LOW TEMPERATURE BIOLOGICAL TREATMENT OF A HIGH AMMONIA MUNICIPAL LANDFILL LEACHATE

By

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ABSTRACT

The single-sludge, biological pre-denitrification (i.e., denitrification being carried out before nitrification), completely-mixed activated sludge system, with hydraulic sludge recycle, known as the Modified Ludzack-Ettinger (MLE) system, has proved to be an efficient method for ammonia nitrogen removal. However, because of the sensitivity of microbial growth to temperature changes, this process may be seriously affected at low temperatures. The objective of this project was to study the effects of low operating temperatures on the biotreatment of a high ammonia-N leachate and to optimize the control for the treatment at temperatures from 20°C to 4°C.

Two identical bench-scale, single-sludge, pre-denitrification, activated sludge systems, with sludge recycle, were employed during this study. Each system consisted of a 5-liter anoxic reactor for denitrification, a 10-liter aerobic reactor for nitrification, and, a 4-liter clarifier for sludge settling. An air diffuser system was installed in the aerobic reactor to ensure that enough dissolved oxygen(more than 1.8 mg/l) was supplied to the nitrifying bacteria. The leachate feed was controlled at 10 liters per day. The settled sludge in the clarifier was returned to the anoxic reactor at a recycle ratio of 6:1 (60 l/d). Methanol was used as an external carbon source for denitrification. Additional phosphorus was added for bacterial growth. Temperatures of 20°C, 12°C and 4°C were studied. Theoretical aerobic SRTs of 20 days and 60 days were operated in system I; theoretical aerobic SRTs of 20 days, 30 days and 40 days were studied in system II. The leachate used in this project was collected from the City of Vancouver Burns Bog landfill in Delta, B.C., Canada. The leachate is characterized by high ammonia-N (average 210 mg/l), low COD

(average 400 mg/l) and low BOD_5 (average 35 mg/l).

This study found that ammonia-N removal of more than 90 %, with effluent ammonia-N of lower than 0.5 mg/l, was achieved at an ambient temperature as low as 12°C, when the theoretical aerobic SRT was set at a minimum of 20 days. Also, an average effluent ammonia-N below 1.9 mg/l was obtained at an ambient temperature of 4°C, when the theoretical aerobic SRT was set at 60 days. However, at a temperature of 4°C, with a theoretical aerobic SRT of only 20 days, the level of ammonia-N removal was observed to be variable and erratic, with average effluent values of 9.2 mg/l.

Methanol, as an external carbon source, was found to have a significant effect on the treatment process. When the temperature was suddenly reduced, it was necessary to increase the aerobic SRT and decrease the methanol addition, to protect the nitrifying bacteria against possible competition from heterotrophic bacteria, utilizing the excess carbon in the aerobic basin. After the nitrifying bacteria had been acclimated, methanol addition was increased to support the denitrifying bacterial population in the anoxic chamber. Despite successful denitrification in the anoxic basin, final effluent NO_x^--N values, at steady state, could still be relatively high, ranging from 20 mgN/l to 50 mgN/l, at various operating temperatures. Optimization of system hydraulic recycle would be necessary to reduce these values even further.

Table of Contents

List of Tables

List of Figures

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Chapter 1

INTRODUCTION

Landfilling is the most common method of solid waste disposal. Leachate is generated when liquid percolates through solid wastes, that are undergoing decomposition, and extracts both biological materials and chemical compounds. Landfill leachate can be a significant source of pollution to the receiving water.

The concentration range of the various compounds in the leachate depends on the age and geological base of the landfill. Leachates from newer landfills are characterized by low pH, high COD and high BOD_5, high BOD_5/COD ratio, low ammonia-N concentration and high metal concentration (*Chian, et al., 1985*). In older landfills, such as Burns Bog in Vancouver (operation was initiated in 1966), the leachate is characterized by a near neutral pH, low COD and BOD_5, low BOD_5/COD ratio, high ammonia-N concentration and low metal concentration.

High concentration of ammonia-N and its oxidized forms, nitrate and nitrite, have been recognized as being potentially detrimental to receiving water systems. High levels of ammonia-N can cause adverse effects on public health, and can contribute to aquatic toxicity, dissolved oxygen depletion, nitrate and nitrite contamination, and eutrophication. N-Nitroso- (NNO-) compounds, readily formed from nitrite, amines or amides, are found to be strong carcinogens (*Mirvish, 1977*). Nitrates in water supplies in concentrations over 45 mg/l (as NO_3^-) have led to numerous cases of infant methomoglobinemia (*Shuval and Gruener, 1977*).

Nitrogen removal from landfill leachate before discharging into the receiving waters has been recognized as essential for minimizing the negative impacts on the aquatic environment. The single-sludge, biological pre-denitrification (i.e. denitrification being carried out before nitrification) completely-mixed, activated sludge system (known as the Modified Ludzack-Ettinger (MLE) system), has proved to be an efficient method for nitrogen removal. In this process, ammonia-N is oxidized to nitrite and further to nitrate by nitrifying bacteria. The sludge, which contains high nitrate, is recycled back to the anoxic reactor where it is reduced to nitrogen gas by denitrifying bacteria. Nitrogen gas is considered to be harmless to the environment. Figure 1.1 presents the biological reaction sequence involved in the MLE process which used in this project.

Nitrifying bacteria, primarily *Nitrosomonas* and *Nitrobacter* are autotrophic bacteria. They utilize inorganic compounds such as ammonia and nitrite as their source of energy and carbon dioxide as their principal source of carbon. Oxygen serves as the final electron acceptor. *Nitrosomonas* can only oxidize ammonia to nitrite and *Nitrobacter* can only oxidize nitrite to nitrate.

During the process of nitrification, alkalinity is consumed. When synthesis is omitted, for every mg of ammonia nitrogen being oxidized, 7.16 mg alkalinity is destroyed (*U.S.E.P.A.*, 1975). Because of the reduction of alkalinity, the pH value is correspondingly reduced.

By assuming that the empirical formulation of bacterial cell is $C_5H_7NO_2$, the synthesis-oxidation for *Nitrosomonas* and *Nitrobacter* can be expressed by the following equations (*U.S.EPA*, 1975):

Nitrosomonas Synthesis:

$$55NH_4^+ + 76O_2 + 109HCO_3^- \longrightarrow C_5H_7NO_2 + 54NO_2^- + 57H_2O + 104H_2CO_3 \quad (1.1)$$

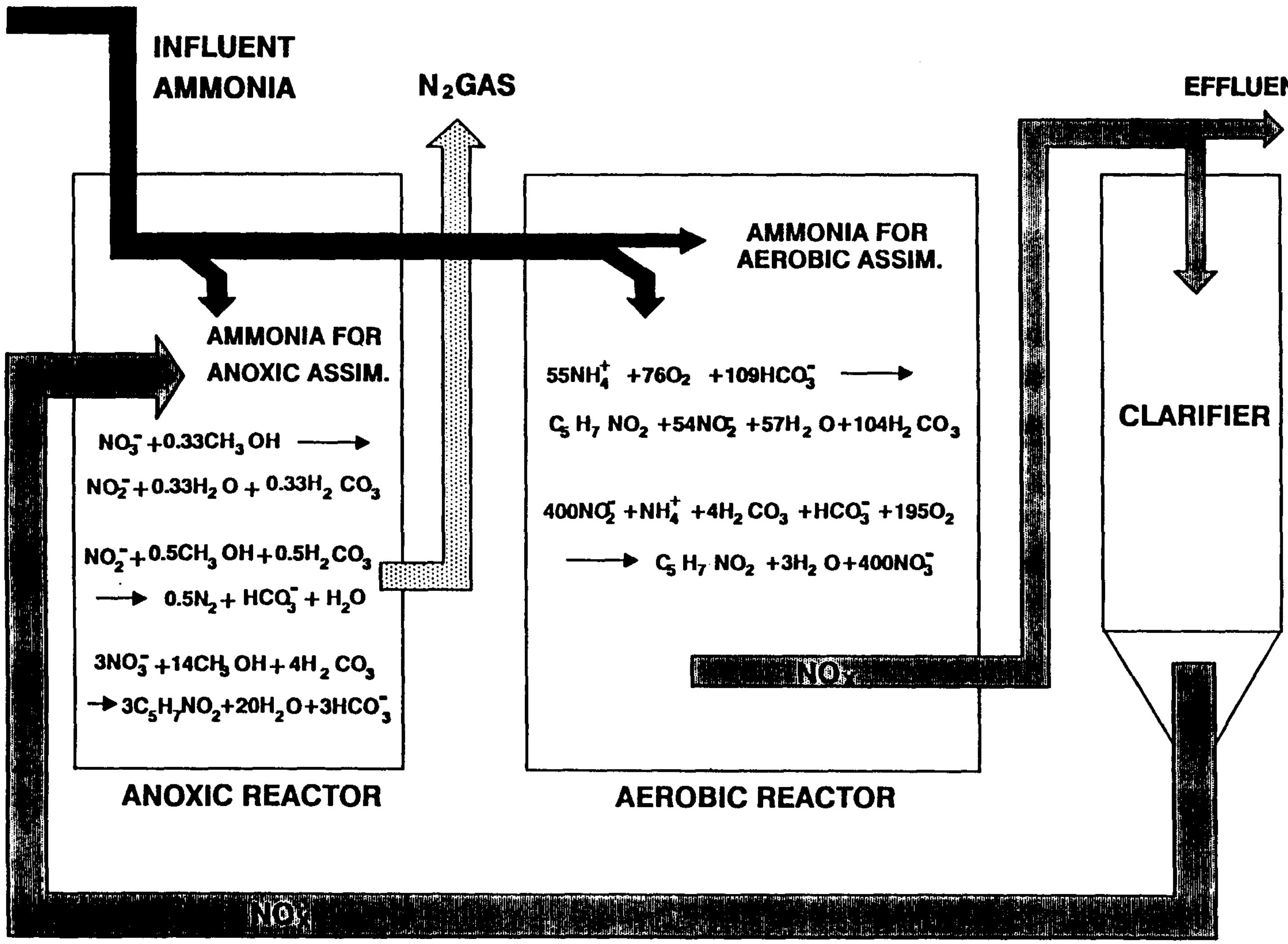


Figure 1.1: Nitrogen Removal Process Schematic

Nitrobacter Synthesis:

$$400NO_2^- + NH_4^+ + 4H_2CO_3 + HCO_3^- + 195O_2 \longrightarrow C_5H_7NO_2 + 3H_2O + 400NO_3^- \quad (1.2)$$

Yields for *Nitrosomonas* and *Nitrobacter* are 0.11 mg cells/mg NH_4^+-N and 0.02 mg cells/mg NO_2^--N, respectively (which are low relative to heterotrophic growth).

The denitrifying bacteria, including *Pseudomonas*, *Micrococcus*, *Archromobacter bacillus* and *Thiobacillus*, are facultative heterotrophic bacteria. They utilize organic carbon as their carbon source, and nitrate, nitrite or oxygen as their final electron acceptor. Since the denitrifying bacteria will utilize oxygen before nitrate and nitrite, the denitrification process must take place in an anoxic environment, to ensure that nitrate and nitrite are utilized.

In contrast to nitrification, denitrification produces alkalinity. As noted by in *U.S.EPA* (1975), 3.0 mg alkalinity as $CaCO_3$ is produced per mg nitrogen reduced. Therefore, there is a tendency for pH to increase during denitrification.

When methanol is utilized as the electron donor, the biological pathway involved in the denitrification process can be expressed by the following equations (*U.S.EPA*, 1975):

Reduction of Nitrate to Nitrite:

$$NO_3^- + 0.33CH_3OH \longrightarrow NO_2^- + 0.33H_2CO_3 + 0.33H_2O \quad (1.3)$$

Reduction of Nitrite to Nitrogen Gas:

$$NO_2^- + 0.5CH_3OH + 0.5H_2CO_3 \longrightarrow 0.5N_2 + HCO_3^- + H_2O \quad (1.4)$$

Denitrifiers Synthesis:

$$3NO_3^- + 14CH_3OH + 4H_2CO_3 \longrightarrow 3C_5H_7NO_2 + 3HCO_3^- + 20H_2O \quad (1.5)$$

Numerous studies on biological leachate treatment have been carried out so far, mostly at room temperature (approximately 20°C). However, the temperature of the leachate generated in North America during winter is often much lower. Temperature has a significant effect on the growth of microorganisms, including nitrifying bacteria and denitrifying bacteria. Therefore, the objective of this investigation was to study the effect of temperature on nitrification and denitrification of a high ammonia municipal landfill leachate in an MLE process, and to optimize the control for the treatment by adjusting methanol addition and utilizing different aerobic SRTs. Burns Bog landfill leachate (a landfill near Vancouver, B.C.) was used as the waste for this project. The lab scale experiment lasted 319 days. Temperatures investigated were 20°C, 12°C and 4°C, in succession, under various experimental conditions.

