AMSTRACT

OPTIMIZATION OF NITROGEN REMOVAL IN SEQUENCING BATCH REACTOR

by
Suppakit Poonyachat

Operating parameters for sequencing batch reactor have the influence on each substrate concentration. Concentration profile changes as operation parameters are changed. The study was conducted to model the variation in effluent concentration from sequencing batch reactor. MLVSS and cycle time are the parameters that were varied. Concentration in Fill, React, and Settle period were calculated by using kinetic equations.

The results can show that these parameters have effects on the concentration profile. The increase of MLVSS can lower the concentration of BOD and ammonium concentration in React period. Increasing MLVSS can show that more substrate utilization and nitrification process occur more rapidly. Concentration of nitrate at the end of settle period varies with the MLVSS concentration in the system. Cycle time is another parameter that shows the effect on concentration profiles. The increasing of react time provides more time for biomass to react and makes the BOD effluent and ammonium concentration decrease. Settle period, which is anoxic, makes the system in denitrification environment influences on nitrate removal. When settle period decreases, nitrate has less time to transform to nitrogen gas.

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A Thesis
Submitted to the Faculty of
New Jersey Institute of Technology
In Partial Fulfillment of the Requirements for the Degree of
Master of Science in Environmental Engineering

Department of Civil and Environmental Engineering

January 2001

APPROVAL PAGE

OPTIMIZATION OF NITROGEN REMOVAL IN SEQUENCING BATCH REACTOR

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This thesis is dedicated

to my beloved family

ACKNOWLEDGMENT

I would like to express my sincere gratitude to my advisor, Dr. Sudhi Mukherjee, for his guidance and support throughout this research. I also would like to thank Prof. Hsin-Neng Hsieh, Professor of Civil and Environmental Engineering and Prof. Methi Wecharatana, Professor of Civil and Environmental Engineering, for their effort and valuable comments as members of the committee.

I am very grateful and thankful to the Department of Civil and Environmental Engineering for funding and support of my study at NJIT.

I also would like to thank the Thai students at NJIT for their friendship and support. And finally, I wish to express my special gratitude to my family for their assistance and love.

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CHAPTER 1

INTRODUCTION

1.1 General

Wastewater is produced by water usage of every community for domestic and industrial activities. It has become a major environmental and social problem in many countries around the world. Discharge of untreated wastewater can cause environmental degradation and affect public health. State and federal regulations have been established to regulate the discharge of wastewater to the environment.

To comply with regulatory standards, wastewater treatment plants are designed and operated to remove gross and specific contaminants from wastewater.

The characteristics of wastewater are an important factor in the design and operation of wastewater treatment facilities. Properties and constituents in wastewater depend primarily on the source of the wastewater. Traditionally wastewater treatment has focused on the removal of gross organic and inorganic constituents and pathogens in wastewater that primarily included carbonaceous BOD and suspended solids removal and disinfection processes. Nutrients such as nitrogen and phosphorus are also considered as a significant problem.

Nutrients have become contaminants of concern in wastewater because both nitrogen and phosphorus are essential nutrients for growth. When discharged to receiving bodies of water, they can lead to the undesirable problems such as algae blooms and eutrophication. The presence of algae and aquatic plants may obstruct the uses of water resources, the growth of aquatic life and cause aesthetic problems. When it is discharged in excessive amounts on land, it can pollute groundwater.

Nutrients in sufficient amounts can result in oxygen depletion in receiving bodies of water. Excess nitrogen is a common problem encountered in the influent and effluents of many wastewater treatment plants. Nitrogen in wastewater is present in different forms depending on the source and characteristics of the wastewater. Organic nitrogen, ammonia nitrogen, nitrite and nitrate are the general forms of nitrogen found in wastewater. Untreated wastewater usually has nitrogen in the form of organic nitrogen and ammonia nitrogen. Organic nitrogen is decomposed to ammonia by microorganisms. Ammonia nitrogen is then oxidized to nitrite and nitrate by certain species of bacteria under suitable conditions (Metcalf & Eddy, 1991). Nitrite and nitrate may be removed from effluent wastewaters in a subsequent denitrification step accomplished by species of denitrifying microorganisms.

Nitrification followed by denitrification is a widespread process for biological nitrogen removal from wastewater (Bernades et al., 1996). While nitrification primarily occurs in an aerobic environment, denitrification occurs in an anoxic or sometimes facultative environment.

Phosphorus is also a nutrient of concern for reasons similar to those for nitrogen. The discharge of phosphorus to receiving bodies of water is also regulated under various state and federal regulations, and a variety of treatment technologies and process modifications have been developed to address this problem. Phosphorus removal has not been studied under the scope of this thesis.

1.2 Objectives of Present Study

The primary objective of this study is to develop a rationale for the optimization of nitrogen removal in existing wastewater treatment plants, specifically the aerobic sequencing batch reactor. The objectives include:

- Optimization of the nitrification process by controlling operating conditions within the reactor.
- Optimization of the denitrification by controlling operating conditions within the reactor.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

In this section, literature review is presented of nutrient removal, nitrogen removal, and sequencing batch reactor. This thesis is considered in the modeling the performance of nutrient removal in Sequencing Batch Reactor (SBR). Operating parameters were varied to investigate the removal efficiency and concentration profile.

2.1 Nutrient Removal

Nutrients are a major concern in the design and operation of wastewater treatment plants. Various treatment methods, such as physical, chemical, and biological, have been used to deal with nutrient control and removal from the discharged system. Nutrient removal can be implemented by using biological treatment system because of it is low-cost, reliable, and effective (Metcalf & Eddy Inc., 1991). Basic steps for the nitrogen removal are nitrification and denitrification, which are used for the operating wastewater treatment system. Classification of nitrogen removal based on carbon sources in denitrification removal (1) in combined carbon oxidation nitrification/denitrification systems using internal and endogenous carbon sources or (2) in separate reactors using methanol or another suitable external source of organic carbon.

Biological nutrient removal (BNR) processes are modifications of activated sludge by using anaerobic, anoxic and aerobic zones to optimize suitable environments for nitrogen and/or phosphorus removal. Low loading rates and a long solid retention time is required to operate sequencing batch reactor for nutrient removal (Jones, 1990).

Ammonia and organic nitrogen are the principal forms of nitrogen in wastewater that may be present in the soluble and particulate forms (Metcalf & Eddy Inc., 1991). Soluble nitrogen is in the form of urea and amino acids. Untreated wastewater usually has little or no nitrite or nitrate. Most of organic nitrogen is transformed to ammonia and inorganic forms.

The two principal mechanisms for the removal of nitrogen are assimilation and nitrification-denitrification. Microorganisms in wastewater can assimilate ammonia-nitrogen into cell mass and can be returned to wastewater when cells die or lysis occurs (Metcalf & Eddy Inc., 1991). Nitrification followed by denitrification is a well-known process for biological nitrogen removal (Bernades et al., 1996).

Nitrification is the first step in nitrogen removal process and it is aerobic process. Oxidation of ammonia to nitrite and then to nitrate is carried out by two bacteria genera, *Nitrosomonas* and *Nitrobacter*. Approximate equations for nitrification process are

For *Nitrosomonas* the equation is

$$55NH_4^+ + 76O_2 + 109HCO_3^- \rightarrow C_5H_7O_2N + 54NO_2^- + 57\,H_2O + 104H_2CO_3$$

For *Nitrobacter* the equation is

$$400NO_2^- + NH_4^+ + 4H_2CO_3 + HCO_3^- + 195O_2 \rightarrow C_5H_7O_2N + 3H_2O + 400NO_3^-$$

From the equations, the nitrification process consumes oxygen and large amount of alkalinity (HCO_3^-). Nitrification processes may be classified into single stage, which carbon oxidation and nitrification occur in the same reactor, and separate-stage, which both processes occur in different reactors (Metcalf & Eddy Inc., 1991). The ability of this process to nitrify relates with the relationship of BOD_5/TKN ratio.

Both are very slow growing and do not compete well with heterotrophic bacteria for oxygen. Therefore, nitrification should be separated from carbon removal (Jones et al., 1990). Ammonia is oxidized to nitrite by *Nitrosomonas*. *Nitrobacter* converts nitrite to nitrate (Coelho et al., 2000, Metcalf & Eddy Inc., 1991, Leslie et al., 1990).

