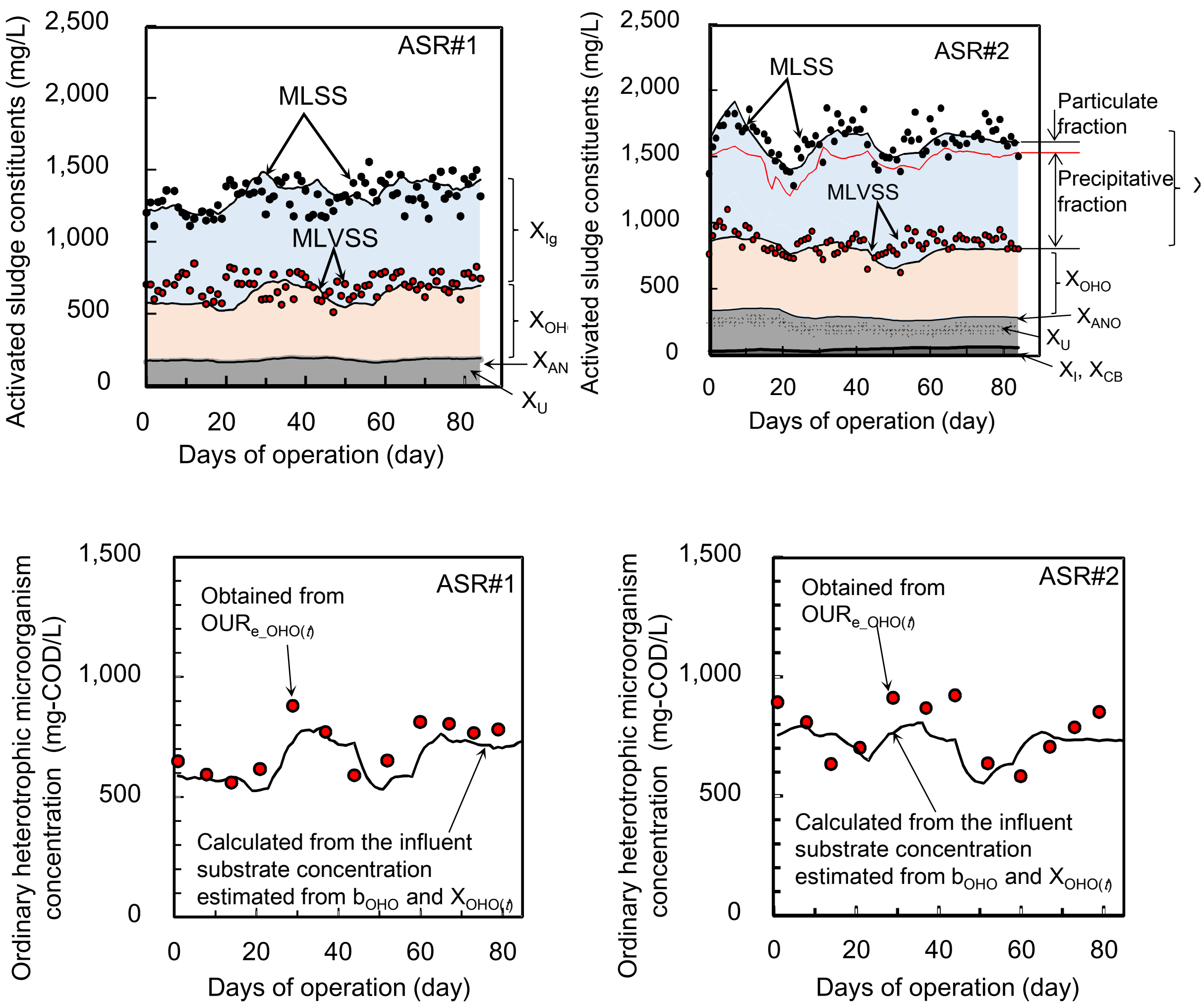


Figure 3.6 Ordinary heterotrophic organism concentration in the activated sludge

(Left: ASR#1 (with primary settling tank), right: ASR#2 (without primary settling tank))

3.3.3 Influent constituents

From the above development, the influent state variables (XC_B, S_B, X_I, X_{Ig}, $XC_{B\_org\ N}$, S_{B_N}) were calculated and used for the dynamic simulation to express MLSS and MLVSS concentrations in the ASRs. As shown in **Fig. 3.7**, the calculated MLSS and MLVSS concentrations and those measured reasonably matched except underestimation of MLVSS concentrations between day 0 and day 20 in ASR#1. Although the exact reason of mismatch was not clear, it was speculated that high inorganic volatile materials (*e.g.* carbonate) might be present during the event.

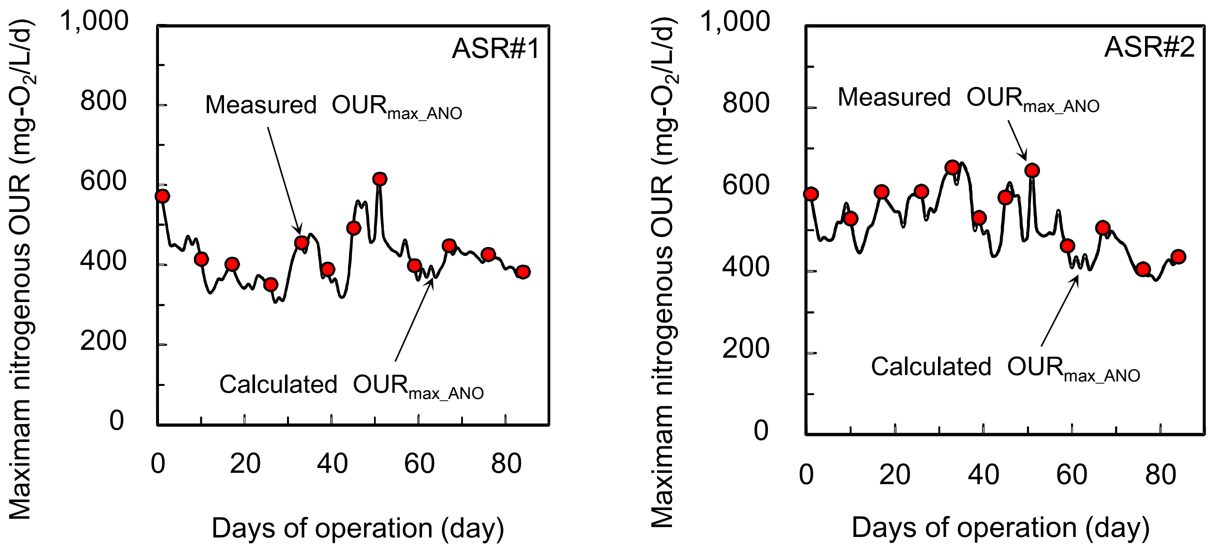


Figure 3.7 Activated sludge constituents (top) and maximum nitrogenous oxygen uptake rate (bottom)

(Left: ASR#1 (with primary settling tank, right: ASR#2 (without primary settling tank))

It appeared that X_{OHO} and X_U fractions corresponded to about 60 % and 40% of MLVSS concentration respectively whilst the fractions for X_{ANO}, X_I and XC_B were of very minor. The inorganic fraction of the activated sludge for ASR#1 (with primary settling tank) was modelled to be a consequence of uptake and/or precipitation of soluble inorganics for the biomass growth (*e.g.* uptake of phosphate, precipitation of calcium, *etc.*).

With respect to the influent nitrogenous substrate concentration, the OUR_{max_ANO} was also acceptably simulated. However, as the OUR_{max_ANO} was almost given from the product of the kinetic parameter (μ_{max_ANO}) and the state variable (X_{ANO}) as well as the stoichiometric parameter (Y_{ANO}), assumption of high/low μ_{max_ANO} reduced the accuracy of influent estimation. For instance, when high μ_{max_ANO} was assumed, correspondingly low X_{ANO} was obtained. This resulted in underestimation of the influent concentration. This uncertainness would affect process design, especially for blower capacity (oxygenation for nitrification). Therefore, a measurement of μ_{max_ANO} should be carried out when nitrification was in a scope of the project.

From the dynamic simulation, the state variables were converted to the conventional water quality indices (*Hydromantis 2014*), and listed in **Table 3.2**. The influent of the WWTP contained about 6.3 mg/L of SS, 2.2 mg/L of VSS, 45.3 mg/L of C-BOD_5, 44.1 mg/L of soluble C-BOD_5. When $\mu_{max\_ANO(20°C)}$ = 1.0 day^{-1} was assumed, 1.1 mg-N/L of particulate biodegradable nitrogen and 4.3 mg-N/L of particulate biodegradable nitrogen were estimated respectively. Comparing to typical wastewater constituents in the countries having no septic tank *(Tchobanoglous 2012 & CH2M 1996)*, noticeably low VSS and C-BOD_5 were obtained, which was in lower range of the filed monitoring by Nguyen 2013 (BOD_5: 30-140 mg/L, SS: 27-200 mg/L and Total nitrogen: 11-40 mg-N/L). This suggested that considerable amount of organics discharged from the households were digested in the septic tanks, and/or a lot of groundwater penetrated into the sewer in the city.

Table 3.2 List of estimated influent material concentrations at Phu Loc WWTP, Vietnam

Time step #	1	2	3	4	5	6	7	8	9	10	11	12	85-day average
Days of operation (day)	1-7	8-14	15-21	22-28	29-35	36-42	43-49	50-57	58-64	65-72	73-79	80-85	0-85
Composite variables													
SS (mg/L)	9.0	5.4	7.6	2.3	5.2	5.3	7.7	8.7	5.6	4.3	6.9	7.0	6.3
= VSS + X_{Ig} (including precipitants)													
VSS (mg/L)	5.0	2.4	1.1	0.3	2.7	1.7	2.9	3.1	1.1	1.3	2.6	2.0	2.2
= $f_{vss/cod} \cdot X_{tot}$													
Carbonaceous BOD_5 (mg/L)	47.0	43.2	40.8	52.0	52.5	45.9	33.0	40.9	49.4	46.7	46.7	46.0	45.3
= $f_{bod\_5\_tot/xcb} \cdot XC_B + f_{bod\_5\_sol/sb} \cdot S_B$													
Soluble carbonaceous BOD_5 (mg/L)	43.0	41.8	40.2	52.0	51.1	45.2	31.3	39.1	49.1	46.7	45.3	45.0	44.1
= $f_{bod\_5\_sol/sb} \cdot S_B$													
Carbonaceous BOD_{30} (mg/L)	57.7	52.4	49.3	62.6	63.6	55.5	40.2	49.7	59.5	56.3	56.6	55.7	54.9
= $f_{bod\_u/cod\_bio} \cdot (XC_B + \cdot S_B) \cdot$													
Soluble carbonaceous BOD_{30} (mg/L)	51.8	50.3	48.3	62.6	61.4	54.4	37.7	47.1	59.1	56.2	54.5	54.2	53.1
= $f_{bod\_u/cod\_bio} \cdot S_B$													
State variables													

Table 3.2 List of estimated influent material concentrations at Phu Loc WWTP, Vietnam

Soluble biodegradable organics (S_B) (mg-COD/L)	60.0	58.3	56.0	72.5	71.2	63.0	43.7	54.6	68.5	65.1	63.2	62.8	61.6
Particulate hydrolysable biodegradable organics (XC_B) (mg-COD/L)	6.9	2.4	1.1	0.0	2.4	1.3	2.9	3.0	0.5	0.1	2.4	1.7	2.1
Particulate inert organics (X_I) (mg-COD/L)	0.6	1.2	0.5	0.5	1.6	1.2	1.4	1.6	1.2	1.8	1.5	1.3	1.2
Soluble biodegradable nitrogen including NH_x (S_{B_N})♣ (mg-N/L)	4.2	3.6	3.9	5.1	3.6	4.7	3.9	4.3	4.4	4.1	4.2	5.1	4.3
Particulate biodegradable nitrogen ($XC_{B\_org\ N}$)♣ (mg-N/L)	0.9	1.1	2.3	1.8	1.4	0.6	1.1	0.5	0.8	0.0	1.3	1.2	1.1
Inorganic particulates including precipitants (X_{Ig}) (mg/L)	16.0	12.0	20.0	18.0	10.0	17.0	14.8	14.5	16.6	15.3	14.3	15.7	15.4
Inorganic particulates excluding precipitants (X_{Ig}) (mg/L)	4.0	3.0	6.5	2.0	2.5	3.6	4.8	5.6	4.5	3.0	4.3	5.0	4.1

$f_{vss/cod}'$ = 0.671, $f_{bod\_5\_tot/xcb}'$ = 0.580, , $f_{bod\_5\_sol/sb}$ = 0.717, f_{bod_u/cod_bio} = 0.863 [12]

♣ Assuming Y_{ANO} = 0.24 g-COD/g-N, μ_{max_ANO} = 1.0 day^{-1}, b_{ANO} = 0.15 day^{-1} [5]

3.3.4 Sampling and Monitoring Frequencies

Since the batch test to measure OUR_{e_OHO} was one of the labour-consuming experiments, minimal sampling frequency from ASRs was elaborated in a statistic manner. Using Bootstrap method (Monte Carlo method), 2~6 samples of b_{OHO} were randomly chosen from the original datasets (12 b_{OHO}) with 1,000 trials, and each subset was averaged. As shown in **Fig. 3.9**, the 25~75 percentile of mean subset b_{OHO} for the 6-sample was ranged between 98 and 104% of the original (0.167~0.177 day^{-1} vs. 0.170 day^{-1}) whilst the 5~95 percentile ranged between 92 and 109% (0.157~0.186 day^{-1}). For the 4-sample, slightly higher variation was obtained than those of the 6-sample (95~105% in 25~75 percentile, 89~114% in 5~95 percentile). On the other hand, it appeared that the median and the mean unmatched when 2~3 b_{OHO} samples were chosen. In case of the 2-sample, 0.157 day^{-1} of median was created whereas 0.170 day^{-1} of mean was obtained. This was because the small datasets had an asymmetric shape against ideal Gaussian distribution (12 b_{OHO} vs. numerous number of samples).

Therefore, it was thought that activated sludge sampling should be conducted at least 4~6 frequencies per field experiment in order to obtain acceptable mean b_{OHO}. When a criterion of variation per the mean was defined to be between 90 and 110% in 5~95 percentile, 6 frequencies would be relevant rather than 4 frequencies. In this case, even if the maximum mean subset b_{OHO} ($b_{OHO\_mean\ subset,\ min}$ = 0.195 day^{-1}) was given to the calculation, this would give a limited underestimation of X_{OHO} to be less than 9% at 10-day sludge retention time (θ_S = 0.1 day^{-1}) (= (θ_S + $b_{OHO\_mean\ subset,\ min}$) / ($\theta_S$ + b_{OHO}) = 0.915). Similarly in case of the minimum mean subset b_{OHO} ($b_{OHO\_maen\ subset,\ max}$ = 0.153 day^{-1}), this gave an overestimation by only 7%.

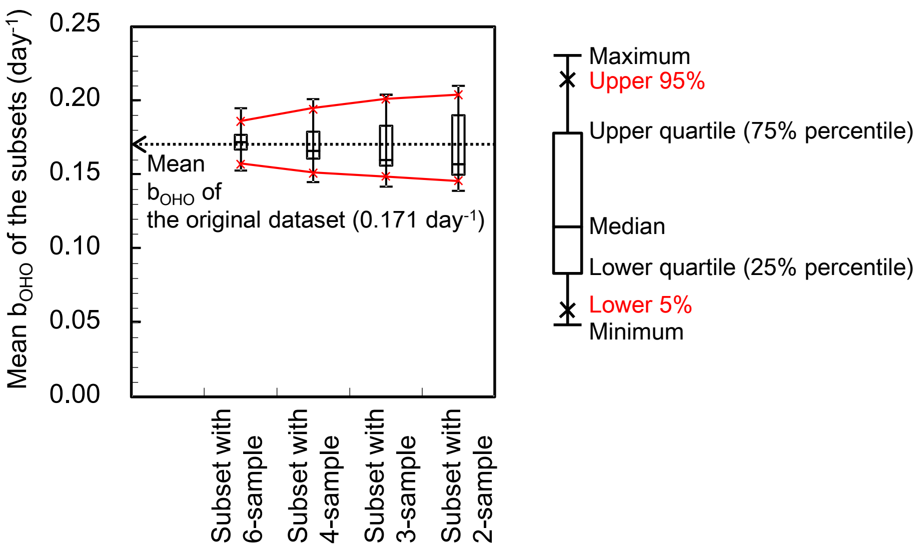


Figure 3.8 Box-and-whisker plot for specific decay rate against sampling frequency

Based on the above, the working load of the developed method was compared to that of the conventional on-site water-sampling as listed in **Table 3.3**. For the conventional method, CH2M Hill Engineering ltd. and Hydromantis Inc. (1996) recommended to install an auto-sampler equipped with refrigerator when on-site water sampling was performed (*Tran 2015*). Because of corruptible organics in the influent, the audit manual pointed out that the storage period in the refrigerator could not last 2-3 days and hence the water samples should be immediately delivered to to laboratories. In fact, total organic carbon concentration in the municipal wastewater was decreased by 20-30% after 2-day storage at 4 °C (data not shown). Therefore, in practice daily sampling might be required even availability of 1-day delivering service at the field testing site. Furthermore, the conventional method required a number of analytical items for SS, VSS, C-BOD_{30}, soluble C-BOD_{30}, COD and soluble COD in order to catch biodegradable organic compounds whilst N-BOD_{30} and soluble N-BOD_{30} were needed for biodegradable nitrogen compounds (total 8 analytical items). This corresponded to 480 analyses if daily sampling was conducted for 60 days.

Table 3.3 List for measuring biodegradable influent material concentrations

Items	This study	Conventional method
Sampling and analytical material	Activated sludge	Wastewater
On-site experimental apparatus	Activated sludge reactors (2 units)	Auto-sampler equipped with refrigerator (1 unit)
Sampling and monitoring frequencies	6 times/test period	Every day in case of 2-day delivery of the sample to labs
Analysis for biodegradable organic compounds	OUR_{e_OHO}, particulate COD and ash fraction (= MLSS-MLVSS)	SS, VSS, C-BOD_{30}, soluble C-BOD_{30}, COD and soluble COD
Analysis for biodegradable nitrogen compounds	OUR_{max_ANO} and maximum specific growth rate of nitrifiers	N-BOD_{30} and soluble N-BOD_{30}
Duration of the test	30 days for start-up + net evaluation period	Net evaluation period + 30 days for incubation of BOD_{30}

On the other hand, the method developed in this study required only OUR_{e_OHO}, OUR_{max_ANO}, particulate COD and ash fraction (=MLSS-MLVSS) of the activated sludge in 2 ASRs (total 10 analytical items) with 6 sampling frequencies. In case of 60-day on-site experiment, total 60 analyses were needed, which was 1/8 of the conventional working load. In addition, because of simple experimental procedures for OUR and COD unlike BOD, the work might be carried out at on-site if quick sample delivery to the laboratory was practically difficult. In this case, as the chronological deterioration of activated sludge was believed to be low comparing to wastewater, the analysis of ash fraction could be conducted using unfresh samples, and hence this would not be problematic.

It was also noted that the limited number of sampling could not detect hourly-daily peak loads of the pollutants entering into the WWTP. In order to detect such short-term fluctuation, the DO concentration in the aeration tank would provide attractive technical information. Although continuous DO monitoring was not conducted in this study, the average DO concentration in the aeration tank was thought to correspond to the estimated average biodegradable influent load. Therefore, focusing on fluctuation of DO concentration, the fluctuation of influent load could be also calculated.

With respect to the total period of evaluation, the developed method required a start-up phase to acclimate the inoculum activated sludge to the experimental site. Assuming that as much as 3 times of sludge retention time was needed for the purpose, and the sludge retention time was set at 10-day, about 30 days should be spent until initiation of the on-site sampling. For the conventional method, additional 30 days should be also needed to measure BOD_{30} of the last sample collected from the experimental site.

In addition to the small working load, it was pronounced that the back-calculation approach allowed enabling various simulations on the ASM platform to assess other possible biological processes in interest (*e.g.* evaluation of trickling filter performance instead of the activated sludge process) (*NDQ Chanh, 2016*).

3.4 Conclusions

A back-calculation of wastewater concentrations from activated sludge constituents was evaluated using a set of lab-scale on-site activated sludge reactors (with and without primary settling tank) and IWA Activated Sludge Model. Following results were obtained in this study.

(1) From the regular monitoring of the endogenous oxygen uptake rate and COD analysis, the influent state variable concentrations for biodegradable organics and biodegradable nitrogenous materials were estimated. The estimated influent load could dynamically simulate the MLSS and MLVSS concentrations in the activated sludge reactors throughout the continuous operation for 90 days.

(2) The statistical analysis using Monte Carlo method indicated that at least 6 samples had to be collected from each reactor to obtain acceptable mean specific decay rate of the active biomass. When the sampling frequency was reduced to less than four per field test, noticeable statistical error was observed.

(3) The developed method to estimate the influent concentrations required total 60 analytical items per field test including oxygen uptake rates, COD MLSS and MLVSS. Comparing to the conventional water analysis, the method enabled to reduce the analytical items by about 80% when 2- month field analysis was conducted.

Chapter 4: Comparative Analysis for Influent Parameter Estimation

4.1 Development of Back-calculation Methods

In Chapter 3, the results of influent concentration was identified by using the equation that connects the input component to sludge concentration. These originated from equation 3.3, it was process rate of ordinary heterotrophic biomass insides the reactors along time

$$\frac{d\,X_{OHO}}{dt} = \theta_H\ Y_{OHO}\left(\left(XC_{B\_inf} - XC_{B\_eff}\right) + \left(S_{B\_inf} - S_{B\_eff}\right)\right) - \left(\theta_S + b_{OHO}\right)X_{OHO} \qquad \textbf{Eq. 3.3}$$

Where, θ_H: reciprocal hydraulic retention time (day^{-1}), θ_S: reciprocal sludge retention time (day^{-1}), Y_{OHO}: X_{OHO} yield coefficient (0.66 g-COD/g-COD), suffix inf: influent, suffix eff: effluent

Then, by neglecting the effluent substrate concentration (in condition of well-operation of AS process), this equation was simplified and rewritten as Equation 3.4. The substrate concentration XC_{B_inf} and S_{B_inf} at time = m could be estimated from function of 2 part. The 1st part is depended on variant SRT, HRT, sludge yield Y and X_{OHO} at the time m. The 2nd one shows the fluctuation from $X_{OHO(m)}$ and $X_{OHO(l)}$ at different time (m and l), all were measured from the OUR analysis.

$$\begin{aligned} XC_{B\_inf(m)} + S_{inf(m)} &\cong \frac{\left(\theta_S + b_{OHO}\right)}{\theta_H}\frac{1}{Y_{OHO}}X_{OHO(m)} + \frac{1}{\theta_H}\frac{1}{Y_{OHO}}\frac{d\,X_{OHO}}{dt} \\ &\approx \frac{\left(\theta_S + b_{OHO}\right)}{\theta_H}\frac{1}{Y_{OHO}}X_{OHO(m)} + \frac{1}{\theta_H}\frac{1}{Y_{OHO}}\left(\frac{X_{OHO(m)} - X_{OHO(l)}}{m - l}\right) \end{aligned} \qquad \textbf{Eq. 3.4}$$

Where, $XC_{B\_inf(m)}$: Influent XC_B concentration at time = m (mg-COD/L), $S_{B\_inf(m)}$: Influent S_B concentration at time = m (mg-COD/L), $X_{OHO(m)}$: X_{OHO} concentration at time = m (mg-COD/L), m and l : time (day) ($m \geq l$).

However, in long interval time (m>>l), the concentration X_{OHO} do not change much (steady-state condition) so that it require the deviation variable to solve this matter. An function $f=exp[-\Theta_s(m-l)]$ was added in 2nd term of Eq. 3.4 to become Eq. 3.5 as follow

$$\begin{cases} XC_{B\_inf(m)} + S_{inf(m)} \cong \dfrac{(\theta_S + b_{OHO})}{\theta_H} \dfrac{1}{Y_{OHO}} X_{OHO(m)} + \dfrac{1}{\theta_H} \dfrac{1}{Y_{OHO}} \left(\dfrac{X_{OHO(m)} - X_{OHO(l)}}{m - l} \right) \times f \\ f = \exp\left(-\theta_S \times (m - l)\right) \end{cases} \quad \textbf{Eq. 3.5}$$

In case of long-term interval or long period of batch test (5, 7 days), the f variable could eliminate the effect from 2nd term and through that way, the influent substrate concentrations were modelled to be changed in a step-wise manner at every time step (e.g. between day l and day m, $S_{inf} = S_{inf(m)}$, between day m and day n, $S_{inf} = S_{inf(n)}$…).

To assess the reliability of achieved results, the simulations of ASRs were conducted with these input (same other parameters and conditions) and the results of mixed liquor suspended solid were presented with measured dataset. In figure 4.1, the simulation results of input data from Eq . 3.4 & 3.5 were shown.

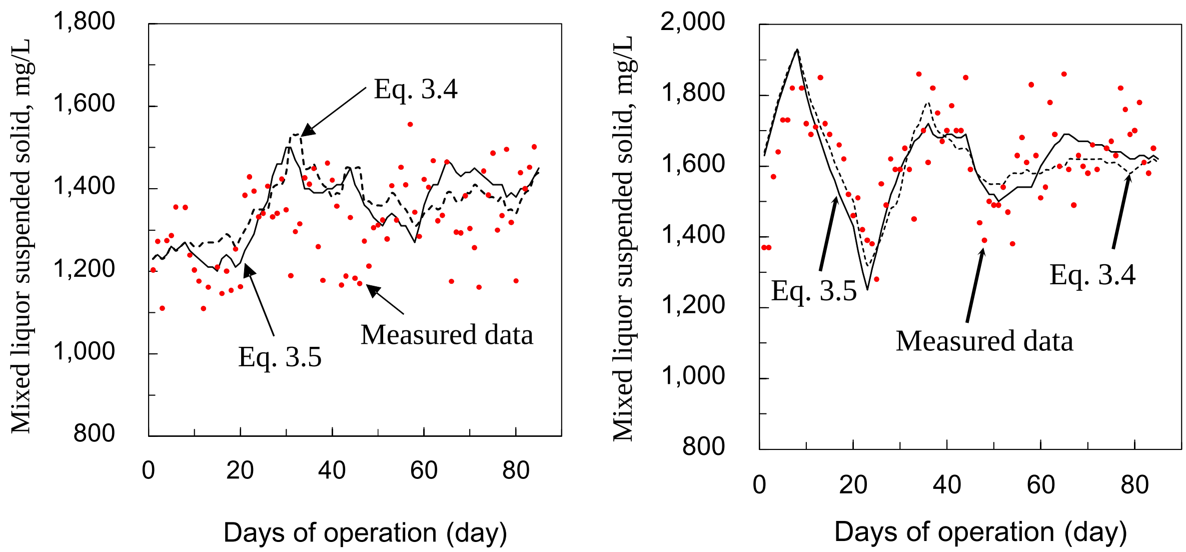


Figure 4.1 Compare simulation results of Equation 3.4 & 3.5 calculation for ASR#, ASR#2

Both of 2 simulated curves were close and trendy with observed dataset, but data achieved from Eq. 3.5 met closer. For the detail, the correlation factor between 2 simulated dataset and measure one were calculated with ASR#1 was 32% and 38% for Eq. 3.4 and 3.5 results respectively. Similar correlation results for ASR#2 was 0.57 & 0.61. It also conclude that the modified in Equation 3.5 with deviation variable was suitable in determining the influent substrate.

4.2 Estimate Influent characteristics through Dynamic Parameter Estimator (DPE)

4.2.1 Introduction

The classical optimization techniques are useful in finding the optimum solution or unconstrained maxima or minima of continuous and differentiable functions. These are analytical methods and make use of differential calculus in locating the optimum solution

GPS-X is the powerful simulator software, developed by Hydromantic Co., and used widely to demonstrate the waste process as well as design tool. Beside the main function of dynamic simulation of wastewater treatment processes, it provide the interesting modules to estimate the input parameter by optimizing the simulated results with observed dataset. With many of the dynamic models used in GPS-X most of the model parameters are assumed to be constant over the entire calibration period. For example, the clarifier's flocculent zone settling parameter is normally set to one specific value for the entire simulation. One reason for doing so is that it is difficult to determine or identify the changes in this parameter over time since it is difficult to measure on-line. The best the modeler can do is assume that the parameter doesn't change over the simulation period, and therefore use only one value to fit the target or measured data.

Optimization involves adjusting certain model parameters to maximize or minimize an objective function. The GPS-X optimizer can be used to fit a model to measured data or to optimize process performance. The procedure of fitting a model to measured data is called “parameter estimation” and involves adjusting selected model parameters to achieve the best possible fit between the model responses and the measured data. Parameter estimation is an important step in preparation of a simulation model because process parameters can vary significantly from plant to plant. A model that has been fitted to actual plant data will be more useful for predicting actual plant behavior. Process optimization involves adjusting certain model parameters to maximize or minimize the value of a model variable or a user-defined variable. For example, you may wish to adjust certain model parameters to minimize a plant's operating cost. The GPS-X optimizer module was developed specifically to solve parameter estimation and process optimization problems involving dynamic wastewater treatment models. It can be used for both steady-state and dynamic optimization. As will be seen in this chapter, the optimizer is a valuable tool for preparing effective models of wastewater treatment facilities.

Simulator optimization can be used for process design and plant optimization. Consider the problem of finding a plant design that meets certain effluent requirements. Another example is finding the best operating mode to reduce the loss of suspended solids during a plant upset. In both cases, there is a desired output, namely the design that meets the effluent limits and the best operating mode. If you have a model of the system, these objectives are achieved by varying plant design or operational parameters and observing the response of the model outputs

The optimizer module is equipped to handle three different types of process measurements: Time series measurements, Long term operational data that are averages of the original process measurements, and on-line measurements. Each type of measurement set leads to a different type of optimization problem in GPS-X. The optimization problem types available in GPS-X are: Time Series, Probability, and DPE

Dynamic parameter estimation is useful for estimating parameters in poorly understood processes. In these cases the model structure is likely to be incorrect. As a result, the model may only be able to represent the data well over short time intervals. In this case, using DPE will help compensate for the model error and allow acceptable fitting of the measured data.

So, in the case of identifying the wastewater characteristics in relation with sludge concentration, DPE is useful when the detecting process changes and upset. For instant, a composite parameter of influent which was found to be relatively constant during normal process operation of sludge concentration in ASP so it can be tracked by using the DPE feature and the dynamic observed datasets. And DPE (Dynamic Parameter Estimator) module of GPS-X can be used to solve this matter.

4.2.2 Method

In the study case of identifying the influent characteristics, the DPE was used with the dataset collected from experimental pilot. In order to catch the influent characteristics, the target parameter, active heterotrophic biomass (X_{BH}, mgCOD/L) was selected to optimized with the calculated values (from calculation topic). The biodegradable substrate S_S (mgCOD/L) was optimized with following conditions:

- Parameter tolerance: 0.01

- Maximum number of optimizer iterations: 100

- DPE time window varied from 7 days, 14 days, 21 days and 90 days (Due to the batch test period of 5-7 days/batch for measured dataset).

4.2.3 Results

Influent estimation by DPE

By using DPE module of GPS-X software, the biodegradable substrate (S_B, mgCOD/L was optimized to catch up the observed target of heterotrophic biomass (X_{BH}, mgCOD/L) with the time step varied from 1 day, 4 days, 7 days, 14 days, 21 days and 90 days. The results was shown in Figure 4.8 as follow.

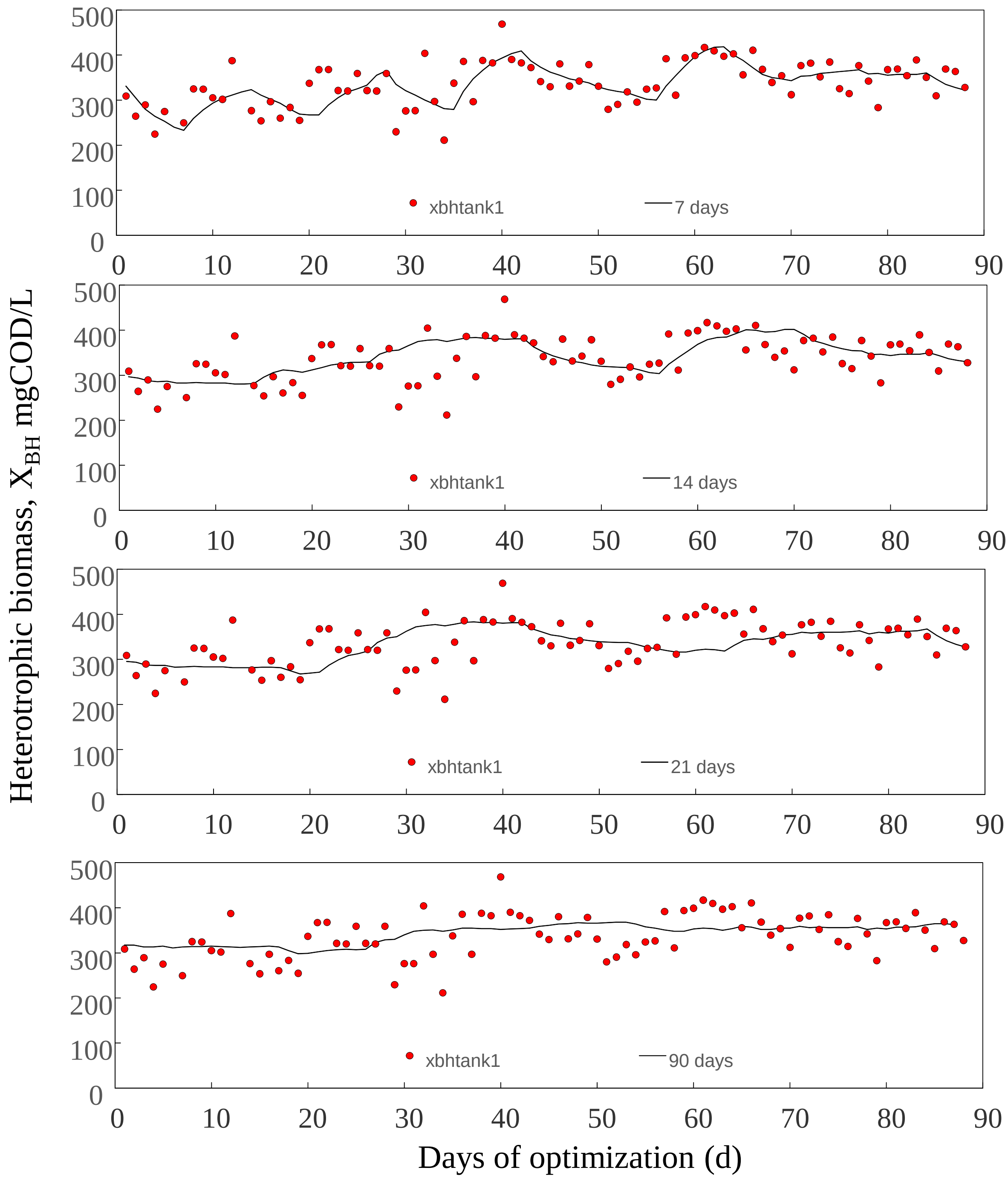


Figure 4.2 DPE results for targer parameter, Heterotrophic biomass X_{BH}

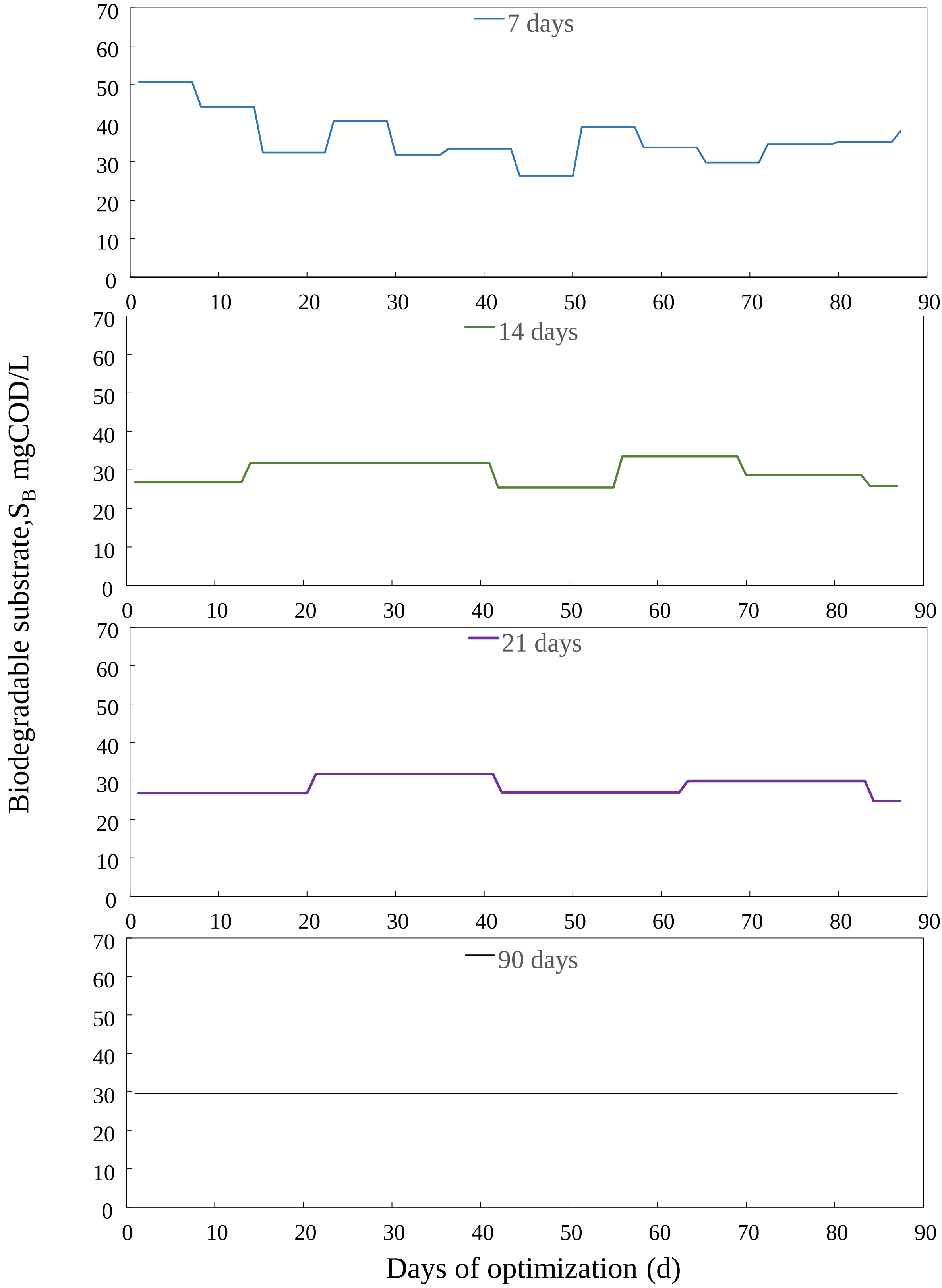


Figure 4.3 DPE results for estimating influent substrate, S_S (mgCOD/L)

It was clear that within short step (1-7 days), the closer simulated curves to observed value (X_{BH}), the more scatter optimized values (S_B) were. In the longer step, the value of SS did not vary much and with the 90-days step (equal to optimization day), it was average value. However, all the curve have similar "shape" to target dataset and they were different in their correlation,

Table 4.1 show the correlation aspect between observed dataset and optimized dataset of X_{BH} (mgCOD/L) following the equation 4.1

$$Correlation(x, \mathrm{y}) = \frac{\sum((x_i - \bar{x})(\mathrm{y}_i - \bar{y}))}{\sqrt{\sum(x_i - \bar{x})^2 \sum(\mathrm{y}_i - \bar{y})^2}} \qquad \text{(Eq. 4.1)}$$

Table 4.1. The correlation of different time step DPE with observed dataset X_{BH}

Correlation factor, r^2			
7 days	***14 days***	***21 days***	***90 days***
0.64	0.50	0.35	0.40

Both kind of variation assessment showed that the more different of SS would lead to more different in X_{BH}. However, in step of 4-days and 7-days, both results brought out that they are could be the acceptable value (in the middle range) for DPE process. It also showed the similar variation of 4-days and 7-days step so that these kinds DPE time step can be reliable parameter.

Table 4.2 shows the detail values along time of soluble substrate S_S (mgCOD/L) from various calculations.

Table 4.2 Compare estimated and DPE influent biodegradable concentrations at Phu Loc WWTP, Vietnam

Days of operation (day)	1-7	8-14	15-21	22-28	29-35	36-42	43-49	50-57	58-64	65-72	73-79	80-85
Calculation method Equation 3.4	60.0	59.6	60.7	62.5	79.2	61.0	47	56	61.5	62	61.1	64
Calculation method Equation 3.5	60.0	58.3	56.0	72.5	71.2	63.0	43.7	54.6	68.5	65.1	63.2	62.8
DPE 7-days	59	58.6	47.8	61.6	56.2	50.3	42.1	61.7	58.7	52.1	52.2	51.9
DPE 14-days	26.8	26.8	31.8	31.8	31.8	31.8	25.4	25.4	33.5	33.5	28.6	28.6
DPE 21-days	26.8	26.8	26.8	31.8	31.8	31.8	27	27	27	30	30	30
DPE 90-days	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6

4.3 Estimation Results Comparison

The calculated results from Equation 3.4 and 3.5 as well as from optimized tool were compared in Table 4.2. DPE with 4-days and 7-days step were chosen due to the results in above topic.

In Figure 4.4, the same results of MLSS simulated were shown with various input concentration from equation 3.5 and DPE optimization with 7-days, 7-days, 21-days and 90-days time steps.

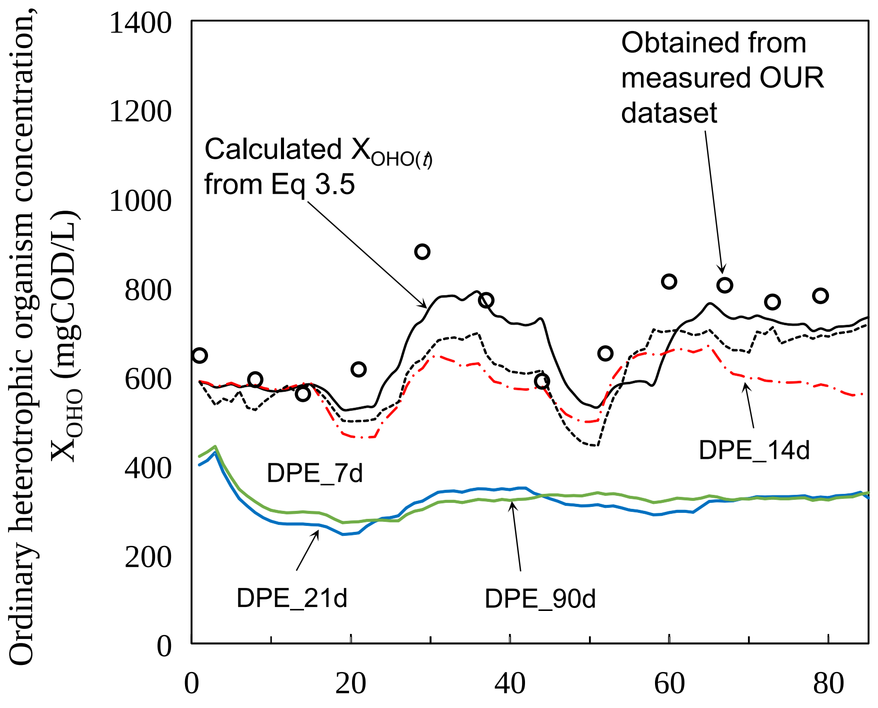


Figure 4.4 Simulated results MLSS with various input dataset calculated

By using the DPE, influent determination was simpler than back-calculation approach, but the results were unclose to measured dataset as well as lower and scatter much than results from back-calculation. However, these kinds of dataset could be acceptable in case of guessing the tendency and fluctuating range of influent substrates.

Table 4.3 shown the correlation between results (from back calculation as well as DPE process) with measured dataset of X_{OHO} along batch times (12 sets). The average was 102% for back calculation while 7-days, 14-days time step of DPE got 93% and 86% in respectively. The results of 21 and 90 days were very further from measured and had the low accuracy (around 50%).

Table 4.3 Correlation between measured dataset and results from back-calculation, DPE (%)

#batch time	1	2	3	4	5	6	7	8	9	10	11	12	Average
Back Calculation	91%	89%	90%	82%	112%	118%	113%	85%	104%	114%	112%	109%	102%
7 days	86%	81%	87%	77%	79%	94%	91%	78%	118%	118%	115%	90%	93%
14 days	85%	90%	84%	72%	75%	84%	89%	85%	101%	96%	91%	85%	86%
21days	62%	45%	41%	38%	49%	54%	51%	48%	45%	49%	51%	51%	49%
91days	65%	49%	46%	42%	47%	50%	51%	52%	50%	50%	51%	50%	50%

In addition, the other results of influent concentration were shown in Figure 4.5 with the soluble biodegradable substrate (ASR#1), biodegradable substrate include the particle (ASR#2) and nitrogen biodegradable matter.