Chapter 2

BACKGROUND AND PREVIOUS STUDIES

This chapter provides an introduction to landfill leachates and a brief literature review on the methods of leachate treatment, particularly those studies involving biological nitrogen removal at low temperatures. The information collected is summarized below.

2.1 Leachate

Sanitary landfilling has become a principal means of municipal solid wastes disposal. It is an economical method of solid waste disposal when compared with other methods. In addition, submarginal land may be reclaimed for use as parking lots, playgrounds, golf courses, airports, etc. However, one of the major problems is caused by the leaching of the fill materials.

2.1.1 Leachate Generation

Refuse landfills receive a full spectrum of solid waste residues produced by highly developed and industrialized metropolitan areas(*Atwater, 1980*). This multiplicity of solid wastes can undergo a complex mix of biological, physical and chemical decomposition processes and interactions. With rainfall infiltration, ground water intrusion or other means of liquid application, leachate is generated. It has been estimated that, for each tonne of solid wastes landfilled, five to ten kilograms of solids will be leached out(*Atwater, 1980*).

2.1.2 Characteristics of Leachate

The composition of landfill leachates depends on the characteristics of the solid wastes, the site temperature, pH, moisture content, age and geometry of the fill, the characteristics of water intruding the fill, and the type of soil adjoining the fill(*Chian and Dewalle, 1977*; *Atwater and Mavinic, 1986*). Common inorganic constituents of leachate include ammonia nitrogen, phosphorus, bicarbonates, calcium, magnesium, potassium, sodium, chloride, sulfate, iron, copper, nickel, chromium, zinc, etc(*Tchobanoglous et al, 1977; Atwater and Mavinic, 1986*).

Chian et al(1985) classified five stages of biological degradation of the wastes in a landfill. The first stage is a short aerobic decomposition phase, which may last from one to six months, depending on the amount of air trapped within the refuse. The second stage, when oxygen is depleted, involves a transition from an aerobic to anoxic/aerobic microbial population. During this process, nitrates or sulfates are utilized instead of oxygen. The third or acid formation stage includes the degradation of organic material into volatile fatty acids by facultative anaerobes. The leachate produced during this stage is therefore characterized by low pH, high BOD_5 and COD, high BOD_5/COD ratio, high ammonia-N and high metal concentrations; thus, is classified as the leachate from a newer landfill. During the fourth stage, methanogenic bacteria utilize the volatile fatty acids to form methane and carbon dioxide. During the period of anaerobic activity, ammonia-N is released as a byproduct (converted from organic nitrogen). This is one reason that "older" landfill leachate contains high ammonia-N concentration(*Henry, 1985*). The final stage involves very little biological activity as the biodegradable material and nutrients have been exhausted.

The major concern for an old landfill leachate is ammonia-N. Ammonia-N concentrations of landfill leachate have been reported at 200-600 mg/l by *Knox (1985)*, 350-390 mg/l by *Maris, et al (1985)*, 790 mg/l by *Robinson and Maris (1985)* and 120 mg/l by *Liu, et al, (1991)*. Ammonia-N concentrations in the Vancouver area leachate are about 26-244 mg/l for the Port Mann landfill leachate(*Atwater and Mavinic, 1986*) and 85-320 mg/l for Burns Bog landfill leachate employed in this project.

2.1.3 High Ammonia Problem

Ammonia can be toxic to fish and aquatic life. *U.S. EPA (1976)* has set the un-ionized ammonia criteria of 0.02 mg/l as a safe water system for aquatic life. High concentration of ammonia-N can cause the dissolved oxygen depletion and eutrophication in natural water systems. The oxidized forms of ammonia-N, nitrite and nitrate, are reported to be related to the causation of infant methomoglobinemia(*Shuval and Gruener, 1977*), formation of carcinogenic compounds and increased risk of gastric cancer(*Mirvish, 1977*).

2.2 Methods of Leachate Treatment

Many studies on leachate nitrogen removal have been undertaken. The methods being used include physical-chemical process, recirculation, irrigation, bacterial assimilation and biological nitrification and denitrification. The last method is most widely used and will be discussed in a separate section (see section 2.3)

2.2.1 Physical-Chemical Treatment

Physical-chemical treatment of leachate includes chemical precipitation and coagulation, chemical oxidation, activated carbon adsorption, air stripping, pH adjustment, ion exchange, and, membrane separation. The advantages of this method are short time for start-up, relative insensitivity to temperature(except air stripping) and the potential for automation(*Forgie, 1988*). However, there are problems such as high cost, inconsistent performance etc.. These problems have limited the wide use of physical-chemical processes (*Metcalf & Eddy, 1991*). *Ehrig (1985)*, after investigating several different physical-chemical methods treating leachates, concluded that it is not possible to substitute the physical-chemical treatment for the biological process.

2.2.2 Recirculation

Leachate recirculation is performed by spraying onto the exposed surface of the landfill or by distribution through perforated pipes beneath the surface of the landfill. This method can offer benefits in reducing the volume (through evaporation) and strength of leachate. However, it cannot be considered to be a complete answer to surface leachate discharges. The most effective option, perhaps, is to combine recirculation together with further aerobic biological treatment(*Robinson and Maris, 1985*). *Lee et al (1986)* suggested that recirculation could reduce contaminants to some extent and provide the same function as a separate biological treatment step.

2.2.3 Irrigation

Irrigation of plants using leachate has not been widely used as a means of treatment or disposal. *Menser (1981)*, after studying irrigation of landfill leachate, suggested that some type of pre-treatment may be needed for successful irrigation with leachate.

2.2.4 Bacterial Assimilation

This process involves the nitrogen being removed as a nutrient source for bacterial synthesis. However, this method requires a high supply of biodegradable organic carbon to be provided for the growth of bacteria; thus, is not suitable for treating an older type of landfill leachate, in which a large portion of organic material consists of relatively refractory compounds(*Robinson and Maris, 1985*). If this method is used, an external supply of carbon must be supplied (with a ratio of BOD_5:N > 20:1) to implement effective nitrogen removal via assimilation.

2.3 Biological Nitrification and Denitrification

During the nitrification process ammonia nitrogen is converted to nitrite and hence to nitrate by nitrifying bacteria. During the denitrifying process nitrite and nitrate are converted to nitrogen gas by denitrifying bacteria.

2.3.1 Nitrifying and Denitrifying Bacteria

Nitrifiers grow over a wide temperature range, 4°C to 45°C, with optima at about 35°C for *Nitrosomonas* (*Buswell et al., 1954*) and 35°C to 42°C for *Nitrobacter* (*Nelson, 1931*). The pH range of the growth of these bacteria are pH 6 - 10, with best growth between pH 7 - 8 (*Painter, 1977*). The maximum possible growth rate, μ_n, for nitrifiers was reported to be 0.465 day^{-1} at a temperature of 20°C, whereas, at a temperature of 10°C, it was only 0.175 day^{-1} (*U.S. EPA, 1975*). Dissolved oxygen concentrations of above 2 mg/l are essential for nitrification to occur (*Metcalf & Eddy Inc., 1991*).

The growth of *Thiobacillus Denitrificans* was found to have an optimum temperature of 28°C to 32°C and an optimum pH value of 6.8 to 7.4 (*Staley et al, 1989*). As reported by *Delwiche (1956)*, at 5°C, *Pseudomonas Denitrificans* reduced nitrate at about one tenth of the rate as at 27°C. Denitrification rates can be up to 0.36 lb NO_3^--N rem./lb MLVSS/day at a temperature of 20°C, whereas at a temperature of 10°C, it might be only 0.10 lb NO_3^--N rem./lb MLVSS/day (*U.S. EPA, 1975*).

2.3.2 Previous Studies

Oleszkiewicz and Berquist (1988), while studying low temperature biological nitrogen removal from a composition of sewage and pharmaceutical wastes using sequencing batch reactors, reported that nitrification was feasible at temperature of as low as 2^oC.

Antoniou et al (1990), while studying nitrification in wastewater treatment process, observed that the optimum pH for nitrification was approximately pH 7.8. The maximum specific growth rate was found to be a monotonically increasing function of temperature in the range of 15°C to 25°C.

Keenan et al (1984) studied a full scale leachate treatment plant and observed that the cold winter temperatures inhibited the biochemical oxidation of ammonia-N, resulting in severe operating problems.

Dedhar (1985) studied ammonia-N removal from a landfill leachate by using a continuous-feed, single sludge pre-denitrification system at room temperature (glucose was added to the anoxic reactor as the carbon source for the denitrifiers). One hundred percent of ammonia-N removal was achieved. The percentage denitrification was observed to vary with the variant carbon loading in the anoxic reactor.

Carley (1988), investigated the effects of excess carbon in the anoxic reactor using a single-sludge pre-denitrification system (at room temperature) with recycle for nitrogen removal from a landfill leachate. Different carbon sources: acetate, methanol, yeast waste and glucose were applied for comparison. He concluded that methanol and acetate were the most efficient and trouble-free carbon sources for denitrification. Methanol addition, as a ratio of COD to NO_x produced, was found to be 6.2:1, when complete denitrification was achieved.

Robinson and Maris (1985) studied aerobic biological leachate treatment and found that the treatment was retarded by the low phosphorus concentration in leachate. They stated that addition of phosphorus nutrient was necessary. They also reported that successful nitrification of ammonia-N in leachate at full-scale would clearly require a high degree of control, particularly at low temperatures of 10°C and below. It was concluded that, at 10°C, with addition of phosphorus, aerobic SRT values of greater than 10 days were required.

Elefsiniotis et al (1989), while studying the effects of sludge recycle ratio on nitrification and denitrification in treatment of a high ammonia-N (200-600 mg/l), low biodegradable carbon landfill leachate (using a single-sludge pre-denitrification process), observed that a recycle ratio of 6:1 was optimum for the process. A higher recycle ratio resulted in very unstable performances of nitrification and denitrification.

Atwater and Mavinic (1986), while studying influent constraints on the treatment of leachate, using the same single-sludge pre-denitrification process, stated that an aerobic SRT of less than 20 days produced inadequate (effluent ammonia-N was beyond 10 mgN/l) treatment at room temperature.

The above selected literatures reviews represent a brief overview of high ammonia-N leachate treatment, and the problems caused by temperature, carbon, phosphorus, SRT etc. This information served as incentive to further investigate high ammonia-N leachate treatment by using the biological pre-denitrification process at low temperatures.

Chapter 3

EXPERIMENTAL SETUP AND OPERATION

Two identical, bench-scale, single sludge, biological pre-denitrification systems, with sludge recycle, were used during this study. The treatment schematic is presented in Figure 3.1. One system operated at the aerobic sludge ages of 20 days and 60 days and one system operated at 20 days, 30 days and 40 days.

3.1 Leachate

The leachate sample used in this project was taken from the City of Vancouver's Burns Bog Landfill in Delta, British Columbia. Initially started in 1966, this leachate can be classified as an older leachate. The leachate was taken, once a month, from a well (adjacent to a drainage ditch, surrounding the landfill), which is located in the south-west corner of the fill (see Figure 3.2) and stored in a refrigerate chamber at 4°C until required. The average ammonia-N concentration of the leachate was around 210 mg/l, with the highest value of 320 mg/l happening in Autumn 1990 and the lowest value of 85 mg/l happening during early Spring 1991, when more precipitation occurred. The BOD_5 level in the leachate was quite low (averaged 35 mg/l). The basic characteristics of the leachate are presented in Table 3.1.