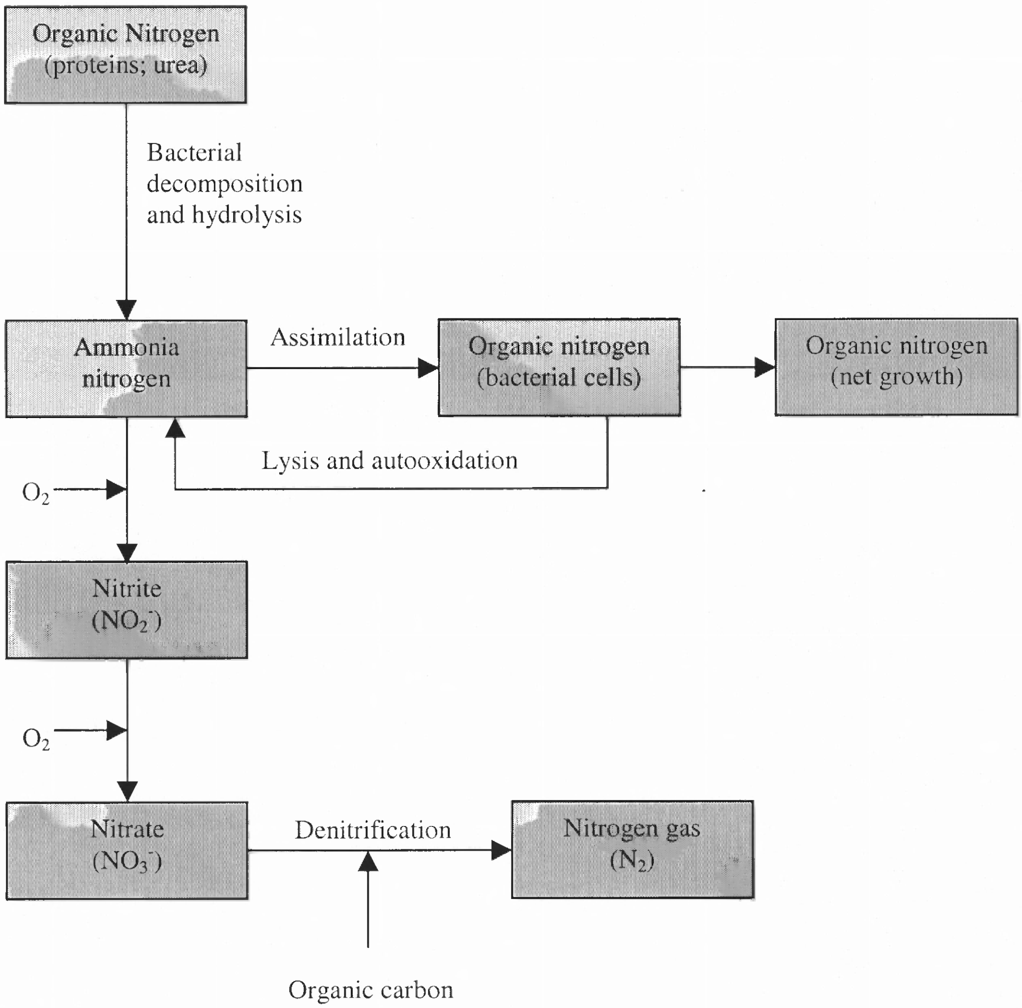

Figure 2.1 Nitrogen transformations in biological treatment process.

Denitrification is the second step in nitrogen removal process. This process occurs under anoxic conditions by transforming nitrate to the form of nitrogen gas. Microbial reduction of nitrate and nitrite is carried out by several types of facultative microorganisms. It is analogous to aerobic heterotrophic metabolism, which nitrate and nitrite acting instead of oxygen as electron acceptor (Jones et al., 1990).

For the removal of nitrate, two types of enzyme systems are involved in the reduction of nitrate: assimilatory and dissimilatory. Nitrate is transformed to ammonia and used by cells for biosynthesis in assimilatory process. This process occurs when nitrate is the only form available in the system. In the dissimilatory process, nitrate reduces to nitrogen gas and results in denitrification process.

In denitrification process, wastewater must contain sufficient carbon sources (organic matter) to be bacteria's energy source in order to convert nitrate to nitrogen gas. Carbon sources can be in the form of internal sources, such as cell material and wastewater, or external sources, such as methanol. If the carbon source is not enough, this process cannot be occurred (Metcalf & Eddy Inc., 1991).

The reactions for denitrifying bacteria, with glucose as the carbon sources as follows:

$$C_6H_{12}O_6 + 12NO_3^- \rightarrow 6CO_2 + 12NO_2^- + 6H_2O + \text{energy}$$

$$C_6H_{12}O_6 + 8NO_2^- + 8H^+ \rightarrow 6CO_2 + 4N_2 + 10H_2O + \text{energy}$$

Facultative anaerobes had an important role in this process by conversion of nitrate to nitrite and then to nitric oxide, nitrous oxide, and nitrogen gas. These reactions are

$$NO_3^- \longrightarrow NO_2^- \longrightarrow NO \longrightarrow N_2O \longrightarrow N_2$$

Conversion of nitrate to nitrogen gas provides energy for growth of anaerobic bacteria. Anyway, bacteria still require a source of carbon for cell synthesis. NO, N_2O

Table 2.1 Summaries of Biological Nutrient Removal Process Zones.

Zone	Biological transformations	Functions	Zone required for
Anaerobic	• Uptake and storage of VFAs by PAOs • Fermentation of readily biodegradable organic matter by heterotrophic bacteria • Phosphorus release	• Selection of PAOs	• Phosphorus removal
Anoxic	• Denitrification • Alkalinity production	• Conversion of NO_3-N to N_2 • Selection of denitrifying bacteria	• Nitrogen removal
Aerobic	• Nitrification • Metabolism of stored and exogenous substrate by PAOs • Metabolism of exogenous substrate by heterotrophic bacteria • Phosphorus uptake • Alkalinity consumption	• Conversion of NH_3-N to NO_3-N • Nitrogen removal through gas stripping • Formation of polyphosphate	• Nitrogen removal • Phosphorus removal

and N_2 are gaseous products and can be released to the atmosphere. In this process dissolved oxygen is critical parameters (Metcalf & Eddy Inc., 1991). Dissolved oxygen should be absent from this process because it will restrain the enzyme system needed for denitrification. Temperature and pH have the effects on the growth of denitrifier. The optimum pH is in the range of 7 and 8 depends on bacterial populations. The organisms are sensitive to the change of temperature. Conversion of nitrate to nitrogen gas produces alkalinity and makes the pH increases.

The effect of cycle time on nutrient removal is showed by Grady, Daigger, and Lim (1999). Their results showed that soluble organics and ammonia N rose during the fill period as wastewater was added. Concentration of Nitrate-N from the previous cycle dropped. Carbon oxidation occurred all over the fill period and this will limit the buildup

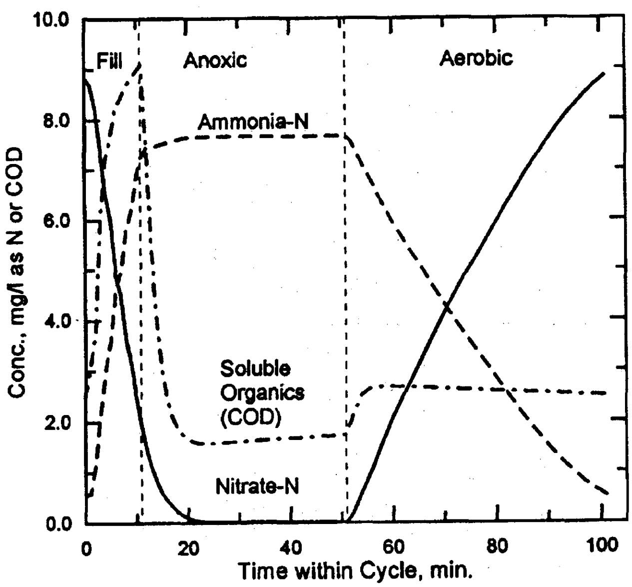

Figure 2.2 Performance of SBR during a single cycle. Anoxic and aerobic periods each occupied 50% of the fill plus react time (Grady et al., 1999).

of soluble organics. Soluble organics and nitrate-N were rapidly depleted upon the completion of fill period. The length of the fill period depends on many factors, including the nature of the facility and treatment objectives. If this period is short, the biomass will be exposed to the high concentration of both organic matter and other wastewater constituents, but the concentration will drop over time. In the other ways, if this period is long, the instantaneous process-loading factor will be small and the biomass will receive low and relatively constant concentrations of wastewater.

In anoxic period, nitrate was rapidly depleted because denitrification process occurred. Ammonia-N remained the same and all nitrate-N was removed while little soluble organic matter existed. Nitrification occurs during aerobic period (react period). In this period, biomass utilizes the organic matters and nitrifying bacteria transforms ammonia nitrogen into nitrate form. Soluble organics rose slightly because of their production by hydrolysis reactions.

Bernades and Klapwijk (1996) conducted the experiment to monitor biological nutrient, nitrification, denitrification, carbon oxidation, and phosphorus removal in sequencing batch reactor. They operated two sequencing batch reactors. Reactor 1 has three periods, mixed fill, mixed react and draw. For reactor 2, the periods are mixed react, mixed fill, mixed react II, aerated react, settle and draw. From their results, the system achieves a good performance in P removal. After aerated react, ammonia will be converted to nitrate so there is nitrate in the effluent. Percentage of phosphorus in microbial is increasing with time. Denitrification rate is related to the presence of soluble substrate in the influent.