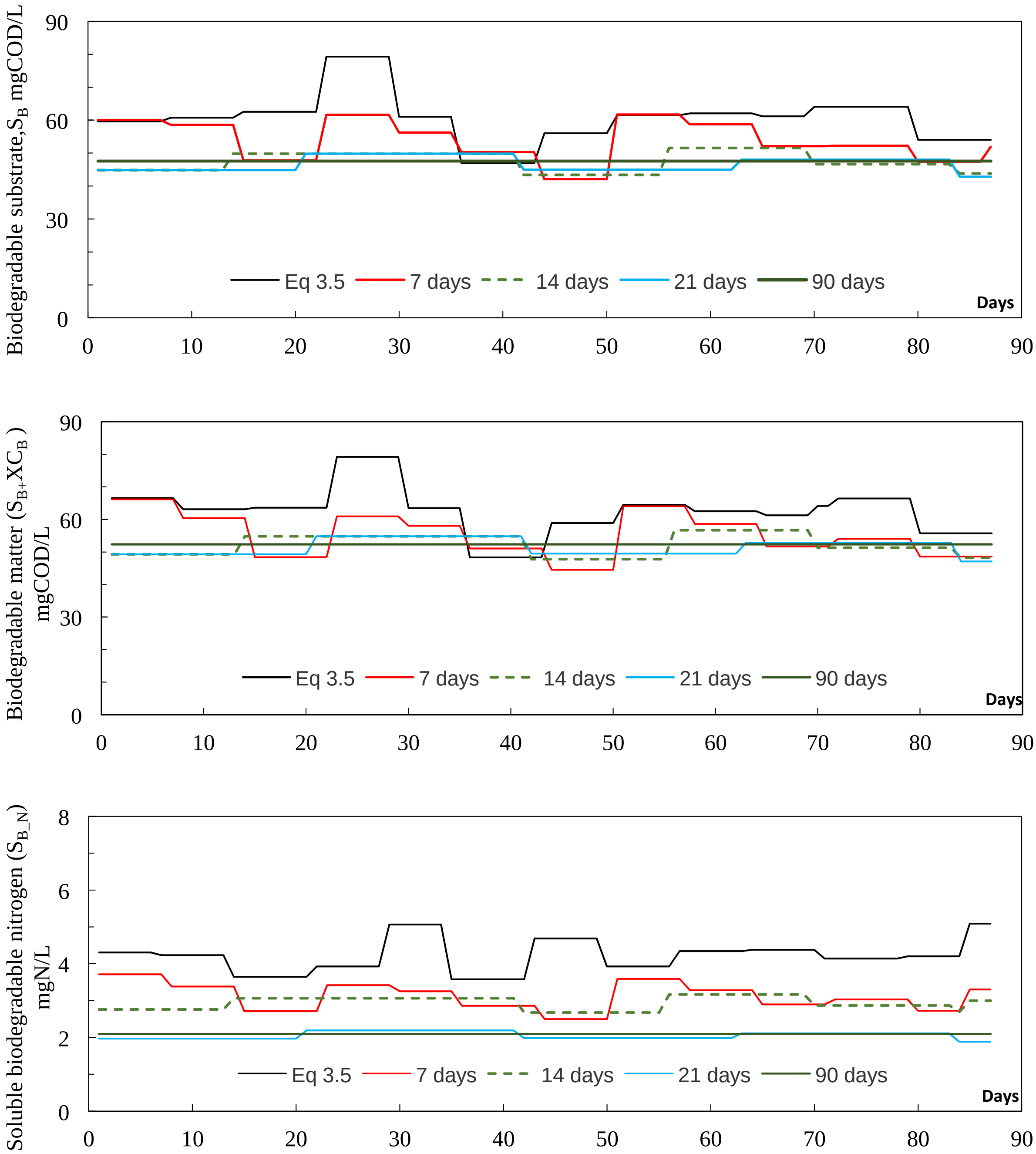
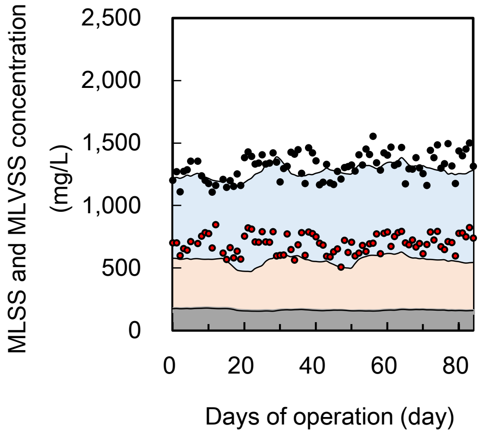
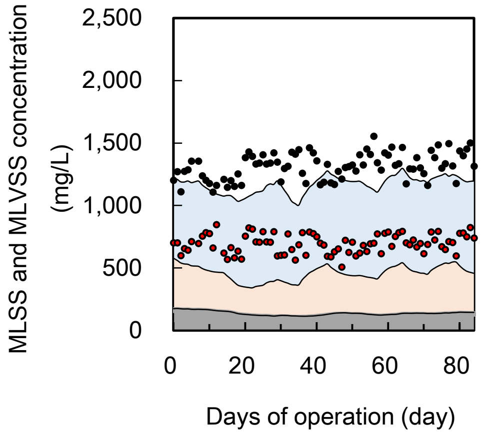


Figure 4.5 Influent concentration results from back-calculation (E.q. 3.5) and DPE approach

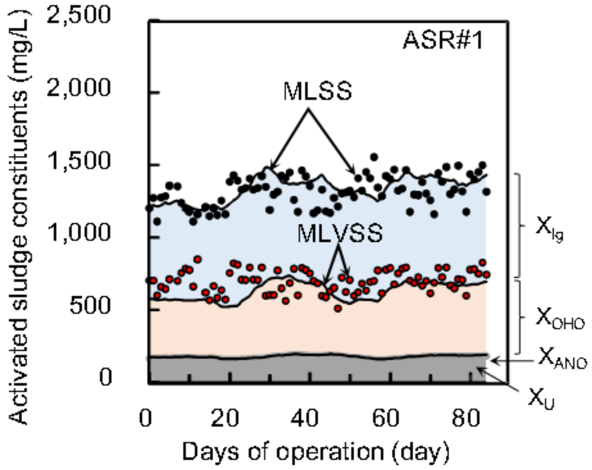
Similarly, the influent concentrations were used for simulation ASR process, shown in Figure 4.6. However, with lower accuracy, DPE results with 7-days, 14-days show the underestimation in compare with back-calculation results (Figure 3.6). For the 21-days 90-days, the data were too further and long time period (compare with 7 days batch test), they were not used in dynamic simulation.



7-days time step



14-days time step



Back-Calculation

Figure 4.6 Dynamic simulation with various influent estimation

4.4 Conclusion

A optimization tool DPE from GPS-X simulator software could use in determining the influent substrate from activated sludge constituents for the target parameters. Following results were obtained in this chapter.

(1) From the calculated data of the sludge concentration X_{BH} as the target for optimizing process, the influent state variable concentrations for biodegradable organics was estimated in various time steps. With the assessment of correlation factors, the time step of 4-days and 7-days should be recommended in this approach.

(2) The statistical analysis and simulation comparison with results from back-calculation equation (simple and with deviation variable) as well DPE tool were conducted. They indicated that the back-calculation brought the reliable dataset of influent substrate especially with deviation function and the DPE tool could provide the trending results for assessment with simple task.

Chapter 5: Parameter Identification of the Trickling Filter Process

5.1 Introduction

In recent years, trickling filter processes receive a keen attention as an alternative energy-saving wastewater treatment to conventional activated systems, although the process was supposed to be rather an old technology until 2000s (*Silva 2015 & Zhang 2015).* In 2014, a full-scale demonstration plant was built in Kochi, Japan under B-DASH project by Ministry Ministry of Land, Infrastructure, Transport and Tourism, Japan after the approval of technology verification by Japan sewage works agency in 2013 (*Tsuji 2014*). In the process, oxygen in ambient air is supplied to the liquid phase with forced or natural ventilation created by the gas-density deference between the reactor and the ambient, which makes it possible to save the oxygenation electricity by about 50% comparing to those of the activated sludge systems.

The pollutants in the wastewater are biologically decomposed in the biofilm growing on the surface of packing media in the trickling filter. To design the trickling filter processes, an empirical method complied by Mohlman *et al.* (1946) are still referred even in recent literature (*Macros 2007, Grady 2011 & Vayenas 1997*). According to the method, the substrate removal efficiency was calculated from the volumetric substrate loading rates and liquid flow rate per cross section area of the reactor. However, since the assumed reactions in the process were considerably simplified, this thumb's rule was only valid for the influents having comparable constituents to those referred in the Mohlman's report. To overcome the limitation, as illustrated in **Fig. 5.1**, relevant biological and physical reactions in the reactor were mathematically modelled in 1990s-2010s (*Vayenas 1997 & Wanner 2006*)

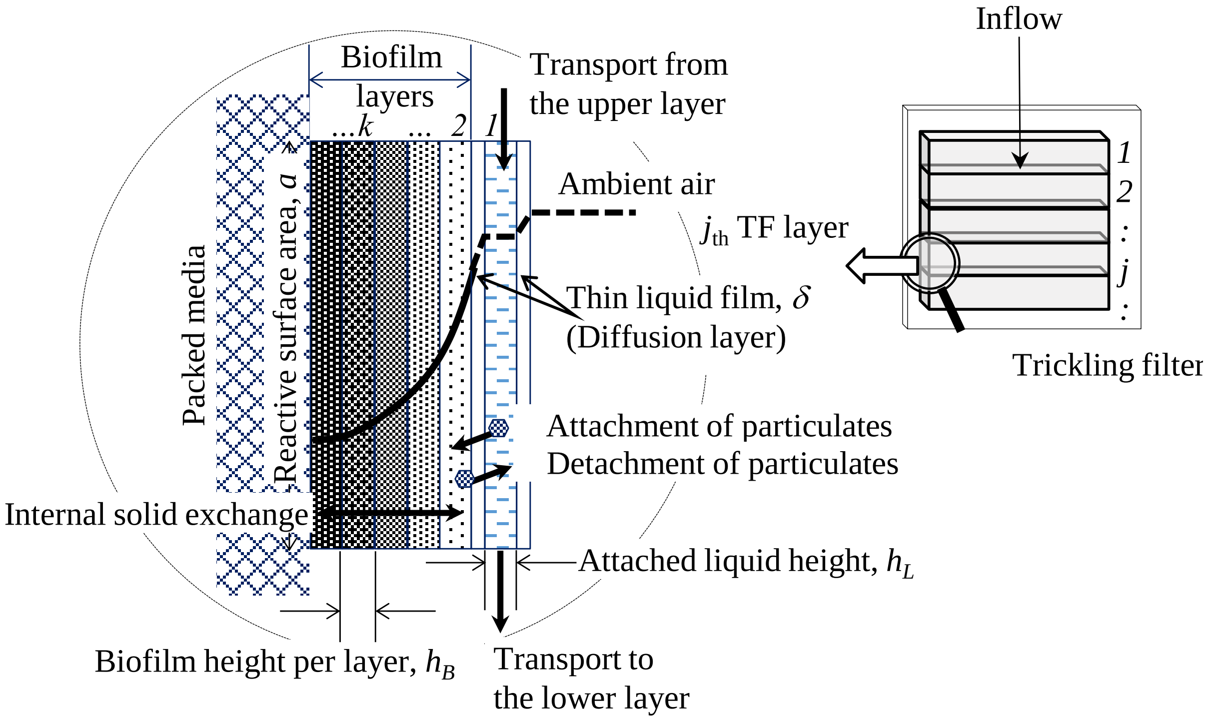


Figure 5.1 Conceptual diagram of the trickling filter model

The concept of the mathematical trickling filter model was expressed by **Eq. 5.1** (soluble materials, S g/m^3) and **Eq. 5.2** (particulate materials, X g/m^3) respectively (*Hydromantis, 2014*). The mass transfer in the reactor was described using the sets of differential equations composed of 2-dimensional discrete layers for the vertical trickling filter bed height (1…*j*) and horizontal biofilm depth (1…*k*).

$$\begin{cases} a \cdot h_L\left(\dfrac{dS_j}{dt}\right) = \dfrac{Q_L}{V}\left(S_{j-1} - S_j\right) - K_B \cdot a\left(S_j - S_{j\_B\#1}\right) + K_L \cdot a\left(S_j^* - S_j\right) \\ \dfrac{\partial S_j}{\partial t} = D_S \dfrac{d^2 S_j}{dl^2} - r_{S,j} \\ K_L = K_B = \dfrac{D_S}{\delta} \\ S_j^* = H_S \cdot P_{S,j} \end{cases} \tag{5.1}$$

$$\begin{cases} a \cdot h_L\left(\dfrac{dX_j}{dt}\right) = \dfrac{Q_L}{V} X\left(X_{j-1} - X_j\right) - k_{attach} \cdot a \cdot X_j + k_{detach} \cdot a \cdot X_{j\_B\#1} \\ a \cdot h_{j\_B\#k}\left(\dfrac{dX_{j\_B\#k}}{dt}\right) = k_{inter-exchange} \cdot a \cdot \left(X_{j\_B\#k-1} - X_{j\_B\#k+1}\right) + a \cdot h_{j\_B\#k} \cdot r_{X,j\_B\#k} \\ X_{j\_B\#k} \le X_{j\_B\#k,\max} \end{cases} \tag{5.2}$$

<u>Reactor operation/ biofilm parameters</u>

a: specific wetted surface area of the trickling filter (m^2/m^3)

h_L: liquid height of the wetted surface area at the trickling filter (m)

$h_{j\_B\#k}$: biofilm height at the k^{th} layer (horizontal layer) (m)

l: biofilm horizontal length (m)

Q_L: liquid flow rate to the trickling filter (m^3/d)

V: volume of trickling filter (m^3)

<u>Physical and kinetic parameters</u>

D_S: soluble material diffusion constant (m^2/d)

H_S: Henry constant (g/m^3/atm) (used for only oxygen)

K_B: overall mass transfer coefficient at liquid/biofilm zone (m/d)

K_L: overall mass transfer coefficient at liquid/gas zone (m/d) (used for only oxygen)

k_{attach}: specific attachment rate of particulates to biofilm(m/d)

k_{detach}: specific detachment rate of particulates from biofilm (m/d)

$k_{inter\text{-}exchange}$: specific particulate inter-exchange rate in biofilm (m/d)

δ: molecule diffusion layer at liquid/gas zone and liquid/biofilm zone (m)

Material concentrations

$P_{S,j}$: partial gas pressure at the j^{th} vertical trickling filter layer (atm) (used for only oxygen)

S_j: soluble material concentration in the attached liquid at the j^{th} vertical trickling filter layer (g/m^3)

$S_{j\_B\#1}$: soluble material concentration in the biofilm surface layer (horizontal 1st layer on biofilm) at the j^{th} vertical trickling filter layer (g/m^3)

S_j^*: air-saturated soluble material concentration in the liquid at the j^{th} vertical trickling filter layer (g/m^3) (used for only oxygen)

X_J: particulate material concentration in the liquid at the j^{th} vertical trickling filter layer (g/m^3)

$X_{j\_B\#1}$: particulate material concentration in the biofilm surface layer (horizontal 1st layer on biofilm) at the j^{th} vertical trickling filter layer (g/m^3)

$X_{j\_B\#k,\max}$: maximum particulate material concentration in the biofilm layer at the j^{th} vertical trickling filter layer (g/m^3)

Biological reaction rates

$r_{s,j}$: process rate for soluble material at the j^{th} vertical trickling filter layer (g/(m^3·d))

$r_{X,j\_B\#k}$: process rate for particulate material in the biofilm layer (horizontal k^{th} layer) at the j^{th} vertical trickling filter layer (g/(m^3·d))

Since the above equations were only developed in theoretical way, this research was aimed at its verification through an experimental approach. In order to calculate the biological reactions in the equations that were engaged with the mass transfer in the reactor, the impact of liquid flow on the mass convection (from the influent to the surface of the biofilm) and advections inside biofilm were needed for the evaluation.

As Activated Sludge Models (ASMs) developed by IWA Task groups ASMs have been widely used for simulating various kinds of biological reactions (Henze 2000), its concept can be transferred to r_S and r_X of the the equations with minimum modification. Hence, to use the model for the designing of trickling filter processes, mechanistic correlation must be developed between the operational conditions and the physical/ kinetic parameters of the model. For instance, as the liquid flow sprayed from the top of the trickling filter wets the surface area of the biofilm, this operational condition dominates the biological reactions. Therefore, when the reactive (wetted) surface area is expressed with the operational conditions, the biological reaction rates of the process can be calculated while reasonable kinetic parameters are applied. Based on this background, the process responses of a pilot-scale trickling filter reactor were investigated by changing the hydraulic loadings and analyzed in this study. The study especially focused on the liquid hold-up in the reactor, which was thought to be correlated with the wetted surface area. A dynamic simulation was also performed to discuss influential kinetic parameters on the calculation.

5.2 Material and Methods

5.2.1 Experimental apparatus

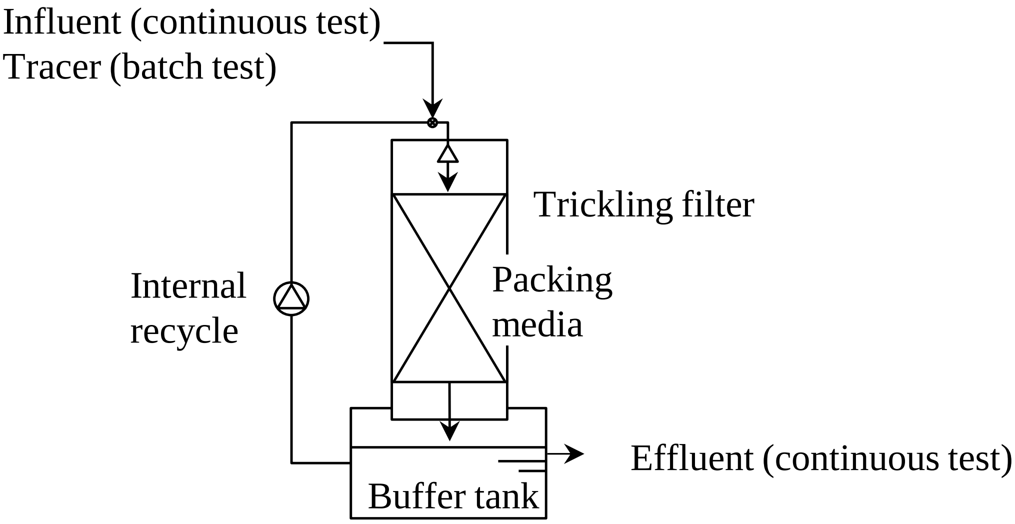


Figure 5.2 Schematic of the trickling filter

A pilot-scale trickling filter reactor (0.5 $m^2 \times 4$ m) was installed at Phu Loc wastewater treatment plant, Da Nang, Vietnam, as illustrated in Fig. 2. The reactor was randomly filled with plastic tubular media having no pores (1.5 cm × 1.5 cm) with internal 3 ribs having 371 m^2/m^3–reactor volume of surface area and 80% of void in reactor volume basis. The influent for the reactor was pre-screened using a sponge-filter column to remove large particulates in order to avoid clogging at the filter. Together with the influent, a part of effluent stored in a 0.2 m3-buffer tank was pumped and recycled to the top of the reactor when the impact of liquid flow rate on the biological performance was examined.

5.2.2 Measurement of liquid hold-up and analysis of wetted surface area

After the operation for over 3 months with feeding about 1 m^3/h of the influent, the liquid hold-up of the reactor was measured using NaCl tracer (500 g/10 L). The NaCl solution was sprayed at the top of the reactor within a few seconds, and the NaCl concentration in the effluent was logged with an electric conductivity meter (ECCM-31P, TOA DKK, Japan) while the effluent of the reactor was continuously recycled to the top without feeding the influent. The tracer test was performed under 3 different recycle flow rates (1, 3 and 9 m^3/h) to evaluate the impact of liquid flow rate on the liquid-hold up. As the tracer concentration slightly decreased along with time due to diffusion to the biofilm, the tracer concentration at t = 0 was extrapolated and used to determine the liquid hold-up (ϕ), as shown in **Eq. 5.3** and **Fig. 5.3** where the diffusion of the tracer into the biofilm was schematically mentioned in the right illustration.

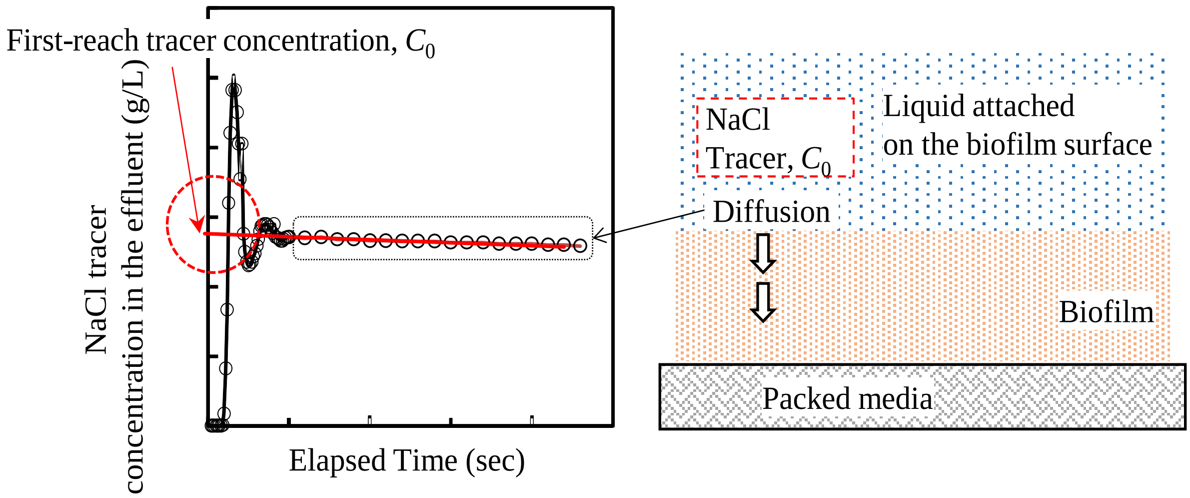


Figure 5.3 Measurement of the tracer concentration in the effluent

$$M = \left(\phi \cdot V + V_{buffer\_tank}\right) \cdot C_0 \tag{5.3}$$

C_0: first-reach tracer concentration of the attached liquid on the biofilm (g/m^3)

M: tracer dose (g)

V: volume of trickling filter reactor (m^3)

V_{buffer_tank}: working volume of the buffer tank (m^3)

ϕ: liquid hold-up of the trickling filter reactor (m^3/m^3)

From the liquid hold-up, the liquid height of the wetted surface area at the trickling filter (h_L) and the specific wetted surface area of the trickling filter (a) were expressed by **Eq. 5.4**.

$$\phi = h_L \cdot a \tag{5.4}$$

a: specific wetted surface area of the trickling filter (m^2/m^3)

h_L: liquid height of the wetted surface area (m)

ϕ: liquid hold-up of the trickling filter reactor (m^3/m^3)

Next, **Eq. 5.5** was introduced from **Eq. 5.1** and **Eq. 5.4** to express h_L. Focusing on the effluent DO concentration (S_{O2}) during the hydraulic stress test, h_L was determined by the curve-fitting while the molecule diffusion layer (δ) was fixed to be about 50 μm *(Hydromantis 2014)*. Based on the determined h_L and ϕ, the specific wetted surface area in the trickling filter (a) was correlated with the sprayed liquid flow per reactor cross-section area (linear velocity of fluid, LV).

$$\phi \cdot r_{O2} = \frac{Q_L \cdot V}{h_L}\left(-S_{O2}\right) - \frac{D_{S,O2}}{\delta} \cdot \frac{\phi}{h_L} \sum_j \sum_k \left(S_{O2,j} - S_{O2,j\_B\#1}\right) + \frac{D_{S,O2}}{\delta} \cdot \frac{\phi}{h_L} \sum_j \sum_k \left(H_{SO2} \cdot P_{SO2} - S_{O2,j}\right) \tag{5.5}$$

r_{O2}: volumetric oxygen consumption rate of the trickling filter (kg/(m^3·d))

5.2.3 Hydraulic stress test

The hydraulic stress test was performed by changing the recycling flow rate for 2 days. The recycling flow rates were controlled at 0, 2.0, 3.0, 4.5, 6.0 and 8.0 m^3/hr with fixing the influent flow rate at about 0.6-1.2 m^3/h. These operating conditions were changed at about 0.3-day interval. Due to typical Vietnamese sewerage combined with septic tanks, the BOD_5 concentration of the influent at the wastewater treatment plant was very low (*ca.* 20 mg/L) while relatively high ammonium was present (*ca.* 10 mgN/L). Before starting the experiment, about 2-3 mg/L of soluble BOD_5 and 2-3 mgN/L of ammonium-nitrogen were detected in the trickling filter effluent. Therefore the reactor O_2 consumption (r_{O2}) could be almost simplified to that from nitrification. To calibrate the nitrification kinetics, NH_4Cl (7 gN/L) was mixed to the influent during the test, yielding the influent ammonium-N concentration to be about 20-70 mgN/L. The influent and effluent nitrogen concentrations were monitored at every 0.5-4 hr intervals. During the tests, the effluent pH was almost kept constant at about 7.0-7.3 while about 10-20 mg-N/L was biologically oxidized in the reactor. The tests were duplicated in Sep/2013 and Sep/2014 respectively.

The concentrations of ammonium-N, nitrite-N and nitrate-N were measured using spectrophotometric testing papers (RQ flex, Merck, Germany). Prior to the measurements the testing papers were calibrated with standard nitrogen solutions. During the tests, DO concentration and liquid temperature were also monitored with a DO meter (TOX-999B, Toko, Japan).

5.2.4 Process simulation

A process simulator (GPS-X ver.6.4, Hydromantis Environmental Software Solutions, Inc., Canada) was used to solve the model equations. Prior to the simulation, the impact of discrete layer number evaluated. Since the layer numbers beyond/ below about 6 did not give considerable difference on the calculation results, 6 layers for both horizontal (1 liquid layer + 5 biofilm layers) and vertical directions (6 trickling filter layers) were selected for the 2-dimensional model. To include two-step nitrification (ammonia oxidation and nitrite oxidation), Activated Sludge Model No.1 (ASM1) was modified accordingly Henze 2000.

Table 5.1 Influent composition used for the simulation

Item (Abbreviation)	Concentration
Soluble ultimate BOD (S_B)	20 mgCOD/L
Particulate ultimate BOD (XC_B)	10 mgCOD/L
Unbiodegradable particulate (X_U)	7 mgCOD/L
Ammonia and ammonium nitrogen (S_{NH})	10 mgN/L
Abiotic inorganic particulate ($X_{A,Ig}$)	10 mg/L

Using the monthly-average influent composition at the wastewater treatment plant in Sep/2013 and Sep/2014 listed in **Table 5.1** (*Corominas, 2010*), the initial biomass concentrations in the reactor was calculated under a steady-state condition to reproduce the comparable effluent concentrations under a preliminarily fixed wetted specific surface area and biological kinetics as shown in **Fig. 5.4**, which was mentioned in the results and discussion section. For the calibration, the following try & error approach was used.

Step 1. Using initially assumed wet surface area of the reactor and biological nitrification kinetics from literature (calibration version 1), a set of first-guess effluent concentrations (ammonium-N (NH_x), nitrite-N (NO_2^-), nitrate-N (NO_3^-) and DO) was obtained.

Step 2. Next, when the calculated effluent concentration did not match the measured ones, the wetted surface area of ver.1 was modified, and a new set of effluent concentrations was calculated (calibration version 2). This calibration was repeated until the results of last two trials fairly matched (calibration version *N*)

Step 3. Finally, the biological nitrification kinetics were slightly manipulated to obtain better matching the effluent nitrogen concentrations (calibration final version).

The above parameters were further calibrated through a curve-fitting of experimental data plots in the dynamic condition, where the initial biomass concentrations in the reactor were again modified according to the calibrated parameters.

5.3 Results and Discussion

5.3.1 Liquid hold-up and specific wetted surface area

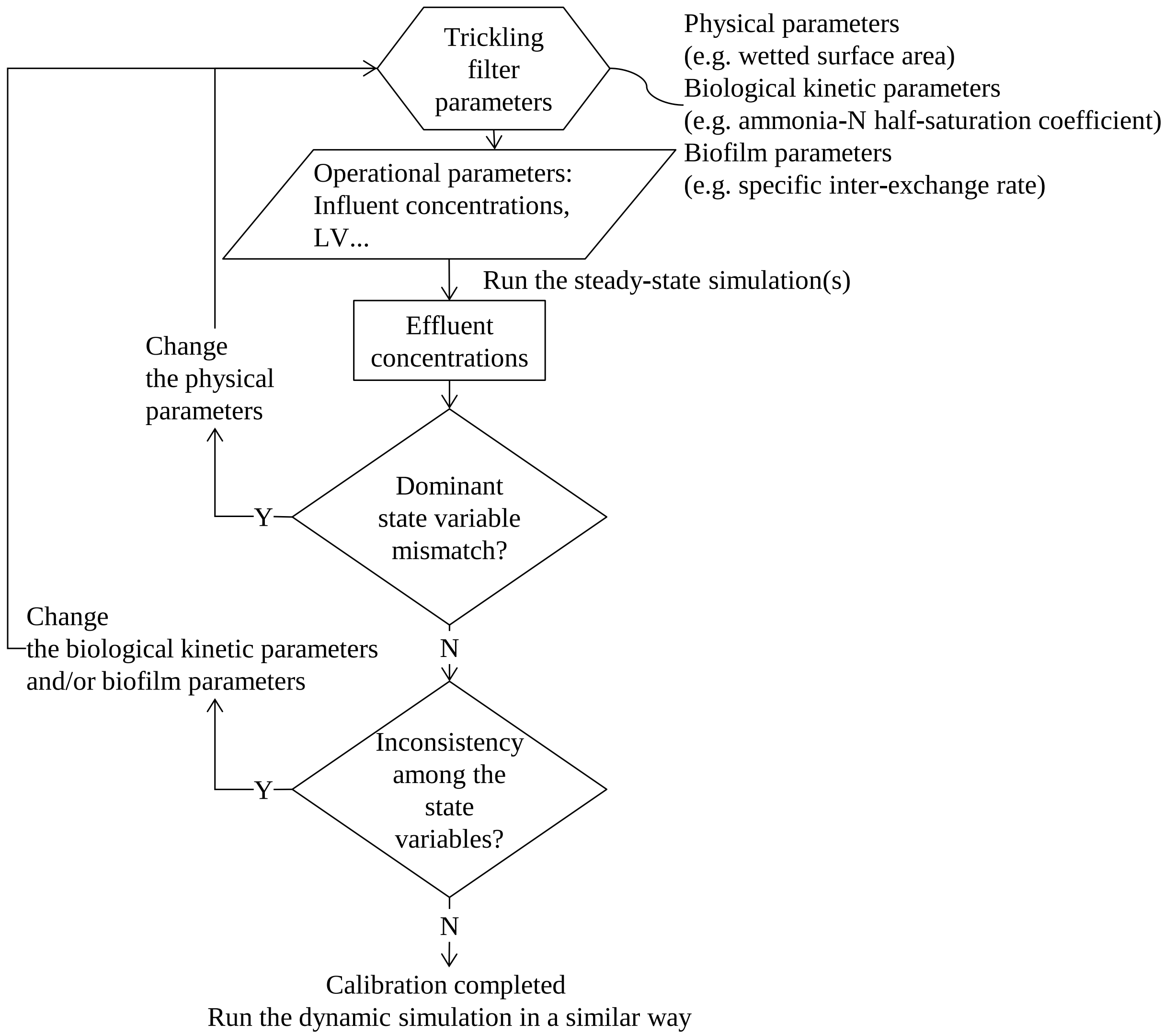


Figure 5.4 Flow-chart for the calibration of trickling filter parameters

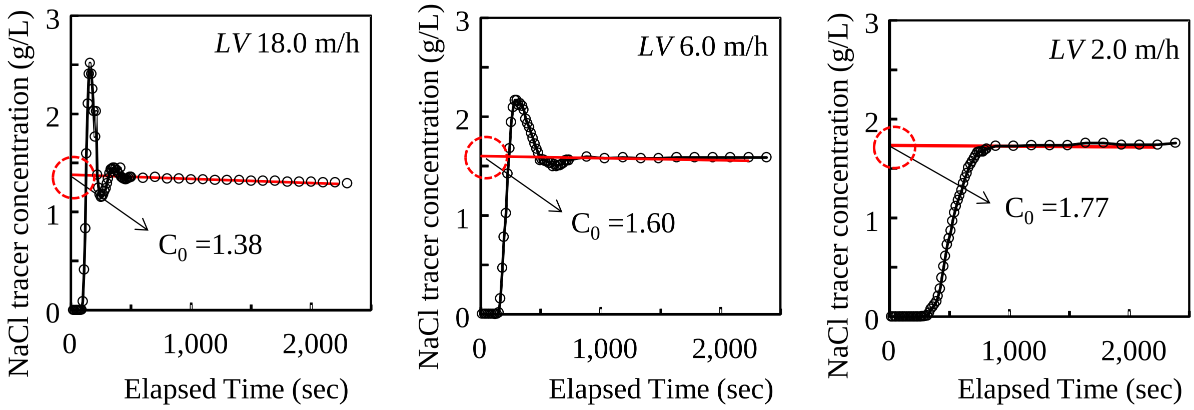


Figure 5.5 First-reach tracer concentration in the trickling filter reactor under different linear velocities

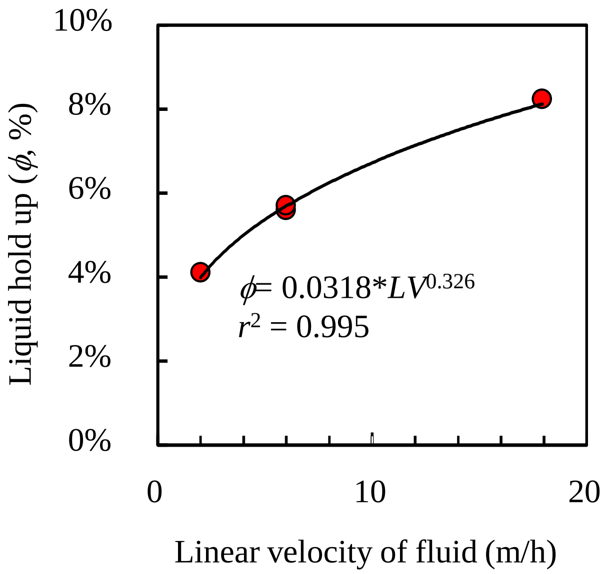


Figure 5.6 Regression of liquid hold-up on the trickling filter against liquid linear velocity

Just after the injection of NaCl tracer, the tracer concentration responded in a sinusoidal damping manner for the initial 300-500 seconds, as shown in **Fig. 5.5.** The tracer concentration was slightly along with time decreased indicating that the tracer was gradually diffused inside the biofilm. The liquid hold-up (ϕ), which was calculated from the extrapolated intersection of the tracer concentration at time = 0 was plotted against the linear velocity (*LV*) of the sprayed tracer liquid as shown in **Fig. 5.6**. As ϕ smoothly increased from 4% to 8% when high *LV* was applied, corresponding coefficients of the empirical equation between the liquid hold-up and *LV* [12] was determined as **Eq. 5.6**.

$$\phi = 0.0318 \cdot LV^{0.326} \tag{5.6}$$

ϕ: liquid hold-up of the trickling filter reactor (m^3/m^3)
LV: linear velocity of fluid (m/h)

When the coefficients of **Eq. (5.6)** were compared with those listed in literature for ordinary counter-flow packed tower processes (scrubber process) where the sprayed liquid adsorbed the target materials in the gas on the wetted surface area (*Otake 1953 & Shulman 1955*), it appeared that the empirical curve in this study showed distinctly lower liquid hold-up than those in the literature. This was because very high upward gas *LV* was applied to the scrubber processes while that of trickling filter processes was negligibly small (gas *LV*/liquid $LV \cong 0$). Considering that the very low upward gas *LV* of the trickling filter process could not sustain much liquid mass in the reactor against gravity, the liquid height (h_L) was assumed to be low and almost constant. Based on this assumption, h_L was calibrated using the effluent DO concentration at the hydraulic stress test. As shown in **Fig. 5.7**, the DO concentration of the effluent was reasonably simulated when h_L = 1.0 mm was applied to the liquid *LV* ranging between 2.4 and 18 m/h with biological kinetics described in the later section. In case that h_L = 0.5 or 2.0 mm were applied, the calculated effluent nitrogen concentrations did not match the measured ones (calculation not shown). From this calibration, the coefficients for **Eq. 5.7** (Otake 1953) were determined to correlate the specific wetted surface area of the trickling filter (*a*) with the liquid *LV*.

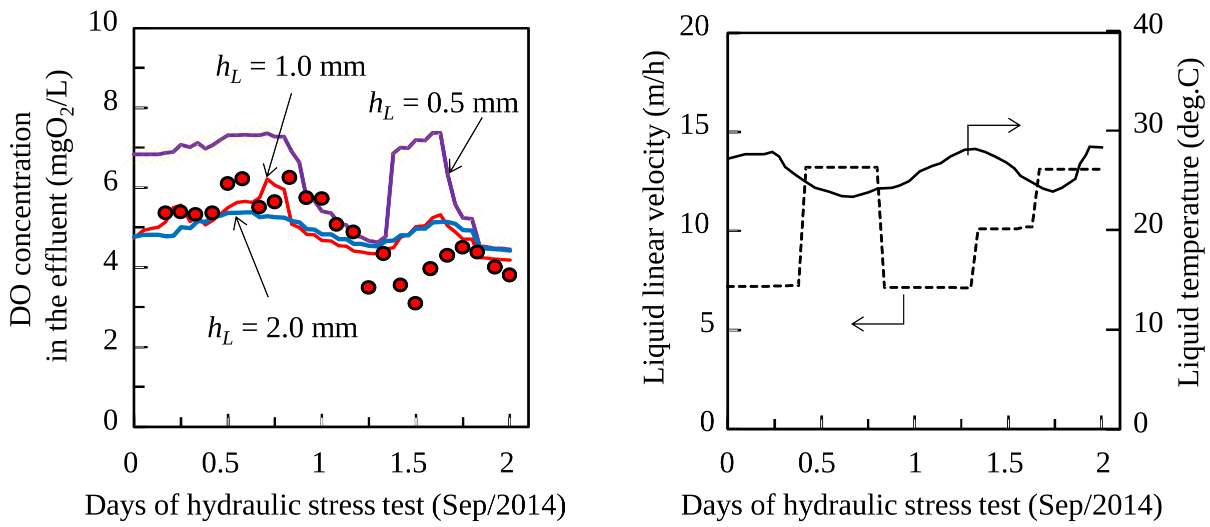


Figure 5.7 Measured and calculated DO concentration in the hydraulic stress test

(Left: circle = Measured DO concentration, lines = calculated DO concentration with different liquid height (h_L); Right: dashed-line = liquid liner velocity, thin-line = liquid temperature)

$$a = 31.8 \cdot LV^{0.326} \tag{5.7}$$

a: specific wetted surface area (m^2/m^3)

LV: linear velocity of fluid (m/h)

The above empirical equation was further structured with non-dimensional engineering parameters in **Eq. 5.8** (*Onda 1968 & Krumin 2000*). Here the estimated specific wetted surface area (a) to the original specific surface area of the packing media in the reactor (a_t) was expressed using $Re_{,b}$, (bed-scale Reynolds number) $Fr_{,b}$ (bed-scale Froude number), $We_{,b}$, (bed-scale Weber number), and five coefficients (**a-e**).

$$a = 1 - \exp\left(-\mathbf{a}\left({\sigma_M}/{\sigma_L} \right)^{\mathbf{b}} \cdot Re_{,b}{}^{\mathbf{c}} \cdot Fr_{,b}{}^{\mathbf{d}} \cdot We_{,b}{}^{\mathbf{e}} \right) \cdot a_t \tag{5.8}$$

$Re_{,b}$ = (Mass flow of the liquid)/(Specific surface area of the packing media × Viscosity of the liquid)

$Fr_{,b}$ = (Specific surface area of the packing media × (Mass flow of the liquid)^2) / ((Liquid density)^2 × Acceleration of gravity)

$We_{,b}$ = (Mass flow of the liquid)^2 / (Liquid density × Liquid/vapor interfacial energy (surface tension of H_2O) × Specific surface area of the packing media)

σ_M:: critical liquid surface tension of liquid (kg/hr^2)

σ_M: critical liquid surface tension of media (kg/hr^2)

a-e: coefficient

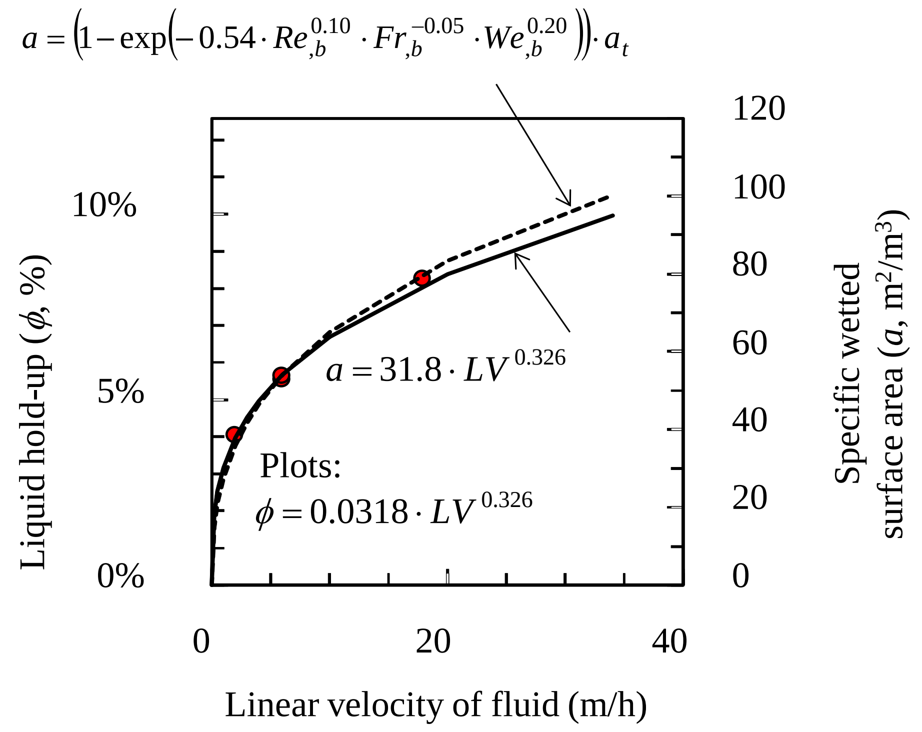


Figure 5.8 Expression of liquid hold-up and specific wetted surface area against. liquid linear velocity

(Circle: measured liquid hold-up, bold-line = calculated wetted surface area based on Eq. 7, dashed-line = calculated wetted surface area based on Eq. 8)

As shown in Y1-axis (*LV* vs. ϕ) and Y2-axis (*LV* vs. *a*) in **Fig. 5.8**, reasonable specific wetted surface area (*a*) was also obtained when same coefficients **c-e** were used as those in Onda *et al*. (1968) (**c** = 0.10, **d** = -0.05, **e** = 0.20) and 0.54 of a composite coefficient (= **a** (σ_M/σ_L)) (*Onda, 2012*). With respect to the composite coefficient, as the packing media of the trickling filter was covered with wet biofilm, σ_M/σ_L =1 could be assumed (hence **a** = 0.54). However, this calibrated parameter was noticeably lower than that than those in scrubber processes (**a** = 1.45) (*Onda, 2012).* Perhaps this was attributed to the lower liquid hold-up than those of the scrubber processes. On the other hand, it was found that the coefficient **e** determined by Krumin *et al.*

(2000) for the nitrifying trickling filter experiment (**e** = 0.4) gave a distinct curve shape and could not match the measured data plots (figure not shown) (*Paul et al, 2012*). The exact reason for the discrepancy was not clear at this present but it might be attributed to the physical property of their packing media. The media was sphere (diameter 6.35 mm) having only 33% of void volume, which was barely used in conventional scrubber/ trickling filter processes.

Both of the empirical equations (**Eq. 5.7** and **Eq. 5.8**) showed that the specific wetted surface area were not linearly increased against the linear velocity of liquid (*e.g.* even *LV* was doubled, *a* could elevate as much as 1.22-1.25 times only). Therefore, it was considered that the operation of high hydraulic influent load would not be an attractive option for the trickling filter process. On the other hand, the increase of the internal recycle flow might improve the process performance to some extent in terms of reactive surface area. This theoretical insight could justify the traditional empirical designing methods of trickling filter processes (*Mohlman 1941*, *Macros 2007*, *Grady 2011*).

5.3.2 Kinetic parameters of the biofilm

The calibrated kinetic parameters for the three kinds of microorganisms (ammonia oxidizing organisms (X_{AOO}), nitrite oxidizing organisms (X_{NOO}) and heterotrophic organisims (X_{OHO})) and three kinds of biofilm particulate advection rates (k_{attach}, k_{detach} and $k_{inter\text{-}exchange}$) were summarized in **Table 5.2**.