The leachate was continuously added to the anoxic reactors at a rate of about 10 liters per day from a continuously-stirred, plastic container. To prevent changing in the characteristics of the leachate by excess aeration, the container was covered with a lid. An aliquot of feed, was taken every other day from the 4°C refrigerated chamber to the

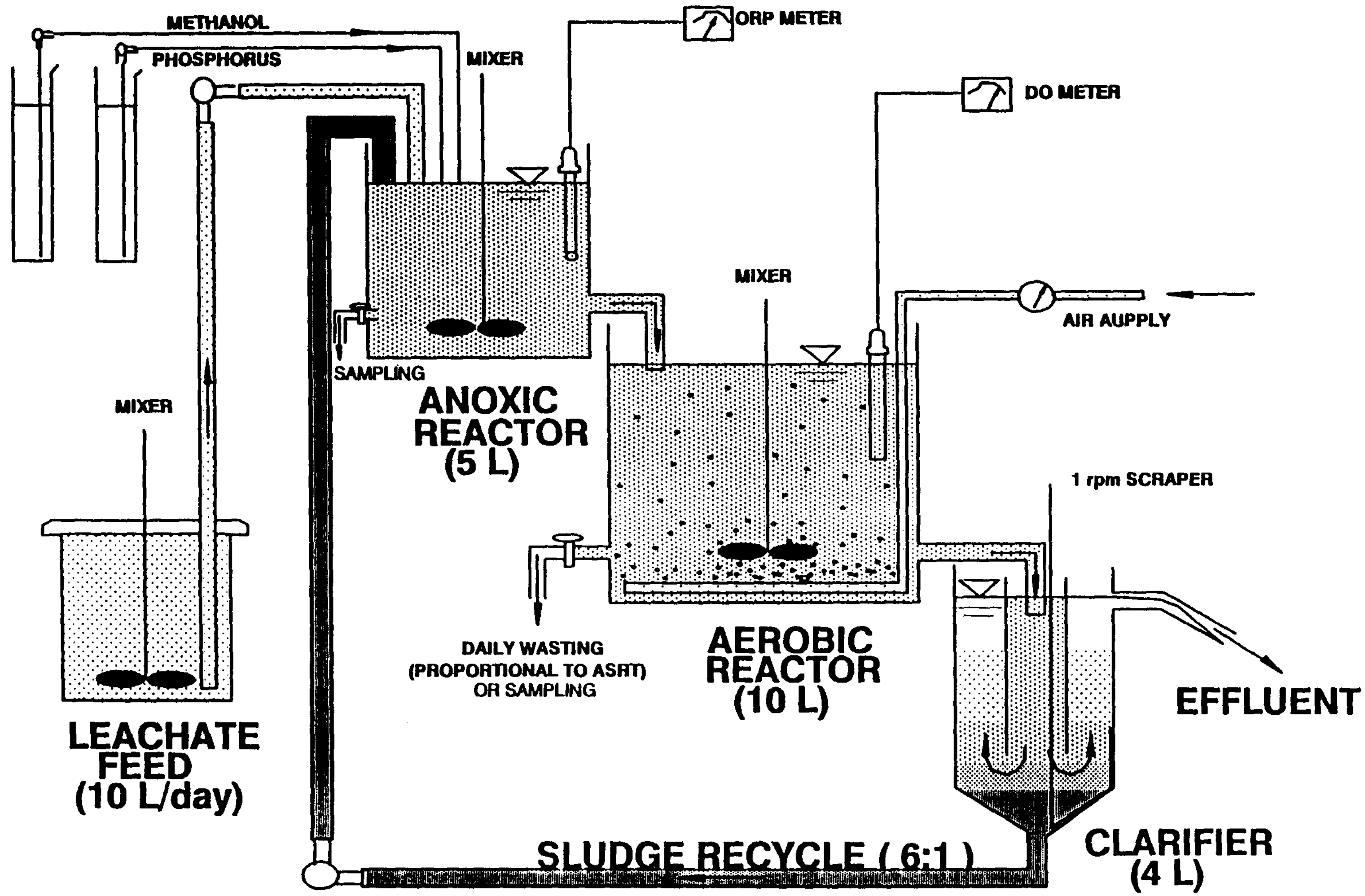


Figure 3.1: Laboratory Biological Leachate Treatment Schematic

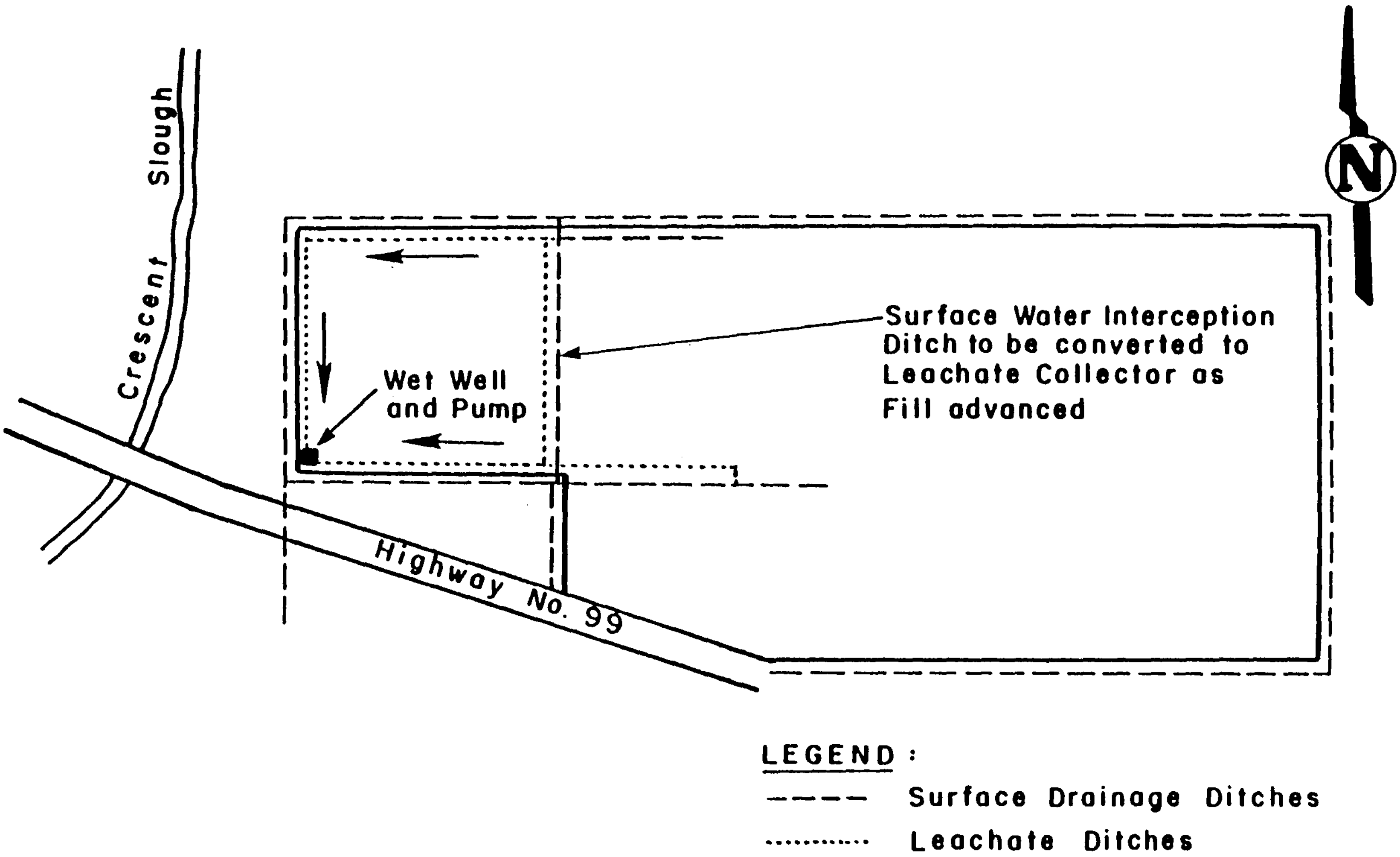


Figure 3.2: Burns Bog Landfill Site (ref: *Atwater, 1980*)

Table 3.1: Basic Characteristic of Burns Bog Leachate

Item	*Concentration (mg/l)*	
	Range	*Mean*
COD	260-565	400
BOD_5	15-55	35
Ammonia-N	85-320	210
Nitrate+Nitrite (NO_x^--N)	0-1.9	0.61
Nitrite (NO_2^--N)	0-0.33	0.18
Ortho-P	0.05-1.6	0.40
TKN[1]	97-350	196
TP	0-2.5	0.17
TSS	18-185	73
VSS	13-115	39
Zn	0-0.11	0.04
Cu	0-0.71	0.13
Alkalinity, as $CaCO_3$ [2]	1240-1920	1560
Conductivity (μS/cm)	2779-6158	4626
pH	7.02-7.65	7.40

[1] Because of instrument problems, the TKN value was generally lower than ammonia-N (thus being used as a reference only).

[2] *Mavinic and Randall, 1989.*

container, allowing the leachate feed to acclimate to the lab temperature before addition to the systems.

3.2 Chemical Addition

Methanol (CH_3OH) and tribasic sodium phosphate($Na_3PO_4 12H_2O$) were applied as the nutrients. They were added to the anoxic reactors of both systems. The concentration of the methanol solution prepared was 50 mg/l, whereas that of phosphate was adjusted according to the flow rates. The chemical addition was checked and adjusted every day. However, since the pumps were not stable, the flow rates were not able to be controlled at a same rate every day. Figure 3.3 and 3.4 illustrate the addition of methanol and ortho-P as a function of time.

3.3 Anoxic Reactor

The primary purpose of the anoxic reactor was to denitrify the highly nitrified return sludge from the clarifier. The reactor, a plastic cylindrical tank, had a liquid volume of 5 liters. It was fed continuously with leachate feed, return sludge, methanol, and ortho-P solution. A stir was installed for complete mixing in the reactor. The mixing speed was controlled between 30 and 50 rpm, in order to avoid excess oxygen intruding into the reactor. An ORP probe was submersed in the reactor for the observation of redox potential in the anoxic reactor.

3.4 Aerobic Reactor

The primary purpose of the aerobic reactor (10 liter size) was to nitrify the high ammonia-N content of the leachate. The mixed liquor from the anoxic reactor hydraulically entered the completely mixed aerobic reactor by gravity. In an attempt to provide sufficient