From Jones, Wilderer, and Schroeder (1990)'s experiments on investigation sequencing batch reactor process, concentration of organic increased rapidly during fill period, and slightly decreased in anaerobic period. And concentration will drop rapidly during aerobic period. Ammonia nitrogen increased during fill period.

Furumai, Kazmi, Fujita, Furuya, and Sasaki (1999) concluded from their experiment about modelling sequencing batch reactor that both disturbed loading, large variation in organic loading, has no effect on carbon oxidation and nitrification. There was a significant change in effluent nitrate and phosphate concentrations when organic loading is changed. During the cycle, there is the release of phosphorus during anoxic and anaerobic conditions during feed and the mixing phase. In the following aeration phase, carbonaceous BOD removal, phosphorus uptake and nitrification take place. Denitrification occurs during settling and the following feed phase.

Artan and Tasli (1999) showed that aeration time fraction is very important to nutrient removal efficiency and filling pattern has an important role in efficient utilization of external carbon source. And for effective nutrient removal, filling under aerobic condition should be avoided.

The experiments by varying solid retention time (SRT) to investigate the efficiency of nutrient removal can show that SRT has little effect on COD removal. At higher SRT, there is less active biomass, so that lower phosphorus removal is occurred. Nitrification is accomplished at all SRT values and carbon source addition during anoxic period would enhance denitrification which leading to lower effluent nitrogen concentration (Mines et al., 1997). Furumai, Kazmi, Furuya, and Sasaki (1999) also conducted the experiment by varying SRT. They concluded that poor nitrification will help higher phosphorus removal activity and carbon source is important to enhance for denitrification and phosphorus removal. Elevated nitrate concentration deteriorates phosphorus removal. Their study has some conflicts with Mines et al.'s because they concluded that higher SRT helps phosphorus-accumulating organisms.

2.2 Sequencing Batch Reactor

The Sequencing Batch Reactor (SBR) is similar to a conventional activated sludge process, operated in a batch mode through a sequence of steps. Typically, the SBR process consists of 5 steps: (1) fill (with or without aeration), (2) react, (3) settle (sedimentation/clarification), (4) decant (draw), and (5) idle. The process starts with the introduction of wastewater to a partially filled reactor containing settled sludge from a previous cycle. Reaction phase is provided for a period of time to produce the effluent of the desired quality. Microbial flocs settles in the subsequent phase and the supernatant is drawn out of the reactor. The idle period is optional and is typically adjusted to meet operational requirements of the production facility.

In many instances a Sequencing Batch Reactor (SBR) systems can be an alternative to the continuous flow treatment systems in meeting effluent quality requirements (Branner, 1997). The major advantage of a SBR system is its operational flexibility to meet a wide range of treatment and operational requirements for a relatively small footprint (Coelho et al., 2000, Zhao et al., 1997).

In continuous wastewater treatment processes, wastewater and biomass have to move from tank to tank within the system. Time spent in each process and environmental conditions are fixed. Hence these systems are not very flexible to change in operational requirement. Batch reactor can overcome this problem by changing the environment temporally as well as change the contact time required for each environment (Leslie et al., 1999, Coelho et al., 2000).

Sequencing batch reactor has been used to successfully for nutrient removal from a range of municipal and industrial wastewaters.

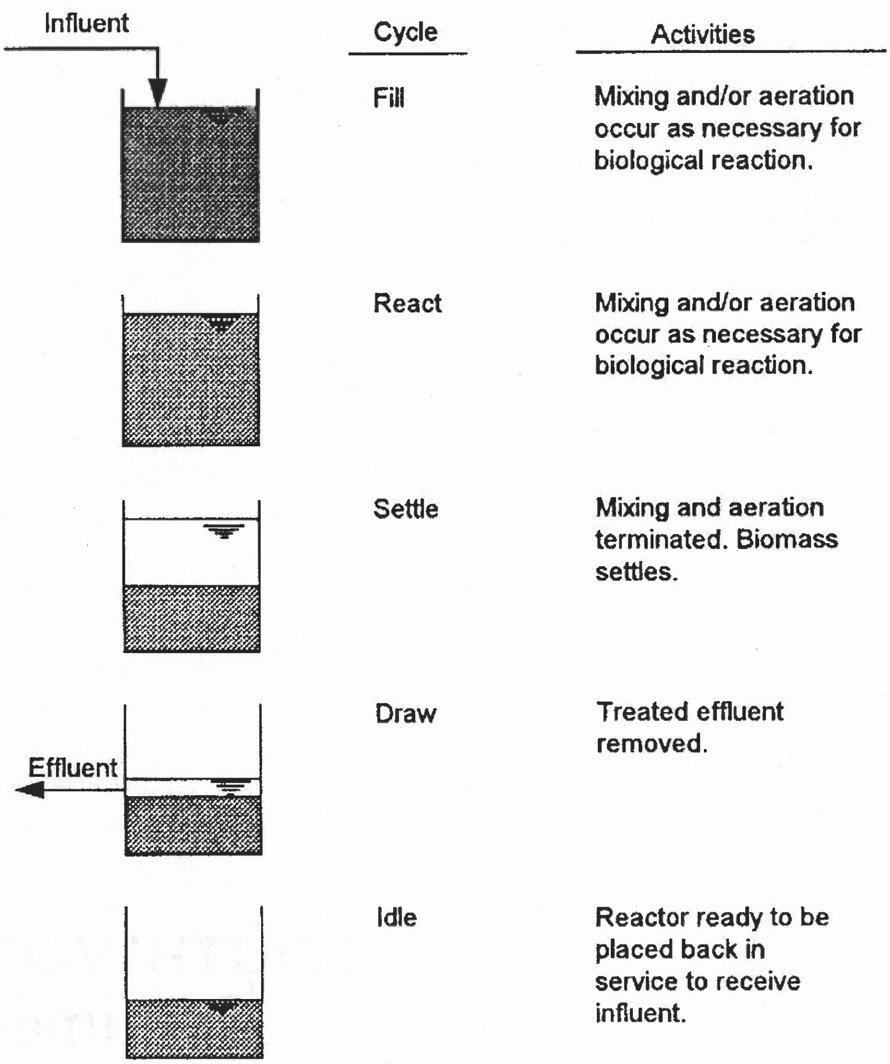

Figure 2.3 Basic steps of the sequencing batch reactor process.

As mentioned earlier, the operation of a SBR has five basic steps (processes): Fill, React, Settle, Decant, and Idle. Each of these processes is correlated as they occur in sequence optionally. Environmental conditions in each of these steps (processes) have designed to optimize removal efficiencies for the different constituents. The alternating of the cycle time and the sequence of each process affects the quality of the effluent. Therefore it is possible to operate within a single SBR conditions which are anaerobic, anoxic and aerobic for simultaneous nitrogen and phosphorus removal in addition to organic carbon removal (Artan et al., 1999, Mines, Jr. et al., 1997).

In order to improve settling performance, floc-forming or filamentous microorganisms maybe selected by changing the filling pattern may influence the sludge settling characteristics, which is called kinetic selection (Artan et al., 1999). The selection is chosen by adjusting the condition, which is suitable for the growth of floc-forming bacteria than filamentous bacteria. High substrate at the beginning of the cycle will result in the dominating of the floc-forming bacteria (Artan et al., 1999).

CHAPTER 3

MODELING AND EXPERIMENTAL METHODS

The main purpose for this study was to find the suitable condition for nutrient removal. Therefore operating parameters were varied and investigate the nutrient removal efficiency. In order to construct concentration profile, kinetic equations were used for calculation.

3.1 Kinetics of Nutrient Removal

Characteristics and the growth patterns of microorganisms have been described by many kinetic equations. For example, Monod equation shows the effect of a limiting nutrient on the specific growth rate.

$$\mu = \mu_m \frac{S}{K_s + S}$$

Substrate utilization rate can be calculated by using

$$r_g = \frac{\mu_m XS}{K_s + S}$$

There are many environmental variables that have effects on operational system. The following equations were used to create the concentration profile and calculate nutrient removal efficiency.