Table 5.2 List of biological and physical parameters in the biofilm used for the simulation

Kinetics and stoichiometry (at 20°C)	Ordinary Heterotrophic	Ammonia Oxidising	Nitrite Oxidising
Maximum specific growth rate	6.0 d^{-1}	0.80 d^{-1}	1.1 d^{-1}
	6.0 (**)	0.2-4.6 (***)	0.02-3.2 (***)
Temperature coefficient on growth	1.07 (*)	1.07 (*)	1.06 (*)
Half-saturation coefficient for substrate	20 mgCOD/L	1.0mgN/L	0.3 mgN/L
	20 (**)	0.06-27.5 (***)	0.004-1.5 (***)
Half-saturation coefficient for S_{O2}	0.2 mgO_2/L	0.3 mgO_2/L	0.4 mgO_2/L
	0.2 (**)	0.03-1.45 (***)	0.3-2.5 (***)
Specific decay rate	0.6 d^{-1}	0.2 d^{-1}	0.1 d^{-1}
	0.62 (**)	0.06-1.0 (***)	0.007-0.87 (***)
Temperature coefficient on decay	1.03 (*)	1.03 (*)	1.03 (*)
Biomass yield	0.67 gCOD/gCOD	0.18 gCOD/gN	0.06 gCOD/gN
	0.67 (**)	0.03-0.13 (****)	0.02-0.06 (****)
Particulate advection rate			
Specific attachment rate		0.5 m/d	
Specific detachment rate		$1 \cdot 10^{-3}$ m/d	
Specific solid inter-exchange rate		$1 \cdot 10^{-5}$ m/d	

(*) Hydromantis 2014; (**) Henze et al, 2000; (***) Chandran, 2010; (****) Makinia, 2010

The nitrifier's kinetics were consistent over the two hydraulic stress tests in 2013 and 2014. Although precise sensitivity analysis was not conducted, the listed biological kinetics were in the range of those in literature (*Henze 2000, Makinia 2010 & Ward 2011*). The maximum specific growth rates were rather sensitive than the half-saturation coefficients on simulating the dynamic change of substrate loadings, especially high loading event. This was because high substrate removal rates (high growth rates) were needed to decompose the substrates under high concentration. To achieve consistent simulations between low and high substrate loadings under various loadings, the specific decay rates were calibrated.

With respect to the specific attachment rate (k_{attach}), since this kinetic parameter was defined as a particulate entrapment rate at the biofilm surface layer (B#1), estimation of k_{attach} was possible by measuring the removal of influent particulate substrate (XC_B) in the reactor. Nevertheless, because of low particulate concentration in the influent, k_{attach} could not be precisely obtained. Therefore, for the dynamic simulation, the specific rate was roughly fixed to be 0.5 m/d in order to attach 80-90% of XC_B in the influent would on the biofilm.

To estimate the specific detachment rate (k_{detach}), since this kinetic parameter affected the biofilm thickness and the biomass concentrations in the biofilm surface ($X_{B\#1}$), assuming the biomass concentration over the biofilm ($X_{B\#1}$-$X_{B\#k}$) to be 0.102 $g/cm^3{}_{\text{-biofim}}$ (*Ward 2011*), a marginal k_{detach} was investigated to produce the experimentally measured effluent concentrations in the simulation. Below the marginal specific rate, thick biofilm was created (*e.g.* 1 mm) having much inert fraction in deep biofilm zone. Beyond the marginal specific rate, the calculated nitrification rate did not meet the measured effluent concentrations. In this way, theoretical maximum k_{detach} was calibrated to be about $1 \cdot 10^{-3}$ m/d (biomass detach per area ≅ 10 $g/(m^2 \cdot d)$). When the value was applied, active biomass existed until 80-100 μm depth of the biofilm.

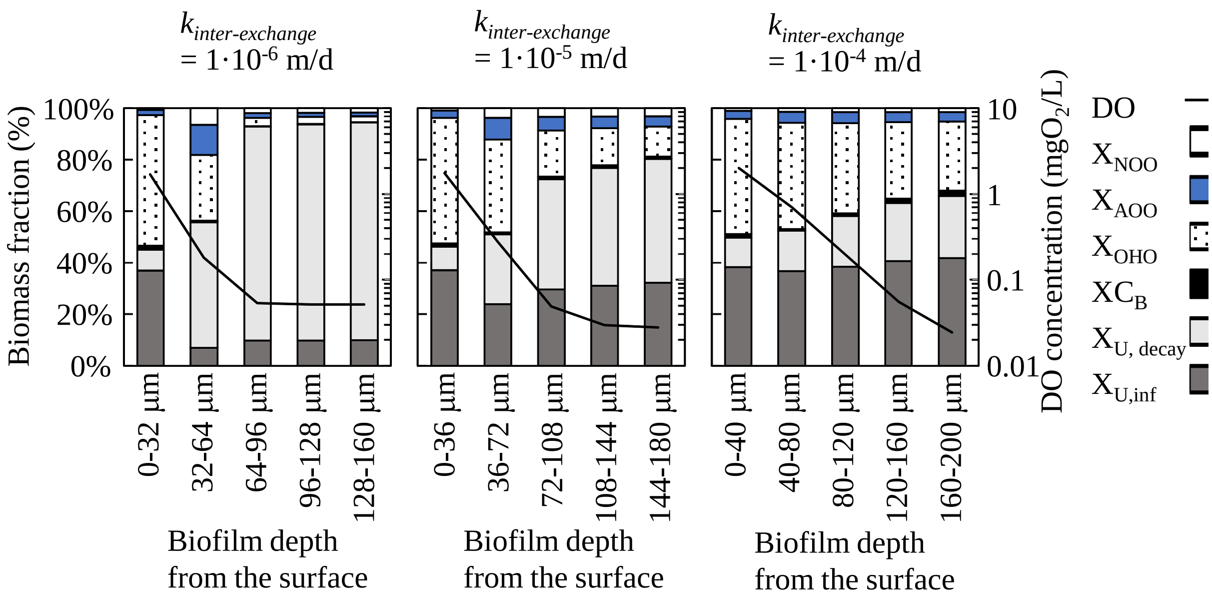


Figure 5.9 Impact of specific solid inter-exchange rate on the biomass distribution in the biofilm at the middle of the trickling filter bed, trickling filter layer $j = 3$

(Bars: state variables (biomass fractions), lines: DO concentration, left: kinter-exchange = 1.10-6 m/d (total biofilm thickness = 160 µm), centre: kinter-exchange = 1.10-5 m/d (total biofilm thickness = 180 µm), right: kinter-exchange = 1.10-4 m/d (total biofilm thickness = 200 µm))

As shown in **Fig. 5.9**, the impact of specific particulate inter-exchange rate ($k_{inter\text{-}exchange}$) on biofilm composition was evaluated. When the parameter was set to be 1/1,000 magnitude of the specific detachment rate ($1{\cdot}10^{-6}$ m/d, graph (a)), the biomass in the surface biofilm layer (B#1) was almost occupied by (i) inert compounds (X_U) captured from the influent, and (ii) ordinary heterotrophic organism (X_{OHO}) having a high biomass yield coefficient. The organisms having low biomass yield coefficients (X_{AOO} and X_{NOO}) existed mostly at the 2nd biofilm layer (B#2). This was because the low-yield growers could not outcompete with high-yield growers at the surface biofilm layer. Consequently the low-yield growers retained in the lower biofilm layers where DO was still present for their growth. Below the 2nd layer (B#3-B#5), the dominant organic solids of the biofilms were inert particulates because of the long particulate retention time.

When as high as 10 times of the $k_{inter\text{-}exchange}$ was applied ($1\cdot10^{-5}$ m/d, graph (b)), the non-uniform biomass distribution was also created. In this case, the biologically working depth was expanded until the bottom biofilm layer (B#5). But, due to low DO concentration (< 0.1 mg/L) in the 3rd–5th layers (B#3-B#5), the impact of the biological reaction on the effluent was thought to be limited. On the other hand, when very high specific inter-exchange rate was applied ($1\cdot10^{-4}$ m/d, graph (c)), the biomass species became homogenously over the biofilm layers. In this case, enough DO for aerobic reactions appeared until the 3rd–the 4th biofilm layers (B#3-B#4).

Nevertheless, even changing the kinetic parameters ($1\cdot10^{-6}$~$1\cdot10^{-4}$ m/d), the comparable effluent nitrogen concentrations were obtained (graphs not shown). This was because the low (high) biomass concentrations in the biofilm layers were almost compensated by the high (low) local DO concentration resulting in the comparable reaction rates. Accordingly $k_{inter\text{-}exchange}$ seemed not to be a strong influential factor on the reactions. Hence, the moderate kinetic parameter ($1\cdot10^{-5}$ m/d) was selected and applied to the dynamic simulation.

Basically modelling the detachment phenomena was quite complicated because a smooth detachment from on the surface layers (erosion) and a release of biofilm chunks from its internal depth (sloughing), might happened simultaneously. Depending on each degree, the biomass composition over biofilm might be differentiated (*Paul et al 2012*). To cope with the problem, instead of the defining the two types, use of the specific particulate inter-exchange rate would be an alternative option since the kinetic parameter also governed the biomass composition in the biofilm. When high specific particulate inter-exchange rate was applied, the biomass composition over biofilm depth became homogenously. Once such biomass was detached from the surface layer, it could be approximated to be a sloughing even the detachment took place at the surface biofilm layer.

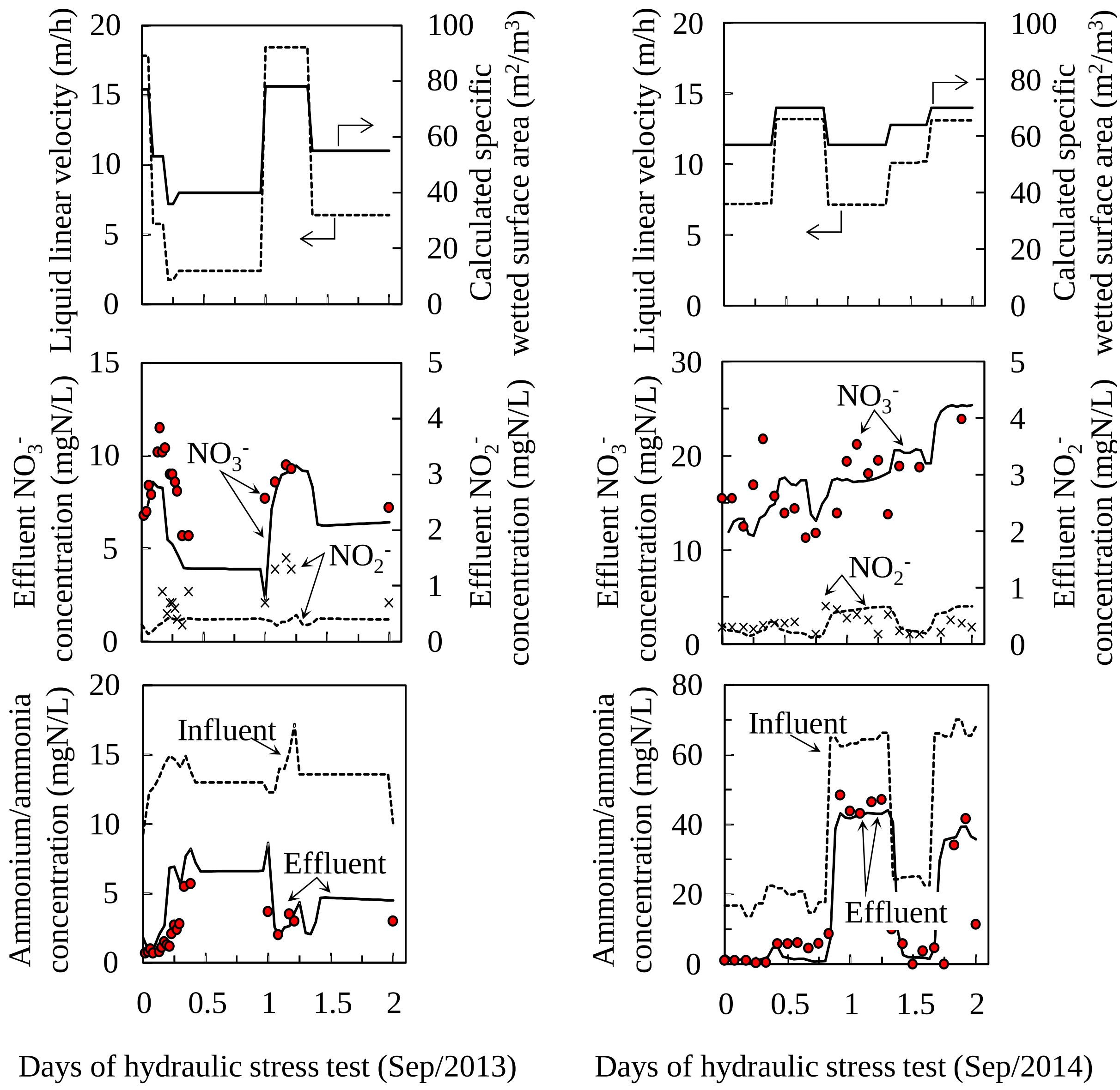


Figure 5.10 Nitrification response and its dynamic simulation

(Upper left and upper right: dashed-line = liquid liner velocity (operational condition), thin-line = calculated specific wetted surface area; middle left and middle right: circle = measured nitrate, corss = measured nitrite, thin-line = measured nitrate, dashed-line = measured nitrite; lower left and lower right: dashed-line = influent ammonium-N, circle = measured effluent ammonium-N, thin-line = calculated effluent ammonium-N)

Based on the above evaluation, the dynamic simulations for the nitrogen compounds were compared with those measured in Sep/2013 and Sep/2014 respectively. As shown in **Fig. 5.10**, the model could fairly reproduce the effluent concentrations of NH_x, NO_2^- and NO_3^- for the two datasets while the liquid *LV* was ranged between 2.4 m/h and 18 m/h. The dynamic simulations demonstrated that most of the biological reactions took place in the biofilm because the biomass concentration in the attached liquid zone on the biofilm was negligibly small. Since the biomass concentration in the attached liquid zone on the biofilm was almost equal to that in the effluent, this very low biomass concentration did not lead comparable reaction rate to that of the biofilm (*e.g.* 24 mgSS/L-effluent vs. about 100,000 mgSS/L-biofilm).

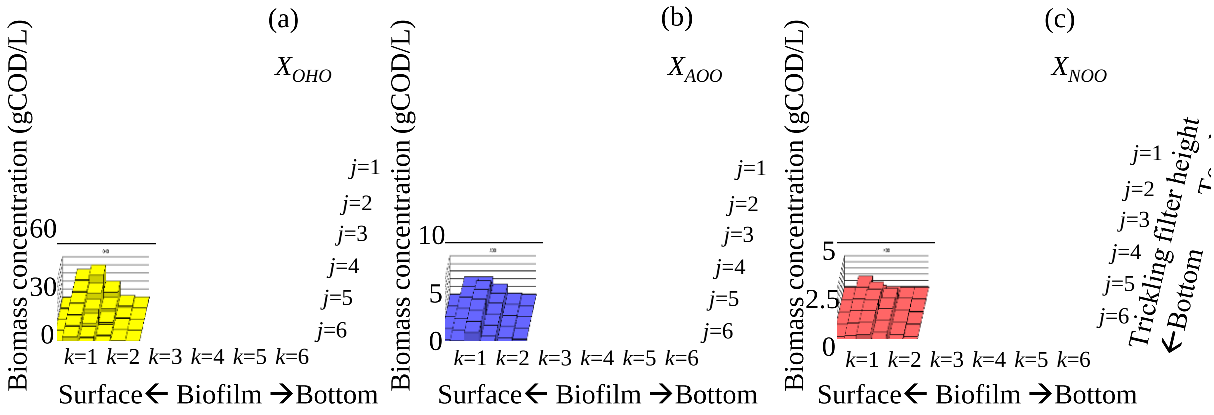


Figure 5.11 Three-dimensional steady-state simulation of the trickling filter on Table 1 with LV = 2m/h

a) Ordinary heterotrophic organisms, b) ammonia oxidizing organism, and c) nitrite oxidizing organism
(*j*=1: Trickling filter top layer, *j*=6 : trickling filter bottom layer; *k*=1: attached liquid on the biofilm, *k*=2: biofilm surface layer, *k*=6 biofilm bottom layer)

As shown in **Fig. 5.11** for the steady-state simulation using Table 5.1 at LV = 2 m/h, the model created differences for fractions of X_{OHO}, X_{AOO} and X_{NOO} along with the trickling filter bed height, which was attributed to the difference of biomass production. Higher X_{OHO} concentration was yielded at the upper trickling filter layers, and higher X_{AOO} and X_{NOO} concentrations were yielded at the lower trickling filter layers. Correspondingly the biofilm thickness was obtained to be about 170 μm, in which slightly thick biofilm was calculated at the top of the trickling filter (173 μm) whilst thin biofilm was made at the bottom of the trickling filter (167 μm). This simulation suggested that higher volumetric nitrification rate was anticipated if higher trickling filter bed was installed.

5.4 Conclusions

A mechanically structured model for trickling filter process composed of physical and biological parameters was evaluated to simulate the process response of the nitrification pilot-scale reactor. Following results were obtained in this study.

(1) Assuming constant liquid height on the packing media, an empirical equation to estimate the wetted reactive surface area from the liquid linear velocity (*LV*) was developed.

(2) The developed empirical equation was further structured using on non-dimensional engineering parameters ($Re_{,b}$, $Fr_{,b}$ and $We_{,b}$).

(3) A modified ASM1 equipped with two-step nitrification could simulate the trickling filter effluent (NH_x, NO_2^-, NO_3^- and DO) in the dynamic condition ranging between 2.4 m/h and 18 m/h of liquid linear velocity.

(4) The impact of biofilm particulate advection rates on the process response was evaluated. In principle, the specific attachment rate was thought to be estimated from the removal of influent particulate BOD compounds, while the specific detachment rate had to be calibrated from the effluent concentrations as a theoretical maximum kinetic parameter. The specific particulate inter-exchange rate had low sensitivity for simulating aerobic biological reactions.

Chapter 6: Computational Simulation for Vietnamese Municipal Wastewater

6.1 Introduction

6.1.1 Case study in Hue city, Vietnam

Hue city is using a combined sewer system for collection both municipal wastewater and storm water. The system, with 199 km length includes various kinds of sewer from concrete pipe to culverts and mainly operate under the principle of gravity without pump station (*Anh TNQ, 2016*). Presently, Hue city does not have any WWTP for domestic wastewater and it only discharge to environment.

From the calculated dataset achieved from new approach method, this study part provide the layout of suggestion WWTP process for Hue domestic wastewater with the capacity 50,000 m^3/day. These water processes are also simulated in GPS-X software with the condition that its effluent would meet the Vietnam National Regulation QCVN 40-2011, Table 6.1

Table 6.1. Vietnam National Regulation Standard for Effluent of WWTP, QCVN 40:2011/BTNMT

No	Parameter	QCVN 40:2011, Class A	Note
1	SS	50	
2	BOD_5	30	
3	COD	75	
4	NH4	5	
5	T-N	20	

6.1.1 Experiment and Calculation

Two sets of lab-scale activated sludge reactors (ASRs) (in chapter 4) were installed at Doan Thi Diem Street, nearby sewage tunnel to Tinh Tam Lake, Hue city, Vietnam. As illustrated in **Figure 4.1**, one of the two ASRs was composed of a primary settling tank, an aeration tank and a secondary settling tank (ASR#1) whilst the other without primary settling tank was equipped (ASR#2).

The hydraulic loadings of the influent to both the ASRs were set at 134 L/d (hydraulic retention time of the aeration tank = 3.9 hrs). The sludge retention times of the ASRs were also identically controlled to be about 10 days. For ASR#1, about 10 mg-Al/L of poly-aluminium chloride and 1 mg/L of anion coagulant (Organo corp., Japan) were dosed on the basis of influent flow to maximize the clarification of primary settling tank. The dissolved oxygen (DO) concentration was also maintained between 5.5-7.0 mg-O_2/L in both the ASRs. Although the pH in the aeration was kept between 6.9 and 7.2 throughout the experiment. The activated sludge sampling from the ASRs was initiated at about 7 day interval between February and May 2017.

Following the method in Chapter 4, the endogenous oxygen uptake rates (OUR) of ordinary heterotrophic organism (X_{OHO}) were measured and from the decrement of DO, a dataset of OUR_{e_OHO} for 7 days was obtained. Based on the decline of OUR_{e_OHO} along with the batch incubation time, specific decay rate of X_{OHO} (b_{OHO}) and the X_{OHO} concentration in the activated sludge were calculated. Similar, autotrophic nitrifying organism concentration (X_{ANO}) and nitrifier's maximum oxygen uptake rates (OUR_{max_ANO}) in ASRs were also regularly monitored with addition of ammonium nitrogen to be 50 mg-N/L, then calculated. S_B concentration was estimated from the analysis of X_{OHO} collected from ASR#1 (with primary settling tank) based on the system condition (b_{OHO}, hydraulic retention time and sludge retention time). X_U concentrations were also determined from X_{OHO} and X_{ANO} and the system condition (b_{OHO}, b_{ANO}, hydraulic retention time and sludge retention time). X_I concentration was calculated from the COD-based activated sludge concentration (X_{total}) ($X_{total} = X_{OHO} + X_{ANO} + X_U + X_I$). XC_B was obtained from the increment of X_{OHO} between ASR#1 and ASR#2 (without primary settling tank). In similar manner, concentrations for $XC_{B\_org\,N}$, S_{B_N} and X_{Ig} were estimated respectively.

6.2 Results of influent constituents

The 24 data sets for b_{OHO} were plotted together with the range of the 95% of confidence interval after normalization at 20 °C with a temperature coefficient θ= 1.07. As shown in **Fig. 6.1**, b_{OHO} of both the ASRs seemed to be almost evenly scattered at around 0.13-0.18 day^{-1}. Based on this and assuming that b_{OHO} was a consistent kinetic parameter of the sewage wastewater (*Nguyen VA 2016)*, the mean of the datasets, $b_{OHO(20°C)}$ = 0.161 day^{-1} was chosen for the analysis.

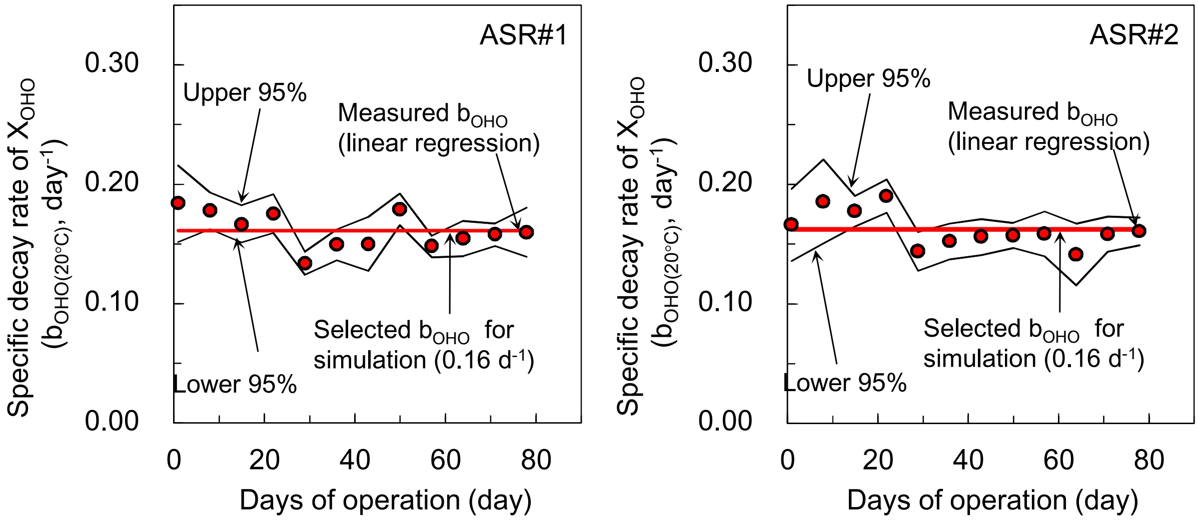


Figure 6.1. Specific decay rate of ordinary heterotrophic organism after normalization into 20 °C

(Left: ASR#1 (with primary settling tank), right: ASR#2 (without primary settling tank))

From the above development and the dynamic simulation, the state variables were converted to the conventional water quality indices, and shown in Figure 6.1

The influent of Doan Thi Diem sewage contained about 31.2 mg/L of SS, 20 mg/L of VSS, 51.7 mg/L of C-BOD_5, 42.9 mg/L of soluble C-BOD_5. On the other hand, nitrogenous matters of influent also were estimated with 4.1 mg-N/L and 3.1 mg-N/L of soluble and particulate biodegradable nitrogen respectively. Comparing to typical wastewater constituents in the countries having no septic tank (*Nguyen 2013*), noticeably low VSS and C-BOD_5 were obtained, which was in lower range of the filed monitoring by *Tran NQA (2016)* (BOD_5: 30-140 mg/L, SS: 27-200 mg/L and Total nitrogen: 11-40 mg-N/L). This suggested that considerable amount of organics discharged from the households were digested in the septic tanks, and/or a lot of groundwater penetrated into the sewer in the city.

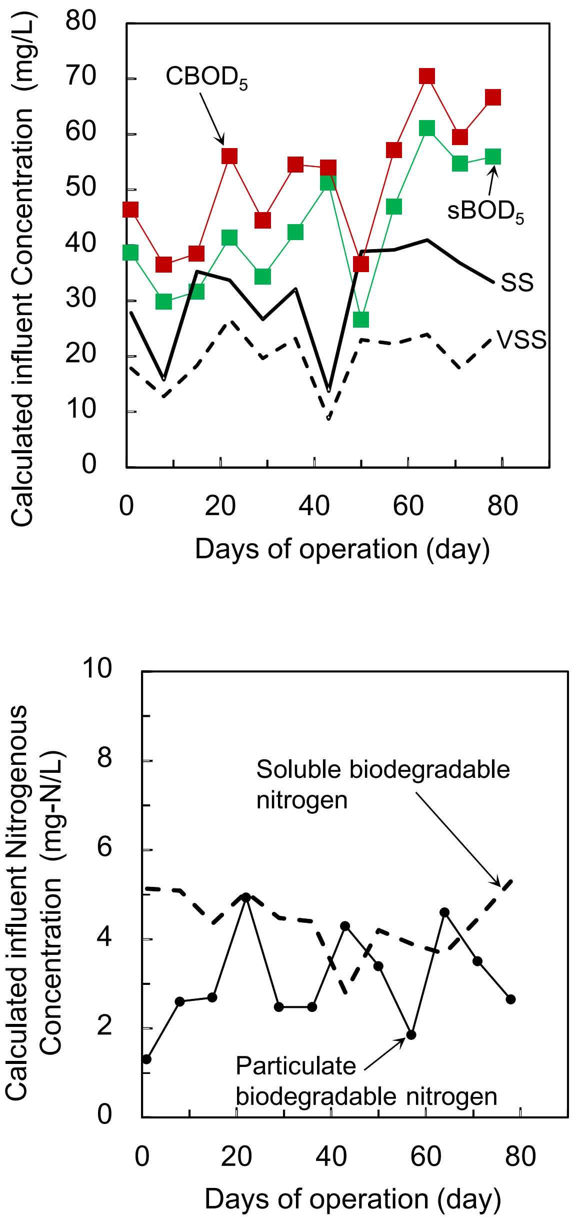


Figure 6.2. Estimate influent material concentration at Doan Thi Diem sewage channel

6.3 Proposal WWTP layout

From the calculated dataset and Vietnam regulation as shown in Table 6.1, the influent BOD was estimated as 90 mgCOD/L (maximum value) while the regulation is 30 mgCOD/L, treating efficiency of wastewater treatment process have to achieve 70% of biodegradable removal.

Also, the influent content some kind of suspended solid and material from sewer, it would be screened and separated through physical treatment phase. For the nitrogen compounds, the estimated values around 10-12 mgN/L of total nitrogen while the ammonia 15 mgN/L was used due to average value NH_4 analyzed results. On the other hand, the standard of effluent is 5 mgN/L and 20 mgN/L for ammonia and total nitrogen respectively. Through the trickling filter (in Chapter 5), ammonia would be utilized to nitrate and nitrite so that effluent's nitrogenous matter can be assure by using the bio-filter. Besides, the effluent would be disinfected before discharge into the environment.

The suggested wastewater treatment process shown in Figure.6.3. There were 2 proposals that include trickling filter and activated sludge reactor. For simulation, the trickling filter process and other using complete mixed activated sludge reactor (ASR) were applied and built in GPS-X version 6.4

Table 6.2 show the design parameters of both processes with 40,000 m^3/d of influent. The TF has smaller footprint less than activated sludge reactor and low HRT.

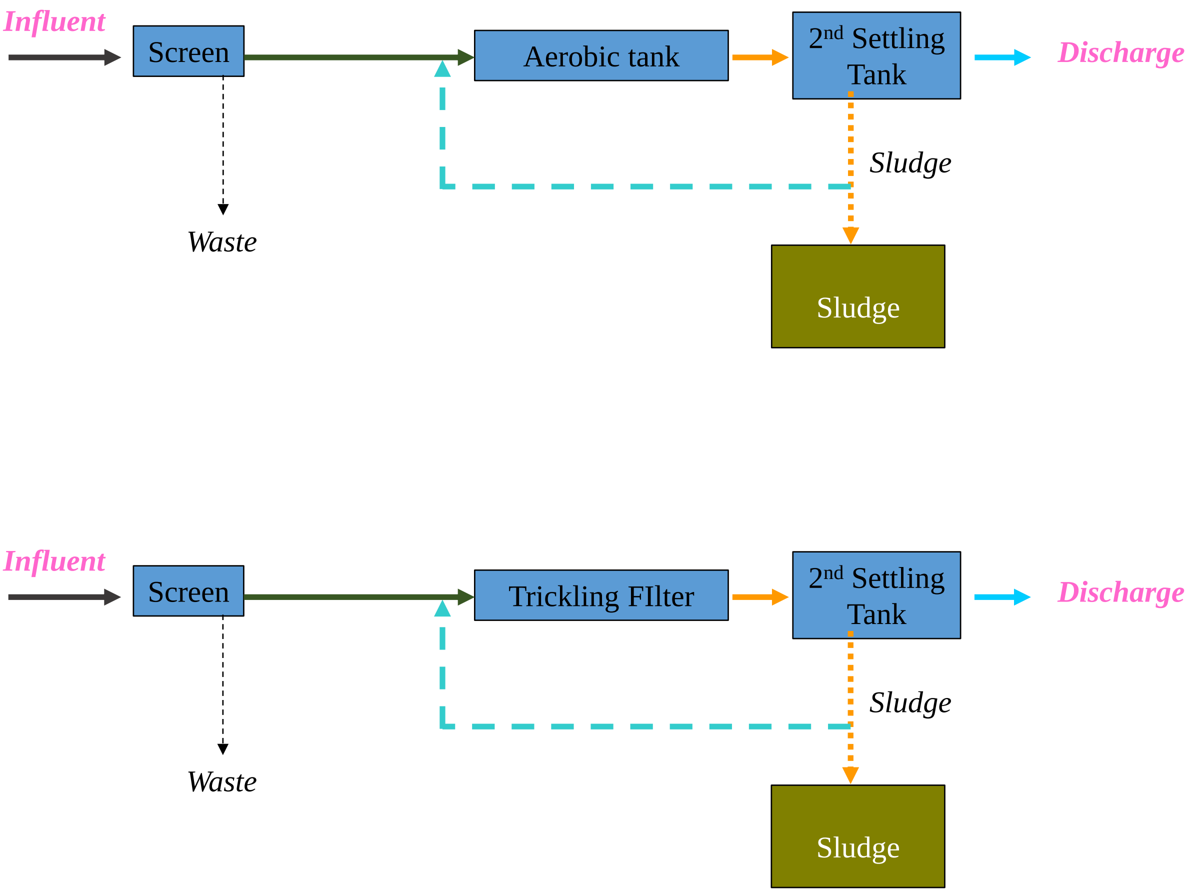
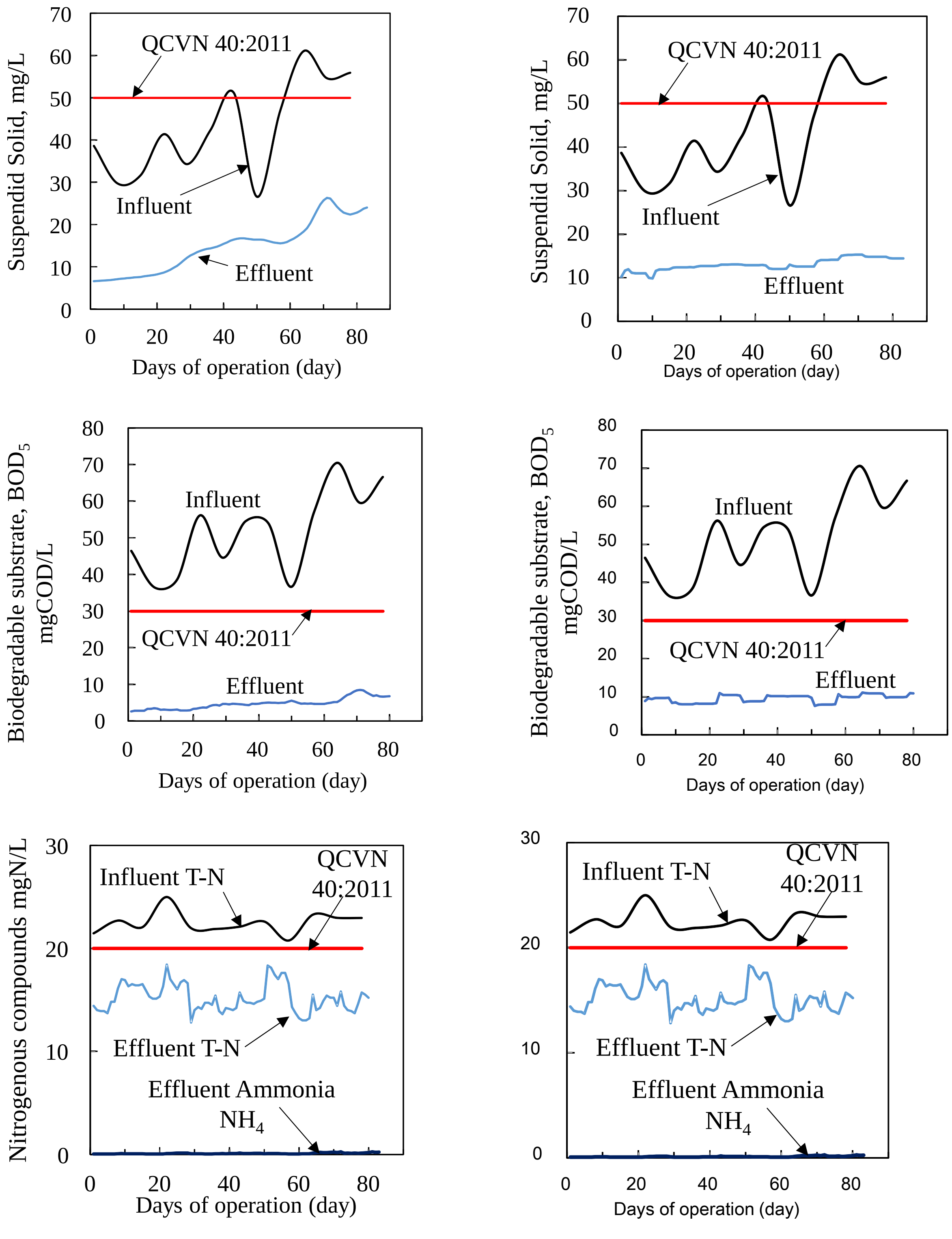


Figure 6.3 Layout of suggestion WWTP

Table 6.2 Parameters of 02 treatment suggestion processes

Parameter	Activated sludge	Trickling filter
Influent flow (m^3/d)	40,000	40,000
Volume (m^3)	4,000	2,400
Dimension		
Area x Height	1,000m^2 x 4m	600m^2 x 4m
HRT (h)	2.4	1.44

Based on the estimation and approach in Chapter 4 and 5, the dynamic simulations for WWTP process were conducted with those calculated in the period of 3months. As shown in **Fig. 6.4**, the model could fairly reproduce the effluent concentrations of suspended solid (SS, mg/L), biodegradable substrate (BOD_5, mgCOD/L) and nitrogen compound (Ammonia and total Nitrogen, mgN/L) with the influent calculated from above. The suggestion process of 40,000 m^3/d WWTP could meet the standard QCVN 40:2011, class A of effluent with high removal efficiency although the influent varied in a bit wide range, Figure 6.2 The effluent SS was always below 30 mg/L while the BOD_5 was under 5mg/L. In addition, Nitrogenous compound could meet the standard although the system have no denitrification process. The well nitrification through trickling filter and activated sludge process could assure the effluent $N\text{-}NH_4$ was always very low (~ 0mg/L) while the total nitrogen was still below 20 mgN/L of standard.



Trickling Filter process *ASR process*

Figure 6.4 Simulation results of WWTP

However, the trickling filter also show the advantage matter than ASR in some aspects. Advantages of TFs are smaller area requirement (Table 6.2) and the low sludge concentration from attached growth process as TF, there are other advantages around reduced complexity and sludge post treatment.

To compare the difference of sludge production between 2 kinds of processes, the calculation for treatment design with differences in SRT of activated sludge process. Table 6.3 shown the sludge production from 2 processes above (data achieved from simulation). It showed that the sludge handling requirement in TF process less than activated sludge process (depend the SRT)

Table 6.3 Sludge production from suggested process

Process type	**Volume of reactor (m^3)**	**Sludge production (kg/d)**
Activated sludge process		
- Conventional AS, SRT: 4 days	2,016	1512
- Normal AS, SRT: 10 days	4,000	1197
- Extended AS, SRT: 20 days	6,100	917
Trickling filter process	2,400	1020

It was easily seen that with activated sludge process, the more SRT the bigger volume of reactors but it would reduce the sludge production daily due to the low volume loading. On the contrary, the TF had the small volume while the daily sludge excess was still small.

In addition, the fixed film systems are less susceptible to toxicity and shock loads than activated sludge systems. However, TFs are more sensitive than suspended growth to temperature drop and typically to cater for cold temperature climates, TFs are oversized for winter. TFs have traditionally taken up more land. With the high rate plastic media TF process, this is no longer the case. Because of the high concentration of biomass attached to the media surface area, the reactors can handle higher loads per unit volume than activated sludge. So, it would be novel application for domestic wastewater in tropical region like Vietnam.

6.4 Conclusion

Through the Hue city case study, the influent estimation method could be used to identifying sewage wastewater characteristics as well as providing necessary information to designing project. These influent state variables (ASM1 based) were also input dataset for simulation.

Combined sewerage wastewater can be treated by using trickling filter process that assure the effluent always met the standard before discharging into watershed. It also was the promising method that can provide suitable operation as well as stable condition with fluctuation of influent characteristics.

Chapter 7: Summary

In the developing countries like Vietnam, along with the rapid growth of population and economy in developing countries, a number of projects to build new municipal wastewater treatment projects were conducted to meet the requirement and ensure water environment. However, the combined sewerage that was very popular lead to many problem and hindrances in wastewater management. The constituents and concentrations of the municipal wastewater were not comparable to those in Western countries due to the installation of septic tank placed prior to the sewer. The requirement of research in technical aspects would be conducted in order to improve the quality of wastewater management as well as providing the suitable solution for Vietnam wastewater issues.

This study need to clarify the current status of wastewater treatment in Vietnam as well as the current applied technologies. Then, some technical matter could solved and improved by following topics. Firstly, an approach of identifying the influent concentration with new method instead of conventional way is provided. Secondary, an insight research of trickling filter was conducted to catch up the engineering parameter of bio-filter process. And, an application fro practical case was present with novel and suitable solution for Vietnam domestic wastewater.

To cope with 1st goal, in the Chapter 3 of this study was aimed at developing an alternative method using on-site lab-scale activated sludge reactors, where a set of mean influent material concentrations was calculated from the analysis of activated sludge constituents of which fluctuation was damped due to long sludge retention time. Focusing on the activated sludge collected from the reactor having a primary settling tank, the soluble biodegradable material concentrations in the influent were calculated using IWA Activated Sludge Model. Similarly the concentrations of inert and biodegradable particulates in the influent were obtained from the increment of activated sludge constituents between the reactor without a primary settling tank and that with a primary settling tank. The specific decay rate of the activated sludge, which was an influential kinetic parameter on the mathematical calculation, was also regularly monitored.

A back-calculation of wastewater concentrations from activated sludge constituents was evaluated using a set of lab-scale on-site activated sludge reactors (with and without primary settling tank) and IWA Activated Sludge Model. From the regular monitoring of the endogenous oxygen uptake rate and COD analysis, the influent state variable concentrations for biodegradable organics and biodegradable nitrogenous materials were estimated. The estimated influent load could dynamically simulate the MLSS and MLVSS concentrations in the activated sludge reactors throughout the continuous operation for 90 days.

The statistical analysis using Monte Carlo method indicated that at least 6 samples had to be collected from each reactor to obtain acceptable mean specific decay rate of the active biomass. When the sampling frequency was reduced to less than four per field test, noticeable statistical error was observed. In addition, the developed method to estimate the influent concentrations required total 60 analytical items per field test including oxygen uptake rates, COD MLSS and MLVSS. Comparing to the conventional water analysis, the method enabled to reduce the analytical items by about 80% when 2- month field analysis was conducted.

On the other hand, the results and comparison in Chapter 4 showed the ability of DPE-optimization tool to estimate the influent characteristics as well as the accuracy in various calculating methods.

On the other hand, ASM-based models can simulate and calculate biological reactors well. Low-cost biological treatment like bio-filter/ trickling filer reactor can be modelled and optimized with a novel design. Hence, to use the model for designing trickling filter process, mechanistic correlations must be developed between the operational conditions and the physical/ kinetic parameters of the model. The process responses of a pilot-scale trickling filter reactor were investigated by changing the hydraulic loadings and analyzed in laboratory.

In Chapter 5, the 2nd topic of this study was answered with a research on investigating influential hydraulic operational parameters on the process performance using a nitrification reactor. The trickling filter process was expressed as 2-dimensional biofilm layers where the influent flowed to the bottom of the filter bed while oxygen was dissolved from the ambient air. The 4 m-height pilot-scale trickling filter filled with tubular plastic media (1.5 cm x 1.5 cm, 371 $m^2/m^3_{\text{–reactor volume}}$) was installed at a municipal wastewater treatment plant in Da Nang, Vietnam. During the 2-day hydraulic stress test, the nitrogen and hydraulic loadings were changed in a step-wise manner. Focusing on the nitrification which was a dominant oxygen uptake, the process performance was dynamically simulated with a modification of IWA Activated Sludge Model.

Assuming constant liquid height on the packing media, an empirical equation to estimate the wetted reactive surface area from the liquid linear velocity (*LV*) was developed. This developed empirical equation was further structured using on non-dimensional engineering parameters ($Re_{,b}$, $Fr_{,b}$ and $We_{,b}$). And, a modified ASM1 equipped with two-step nitrification could simulate the trickling filter effluent (NH_x, NO_2^-, NO_3^- and DO) in the dynamic condition ranging between 2.4 m/h and 18 m/h of liquid linear velocity. Besides, the impact of biofilm particulate advection rates on the process response was evaluated. In principle, the specific attachment rate was thought to be estimated from the removal of influent particulate BOD compounds, while the specific detachment rate had to be calibrated from the effluent concentrations as a theoretical maximum kinetic parameter. The specific particulate inter-exchange rate had low sensitivity for simulating aerobic biological reactions.

Through these above results, Chapter 6 present the application for case study of domestic wastewater in Hue city, Vietnam. A calculation of Hue sewage components was illustrated and they could used for wastewater management. In addition, the layout of suggested wastewater treatment process and its simulation results provide the sustainable and low-cost approach for combined drainage system.

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Publication List

Journal Papers

1. **Nguyen Duong Quang Chanh**, Liu Bing, Tran Van Quang, Mitsuharu Terashima, Rajeev Goel, Hidenari Yasui (2016). Dynamic Simulation of Trickling Filter Process with Hydraulic Stress Tests. J**ournal of Water and Environment Technology** Vol.14, No.5, pp.398-410.

2. Bing Liu, Ian Jarvis, Hong Ren, **Chanh Nguyen Duong Quang**, Mitsuharu Terashima, Hidenari Yasui (2016). Biofilm Modelling and Kinetics in a Trickling Filter Process. **Journal of Water and Environment Technology** Vol.14, No.3, pp.200-210.

3. **Nguyen Duong Quang Chanh**, Le Van Tuan, Tran Van Quang, Bing Liu, Mitsuharu Terashima, Nguyen Thi Ha, Le Van Chieu, Hidenori Harada, Hidenari Yasui. An Alternative Method to estimate Influent Concentration using On-site Lab-scale Activated Sludge Reactors. **Journal of Water and Environment Technology** (In progress).

International conference paper

1. **Nguyen Duong Quang Chanh,** Liu Bing, Tran Van Quang, Mitsuharu Terashima, Rajeev Goel, Hidenari Yasui. Engineering Keys on Modelling a Trickling Filter Process. **Proceeding of the 6th IWA-ASPIRE Conference and Exhibition**, 20-24th September, 2015 Beijing, China.

2. **Nguyen Duong Quang Chanh**, Tran Van Quang,Bing Liu, Mitsuharu Terashima, Hidenari Yasui. An Approach to Calculate Wastewater Organic Concentrations from the Activated Sludge Reactor. Water and Environment Technology conference 2016, 27-28th August, 2016, Tokyo, Japan.