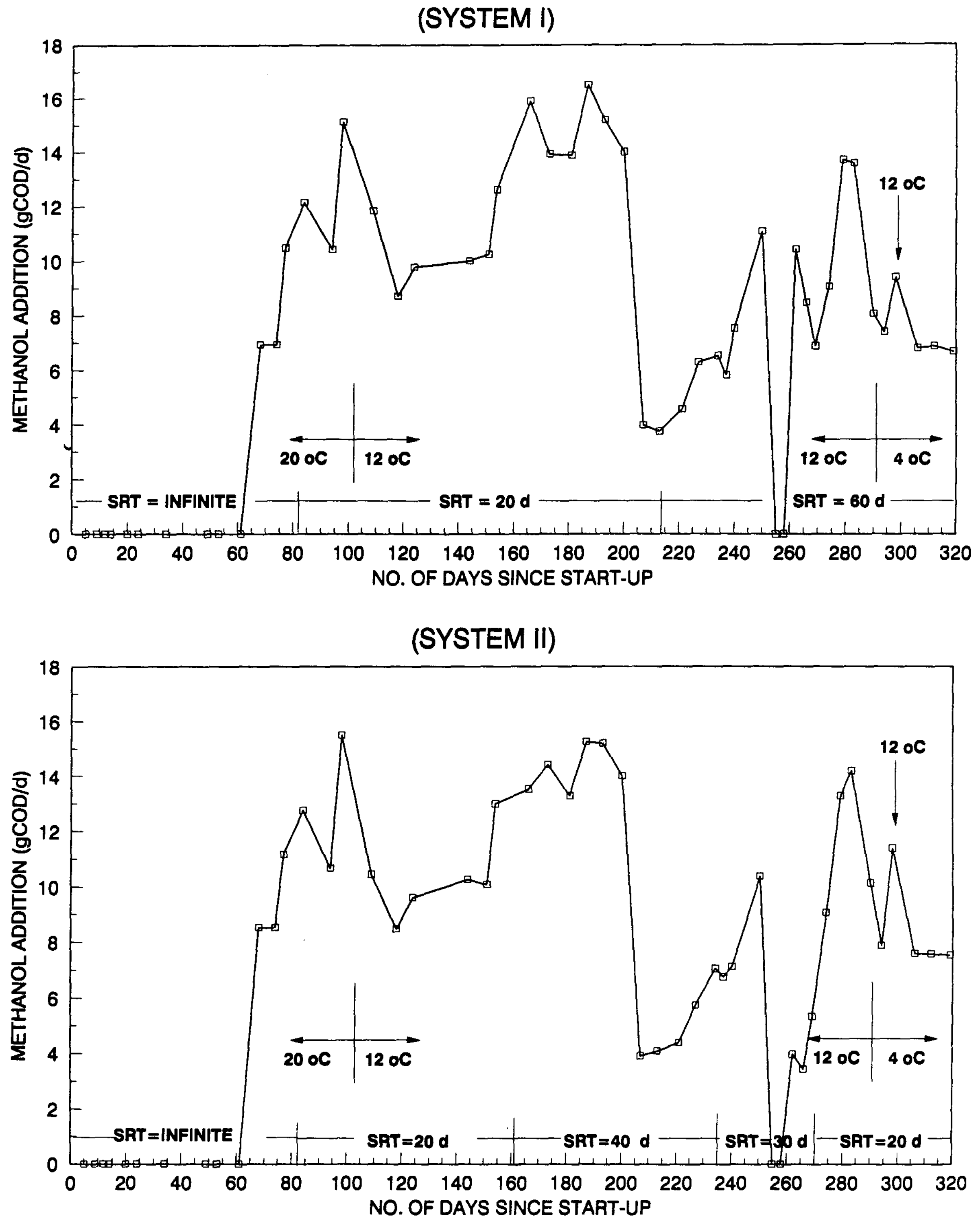


Figure 3.3: Methanol Addition vs. Time

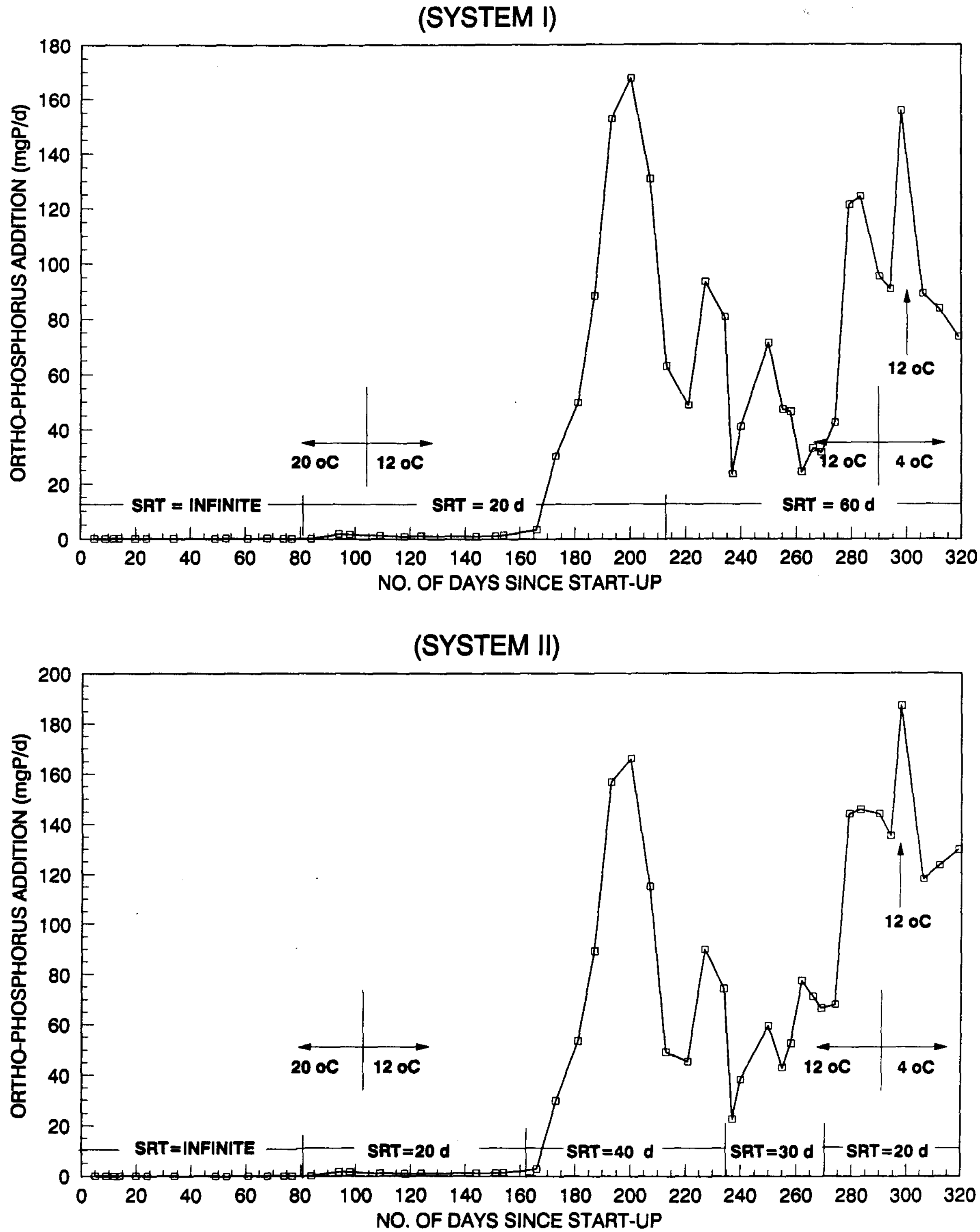


Figure 3.4: Ortho-phosphorus Addition vs. Time

oxygen for the nitrifying bacteria, the reactor was aerated by means of compressed air, which was passed through a perforated tubing diffuser fitted to the bottom of the tank. A stir was installed for completely mixing. A DO probe was submersed in the mixed liquor constantly. The air supply flow was adjusted in order to maintain the dissolved oxygen concentration in the reactor at levels above 2 mg/l to avoid depressing effects of low DO on the rate of nitrification. To achieve the selected sludge age or Solids Retention Time (SRT) of the systems, wasting was performed daily directly from the aerobic reactor.

3.5 Clarifier

The mixed liquor from the aerobic reactor flowed by gravity into a 4-liter conical plexiglass clarifier, where the solids were settled by gravity; the supernatant flowed to the drainage system. The settled and thickened solids at the bottom were recycled to the anoxic reactor. The ratio of returned sludge flow to the leachate feed flow was 6:1. To clear the recycle line from blockage as well as provide proper volumetric throughput, the recycle pumps were operated on a cycle of two minutes off and two minutes on. A 1 rpm scraper mechanism was installed to prevent the settling sludge from adhering to the side walls of the clarifier.

3.6 Basic Operation

The basic operating conditions for two systems are presented in Table 3.2. The operation commenced on July 20, 1990 and lasted for 319 days. Each reactor was filled with sewage sludge seed taken from the University of British Colombia mobile sewage treatment pilot plant. Both systems were operated at an infinite theoretical aerobic Solids Retention Time (SRT) until day 82, when complete nitrification of the leachate was established. Daily wasting of 500 ml mixed liquor was started on that day, in order to reach an ASRT

Table 3.2: Basic Operating Conditions

Day Started	*Temperature* ^oC	*SRTs System I* *Days*		*SRTs System II* *Days*	
		ASRT [1]	*Mean SSRT* [2]	*ASRT*	*Mean SSRT*
0	20	infinite	37	infinite	62
82	20	20	17	20	13
104	12	20	17	20	22
162	12	20	17	40	17
213	12	60	12	40	17
235	12	60	12	30	13
270	12	60	12	20	18
298	4	60	29	20	18

[1] ASRT = Theoretical Aerobic Solids Retention Time

$$= \frac{\text{Mass volatile susp.solids in the aerobic reactor}}{\text{Mass volatile susp. solids wasted daily from the reactor}}$$

[2] SSRT = System Solids Retention Time

$$= \frac{\text{Total mass volatile susp. solids in the system}}{\text{Total mass volatile susp. solids wasted from the system}}$$

of 20 days.

As shown in Table 3.2, the successive temperatures studied were 20°C, 12°C and 4°C. At a temperature of 20°C, a ASRT of 20 days was studied; at 12°C, ASRTs of 60, 40, 30, and 20 days were studied; and, at 4°C, ASRTs of 60 and 20 days were studied. In system I, the ASRT of 60 days started on day 213, and continued until the end of the project. In system II, the ASRT of 40 days started on day 162, the ASRT of 30 days started on day 235 and the ASRT of 20 days started on day 270.

Since the volume of the whole system was about 19.5 L, almost twice as much as the aerobic reactor, ideally, the system solids retention time (SSRT) should be almost twice as much as ASRT. However, because of a significant amount of solids loss from the clarifier effluent, the SSRT was not proportional to ASRT. It varied with the solids loss from both aerobic waste line and the effluent. As shown on Table 3.2, SSRT was close to ASRT when aerobic SRT was set at 20 days. At higher ASRT, SSRT was more dependent on the effluent VSS, which will be discussed later.

The effect of methanol and ortho-P addition on the treatment systems was also studied. In order to encourage the nitrifying bacteria to acclimate to the 12°C temperature, on day 199, methanol addition was reduced from 14 gCOD/d to 4 gCOD/d. On day 253, in an attempt to see how the methanol addition affected the system, both systems operated without methanol feed for 7 days. Ortho-P dosage remained at around 1 mgP/d until day 116, when it was increased to 3.3 mgP/d and then gradually further increased to 167 mgP/d by day 200.

On day 294, after first sampling at 4°C, the laboratory power supply system failed. The ambient temperature rose to 23°C. One day later, a temporary power supply was connected to support the system operation. However, the cooling system still did not work. On day 297, the breakdown was fixed and the temperature was adjusted at 12°C. On day 298, after sampling, the ambient temperature was reduced back to 4°C.

Chapter 4

ANALYTICAL METHODS

4.1 Introduction

This chapter describes the parameters used for data analysis and the methods of their physical or chemical determination.

Samples were taken once for every four or five days. Seven samples were taken at once from one influent line (leachate feed), each of the two anoxic reactors, aerobic reactors and clarifier effluents. Anoxic and aerobic samples were taken from the waste lines. A small volume of sludge, which was sitting at the valve, was flushed back to the reactor before taking the sample.

The concentrations of NH_3, NO_x^-, NO_2^-, PO_4^{3-}, TKN and TP were measured by colorimetric methods. Two instruments were used for the analysis of NH_3, NO_x^- and NO_2^- in two different stages of the research: before day 124, Technicon Autoanalyzer II and after day 124, QuikChem Automated Ion Analyzer. Since both are based on colorimetric principles, these two instruments made no difference in the analysis of the same sample, except that the new one had a higher accuracy. TKN and TP were analyzed by the Technicon Autoanalyzer II throughout the entire project.

The concentrations of NH_3, NO_x^-, NO_2^-, and TKN used in this research were all expressed as mg/l of nitrogen. The concentrations of PO_4^{3-} and TP used in this research were all expressed as mg/l of phosphorus.

4.2 Oxidation-Reduction Potential (ORP)

ORP was measured using a Cole-Parmer Chemicadet pH meter connected to a Broadlley James Corporation ORP Electrode. It is a combination electrode with a Ag-AgCl type probe, which utilized a 3.8 M KCl electrolyte salt bridge and platinum (Pt) band electrode built into one electrode body. The pH meter was set to the millivolt scale. An ORP probe was submersed in each anoxic reactor of the two systems. The ORP value was recorded daily in order to observe changes in the redox potential and denitrification conditions.

4.3 Dissolved Oxygen (DO)

The DO value was determined by a Yellow Spring Instrument Co. Model 54A Dissolved Oxygen meter with a Yellow Spring Instrument 5739 submersible DO probe. The membrane of the probe was changed biweekly and calibrated using the air calibration method (*Instruction Manual YSI Models 54 ARC and 54 ABP Dissolved Oxygen Meter*). The DO probe was submersed in the aerobic reactor. A DO reading was taken daily, in order to ensure that sufficient DO (more than 2 mg/l) was for nitrification and carbon oxidation.

4.4 pH

The pH value was measured using a Beckman pH meter connected with a Fisher combination electrode, using an Ag-AgCl reference element. The probe was calibrated with standard buffer each time before using. The pH value was recorded twice a week.

4.5 Conductivity

A conductivity meter type CDM3 was used to measure the conductivity of the landfill leachate sample. Readings were as $\mu S/cm$.

4.6 Temperature

The whole research system was maintained in a controlled temperature room in order to maintain a given constant ambient temperature.