For nitrification process, DO level has the effect on maximum specific growth rate μ_m of nitrifying organisms and nitrification rate decreases when temperature is decreased (Metcalf & Eddy, Inc., 1991).

$$\mu'_m = \mu_m e^{0.098(T-15)}$$

DO concentration also has the influence on maximum specific growth rate μ_m of the nitrifying organisms.

$$\mu'_m = \mu_m \frac{DO}{K_{O_2} + DO}$$

Maximum rate of nitrification occurs when pH values between 7.2 and 9.0.

$$\mu'_m = \mu[1 - 0.833(7.2 - pH)]$$

To determine the maximum growth rate of nitrifying organisms, the effects of pH, DO concentration and temperature are involved.

$$\mu'_m = \mu_m e^{0.098(T-15)} \times \frac{DO}{K_{O_2} + DO} \times [1 - 0.833(7.2 - pH)]$$

Maximum rate of substrate utilization *k* can be calculated by:

$$k' = \frac{\mu'_m}{Y}$$

To determine the mean cell-residence times and substrate-utilization factor U, these equations can be used:

$$\frac{1}{\theta_c} \sim Yk' - k_d$$

$$\frac{1}{\theta_c} = YU - k_d$$

Substrate concentration in effluent can be determined by:

$$S = S_0 - U6X$$

These equations are used to determine both BOD and N effluent in nitrification process. The different is between the constant for BOD utilization and nitrification process. In denitrification process, dissolved oxygen concentration, wastewater temperature and carbon source have the influences on denitrification rate. Rate of denitrification can be described by:

$$U'_{DN} = U_{DN} \times 1.09^{(T-20)}(1-DO)$$

Other operational parameters and environmental variables that have the effects are nitrate concentration and pH (Metcalf & Eddy, Inc., 1991). In the fill cycle period, the assumption is made that there will be no reaction or degradation of both BOD and nitrogen.

Nomenclature

k	maximum rate of substrate utilization, time $^{-1}$
DO	dissolved oxygen concentration, mass per unit volume
T	temperature, ^{o}C
pH	operating pH, the numerical value of the pH term is taken as 1 for the above values
k_d	endogenous decay coefficient, time^{-1}
K_{O2}	dissolved-oxygen half velocity constant
K_s	half-velocity constant, substrate concentration at one-half the maximum growth rate, mass per unit volume
S	substrate concentration in solution, mass per unit volume
S_0	influent concentration, mass per unit volume
μ	specific growth rate, time $^{-1}$
μ_m	maximum specific growth rate, time^{-1}

μ'_m growth rate under the stated conditions of temperature, dissolved oxygen, and pH, $time^{-1}$

θ hydraulic detention time, time

θ_c design mean cell-residence time, time

U substrate utilization rate, $time^{-1}$

U_{DN} overall denitrification rate, $time^{-1}$

U'_{DN} specific denitrification rate under the stated conditions of temperature, and dissolved oxygen, $time^{-1}$

X concentration of microorganisms, mass per unit volume

X_n concentratnion of nitrifier, mass per unit volume

Y maximum yield coefficient measured during a finite period of logarithmic growth, mass of cell formed per mass of substrate consumed, mass of cell formed per mass of substrate consumed

3.2 Modeling Procedures

Spreadsheets are built from these above equations and illustrate the concentration profile of each nitrogen components and BOD profile.

In this study, two parameters are varied.

1.MLVSS

2.Cycle time (fill-react-settle period)

MLVSS or biomass concentration in wastewater treatment system has the ability to utilize substrate in wastewater. Variation of MLVSS can show the influence of biomass on the nutrient removal efficiency. The unique point of sequencing batch reactor is the operation by varying cycle time. This study also tries to investigate the effects of cycle time variation in Fill, React, and Idle.

3.2.1 MLVSS Variation

This model MLVSS is varied to study the effects of active biomass concentration on nitrogen profile in SBR system and the effluent concentration after settle period. In order to monitor on the effects, other parameters besides MLVSS are fixed. Those parameters are μ_m, μ'_m, k', θ_c, θ_c', U (for ammonium removal), U (for BOD removal), and U (denitrification). Table 3.1 shows the set of cases that was conducted by using spreadsheet.

Table 3.1 Modeling condition for different MLVSS.

No.	X (mg/l)	X_n (mg/l)	Fill-React-Settle (hrs.)
1	1500	120	0.6-2.4-1
2	2000	160	0.6-2.4-1
3	2500	200	0.6-2.4-1
4	3000	240	0.6-2.4-1
5	3500	280	0.6-2.4-1
6	4000	320	0.6-2.4-1
7	5000	400	0.6-2.4-1

In this model, designed parameters are: influent flow rate = 3400 CMD, designed temperature = 15 °C, maximum specific growth rate (μ_m) = 0.5 d^{-1}, yield (for BOD removal) = 0.5), yield (for nitrogen removal) = 0.2, and pH for the system = 7.2.

3.2.2 Cycle Time Variation

This model is conducted to study the effects of cycle time on nitrogen and BOD profile in sequencing batch reactor system. For this model, X, X_n, μ_m, μ'_m, k', θ_c, θ_c', U (for ammonium removal), U (for BOD removal), and U (denitrification) are fixed. The cycle time is the varied variable.

Table 3.2 Modeling condition for different cycle time.

No.	Cycle time (hrs.)		
	Fill	React	Settle
1	0.5	2.25	1.25
2	0.5	2.5	1.0
3	0.5	2.75	0.75
4	0.5	3.0	0.5
5	0.7	2.05	1.25
6	0.9	1.85	1.25
7	0.7	2.25	1.05
8	0.9	2.25	0.85

Table 3.2 shows set of cases in this modeling. In first series, model no.1-4, Fill period is constant; React period is increased while Settle period is decreased. The second series is no.1, 5, and 6, Fill period is increased, React period is decreased, and Settle is fixed. The last series, Fill period is increased, React period is constant and Settle period is decreased.

In this model, parameters that were used for calculating are the same with the one that first modeling used.

CHAPTER 4

RESULTS AND DISCUSSIONS

The primary objective of this study was to develop a rationale for the optimization of process conditions for adapting existing SBR systems for enhanced nutrient (nitrogen) removal capabilities. The operating parameters that were identified as being the most effective and relatively easy to control were – the active biomass inventory in the system and the hydraulic retention time in the different operational phases of the SBR.

4.1 MLVSS Variation

This study of MLVSS variation was conducted in order to understand the effects of MLVSS concentration on BOD and nitrogen removal as described from the Table 3.1. The concentration profiles describe the concentration from fill period, react period, and settle period.

Table 4.1, Figure 4.1 and Figure 4.2 present effluent concentration of nitrogen in the form of ammonium, nitrate, and BOD removal. The model assumes that there is no reaction in the fill period.

Table 4.1 Nitrogen and BOD effluent from MLVSS variation

No.	X	X_n	NH_4^+	NO_3^-	BOD
1	1500	120	30.31	5.67	148.53
2	2000	160	27.07	7.56	131.37
3	2500	200	23.84	9.46	114.21

No.	X	X_n	NH_4^+	NO_3^-	BOD
4	3000	240	20.61	11.35	97.05
5	3500	280	17.38	13.24	79.90
6	4000	320	14.15	15.13	62.74
7	5000	400	7.68	18.91	28.42

From the results in Figure 4.3 and 4.4, ammonium-nitrogen and BOD concentration after settle period decrease when MLVSS increases. In the other ways, nitrate concentration increases with the increase of MLVSS. Increasing MLVSS from 1500 mg/l to 5000 mg/l can lower the BOD concentration 80.9% (from 148.53 mg/l to 28.42 mg/l) and ammonium concentration 74.66% (from 30.31 mg/l to 7.68 mg/l). But increase nitrate nitrogen 233.5% (from 5.67 mg/l to 18.91 mg/l).

Figure 4.3 and 4.4 show that nitrogen concentration profile from fill period to settle period and the BOD concentration profile from fill period to react period. These figures present the variation of MLVSS has the effects on the concentration of the BOD, ammonium-nitrogen and nitrate-nitrogen. Concentration changes according to MLVSS, as MLVSS increases, slope of BOD concentration in react period increases, which means that more BOD is consumed. Ammonium concentration in react period drops rapidly when MLVSS increases. In the settle period, which is anoxic condition, it is assumed that ammonium has no reaction. Slope of nitrate concentration in react period decreases rapidly and concentration of nitrate effluent also increases as MLVSS increases. The results show that variation of MLVSS or biomass in the system has the effects on the concentration of substrate in the system. Biomass has the ability to utilize substrate in