3. **Chanh Quang Nguyen Duong**, Mitsuharu Terashima1, Hidenari Yasui, Tuan Van Le, Ha Thi Nguyen, Chieu Van Le. Estimation of biodegradable material concentrations in the sewage using IWA activated sludge model. International Forum on Green Technology and Management (IFGTM) 2017. (In progress)

Appendix

- Data collected from ASM experimental pilot in Danang city and Hue city

    + OUR datasets

    + NOUR datasets

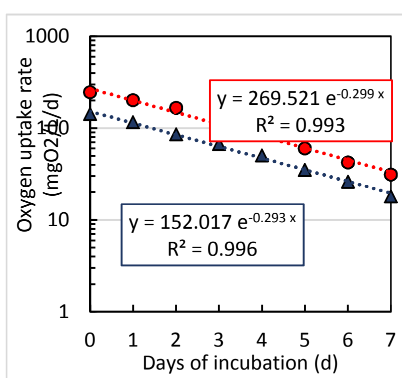
    + Calculated results from ASM based equation

    + Layout and simulation condition of ASP in GPS-X

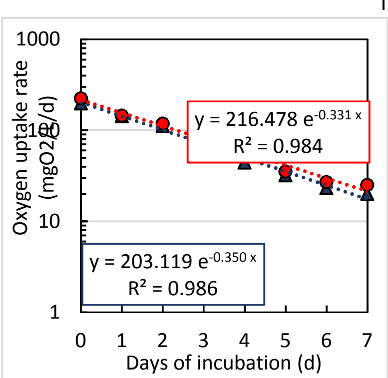
- Data of Trickling Filter process

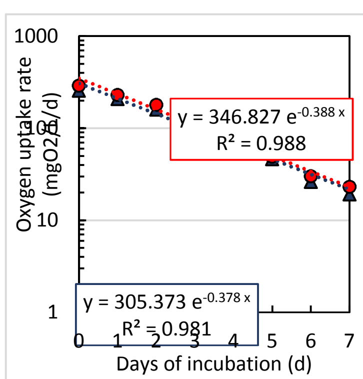
Oxygen uptake rate		Sep/01-Sep/08	
Danang wastewater		ASR #1	ASR #2
Phu loc WWTP		OUR (mgO_2/L/d)	OUR (mgO_2/L/d)
	0	142	245
	1	115	200
	2	85	165
	3	67	112
	4	50	87
	5	35	60
	6	26	42
	7	18	31
	8	15	26
		ln(OUR)	
	0	4.96	5.50
	1	4.74	5.30
	2	4.44	5.11
	3	4.20	4.72
	4	3.91	4.47
	5	3.56	4.09
	6	3.26	3.74
	7	2.89	3.43
	8	2.71	3.26
Specific decay rate ,day^{-1}			
$b'_{H\ (ASM3)}$		0.293	0.299
$b'_{H\ (min.\ 95\%)}$		0.270	0.276
$b'_{H\ (max.\ 95\%)}$		0.320	0.321
Intercept (regression)		5.02	5.59
Intercept (min. 95%)		5.10	5.70
Intercept (max. 95%)		4.94	5.49

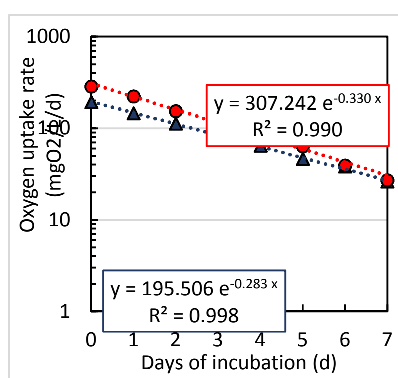
Thickend sludge		
Initial OUR, mgO2/L/d	142	245
Estimated initial X_{BH} (thickened), mgCOD/L	606	1023
MLSS, mg/L	1203	1366
MLVSS, mg/L	702	757
MLVSS $_{(thickened)}$,mg/L	657	869
$X_{total\_org\ (thickened)}$, mgCOD/L	959	1269
Thickening factor	94%	115%
X_{OHO} ,mgCOD/L	647	891



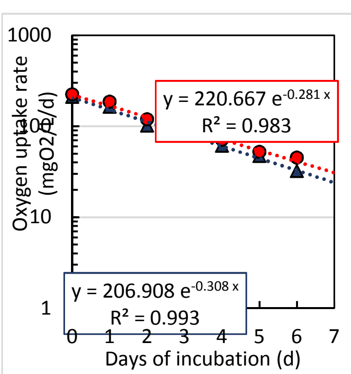
Sep/09-Sep/15		Sep/16-Sep/22		Sep/23-Sep/29	
ASR #1	ASR #2	ASR #1	ASR #2	ASR #1	ASR #2
OUR ($mgO_2/L/d$)	OUR ($mgO_2/L/d$)	OUR ($mgO_2/L/d$)	OUR ($mgO_2/L/d$)	OUR ($mgO_2/L/d$)	OUR ($mgO_2/L/d$)
196	224	254	289	192	285
142	145	206	228	145	222
112	118	158	179	112	153
79	86	112	131	86	121
44	59	83	80	64	96
32	35	46	49	46	63
23	27	26	30	38	39
20	25	19	23	26	27
		16	15	20	23
ln(OUR)		ln(OUR)		ln(OUR)	
5.28	5.41	5.54	5.67	5.26	5.65
4.96	4.98	5.33	5.43	4.98	5.40
4.72	4.77	5.06	5.19	4.72	5.03
4.37	4.45	4.72	4.88	4.45	4.80
3.78	4.08	4.42	4.38	4.16	4.56
3.47	3.56	3.83	3.89	3.83	4.14
3.14	3.30	3.26	3.40	3.64	3.66
3.00	3.22	2.94	3.14	3.26	3.30
		2.77	2.71	3.00	3.14
0.350	0.331	0.378	0.388	0.283	0.330
0.308	0.297	0.331	0.350	0.253	0.300
0.392	0.365	0.425	0.426	0.302	0.359
5.31	5.69	5.72	5.84	5.27	5.72
5.14	5.83	5.95	5.67	5.32	5.86
5.49	5.55	5.49	6.02	5.22	5.58
196	224	254	289	192	285
699	846	840	932	849	1080
1110	1852	1200	1616	1332	1622
661	956	665	786	710	868
780	1002	997	1160	979	1338
1139	1463	1456	1694	1429	1953
118%	105%	150%	148%	138%	154%
593	807	560	631	615	700

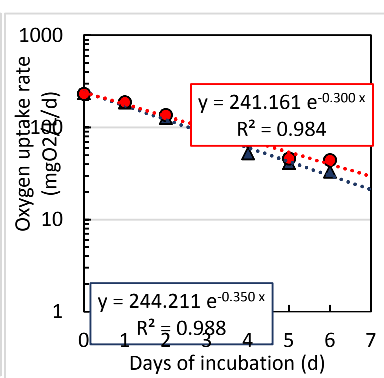


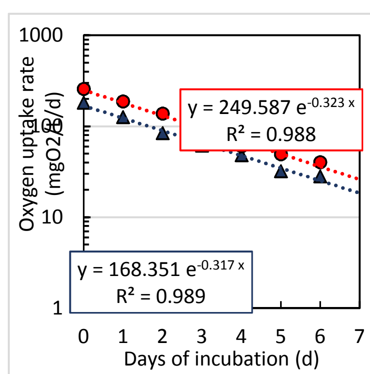




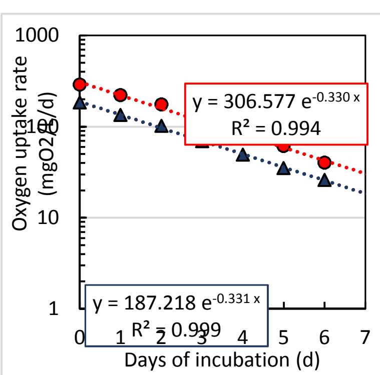
Sep/30-Oct/06		Oct/07-Oct/14		Oct/15-Oct/21	
ASR #1	ASR #2	ASR #1	ASR #2	ASR #1	ASR #2
OUR ($mgO_2/L/d$)	OUR ($mgO_2/L/d$)	OUR ($mgO_2/L/d$)	OUR ($mgO_2/L/d$)	OUR ($mgO_2/L/d$)	OUR ($mgO_2/L/d$)
209	224	234	230	180	255
163	185	186	187	125	186
101	119	127	136	84	137
80	85	86	102	61	89
61	71	52	72	48	60
47	52	41	46	32	49
32	45	33	44	28	40
ln(OUR)		ln(OUR)		ln(OUR)	
5.34	5.41	5.46	5.44	5.19	5.54
5.09	5.22	5.23	5.23	4.83	5.23
4.62	4.78	4.84	4.91	4.43	4.92
4.38	4.44	4.45	4.62	4.11	4.49
4.11	4.26	3.95	4.28	3.87	4.09
3.85	3.95	3.71	3.83	3.47	3.89
3.47	3.81	3.50	3.78	3.33	3.69
0.308	0.281	0.355	0.300	0.317	0.323
0.277	0.238	0.305	0.256	0.278	0.281
0.338	0.323	0.394	0.344	0.354	0.364
5.33	5.39	5.49	5.48	5.12	5.52
5.44	5.54	5.65	5.64	5.26	5.60
5.22	5.24	5.33	5.32	4.98	5.36
209	224	234	230	180	255
847	998	824	957	711	988
1426	1696	1421	1770	1170	1436
650	860	777	875	631	730
626	943	831	966	761	784
914	1377	1213	1410	1111	1145
96%	110%	107%	110%	121%	107%
880	910	771	867	589	920

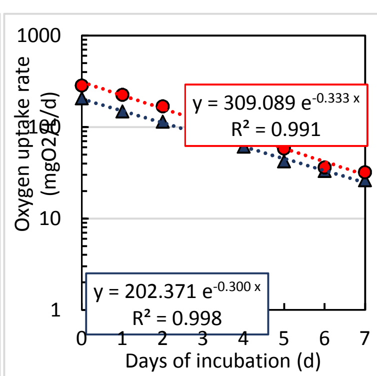


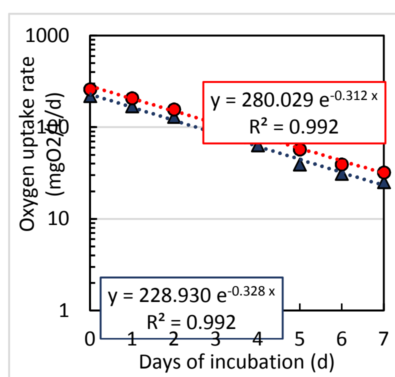




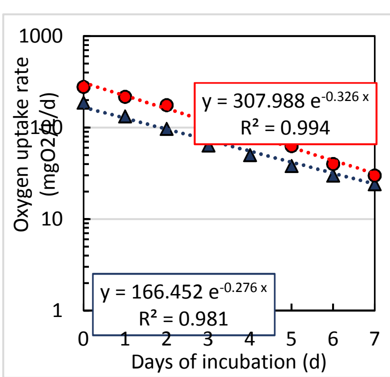
Oct/22-Oct/28		Oct/23-Nov/4		Nov/5-Nov/10	
ASR #1	ASR #2	ASR #1	ASR #2	ASR #1	ASR #2
OUR (mgO_2/L/d)	OUR (mgO_2/L/d)	OUR (mgO_2/L/d)	OUR (mgO_2/L/d)	OUR (mgO_2/L/d)	OUR (mgO_2/L/d)
183	287	205	284	218	257
134	220	147	224	168	206
102	175	114	168	129	156
69	113	83	123	87	118
49	82	61	84	63	87
35	61	42	58	39	57
26	40	33	36	31	39
		26	32	25	32
ln(OUR)		ln(OUR)		ln(OUR)	
5.21	5.66	5.32	5.65	5.38	5.55
4.90	5.39	4.99	5.41	5.12	5.33
4.62	5.16	4.74	5.12	4.86	5.05
4.23	4.73	4.42	4.81	4.47	4.77
3.89	4.41	4.11	4.43	4.14	4.47
3.56	4.11	3.74	4.06	3.66	4.04
3.26	3.69	3.50	3.58	3.43	3.66
		3.26	3.47	3.22	3.47
0.331	0.330	0.300	0.333	0.328	0.312
0.316	0.300	0.285	0.305	0.298	0.284
0.345	0.359	0.315	0.365	0.356	0.339
5.23	5.72	5.31	5.73	5.45	5.63
5.28	5.83	5.37	5.87	5.53	5.75
5.18	5.61	5.24	5.59	5.31	5.52
183	287	205	284	218	257
691	1087	853	1066	831	1029
1278	1470	1423	1536	1293	1598
599	757	778	840	726	875
636	1298	817	1538	750	1279
929	1895	1193	2245	1095	1867
106%	171%	105%	183%	103%	146%
651	634	813	582	804	704

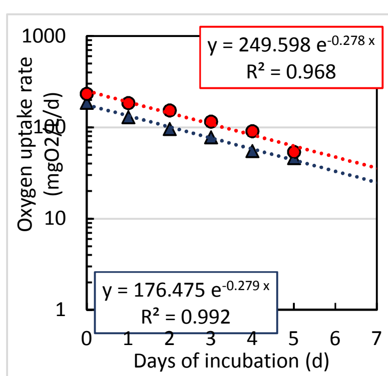






Nov/11-Nov/18		Nov/19-Nov/25	
ASR #1	ASR #2	ASR #1	ASR #2
OUR (mgO_2/L/d)	OUR (mgO_2/L/d)	OUR (mgO_2/L/d)	OUR (mgO_2/L/d)
188	279	186	233
133	217	130	185
97	176	96	153
64	123	78	116
50	88	55	91
38	63	46	54
30	40		
24	30		
22	23		
ln(OUR)		ln(OUR)	
5.24	5.63	5.23	5.45
4.89	5.38	4.87	5.22
4.57	5.17	4.56	5.03
4.16	4.81	4.36	4.75
3.91	4.48	4.01	4.51
3.64	4.14	3.83	3.99
3.40	3.69		
3.18	3.40		
3.09	3.14		
0.276	0.326	0.279	0.278
0.241	0.303	0.243	0.234
0.311	0.348	0.315	0.304
5.11	5.73	5.17	5.51
5.28	5.84	5.28	5.73
4.94	5.62	5.06	5.30
188	279	186	233
853	1071	834	1046
1335	1758	1315	1497
649	892	742	798
722	1216	793	982
1054	1775	1158	1434
111%	136%	107%	123%
767	785	781	850





Nitrogenous Oxygen Uptake Rate

$Y_{B,H}$	**0.24**	COD/gCOD
$\mu_{maxANO,2}$	**1.00**	day^{-1}
b_{ANO}	**0.15**	day^{-1}

q	1.070	-
q_H	day^{-1}	4.5
q_S	day^{-1}	0.1

2016

Date	Temp	μ_{maxANO}	NOUR		$X_{A,H}$		b_{ANO}	Snh	snh+xnd	xnd
	^oC	day^{-1}	mgO2/L.d		mgCOD/L		day^{-1}	mgN/L	mgN/L	mgN/L
			ASR#1	ASR#2	ASR#1	ASR#2				
1-Sep	28.6	1.789	407	412	12.6	12.8	0.27	**4.3**	**4.4**	**0.1**
2-Sep	27.5	1.661	421	385	14.0	12.9	0.25	4.3	4.4	0.1
3-Sep	26.5	1.552	382	380	13.6	13.6	0.23	4.3	4.4	0.1
4-Sep	27.0	1.606	364	409	12.6	14.1	0.24	4.3	4.4	0.1
5-Sep	27.0	1.606	379	400	13.1	13.8	0.24	4.3	4.4	0.1
6-Sep	27.3	1.639	329	413	11.1	14.0	0.25	4.3	4.4	0.1
7-Sep	28.5	1.777	329	413	11.1	14.0	0.27	4.3	4.4	0.1
8-Sep	28.0	1.718	395	467	12.8	15.1	0.26	**4.2**	**5.1**	**0.9**
9-Sep	28.5	1.777	356	385	11.1	12.0	0.27	4.2	5.1	0.9
10-Sep	27.0	1.606	342	550	11.8	19.0	0.24	4.2	5.1	0.9
11-Sep	25.0	1.403	329	550	13.0	21.7	0.21	4.2	5.1	0.9
12-Sep	24.0	1.311	336	513	14.2	21.7	0.20	4.2	5.1	0.9
13-Sep	24.5	1.356	334	515	13.6	21.1	0.20	4.2	5.1	0.9
14-Sep	25.5	1.451	334	515	13.6	21.1	0.22	4.2	5.1	0.9
15-Sep	26.0	1.501	331	422	12.2	15.6	0.23	**3.6**	**4.7**	**1.1**
16-Sep	27.0	1.606	355	603	12.2	20.8	0.24	3.6	4.7	1.1
17-Sep	28.0	1.718	367	522	11.8	16.9	0.26	3.6	4.7	1.1
18-Sep	27.6	1.672	307	472	10.2	15.6	0.25	3.6	4.7	1.1
19-Sep	27.3	1.639	346	546	11.7	18.5	0.25	3.6	4.7	1.1
20-Sep	27.0	1.606	382	548	13.2	18.9	0.24	3.6	4.7	1.1
21-Sep	27.5	1.661	376	524	12.6	17.5	0.25	3.6	4.7	1.1
22-Sep	27.0	1.606	345	530	11.9	18.3	0.24	3.6	4.7	1.1
23-Sep	28.0	1.718	345	530	11.9	18.3	0.26	**3.9**	**6.2**	**2.3**
24-Sep	28.5	1.777	430	552	13.4	17.2	0.27	3.9	6.2	2.3
25-Sep	28.5	1.777	567	577	17.7	18.0	0.27	3.9	6.2	2.3
26-Sep	28.5	1.777	441	494	13.8	15.4	0.27	3.9	6.2	2.3
27-Sep	26.5	1.552	505	504	18.0	18.0	0.23	3.9	6.2	2.3
28-Sep	27.0	1.606	300	581	10.3	20.0	0.24	3.9	6.2	2.3
29-Sep	26.8	1.584	448	514	15.7	18.0	0.24	3.9	6.2	2.3
30-Sep	27.0	1.606	448	618	15.5	21.3	0.24	**5.1**	**6.9**	**1.8**
1-Oct	27.5	1.661	266	625	8.9	20.9	0.25	5.1	6.9	1.8
2-Oct	27.6	1.672	267	649	8.8	21.5	0.25	5.1	6.9	1.8
3-Oct	27.5	1.661	399	494	13.3	16.5	0.25	5.1	6.9	1.8
4-Oct	26.4	1.542	411	563	14.8	20.3	0.23	5.1	6.9	1.8
5-Oct	27.4	1.650	389	504	13.1	16.9	0.25	5.1	6.9	1.8
6-Oct	28.2	1.742	362	483	11.5	15.4	0.26	**3.6**	**5.0**	**1.4**
7-Oct	28.0	1.718	420	467	13.6	15.1	0.26	3.6	5.0	1.4
8-Oct	25.6	1.461	376	618	14.3	23.5	0.22	3.6	5.0	1.4
9-Oct	26.8	1.584	405	576	14.2	20.1	0.24	3.6	5.0	1.4
10-Oct	26.0	1.501	389	493	14.4	18.2	0.23	3.6	5.0	1.4
11-Oct	26.5	1.552	412	484	14.7	17.3	0.23	3.6	5.0	1.4

Date	Temp	μ_{maxANO}	NOUR		$X_{A,H}$		b_{ANO}	Snh	snh+xnd	xnd
	^oC	*day*$^{-1}$	*mgO2/L.d*		*mgCOD/L*		**day**$^{-1}$	mgN/L	mgN/L	mgN/L
			ASR#1	**ASR#2**	**ASR#1**	**ASR#2**				
12-Oct	25.0	1.403	376	691	14.9	27.3	0.21	3.6	5.0	1.4
13-Oct	25.2	1.422	397	599	15.5	23.4	0.21	3.6	5.0	1.4
14-Oct	26.0	1.501	405	467	15.0	17.3	0.23	**4.7**	**5.3**	**0.6**
15-Oct	28.2	1.742	395	513	12.6	16.3	0.26	4.7	5.3	0.6
16-Oct	28.7	1.802	420	430	12.9	13.2	0.27	4.7	5.3	0.6
17-Oct	27.6	1.672	399	421	13.2	13.9	0.25	4.7	5.3	0.6
18-Oct	27.4	1.650	384	655	12.9	22.0	0.25	4.7	5.3	0.6
19-Oct	24.4	1.347	389	517	16.0	21.3	0.20	4.7	5.3	0.6
20-Oct	24.6	1.365	387	411	15.7	16.7	0.20	4.7	5.3	0.6
21-Oct	29.0	1.838	392	515	11.8	15.5	0.28	**3.9**	**5.0**	**1.1**
22-Oct	26.1	1.511	430	540	15.8	19.8	0.23	3.9	5.0	1.1
23-Oct	26.0	1.501	429	460	15.8	17.0	0.23	3.9	5.0	1.1
24-Oct	26.2	1.521	394	495	14.4	18.0	0.23	3.9	5.0	1.1
25-Oct	26.6	1.563	386	220	13.7	7.8	0.23	3.9	5.0	1.1
26-Oct	26.7	1.574	385	461	13.6	16.2	0.24	3.9	5.0	1.1
27-Oct	28.3	1.753	397	458	12.6	14.5	0.26	3.9	5.0	1.1
28-Oct	26.8	1.584	404	448	14.2	15.7	0.24	**4.3**	**4.8**	**0.5**
29-Oct	26.6	1.563	498	554	17.7	19.6	0.23	4.3	4.8	0.5
30-Oct	25.3	1.431	386	508	14.9	19.7	0.21	4.3	4.8	0.5
31-Oct	26.5	1.552	377	483	13.5	17.2	0.23	4.3	4.8	0.5
1-Nov	25.7	1.471	412	446	15.5	16.8	0.22	4.3	4.8	0.5
2-Nov	26.9	1.595	382	283	13.3	9.8	0.24	4.3	4.8	0.5
3-Nov	25.6	1.461	410	406	15.6	15.4	0.22	4.3	4.8	0.5
4-Nov	26.0	1.501	386	452	14.3	16.7	0.23	**4.4**	**5.1**	**0.8**
5-Nov	26.5	1.552	421	476	15.0	17.0	0.23	4.4	5.1	0.8
6-Nov	27.9	1.707	367	171	11.9	5.6	0.26	4.4	5.1	0.8
7-Nov	27.0	1.606	403	503	13.9	17.3	0.24	4.4	5.1	0.8
8-Nov	27.3	1.639	410	506	13.9	17.1	0.25	4.4	5.1	0.8
9-Nov	26.8	1.584	392	543	13.7	19.0	0.24	4.4	5.1	0.8
10-Nov	26.5	1.552	429	446	15.3	15.9	0.23	4.4	5.1	0.8
11-Nov	27.0	1.606	390	368	13.5	12.7	0.24	**4.1**	**3.9**	**0.0**
12-Nov	26.8	1.584	389	319	13.6	11.2	0.24	4.1	3.9	0.0
13-Nov	26.5	1.552	419	446	15.0	15.9	0.23	4.1	3.9	0.0
14-Nov	26.3	1.532	377	438	13.7	15.9	0.23	4.1	3.9	0.0
15-Nov	27.0	1.606	427	456	14.7	15.7	0.24	4.1	3.9	0.0
16-Nov	26.7	1.574	372	496	13.1	17.5	0.24	4.1	3.9	0.0
17-Nov	27.0	1.606	399	474	13.8	16.4	0.24	4.1	3.9	0.0
18-Nov	26.7	1.574	419	516	14.8	18.2	0.24	4.1	3.9	0.0
19-Nov	26.0	1.501	382	464	14.1	17.1	0.23	**4.2**	**5.5**	**1.3**
20-Nov	26.0	1.501	465	482	17.2	17.8	0.23	4.2	5.5	1.3
21-Nov	25.8	1.481	423	439	15.8	16.4	0.22	4.2	5.5	1.3
22-Nov	25.0	1.403	386	509	15.3	20.1	0.21	4.2	5.5	1.3
23-Nov	25.3	1.431	317	379	12.3	14.7	0.21	4.2	5.5	1.3
24-Nov	25.4	1.441	422	428	16.2	16.5	0.22	4.2	5.5	1.3
25-Nov	25	1	435	535	17.2	21.1	0.21	**5.1**	**6.3**	**1.2**

Oxygen uptake rate

Danang wastewater

Phu loc WWTP

ASR#1

		Specific decay rate								
	Temperatu	b_H (ASM3) average	b_H (min. 95%)	b_H (max. 95%)				b_{H_20}		
	Celsius				**Ө**	**T0**	**ΔT**	**average**	**lower 95%**	**upper 95%**
Sep/01-Sep/08	29.6	0.293	0.270	0.320	1.07	20	9.6	0.153	0.141	0.167
Sep/09-Sep/15	30.6	0.350	0.308	0.392	1.07	20	10.6	0.171	0.150	0.191
Sep/16-Sep/22	30.6	0.378	0.331	0.425	1.07	20	10.6	0.185	0.162	0.207
Sep/23-Sep/29	29.3	0.283	0.253	0.302	1.07	20	9.3	0.151	0.135	0.161
Sep/30-Oct/06	28.3	0.308	0.277	0.338	1.07	20	8.3	0.176	0.158	0.193
Oct/07-Oct/14	27.9	0.355	0.305	0.394	1.07	20	7.9	0.208	0.179	0.231
Oct/15-Oct/21	29.0	0.317	0.278	0.354	1.07	20	9.0	0.172	0.151	0.193
Oct/22-Oct/28	29.7	0.331	0.316	0.345	1.07	20	9.7	0.172	0.164	0.179
Oct/23-Nov/4	27.9	0.300	0.285	0.315	1.07	20	7.9	0.176	0.167	0.185
Nov/5-Nov/10	28.6	0.328	0.298	0.356	1.07	20	8.6	0.183	0.167	0.199
Nov/11-Nov/18	28.9	0.276	0.241	0.311	1.07	20	8.9	0.151	0.132	0.170
Nov/19-Nov/25	29.0	0.279	0.243	0.315	1.07	20	9.0	0.152	0.132	0.171

ASR#2

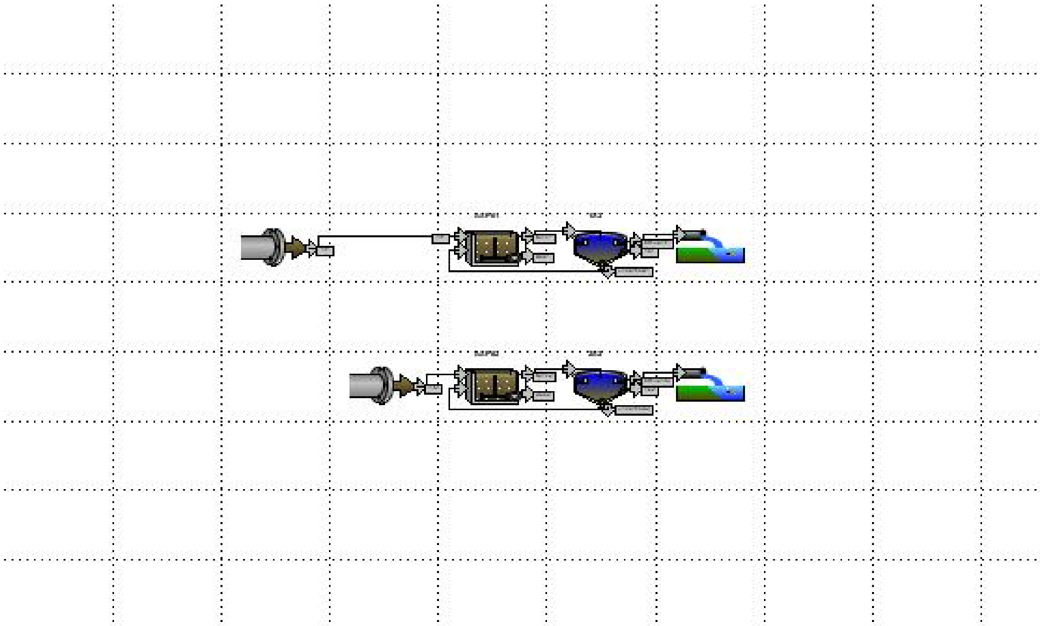
		Specific decay rate							b_{H_20}	
	Temperatu Celsius	b_H (ASM3) average	b_H (min. 95%)	b_H (max. 95%)	**Ɵ**	**T0**	**ΔT**	**average**	**lower 95%**	**upper 95%**
Sep/01-Sep/08	29.6	0.299	0.276	0.321	1.07	20	9.6	0.156	0.144	0.168
Sep/09-Sep/15	30.6	0.331	0.297	0.365	1.07	20	10.6	0.162	0.145	0.178
Sep/16-Sep/22	29.6	0.388	0.350	0.426	1.07	20	9.6	0.202	0.183	0.222
Sep/23-Sep/29	29.3	0.330	0.300	0.359	1.07	20	9.3	0.176	0.160	0.191
Sep/30-Oct/06	28.3	0.281	0.238	0.323	1.07	20	8.3	0.160	0.136	0.184
Oct/07-Oct/14	27.4	0.300	0.256	0.344	1.07	20	7.4	0.182	0.155	0.209
Oct/15-Oct/21	29.7	0.323	0.281	0.364	1.07	20	9.7	0.167	0.146	0.189
Oct/22-Oct/28	30.0	0.330	0.300	0.359	1.07	20	10.0	0.168	0.153	0.182
Oct/23-Nov/4	28.6	0.333	0.305	0.365	1.07	20	8.6	0.186	0.170	0.204
Nov/5-Nov/10	28.9	0.312	0.284	0.339	1.07	20	8.9	0.171	0.156	0.186
Nov/11-Nov/18	28.9	0.326	0.303	0.348	1.07	20	8.9	0.178	0.166	0.191
Nov/19-Nov/25	29.0	0.278	0.234	0.304	1.07	20	9.0	0.151	0.127	0.165

Maximum Nitrogenous oxygen uptake rate

		Simulation		Measured	
	t	MaxNOUR#1	MaxNOUR#2	ASR#1	ASR#2
	days	mgO2/(L.d)	mgO2/(L.d)	mgO2/(L.d)	mgO2/(L.d)
1-Sep	1	571	587	398	403
2-Sep	2	507	526	407	412
3-Sep	3	448	476	421	423
4-Sep	4	449	482	382	385
5-Sep	5	441	475	364	409
6-Sep	6	436	479	379	400
7-Sep	7	470	517	329	413
8-Sep	8	450	520		
9-Sep	9	462	565	395	467
10-Sep	10	414	528	356	385
11-Sep	11	358	469	342	550
12-Sep	12	329	444	329	550
13-Sep	13	338	465	336	513
14-Sep	14	362	503	334	515
15-Sep	15	362	515		
16-Sep	16	382	553	331	654
17-Sep	17	400	592	355	603
18-Sep	18	374	575	367	522
19-Sep	19	351	560	307	472
20-Sep	20	340	545	346	546
21-Sep	21	350	543	382	548
22-Sep	22	339	508	376	524
23-Sep	23	370	571	345	530
24-Sep	24	367	586		
25-Sep	25	355	585	430	552
26-Sep	26	349	593	567	577
27-Sep	27	306	525	441	494
28-Sep	28	316	552	505	509
29-Sep	29	310	545	300	581
30-Sep	30	355	580	448	514
1-Oct	31	407	622	448	618
2-Oct	32	437	641	266	625
3-Oct	33	454	652	267	649
4-Oct	34	429	611	399	494
5-Oct	35	473	662	411	563
6-Oct	36	468	650	389	504
7-Oct	37	449	612	362	483
8-Oct	38	368	501	420	467
9-Oct	39	388	530	376	618
10-Oct	40	356	491	405	576
11-Oct	41	362	497	389	493
12-Oct	42	321	438	412	484
13-Oct	43	321	439	376	691

14-Oct	44	369	470	397	599
15-Oct	45	491	579	405	467
16-Oct	46	557	616	395	513
17-Oct	47	542	583	420	430
18-Oct	48	554	582	399	421
19-Oct	49	456	475	384	655
20-Oct	50	466	483	389	517
21-Oct	51	614	646	387	411
22-Oct	52	473	505	392	515
23-Oct	53	450	488	430	540
24-Oct	54	436	486	429	460
25-Oct	55	430	493	394	495
26-Oct	56	422	492	386	425
27-Oct	57	461	548	385	461
28-Oct	58	418	487	397	458
29-Oct	59	397	460	404	448
30-Oct	60	360	408	498	554
31-Oct	61	388	434	386	508
1-Nov	62	367	407	377	483
2-Nov	63	395	440	412	446
3-Nov	64	367	403	382	436
4-Nov	65	385	421	410	426
5-Nov	66	405	449	386	452
6-Nov	67	447	505	421	476
7-Nov	68	425	481	367	378
8-Nov	69	442	497	403	503
9-Nov	70	429	482	410	506
10-Nov	71	425	471	392	543
11-Nov	72	431	462	429	446
12-Nov	73	425	436	390	398
13-Nov	74	414	412	389	419
14-Nov	75	405	393	419	446
15-Nov	76	424	404	377	438
16-Nov	77	417	389	427	456
17-Nov	78	416	389	372	496
18-Nov	79	410	377	399	474
19-Nov	80	389	389	419	516
20-Nov	81	393	414	382	464
21-Nov	82	389	427	465	482
22-Nov	83	369	415	423	439
23-Nov	84	381	434	386	509
24-Nov	85	388	442	317	379

asp_n



Simulation Setup		
Time		
stopping time	150	[d]
communication interval	1	[h]
date and time at t=0	2016	[yr,m,d,h,min,s]
	5	
	1	
	10	
	0	
	0	
initial time	0	[d]
Rounding		
round seconds to full minutes	Off	
round minutes to quarter hours	Off	
Repeat Runs		
number of reruns	0	
Consistency Check		
show process warnings	Off	
Process Warnings		
write process warnings into file	Off	
process warnings only once per run	On	
Aeration Limit Settings		
apply aeration limits (airflow per diffuser)	Off	
show aeration limit warning	On	
Model Check		
warn user when states and models don't match	On	
Display of Discontinuous Pump Flows (SBR and BAF units only)		
display concentrations in discontinuous pump flows at all	Off	

Physical

Oxygen Solubility (layout-wide settings)

liquid temperature	20	[C]
blower inlet air temperature	20	[C]
elevation above sea level	0	[m]
barometric pressure at sea level	1	[atm]
standard air conditions	U.S. (air temp 20C, 36% humidity)	
Physical Constants		
molecular weight of air (@ U.S. Standard Conditions)	29	[g/mol]
gas constant	8310	[J/kmol.K]
Antoine coefficient A1	8.11	[-]
Antoine coefficient A2	1750	[-]
Antoine coefficient A3	235	[-]
Properties of User-Defined Air		
mole fraction of oxygen in user-defined air	1	[-]
density of user-defined air	1430	[mg/L]
molecular weight of user-defined air	32	[g/mole]
exponent in blower power equation	0.284	[-]
SOTE Regression Coefficients		
SOTE regression constant A1 (ceramic disc)	12.1	[-]
SOTE regression constant A2 (ceramic disc)	-3.24	[-]
SOTE regression constant A3 (ceramic disc)	0.0816	[-]
SOTE regression constant A4 (ceramic disc)	1.22	[-]
SOTE regression constant A5 (ceramic disc)	0.158	[-]
SOTE regression constant A1 (ceramic dome)	19.8	[-]
SOTE regression constant A2 (ceramic dome)	-13.6	[-]
SOTE regression constant A3 (ceramic dome)	3.07	[-]
SOTE regression constant A4 (ceramic dome)	1.11	[-]
SOTE regression constant A5 (ceramic dome)	0.172	[-]
SOTE regression constant A1 (membrane disc)	8.48	[-]
SOTE regression constant A2 (membrane disc)	-5.38	[-]
SOTE regression constant A3 (membrane disc)	1.06	[-]
SOTE regression constant A4 (membrane disc)	1.73	[-]
SOTE regression constant A5 (membrane disc)	-0.0233	[-]
SOTE regression constant A1 (membrane tube)	7.57	[-]
SOTE regression constant A2 (membrane tube)	-2.72	[-]
SOTE regression constant A3 (membrane tube)	0.15	[-]
SOTE regression constant A4 (membrane tube)	1.5	[-]
SOTE regression constant A5 (membrane tube)	0.156	[-]
SOTE regression constant A1 (coarse bubble)	3.79	[-]
SOTE regression constant A2 (coarse bubble)	-0.0927	[-]
SOTE regression constant A3 (coarse bubble)	0.00108	[-]
SOTE regression constant A4 (coarse bubble)	0.266	[-]
SOTE regression constant A5 (coarse bubble)	0.0236	[-]
SOTE regression constant A1 (jet)	1.43	[-]
SOTE regression constant A2 (jet)	-0.268	[-]
SOTE regression constant A3 (jet)	0.00424	[-]
SOTE regression constant A4 (jet)	1.35	[-]
SOTE regression constant A5 (jet)	0.00522	[-]
Deep Tank SOTE Regression Coefficients		
Deep Tank SOTE regression constant A6 (ceramic disc)	-0.00419	[-]
Deep Tank SOTE regression constant A6 (ceramic dome)	-0.00389	[-]
Deep Tank SOTE regression constant A6 (membrane disc)	-0.00909	[-]
Deep Tank SOTE regression constant A6 (membrane tube	-0.00725	[-]

Settling Correlations

SVI Correlation Coefficients

SVI correlation coeff. 1	710
SVI correlation coeff. 2	-4.67
SVI correlation coeff. 3	0.018
SVI correlation coeff. 4	0.000266
SVI correlation coeff. 5	-2.9E-06
SVI correlation coeff. 6	2.5E-08
SVI correlation coeff. 7	-0.00016
SVI correlation coeff. 8	0.0049
SVI correlation coeff. 9	0.000647

Steady-State

Steady-State Parameters

number of retries on iteration	1
error limit on individual variables	1E-10
iteration termination criteria	5
maximum number of iterations	100000
maximum number of unsuccessful iterations	20000

Iteration Search Setup

force iteration even if model converged	On
contract constant	0.982
expand constant	1
maximum step size in one iteration	0.5
damping factor on final approach	1
initial perturbation	0.05
convergence output interval	200
steady-state loop counter initial value	0

Trim Parameters

print value of dsum	1E+10 [d]
display improved iterations only	On
iteration output interval in trim	50000

Analyzer

Monte Carlo Analysis

number of runs	1000

Optimizer

Static

number of optimized parameters	1
number of data points (at least 2)	2048
parameter tolerance	0.000001
objective function tolerance	-1E+10
scaled termination value for objective function	0.1
maximum number of optimizer iterations	200
detailed statistical report	Off
solution report to file	Off

Optimizer Settings

scaled step size in initial guess	0.2
reflection constant	0.95
contraction constant	0.45
expansion constant	1.9
shrink constant	0.5

Dynamic

DPE timewindow	1E+10 [d]

Maximum Likelihood		
error distribution	Normal	
estimate standard deviations of errors	On	
standard deviations of errors		
use specified standard deviations as reference	Off	
level of significance	0.05	[-]
heteroscedasticity model	Off	
heteroscedasticity parameters		
Derivative Information		
report objective function gradient and Hessian	Off	
report model sensitivity coefficients	Off	
finite-difference relative perturbation size	1E-07	
Confidence Limits		
printing of confidence limits	Off	
confidence level for confidence limits	0.95	[-]
treat the different target variables as one target	Off	
Significance of the Regression		
level of significance for significance of regression test	0.05	[-]
Lack of Fit		
lack of fit test	Off	
level of significance for lack of fit test	0.05	[-]
replication sum of squares	User Supplied	
relative tolerance used to detect repeat measurements	0.0001	[-]
User Supplied Replication Sum of Squares		
number of target variables	1	
replication sum of squares	1	
degrees of freedom for replication sum of squares	5	
Portmanteau		
Portmanteau test on weighted residuals	Off	
level of significance for portmanteau test	0.05	[-]
maximum number of lags used in portmanteau test	20	

Matlab Link

Matlab Link		
Matlab link control	On	
Diagnostics		
show messages in log window	Off	
print Matlab output in log window	Off	

On-Line Operation

On-Line Run		
on-line run	Off	
wait for all data to synchronize	Off	
waiting period	2	[h]
sampling rate from data base	60	[s]
DDE		
clipboard format	Xltable	
wait for DDE transactions	10	
Input Files		
input file extension (in offline mode)	dat	
replace failed data with form value	Off	
plant #1 name (for data file)	blank	
Data Files		
plant #2 name (for data file)	blank	

plant #3 name (for data file)	blank	
plant #4 name (for data file)	blank	
plant #5 name (for data file)	blank	
plant #6 name (for data file)	blank	
plant #7 name (for data file)	blank	
plant #8 name (for data file)	blank	
plant #9 name (for data file)	blank	
plant #10 name (for data file)	blank	
Output Files		
use global alarm file	Off	
alarm file name	blank	
Real Time Synchronized Mode		
real time synchronized mode	Off	
real time acceleration factor	1	
Data Transfer		
send data to simulator module	Off	
max number of control and output variables	100	
max number of datapoints	100	
Communication		
output into Matlab format	Off	
send warnings to log window	On	
send optimizer status to log window	On	
send DPE status to log window	On	

Numerical

Bounding

number of iterations in IMPL operator	30	
error bound in IMPL operator	0.000001	
bottom bound on flows	1E-10	[m3/d]
top bound on flows	1E+10	[m3/d]
bottom bound on initial concentrations	0.000001	[mg/L]
top bound on initial concentrations	1E+10	[mg/L]
bottom bound on concentrations	0	[mg/L]
top bound on concentrations	1E+10	[mg/L]
bottom bound on derivatives	-1E+33	[mg/(L.d)]
top bound on derivatives	1E+33	[mg/(L.d)]
bottom bound on volumes	1E-10	[m3]
ignore dilution rate below this volume	0.0001	[m3]
ignore dilution rate below this layer thickness	0.0001	[m]
top bound on volumes	1E+10	[m3]
bottom bound on parameters	1E-10	
top bound on parameters	1E+10	
top bound on integers	999999	
initial iteration on loops	100	
top bound on exponential (xmin)	1000	[mg/L]
Speed		
smooth pump discharge at discontinuities	Off	
smoothing period	0.00001	[d]
smooth factor (logistic parameter)	15	
smooth at flow changes larger than	50	[%]

Miscellaneous

General

controller tuning array size	3000	

controller sampling time	0.0035	[d]
controller damping in steady-state	100	[d]

Operating Cost

Energy Cost

energy pricing	Constant Price	

Constant Price

energy price	0.1	[$/KWh]

Time-Based Pricing

number of price levels	2	
energy price	0.06	[$/KWh]
	0.11	
price level starting hour (24-hour clock)	6	
	18	

Integration Control

Integration Settings

numerical solver	Runge-Kutta-Fehlberg(2)	
initial number of integration steps	50	
minimum integration step size	0	[d]
maximum integration step size	0.1	[d]

Output Variables

General Program Variables

Library Variables

biological model ID	4	

Dynamic Run

simulation time	85	[d]
completed part of dynamic run	100	[%]

Steady-State

convergence	100	[%]
steady-state loop counter	803	

Time Variables

day of the week (Sun=1,Mon=2,Tues=3,etc.)	2	
year	2020	
month	7	
day	25	
hour	10	
minute	0	
second	5	

Integration Variables

last integration step size (GPS-X)	0.000034	[d]
average integration step size	0.000032	[d]
sum of absolute values of derivatives	1040	[mg/(L.d)]

Physical

dynamic viscosity	1000	[Pa.s]
density of water	998000	[mg/L]
kinematic viscosity	1	[m2/s]

Numerical

zero	0	

Alarm

data failure in fileinput controllers	0	

Simulation Setup

Time

	stopping time	85	[d]
	communication interval	1	[h]
	date and time at t=0	2020	[yr,m,d,h,min,s]
		5	
		1	
		10	
		0	
		0	
	initial time	0	[d]
Rounding			
	round seconds to full minutes	0	
	round minutes to quarter hours	0	
Repeat Runs			
	number of reruns	0	
Consistency Check			
	show process warnings	0	
Process Warnings			
	write process warnings into file	0	
	process warnings only once per run	1	
Aeration Limit Settings			
	apply aeration limits (airflow per diffuser)	0	
	show aeration limit warning	1	
Model Check			
	warn user when states and models don't match	1	
Display of Discontinuous Pump Flows (SBR and BAF units only)			
	display concentrations in discontinuous pump flows at all times	0	
Physical			
Oxygen Solubility (layout-wide settings)			
	liquid temperature	20	[C]
	blower inlet air temperature	20	[C]
	elevation above sea level	0	[m]
	barometric pressure at sea level	1	[atm]
	standard air conditions	1	
Physical Constants			
	molecular weight of air (@ U.S. Standard Conditions)	29	[g/mol]
	gas constant	8310	[J/kmol.K]
	Antoine coefficient A1	8.11	[-]
	Antoine coefficient A2	1750	[-]
	Antoine coefficient A3	235	[-]
Properties of User-Defined Air			
	mole fraction of oxygen in user-defined air	1	[-]
	density of user-defined air	1430	[mg/L]
	molecular weight of user-defined air	32	[g/mole]
	exponent in blower power equation	0.284	[-]
SOTE Regression Coefficients			
	SOTE regression constant A1 (ceramic disc)	12.1	[-]
	SOTE regression constant A2 (ceramic disc)	-3.24	[-]
	SOTE regression constant A3 (ceramic disc)	0.0816	[-]
	SOTE regression constant A4 (ceramic disc)	1.22	[-]
	SOTE regression constant A5 (ceramic disc)	0.158	[-]
	SOTE regression constant A1 (ceramic dome)	19.8	[-]
	SOTE regression constant A2 (ceramic dome)	-13.6	[-]
	SOTE regression constant A3 (ceramic dome)	3.07	[-]
	SOTE regression constant A4 (ceramic dome)	1.11	[-]