4.7 Solids

4.7.1 Total Suspended Solids(TSS)

The TSS analysis consisted of vacuum filtration of a certain volume of sample through a preweighed filter paper and oven drying both paper and sample overnight at 104°C; cooling and weighing were performed in accordance with Standard Methods (*A.P.H.A. et al, 1989*). The filter paper was prewashed and prefired at 550°C before using.

4.7.2 Volatile Suspended Solids (VSS)

The VSS were measured by heating the solids obtained in the previous section at 550°C for 90 minutes, and then operating in a similar way according to Standard Methods (*A.P.H.A. et al, 1989*).

4.8 Chemical Oxygen Demand (COD)

The unfiltered COD was measured. The sample was preserved with concentrated sulphuric acid ($pH < 2.0$) and stored in a refrigerated chamber at 4°C. COD samples were taken once every four to five days and analyzed using the Closed Reflux Titrimetric Method, following the instruction outlined in Standard Methods (*A.P.H.A. et al., 1980*).

4.9 Biochemical Oxygen Demand (BOD_5)

Unfiltered BOD_5 samples were taken once every four to five days commencing on day 207. They were analyzed in accordance with Standard Methods (*A.P.H.A. et al., 1989*). The initial and final dissolved oxygen reading were obtained using a Yellow Springs Instrument Co. Dissolved Oxygen meter, Model 54, with a self-mixing membrane covered probe. The meter was calibrated using the azide modification titration method as described in Standard Methods (*A.P.H.A. et al., 1989*).

4.10 Ammonia-N

Two instruments were involved in the analysis of ammonia-N.

Before day 124, a Technicon Autoanalyzer II, Colorimeter was used in accordance with the directions outlined in the accompanying manual (*U.S. EPA, 1979*). The samples were filtered with Whatman #4 filter paper and preserved with one drop of concentrated sulphuric acid and stored at 4°C.

Starting on day 124, a Lachat Quikchem Automated Ion Analyzer was used in accordance with the *Methods Manual for the QuikChem Automated Ion Analyzer (1987).* The samples were membrane filtered and preserved with one drop of concentrated sulphuric acid.

4.11 Nitrate and Nitrite (NO_x^-)

Before day 124, NO_x^- was measured on a Technicon Autoanalyzer II, following the instruction of the *Technicon Industrial Methods No. 100-70W (1973).* In the process, nitrate is reduced to nitrite by a copper-cadmium reduction method. The sample was membrane filtered, preserved with one drop of mercuric acid and stored at 4°C.

Starting on day 124, a Lachat QuikChem Automated Ion Analyzer was used. The sample was membrane filtered and preserved with one drop of concentrated sulphuric acid.

4.12 Nitrite (NO_2^-)

The analytical method and the chemical used were identical to those utilized in measuring NO_x^-, except that the copper-cadmium reductor column was not used. The analysis was also performed using a Technicon Autoanalyzer II during first half period of this project and a Lachat QuikChem Automated Ion Analyzer after day 124.

4.13 Total Kjeldahl Nitrogen (TKN)

The sample was first digested in a Technicon Block Digester BD40. The digestion was done following the instructions of the *Technicon Block Industrial Method No. 376-75W(1975)*. The digested sample was analyzed in accordance with the *Technicon Methodology No. 329-74W (1975)*. Because of questionable accuracy of the instrumental analysis (unfiltered TKN concentration was frequently lower than filtered ammonia-N concentration, which was unreasonable), the TKN data were not used for discussion.

4.14 Ortho-phosphate

Before day 124, a Technicon Autoanalyzer II was used . The analytical procedure was conducted following the instructions in *Technicon Industrial Method No. 94-70W (1973)*. The sample was membrane filtered and preserved with one drop of phenyl mercuric acetate.

Starting on day 124, a Lachat QuikChem Automated Ion Analyzer was used. The analytical procedure was performed according to the *Operating Manual for the QuikChem Automated Ion Analyzer (1990)*. The sample was membrane filtered, preserved with one drop of concentrated sulphuric acid and stored at 4°C.

4.15 Total Phosphorus (TP)

The sample was digested in a Technicon Block Digester BD40 following the instructions in *Technicon Block Industrial Method No. 376-75W (1975)*. The digested sample was analyzed using the Technicon Autoanalyzer II, in accordance with *Technicon Industrial Method No. 327-74W (1974)*. The principle behind this measurement is similar to that of ortho-phosphate measurement.

4.16 Metals

Since metal effects were not a main objective to be studied in this research (in addition, the metal concentration was very low to begin with), only the dissolved zinc and copper of the leachate were monitored. The sample was filtered with Whatman #541 filter paper, which was prewashed with 0.1 N nitric acid, and digested using nitric acid in accordance with *Standard Methods (1989)*. Zinc and copper concentrations were determined by Flame Atomic Absorption Spectro(photo)metry, using a Thermo Jarrell Ash Video 22 instrument , following the instructions provided in Atomic Absorption Methods Manual.

4.17 Alkalinity

According to the results measured by previous researchers (*Mavinic and Randall, 1989*), alkalinity in Burns Bog's landfill leachate was enough (average 1560 mg/l) for nitrification; thus it was not monitored regularly in this research.

Chapter 5

RESULTS AND DISCUSSION

This chapter deals with the results obtained from the Modified Ludzack-Ettinger process. Two sets of continuous, single-sludge, pre-denitrification systems were operated with a sludge recycle ratio of 6:1. In system I, ASRTs of 20 and 60 days were applied. In system II, ASRTs of 20, 30 and 40 days were applied. Both systems were operated at ambient temperature of 20°C, 12°C, and 4°C. The effects of different dosages of methanol and ortho-P were investigated. The raw data and basic results are illustrated in Appendix D and E.

Data were analyzed on an IBM personal computer using Lotus 123 Release 3 software. The graphs were drawn using a Freelance program.

5.1 Oxidation-Reduction Potential (ORP)

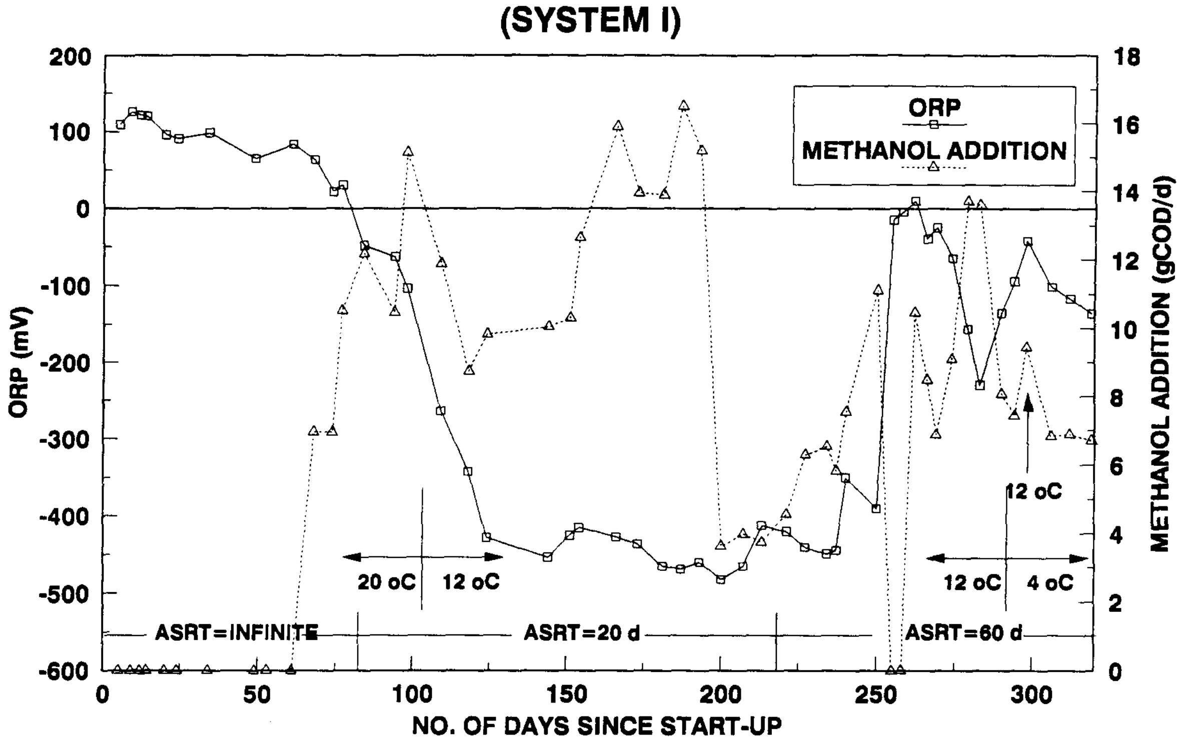
The value of ORP depends on the type of probe and the method of calibration. In this project, two Ag-AgCl type electrodes were utilized as ORP probes. The probes were submersed in the respective anoxic reactors of the two systems throughout the experiment. These two probes were similarly calibrated in an attempt to synchronize the readings. Unfortunately, since these two ORP probes reacted differently, the ORP values recorded could only be used as a reference for the operation of each system, rather than being used for lateral comparison or as absolute values (Due to short of supply, the probes were not able to be replaced immediately).

Figure 5.1 presents the changes in ORP value and methanol addition with time.

Methanol addition started on day 66 (at 20°C). The reduction of ORP value started immediately after that date. On day 82, both systems started operating with an ASRT of 20 days (Mean SSRT was 17 days in system I and 13 days in system II). The anoxic ORP of both system I and system II continued to drop (from 100 mV to -100 mV) as the methanol addition increased (from zero to 11 gCOD/d). On day 104, the lab ambient temperature was reduced from 20°C to 12°C. The ORP value in the two systems continued to drop, and finally levelled off at around -450 mV in system I and -650 mV in system II, when the methanol addition of both systems was approximately 13 gCOD/d to 14 gCOD/d and ASRT was set at 20 days (Mean SSRT, then, was 17 days in system I and 22 days in system II). The different ORP value between the two systems might have been caused by the different solids contents between the two systems and the different reactivity of the two ORP probes.

On day 253, the two systems started operating without methanol feed for seven days. Within one day, the ORP of system I (ASRT = 60 days, SSRT = 12 days) jumped from around -350 mV to -10 mV, and the ORP of system II (ASRT = 30 days, SSRT = 13 days) jumped from -650 mV to -200 mV. As the methanol addition resumed, the ORP of both systems dropped again. This pattern indicated that the ORP value changed in proportion to the methanol addition. Since the denitrifying bacteria are heterotrophic organisms, they utilize the organic carbon as their energy source. Therefore, methanol here served as a reductant. When a higher amount of methanol was added, the concentration of reductant increased, which in turn, resulted in the dropping of the ORP value.