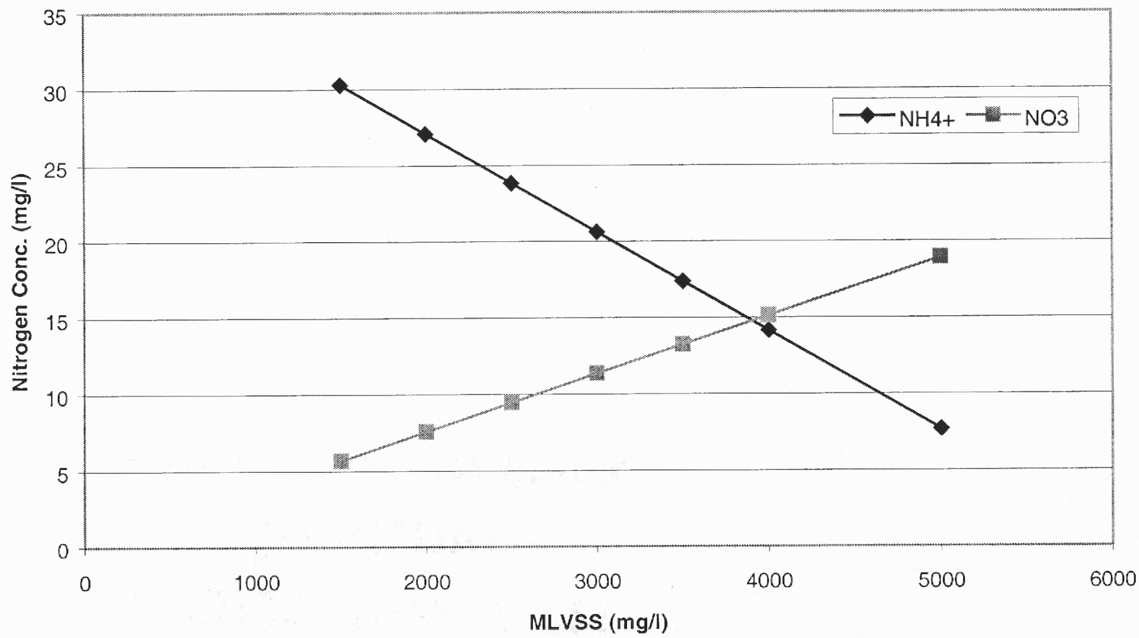

Figure 4.1 Effluent nitrogen concentrations at different MLVSS in the SBR.

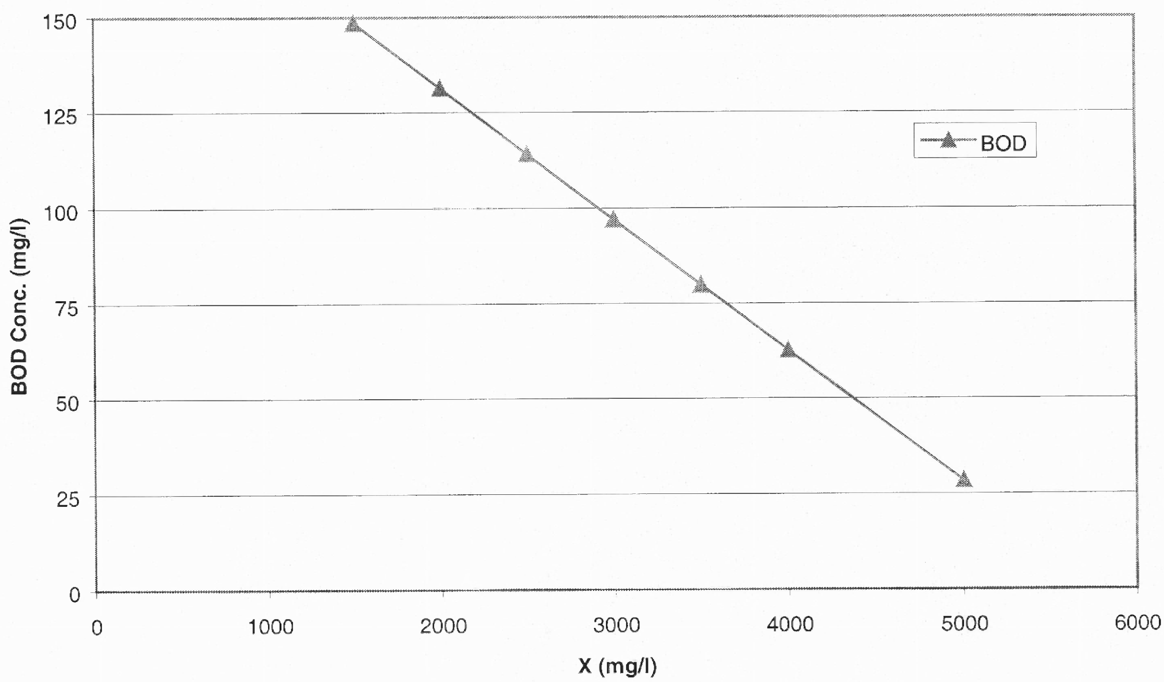

Figure 4.2 Effluent BOD concentrations at different MLVSS in the SBR.

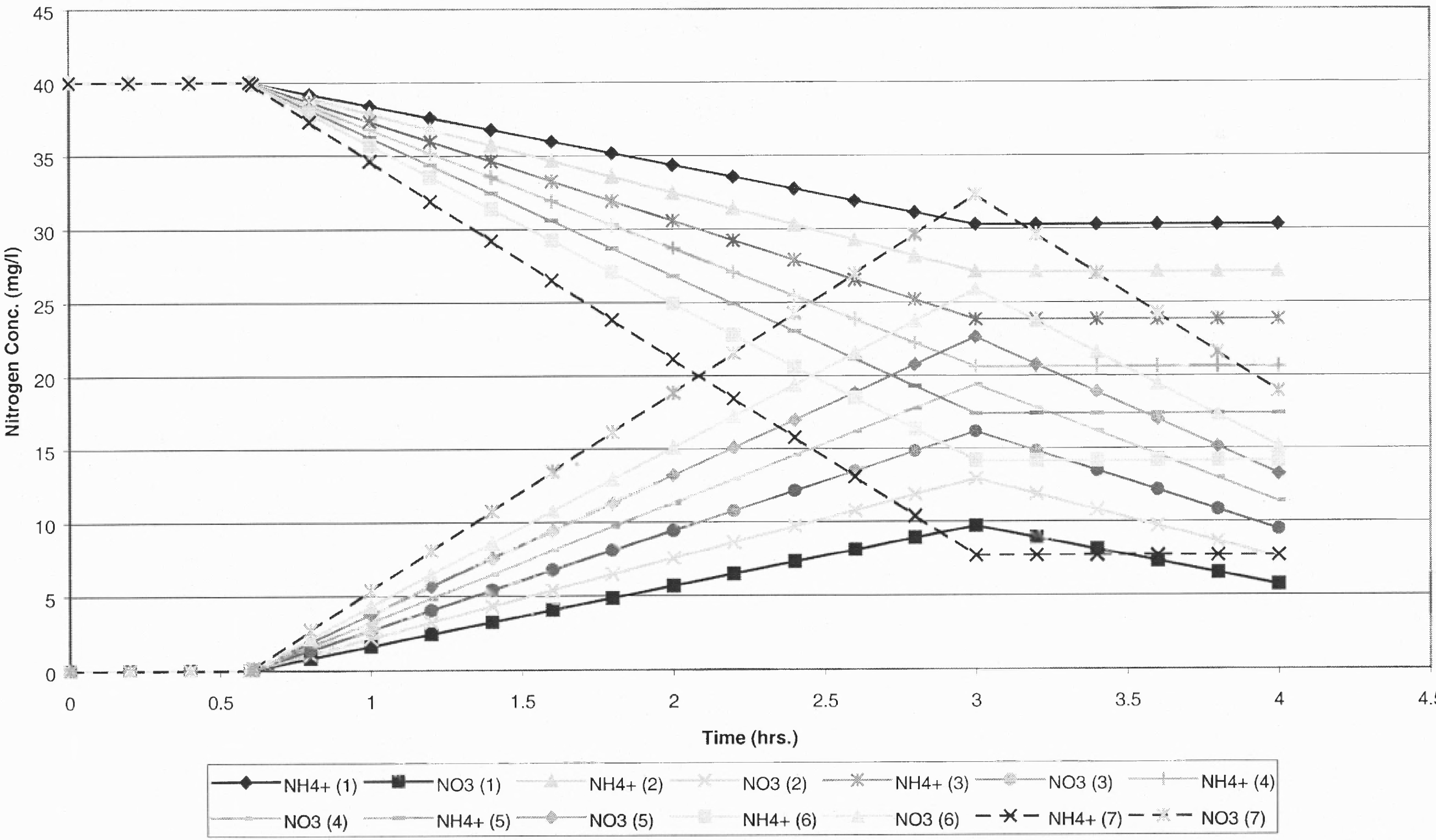

Figure 4.3 Concentration profile for different nitrogen species when MLVSS is varied in the SBR.