SOTE regression constant A5 (ceramic dome)	0.172	[-]
SOTE regression constant A1 (membrane disc)	8.48	[-]
SOTE regression constant A2 (membrane disc)	-5.38	[-]
SOTE regression constant A3 (membrane disc)	1.06	[-]
SOTE regression constant A4 (membrane disc)	1.73	[-]
SOTE regression constant A5 (membrane disc)	-0.0233	[-]
SOTE regression constant A1 (membrane tube)	7.57	[-]
SOTE regression constant A2 (membrane tube)	-2.72	[-]
SOTE regression constant A3 (membrane tube)	0.15	[-]
SOTE regression constant A4 (membrane tube)	1.5	[-]
SOTE regression constant A5 (membrane tube)	0.156	[-]
SOTE regression constant A1 (coarse bubble)	3.79	[-]
SOTE regression constant A2 (coarse bubble)	-0.0927	[-]
SOTE regression constant A3 (coarse bubble)	0.00108	[-]
SOTE regression constant A4 (coarse bubble)	0.266	[-]
SOTE regression constant A5 (coarse bubble)	0.0236	[-]
SOTE regression constant A1 (jet)	1.43	[-]
SOTE regression constant A2 (jet)	-0.268	[-]
SOTE regression constant A3 (jet)	0.00424	[-]
SOTE regression constant A4 (jet)	1.35	[-]
SOTE regression constant A5 (jet)	0.00522	[-]

Deep Tank SOTE Regression Coefficients

Deep Tank SOTE regression constant A6 (ceramic disc)	-0.00419	[-]
Deep Tank SOTE regression constant A6 (ceramic dome)	-0.00389	[-]
Deep Tank SOTE regression constant A6 (membrane disc)	-0.00909	[-]
Deep Tank SOTE regression constant A6 (membrane tube)	-0.00725	[-]

Settling Correlations

SVI Correlation Coefficients

SVI correlation coeff. 1	710
SVI correlation coeff. 2	-4.67
SVI correlation coeff. 3	0.018
SVI correlation coeff. 4	0.000266
SVI correlation coeff. 5	-2.9E-06
SVI correlation coeff. 6	2.5E-08
SVI correlation coeff. 7	-0.00016
SVI correlation coeff. 8	0.0049
SVI correlation coeff. 9	0.000647

Steady-State

Steady-State Parameters

number of retries on iteration	1
error limit on individual variables	1E-10
iteration termination criteria	5
maximum number of iterations	100000
maximum number of unsuccessful iterations	20000

Iteration Search Setup

force iteration even if model converged	1
contract constant	0.982
expand constant	1
maximum step size in one iteration	0.5
damping factor on final approach	1
initial perturbation	0.05
convergence output interval	200
steady-state loop counter initial value	0

Trim Parameters

print value of dsum	1E+10	[d]
display improved iterations only	1	

	iteration output interval in trim	50000	
Analyzer			
Monte Carlo Analysis			
	number of runs	1000	
Optimizer			
Static			
	parameter tolerance	0.000001	
	objective function tolerance	-1E+10	
	scaled termination value for objective function	0.1	
	maximum number of optimizer iterations	200	
	detailed statistical report	0	
	solution report to file	0	
Optimizer Settings			
	scaled step size in initial guess	0.2	
	reflection constant	0.95	
	contraction constant	0.45	
	expansion constant	1.9	
	shrink constant	0.5	
Dynamic			
	DPE timewindow	1E+10	[d]
Maximum Likelihood			
	error distribution	1	
	estimate standard deviations of errors	1	
	use specified standard deviations as reference	0	
	level of significance	0.05	[-]
	heteroscedasticity model	0	
Derivative	heteroscedasticity parameters		
	report objective function gradient and Hessian	0	
	report model sensitivity coefficients	0	
	finite-difference relative perturbation size	1E-07	
Confidence Limits			
	printing of confidence limits	0	
	confidence level for confidence limits	0.95	[-]
	treat the different target variables as one target	0	
Significance of the Regression			
	level of significance for significance of regression test	0.05	[-]
Lack of Fit			
	lack of fit test	0	
	level of significance for lack of fit test	0.05	[-]
	replication sum of squares	1	
	relative tolerance used to detect repeat measurements	0.0001	[-]
User Supplied Replication Sum of Squares			
	replication sum of squares	1	
	degrees of freedom for replication sum of squares	5	
Portmanteau			
	Portmanteau test on weighted residuals	0	
	level of significance for portmanteau test	0.05	[-]
	maximum number of lags used in portmanteau test	20	
Matlab Link			
Matlab Link			
	Matlab link control	1	
Diagnostics			
	show messages in log window	0	
	print Matlab output in log window	0	
On-Line Operation			
On-Line Run			

on-line run	0	
wait for all data to synchronize	0	
waiting period	2	[h]
sampling rate from data base	60	[s]

DDE

clipboard format	1	
wait for DDE transactions	10	[msec]

Input Files

input file extension (in offline mode)	2	
replace failed data with form value	0	
plant #1 name (for data file)		

Data Files

plant #2 name (for data file)		
plant #3 name (for data file)		
plant #4 name (for data file)		
plant #5 name (for data file)		
plant #6 name (for data file)		
plant #7 name (for data file)		
plant #8 name (for data file)		
plant #9 name (for data file)		
plant #10 name (for data file)		

Output Files

use global alarm file	0	
alarm file name		

Real Time Synchronized Mode

real time synchronized mode	0	
real time acceleration factor	1	

Data Transfer

send data to simulator module	0	

Communication

output into Matlab format	0	
send warnings to log window	1	
send optimizer status to log window	1	
send DPE status to log window	1	

Numerical

Bounding

number of iterations in IMPL operator	30	
error bound in IMPL operator	0.000001	
bottom bound on flows	1E-10	[m3/d]
top bound on flows	1E+10	[m3/d]
bottom bound on initial concentrations	0.000001	[mg/L]
top bound on initial concentrations	1E+10	[mg/L]
bottom bound on concentrations	0	[mg/L]
top bound on concentrations	1E+10	[mg/L]
bottom bound on derivatives	-1E+33	[mg/(L.d)]
top bound on derivatives	1E+33	[mg/(L.d)]
bottom bound on volumes	1E-10	[m3]
ignore dilution rate below this volume	0.0001	[m3]
ignore dilution rate below this layer thickness	0.0001	[m]
top bound on volumes	1E+10	[m3]
bottom bound on parameters	1E-10	
top bound on parameters	1E+10	
top bound on integers	1000000	
initial iteration on loops	100	
top bound on exponential (xmin)	1000	[mg/L]

Speed

smooth pump discharge at discontinuities	0	
smoothing period	0.00001	[d]
smooth factor (logistic parameter)	15	
smooth at flow changes larger than	50	[%]

Miscellaneous

General

controller sampling time	0.0035	[d]
controller damping in steady-state	100	[d]

Operating Cost

Energy Cost

energy pricing	1	

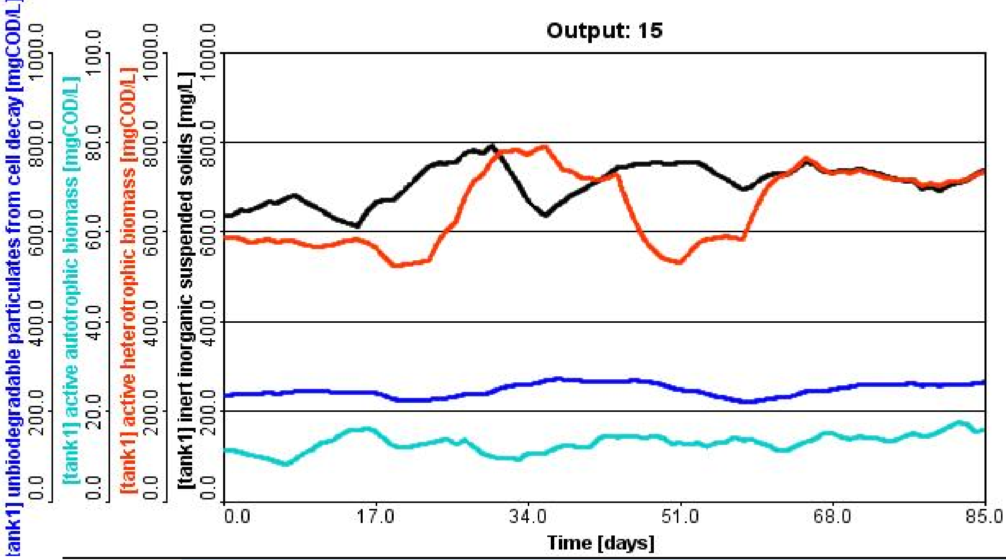
Constant Price

energy price	0.1	[$/KWh]

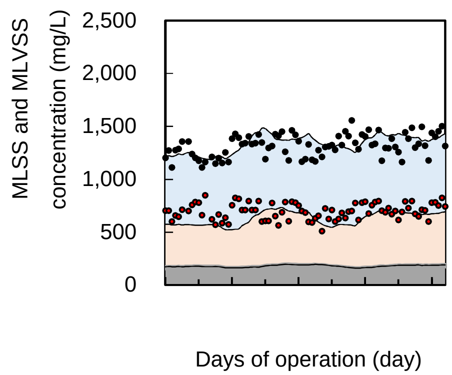
Time-Based Pricing

energy price	0.06	[$/KWh]
	0.11	
price level starting hour (24-hour clock)	6	
	18	

ASR#1 MLSS & MLVSS concentration



	X_U	X_{ANO}	X_{OHO}	X_{ig}	X_U	X_{ANO}	X_{OHO}
days	mgCOD/L	mgCOD/L	mgCOD/L	mg/L	mg/L	mg/L	mg/L
1	237	13.7	588	637	162	9	403
2	240	13.1	585	648	164	9	401
3	239	12.4	576	648	164	8	395
4	239	12	579	655	164	8	397
5	242	11.7	583	666	166	8	399
6	239	11.4	577	665	164	8	395
7	242	11.2	580	674	166	8	397
8	244	11.2	578	682	167	8	396
9	245	11.2	572	668	168	8	392
10	247	11.2	567	658	169	8	388
11	246	11.2	567	647	168	8	388
12	244	11	570	634	167	8	390
13	241	10.9	576	625	165	7	395
14	241	10.9	581	618	165	7	398
15	241	10.8	582	614	165	7	399
16	242	10.9	576	644	166	7	395
17	241	10.8	564	665	165	7	386
18	235	10.5	543	671	161	7	372
19	227	10.2	526	671	155	7	360
20	225	10.2	526	689	154	7	360
21	225	10.2	529	708	154	7	362
22	226	10.2	533	729	155	7	365
23	226	10.2	537	746	155	7	368
24	228	9.53	579	753	156	7	397
25	230	9.03	604	753	158	6	414
26	233	8.76	626	757	160	6	429
27	238	8.66	679	776	163	6	465
28	239	8.49	713	781	164	6	488
29	238	8.37	729	775	163	6	499
30	244	9.51	758	790	167	7	519
31	252	10.6	777	766	173	7	532
32	256	11.4	780	734	175	8	534
33	260	12	781	704	178	8	535
34	259	12.2	772	668	177	8	529

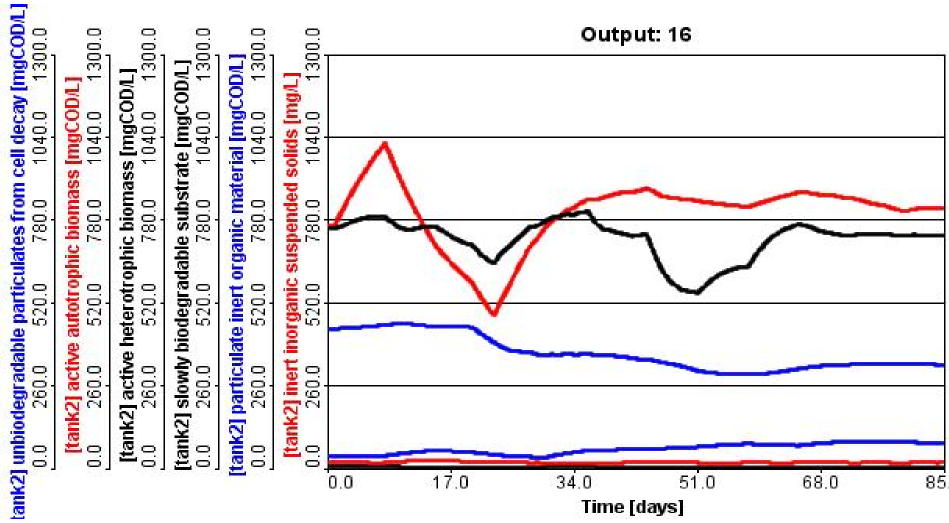


1	2	3	4		xtank1	vsstank1
mg/L	**mg/L**	**mg/L**	**mg/L**		mg/L	mg/L
162	172	574	1211		1203	702
164	173	574	1222		1272	702
164	172	567	1215		1110	601
164	172	568	1223		1274	658
166	174	573	1239		1286	645
164	172	567	1232		1356	712
166	173	571	1245		-1	-1
167	175	571	1253		1355	698
168	175	567	1235		1239	756
169	177	565	1223		1203	784
168	176	565	1212		1176	777
167	175	565	1199		1110	661
165	173	567	1192		1162	849
165	173	570	1188		-1	-1
165	172	571	1185		1210	620
166	173	568	1212		1146	569
165	172	559	1224		1200	665
161	168	540	1211		1154	583
155	162	523	1194		1254	636
154	161	521	1210		1163	572
154	161	523	1231		1384	755
155	162	527	1256		1429	824
155	162	530	1276		1394	813
156	163	559	1312		1332	710
158	164	577	1330		1341	707
160	166	594	1351		1406	793
163	169	634	1410		1332	710
164	170	658	1439		1341	707
163	169	668	1443		1423	793
167	174	693	1483		1349	598
173	180	712	1478		1189	604
175	183	717	1451		1296	605
178	186	721	1425		1315	775
177	186	715	1383		1426	650

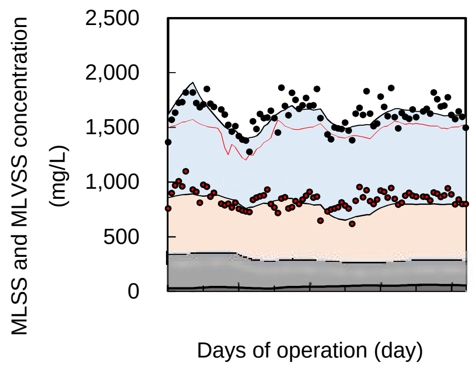
35	263	12.6	784	650	180	9	537
36	269	11.7	789	637	184	8	540
37	272	11.4	761	656	186	8	521
38	272	11	738	669	186	8	505
39	271	10.6	733	684	186	7	502
40	268	10.2	720	692	184	7	493
41	267	10	719	705	183	7	492
42	266	9.82	716	715	182	7	490
43	265	9.67	721	728	182	7	494
44	267	10.8	726	743	183	7	497
45	267	12.8	668	745	183	9	458
46	269	14.3	621	750	184	10	425
47	267	15.3	583	750	183	10	399
48	264	16	560	753	181	11	384
49	259	16.3	542	753	177	11	371
50	253	16.5	535	752	173	11	366
51	248	15.6	532	753	170	11	364
52	246	14.4	553	754	168	10	379
53	244	13.5	575	754	167	9	394
54	239	12.7	584	743	164	9	400
55	233	12	586	728	160	8	401
56	230	11.5	589	719	158	8	403
57	225	11.2	588	706	154	8	403
58	222	11.5	584	694	152	8	400
59	221	11.1	632	702	151	8	433
60	225	11	675	717	154	8	462
61	228	11	706	727	156	8	484
62	231	11	722	731	158	8	495
63	231	10.9	729	728	158	7	499
64	237	11.1	745	741	162	8	510
65	244	11.6	764	755	167	8	523
66	246	11.9	754	748	168	8	516
67	245	12.1	738	735	168	8	505
68	248	12.3	730	732	170	8	500
69	253	12.6	734	737	173	9	503
70	255	12.7	731	735	175	9	501
71	259	12.9	737	741	177	9	505
72	258	12.5	731	734	177	9	501
73	260	12.4	726	730	178	8	497
74	261	12.3	720	723	179	8	493
75	260	12.2	717	718	178	8	491
76	261	12.1	717	714	179	8	491
77	263	12.1	717	714	180	8	491
78	257	11.8	703	697	176	8	482
79	260	11.8	708	699	178	8	485
80	258	11.9	704	692	177	8	482
81	259	12.2	711	704	177	8	487
82	260	12.3	713	709	178	8	488
83	260	12.4	716	715	178	8	490
84	263	12.6	727	728	180	9	498
85	265	12.7	733	738	182	9	502

180	189	726	1376	1411	564
184	192	733	1370	1449	686
186	194	715	1371	1259	784
186	194	699	1368	1178	603
186	193	695	1379	1463	788
184	191	684	1376	1421	777
183	190	682	1387	1358	752
182	189	679	1394	1167	700
182	188	682	1410	1188	685
183	190	688	1431	1330	596
183	192	649	1394	1183	590
184	194	619	1369	1170	631
183	193	593	1343	1273	654
181	192	575	1328	1212	508
177	189	560	1313	1305	723
173	185	551	1303	1312	625
170	181	545	1298	1324	708
168	178	557	1311	1278	599
167	176	570	1324	1407	622
164	172	572	1315	1324	681
160	168	569	1297	1452	633
158	165	569	1288	1409	694
154	162	565	1271	1556	699
152	160	560	1254	1343	774
151	159	592	1294	1284	615
154	162	624	1341	1423	778
156	164	647	1374	1404	788
158	166	660	1391	1468	675
158	166	665	1393	1323	754
162	170	680	1421	1335	785
167	175	698	1453	1465	794
168	177	693	1441	1176	702
168	176	682	1417	1295	687
170	178	678	1410	1293	726
173	182	685	1422	1383	669
175	183	684	1419	1303	698
177	186	691	1432	1257	616
177	185	686	1420	1161	689
178	187	684	1414	1443	789
179	187	680	1403	1385	726
178	186	678	1396	1486	794
179	187	678	1392	1300	672
180	188	680	1394	1335	649
176	184	666	1363	1495	712
178	186	671	1370	1318	706
177	185	667	1359	1177	599
177	186	673	1377	1438	778
178	187	675	1384	1400	781
178	187	677	1392	1452	750
180	189	687	1415	1502	824
182	190	692	1430	1315	742

ASR#1 MLSS & MLVSS concentration



days	XCB mgCOD/L	X_I mgCOD/L	X_U mgCOD/L	X_{ANO} mgCOD/L	X_{OHO} mgCOD/L	X_{ig} mg/L	XCB mg/L
1	4.66	38.1	438	16.1	754	762	3
2	4.91	38.4	440	15.5	761	808	3
3	4.85	38.7	442	15.1	770	850	3
4	4.8	39	443	14.7	780	890	3
5	4.88	39.2	444	14.5	786	926	3
6	4.91	39.4	446	14.3	790	960	3
7	4.95	39.6	448	14.2	793	992	3
8	5.06	39.8	451	14.8	790	1020	3
9	4.62	43	453	15.6	771	965	3
10	4.43	46	455	16.1	755	910	3
11	4.21	48.7	454	16.5	750	861	3
12	4.12	51.2	452	16.7	752	815	3
13	4.19	53.6	449	16.9	758	773	3
14	4.3	55.8	448	17.1	760	734	3
15	4.26	57.7	447	17.2	758	697	3
16	4.28	56.1	446	17.6	744	671	3
17	4.3	54.6	446	17.8	730	646	3
18	4.19	53.3	446	17.9	717	623	3
19	4.1	52	445	18	707	602	3
20	4.03	50.8	443	18	700	581	3
21	3.94	48	425	17.4	676	543	3
22	3.79	45.5	410	16.9	657	510	3
23	3.74	43.3	395	17.1	646	483	3
24	3.96	41.3	382	16.5	677	530	3
25	4.08	39.4	372	16.1	697	572	3
26	4.21	38.2	368	16.1	719	617	3
27	4.12	37.2	366	16.1	738	660	3
28	4.28	36.3	364	16.2	759	699	3
29	4.28	35	358	16.1	762	724	3
30	4.52	34.6	357	16.9	775	756	3
31	4.64	39.3	358	17.6	788	777	3
32	4.67	43.5	357	18	792	792	3
33	4.7	47.4	359	18.5	797	810	3
34	4.58	50.7	358	18.7	797	820	3



X_I	X_U	X_{ANO}	X_{OHO}	X_{ig_tol}	X_{ig_s}	$X_{ig\_precipitant}$	1	2
mg/L	mg/L	mg/L	mg/L	mg/L		mg/L	mg/L	mg/L
26	300	11	516	762	637	125	26	29
26	301	11	521	808	648	160	26	30
27	303	10	527	850	648	202	27	30
27	303	10	534	890	655	235	27	30
27	304	10	538	926	666	260	27	30
27	305	10	541	960	665	295	27	30
27	307	10	543	992	674	318	27	31
27	309	10	541	1020	682	338	27	31
29	310	11	528	965	668	297	29	33
32	312	11	517	910	658	252	32	35
33	311	11	514	861	647	214	33	36
35	310	11	515	815	634	181	35	38
37	308	12	519	773	625	148	37	40
38	307	12	521	734	618	116	38	41
40	306	12	519	697	614	83	40	42
38	305	12	510	671	574	97	38	41
37	305	12	500	646	455	191	37	40
37	305	12	491	637	403	234	37	39
36	305	12	484	637	503	134	36	38
35	303	12	479	637	485	152	35	38
33	291	12	463	637	466	171	33	36
31	281	12	450	637	445	192	31	34
30	271	12	442	637	443	194	30	32
28	262	11	464	637	483	154	28	31
27	255	11	477	637	473	164	27	30
26	252	11	492	637	517	120	26	29
25	251	11	505	660	525	135	25	28
25	249	11	520	699	554	145	25	28
24	245	11	522	724	573	151	24	27
24	245	12	531	756	589	167	24	27
27	245	12	540	777	667	110	27	30
30	245	12	542	792	734	58	30	33
32	246	13	546	810	704	106	32	36
35	245	13	546	820	668	152	35	38

3	4	5	6	7		xtank2	vsstank2
mg/L	**mg/L**	**mg/L**	**mg/L**	**mg/L**		mg/L	mg/L
329	340	857	1494	1619		1366	757
331	342	863	1511	1671		1569	897
333	343	870	1518	1720		1635	968
333	343	878	1533	1768		1725	1006
334	344	883	1549	1809		1731	960
336	346	887	1552	1847		1820	1097
337	347	890	1564	1882			
340	350	891	1573	1911		1820	930
343	354	882	1550	1847		1724	910
346	357	874	1532	1784		1685	811
347	359	872	1519	1733		1712	976
347	359	874	1508	1689		1852	956
347	359	878	1503	1651		1718	867
348	360	880	1498	1614		1687	901
349	360	880	1494	1577			
347	359	868	1442	1539		1665	800
346	358	858	1313	1504		1616	786
345	357	848	1251	1485		1524	802
343	356	840	1343	1477		1463	765
341	353	833	1318	1470		1510	809
327	339	802	1268	1439		1419	754
315	326	776	1221	1413		1388	740
303	314	757	1200	1394		1380	730
293	304	768	1251	1405		1277	725
285	296	773	1246	1410		1554	835
281	292	785	1302	1422		1486	857
279	290	795	1320	1455		1622	868
277	288	808	1362	1507		1586	879
272	283	805	1378	1529		1589	930
271	283	814	1403	1570		1653	798
275	287	827	1494	1604		1585	766
278	290	832	1566	1624		1452	717
282	294	840	1544	1650		1863	847
283	296	842	1510	1662		1696	860

35	4.73	53.9	358	18.9	805	834	3
36	4.75	56.7	359	17.6	805	846	3
37	4.53	56.9	356	16.8	770	844	3
38	4.19	57.6	356	16.3	752	850	3
39	4.27	58.3	354	15.9	747	857	3
40	4.17	59	353	15.5	741	864	3
41	4.19	59.4	350	15.2	737	868	3
42	4.01	59.6	346	14.9	729	867	3
43	4.04	60	343	14.7	733	872	3
44	4.23	60.7	342	15.2	734	879	3
45	4.13	61.9	339	16.5	679	870	3
46	3.89	62.6	333	17.3	628	856	3
47	3.61	63.9	330	17.9	595	852	2
48	3.47	65.1	325	18.3	574	849	2
49	3.18	66.1	320	18.4	559	845	2
50	3.16	67.2	313	18.6	556	844	2
51	3.46	68	307	17.8	553	840	2
52	3.36	69.7	303	16.6	570	835	2
53	3.46	71.5	300	15.8	592	834	2
54	3.57	73	298	15.2	609	831	2
55	3.66	74.3	296	14.8	620	828	3
56	3.71	75.5	295	14.5	627	825	3
57	3.87	76.8	296	14.4	632	824	3
58	3.6	77.6	296	14.6	633	821	2
59	3.77	76.5	296	14.2	669	829	3
60	3.81	75.6	298	13.9	697	836	3
61	4.05	74.7	299	13.8	722	843	3
62	4.07	74	303	13.8	738	850	3
63	4.25	73.3	306	13.8	751	856	3
64	4.17	72.8	310	13.9	758	862	3
65	4.23	72.4	313	14.3	767	867	3
66	4.26	74.9	317	14.9	763	867	3
67	4.36	77	319	15.3	755	863	3
68	4.21	78.7	322	15.6	744	859	3
69	4.22	80.7	324	15.9	742	859	3
70	4.14	82.1	325	16	736	856	3
71	4.09	83.3	325	16.1	733	851	3
72	4.28	84.6	326	15.2	733	850	3
73	4.28	84.5	328	14.6	734	845	3
74	4.25	84.3	328	14.1	734	839	3
75	4.23	83.8	328	13.6	734	832	3
76	4.31	83.8	329	13.4	737	828	3
77	4.28	83.6	330	13.1	736	824	3
78	4.29	83.1	329	12.9	733	817	3
79	4.25	82.7	329	12.7	731	811	3
80	4.15	82.7	330	13.6	733	810	3
81	4.15	81.7	330	14.3	734	815	3
82	4.13	80.6	329	14.8	733	817	3
83	4.04	79.4	327	15.1	730	816	3
84	4.08	78.4	326	15.4	733	818	3
85	4.07	77.2	323	15.5	730	816	3

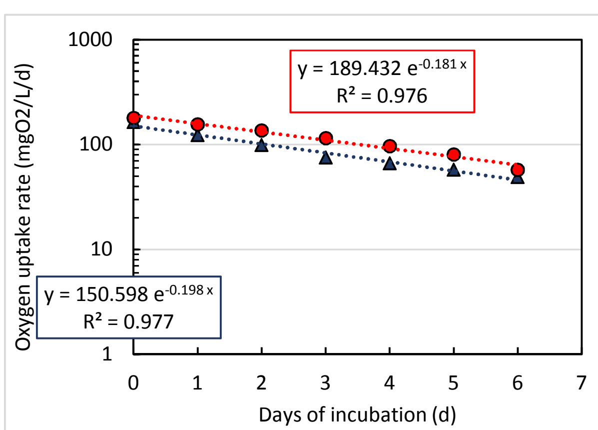
37	245	13	551	834	650	184	37	40
39	246	12	551	846	637	209	39	42
39	244	12	527	844	656	188	39	42
39	244	11	515	850	669	181	39	42
40	242	11	512	857	684	173	40	43
40	242	11	508	864	692	172	40	43
41	240	10	505	868	705	163	41	44
41	237	10	499	867	715	152	41	44
41	235	10	502	872	728	144	41	44
42	234	10	503	879	743	136	42	44
42	232	11	465	870	745	125	42	45
43	228	12	430	856	750	106	43	46
44	226	12	408	852	750	102	44	46
45	223	13	393	849	753	96	45	47
45	219	13	383	845	753	92	45	47
46	214	13	381	844	752	92	46	48
47	210	12	379	840	753	87	47	49
48	208	11	390	835	754	81	48	50
49	205	11	405	834	754	80	49	51
50	204	10	417	831	743	88	50	52
51	203	10	425	828	728	100	51	53
52	202	10	429	825	719	106	52	54
53	203	10	433	824	706	118	53	55
53	203	10	434	821	694	127	53	56
52	203	10	458	829	702	127	52	55
52	204	10	477	836	717	119	52	54
51	205	9	495	843	727	116	51	54
51	208	9	505	850	731	119	51	53
50	210	9	514	856	728	128	50	53
50	212	10	519	862	741	121	50	53
50	214	10	525	867	755	112	50	52
51	217	10	523	867	748	119	51	54
53	218	10	517	863	735	128	53	56
54	221	11	510	859	732	127	54	57
55	222	11	508	859	737	122	55	58
56	223	11	504	856	735	121	56	59
57	223	11	502	851	741	110	57	60
58	223	10	502	850	734	116	58	61
58	225	10	503	845	730	115	58	61
58	225	10	503	839	723	116	58	61
57	225	9	503	832	718	114	57	60
57	225	9	505	828	714	114	57	60
57	226	9	504	824	714	110	57	60
57	225	9	502	817	697	120	57	60
57	225	9	501	811	699	112	57	60
57	226	9	502	810	692	118	57	59
56	226	10	503	815	704	111	56	59
55	225	10	502	817	709	108	55	58
54	224	10	500	816	715	101	54	57
54	223	11	502	818	728	90	54	56
53	221	11	500	816	738	78	53	56

285	298	850	1500	1684	1611	759
288	300	851	1488	1697	1817	769
286	297	825	1481	1669	1752	825
286	297	812	1481	1662	1669	798
285	296	808	1492	1665	1703	840
285	296	803	1495	1667	1770	875
283	294	798	1503	1666	1697	911
281	291	790	1505	1657	1701	858
279	289	791	1519	1663	1851	865
279	289	792	1535	1671	1585	645
277	289	754	1499	1624		
274	285	716	1466	1572	1436	730
272	285	692	1442	1544	1392	749
270	282	675	1428	1524	1500	759
267	279	662	1415	1507	1489	768
263	275	656	1408	1500	1485	813
259	271	650	1403	1490	1544	784
258	269	659	1413	1494	1470	757
257	268	673	1427	1507	1382	618
257	267	684	1427	1515	1627	828
256	266	691	1419	1519	1679	954
256	266	696	1415	1521	1615	859
258	268	701	1407	1525	1830	925
258	268	702	1396	1523	1625	825
258	267	726	1428	1555	1512	798
259	268	745	1462	1581	1536	840
259	268	763	1490	1606	1781	921
261	270	776	1507	1626	1688	911
263	272	787	1515	1643	1603	858
265	275	794	1535	1656	1859	945
267	277	802	1557	1669	1592	845
271	282	804	1552	1671	1492	794
274	285	802	1537	1665	1630	810
277	288	798	1530	1657	1598	875
280	291	799	1536	1658	1580	900
282	293	797	1532	1653	1664	876
282	293	796	1537	1647	1593	865
284	295	797	1531	1647		
285	295	798	1528	1643	1647	867
285	295	798	1521	1637	1669	864
285	294	797	1515	1629	1626	831
286	295	800	1514	1628	1821	904
286	295	799	1513	1623	1758	892
285	294	796	1493	1613	1689	864
285	294	794	1493	1605	1700	877
286	295	797	1489	1607	1776	943
285	295	797	1501	1612	1615	888
283	294	796	1505	1613	1576	797
281	291	791	1506	1607	1647	841
280	290	792	1520	1610	1597	798
277	288	788	1526	1604	1497	798

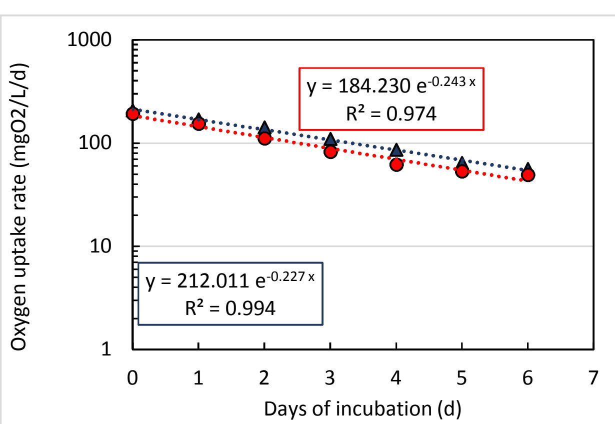
Hue city
Domestic Wastewater

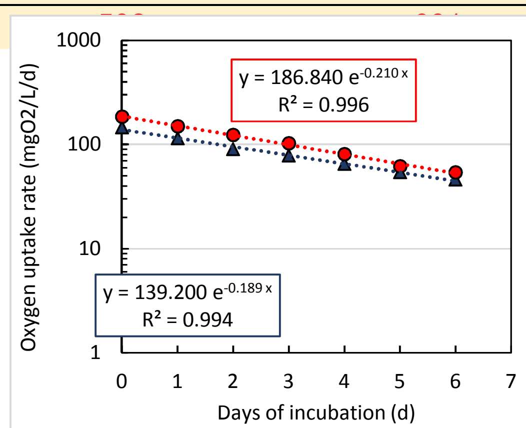
	d	ASR #1	ASR #2
		Feb/6 --> Feb/12	
		ASR #1	ASR #2
	d	OUR (mgO_2/L/d)	OUR (mgO_2/L/d)
	0	164	179
	1	123	156
	2	98	137
	3	75	115
	4	66	96
	5	58	81
	6	49	58

	d	ln(OUR)	
	0	5.10	5.19
	1	4.81	5.05
	2	4.59	4.92
	3	4.32	4.75
	4	4.19	4.57
	5	4.05	4.39
	6	3.89	4.05
	7		
	8		
Specific decay rate ,day^{-1}			
$b'_{H\ (ASM3)}$		0.198	0.181
$b'_{H\ (min.\ 95\%)}$		0.163	0.148
$b'_{H\ (max.\ 95\%)}$		0.232	0.214
Intercept (regression)		5.01	5.24
Intercept (min. 95%)		5.14	5.36
Intercept (max. 95%)		4.89	5.13
Thickend sludge			
Initial OUR, mgO2/L/d		164	179
Estimated initial X_{BH} (thickened), mgCOD		829	988
MLSS, mg/L		1472	1878
MLVSS, mg/L		786	1285
MLVSS $_{(thickened)}$,mg/L		978	1452
$X_{total\_org\ (thickened)}$, mgCOD/L		1428	2120
Thickening factor		124%	113%
X_{OHO} ,mgCOD/L		666	875

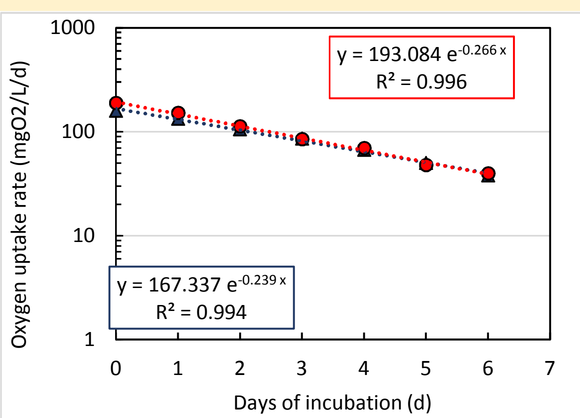


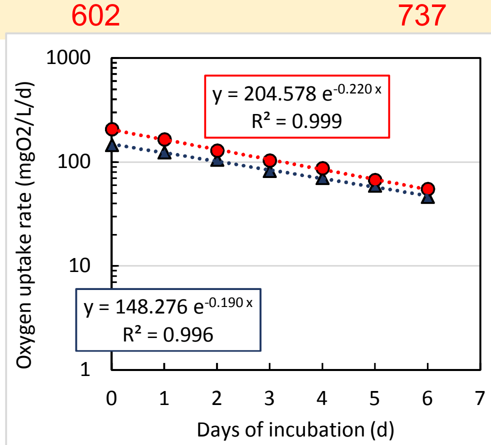
Feb/13 --> Feb/19		Feb/20--> Feb/26	
ASR #1	ASR #2	ASR #1	ASR #2
OUR (mgO_2/L/d)	OUR (mgO_2/L/d)	OUR (mgO_2/L/d)	OUR (mgO_2/L/d)
206	192	146	185
169	154	115	150
141	111	90	124
109	82	78	103
86	62	65	81
64	53	54	62
56	49	46	54
ln(OUR)		ln(OUR)	
5.33	5.26	4.98	5.22
5.13	5.04	4.74	5.01
4.95	4.71	4.50	4.82
4.69	4.41	4.36	4.63
4.45	4.13	4.17	4.39
4.16	3.97	3.99	4.13
4.03	3.89	3.83	3.99
0.227	0.243	0.189	0.210
0.207	0.197	0.172	0.195
0.246	0.289	0.207	0.225
5.36	5.22	4.94	5.23
5.43	5.38	5.00	5.28
5.29	5.05	4.87	5.18
206	192	146	185
908	790	772	881
1364	1419	1305	1635
631	845	734	1102
953	1024	974	1425
1391	1495	1422	2081
151%	121%	133%	129%
601	652	[illegible]	[illegible]



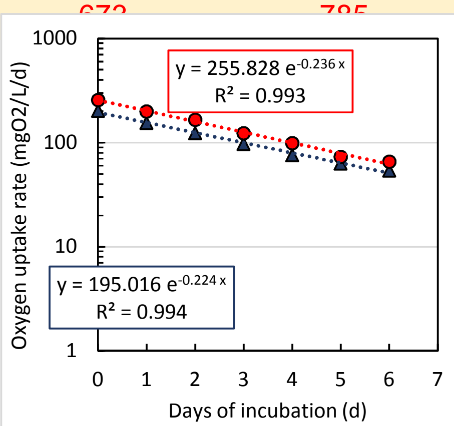


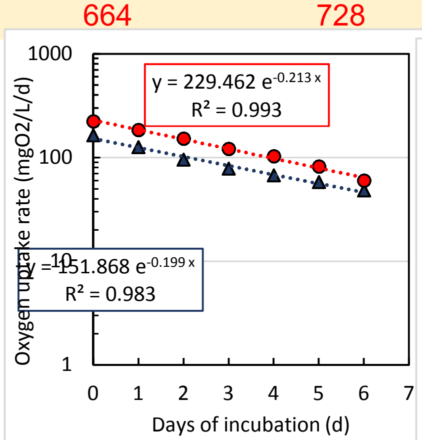
Feb/27 --> Mar/5		Mar/6 --> Mar/12	
ASR #1	ASR #2	ASR #1	ASR #2
OUR (mgO_2/L/d)	OUR (mgO_2/L/d)	OUR (mgO_2/L/d)	OUR (mgO_2/L/d)
158	190	145	207
133	152	123	165
105	113	105	129
86	85	82	104
67	70	70	87
50	48	59	67
38	40	46	55
ln(OUR)		ln(OUR)	
5.06	5.25	4.98	5.33
4.89	5.02	4.81	5.11
4.65	4.73	4.65	4.86
4.45	4.44	4.41	4.64
4.20	4.25	4.25	4.47
3.91	3.87	4.08	4.20
3.64	3.69	3.83	4.01
0.239	0.266	0.190	0.220
0.217	0.247	0.176	0.210
0.261	0.286	0.204	0.230
5.12	5.26	5.00	5.32
5.20	5.33	5.05	5.36
5.04	5.19	4.95	5.29
158	190	145	207
663	715	763	941
1425	1908	1360	1688
753	1057	755	1020
878	1212	957	1302
1282	1770	1397	1901
117%	115%	127%	128%
568	623	602	737

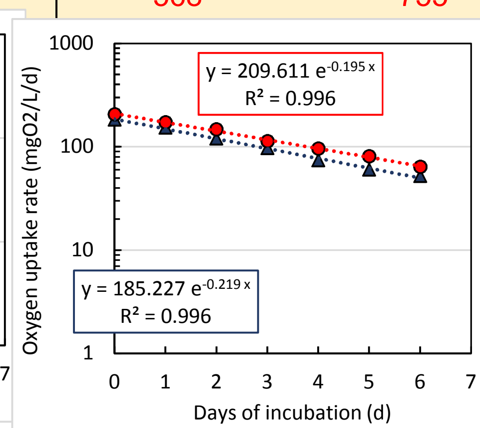




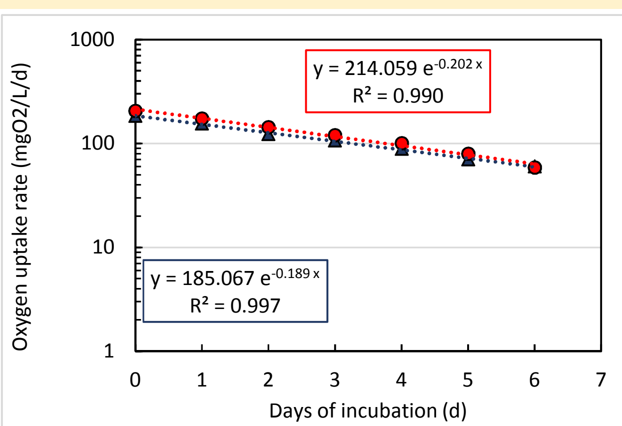
Mar/13 --> Mar/19		Mar/20 --> Mar/26		Mar/27 --> Apr/2	
ASR #1	ASR #2	ASR #1	ASR #2	ASR #1	ASR #2
OUR (mgO_2/L/d)	OUR (mgO_2/L/d)	OUR (mgO_2/L/d)	OUR (mgO_2/L/d)	OUR (mgO_2/L/d)	OUR (mgO_2/L/d)
203	257	163	224	183	207
155	200	126	184	153	172
124	166	95	152	120	148
97	124	78	121	97	113
76	99	67	103	74	96
63	73	58	82	60	81
54	66	48	60	52	64
ln(OUR)		ln(OUR)		ln(OUR)	
5.31	5.55	5.10	5.41	5.21	5.33
5.04	5.30	4.84	5.21	5.03	5.15
4.82	5.11	4.55	5.02	4.79	5.00
4.57	4.82	4.36	4.80	4.57	4.73
4.33	4.60	4.20	4.63	4.30	4.56
4.14	4.29	4.06	4.41	4.09	4.39
3.99	4.19	3.87	4.09	3.95	4.16
0.224	0.236	0.199	0.213	0.219	0.195
0.204	0.213	0.169	0.192	0.203	0.182
0.243	0.259	0.229	0.233	0.235	0.208
5.27	5.54	5.02	5.44	5.22	5.35
5.34	5.63	5.13	5.51	5.28	5.39
5.20	5.46	4.92	5.36	5.16	5.30
203	257	163	224	183	207
906	1089	821	1052	836	1062
1369	1953	1521	1807	1458	1806
818	1084	881	1054	900	1198
1102	1504	1089	1523	1324	1685
1609	2196	1590	2224	1933	2460
135%	139%	124%	144%	147%	141%
672	785	664	728	568	755

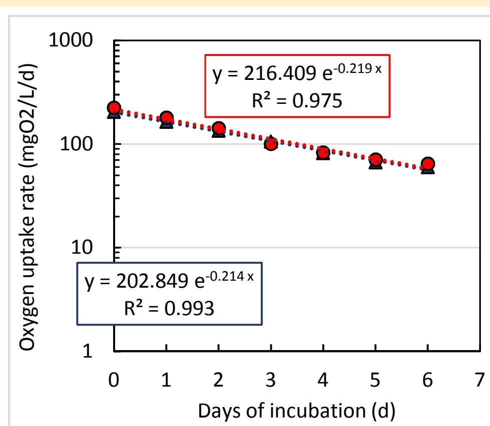




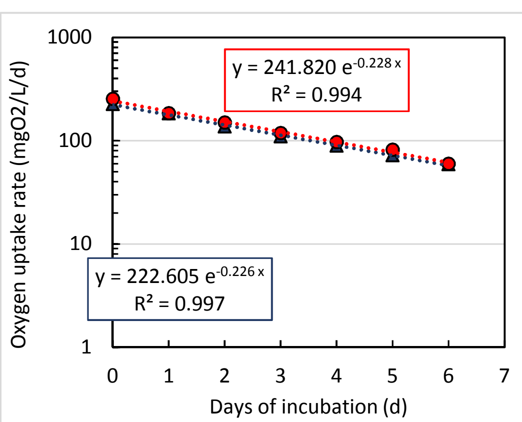


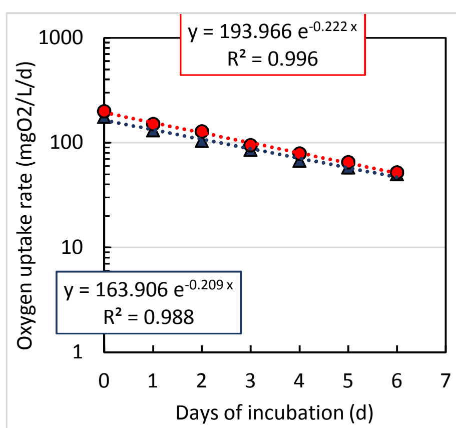
Apr/3 --> Apr/9		Apr/10 --> Apr/16	
ASR #1	ASR #2	ASR #1	ASR #2
OUR (mgO_2/L/d)	OUR (mgO_2/L/d)	OUR (mgO_2/L/d)	OUR (mgO_2/L/d)
185	206	205	225
155	174	165	180
123	144	135	143
107	120	106	101
89	101	82	83
70	80	67	71
60	59	60	65
ln(OUR)		ln(OUR)	
5.22	5.33	5.32	5.42
5.04	5.16	5.10	5.19
4.81	4.97	4.91	4.96
4.67	4.79	4.66	4.62
4.49	4.62	4.41	4.42
4.25	4.38	4.20	4.26
4.09	4.08	4.09	4.17
0.189	0.202	0.214	0.219
0.177	0.178	0.193	0.179
0.200	0.226	0.234	0.259
5.22	5.37	5.31	5.38
5.26	5.45	5.39	5.52
5.18	5.28	5.24	5.23
185	206	205	225
978	1020	958	1027
1550	1856	1389	2087
862	1098	857	1285
1135	1516	1086	1725
1657	2213	1586	2519
132%	138%	127%	134%
743	739	756	765