The reduction of temperature from 20^0C to 12°C might have contributed somewhat to the reduction in ORP value starting on day 104. However, ORP values did not show a significant change in either system I (ASRT = 60 days, SSRT = 29 days) or system II (ASRT = 20 days, SSRT = 18 days) after the reduction in temperature from 12°C to 4°C (methanol addition was reduced). The change in the concentration of the methanol



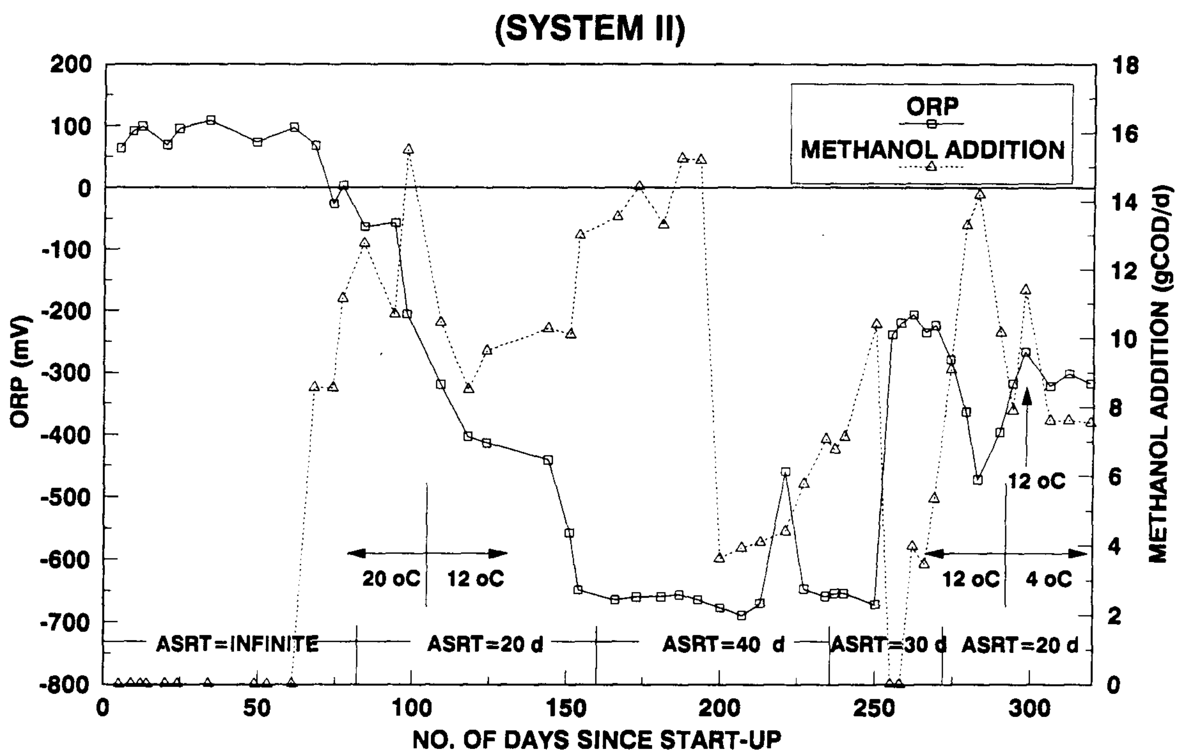


Figure 5.1: ORP Value and Methanol Addition vs. Time

affected the ORP value much more significantly than it would have affected the change in the temperature. Ortho-P addition was not observed to have an obvious effect on ORP values.

Figure 5.2 presents the relationship between ORP and the ratio of methanol addition to NO_x^--N entering the anoxic reactor. The more COD (of methanol) added, the lower the ORP value reached. In the anoxic reactor, when less NO_x^--N entered it, the growth in the denitrifying population could be limited, therefore, excess COD could also be utilized by facultative anaerobic bacteria(*Wilderer et al, 1987* and *Mavinic and Randall, 1989*), thus, dropping the ORP value. As also shown in this Figure, at a same ratio of methanol added to NO_x^--N entering the anoxic reactor, up to this ratio of 6:1, the ORP value at 20°C was mostly higher than that at 12°C and 4°C, indicating that temperature appeared to have a slight affect on the ORP value.

5.2 pH

The pH value of the leachate was fairly constant, ranging from 7.0 to 8.0, and did not appear to affect the treatment systems used. When higher levels of nitrification occurred the pH value measured in the anoxic reactor was usually higher than that observed in the aerobic reactor. The larger this difference, the higher the level of nitrification and subsequent denitrification achieved (Figure 5.3)(Note: the data on this figure is collected from system I and II). This confirmed that nitrifying bacteria utilize alkalinity during their synthesis and denitrification releases alkalinity back to the system.

The pH value in the anoxic reactor was always higher than that of the original leachate sample when denitrification occurred. Figure 5.4 (Note: the data on this figure is collected from system I and II) shows that the higher the denitrification level, the larger the difference was in the pH value between the anoxic mixed liquor and the leachate sample.

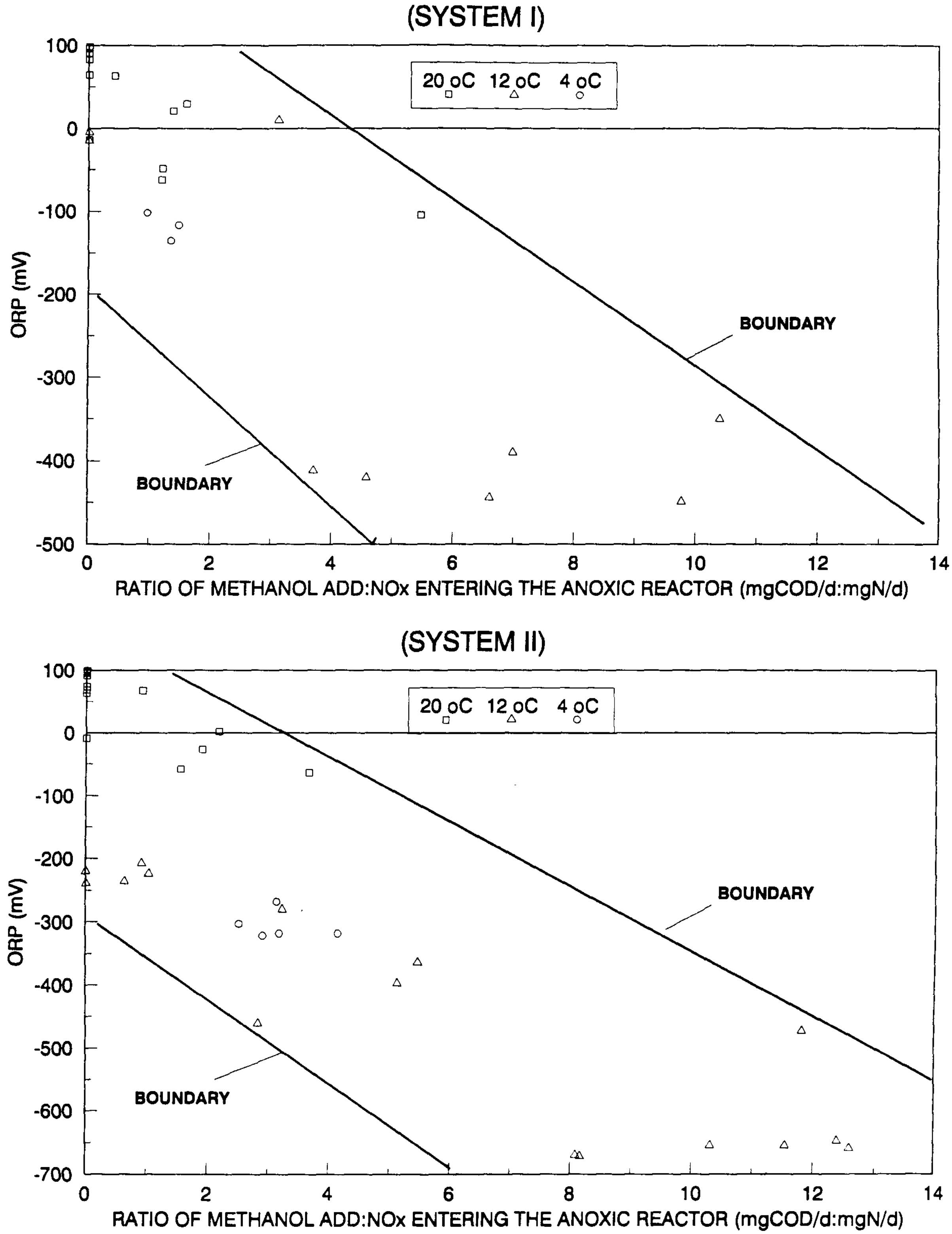


Figure 5.2: ORP Value vs. The Ratio of Methanol Addition to NO_x^--N Entering the Anoxic Reactor

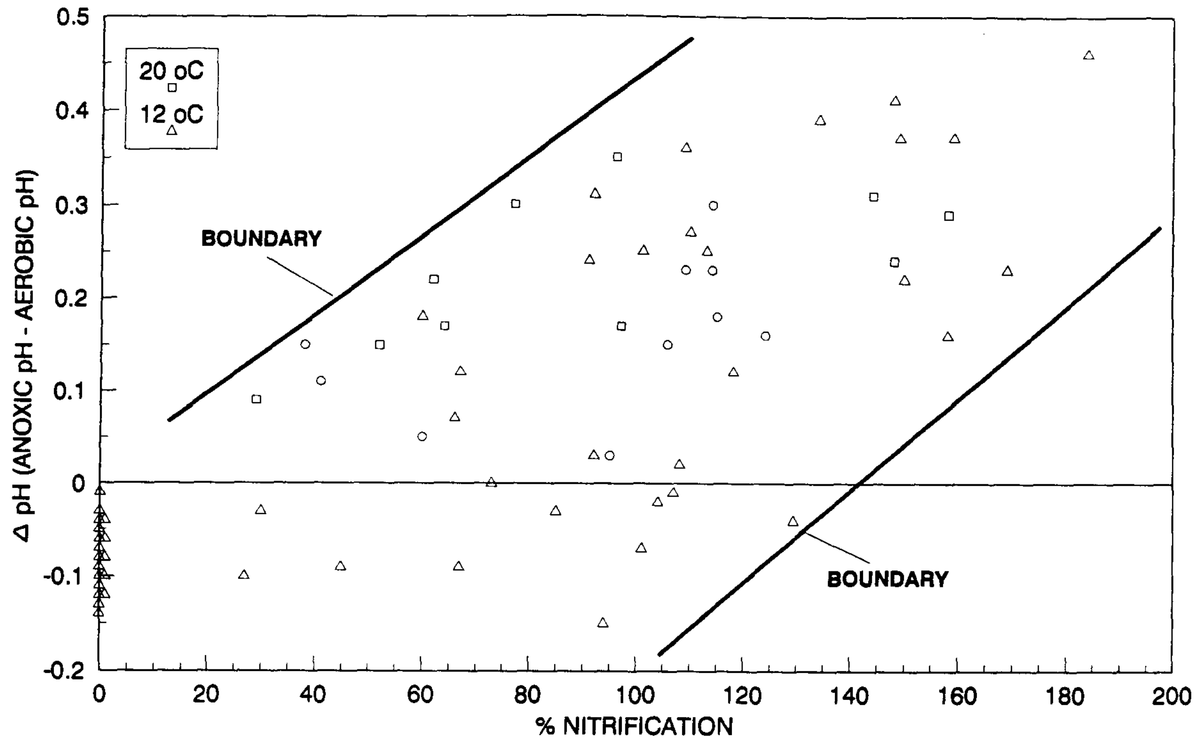


Figure 5.3: ΔpH (Anoxic pH - Aerobic pH) vs. Nitrification

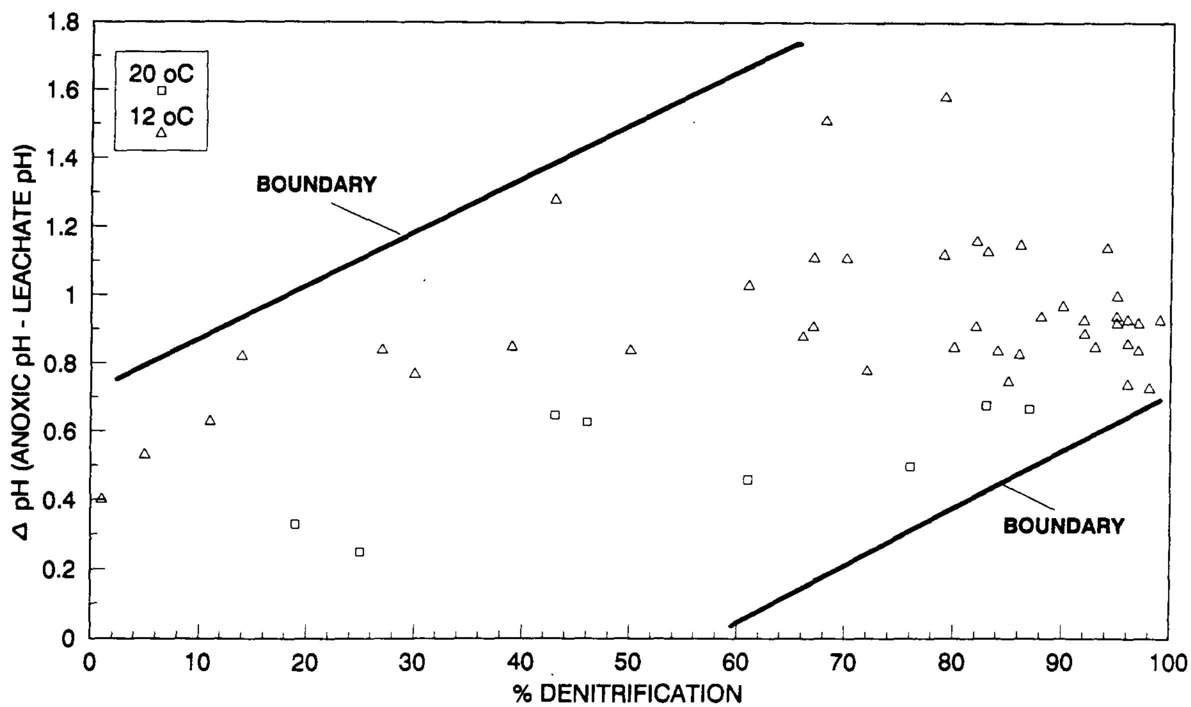


Figure 5.4: ΔpH (Anoxic pH - Leachate pH) vs. Denitrification

This again can be attributed to the presence of the denitrifying bacteria and the release of alkalinity during their metabolism.