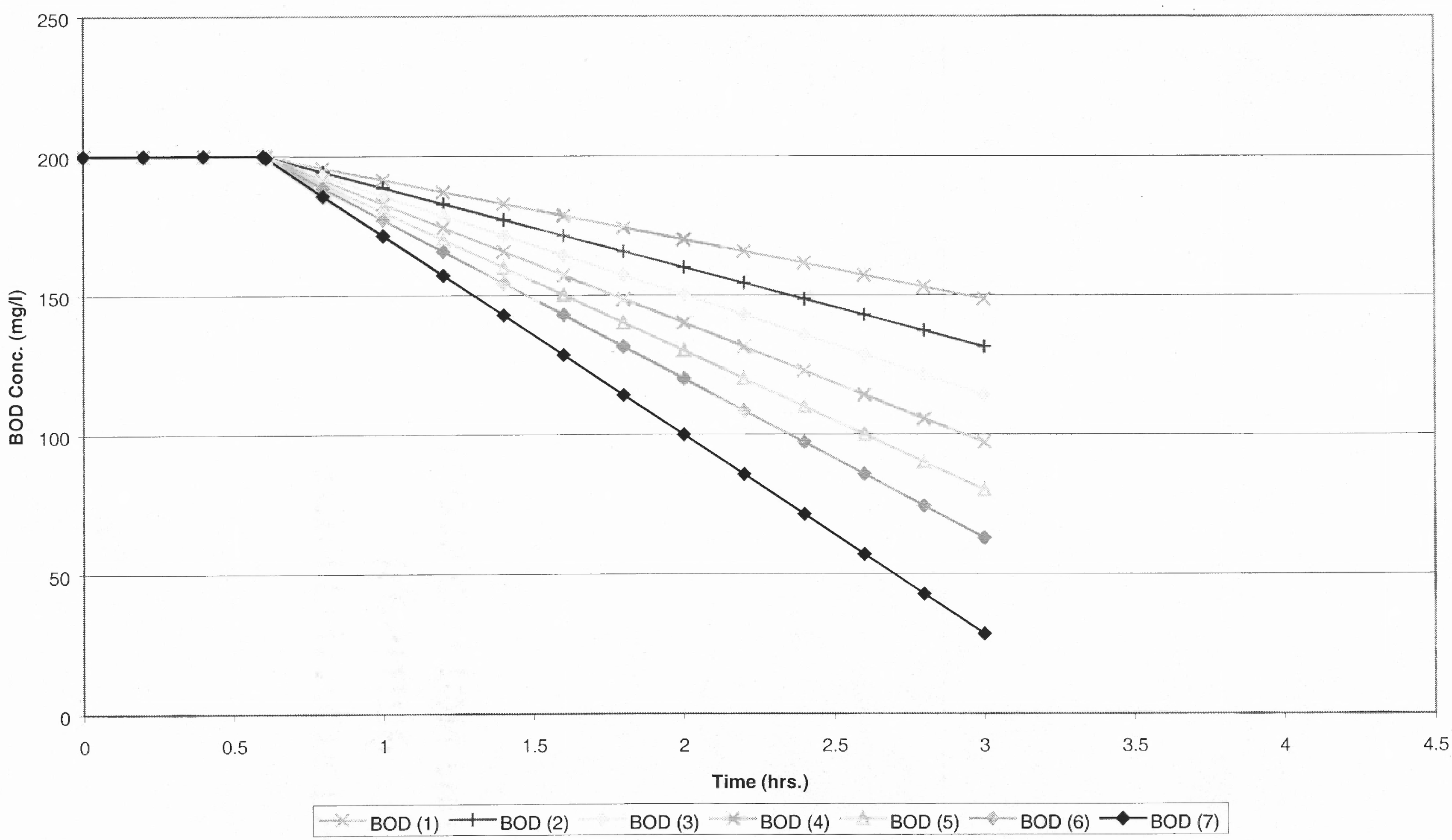

Figure 4.4 Concentration profile for different BOD when MLVSS is varied in the SBR.

wastewater, so that the changes of concentration of biomass must have the influence on BOD concentration. From kinetic equations in chapter 3, X or MLVSS is the parameter, which is able to make the effluent concentration changes. Nitrogen in wastewater also has the effects from the variation of biomass. When nitrifying and denitrifying biomass are increased, there is the increasing ability to obtain more ammonium nitrogen and changing it to oxidized nitrogen. As from Figure 4.3, the more biomass in the system, the more nitrification occurred. This process shows that ammonium nitrogen decreases as biomass increases. In the other words, when nitrification occurs, nitrite and nitrate are produced.

4.2 Cycle Time Variation

Cycle time, fill, react and settle period, in the second case are varied but the total time of these three periods are four hours. In this case, it can be separated into three series: first, constant fill period, increasing react period, and decreasing settle period. Second, increasing fill period, decreasing react period, and constant settle period. Third, increasing fill period, constant react period, and decreasing settle period.

Figure 4.5 and 4.6 present the first series, no.1-4. As react period increases, therefore, there is more time for the reaction. So that, BOD concentration is lower in the case that has more reaction time. Ammonium effluent decreases when reaction time increases because ammonium has more time to change into nitrate form. Thus, nitrate in react period that has longer react time increases to the higher concentration before drops down. Nitrate concentration after settle period varies with the reaction time and inverse varies with the settle time. From the model, case no.1, which has the longest react

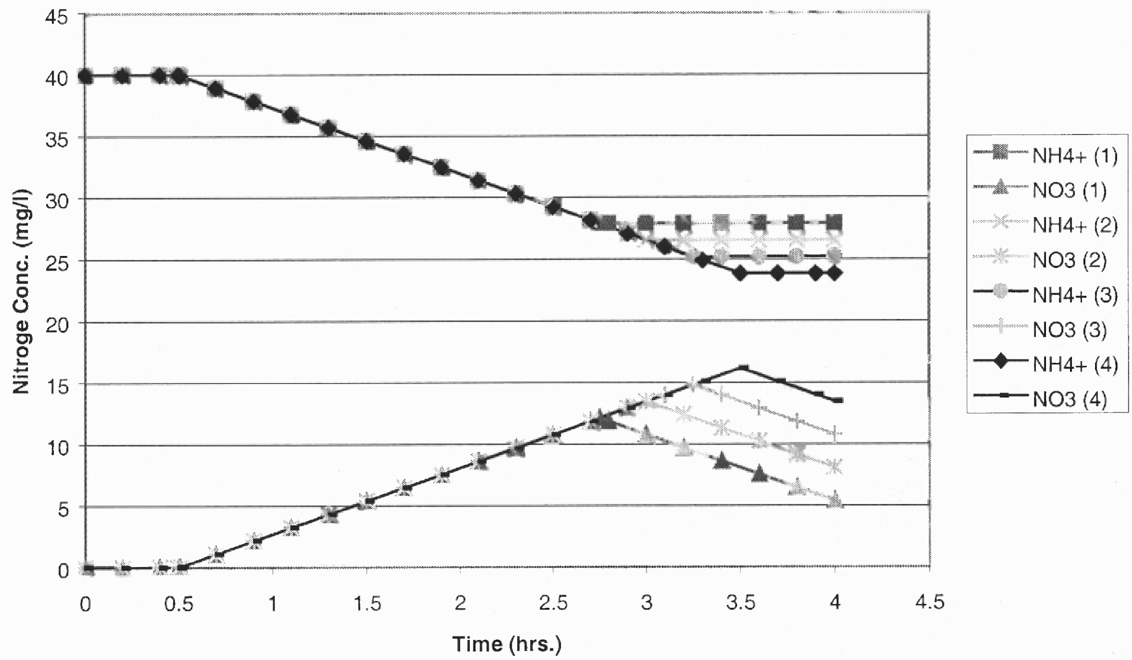

Figure 4.5 Nitrogen concentration profile when cycle time is varied (constant fill period, increasing react period, and decreasing settle period).

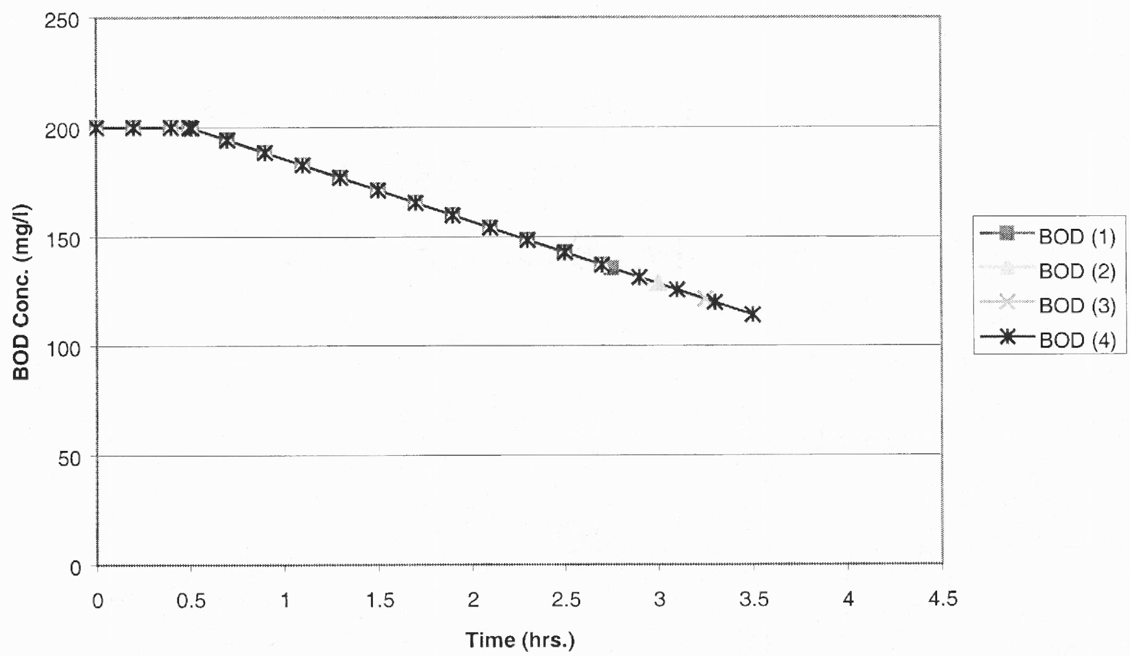

Figure 4.6 BOD concentration profile when cycle time is varied (constant fill period, increasing react period, and decreasing settle period).

period and shortest settle time, has the highest ammonium concentration and the lowest nitrate concentration.