Apr/17 --> Apr/23		Apr/24 --> Apr/30	
ASR #1	ASR #2	ASR #1	ASR #2
OUR (mgO_2/L/d)	OUR (mgO_2/L/d)	OUR (mgO_2/L/d)	OUR (mgO_2/L/d)
226	254	176	200
183	185	131	151
137	150	104	128
110	119	85	95
89	97	67	79
72	82	58	65
59	60	50	52
ln(OUR)		ln(OUR)	
5.42	5.54	5.17	5.30
5.21	5.22	4.88	5.02
4.92	5.01	4.64	4.85
4.70	4.78	4.44	4.55
4.49	4.57	4.20	4.37
4.28	4.41	4.06	4.17
4.08	4.09	3.91	3.95
0.226	0.228	0.209	0.222
0.212	0.207	0.182	0.206
0.239	0.249	0.236	0.238
5.41	5.49	5.10	5.27
5.45	5.56	5.20	5.33
5.36	5.41	5.00	5.21
226	254	176	200
1000	1114	842	901
1613	1975	1738	1947
985	1230	1126	1214
1324	1823	1465	1530
1933	2662	2139	2234
134%	148%	130%	126%
744	752	647	715





Hue domestic wastewater

ASR#1

				Specific decay rate								
			Temperature	b_H (ASM3) average	b_H (min. 95%)	b_H (max. 95%)	**Θ**	**T0**	**ΔT**	**b_{H_20}**		
Date	**Batch**	**Days**	Celsius							**average**	**lower 95%**	**upper 95%**
Feb/6 --> Feb/12	1	1	21.1	0.198	0.163	0.232	1.07	20	1.1	0.184	0.151	0.215
Feb/13 --> Feb/19	2	8	23.6	0.227	0.207	0.246	1.07	20	3.6	0.178	0.162	0.193
Feb/20--> Feb/26	3	15	21.9	0.189	0.172	0.207	1.07	20	1.9	0.166	0.151	0.182
Feb/27 --> Mar/5	4	22	24.6	0.239	0.217	0.261	1.07	20	4.6	0.175	0.159	0.191
Mar/6 --> Mar/12	5	29	25.2	0.190	0.176	0.204	1.07	20	5.2	0.134	0.124	0.143
Mar/13 --> Mar/19	6	36	26.0	0.224	0.204	0.243	1.07	20	6.0	0.149	0.136	0.162
Mar/20 --> Mar/26	7	43	24.2	0.199	0.169	0.229	1.07	20	4.2	0.150	0.127	0.172
Mar/27 --> Apr/2	8	50	23.0	0.219	0.203	0.235	1.07	20	3.0	0.179	0.166	0.192
Apr/3 --> Apr/9	9	57	23.6	0.189	0.177	0.200	1.07	20	3.6	0.148	0.139	0.157
Apr/10 --> Apr/16	10	64	24.8	0.214	0.193	0.234	1.07	20	4.8	0.155	0.139	0.169
Apr/17 --> Apr/23	11	71	25.3	0.226	0.212	0.239	1.07	20	5.3	0.158	0.148	0.167
Apr/24 --> Apr/30	12	78	24.0	0.209	0.182	0.236	1.07	20	4.0	0.159	0.139	0.180

ASR#2

				Specific decay rate								
			Temperature	b_H (ASM3)	b_H (min.	b_H (max.	**ϴ**	**T0**	**ΔT**	**b_{H_20}**		
Date	Batch	Days	Celsius	average	95%)	95%)				**average**	**lower 95%**	**upper 95%**
Feb/6 --> Feb/12	1	1	21.3	0.181	0.148	0.214	1.07	20	1.3	0.166	0.136	0.196
Feb/13 --> Feb/19	2	8	24.0	0.243	0.197	0.289	1.07	20	4.0	0.185	0.150	0.220
Feb/20--> Feb/26	3	15	22.5	0.210	0.195	0.225	1.07	20	2.5	0.177	0.165	0.190
Feb/27 --> Mar/5	4	22	25.0	0.266	0.247	0.286	1.07	20	5.0	0.190	0.176	0.204
Mar/6 --> Mar/12	5	29	26.3	0.220	0.195	0.245	1.07	20	6.3	0.144	0.127	0.160
Mar/13 --> Mar/19	6	36	26.5	0.236	0.213	0.259	1.07	20	6.5	0.152	0.137	0.167
Mar/20 --> Mar/26	7	43	24.6	0.213	0.192	0.233	1.07	20	4.6	0.156	0.141	0.171
Mar/27 --> Apr/2	8	50	23.2	0.195	0.182	0.208	1.07	20	3.2	0.157	0.147	0.168
Apr/3 --> Apr/9	9	57	23.6	0.202	0.178	0.226	1.07	20	3.6	0.158	0.140	0.177
Apr/10 --> Apr/16	10	64	26.5	0.219	0.179	0.259	1.07	20	6.5	0.141	0.115	0.167
Apr/17 --> Apr/23	11	71	25.4	0.228	0.207	0.249	1.07	20	5.4	0.158	0.144	0.173
Apr/24 --> Apr/30	12	78	24.8	0.222	0.206	0.238	1.07	20	4.8	0.160	0.149	0.172

$Y_{B,H}$	**0.24**	COD/gCOD
$\mu_{maxANO,20}$	**1.00**	day^{-1}
b_{ANO}	**0.15**	day^{-1}
q	**1.07**	-

q_H	day^{-1}	4.5
q_S	day^{-1}	0.1

	Date	**Temp**	μ_{maxANO}	**NOUR**		$X_{A,H}$		$X_{A,H}$		b_{ANO}	**Snh**	**snh+xnd**	**xnd**
		^oC	*day^{-1}*	*mgO2/L.d*		*mgCOD/L*		*mg/L*		**day^{-1}**	mgN/L	mgN/L	mgN/L
				ASR#1	**ASR#2**	**ASR#1**	**ASR#2**	**ASR#1**	**ASR#2**				
1	6-Feb	25.4	1.441	456	573	17.6	22.0	12.0	15.1	0.22	**5.1**	**6.4**	**1.3**
2	7-Feb		0.258	484	549	103.7	117.8	71.1	80.7	0.04	5.1	6.4	1.3
3	8-Feb	25.1	1.412	413	509					0.21	5.1	6.4	1.3
4	9-Feb	25.8	1.481	357	497	13.4	18.6	9.1	12.7	0.22	5.1	6.4	1.3
5	10-Feb	21.4	1.099	447	585	22.5	29.5	15.4	20.2	0.16	5.1	6.4	1.3
6	11-Feb	21.3	1.092	313	487	15.9	24.7	10.9	16.9	0.16	5.1	6.4	1.3
7	12-Feb	20.5	1.034	362	564	19.4	30.2	13.3	20.7	0.16	5.1	6.4	1.3
8	13-Feb	20.6	1.041	387	567	20.6	30.2	14.1	20.7	0.16	**5.1**	**7.7**	**2.6**
9	14-Feb	21.2	1.085	331	444	16.9	22.7	11.6	15.6	0.16	5.1	7.7	2.6
10	15-Feb	23.6	1.276	400	798	17.4	34.6	11.9	23.7	0.19	5.1	7.7	2.6
11	16-Feb	23.1	1.233	368	764	16.5	34.3	11.3	23.5	0.19	5.1	7.7	2.6
12	17-Feb	23.5	1.267	386	732					0.19	5.1	7.7	2.6
13	18-Feb	24.0	1.311	361	690	15.2	29.2	10.4	20.0	0.20	5.1	7.7	2.6
14	19-Feb	23.9	1.302	327	626	13.9	26.7	9.5	18.3	0.20	5.1	7.7	2.6
15	20-Feb	23.5	1.267	391	617	17.1	27.0	11.7	18.5	0.19	**4.4**	**7.0**	**2.7**
16	21-Feb	25.7	1.471	337	711	12.7	26.8	8.7	18.3	0.22	4.4	7.0	2.7
17	22-Feb	26.4	1.542	404	713	14.5	25.6	9.9	17.5	0.23	4.4	7.0	2.7
18	23-Feb	26.9	1.595	301	574	10.5	19.9	7.2	13.7	0.24	4.4	7.0	2.7
19	24-Feb	26.2	1.521	322	630	11.7	23.0	8.0	15.7	0.23	4.4	7.0	2.7
20	25-Feb	22.7	1.200	447	795	20.6	36.7	14.1	25.2	0.18	4.4	7.0	2.7
21	26-Feb	22.0	1.145	421	728	20.4	35.3	14.0	24.1	0.17	4.4	7.0	2.7
22	27-Feb	21.6	1.114	397	756	19.7	37.6	13.5	25.7	0.17	**5.1**	**10.0**	**4.9**
23	28-Feb	23.0	1.225	373	710	16.9	32.1	11.5	22.0	0.18	5.1	10.0	4.9
24	1-Mar	24.9	1.393	422	670	16.8	26.7	11.5	18.3	0.21	5.1	10.0	4.9
25	2-Mar	22.6	1.192	669	844	31.1	39.2	21.3	26.9	0.18	5.1	10.0	4.9
26	3-Mar	22.1	1.153	419	582	20.2	28.0	13.8	19.2	0.17	5.1	10.0	4.9
27	4-Mar	23.1	1.233	555	688	24.9	30.9	17.1	21.2	0.19	5.1	10.0	4.9
28	5-Mar	26.7	1.574	294	706	10.3	24.9	7.1	17.0	0.24	5.1	10.0	4.9
29	6-Mar	25.2	1.422	416	593	16.2	23.1	11.1	15.8	0.21	**4.5**	**5.8**	**1.3**

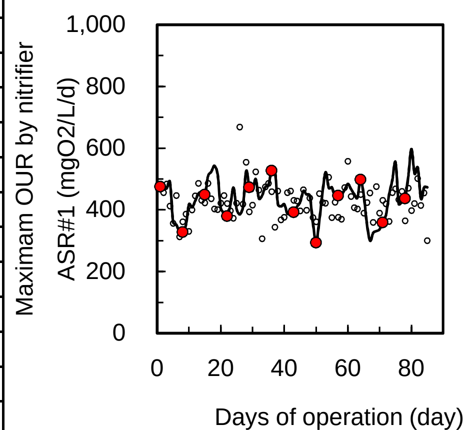
30	7-Mar	24.9	1.393	524	896	20.9	35.6	14.3	24.4	0.21	4.5	5.8	1.3
31	8-Mar	26.1	1.511	298	868	10.9	31.8	7.5	21.8	0.23	4.5	5.8	1.3
32	9-Mar	24.3	1.338	307	925	12.7	38.3	8.7	26.2	0.20	4.5	5.8	1.3
33	10-Mar	24.7	1.374	431	661	17.4	26.7	11.9	18.3	0.21	4.5	5.8	1.3
34	11-Mar	25.7	1.471	403	685	15.2	25.8	10.4	17.7	0.22	4.5	5.8	1.3
35	12-Mar	26.0	1.501	460	738	17.0	27.2	11.6	18.7	0.23	4.5	5.8	1.3
36	13-Mar	27.5	1.661	344	569	11.5	19.0	7.9	13.0	0.25	**3.4**	**5.9**	**2.5**
37	14-Mar	29.0	1.838	462	636	13.9	19.2	9.5	13.1	0.28	3.4	5.9	2.5
38	15-Mar	26.6	1.563	368	751	13.1	26.6	8.9	18.2	0.23	3.4	5.9	2.5
39	16-Mar	27.1	1.617	377	664	12.9	22.8	8.8	15.6	0.24	3.4	5.9	2.5
40	17-Mar	27.9	1.707	456	715	14.8	23.2	10.1	15.9	0.26	3.4	5.9	2.5
41	18-Mar	27.2	1.628	462	673	15.7	22.9	10.8	15.7	0.24	3.4	5.9	2.5
42	19-Mar	27.8	1.695	432	986	14.1	32.2	9.7	22.1	0.25	3.4	5.9	2.5
43	20-Mar	27.9	1.707	429	802	13.9	26.1	9.5	17.8	0.26	**4.8**	**9.1**	**4.3**
44	21-Mar	28.1	1.730	397	568	12.7	18.2	8.7	12.5	0.26	4.8	9.1	4.3
45	22-Mar	28.2	1.742	466	751	14.8	23.9	10.2	16.4	0.26	4.8	9.1	4.3
46	23-Mar	29.0	1.838	399	507	12.0	15.3	8.2	10.5	0.28	4.8	9.1	4.3
47	24-Mar	28.3	1.753	439	574	13.9	18.1	9.5	12.4	0.26	4.8	9.1	4.3
48	25-Mar	27.9	1.707	376	796	12.2	25.8	8.4	17.7	0.26	4.8	9.1	4.3
49	26-Mar	22.3	1.168	362	597	17.2	28.3	11.7	19.4	0.18	4.8	9.1	4.3
50	27-Mar	21.5	1.107	453	596	22.7	29.9	15.5	20.4	0.17	**6.2**	**7.6**	**1.4**
51	28-Mar	23.2	1.242	424	689	18.9	30.8	13.0	21.1	0.19	6.2	7.6	1.4
52	29-Mar	25.5	1.451	422	656	16.1	25.1	11.0	17.2	0.22	6.2	7.6	1.4
53	30-Mar	26.8	1.584	506	673	17.7	23.5	12.1	16.1	0.24	6.2	7.6	1.4
54	31-Mar	24.9	1.393	375	583	14.9	23.2	10.2	15.9	0.21	6.2	7.6	1.4
55	1-Apr	24.7	1.374	425	300	17.1	12.1	11.7	8.3	0.21	6.2	7.6	1.4
56	2-Apr	23.4	1.259	377	560	16.6	24.7	11.4	16.9	0.19	6.2	7.6	1.4
57	3-Apr	23.6	1.276	370	529	16.1	23.0	11.0	15.7	0.19	**3.9**	**5.7**	**1.8**
58	4-Apr	25.0	1.403	473	650	18.7	25.7	12.8	17.6	0.21	3.9	5.7	1.8
59	5-Apr	26.5	1.552	558	769	19.9	27.5	13.6	18.8	0.23	3.9	5.7	1.8
60	6-Apr	27.9	1.707	444	725	14.4	23.5	9.9	16.1	0.26	3.9	5.7	1.8
61	7-Apr		0.258	408	647	87.4	138.7	59.9	95.0	0.04	3.9	5.7	1.8
62	8-Apr		0.258	403	542	86.5	116.2	59.3	79.6	0.04	3.9	5.7	1.8
63	9-Apr		0.258	450	414	96.6	88.8	66.2	60.8	0.04	3.9	5.7	1.8
64	10-Apr	30.1	1.981	390	478	10.9	13.4	7.5	9.2	0.30	**3.7**	**4.3**	**0.6**
65	11-Apr	29.9	1.954	424	617	12.0	17.5	8.2	12.0	0.29	3.7	4.3	0.6
66	12-Apr	27.5	1.661	455	637	15.2	21.3	10.4	14.6	0.25	3.7	4.3	0.6

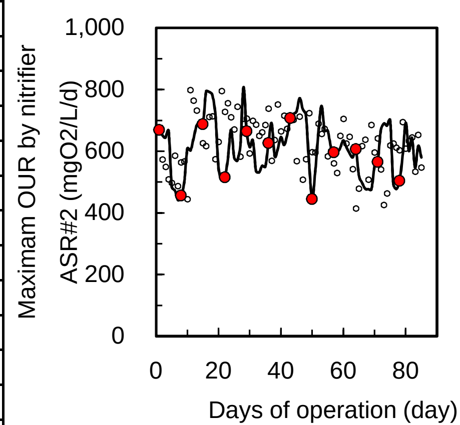
67	13-Apr	25.9	1.491	360	208	13.4	7.7	9.2	5.3	0.22	3.7	4.3	0.6
68	14-Apr	27.7	1.684	476	735	15.7	24.2	10.7	16.6	0.25	3.7	4.3	0.6
69	15-Apr	28.2	1.742	390	596	12.4	19.0	8.5	13.0	0.26	3.7	4.3	0.6
70	16-Apr	28.6	1.789	431	741	13.3	22.9	9.1	15.7	0.27	3.7	4.3	0.6
71	17-Apr	29.5	1.902	420	541	12.2	15.8	8.4	10.8	0.29	**4.5**	**5.8**	**1.3**
72	18-Apr	29.0	1.838	363	425	10.9	12.8	7.5	8.8	0.28	4.5	5.8	1.3
73	19-Apr	30.3	2.007	456	463	12.6	12.8	8.6	8.8	0.30	4.5	5.8	1.3
74	20-Apr	30.9	2.091	469	619	12.4	16.4	8.5	11.2	0.31	4.5	5.8	1.3
75	21-Apr	32	2.237	434	625	10.8	15.5	7.4	10.6	0.34	4.5	5.8	1.3
76	22-Apr	27	1.650	461	611	15.5	20.5	10.6	14.1	0.25	4.5	5.8	1.3
77	23-Apr	27	1.650	365	603	12.3	20.2	8.4	13.9	0.25	4.5	5.8	1.3
78	24-Apr	28	1.672	471	694	15.6	23.0	10.7	15.8	0.25	**5.3**	**7.9**	**2.7**
79	25-Apr	29	1.826	398	608	12.1	18.5	8.3	12.6	0.27	5.3	7.9	2.7
80	26-Apr	31	2.049	421	633	11.4	17.1	7.8	11.7	0.31	5.3	7.9	2.7
81	27-Apr	28	1.718	502	645	16.2	20.8	11.1	14.3	0.26	5.3	7.9	2.7
82	28-Apr	29	1.777	415	533	12.9	16.6	8.9	11.4	0.27	5.3	7.9	2.7
83	29-Apr	26	1.451	455	744	17.4	28.4	11.9	19.5	0.22	5.3	7.9	2.7
84	30-Apr	27	1.574	301	447	10.6	15.7	7.3	10.8	0.24	5.3	7.9	2.7

		Simulation		Measured	
	t	MaxNOUR#1	MaxNOUR#2	ASR#1	ASR#2
Date	days	mgO2/(L.d)	mgO2/(L.d)	mgO2/(L.d)	mgO2/(L.d)
6-Feb	1	475	668	-1	-1
7-Feb	2	470	652	456	573
8-Feb	3	470	644	484	549
9-Feb	4	491	666	413	509
10-Feb	5	360	485	357	497
11-Feb	6	352	473	447	585
12-Feb	7	329	441	313	487
13-Feb	8	328	456	362	564
14-Feb	9	349	498	387	567
15-Feb	10	418	609	331	444
16-Feb	11	408	602	400	798
17-Feb	12	430	642	446	764
18-Feb	13	453	684	486	732
19-Feb	14	457	694	432	690
20-Feb	15	449	687	423	626
21-Feb	16	510	794	486	617
22-Feb	17	523	792	437	711
23-Feb	18	543	783	404	713
24-Feb	19	518	717	401	574
25-Feb	20	407	544	422	630
26-Feb	21	389	506	447	795
27-Feb	22	380	515	421	728
28-Feb	23	415	576	397	756
1-Mar	24	472	670	373	710
2-Mar	25	402	580	422	670
3-Mar	26	385	569	669	744
4-Mar	27	410	620	419	582
5-Mar	28	526	808	555	688
6-Mar	29	473	664	394	706
7-Mar	30	462	613	416	593
8-Mar	31	500	635	524	698
9-Mar	32	437	536	465	686
10-Mar	33	446	531	307	650
11-Mar	34	474	553	475	661
12-Mar	35	480	550	487	685
13-Mar	36	527	626	460	738
14-Mar	37	533	691	344	569
15-Mar	38	417	584	462	636
16-Mar	39	411	608	368	751
17-Mar	40	418	646	377	664
18-Mar	41	387	620	456	715
19-Mar	42	395	652	462	673
20-Mar	43	392	707	432	701
21-Mar	44	410	721	429	702
22-Mar	45	425	729	397	568
23-Mar	46	461	772	466	712
24-Mar	47	450	736	399	507

Measured/Estimation

t	ASR#1	ASR#2
days	mgO2/(L.d)	mgO2/(L.d)
1	475	668
8	328	456
15	449	687
22	380	515
29	473	664
36	527	626
43	392	707
50	294	444
57	446	596
64	498	606
71	359	565
78	437	503





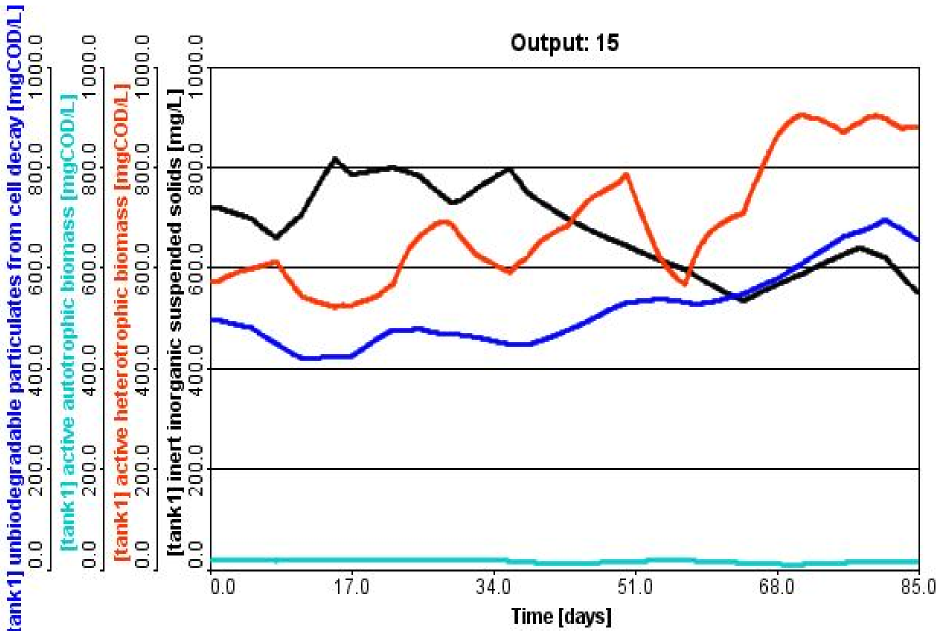
25-Mar	48	447	716	439	574
26-Mar	49	358	564	376	723
27-Mar	50	294	444	362	597
28-Mar	51	362	535	453	596
29-Mar	52	454	660	424	689
30-Mar	53	522	747	422	656
31-Mar	54	471	667	506	673
1-Apr	55	473	667	375	583
2-Apr	56	438	614	425	600
3-Apr	57	446	596	377	560
4-Apr	58	450	595	370	529
5-Apr	59	465	611	473	650
6-Apr	60	484	635	558	705
7-Apr	61	467	612	444	625
8-Apr	62	451	593	408	647
9-Apr	63	439	580	403	542
10-Apr	64	498	606	450	414
11-Apr	65	448	520	390	478
12-Apr	66	354	498	424	617
13-Apr	67	300	478	455	637
14-Apr	68	326	477	360	508
15-Apr	69	331	476	476	685
16-Apr	70	337	551	390	596
17-Apr	71	359	565	431	641
18-Apr	72	383	668	420	541
19-Apr	73	450	690	363	425
20-Apr	74	496	683	456	463
21-Apr	75	555	701	469	619
22-Apr	76	419	493	434	625
23-Apr	77	425	477	461	611
24-Apr	78	437	503	365	603
25-Apr	79	506	585	471	694
26-Apr	80	597	692	398	608
27-Apr	81	517	601	421	633
28-Apr	82	537	643	502	645
29-Apr	83	436	547	415	533
30-Apr	84	473	617	455	653
	85	473	580	301	547

Hue Domestic Wastewater Concentration (Back-Calculation method)

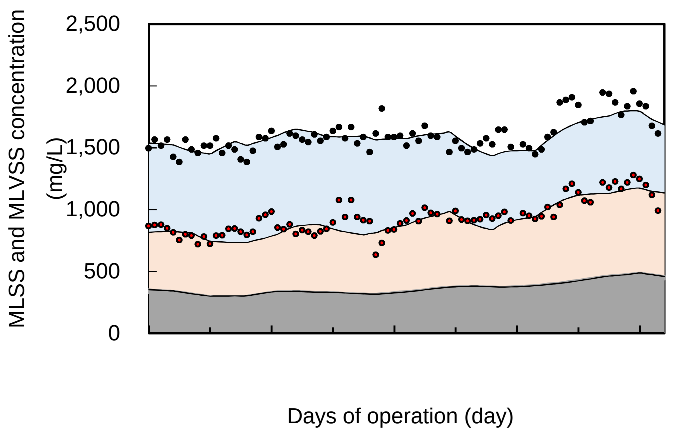
	Feb/6 --> Feb/12	Feb/13 --> Feb/19	Feb/20--> Feb/26	Feb/27 --> Mar/5	Mar/6 --> Mar/12	Mar/13 --> Mar/19	Mar/20 --> Mar/26	Mar/27 --> Apr/2
ssconinf2	53.9	41.5	44.1	57.8	47.8	59.1	71.5	37.1
XCB	13.4	11.6	11.9	25.4	17.7	21.0	4.7	17.3
Xi	13.2	7.5	15.4	14.4	11.6	13.5	8.3	16.9
SND	5.1	5.1	4.4	5.1	4.5	4.4	2.8	4.2
XND	1.3	2.6	2.7	4.9	2.5	2.5	4.3	3.4
Xig1	8.0	15.0	5.0	5.0	5.0	5.5	2.6	5.5
Xigtol	10.0	3.0	17.0	7.0	7.0	9.0	5.0	16.0
SS	27.8	15.8	35.3	33.7	26.6	32.2	13.7	38.9
VSS	17.8	12.8	18.3	26.7	19.6	23.2	8.7	22.9
CBOD5	46.4	36.5	38.5	56.1	44.5	54.5	53.9	36.6
sBOD5	38.6	29.8	31.6	41.4	34.3	42.3	51.2	26.6
CBOD30	58.1	45.8	48.3	71.7	56.5	69.1	65.7	46.9
sBOD30	46.5	35.9	38.1	49.8	41.3	51.0	61.7	32.0

	Apr/3 --> Apr/9	Apr/10 --> Apr/16	Apr/17 --> Apr/23	Apr/24 --> Apr/30	Avaerage
ssconinf2	65.6	85.2	76.2	78.0	59.8
XCB	17.5	16.3	8.4	18.4	15.3
Xi	15.6	19.4	18.1	16.4	14.2
SND	3.9	3.7	4.5	5.3	4.4
XND	1.8	4.6	3.5	2.7	3.1
Xig1	4.5	4.0	8.0	5.0	6.1
Xigtol	17.0	17.0	19.0	10.0	11.4
SS	39.2	40.9	36.8	33.4	31.2
VSS	22.2	23.9	17.8	23.4	19.8
CBOD5	57.1	70.5	59.5	66.6	51.7
sBOD5	47.0	61.1	54.7	55.9	42.9
CBOD30	71.7	87.5	73.0	83.2	64.8
sBOD30	56.6	73.5	65.8	67.3	51.6

Hue experiment



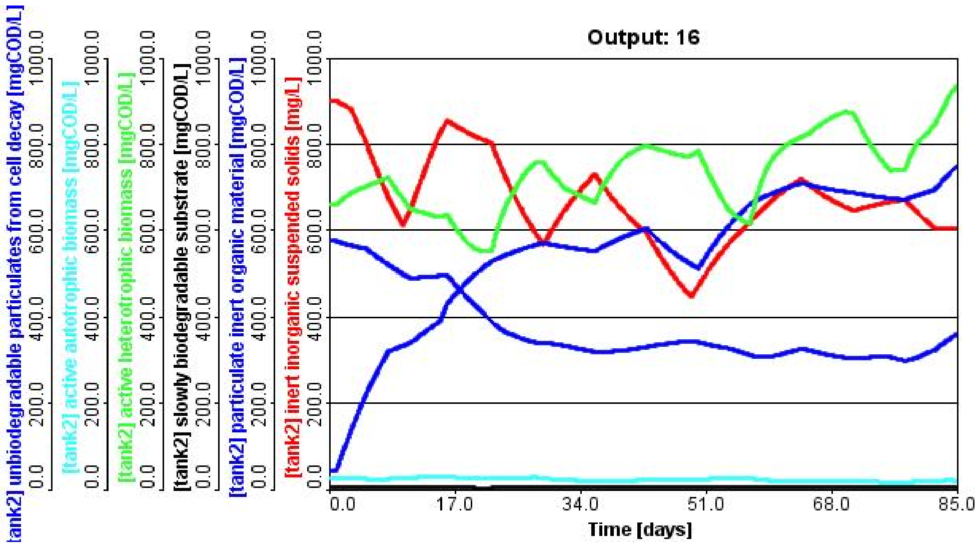
Date		X_U	X_{ANO}	X_{OHO}	X_{ig}	X_U	X_{ANO}	X_{OHO}
	days	mgCOD/L	mgCOD/L	mgCOD/L	mg/L	mg/L	mg/L	mg/L
6-Feb	1	497	18.6	677	720	340	13	464
7-Feb	2	492	18.4	687	714	337	13	471
8-Feb	3	488	18.3	694	709	334	13	475
9-Feb	4	484	18.2	700	703	332	12	479
10-Feb	5	481	18.1	703	698	329	12	482
11-Feb	6	470	17.8	708	684	322	12	485
12-Feb	7	459	17.6	713	671	314	12	488
13-Feb	8	449	17.4	718	659	308	12	492
14-Feb	9	439	17.8	692	676	301	12	474
15-Feb	10	428	18	670	692	293	12	459
16-Feb	11	420	18.2	648	707	288	12	444
17-Feb	12	421	18.7	642	737	288	13	440
18-Feb	13	421	19	637	765	288	13	436
19-Feb	14	422	19.3	631	792	289	13	432
20-Feb	15	422	19.5	628	816	289	13	430
21-Feb	16	422	19	631	800	289	13	432
22-Feb	17	424	18.6	630	785	290	13	432
23-Feb	18	436	18.6	637	788	299	13	436
24-Feb	19	447	18.6	642	791	306	13	440
25-Feb	20	458	18.7	648	794	314	13	444
26-Feb	21	468	18.8	661	797	321	13	453
27-Feb	22	476	18.9	675	799	326	13	462
28-Feb	23	475	18.7	716	794	325	13	490
1-Mar	24	476	18.6	746	789	326	13	511
2-Mar	25	479	18.6	766	784	328	13	525
3-Mar	26	475	18.4	779	769	325	13	534
4-Mar	27	471	18.3	791	755	323	13	542
5-Mar	28	468	18.3	798	742	321	13	547
6-Mar	29	468	18.3	792	730	321	13	542
7-Mar	30	467	18.2	767	734	320	12	525



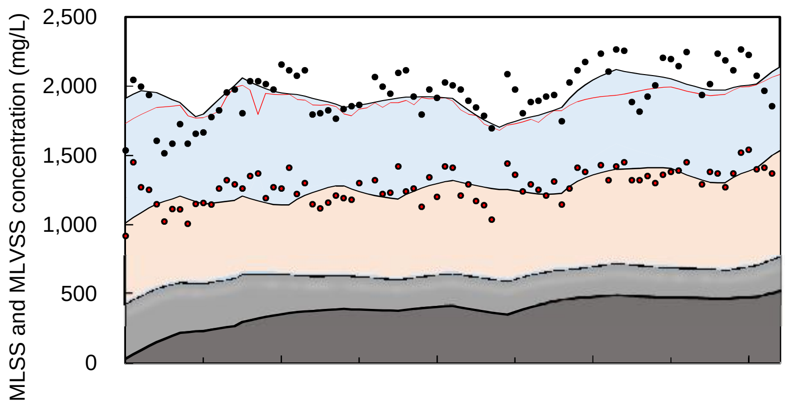
1	2	3	4		xtank1	vsstank1
mg/L	**mg/L**	**mg/L**	**mg/L**		mg/L	mg/L
340	353	817	1537		1495	867
337	350	820	1534		1565	873
334	347	822	1531		1515	876
332	344	823	1526		1565	848
329	342	823	1521		1425	815
322	334	819	1503		1385	752
314	326	815	1486		1565	799
308	319	811	1470		1485	789
301	313	787	1463		1455	718
293	305	764	1456		1515	782
288	300	744	1451		1515	722
288	301	741	1478		1575	789
288	301	738	1503		1455	792
289	302	734	1526		1515	843
289	302	733	1549		1485	845
289	302	734	1534		1405	821
290	303	735	1520		1385	795
299	311	748	1536		1475	821
306	319	759	1550		1585	929
314	327	770	1564		1575	957
321	333	786	1583		1635	984
326	339	801	1600		1505	854
325	338	829	1623		1525	840
326	339	850	1639		1615	879
328	341	865	1649		1595	801
325	338	872	1641		1565	833
323	335	877	1632		1545	819
321	333	880	1622		1605	789
321	333	876	1606		1555	823
320	332	858	1592		1585	842

8-Mar	31	464	18.1	749	746	318	12	513
9-Mar	32	462	18	731	758	316	12	501
10-Mar	33	458	17.8	721	769	314	12	494
11-Mar	34	454	17.7	713	779	311	12	488
12-Mar	35	451	17.5	704	789	309	12	482
13-Mar	36	448	17.4	697	797	307	12	477
14-Mar	37	447	15.8	715	772	306	11	490
15-Mar	38	447	14.6	725	750	306	10	497
16-Mar	39	452	13.9	747	738	310	10	512
17-Mar	40	457	13.4	763	727	313	9	523
18-Mar	41	464	13	773	717	318	9	529
19-Mar	42	470	12.7	783	707	322	9	536
20-Mar	43	477	12.5	790	697	327	9	541
21-Mar	44	484	12.9	814	688	332	9	558
22-Mar	45	492	13.3	833	680	337	9	571
23-Mar	46	500	13.7	847	672	342	9	580
24-Mar	47	509	14	856	665	349	10	586
25-Mar	48	517	14.3	865	657	354	10	592
26-Mar	49	525	14.5	874	650	360	10	599
27-Mar	50	530	14.7	890	644	363	10	610
28-Mar	51	533	16.1	844	636	365	11	578
29-Mar	52	535	17.2	801	629	366	12	549
30-Mar	53	536	18	760	622	367	12	521
31-Mar	54	538	18.6	725	615	368	13	497
1-Apr	55	536	18.9	701	609	367	13	480
2-Apr	56	534	19.1	683	603	366	13	468
3-Apr	57	531	19.2	674	597	364	13	462
4-Apr	58	529	17.6	721	586	362	12	494
5-Apr	59	529	16.4	755	577	362	11	517
6-Apr	60	532	15.5	777	567	364	11	532
7-Apr	61	536	14.8	790	558	367	10	541
8-Apr	62	540	14.3	800	550	370	10	548
9-Apr	63	544	14	808	541	373	10	553
10-Apr	64	549	13.7	816	534	376	9	559
11-Apr	65	556	12.5	860	543	381	9	589
12-Apr	66	565	11.6	896	551	387	8	614
13-Apr	67	572	11	933	559	392	8	639
14-Apr	68	579	10.6	967	567	397	7	662
15-Apr	69	588	10.4	987	574	403	7	676
16-Apr	70	599	10.3	1001	581	410	7	686
17-Apr	71	609	10.3	1010	588	417	7	692
18-Apr	72	620	11.3	1004	597	425	8	688
19-Apr	73	630	12.2	1001	605	432	8	686
20-Apr	74	641	12.9	993	613	439	9	680
21-Apr	75	652	13.5	985	620	447	9	675
22-Apr	76	662	13.9	975	627	453	10	668
23-Apr	77	668	14.1	986	634	458	10	675
24-Apr	78	673	14.3	995	640	461	10	682
25-Apr	79	679	15.1	1005	633	465	10	688
26-Apr	80	687	15.8	1008	627	471	11	690
27-Apr	81	695	16.4	1002	620	476	11	686
28-Apr	82	685	16.5	992	601	469	11	679
29-Apr	83	676	16.5	982	582	463	11	673
30-Apr	84	664	16.5	986	565	455	11	675
1-May	85	655	16.4	985	550	449	11	675

318	330	843	1589		1635	895
316	329	829	1587		1665	1076
314	326	820	1589		1575	940
311	323	811	1590		1665	1076
309	321	803	1592		1535	940
307	319	796	1593		1585	913
306	317	807	1579		1465	905
306	316	813	1563		1615	633
310	319	831	1569		1815	729
313	322	845	1572		1585	831
318	327	856	1573		1585	837
322	331	867	1574		1595	886
327	335	876	1573		1515	911
332	340	898	1586		1615	968
337	346	917	1597		1555	906
342	352	932	1604		1675	1014
349	358	945	1610		1595	973
354	364	956	1613		1585	963
360	370	968	1618			
363	373	983	1627		1465	909
365	376	954	1590		1555	987
366	378	927	1556		1495	919
367	379	900	1522		1465	907
368	381	878	1493		1485	914
367	380	860	1469		1535	922
366	379	847	1450		1575	955
364	377	838	1435		1525	925
362	374	868	1454		1645	949
362	374	891	1468		1645	979
364	375	907	1474		1505	910
367	377	918	1476			
370	380	928	1478		1525	971
373	382	936	1477		1495	950
376	385	944	1478		1445	924
381	389	978	1521		1485	944
387	395	1009	1560		1585	1019
392	399	1038	1597		1625	940
397	404	1066	1633		1865	1036
403	410	1086	1660		1885	1167
410	417	1103	1684		1905	1207
417	424	1116	1704		1845	1137
425	432	1120	1717		1705	1072
432	440	1125	1730		1715	1059
439	448	1128	1741			
447	456	1130	1750		1945	1217
453	463	1131	1758		1935	1177
458	467	1143	1777		1865	1227
461	471	1152	1792		1765	1167
465	475	1164	1797		1835	1217
471	481	1172	1799		1955	1277
476	487	1174	1794		1855	1247
469	480	1160	1761		1835	1197
463	474	1147	1729		1675	1117
455	466	1141	1706		1615	991
449	460	1135	1685			



Date		XCB	X_I	X_U	X_{ANO}	X_{OHO}	X_{ig}	XCB
	days	mgCOD/L	mgCOD/L	mgCOD/L	mgCOD/L	mgCOD/L	mg/L	mg/L
6-Feb	1	3.75	45	575	26	828	900	3
7-Feb	2	4.06	93	570	26	843	890	3
8-Feb	3	4.12	138	565	25	855	881	3
9-Feb	4	4.17	181	561	25	864	842	3
10-Feb	5	4.25	221	558	24	869	805	3
11-Feb	6	3.96	256	545	24	877	759	3
12-Feb	7	3.99	289	532	24	884	717	3
13-Feb	8	3.97	320	521	24	891	677	3
14-Feb	9	3.76	327	510	25	864	644	3
15-Feb	10	3.85	334	499	26	841	614	3
16-Feb	11	3.71	340	490	27	817	650	3
17-Feb	12	3.71	354	491	28	812	697	3
18-Feb	13	3.73	366	492	29	808	743	3
19-Feb	14	3.7	379	494	29	803	786	3
20-Feb	15	3.67	391	495	30	799	827	3
21-Feb	16	3.83	432	495	30	802	854	3
22-Feb	17	3.75	452	475	28	775	843	3
23-Feb	18	3.66	470	457	27	753	833	3
24-Feb	19	3.52	487	440	26	734	825	2
25-Feb	20	3.26	502	423	25	722	816	2
26-Feb	21	3.21	516	405	24	721	809	2
27-Feb	22	3.91	529	389	26	723	801	3
28-Feb	23	4.29	537	374	26	785	757	3
1-Mar	24	4.61	544	364	26	829	718	3
2-Mar	25	4.62	550	357	27	859	681	3
3-Mar	26	4.72	556	351	27	888	648	3
4-Mar	27	4.89	562	345	28	912	618	3
5-Mar	28	5.22	567	341	28	927	591	4
6-Mar	29	4.78	571	341	26	926	568	3
7-Mar	30	4.61	567	339	24	901	598	3



X_I	X_U	X_{ANO}	X_{OHO}	X_{ig_tol}	X_{ig_s}	$X_{ig\_precipitant}$	1	2
mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
31	394	18	567	900	720	180	31	33
63	390	17	577	890	714	176	63	66
95	387	17	586	881	709	172	95	97
124	384	17	592	842	703	139	124	127
151	382	17	595	805	698	107	151	154
175	373	16	601	759	684	75	175	178
198	364	16	605	717	671	46	198	201
219	357	17	610	677	659	18	219	222
224	349	17	592	644	602	42	224	227
229	342	18	576	614	603	11	229	231
233	336	18	560	650	625	25	233	235
242	336	19	556	697	637	60	242	245
251	337	20	553	743	656	87	251	253
260	338	20	550	786	753	33	260	262
268	339	20	547	827	816	11	268	270
296	339	20	549	854	800	54	296	299
310	325	19	531	843	785	58	310	312
322	313	18	516	833	625	208	322	324
334	301	18	503	825	791	34	334	336
344	290	17	495	816	794	22	344	346
353	277	17	494	809	797	12	353	356
362	266	17	495	801	799	2	362	365
368	256	18	538	757	724	33	368	371
373	249	18	568	718	689	29	373	376
377	245	18	588	681	635	46	377	380
381	240	19	608	648	612	36	381	384
385	236	19	625	618	601	17	385	388
388	234	19	635	591	575	16	388	392
391	234	18	634	568	521	47	391	394
388	232	17	617	598	531	67	388	392

3	4	5	6	7		xtank2	vsstank2
mg/L	**mg/L**	**mg/L**	**mg/L**	**mg/L**		mg/L	mg/L
427	445	1012	1732	1912		1535	917
457	474	1052	1766	1942		2045	1450
484	501	1087	1796	1968		1995	1270
511	528	1120	1823	1962		1935	1250
536	553	1148	1846	1953		1605	1146
551	568	1168	1852	1927		1515	1022
565	581	1187	1858	1904		1585	1112
579	595	1206	1865	1883		1725	1110
576	593	1185	1787	1829		1585	1005
573	591	1167	1770	1781		1655	1149
571	589	1149	1774	1799		1665	1155
581	600	1157	1794	1854		1775	1145
590	610	1163	1819	1906		1825	1260
600	621	1171	1924	1957		1955	1320
609	630	1177	1993	2004		1975	1290
638	658	1207	2007	2061		1805	1260
638	657	1188	1973	2031		2035	1350
637	656	1172	1797	2005		2035	1370
637	655	1158	1949	1983		2015	1190
636	653	1147	1941	1963		1975	1270
633	650	1144	1941	1953		2155	1260
631	649	1144	1943	1945		2115	1410
627	645	1182	1906	1939		2075	1220
625	643	1211	1900	1929		2115	1300
624	643	1231	1866	1912		1795	1147
624	643	1251	1863	1899		1805	1116
625	644	1268	1869	1886		1825	1158
625	645	1280	1855	1871		1765	1210
628	645	1280	1801	1848		1835	1190
624	640	1257	1788	1855		1855	1180

8-Mar	31	4.6	564	336	23	882	625	3
9-Mar	32	4.39	561	333	22	864	650	3
10-Mar	33	4.37	559	329	21	856	673	3
11-Mar	34	4.4	556	325	21	848	694	3
12-Mar	35	4.38	554	322	20	840	713	3
13-Mar	36	4.71	552	320	21	834	729	3
14-Mar	37	5.04	562	319	21	871	704	3
15-Mar	38	4.98	571	320	21	895	681	3
16-Mar	39	5.14	579	321	21	921	660	4
17-Mar	40	5.3	586	323	21	938	641	4
18-Mar	41	5.3	593	326	21	949	624	4
19-Mar	42	5.41	599	328	21	959	608	4
20-Mar	43	4.56	603	331	23	965	593	3
21-Mar	44	4.51	586	334	23	959	562	3
22-Mar	45	4.5	571	336	23	954	535	3
23-Mar	46	4.55	557	339	23	949	510	3
24-Mar	47	4.45	544	341	23	943	487	3
25-Mar	48	4.4	532	343	23	941	466	3
26-Mar	49	4.09	521	344	23	942	448	3
27-Mar	50	4.61	513	342	22	951	473	3
28-Mar	51	4.58	540	337	24	913	500	3
29-Mar	52	4.59	565	334	25	879	525	3
30-Mar	53	4.53	588	330	26	846	548	3
31-Mar	54	4.26	609	327	26	818	568	3
1-Apr	55	4.17	628	322	27	802	587	3
2-Apr	56	4.04	646	317	27	790	604	3
3-Apr	57	4.04	662	312	26	788	620	3
4-Apr	58	4.45	671	308	23	855	638	3
5-Apr	59	4.8	679	307	22	903	655	3
6-Apr	60	5.08	686	309	20	934	671	3
7-Apr	61	5.19	693	313	20	953	685	4
8-Apr	62	5.26	699	318	19	967	698	4
9-Apr	63	5.31	705	322	18	977	709	4
10-Apr	64	5.11	710	326	20	985	719	4
11-Apr	65	4.96	705	323	20	994	705	3
12-Apr	66	4.97	701	318	20	1007	692	3
13-Apr	67	4.98	698	314	20	1019	680	3
14-Apr	68	5.03	695	311	20	1030	670	3
15-Apr	69	5.07	692	308	20	1037	661	3
16-Apr	70	5.29	689	306	20	1043	653	4
17-Apr	71	5.02	687	306	19	1038	646	3
18-Apr	72	5.02	684	306	20	1006	651	3
19-Apr	73	5	681	306	19	975	655	3
20-Apr	74	4.91	679	307	18	948	659	3
21-Apr	75	4.89	676	307	17	925	663	3
22-Apr	76	4.35	674	307	16	906	666	3
23-Apr	77	4.34	673	302	16	908	669	3
24-Apr	78	4.88	671	299	16	911	670	3
25-Apr	79	5.24	678	303	18	953	651	4
26-Apr	80	5.57	684	309	18	980	634	4
27-Apr	81	5.39	689	318	19	994	619	4
28-Apr	82	5.54	695	324	20	1015	605	4
29-Apr	83	5.42	715	337	21	1046	605	4
30-Apr	84	5.7	733	349	22	1081	605	4
1-May	85	5.82	750	361	20	1103	605	4