Figure 5.5 presents the changes in pH value when the ambient temperature was suddenly reduced from 20°C to 12°C, commencing on day 104. Within 11 days from the reduction of temperature, the anoxic pH value increased from 8.14 to 8.35 in system I and from 8.10 to 8.36 in system II. The aerobic pH value increased from 7.97 to 8.39 in system I and from 8.01 to 8.40 in system II. These changes could be related to the inhibition of the growth of nitrifying bacteria, which consume alkalinity during their metabolism. Less ammonia-N evaporation at low temperature might be an additional reason for the increase in pH value. There was no such temperature effect on the pH value when the ambient temperature was reduced from 12°C to 4°C.

Methanol addition and different SRTs were not observed to significantly affect the pH value in this study.

5.3 SRTs

The theoretical Aerobic Solids Retention Time (ASRT) was controlled through a proportional amount of solids wasting from the aerobic reactor. System Solids Retention Time (SSRT) was calculated through the total solids leaving the system, including aerobic solids wasting and clarifier effluent solids lost. The following equations were used for the calculation:

$$\begin{aligned}
\text{ASRT} &= \text{Theoretical Aerobic Solids Retention Time} \\
&= \frac{\text{Mass volatile susp.solids in the aerobic reactor}}{\text{Mass volatile susp. solids wasted daily from the reactor}} \\
&= \frac{\text{Aerobic VSS} \times \text{Aerobic Vol.}}{\text{Aerobic VSS} \times \text{Daily Vol.of aerobic solids wasted}} \\
&= \frac{\text{Aerobic Vol.}}{\text{Daily Vol. aerobic solids wasted}}
\end{aligned}$$

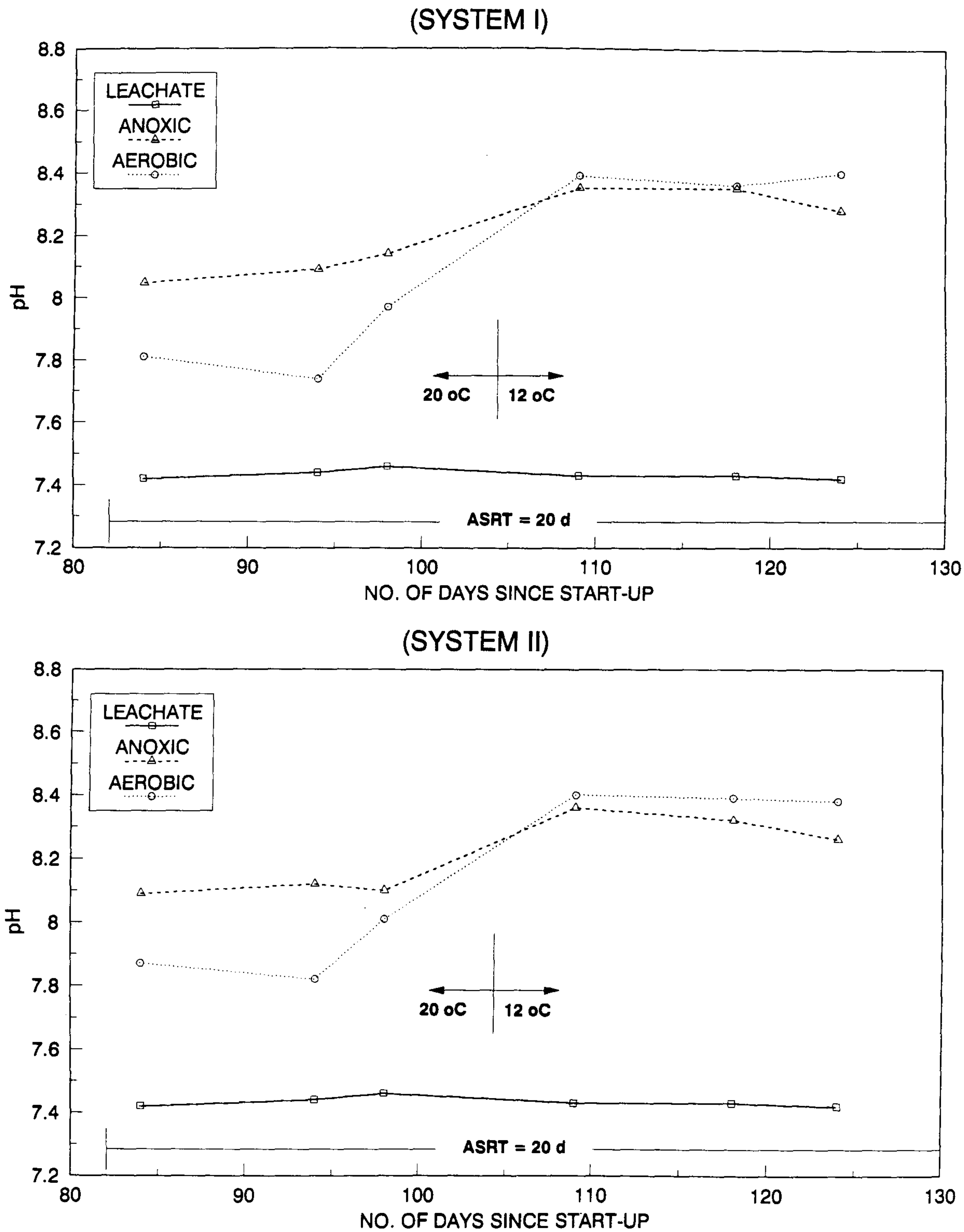


Figure 5.5: Effect of Temperature on pH Value

$$\begin{aligned}\text{SSRT}^{1} &= \text{System Solids Retention Time} \\ &= \frac{\text{Total mass volatile susp. solids in the system}}{\text{Total mass volatile susp. solids wasted from the system}} \\ &= \frac{\text{Anox VSS} \times \text{Anox Vol.} + \text{Aer VSS} \times (\text{Aer} + \text{Clar} + \text{Recl}) \text{ Vol.}}{\text{Aer VSS} \times \text{Daily Vol.of aer solids wasted} + \text{Effl VSS} \times \text{Infl flow}}\end{aligned}$$

[1] Assume VSS in the clarifier (4L) and recycle tubing (0.5L) was identical to aerobic VSS if stirred. Accuracy for this calculation is ±10%.

In this research, change of SSRT was not correlated with the change of ASRT (Figure 5.6), because a large portion of solids was lost from the system through the clarifier effluent.

As shown in Table 5.1, at a certain temperature, sludge settleability dropped with the increase in ASRT, i.e., higher ASRT partly contributed higher Volatile Suspended Solids (VSS) loss from the clarifier effluent, thus leading to a lower SSRT.

Table 5.1: Comparison of ASRT with SSRT

Temperature	Mean ASRT	Mean Effluent VSS	Mean SSRT
12°C	20	124	18
	30	202	13
	40	220	17
	60	303	12
4°C	20	152	18
	60	160	29

Note: The data in this table is collected from both systems I and II

5.4 Solids

Because of the interconnected nature of the reactors, the VSS value in the anoxic reactor was expected to be close to that in the aerobic reactor. However, during this research,

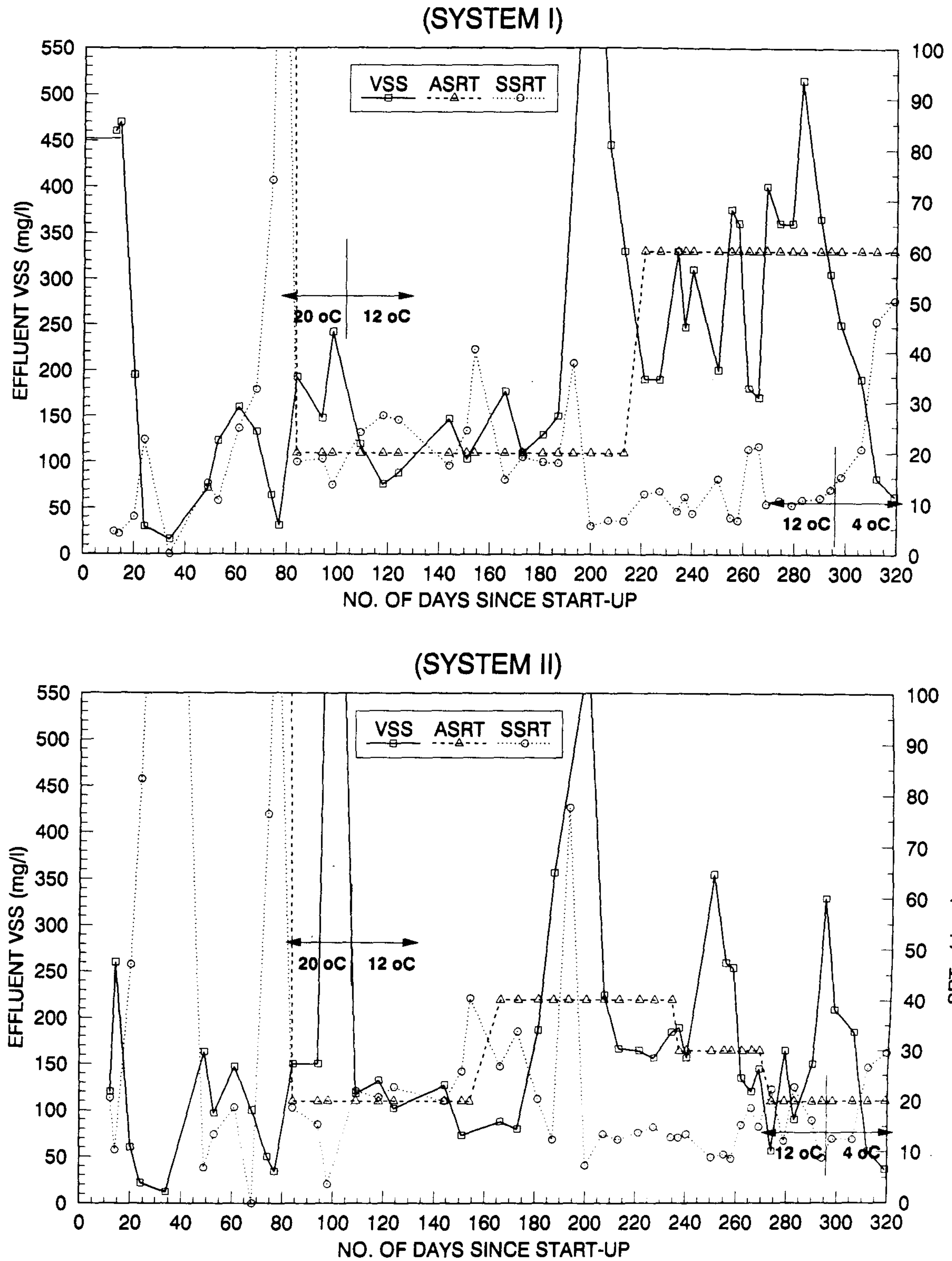


Figure 5.6: Comparison of ASRT with SSRT

the VSS value detected in the aerobic reactor was frequently higher than that in the anoxic reactor (see Figure 5.7), which was possibly caused by the high effluent VSS loss leading to less solids being recycled to the anoxic basin. Incontinuous sludge pumping flow (2 min on and 2 min off) might have affected the sampling accuracy and contributed to this VSS difference. This is also reflected in the fact that the values of the parameters measured without filtering, such as COD, BOD_5, TKN and TP (see discussion elsewhere) were generally higher in the aerobic reactor than in the anoxic reactor.

Total Suspended Solids (TSS) and Volatile Suspended Solids (VSS) were seriously affected by methanol addition (increased and decreased in response to the increase and decrease of methanol addition), but less affected by temperature and SRTs. The ratio of VSS to TSS was variable, ranging from 0.4 to 0.8.