Table 4.2 Nitrogen and BOD effluent from cycle time variation (constant fill period, increasing react period, and decreasing settle period).

No.	Fill (hrs.)	React (hrs.)	Settle (hrs.)	NH_4^+	NO_3^-	BOD
1	0.5	2.25	1.25	27.88	5.42	135.66
2	0.5	2.5	1.0	26.54	8.10	128.51
3	0.5	2.75	0.75	25.19	10.79	121.36
4	0.5	3.0	0.5	23.84	13.48	114.21

In the second series, fill period is increased, react period is decreased, and settle period is fixed. Ammonium-nitrogen in the system that has lower fill period starts dropping down first. But the total time for fill and react period is constant, so that for the case that has shorter fill period, the react period is longer. There is more react time for ammonium to transform to nitrate for case no.1; thus, in this period has the lowest ammonium concentration and the ammonium concentration increases as fill period decreases. Nitrate in case no.1, which has shortest fill period, start increasing up first and because there is longer react period, nitrate concentration in this case is the highest one. From Figure 4.7 and 4.8, nitrate concentration after settle period decreases the fill period decreases. When fill period decreases and react period increases, BOD concentration after react period decreases.

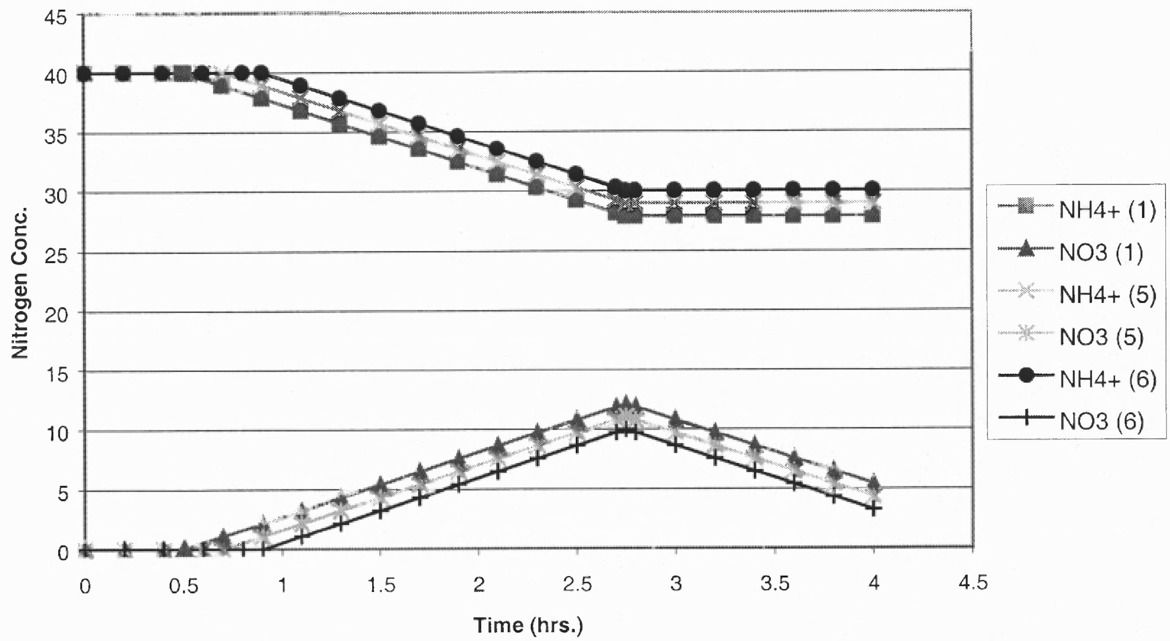

Figure 4.7 Nitrogen concentration profile when cycle time is varied (increasing fill period, decreasing react period, and constant settle period).

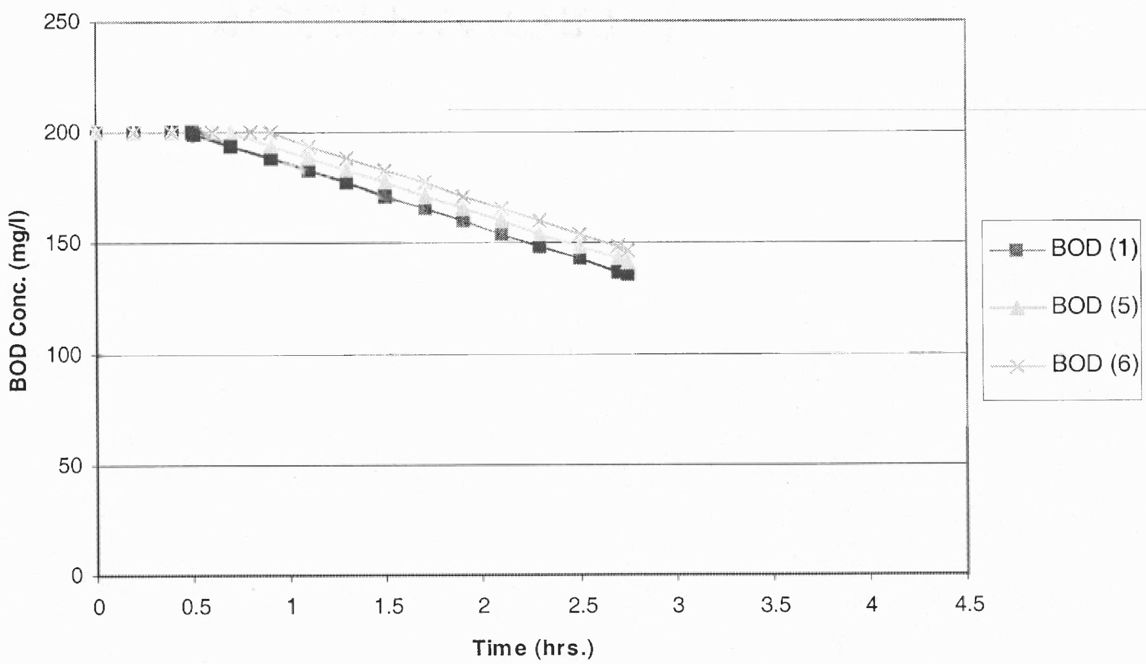

Figure 4.8 BOD concentration profile when cycle time is varied (increasing fill period, decreasing react period, and constant settle period).

Table 4.3 Nitrogen and BOD effluent from cycle time variation (increasing fill period, decreasing react period, and constant settle period).