386	230	16	604	625	596	29	386	389
384	228	15	592	650	624	26	384	387
383	225	15	586	673	668	5	383	386
381	223	14	581	694	645	49	381	384
379	221	14	575	713	689	24	379	382
378	219	14	571	729	697	32	378	381
385	218	14	597	704	681	23	385	388
391	219	14	613	681	625	56	391	395
397	220	14	631	660	654	6	397	400
401	221	14	642	641	627	14	401	405
406	223	14	650	624	617	7	406	410
410	225	14	657	608	607	1	410	414
413	227	15	661	593	574	19	413	416
401	229	16	657	562	524	38	401	404
391	230	16	653	535	506	29	391	394
382	232	16	650	510	507	3	382	385
373	234	16	646	487	457	30	373	376
364	235	16	645	466	442	24	364	367
357	236	16	645	448	425	23	357	360
351	234	15	651	473	465	8	351	355
370	231	16	625	500	485	15	370	373
387	229	17	602	525	506	19	387	390
403	226	18	579	548	532	16	403	406
417	224	18	560	568	516	52	417	420
430	221	18	549	587	565	22	430	433
442	217	18	541	604	603	1	442	445
453	214	18	540	620	597	23	453	456
460	211	16	586	638	586	52	460	463
465	210	15	618	655	577	78	465	468
470	212	14	640	671	567	104	470	473
475	214	13	653	685	558	127	475	478
479	218	13	662	698	550	148	479	482
483	221	13	669	709	541	168	483	487
486	223	14	675	719	534	185	486	490
483	221	14	681	705	543	162	483	486
480	218	14	690	692	551	141	480	484
478	215	14	698	680	559	121	478	481
476	213	13	705	670	567	103	476	479
474	211	13	710	661	574	87	474	477
472	210	13	714	653	581	72	472	476
471	210	13	711	646	588	58	471	474
468	210	14	689	651	597	54	468	472
466	210	13	668	655	605	50	466	470
465	210	12	649	659	613	46	465	468
463	210	12	634	663	620	43	463	466
462	210	11	621	666	627	39	462	465
461	207	11	622	669	634	35	461	464
460	205	11	624	670	640	30	460	463
464	208	12	653	651	633	18	464	468
468	212	13	671	634	627	7	468	472
472	218	13	681	619	610	9	472	476
476	222	13	695	605	601	4	476	480
490	231	14	716	605	582	23	490	493
502	239	15	740	605	565	40	502	506
514	247	14	755	605	550	55	514	518

620	635	1239	1835	1864		1865	1300
615	630	1222	1846	1872			
611	626	1212	1880	1885		2065	1320
606	621	1201	1846	1895		1995	1220
603	617	1192	1881	1905		1945	1230
600	615	1186	1883	1915		2095	1420
607	621	1217	1898	1921		2115	1240
614	628	1241	1866	1922		1925	1260
620	634	1265	1919	1925		1795	1128
626	640	1283	1910	1924		1975	1340
633	647	1297	1914	1921		1915	1200
639	653	1310	1917	1918		2025	1420
643	658	1319	1893	1912		2005	1410
633	649	1306	1830	1868		1975	1210
624	640	1293	1799	1828		1895	1290
617	633	1283	1790	1793		1845	1170
609	625	1271	1728	1758		1785	1140
602	618	1263	1705	1729		1695	1036
595	611	1256	1681	1704			
589	604	1255	1720	1728		2085	1440
604	620	1245	1730	1745		1975	1360
619	636	1238	1744	1763		1805	1240
632	650	1229	1761	1777		1885	1290
644	662	1222	1738	1790		1895	1250
654	672	1221	1786	1808		1925	1210
662	681	1222	1825	1826		1935	1310
670	687	1227	1824	1847		1745	1145
674	690	1275	1861	1913		2025	1260
679	693	1312	1889	1967		2115	1410
685	699	1339	1906	2010		2175	1380
693	706	1359	1917	2044			
700	713	1375	1925	2073		2235	1430
707	720	1389	1930	2098		2105	1320
713	727	1402	1936	2121		2265	1420
708	721	1402	1945	2107		2255	1450
701	715	1405	1956	2097		1885	1320
697	710	1408	1967	2088		1815	1320
692	706	1411	1978	2081		1925	1350
688	702	1412	1986	2073		2005	1300
685	699	1413	1994	2066		2205	1360
684	697	1408	1996	2054		2195	1380
682	695	1384	1981	2035		2145	1390
679	692	1360	1965	2015		2245	1450
679	691	1340	1953	1999			
677	688	1322	1942	1985		1935	1290
675	686	1307	1934	1973		2015	1380
671	682	1304	1938	1973		2235	1370
668	679	1303	1943	1973		2185	1270
676	687	1340	1973	1991		2115	1370
684	697	1368	1995	2002		2265	1520
693	707	1387	1997	2006		2225	1540
702	715	1410	2011	2015		2075	1400
724	738	1455	2037	2060		1965	1410
745	760	1500	2065	2105		1855	1370
765	779	1534	2084	2139			

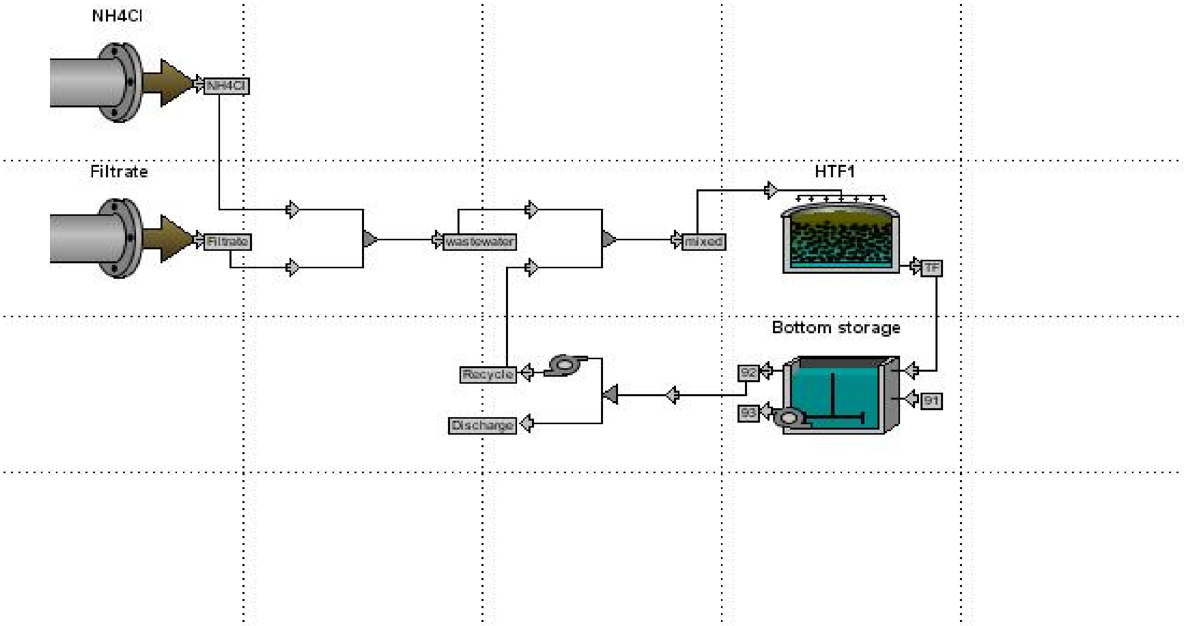
Trickling Filter Simulation data sheet

Data at Phu Loc wastewater treatment plant

Danang city, Vietnam

2014-2015

2014chanh Wed Jun 24 11:39:11 JST 2015



Simulation Setup

Time

stopping time	3	[d]
communication interval	3	[min]
date and time at t=0	2013	[yr,m,d,h,min,s]
	9	
	20	
	9	
	0	
	0	
initial time	1	[d]

Rounding

round seconds to full minutes	Off
round minutes to quarter hours	Off

Repeat Runs

number of reruns	0

Consistency Check

show process warnings	Off

Process Warnings

write process warnings into file	Off
process warnings only once per run	On

Aeration Limit Settings

apply aeration limits (airflow per diffuser)	Off
show aeration limit warning	On

Model Check

warn user when states and models don't match	Off

Display of Discontinuous Pump Flows (SBR and BAF units only)

display concentrations in discontinuous pump flows at all tim	Off

Physical

Oxygen Solubility (layout-wide settings)

liquid temperature	20	[C]
blower inlet air temperature	20	[C]
elevation above sea level	0	[m]
barometric pressure at sea level	1	[atm]
standard air conditions	U.S. (air temp 20C, 36% humidity)	
Physical Constants		
molecular weight of air (@ U.S. Standard Conditions)	29	[g/mol]
gas constant	8310	[J/kmol.K]
Antoine coefficient A1	8.11	[-]
Antoine coefficient A2	1750	[-]
Antoine coefficient A3	235	[-]
Properties of User-Defined Air		
mole fraction of oxygen in user-defined air	1	[-]
density of user-defined air	1430	[mg/L]
molecular weight of user-defined air	32	[g/mole]
exponent in blower power equation	0.284	[-]
SOTE Regression Coefficients		
SOTE regression constant A1 (ceramic disc)	12.1	[-]
SOTE regression constant A2 (ceramic disc)	-3.24	[-]
SOTE regression constant A3 (ceramic disc)	0.0816	[-]
SOTE regression constant A4 (ceramic disc)	1.22	[-]
SOTE regression constant A5 (ceramic disc)	0.158	[-]
SOTE regression constant A1 (ceramic dome)	19.8	[-]
SOTE regression constant A2 (ceramic dome)	-13.6	[-]
SOTE regression constant A3 (ceramic dome)	3.07	[-]
SOTE regression constant A4 (ceramic dome)	1.11	[-]
SOTE regression constant A5 (ceramic dome)	0.172	[-]
SOTE regression constant A1 (membrane disc)	8.48	[-]
SOTE regression constant A2 (membrane disc)	-5.38	[-]
SOTE regression constant A3 (membrane disc)	1.06	[-]
SOTE regression constant A4 (membrane disc)	1.73	[-]
SOTE regression constant A5 (membrane disc)	-0.0233	[-]
SOTE regression constant A1 (membrane tube)	7.57	[-]
SOTE regression constant A2 (membrane tube)	-2.72	[-]
SOTE regression constant A3 (membrane tube)	0.15	[-]
SOTE regression constant A4 (membrane tube)	1.5	[-]
SOTE regression constant A5 (membrane tube)	0.156	[-]
SOTE regression constant A1 (coarse bubble)	3.79	[-]
SOTE regression constant A2 (coarse bubble)	-0.0927	[-]
SOTE regression constant A3 (coarse bubble)	0.00108	[-]
SOTE regression constant A4 (coarse bubble)	0.266	[-]
SOTE regression constant A5 (coarse bubble)	0.0236	[-]
SOTE regression constant A1 (jet)	1.43	[-]
SOTE regression constant A2 (jet)	-0.268	[-]
SOTE regression constant A3 (jet)	0.00424	[-]
SOTE regression constant A4 (jet)	1.35	[-]
SOTE regression constant A5 (jet)	0.00522	[-]
Deep Tank SOTE Regression Coefficients		
Deep Tank SOTE regression constant A6 (ceramic disc)	-0.00419	[-]
Deep Tank SOTE regression constant A6 (ceramic dome)	-0.00389	[-]
Deep Tank SOTE regression constant A6 (membrane disc)	-0.00909	[-]
Deep Tank SOTE regression constant A6 (membrane tube)	-0.00725	[-]

Settling Correlations

SVI Correlation Coefficients

SVI correlation coeff. 1	710	
SVI correlation coeff. 2	-4.67	
SVI correlation coeff. 3	0.018	
SVI correlation coeff. 4	0.000266	
SVI correlation coeff. 5	-2.9E-06	
SVI correlation coeff. 6	2.5E-08	
SVI correlation coeff. 7	-0.00016	
SVI correlation coeff. 8	0.0049	
SVI correlation coeff. 9	0.000647	

Steady-State

Steady-State Parameters

number of retries on iteration	1	
error limit on individual variables	1E-10	
iteration termination criteria	5	
maximum number of iterations	100000	
maximum number of unsuccessful iterations	20000	

Iteration Search Setup

force iteration even if model converged	On	
contract constant	0.982	
expand constant	1	
maximum step size in one iteration	0.5	
damping factor on final approach	1	
initial perturbation	0.05	
convergence output interval	200	
steady-state loop counter initial value	0	

Trim Parameters

print value of dsum	1E+10	[d]
display improved iterations only	On	
iteration output interval in trim	50000	

Analyzer

Monte Carlo Analysis

number of runs	1000	

Optimizer

Static

number of optimized parameters	2	
number of data points (at least 2)	50	
parameter tolerance	0.000001	
objective function tolerance	-1E+10	
scaled termination value for objective function	0.1	
maximum number of optimizer iterations	200	
detailed statistical report	On	
solution report to file	Off	

Optimizer Settings

scaled step size in initial guess	0.2	
reflection constant	0.95	
contraction constant	0.45	
expansion constant	1.9	
shrink constant	0.5	

Dynamic

DPE timewindow	1E+10	[d]

Maximum Likelihood		
error distribution	Normal	
estimate standard deviations of errors	On	
standard deviations of errors		
use specified standard deviations as reference	Off	
level of significance	0.05	[-]
heteroscedasticity model	On	
heteroscedasticity parameters		
Derivative Information		
report objective function gradient and Hessian	Off	
report model sensitivity coefficients	Off	
finite-difference relative perturbation size	1E-07	
Confidence Limits		
printing of confidence limits	On	
confidence level for confidence limits	0.95	[-]
treat the different target variables as one target	Off	
Significance of the Regression		
level of significance for significance of regression test	0.05	[-]
Lack of Fit		
lack of fit test	Off	
level of significance for lack of fit test	0.05	[-]
replication sum of squares	User Supplied	
relative tolerance used to detect repeat measurements	0.0001	[-]
User Supplied Replication Sum of Squares		
number of target variables	1	
replication sum of squares	1	
degrees of freedom for replication sum of squares	5	
Portmanteau		
Portmanteau test on weighted residuals	On	
level of significance for portmanteau test	0.05	[-]
maximum number of lags used in portmanteau test	20	

Matlab Link

Matlab Link		
Matlab link control	On	
Diagnostics		
show messages in log window	Off	
print Matlab output in log window	Off	

On-Line Operation

On-Line Run		
on-line run	Off	
wait for all data to synchronize	Off	
waiting period	2	[h]
sampling rate from data base	60	[s]
DDE		
clipboard format	Xltable	
wait for DDE transactions	10	
Input Files		
input file extension (in offline mode)	dat	
replace failed data with form value	Off	
plant #1 name (for data file)	blank	
Data Files		
plant #2 name (for data file)	blank	

plant #3 name (for data file)	blank	
plant #4 name (for data file)	blank	
plant #5 name (for data file)	blank	
plant #6 name (for data file)	blank	
plant #7 name (for data file)	blank	
plant #8 name (for data file)	blank	
plant #9 name (for data file)	blank	
plant #10 name (for data file)	blank	
Output Files		
use global alarm file	Off	
alarm file name	blank	
Real Time Synchronized Mode		
real time synchronized mode	Off	
real time acceleration factor	1	
Data Transfer		
send data to simulator module	Off	
max number of control and output variables	100	
max number of datapoints	100	
Communication		
output into Matlab format	Off	
send warnings to log window	On	
send optimizer status to log window	On	
send DPE status to log window	On	

Numerical

Bounding		
number of iterations in IMPL operator	30	
error bound in IMPL operator	0.000001	
bottom bound on flows	1E-10	[m3/d]
top bound on flows	1E+10	[m3/d]
bottom bound on initial concentrations	0.000001	[mg/L]
top bound on initial concentrations	1E+10	[mg/L]
bottom bound on concentrations	0	[mg/L]
top bound on concentrations	1E+10	[mg/L]
bottom bound on derivatives	-1E+33	[mg/(L.d)]
top bound on derivatives	1E+33	[mg/(L.d)]
bottom bound on volumes	1E-10	[m3]
ignore dilution rate below this volume	0.0001	[m3]
ignore dilution rate below this layer thickness	0.0001	[m]
top bound on volumes	1E+10	[m3]
bottom bound on parameters	1E-10	
top bound on parameters	1E+10	
top bound on integers	999999	
initial iteration on loops	100	
top bound on exponential (xmin)	1000	[mg/L]
Speed		
smooth pump discharge at discontinuities	Off	
smoothing period	0.00001	[d]
smooth factor (logistic parameter)	15	
smooth at flow changes larger than	50	[%]

Miscellaneous

General		
controller tuning array size	3000	

controller sampling time	0.0035	[d]
controller damping in steady-state	100	[d]

Operating Cost

Energy Cost

energy pricing	Constant Price	

Constant Price

energy price	0.1	[$/KWh]

Time-Based Pricing

number of price levels	2	
energy price	0.06	[$/KWh]
	0.11	
price level starting hour (24-hour clock)	6	
	18	

Integration Control

Integration Settings

numerical solver	Runge-Kutta-Fehlberg(2)	
initial number of integration steps	50	
minimum integration step size	0	[d]
maximum integration step size	0.1	[d]

Output Variables

General Program Variables

Library Variables

macro library		
biological model ID	4	
biological model		

Dynamic Run

simulation time	3	[d]
completed part of dynamic run	100	[%]

Steady-State

convergence	100	[%]
steady-state loop counter	3840	
year	2010	
month	9	
day	23	
hour	9	
minute	2	
second	54	
last integration step size (from MGA)		
last integration step size (GPS-X)	3.83E-06	[d]
average integration step size	1.97E-06	[d]
sum of absolute values of derivatives	77000	[mg/(L.d)]

Physical

dynamic viscosity	1000	[Pa.s]
density of water	998000	[mg/L]
kinematic viscosity	1	[m2/s]

Numerical

zero	0	

Optimizer

error (data/simulation)		

Alarm

alarmtext		
data failure in fileinput controllers	0	
failed cryptic variable names		

Simulation Setup

Time

stopping time	3	[d]
communication interval	0.05	[h]
date and time at t=0	2010	[yr,m,d,h,min,s]
	9	
	20	
	9	
	0	
	0	
initial time	1	[d]

Rounding

round seconds to full minutes	0	
round minutes to quarter hours	0	

Repeat Runs

number of reruns	0	

Consistency Check

show process warnings	0	

Process Warnings

write process warnings into file	0	
process warnings only once per run	1	

Aeration Limit Settings

apply aeration limits (airflow per diffuser)	0	
show aeration limit warning	1	

Model Check

warn user when states and models don't match	0	

Display of Discontinuous Pump Flows (SBR and BAF units only)

display concentrations in discontinuous pump flows at all times	0	

Physical

Oxygen Solubility (layout-wide settings)

liquid temperature	20	[C]
blower inlet air temperature	20	[C]
elevation above sea level	0	[m]
barometric pressure at sea level	1	[atm]
standard air conditions	1	

Physical Constants

molecular weight of air (@ U.S. Standard Conditions)	29	[g/mol]
gas constant	8310	[J/kmol.K]
Antoine coefficient A1	8.11	[-]
Antoine coefficient A2	1750	[-]
Antoine coefficient A3	235	[-]

Properties of User-Defined Air

mole fraction of oxygen in user-defined air	1	[-]
density of user-defined air	1430	[mg/L]
molecular weight of user-defined air	32	[g/mole]
exponent in blower power equation	0.284	[-]

SOTE Regression Coefficients

SOTE regression constant A1 (ceramic disc)	12.1	[-]
SOTE regression constant A2 (ceramic disc)	-3.24	[-]
SOTE regression constant A3 (ceramic disc)	0.0816	[-]
SOTE regression constant A4 (ceramic disc)	1.22	[-]
SOTE regression constant A5 (ceramic disc)	0.158	[-]

SOTE regression constant A1 (ceramic dome)	19.8	[-]
SOTE regression constant A2 (ceramic dome)	-13.6	[-]
SOTE regression constant A3 (ceramic dome)	3.07	[-]
SOTE regression constant A4 (ceramic dome)	1.11	[-]
SOTE regression constant A5 (ceramic dome)	0.172	[-]
SOTE regression constant A1 (membrane disc)	8.48	[-]
SOTE regression constant A2 (membrane disc)	-5.38	[-]
SOTE regression constant A3 (membrane disc)	1.06	[-]
SOTE regression constant A4 (membrane disc)	1.73	[-]
SOTE regression constant A5 (membrane disc)	-0.0233	[-]
SOTE regression constant A1 (membrane tube)	7.57	[-]
SOTE regression constant A2 (membrane tube)	-2.72	[-]
SOTE regression constant A3 (membrane tube)	0.15	[-]
SOTE regression constant A4 (membrane tube)	1.5	[-]
SOTE regression constant A5 (membrane tube)	0.156	[-]
SOTE regression constant A1 (coarse bubble)	3.79	[-]
SOTE regression constant A2 (coarse bubble)	-0.0927	[-]
SOTE regression constant A3 (coarse bubble)	0.00108	[-]
SOTE regression constant A4 (coarse bubble)	0.266	[-]
SOTE regression constant A5 (coarse bubble)	0.0236	[-]
SOTE regression constant A1 (jet)	1.43	[-]
SOTE regression constant A2 (jet)	-0.268	[-]
SOTE regression constant A3 (jet)	0.00424	[-]
SOTE regression constant A4 (jet)	1.35	[-]
SOTE regression constant A5 (jet)	0.00522	[-]

Deep Tank SOTE Regression Coefficients

Deep Tank SOTE regression constant A6 (ceramic disc)	-0.00419	[-]
Deep Tank SOTE regression constant A6 (ceramic dome)	-0.00389	[-]
Deep Tank SOTE regression constant A6 (membrane disc)	-0.00909	[-]
Deep Tank SOTE regression constant A6 (membrane tube)	-0.00725	[-]

Settling Correlations

SVI Correlation Coefficients

SVI correlation coeff. 1	710
SVI correlation coeff. 2	-4.67
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SVI correlation coeff. 6	2.5E-08
SVI correlation coeff. 7	-0.00016
SVI correlation coeff. 8	0.0049
SVI correlation coeff. 9	0.000647

Steady-State

Steady-State Parameters

number of retries on iteration	1
error limit on individual variables	1E-10
iteration termination criteria	5
maximum number of iterations	100000
maximum number of unsuccessful iterations	20000

Iteration Search Setup

force iteration even if model converged	1
contract constant	0.982
expand constant	1
maximum step size in one iteration	0.5
damping factor on final approach	1
initial perturbation	0.05
convergence output interval	200

	steady-state loop counter initial value	0	
Trim Parameters			
	print value of dsum	1E+10	[d]
	display improved iterations only	1	
	iteration output interval in trim	50000	
Analyzer			
Monte Carlo Analysis			
	number of runs	1000	
Optimizer			
Static			
	parameter tolerance	0.000001	
	objective function tolerance	-1E+10	
	scaled termination value for objective function	0.1	
	maximum number of optimizer iterations	200	
	detailed statistical report	1	
	solution report to file	0	
Optimizer Settings			
	scaled step size in initial guess	0.2	
	reflection constant	0.95	
	contraction constant	0.45	
	expansion constant	1.9	
	shrink constant	0.5	
Dynamic			
	DPE timewindow	1E+10	[d]
Maximum Likelihood			
	error distribution	1	
	estimate standard deviations of errors	1	
	use specified standard deviations as reference	0	
	level of significance	0.05	[-]
	heteroscedasticity model	1	
Derivative	heteroscedasticity parameters		
	report objective function gradient and Hessian	0	
	report model sensitivity coefficients	0	
	finite-difference relative perturbation size	1E-07	
Confidence Limits			
	printing of confidence limits	1	
	confidence level for confidence limits	0.95	[-]
	treat the different target variables as one target	0	
Significance of the Regression			
	level of significance for significance of regression test	0.05	[-]
Lack of Fit			
	lack of fit test	0	
	level of significance for lack of fit test	0.05	[-]
	replication sum of squares	1	
	relative tolerance used to detect repeat measurements	0.0001	[-]
User Supplied Replication Sum of Squares			
	replication sum of squares	1	
	degrees of freedom for replication sum of squares	5	
Portmanteau			
	Portmanteau test on weighted residuals	1	
	level of significance for portmanteau test	0.05	[-]
	maximum number of lags used in portmanteau test	20	
Matlab Link			
Matlab Link			
	Matlab link control	1	
Diagnostics			

show messages in log window	0	
print Matlab output in log window	0	

On-Line Operation

On-Line Run

on-line run	0	
wait for all data to synchronize	0	
waiting period	2	[h]
sampling rate from data base	60	[s]

DDE

clipboard format	1	
wait for DDE transactions	10	[msec]

Input Files

input file extension (in offline mode)	2	
replace failed data with form value	0	
plant #1 name (for data file)		

Data Files

plant #2 name (for data file)		
plant #3 name (for data file)		
plant #4 name (for data file)		
plant #5 name (for data file)		
plant #6 name (for data file)		
plant #7 name (for data file)		
plant #8 name (for data file)		
plant #9 name (for data file)		
plant #10 name (for data file)		

Output Files

use global alarm file	0	
alarm file name		

Real Time Synchronized Mode

real time synchronized mode	0	
real time acceleration factor	1	

Data Transfer

send data to simulator module	0	

Communication

output into Matlab format	0	
send warnings to log window	1	
send optimizer status to log window	1	
send DPE status to log window	1	

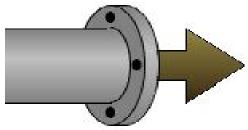
Numerical

Bounding

number of iterations in IMPL operator	30	
error bound in IMPL operator	0.000001	
bottom bound on flows	1E-10	[m3/d]
top bound on flows	1E+10	[m3/d]
bottom bound on initial concentrations	0.000001	[mg/L]
top bound on initial concentrations	1E+10	[mg/L]
bottom bound on concentrations	0	[mg/L]
top bound on concentrations	1E+10	[mg/L]
bottom bound on derivatives	-1E+33	[mg/(L.d)]
top bound on derivatives	1E+33	[mg/(L.d)]
bottom bound on volumes	1E-10	[m3]
ignore dilution rate below this volume	0.0001	[m3]
ignore dilution rate below this layer thickness	0.0001	[m]
top bound on volumes	1E+10	[m3]
bottom bound on parameters	1E-10	
top bound on parameters	1E+10	

	top bound on integers	1000000	
	initial iteration on loops	100	
	top bound on exponential (xmin)	1000	[mg/L]
Speed			
	smooth pump discharge at discontinuities	0	
	smoothing period	0.00001	[d]
	smooth factor (logistic parameter)	15	
	smooth at flow changes larger than	50	[%]
Miscellaneous			
General			
	controller sampling time	0.0035	[d]
	controller damping in steady-state	100	[d]
Operating Cost			
Energy Cost			
	energy pricing	1	
Constant Price			
	energy price	0.1	[$/KWh]
Time-Based Pricing			
	energy price	0.06	[$/KWh]
		0.11	
	price level starting hour (24-hour clock)	6	
		18	

Wastewater Influent



states	NH4Cl		Filtrate	
Influent Composition				
Inorganic Suspended Solids				
inert inorganic suspended solids	0	[g/m3]	10	[g/m3]
Organic Variables				
soluble inert organic material	0	[gCOD/m3]	15	[gCOD/m3]
readily biodegradable substrate	0	[gCOD/m3]	20	[gCOD/m3]
rapidly hydrolyzable substrate	0	[gCOD/m3]	0	[gCOD/m3]
particulate inert organic material	0	[gCOD/m3]	7	[gCOD/m3]
slowly biodegradable substrate	0	[gCOD/m3]	10	[gCOD/m3]
active heterotrophic biomass	0	[gCOD/m3]	0	[gCOD/m3]
active ammonia oxidizing biomass	0	[gCOD/m3]	0	[gCOD/m3]
active nitrite oxidizing biomass	0	[gCOD/m3]	0	[gCOD/m3]
unbiodegradable particulates from cell	0	[gCOD/m3]	0	[gCOD/m3]
Dissolved Oxygen				
dissolved oxygen	0	[gO2/m3]	0	[gO2/m3]
Nitrogen Compounds				
free and ionized ammonia	7000	[gN/m3]	10	[gN/m3]
soluble biodegradable organic nitroger	0	[gN/m3]	0	[gN/m3]
soluble inert organic nitrogen	0	[gN/m3]	0	[gN/m3]
particulate biodegradable organic nitro	0	[gN/m3]	0	[gN/m3]
particulate inert organic nitrogen	0	[gN/m3]	0	[gN/m3]
nitrite	0	[gN/m3]	0	[gN/m3]
nitrate	0	[gN/m3]	0	[gN/m3]
Alkalinity				
alkalinity	7	[mole/m3]	7	[mole/m3]
Influent Stoichiometry				
Local Model Selection				
base composite variables on ...	TwoStepMantis		TwoStepMantis	
Influent Fractions				
XCOD/VSS ratio	1.8	[gCOD/gVSS]	1.43	[gCOD/gVSS]
BOD5/BODultimate ratio	0.66	[-]	0.66	[-]
Mantis Nutrient Fractions				
N content of active biomass	0.068	[gN/gCOD]	0.068	[gN/gCOD]
N content of endogenous/inert mass	0.068	[gN/gCOD]	0.068	[gN/gCOD]
TwoStepMantis Nutrient Fractions				
N content of active biomass	0.086	[gN/gCOD]	0.086	[gN/gCOD]
Operating Cost				
Pumping Cost				
hydraulic head	0	[m]	0	[m]
pump efficiency	0.7	[-]	0.7	[-]
pumping headloss	0	[m]	0	[m]

Flow Data

Flow Type

flow type		Data			Data	

Data

influent flow		0	[L/min]		1	[m3/h]

Other Flow Options

Sinusoidal

amplitude scaling factor		0.2	[-]		0.2	[-]
time shift		0.35	[d]		0.35	[d]
sine wave frequency		1	[1/d]		1	[1/d]

Diurnal Flow

diurnal flow data	0	1480	[m3/d]	0	1480	[m3/d]
	1	1380		1	1380	
	2	1280		2	1280	
	3	1260		3	1260	
	4	1240		4	1240	
	5	1670		5	1670	
	6	2100		6	2100	
	7	2160		7	2160	
	8	2220		8	2220	
	9	2160		9	2160	
	#	2100		10	2100	
	#	2110		11	2110	
	#	2120		12	2120	
	#	2070		13	2070	
	#	2020		14	2020	
	#	2100		15	2100	
	#	2180		16	2180	
	#	2300		17	2300	
	#	2420		18	2420	
	#	2560		19	2560	
	#	2700		20	2700	
	#	2410		21	2410	
	#	2120		22	2120	
	#	1800		23	1800	

Diurnal Flow Factor (to average)

diurnal flow factor	0	0.74	[-]	0	0.74	[-]
	1	0.68		1	0.68	
	2	0.64		2	0.64	
	3	0.63		3	0.63	
	4	0.62		4	0.62	
	5	0.83		5	0.83	
	6	1.05		6	1.05	
	7	1.07		7	1.07	
	8	1.11		8	1.11	
	9	1.07		9	1.07	
	#	1.05		10	1.05	
	#	1.06		11	1.06	
	#	1.06		12	1.06	
	#	1.03		13	1.03	
	#	1.01		14	1.01	
	#	1.03		15	1.03	
	#	1.09		16	1.09	
	#	1.13		17	1.13	
	#	1.21		18	1.21	

		#	1.27		19	1.27
		#	1.35		20	1.35
		#	1.2		21	1.2
		#	1.06		22	1.06
		#	1.02		23	1.02

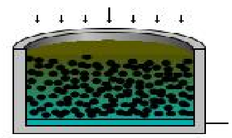
Runoff					
	rainfall depths	0	[mm/h]	0	[mm/h]
	catchment area	1E+08	[m2]	1E+08	[m2]
	direct runoff coefficient	0.15		0.15	
	indirect runoff coefficient	0.2		0.2	
	direct decay	0.9	[1/d]	0.9	[1/d]
	indirect decay	0.5	[1/d]	0.5	[1/d]
	initial direct volume	0	[m3]	0	[m3]
	initial indirect volume	0	[m3]	0	[m3]

Output Variables(influent)		**NH4Cl**		**Filtrate**	
Model Information					
Biological Model					
	biological model ID	5		5	
	biological model				
Flow					
Flow					
	flow	0	[m3/d]	28.8	[m3/d]
Composite Variables					
Volatile Fraction					
	VSS/TSS ratio	0	[gVSS/gTSS]	0.543	[gVSS/gTSS]
Composite Variables					
	total suspended solids	0	[mg/L]	21.9	[mg/L]
	volatile suspended solids	0	[mg/L]	11.9	[mg/L]
	total inorganic suspended solids	0	[mg/L]	10	[mg/L]
	total carbonaceous BOD5	0	[mgO2/L]	19.8	[mgO2/L]
	total COD	0	[mgCOD/L]	52	[mgCOD/L]
	total TKN	7000	[mgN/L]	10	[mgN/L]
Additional Composite Variables					
	filtered carbonaceous BOD5	0	[mgO2/L]	13.2	[mgO2/L]
	particulate carbonaceous BOD5	0	[mgO2/L]	6.6	[mgO2/L]
	filtered ultimate carbonaceous BOD	0	[mgO2/L]	20	[mgO2/L]
	particulate ultimate carbonaceous BOD	0	[mgO2/L]	10	[mgO2/L]
	total ultimate carbonaceous BOD	0	[mgO2/L]	30	[mgO2/L]
	filtered COD	0	[mgCOD/L]	35	[mgCOD/L]
	particulate COD	0	[mgCOD/L]	17	[mgCOD/L]
	filtered TKN	7000	[mgN/L]	10	[mgN/L]
	particulate TKN	0	[mgN/L]	0	[mgN/L]
	total oxidized nitrogen	0	[mgN/L]	0	[mgN/L]
	total nitrogen	7000	[mgN/L]	10	[mgN/L]
State Variables					
Inorganic Suspended Solids					
	inert inorganic suspended solids	0	[mg/L]	10	[mg/L]
Organic Variables					
	soluble inert organic material	0	[mgCOD/L]	15	[mgCOD/L]
	readily biodegradable substrate	0	[mgCOD/L]	20	[mgCOD/L]
	rapidly hydrolyzable substrate	0	[mgCOD/L]	0	[mgCOD/L]
	particulate inert organic material	0	[mgCOD/L]	7	[mgCOD/L]

	slowly biodegradable substrate	0	[mgCOD/L]	10	[mgCOD/L]
	active heterotrophic biomass	0	[mgCOD/L]	0	[mgCOD/L]
	active ammonia oxidizing biomass	0	[mgCOD/L]	0	[mgCOD/L]
	active nitrite oxidizing biomass	0	[mgCOD/L]	0	[mgCOD/L]
	unbiodegradable particulates from cell de	0	[mgCOD/L]	0	[mgCOD/L]
Dissolved Oxygen					
	dissolved oxygen	0	[mgO2/L]	0	[mgO2/L]
Nitrogen Compounds					
	free and ionized ammonia	7000	[mgN/L]	10	[mgN/L]
	soluble biodegradable organic nitrogen	0	[mgN/L]	0	[mgN/L]
	soluble inert organic nitrogen	0	[mgN/L]	0	[mgN/L]
	particulate biodegradable organic nitroger	0	[mgN/L]	0	[mgN/L]
	particulate inert organic nitrogen	0	[mgN/L]	0	[mgN/L]
	nitrite	0	[mgN/L]	0	[mgN/L]
	nitrate	0	[mgN/L]	0	[mgN/L]
Alkalinity					
	alkalinity	350	[mgCaCO3/L]	350	[mgCaCO3/L]
Runoff Variables					
Runoff Variables					
	stored direct volume	1E-10	[m3]	1E-10	[m3]
	stored indirect volume	1E-10	[m3]	1E-10	[m3]
	stored direct volume change	0	[m3]	0	[m3]
	stored indirect volume change	0	[m3]	0	[m3]
	excess rainfall	0	[m3/d]	0	[m3/d]
Model Stoichiometry					
Organic Fractions					
	XCOD/VSS ratio	1.8	[gCOD/gVSS]	1.43	[gCOD/gVSS]
	BOD5/BODultimate ratio	0.66	[-]	0.66	[-]
Nutrient Fractions					
	N content of particulate inert organic mate	0	[gN/gCOD]	0	[gN/gCOD]
	N content of unbiodegradable particulates	0.086	[gN/gCOD]	0.086	[gN/gCOD]
	N content of active heterotrophic biomass	0.086	[gN/gCOD]	0.086	[gN/gCOD]
	N content of active ammonia oxidizing bio	0.086	[gN/gCOD]	0.086	[gN/gCOD]
	N content of active nitrite oxidizing biomas	0.086	[gN/gCOD]	0.086	[gN/gCOD]
Operating Cost					
Pumping Energy Cost					
	pumping power	0	[kW]	0	[kW]
	cumulative pumping energy required	0	[kWh]	0	[kWh]
	cumulative pumping energy cost	0	[$]	0	[$]
Influent Composition					
Inorganic Suspended Solids					
	inert inorganic suspended solids	0	[mg/L]	10	[mg/L]
Organic Variables					
	soluble inert organic material	0	[mgCOD/L]	15	[mgCOD/L]
	readily biodegradable substrate	0	[mgCOD/L]	20	[mgCOD/L]
	rapidly hydrolyzable substrate	0	[mgCOD/L]	0	[mgCOD/L]
	particulate inert organic material	0	[mgCOD/L]	7	[mgCOD/L]
	slowly biodegradable substrate	0	[mgCOD/L]	10	[mgCOD/L]
	active heterotrophic biomass	0	[mgCOD/L]	0	[mgCOD/L]
	active ammonia oxidizing biomass	0	[mgCOD/L]	0	[mgCOD/L]
	active nitrite oxidizing biomass	0	[mgCOD/L]	0	[mgCOD/L]
	unbiodegradable particulates from cell de	0	[mgCOD/L]	0	[mgCOD/L]
Dissolved Oxygen					
	dissolved oxygen	0	[mgO2/L]	0	[mgO2/L]
Nitrogen Compounds					
	free and ionized ammonia	7000	[mgN/L]	10	[mgN/L]

	soluble biodegradable organic nitrogen	0	[mgN/L]	0	[mgN/L]
	soluble inert organic nitrogen	0	[mgN/L]	0	[mgN/L]
	particulate biodegradable organic nitroger	0	[mgN/L]	0	[mgN/L]
	particulate inert organic nitrogen	0	[mgN/L]	0	[mgN/L]
	nitrite	0	[mgN/L]	0	[mgN/L]
	nitrate	0	[mgN/L]	0	[mgN/L]
Alkalinity					
	alkalinity	350	[mgCaCO3/L]	350	[mgCaCO3/L]
Influent Stoichiometry					
Local Model Selection					
	base composite variables on ...	5		5	
Influent Fractions					
	XCOD/VSS ratio	1.8	[gCOD/gVSS]	1.43	[gCOD/gVSS]
	BOD5/BODultimate ratio	0.66	[-]	0.66	[-]
Mantis Nutrient Fractions					
	N content of active biomass	0.068	[gN/gCOD]	0.068	[gN/gCOD]
	N content of endogenous/inert mass	0.068	[gN/gCOD]	0.068	[gN/gCOD]
TwoStepMantis Nutrient Fractions					
	N content of active biomass	0.086	[gN/gCOD]	0.086	[gN/gCOD]
Operating Cost					
Pumping Cost					
	hydraulic head	0	[m]	0	[m]
	pump efficiency	0.7	[-]	0.7	[-]
	pumping headloss	0	[m]	0	[m]
Flow Data					
Flow Type					
	flow type	1		1	
Data					
	influent flow	0	[m3/d]	28.8	[m3/d]
Other Flow Options					
Sinusoidal					
	amplitude scaling factor	0.2	[-]	0.2	[-]
	time shift	0.35	[d]	0.35	[d]
	sine wave frequency	1	[1/d]	1	[1/d]
Runoff					
	rainfall depths	0	[mm/h]	0	[mm/h]
	catchment area	1E+08	[m2]	1E+08	[m2]
	direct runoff coefficient	0.15		0.15	
	indirect runoff coefficient	0.2		0.2	
	direct decay	0.9	[1/d]	0.9	[1/d]
	indirect decay	0.5	[1/d]	0.5	[1/d]
	initial direct volume	0	[m3]	0	[m3]
	initial indirect volume	0	[m3]	0	[m3]

Trickling Filter



tsn2	HTF1	
Physical		
Unit Dimensions		
filter bed depth	4	[m]
filter bed surface	0.5	[m2]
General		
beta factor (for DO saturation)	0.95	[-]
temperature coefficient for KLa	1.02	[-]
Local Environment Selection		
use local settings for O2 solubility and biological activit	On	
Oxygen Solubility (if individual settings are used)		
liquid temperature	26	[C]
elevation above sea level	0	[m]
Properties of User-Defined Air		
mole fraction of oxygen in user-defined air	1	[mole/mole]
density of user-defined air	1430	[mg/L]
molecular weight of user-defined air	32	[g/mol]
exponent in blower power equation	0.284	[-]
Media		
specific surface of media	37	[1/m]
liquid retention time in filter	4	[min]
maximum attached liquid film thickness	0.05	[mm]
maximum biofilm thickness	0.3	[mm]
density of biofilm	1020	[kg/m3]
dry material content of biofilm	0.1	[-]
Model Dimensions		
number of horizontal layers in filter	6	
Speed		
soluble integration period	0.1	[min]
soluble integration length	0.1	[min]
Mass Transport		
Diffusion of Components in Water:		
diffusion constant for readily biodegradable substrate	0.00001	[cm2/s]
diffusion constant for soluble inert organic material	0.00001	[cm2/s]
diffusion constant for dissolved oxygen	0.000025	[cm2/s]
diffusion constant for nitrite	0.000021	[cm2/s]
diffusion constant for nitrate	0.00002	[cm2/s]
diffusion constant for free and ionized ammonia	0.000025	[cm2/s]
diffusion constant for soluble biodegradable organic ni	0.00001	[cm2/s]
diffusion constant for soluble inert organic nitrogen	0.00001	[cm2/s]
diffusion constant for alkalinity	0.00002	[cm2/s]
diffusion constant for rapidly hydrolyzable substrate	0	[cm2/s]
Effect of Biofilm on Diffusion		
reduction in diffusion in biofilm	1	[-]
Solids		
attachment rate	0.5	[m/d]

detachment rate	10	[g/m2/d]
internal solids exchange rate	0.00001	[m/d]

Composite Variable Stoichiometry

Composite Variable Stoichiometry		
Organic Fractions		
XCOD/VSS ratio	1.48	[gCOD/gVSS]
BOD5/BODultimate ratio	0.66	[-]
Nutrient Fractions		
N content of active biomass	0.086	[gN/gCOD]

Model Stoichiometry

Active Heterotrophic Biomass		
aerobic heterotrophic yield	0.666	[gCOD/gCOD]
anoxic heterotrophic yield	0.533	[gCOD/gCOD]
heterotrophic endogenous fraction	0.08	[gCOD/gCOD]
Active Autotrophic Biomass		
active ammonia oxidizing biomass yield	0.18	[gCOD/gN]
active nitrite oxidizing biomass yield	0.06	[gCOD/gN]

Kinetic

Active Heterotrophic Biomass		
heterotrophic maximum specific growth rate	6	[1/d]
readily biodegradable substrate half saturation coeffici	20	[mgCOD/L]
aerobic oxygen half saturation coefficient for heterotro	0.2	[mgO2/L]
anoxic oxygen half saturation coefficient for heterotrop	0.2	[mgO2/L]
heterotrophic decay rate	0.62	[1/d]
nitrite half saturation coefficient	0.75	[mgN/L]
nitrate half saturation coefficient	0.5	[mgN/L]
nitrate+ nitrite half saturation coefficient	0.1	[mgN/L]
anoxic growth reduction factor	0.32	[-]
Active Ammonia Oxidizing Biomass		
active ammonia oxidizing biomass maximum specific g	0.8	[1/d]
ammonia (as substrate) half saturation coefficient	1	[mgN/L]
oxygen half saturation coefficient for active ammonia o	0.3	[mgO2/L]
active ammonia oxidizing biomass organism decay rate	0.2	[1/d]
Active Nitrite Oxidizing Biomass		
active nitrite oxidizing biomass maximum specific grow	1.1	[1/d]
nitrite half saturation coefficient	0.5	[mgN/L]
oxygen half saturation coefficient for active nitrite oxidi	0.4	[mgO2/L]
active nitrite oxidizing biomass organism decay rate	0.1	[1/d]
General Half-Saturation Coefficients		
ammonia (as nutrient) half saturation coefficient	0.05	[mgN/L]
Hydrolysis		
slowly biodegradable substrate maximum specific hydr	3	[1/d]
slowly biodegradable substrate half saturation coefficie	0.1	[gCOD/gCOD]
anoxic hydrolysis reduction factor	0.28	[-]
Ammonification		
ammonification rate	0.08	[m3/gCOD/d]
TEMPERATURE		
Temperature coefficient for muh	1.07	
Temperature coefficient for bh	1.03	
Temperature coefficient for muai	1.07	

Temperature coefficient for bai	1.03	
Temperature coefficient for muaa	1.06	
Temperature coefficient for baa	1.03	
Temperature coefficient for kh	1.12	
Temperature coefficient for ka	1.07	

Operating Cost

Miscellaneous Energy Cost (rotating arm, etc.)

miscellaneous energy use	0	[kW]