No.	Fill (hrs.)	React (hrs.)	Settle (hrs.)	NH_4^+	NO_3^-	BOD
1	0.5	2.25	1.25	27.88	5.42	135.66
5	0.7	2.05	1.25	28.96	4.34	141.38
6	0.9	1.85	1.25	30.04	3.26	147.10

The third series of the case represents the cycle time variation by varying fill period and settle period. Fill period is increased while settle period is decreased and react period is fixed. Summation of the fill period and settle period is 1.75 hours and react

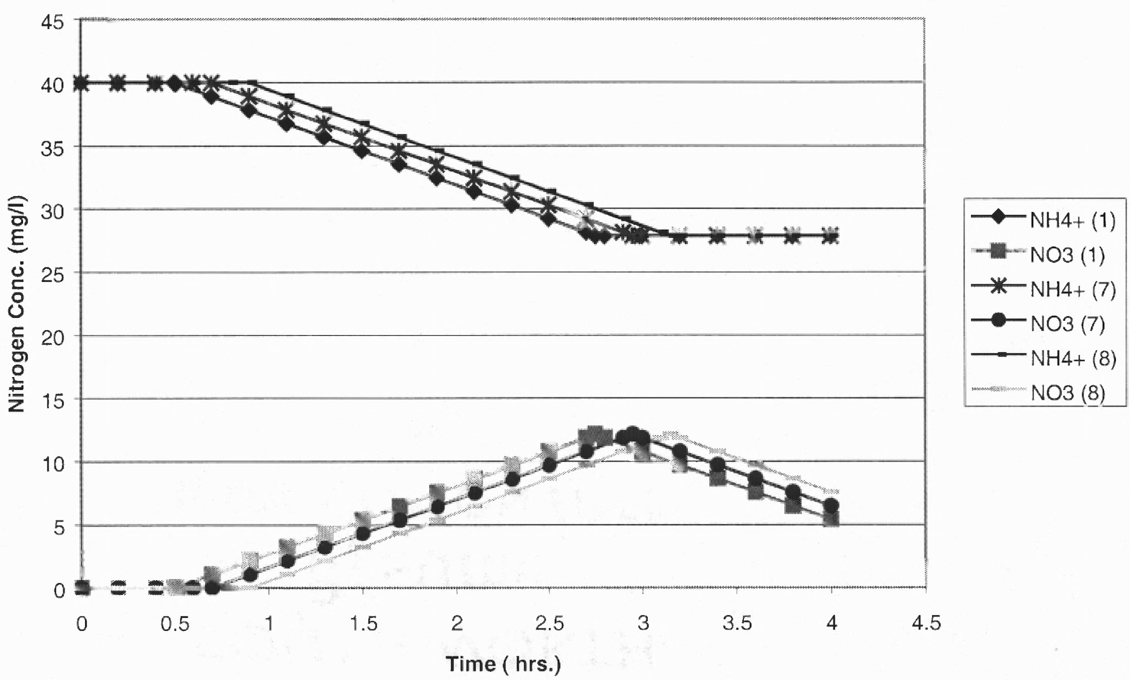

Figure 4.9 Nitrogen concentration profile when cycle time is varied (increasing fill period, constant react period, and decreasing settle period).

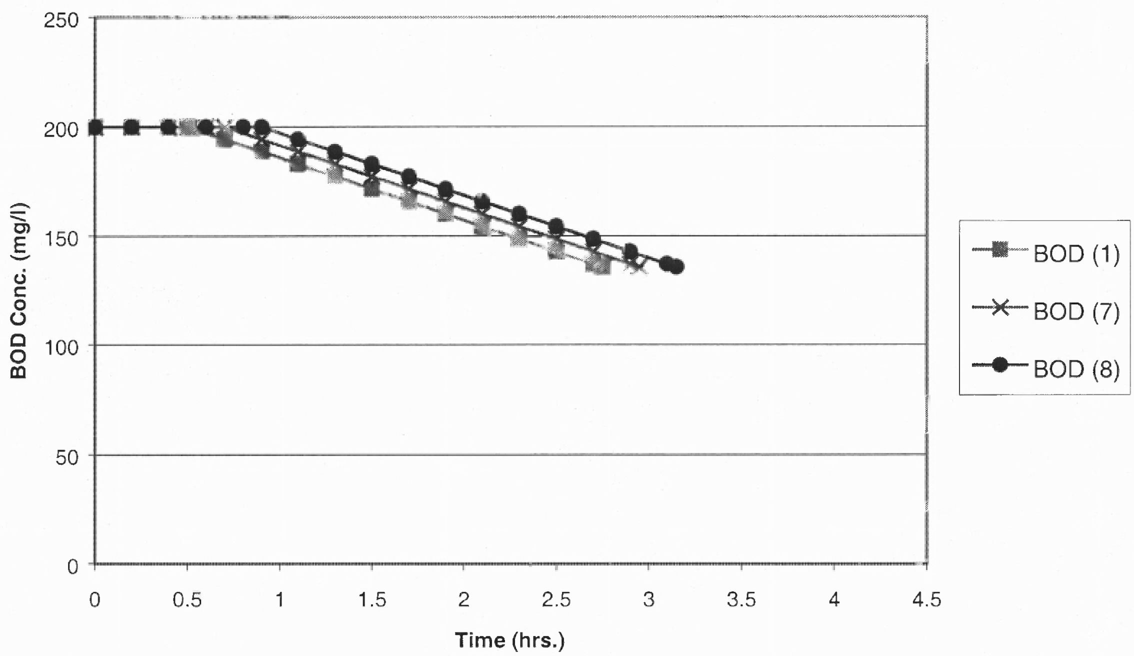

Figure 4.10 BOD concentration profile when cycle time is varied (increasing fill period, constant react period, and decreasing settle period).

period is 2.25 hours for all 3 cases. From Figure 4.8, and 4.9 it can show that reaction time has effects on the effluent concentration. In this series, ammonium concentration for 3 cases after react period is equal because they have the same react period. Even though, this process has different fill period but they have the same react time, so nitrate concentration increases to the same level. Nitrate concentration drops down in the settle period because it converts to nitrogen gas. In case no.1, which has longest settle period, has the lowest nitrate concentration. BOD concentration in this series is the same because they have the same reaction time to remove BOD.

The results are based on the assumption that there is no reaction in fill, and in the settle period. It is also assumed that in settle period is in completed anoxic condition, thus, there is no nitrification for ammonium.

Table 4.4 Nitrogen and BOD effluent from cycle time variation (increasing fill period, constant react period, and decreasing settle period).

No.	Fill (hrs.)	React (hrs.)	Settle (hrs.)	NH_4^+	NO_3^-	BOD
1	0.5	2.25	1.25	27.88	5.42	135.66
7	0.7	2.25	1.05	27.88	6.49	135.66
8	0.9	2.25	0.85	27.88	7.56	135.66

The model results can show that variation of cycle time has the effects on the substrate removal efficiency. Increase of fill, which provides more aerobic period, makes the system, has more time to remove BOD and ammonium nitrogen. In the other ways, the decrement of ammonium nitrogen makes the system has more nitrate nitrogen. Settle period, which is anoxic and nitrate is transformed to nitrogen gas, increases, nitrate concentration decreases.

Artan and Tasli (1999)'s experiment, which was investigated on effect of aeration and filling patterns, also shows that aerated time fraction is the most important parameter that influence nutrient removal efficiency. But concentration of substrate in the system is the parameter that has to pay attention on because when COD/TKN is low, high-unaerated period maybe required.

In the first and third series, results can show that the effects of the anoxic period on the concentration of the nitrate. As this period increases, nitrate concentration decreases. Niaki (2000) had the experiment to implementation of nutrient removal by using SBR. The results can show that nitrogen removal by SBR system increases when anoxic cycle increases from one to 1.5 hours and decreased the effluent nitrate concentration by 53%.

CHAPTER 5

CONCLUSIONS

The objective of this study was to optimize the operation of existing sequencing batch reactors (SBR) for nitrogen removal. The effects of operational parameters on nutrient removal efficiency were observed. In this study, the concentration of active biomass (MLVSS) and cycle time were varied. MLVSS concentrations ranging from 1500 mg/l to 5000 mg/l were used for modeling the nutrient concentration profile during the fill, react, and settle phases. Effect of cycle time on nutrient removal efficiency was also studied. From this study it was concluded that:

1. Concentration of active biomass in the SBR and cycle time can be used as effective control parameters for optimization of nutrient (nitrogen) removal in existing SBR systems. Since the process is sequential, i.e. products from one phase of operation are inputs to the subsequent phase; optimization of the process requires a holistic overview of system dynamics through different operational phases.
2. Optimization of MLVSS concentration in the reactor and react time can enhance the effective rate and extent of conversion of ammonia nitrogen to nitrate nitrogen during the react phase. Since the fraction of nitrifiers in the active biomass is dependent on the ratio of TKN to BOD5 content of the particular wastewater, the concentration of MLVSS in the system to achieve design nitrifying efficiency has to be estimated on a case by case basis.

3. The hydraulic retention time of the react phase has to selected as being greater of (i) the retention time required to achieve design carbonaceous BOD removal or (ii) the retention time required to achieve desired nitrification. It is important to note here that the design carbonaceous BOD removal should be based on the minimum substrate requirements for the denitrification stage of the process, failing which additional substrate such as methanol may need to be added to accomplish denitrification.
4. Variation in fill time did not show any benefit to the nitrifying process. This was primarily due to lack of D.O. during this phase of operation. Since the fill period also acts as a selection phase for floc formers, the effect of enhancing D.O. in this phase to help nitrification has to be evaluated on a case-by-case basis.
5. Denitrification occurs primarily during the settle phase of the SBR operation. In addition to maintaining optimum MLVSS concentration in the reactor, availability of sufficient easily biodegradable substrate and depressed D.O. conditions in the reactor are critical to this phase of operation.
6. The hydraulic retention time of the settle phase has to be selected as being the greater of either (i) the settle time required as calculated by the Sludge Volume Index (SVI) of the sludge, or (ii) the time required for anoxic denitrification.

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