Initial Concentration Profiles

From Liquid Film Towards Media

Inorganic Suspended Solids

initial inert inorganic suspended solids	10	[mg/L]
	10	
	10	
	10	
	10	
	10	

Organic Variables

initial soluble inert organic material	30	[mgCOD/L]
	30	
	30	
	30	
	30	
	30	
initial readily biodegradable substrate	10	[mgCOD/L]
	10	
	10	
	10	
	10	
	10	
initial particulate inert organic material	20	[mgCOD/L]
	20	
	20	
	20	
	20	
	20	
initial slowly biodegradable substrate	20	[mgCOD/L]
	20	
	20	
	20	
	20	
	20	
initial active heterotrophic biomass	1	[mgCOD/L]
	1	
	1	
	1	
	1	
	1	
initial active ammonia oxidizing biomass	1	[mgCOD/L]
	1	
	1	

		1	
		1	
		1	
	initial active nitrite oxidizing biomass	1	[mgCOD/L]
		1	
		1	
		1	
		1	
		1	
	initial unbiodegradable particulates from cell decay	20	[mgCOD/L]
		20	
		20	
		20	
		20	
		20	
Dissolved Oxygen			
	initial dissolved oxygen	5	[mgO2/L]
		5	
		5	
		5	
		5	
		5	
Nitrogen Compounds			
	initial free and ionized ammonia	20	[mgN/L]
		15	
		15	
		15	
		15	
		15	
	initial soluble biodegradable organic nitrogen	1	[mgN/L]
		1	
		1	
		1	
		1	
		1	
	initial soluble inert organic nitrogen	1	[mgN/L]
		1	
		1	
		1	
		1	
		1	
	initial particulate biodegradable organic nitrogen	2	[mgN/L]
		2	
		2	
		2	
		2	
		2	
	initial particulate inert organic nitrogen	50	[mgN/L]
		50	
		50	
		50	
		50	
		50	
	initial nitrite	0	[mgN/L]
		0	
		0	

		0.2	
		0.3	
		0.4	
	initial nitrate	0	[mgN/L]
		0	
		4	
		4	
		4	
		4	
Alkalinity			
	initial alkalinity	350	[mgCaCO3/L]
		350	
		350	
		350	
		350	
		350	
Extra State Variables			
	rapidly hydrolyzable substrate	0	[mgCOD/L]
		0	
		0	
		0	
		0	
		0	

Output Variables(input)		**mixed**	
Model Information			
Biological Model			
	biological model ID	5	
	biological model		
Flow			
Flow			
	flow	76.8	[m3/d]
Composite Variables			
Volatile Fraction			
	VSS/TSS ratio	0.573	[gVSS/gTSS]
Composite Variables			
	total suspended solids	23.1	[mg/L]
	volatile suspended solids	13.3	[mg/L]
	total inorganic suspended solids	9.86	[mg/L]
	total carbonaceous BOD5	14.3	[mgO2/L]
	total COD	44.5	[mgCOD/L]
	total TKN	7.36	[mgN/L]
Additional Composite Variables			
	filtered carbonaceous BOD5	6.68	[mgO2/L]
	particulate carbonaceous BOD5	7.63	[mgO2/L]
	filtered ultimate carbonaceous BOD	10.1	[mgO2/L]
	particulate ultimate carbonaceous BOD	11.6	[mgO2/L]
	total ultimate carbonaceous BOD	21.7	[mgO2/L]
	filtered COD	25.1	[mgCOD/L]
	particulate COD	19.4	[mgCOD/L]
	filtered TKN	6.76	[mgN/L]
	particulate TKN	0.599	[mgN/L]
	total oxidized nitrogen	4.26	[mgN/L]

total nitrogen	11.6	[mgN/L]
State Variables		
Inorganic Suspended Solids		
inert inorganic suspended solids	9.86	[mg/L]
Organic Variables		
soluble inert organic material	15	[mgCOD/L]
readily biodegradable substrate	10.1	[mgCOD/L]
rapidly hydrolyzable substrate	0	[mgCOD/L]
particulate inert organic material	6.9	[mgCOD/L]
slowly biodegradable substrate	5.6	[mgCOD/L]
active heterotrophic biomass	5.45	[mgCOD/L]
active ammonia oxidizing biomass	0.364	[mgCOD/L]
active nitrite oxidizing biomass	0.14	[mgCOD/L]
unbiodegradable particulates from cell decay	0.938	[mgCOD/L]
Dissolved Oxygen		
dissolved oxygen	2.79	[mgO2/L]
Nitrogen Compounds		
free and ionized ammonia	6.55	[mgN/L]
soluble biodegradable organic nitrogen	0.207	[mgN/L]
soluble inert organic nitrogen	0	[mgN/L]
particulate biodegradable organic nitrogen	0.0062	[mgN/L]
particulate inert organic nitrogen	0.0807	[mgN/L]
nitrite	0.249	[mgN/L]
nitrate	4.01	[mgN/L]
Alkalinity		
alkalinity	314	[mgCaCO3/L]
Model Stoichiometry		
Organic Fractions		
XCOD/VSS ratio	1.46	[gCOD/gVSS]
BOD5/BODultimate ratio	0.66	[-]
Nutrient Fractions		
N content of particulate inert organic material	0	[gN/gCOD]
N content of unbiodegradable particulates from cell decay	0.086	[gN/gCOD]
N content of active heterotrophic biomass	0.086	[gN/gCOD]
N content of active ammonia oxidizing biomass	0.086	[gN/gCOD]
N content of active nitrite oxidizing biomass	0.086	[gN/gCOD]

Output Variables(effluent)	**TF**	
Model Information		
Biological Model		
biological model ID	5.56E+08	
biological model		
Flow		
Flow		
flow	76.8	[m3/d]
Composite Variables		
Volatile Fraction		
VSS/TSS ratio	0.59	[gVSS/gTSS]
Composite Variables		
total suspended solids	23.9	[mg/L]
volatile suspended solids	14.1	[mg/L]
total inorganic suspended solids	9.78	[mg/L]
total carbonaceous BOD5	11	[mgO2/L]
total COD	40	[mgCOD/L]
total TKN	5.77	[mgN/L]
Additional Composite Variables		

filtered carbonaceous BOD5	2.76	[mgO2/L]
particulate carbonaceous BOD5	8.25	[mgO2/L]
filtered ultimate carbonaceous BOD	4.19	[mgO2/L]
particulate ultimate carbonaceous BOD	12.5	[mgO2/L]
total ultimate carbonaceous BOD	16.7	[mgO2/L]
filtered COD	19.2	[mgCOD/L]
particulate COD	20.8	[mgCOD/L]
filtered TKN	4.81	[mgN/L]
particulate TKN	0.959	[mgN/L]
total oxidized nitrogen	6.81	[mgN/L]
total nitrogen	12.6	[mgN/L]

State Variables

Inorganic Suspended Solids

inert inorganic suspended solids	9.78	[mg/L]

Organic Variables

soluble inert organic material	15	[mgCOD/L]
readily biodegradable substrate	4.19	[mgCOD/L]
rapidly hydrolyzable substrate	0	[mgCOD/L]
particulate inert organic material	6.85	[mgCOD/L]
slowly biodegradable substrate	2.97	[mgCOD/L]
active heterotrophic biomass	8.72	[mgCOD/L]
active ammonia oxidizing biomass	0.583	[mgCOD/L]
active nitrite oxidizing biomass	0.224	[mgCOD/L]
unbiodegradable particulates from cell decay	1.5	[mgCOD/L]

Dissolved Oxygen

dissolved oxygen	4.46	[mgO2/L]

Nitrogen Compounds

free and ionized ammonia	4.48	[mgN/L]
soluble biodegradable organic nitrogen	0.331	[mgN/L]
soluble inert organic nitrogen	0	[mgN/L]
particulate biodegradable organic nitrogen	0.00992	[mgN/L]
particulate inert organic nitrogen	0.129	[mgN/L]
nitrite	0.398	[mgN/L]
nitrate	6.41	[mgN/L]

Alkalinity

alkalinity	293	[mgCaCO3/L]

Model Stoichiometry

Organic Fractions

XCOD/VSS ratio	1.48	[gCOD/gVSS]
BOD5/BODultimate ratio	0.66	[-]

Nutrient Fractions

N content of particulate inert organic material	0	[gN/gCOD]
N content of unbiodegradable particulates from cell decay	0.086	[gN/gCOD]
N content of active heterotrophic biomass	0.086	[gN/gCOD]
N content of active ammonia oxidizing biomass	0.086	[gN/gCOD]
N content of active nitrite oxidizing biomass	0.086	[gN/gCOD]

DO Saturation

DO Saturation

oxygen saturation (field conditions)	7.35	[mg/L]
surface oxygen saturation (at temp)	7.73	[mg/L]

Correction Factors for Field Conditions

temperature correction factor	0.851	[-]
pressure correction factor	1	[-]
depth correction factor		
ratio of air volume at standard conditions to field conditions		

Pressures

barometric pressure at elevation and temp	1	[atm]
water vapour pressure at temp	0.0389	[atm]
effective pressure at depth		

Physical

Physical Variables

filter bed volume	2	[m3]
total liquid volume in filter	0.116	[m3]
filter depth	4	[m]

Media Variables

total filter media surface	110	[m2]
filter media surface in a single unit grid	18.3	[m2]
liquid film thickness in filter	0.00106	[m]
liquid volume in a single unit grid	0.0194	[m3]
total biofilm volume	0.033	[m3]
single biofilm layer volume of a single unit grid	0.0011	[m3]
biofilm grid thickness	0.00006	[m]
mass in biofilm	1.87	[kg]
media specific area	55	[1/m]

Performance Variables

Performance Variables

hydraulic loading rate	6.4	[m/h]
hydraulic loading rate	549	[gBOD/(m3.d)]
BOD5 removal efficiency	0.23	[-]

Operating Cost

Miscellaneous Energy Cost

miscellaneous power	0	[kW]
cumulative misc. energy required	0	[kWh]
cumulative misc. energy cost	0	[$]

Physical

Unit Dimensions

filter bed depth	4	[m]
filter bed surface	0.5	[m2]

General

beta factor (for DO saturation)	0.95	[-]
temperature coefficient for KLa	1.02	[-]

Local Environment Selection

use local settings for O2 solubility and biological activity	1	

Oxygen Solubility (if individual settings are used)

liquid temperature	28.7	[C]
elevation above sea level	0	[m]

Properties of User-Defined Air

mole fraction of oxygen in user-defined air	1	[mole/mole]
density of user-defined air	1430	[mg/L]
molecular weight of user-defined air	32	[g/mol]
exponent in blower power equation	0.284	[-]

Media

specific surface of media	55	[1/m]
liquid retention time in filter	2.18	[min]
maximum attached liquid film thickness	0.00005	[m]
maximum biofilm thickness	0.0003	[m]
density of biofilm	1020000	[mg/L]
dry material content of biofilm	0.1	[-]

Speed

soluble integration period	6.94E-05	[d]
soluble integration length	6.94E-05	[d]

Mass Transport

Diffusion of Components in Water:

diffusion constant for readily biodegradable substrate	0.00001	[cm2/s]
diffusion constant for soluble inert organic material	0.00001	[cm2/s]
diffusion constant for dissolved oxygen	0.000025	[cm2/s]
diffusion constant for nitrite	0.000021	[cm2/s]
diffusion constant for nitrate	0.00002	[cm2/s]
diffusion constant for free and ionized ammonia	0.000025	[cm2/s]
diffusion constant for soluble biodegradable organic nitroge	0.00001	[cm2/s]
diffusion constant for soluble inert organic nitrogen	0.00001	[cm2/s]
diffusion constant for alkalinity	0.00002	[cm2/s]
diffusion constant for rapidly hydrolyzable substrate	0	[cm2/s]

Effect of Biofilm on Diffusion

reduction in diffusion in biofilm	1	[-]

Solids

attachment rate	0.5	[m/d]
detachment rate	0.01	[kg/(m2.d)]
internal solids exchange rate	0.00001	[m/d]

Composite Variable Stoichiometry

Organic Fractions

XCOD/VSS ratio	1.48	[gCOD/gVSS]
BOD5/BODultimate ratio	0.66	[-]

Nutrient Fractions

N content of active biomass	0.086	[gN/gCOD]

Model Stoichiometry

Active Heterotrophic Biomass

aerobic heterotrophic yield	0.666	[gCOD/gCOD]
anoxic heterotrophic yield	0.533	[gCOD/gCOD]
heterotrophic endogenous fraction	0.08	[gCOD/gCOD]

Active Autotrophic Biomass

active ammonia oxidizing biomass yield	0.18	[gCOD/gN]
active nitrite oxidizing biomass yield	0.06	[gCOD/gN]

Kinetic

Active Heterotrophic Biomass

heterotrophic maximum specific growth rate	6	[1/d]
readily biodegradable substrate half saturation coefficient	20	[mgCOD/L]
aerobic oxygen half saturation coefficient for heterotrophs	0.2	[mgO2/L]
anoxic oxygen half saturation coefficient for heterotrophs	0.2	[mgO2/L]
heterotrophic decay rate	0.62	[1/d]
nitrite half saturation coefficient	0.75	[mgN/L]
nitrate half saturation coefficient	0.5	[mgN/L]
nitrate+ nitrite half saturation coefficient	0.1	[mgN/L]
anoxic growth reduction factor	0.32	[-]

Active Ammonia Oxidizing Biomass

active ammonia oxidizing biomass maximum specific growtl	0.8	[1/d]
ammonia (as substrate) half saturation coefficient	1	[mgN/L]
oxygen half saturation coefficient for active ammonia oxidisi	0.3	[mgO2/L]
active ammonia oxidizing biomass organism decay rate	0.2	[1/d]

Active Nitrite Oxidizing Biomass

active nitrite oxidizing biomass maximum specific growth ra	1.1	[1/d]
nitrite half saturation coefficient	0.3	[mgN/L]
oxygen half saturation coefficient for active nitrite oxidising l	0.4	[mgO2/L]
active nitrite oxidizing biomass organism decay rate	0.1	[1/d]

General Half-Saturation Coefficients

ammonia (as nutrient) half saturation coefficient	0.05	[mgN/L]

Hydrolysis

slowly biodegradable substrate maximum specific hydrolysi	3	[1/d]

slowly biodegradable substrate half saturation coefficient	0.1	[gCOD/gCOD]
anoxic hydrolysis reduction factor	0.28	[-]
Ammonification		
ammonification rate	0.08	[m3/gCOD/d]
TEMPERATURE		
Temperature coefficient for muh	1.07	
Temperature coefficient for bh	1.03	
Temperature coefficient for muai	1.07	
Temperature coefficient for bai	1.03	
Temperature coefficient for muaa	1.06	
Temperature coefficient for baa	1.03	
Temperature coefficient for kh	1.12	
Temperature coefficient for ka	1.07	
Operating Cost		
Miscellaneous Energy Cost (rotating arm, etc.)		
miscellaneous energy use	0	[kW]
Initial Concentration Profiles		
Inorganic Suspended Solids		
initial inert inorganic suspended solids	10	[mg/L]
	10	
	10	
	10	
	10	
	10	
Organic Variables		
initial soluble inert organic material	30	[mgCOD/L]
	30	
	30	
	30	
	30	
	30	
initial readily biodegradable substrate	10	[mgCOD/L]
	10	
	10	
	10	
	10	
	10	
initial particulate inert organic material	20	[mgCOD/L]
	20	
	20	
	20	
	20	
	20	
initial slowly biodegradable substrate	20	[mgCOD/L]
	20	
	20	
	20	
	20	
	20	
initial active heterotrophic biomass	1	[mgCOD/L]
	1	
	1	
	1	
	1	
	1	
initial active ammonia oxidizing biomass	1	[mgCOD/L]

		1	
		1	
		1	
		1	
		1	
	initial active nitrite oxidizing biomass	1	[mgCOD/L]
		1	
		1	
		1	
		1	
		1	
	initial unbiodegradable particulates from cell decay	20	[mgCOD/L]
		20	
		20	
		20	
		20	
		20	
Dissolved Oxygen			
	initial dissolved oxygen	5	[mgO2/L]
		5	
		5	
		5	
		5	
		5	
Nitrogen Compounds			
	initial free and ionized ammonia	20	[mgN/L]
		15	
		15	
		15	
		15	
		15	
	initial soluble biodegradable organic nitrogen	1	[mgN/L]
		1	
		1	
		1	
		1	
		1	
	initial soluble inert organic nitrogen	1	[mgN/L]
		1	
		1	
		1	
		1	
		1	
	initial particulate biodegradable organic nitrogen	2	[mgN/L]
		2	
		2	
		2	
		2	
		2	
	initial particulate inert organic nitrogen	50	[mgN/L]
		50	
		50	
		50	
		50	
		50	
	initial nitrite	0	[mgN/L]

	0	
	0	
	0.2	
	0.3	
	0.4	
initial nitrate	0	[mgN/L]
	0	
	4	
	4	
	4	
	4	
Alkalinity		
initial alkalinity	350	[mgCaCO3/L]
	350	
	350	
	350	
	350	
	350	
Extra State Variables		
rapidly hydrolyzable substrate	0	[mgCOD/L]
	0	
	0	
	0	
	0	
	0	
Output Variables(layer)	**TF**	
Trickling Filter Variables		
Trickling Filter Variables		
biofilm layer thickness downwards	0.168	[mm]
	0.167	
	0.167	
	0.166	
	0.165	
	0.165	
Biofilm Profiles		
1st Section (top of filter)		
soluble inert organics	15	[mgCOD/L]
	15	
	15	
	15	
	15	
	15	
readily biodegradable (soluble) substrate	8.5	[mgCOD/L]
	4.57	
	2.66	
	2.5	
	2.49	
	2.49	
rapidly hydrolyzable substrate	0	[mgCOD/L]
	0	
	0	
	0	
	0	
	0	
particulate inert organics	6.87	[mgCOD/L]

	24300	
	13600	
	13700	
	2070	
	310	
slowly biodegr. (stored, particulate) substrate	5.04	[mgCOD/L]
	1370	
	1070	
	851	
	119	
	14.5	
active heterotrophic biomass	6.35	[mgCOD/L]
	51000	
	65300	
	27200	
	3180	
	370	
active ammonia-oxidizing biomass	0.385	[mgCOD/L]
	2070	
	3370	
	2170	
	290	
	38.9	
active nitrite-oxidizing biomass	0.142	[mgCOD/L]
	592	
	83.3	
	7.51	
	0.419	
	0.0233	
unbiodegradable particulates from cell decay	1.07	[mgCOD/L]
	8120	
	32200	
	47100	
	7340	
	1120	
dissolved oxygen	3.9	[mgO2/L]
	1.52	
	0.273	
	0.0576	
	0.0379	
	0.0358	
nitrite	0.455	[mgN/L]
	0.693	
	0.933	
	0.976	
	0.98	
	0.98	
nitrate	4.08	[mgN/L]
	4.16	
	4.08	
	4.04	
	4.03	
	4.03	
free and ionized ammonia	7.42	[mgN/L]
	6.95	
	6.69	

		6.65	
		6.64	
		6.64	
	soluble biodegradable organic nitrogen (in ss)	0.236	[mgN/L]
		0.306	
		0.353	
		0.367	
		0.368	
		0.368	
	particulate biodegr. organic nitrogen (in xs)	0.00723	[mgN/L]
		57.1	
		92	
		73.2	
		10.2	
		1.24	
	alkalinity	312	[mgCaCO3/L]
		308	
		307	
		307	
		307	
		307	
	dinitrogen		[mgN/L]
	suspended solids	23.2	[mg/L]
		93800	
		97600	
		81100	
		11700	
		1700	
2nd Section			
	soluble inert organics	15	[mgCOD/L]
		15	
		15	
		15	
		15	
		15	
	readily biodegradable (soluble) substrate	7.22	[mgCOD/L]
		4.14	
		2.89	
		2.85	
		2.85	
		2.85	
	rapidly hydrolyzable substrate	0	[mgCOD/L]
		0	
		0	
		0	
		0	
		0	
	particulate inert organics	6.86	[mgCOD/L]
		25800	
		18500	
		17400	

	2550	
	368	
slowly biodegr. (stored, particulate) substrate	4.54	[mgCOD/L]
	1280	
	997	
	802	
	108	
	12.8	
active heterotrophic biomass	7.07	[mgCOD/L]
	50300	
	49700	
	17600	
	1970	
	220	
active ammonia-oxidizing biomass	0.418	[mgCOD/L]
	2660	
	5760	
	2930	
	368	
	46.3	
active nitrite-oxidizing biomass	0.154	[mgCOD/L]
	972	
	2400	
	1680	
	228	
	30.8	
unbiodegradable particulates from cell decay	1.18	[mgCOD/L]
	8120	
	29100	
	36200	
	5430	
	799	
dissolved oxygen	4.28	[mgO2/L]
	1.59	
	0.168	
	0.0237	
	0.013	
	0.0119	
nitrite	0.477	[mgN/L]
	0.502	
	0.51	
	0.501	
	0.5	
	0.5	
nitrate	4.42	[mgN/L]
	4.83	
	5.04	
	5.03	
	5.03	
	5.03	
free and ionized ammonia	6.87	[mgN/L]
	6.35	
	6.06	
	6.04	
	6.04	
	6.04	

	soluble biodegradable organic nitrogen (in ss)	0.261	[mgN/L]
		0.321	
		0.359	
		0.37	
		0.371	
		0.371	
	particulate biodegr. organic nitrogen (in xs)	0.00805	[mgN/L]
		55.9	
		85.5	
		68.9	
		9.27	
		1.1	
	alkalinity	309	[mgCaCO3/L]
		305	
		303	
		303	
		303	
		303	
	dinitrogen		[mgN/L]
	suspended solids	23.5	[mg/L]
		97100	
		98300	
		76700	
		10800	
		1530	
3rd Section			
	soluble inert organics	15	[mgCOD/L]
		15	
		15	
		15	
		15	
		15	
	readily biodegradable (soluble) substrate	6.21	[mgCOD/L]
		3.74	
		2.89	
		2.87	
		2.88	
		2.88	
	rapidly hydrolyzable substrate	0	[mgCOD/L]
		0	
		0	
		0	
		0	
		0	
	particulate inert organics	6.85	[mgCOD/L]
		27000	
		22600	
		19700	
		2850	
		410	
	slowly biodegr. (stored, particulate) substrate	4.08	[mgCOD/L]

	1190	
	832	
	631	
	83.4	
	9.89	
active heterotrophic biomass	7.64	[mgCOD/L]
	49300	
	38500	
	12600	
	1390	
	154	
active ammonia-oxidizing biomass	0.456	[mgCOD/L]
	3070	
	6940	
	3270	
	404	
	50.2	
active nitrite-oxidizing biomass	0.169	[mgCOD/L]
	1190	
	3400	
	2190	
	293	
	39.3	
unbiodegradable particulates from cell decay	1.28	[mgCOD/L]
	8170	
	26000	
	28400	
	4210	
	615	
dissolved oxygen	4.41	[mgO2/L]
	1.61	
	0.149	
	0.0197	
	0.0105	
	0.0096	
nitrite	0.469	[mgN/L]
	0.46	
	0.436	
	0.425	
	0.424	
	0.424	
nitrate	4.85	[mgN/L]
	5.38	
	5.67	
	5.68	
	5.68	
	5.68	
free and ionized ammonia	6.29	[mgN/L]
	5.73	
	5.44	
	5.41	
	5.41	
	5.41	
soluble biodegradable organic nitrogen (in ss)	0.282	[mgN/L]
	0.334	
	0.365	

	0.374	
	0.375	
	0.375	
particulate biodegr. organic nitrogen (in xs)	0.0087	[mgN/L]
	54.6	
	71.4	
	54.3	
	7.18	
	0.851	
alkalinity	305	[mgCaCO3/L]
	301	
	298	
	298	
	298	
	298	
dinitrogen		[mgN/L]
suspended solids	23.6	[mg/L]
	99300	
	98700	
	73400	
	10300	
	1450	

4th Section

soluble inert organics	15	[mgCOD/L]
	15	
	15	
	15	
	15	
	15	
readily biodegradable (soluble) substrate	5.39	[mgCOD/L]
	3.41	
	2.81	
	2.82	
	2.83	
	2.83	
rapidly hydrolyzable substrate	0	[mgCOD/L]
	0	
	0	
	0	
	0	
	0	
particulate inert organics	6.85	[mgCOD/L]
	27800	
	25600	
	21200	
	3040	
	435	
slowly biodegr. (stored, particulate) substrate	3.67	[mgCOD/L]
	1110	
	697	
	501	

	65.8	
	7.81	
active heterotrophic biomass	8.09	[mgCOD/L]
	48300	
	30900	
	9450	
	1020	
	112	
active ammonia-oxidizing biomass	0.497	[mgCOD/L]
	3410	
	7540	
	3430	
	421	
	52.1	
active nitrite-oxidizing biomass	0.187	[mgCOD/L]
	1350	
	3950	
	2420	
	323	
	43.1	
unbiodegradable particulates from cell decay	1.36	[mgCOD/L]
	8280	
	23600	
	23500	
	3440	
	501	
dissolved oxygen	4.45	[mgO2/L]
	1.6	
	0.143	
	0.0188	
	0.0101	
	0.00918	
nitrite	0.45	[mgN/L]
	0.428	
	0.392	
	0.381	
	0.38	
	0.38	
nitrate	5.34	[mgN/L]
	5.93	
	6.27	
	6.28	
	6.28	
	6.28	
free and ionized ammonia	5.7	[mgN/L]
	5.12	
	4.82	
	4.79	
	4.79	
	4.79	
soluble biodegradable organic nitrogen (in ss)	0.3	[mgN/L]
	0.345	
	0.372	
	0.38	
	0.381	
	0.381	

particulate biodegr. organic nitrogen (in xs)	0.00921	[mgN/L]
	53.2	
	59.8	
	43.1	
	5.65	
	0.672	
alkalinity	301	[mgCaCO3/L]
	297	
	294	
	294	
	294	
	294	
dinitrogen		[mgN/L]
suspended solids	23.7	[mg/L]
	101000	
	98900	
	71000	
	9950	
	1400	

5th Section

soluble inert organics	15	[mgCOD/L]
	15	
	15	
	15	
	15	
	15	
readily biodegradable (soluble) substrate	4.73	[mgCOD/L]
	3.11	
	2.7	
	2.73	
	2.73	
	2.73	
rapidly hydrolyzable substrate	0	[mgCOD/L]
	0	
	0	
	0	
	0	
	0	
particulate inert organics	6.85	[mgCOD/L]
	28400	
	27500	
	21800	
	3120	
	446	
slowly biodegr. (stored, particulate) substrate	3.3	[mgCOD/L]
	1040	
	603	
	419	
	54.9	
	6.57	
active heterotrophic biomass	8.45	[mgCOD/L]

	47300	
	26000	
	7520	
	801	
	87.3	
active ammonia-oxidizing biomass	0.539	[mgCOD/L]
	3710	
	7860	
	3530	
	434	
	53.8	
active nitrite-oxidizing biomass	0.205	[mgCOD/L]
	1490	
	4270	
	2560	
	341	
	45.5	
unbiodegradable particulates from cell decay	1.43	[mgCOD/L]
	8470	
	22100	
	20700	
	3020	
	437	
dissolved oxygen	4.46	[mgO2/L]
	1.59	
	0.142	
	0.0189	
	0.0102	
	0.00929	
nitrite	0.426	[mgN/L]
	0.398	
	0.356	
	0.345	
	0.344	
	0.344	
nitrate	5.86	[mgN/L]
	6.5	
	6.86	
	6.88	
	6.88	
	6.88	
free and ionized ammonia	5.09	[mgN/L]
	4.5	
	4.2	
	4.18	
	4.18	
	4.18	
soluble biodegradable organic nitrogen (in ss)	0.317	[mgN/L]
	0.356	
	0.379	
	0.386	
	0.387	
	0.387	
particulate biodegr. organic nitrogen (in xs)	0.00961	[mgN/L]
	52	
	51.6	

	36	
	4.72	
	0.565	
alkalinity	297	[mgCaCO3/L]
	292	
	290	
	290	
	290	
	290	
dinitrogen		[mgN/L]
suspended solids	23.8	[mg/L]
	102000	
	98900	
	69400	
	9710	
	1370	

6th Section

soluble inert organics	15	[mgCOD/L]
	15	
	15	
	15	
	15	
	15	
readily biodegradable (soluble) substrate	4.19	[mgCOD/L]
	2.86	
	2.56	
	2.6	
	2.61	
	2.61	
rapidly hydrolyzable substrate	0	[mgCOD/L]
	0	
	0	
	0	
	0	
	0	
particulate inert organics	6.85	[mgCOD/L]
	28800	
	28300	
	21700	
	3090	
	442	
slowly biodegr. (stored, particulate) substrate	2.97	[mgCOD/L]
	979	
	548	
	382	
	50.9	
	6.21	
active heterotrophic biomass	8.72	[mgCOD/L]
	46300	
	23400	
	6630	

	706	
	77.3	
active ammonia-oxidizing biomass	0.583	[mgCOD/L]
	3980	
	8050	
	3700	
	459	
	57.9	
active nitrite-oxidizing biomass	0.224	[mgCOD/L]
	1620	
	4490	
	2720	
	364	
	49.1	
unbiodegradable particulates from cell decay	1.5	[mgCOD/L]
	8780	
	21700	
	19500	
	2840	
	412	
dissolved oxygen	4.46	[mgO2/L]
	1.59	
	0.144	
	0.0193	
	0.0104	
	0.00942	
nitrite	0.398	[mgN/L]
	0.366	
	0.32	
	0.309	
	0.308	
	0.308	
nitrate	6.41	[mgN/L]
	7.07	
	7.45	
	7.47	
	7.48	
	7.48	
free and ionized ammonia	4.48	[mgN/L]
	3.89	
	3.58	
	3.56	
	3.56	
	3.56	
soluble biodegradable organic nitrogen (in ss)	0.331	[mgN/L]
	0.366	
	0.388	
	0.394	
	0.395	
	0.395	
particulate biodegr. organic nitrogen (in xs)	0.00992	[mgN/L]
	50.8	
	46.9	
	32.9	
	4.38	
	0.534	

alkalinity	293	[mgCaCO3/L]
	288	
	286	
	286	
	286	
	286	
dinitrogen		[mgN/L]
suspended solids	23.9	[mg/L]
	102000	
	98900	
	67900	
	9500	
	1340	

Liquid Film Concentrations

State variable liquid film concentrations

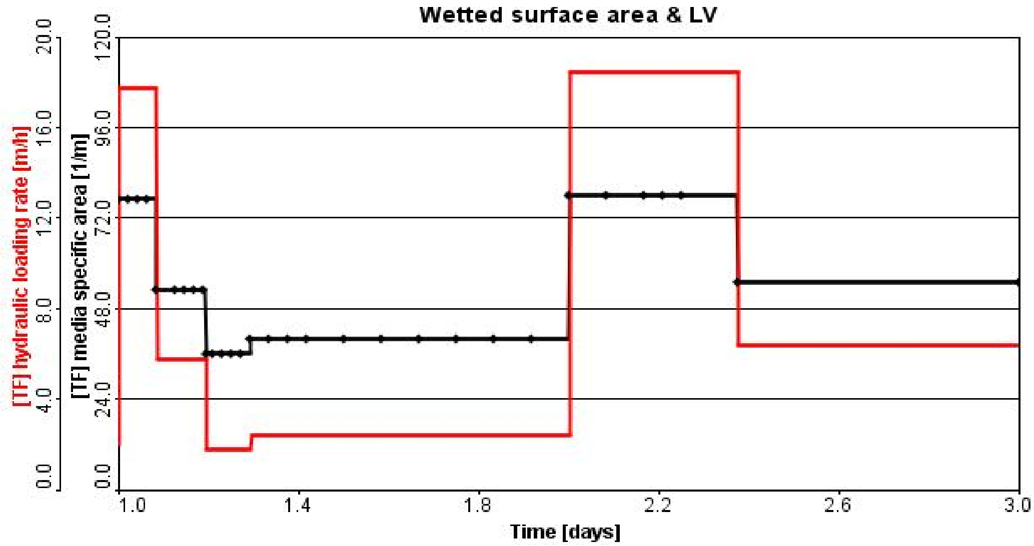
soluble inert organics	15	[mgCOD/L]
	15	
	15	
	15	
	15	
	15	
readily biodegradable (soluble) substrate	8.5	[mgCOD/L]
	7.22	
	6.21	
	5.39	
	4.73	
	4.19	
rapidly hydrolyzable substrate i	0	[mgCOD/L]
	0	
	0	
	0	
	0	
	0	
particulate inert organics	6.87	[mgCOD/L]
	6.86	
	6.85	
	6.85	
	6.85	
	6.85	
slowly biodegr. (stored, particulate) substrate	5.04	[mgCOD/L]
	4.54	
	4.08	
	3.67	
	3.3	
	2.97	
active heterotrophic biomass	6.35	[mgCOD/L]
	7.07	
	7.64	
	8.09	
	8.45	
	8.72	

active ammonia-oxidizing biomass	0.385	[mgCOD/L]
	0.418	
	0.456	
	0.497	
	0.539	
	0.583	
active nitrite-oxidizing biomass	0.142	[mgCOD/L]
	0.154	
	0.169	
	0.187	
	0.205	
	0.224	
unbiodegradable particulates from cell decay	1.07	[mgCOD/L]
	1.18	
	1.28	
	1.36	
	1.43	
	1.5	
dissolved oxygen	3.9	[mgO2/L]
	4.28	
	4.41	
	4.45	
	4.46	
	4.46	
nitrite	0.455	[mgN/L]
	0.477	
	0.469	
	0.45	
	0.426	
	0.398	
nitrate	4.08	[mgN/L]
	4.42	
	4.85	
	5.34	
	5.86	
	6.41	
free and ionized ammonia	7.42	[mgN/L]
	6.87	
	6.29	
	5.7	
	5.09	
	4.48	
soluble biodegradable organic nitrogen (in ss)	0.236	[mgN/L]
	0.261	
	0.282	
	0.3	
	0.317	
	0.331	
particulate biodegr. organic nitrogen (in xs)	0.00723	[mgN/L]
	0.00805	
	0.0087	
	0.00921	
	0.00961	
	0.00992	
alkalinity	312	[mgCaCO3/L]
	309	

		305
		301
		297
		293
	dinitrogen	[mgN/L]

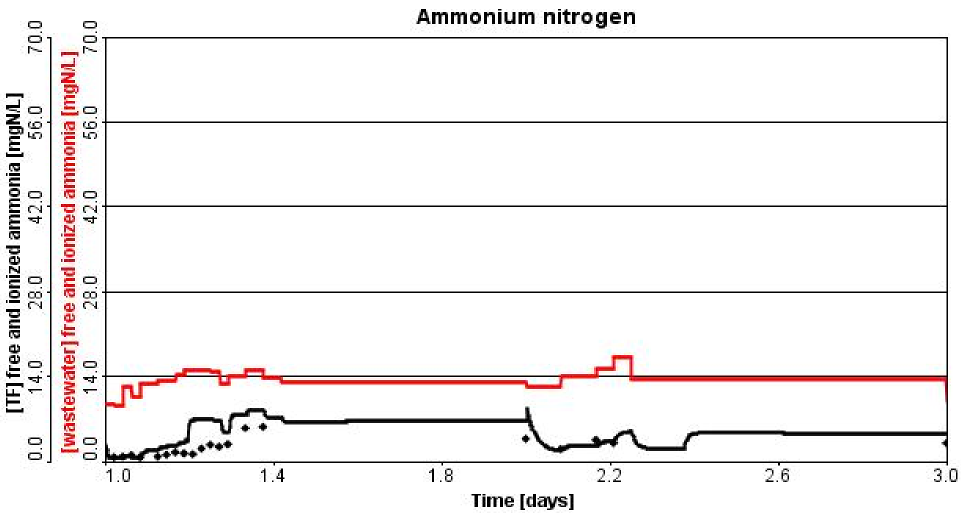
2-D State Variables

Inorganic Suspended Solids	
Organic V	inert inorganic suspended solids
Dissolved	unbiodegradable particulates from cell decay
Nitrogen (	dissolved oxygen
Alkalinity	nitrate
	alkalinity



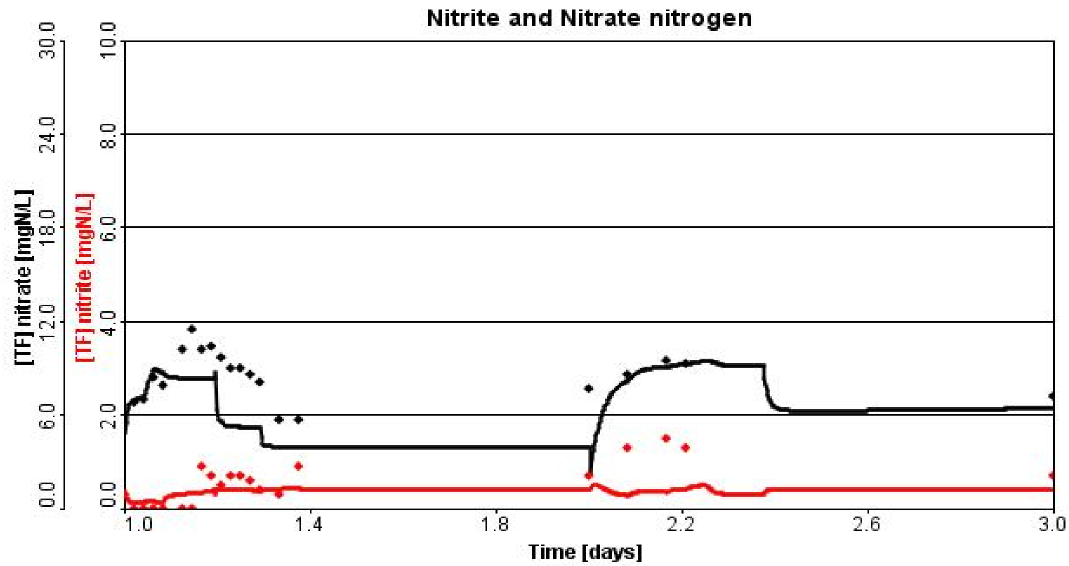
pitch					
20	**days**	**aspecTF**	**h**lrTF	days	cal.
1	1	77	17.8	0	77
21	1.05	77	17.8	0.05	77
41	1.09	53	5.76	0.09	53
61	1.13	53	5.76	0.13	53
81	1.17	53	5.76	0.17	53
101	1.21	36	1.76	0.21	36
121	1.25	36	1.76	0.25	36
141	1.3	40	2.4	0.3	40
161	1.34	40	2.4	0.34	40
181	1.38	40	2.4	0.38	40
201	1.42	40	2.4	0.42	40
221	1.46	40	2.4	0.46	40
241	1.5	40	2.4	0.5	40
261	1.55	40	2.4	0.55	40
281	1.59	40	2.4	0.59	40
301	1.63	40	2.4	0.63	40
321	1.67	40	2.4	0.67	40
341	1.71	40	2.4	0.71	40
361	1.75	40	2.4	0.75	40
381	1.8	40	2.4	0.8	40
401	1.84	40	2.4	0.84	40
421	1.88	40	2.4	0.88	40
441	1.92	40	2.4	0.92	40
461	1.96	40	2.4	0.96	40
481	2	78	18.4	1	78
501	2.05	78	18.4	1.05	78
521	2.09	78	18.4	1.09	78
541	2.13	78	18.4	1.13	78
561	2.17	78	18.4	1.17	78
581	2.21	78	18.4	1.21	78

601	2.25	78	18.4	1.25	78
621	2.3	78	18.4	1.3	78
641	2.34	78	18.4	1.34	78
661	2.38	55	6.4	1.38	55
681	2.42	55	6.4	1.42	55
701	2.46	55	6.4	1.46	55
721	2.5	55	6.4	1.5	55
741	2.55	55	6.4	1.55	55
761	2.59	55	6.4	1.59	55
781	2.63	55	6.4	1.63	55
801	2.67	55	6.4	1.67	55
821	2.71	55	6.4	1.71	55
841	2.75	55	6.4	1.75	55
861	2.8	55	6.4	1.8	55
881	2.84	55	6.4	1.84	55
901	2.88	55	6.4	1.88	55
921	2.92	55	6.4	1.92	55
941	2.96	55	6.4	1.96	55
961	3	55	6.4	2	55



pitch			
20	days	snhwastwater	snhTF
1	1	9.3	1.81
21	1.05	12.3	0.706
41	1.09	12.7	1.14
61	1.13	13.4	2.07
81	1.17	14.3	2.67
101	1.21	14.9	6.85
121	1.25	14.7	6.91
141	1.3	14.1	5.63
161	1.34	14.9	7.68
181	1.38	13.8	8.22
201	1.42	13	7.2
221	1.46	13	6.58
241	1.5	13	6.58
261	1.55	13	6.58
281	1.59	13	6.59
301	1.63	13	6.59
321	1.67	13	6.59
341	1.71	13	6.6
361	1.75	13	6.6
381	1.8	13	6.6
401	1.84	13	6.61
421	1.88	13	6.61
441	1.92	13	6.61
461	1.96	13	6.62
481	2	12.3	8.62
501	2.05	12.3	2.57
521	2.09	14	1.94
541	2.13	14	2.53
561	2.17	15.2	2.65
581	2.21	17.2	3.6

601	2.25	13.6	4.35
621	2.3	13.6	2.14
641	2.34	13.6	2.07
661	2.38	13.6	2.92
681	2.42	13.6	4.67
701	2.46	13.6	4.69
721	2.5	13.6	4.68
741	2.55	13.6	4.66
761	2.59	13.6	4.65
781	2.63	13.6	4.63
801	2.67	13.6	4.61
821	2.71	13.6	4.59
841	2.75	13.6	4.58
861	2.8	13.6	4.56
881	2.84	13.6	4.54
901	2.88	13.6	4.53
921	2.92	13.6	4.51
941	2.96	13.6	4.5
961	3	10	4.48



pitch									
20	**days**	**snoiTF**	**snoaTF**	days	cal.	cal.	days	monitored	monitored
1	1	0.309	5.49	0	0.309				
21	1.05	0.135	7.34	0.05	0.135	7.34			
41	1.09	0.192	8.57	0.09	0.192	8.57	0		
61	1.13	0.296	8.3	0.13	0.296	8.3	0.02		6.8
81	1.17	0.342	8.27	0.17	0.342	8.27	0.04		7
101	1.21	0.417	5.48	0.21	0.417	5.48	0.06		8.4
121	1.25	0.415	5.22	0.25	0.415	5.22	0.08		7.9
141	1.3	0.383	4.55	0.3	0.383	4.55	0.13		10.2
161	1.34	0.413	3.95	0.34	0.413	3.95	0.15		11.5
181	1.38	0.422	3.93	0.38	0.422	3.93	0.17	0.9	10.2
201	1.42	0.409	3.92	0.42	0.409	3.92	0.19		10.4
221	1.46	0.4	3.92	0.46	0.4	3.92	0.19		
241	1.5	0.401	3.91	0.5	0.401	3.91	0.21	0.5	
261	1.55	0.402	3.91	0.55	0.402	3.91	0.23	0.7	9
281	1.59	0.403	3.91	0.59	0.403	3.91	0.25	0.7	9
301	1.63	0.404	3.91	0.63	0.404	3.91	0.27	0.6	8.6
321	1.67	0.405	3.91	0.67	0.405	3.91	0.29	0.4	8.1
341	1.71	0.406	3.9	0.71	0.406	3.9	0.33	0.3	5.7
361	1.75	0.407	3.9	0.75	0.407	3.9	0.38	0.9	5.7
381	1.8	0.408	3.9	0.8	0.408	3.9	0.42		
401	1.84	0.409	3.9	0.84	0.409	3.9	0.5		
421	1.88	0.41	3.9	0.88	0.41	3.9	0.58		
441	1.92	0.411	3.89	0.92	0.411	3.89	0.67		
461	1.96	0.412	3.89	0.96	0.412	3.89	0.75		
481	2	0.394	2.28	1	0.394	2.28	0.83		
501	2.05	0.364	7.14	1.05	0.364	7.14	0.92		
521	2.09	0.287	8.25	1.09	0.287	8.25	1	0.7	7.7
541	2.13	0.354	8.95	1.13	0.354	8.95	1.08	1.3	8.6
561	2.17	0.357	9.07	1.17	0.357	9.07	1.17	1.5	9.5
581	2.21	0.42	9.27	1.21	0.42	9.27	1.21	1.3	9.3

601	2.25	0.477	9.45	1.25	0.477	9.45	1.25		
621	2.3	0.31	9.17	1.3	0.31	9.17	1.38		
641	2.34	0.3	9.15	1.34	0.3	9.15	2	0.7	7.2
661	2.38	0.331	8.31	1.38	0.331	8.31			
681	2.42	0.417	6.3	1.42	0.417	6.3			
701	2.46	0.415	6.24	1.46	0.415	6.24			
721	2.5	0.414	6.24	1.5	0.414	6.24			
741	2.55	0.412	6.25	1.55	0.412	6.25			
761	2.59	0.411	6.27	1.59	0.411	6.27			
781	2.63	0.409	6.28	1.63	0.409	6.28			
801	2.67	0.408	6.3	1.67	0.408	6.3			
821	2.71	0.407	6.31	1.71	0.407	6.31			
841	2.75	0.405	6.33	1.75	0.405	6.33			
861	2.8	0.404	6.34	1.8	0.404	6.34			
881	2.84	0.403	6.36	1.84	0.403	6.36			
901	2.88	0.402	6.37	1.88	0.402	6.37			
921	2.92	0.401	6.38	1.92	0.401	6.38			
941	2.96	0.399	6.4	1.96	0.399	6.4			
961	3	0.398	6.41	2	0.398	6.41			