5.4.1 Effect of Temperature on the VSS

VSS levels decreased by just under 20% with the reduction in temperature, confirming that bacterial growth was inhibited by the low temperature. The TSS value varied according to changes in the VSS value.

5.4.2 Effect of Methanol Addition on the TSS and VSS

Anoxic TSS and VSS

Figures 5.8 and 5.9 present the anoxic TSS and VSS values as affected by the addition of methanol. It can be observed that the anoxic TSS and VSS values changed in a pattern corresponding to the rate of methanol addition. This can be attributed to the excess COD being added to the anoxic basin (in excess of denitrification requirements for the limited NO_x^--N).

Commencing on day 66, methanol was added to both system I and system II. System

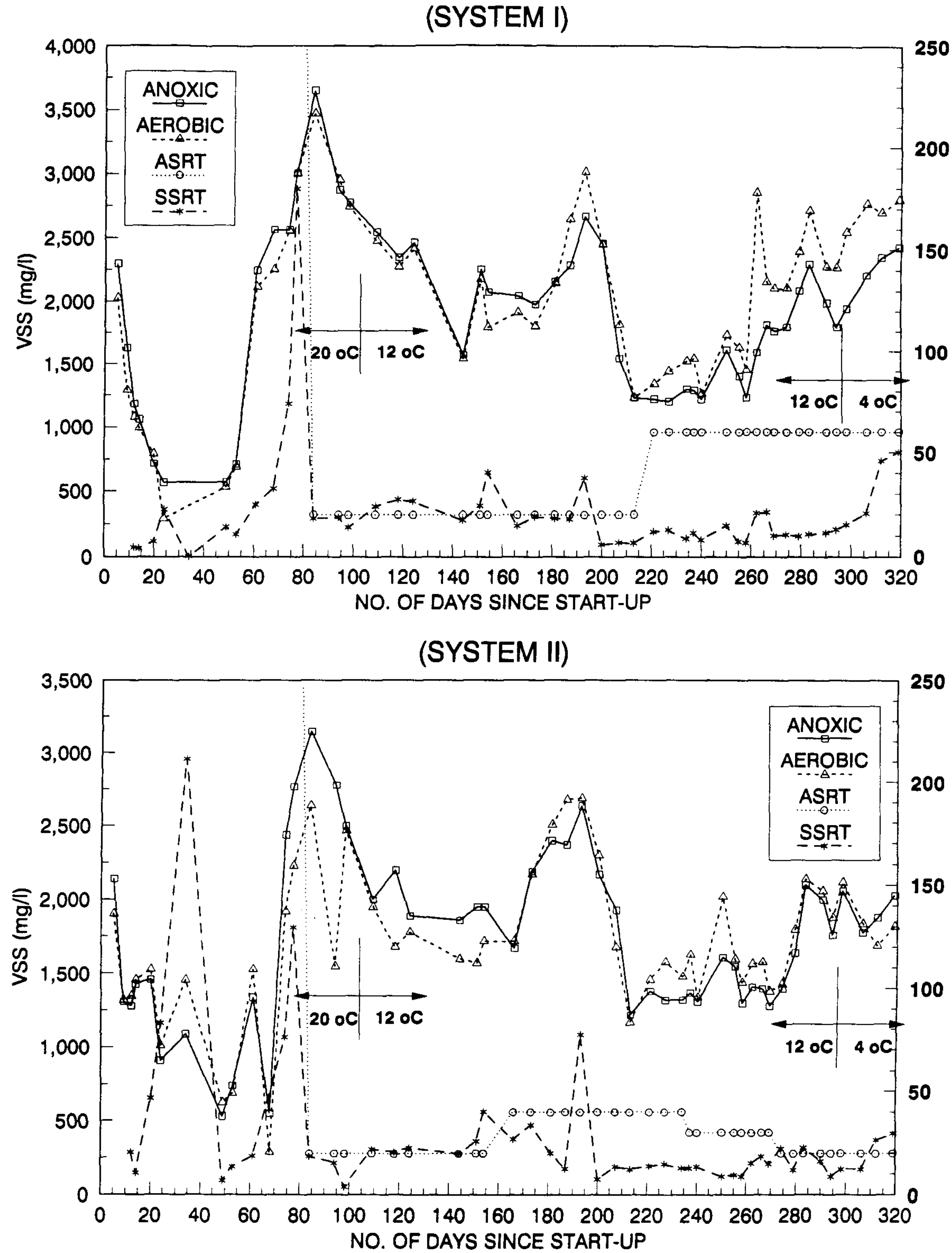


Figure 5.7: Volatile Suspended Solids vs. Time

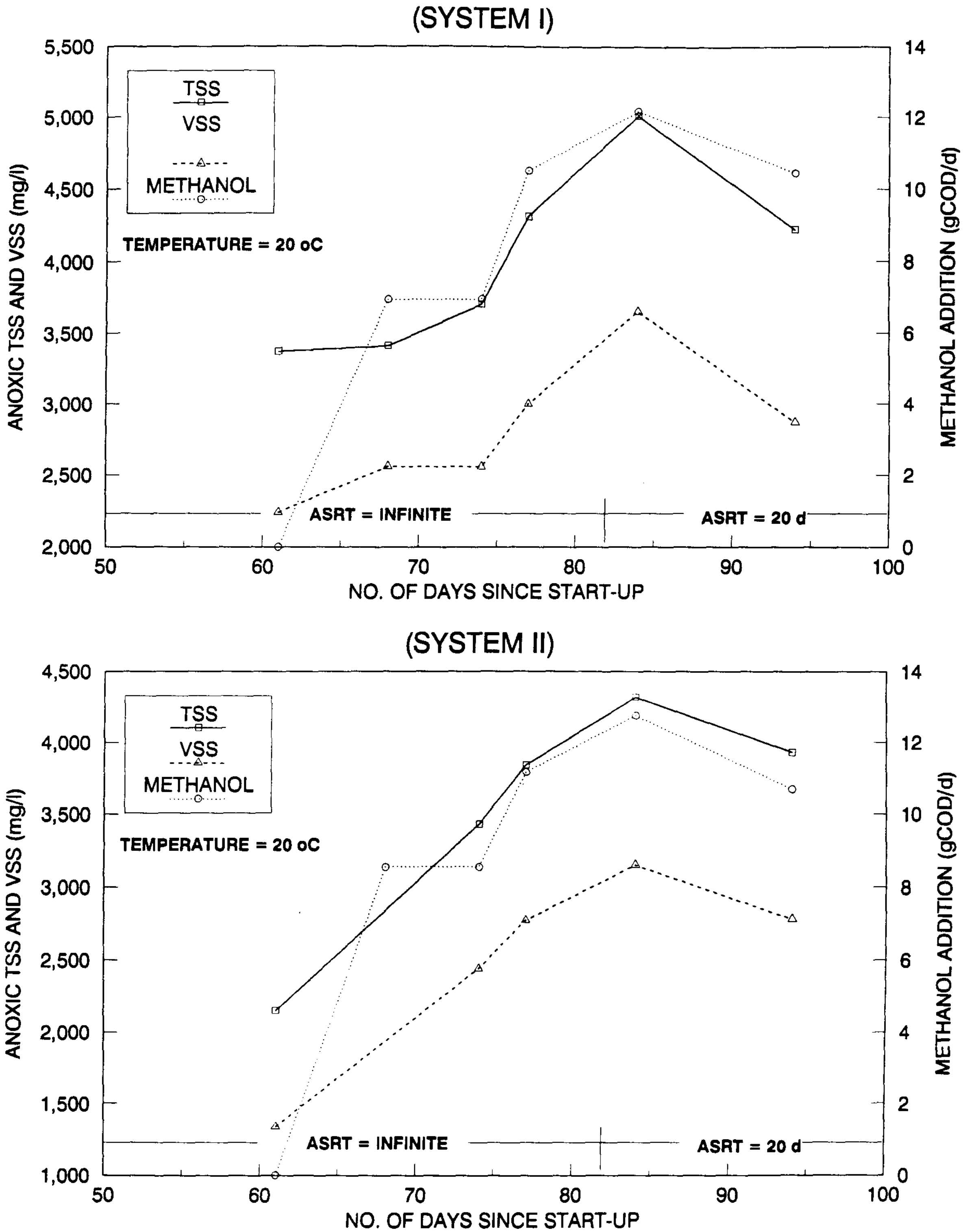


Figure 5.8: Effect of Methanol Addition on the Anoxic TSS and VSS (A)

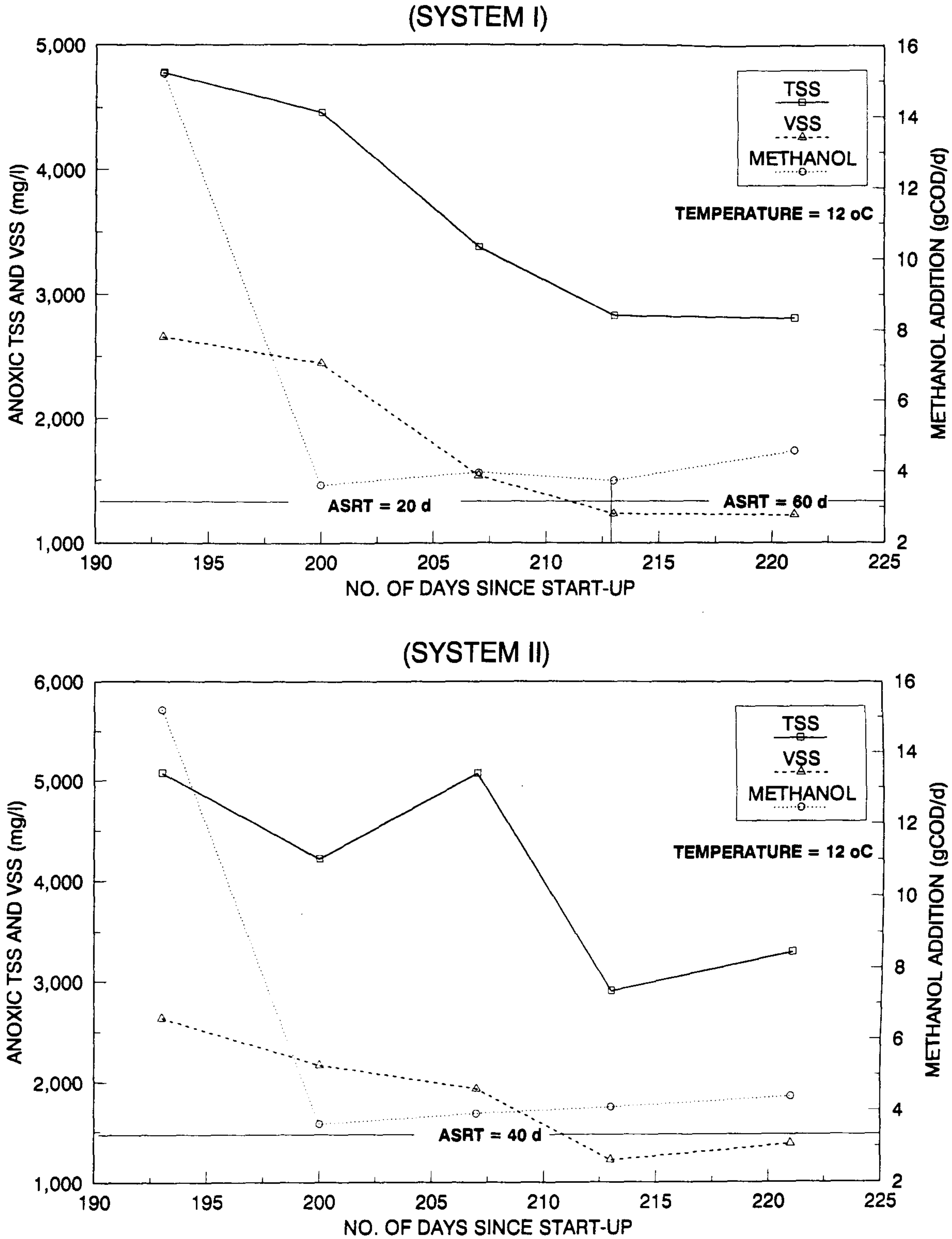


Figure 5.9: Effect of Methanol Addition on the Anoxic TSS and VSS (B)

I had an initial addition rate of 6.9 gCOD/d, which was gradually increased to 12.2 gCOD/d by day 84. System II had an initial addition rate of 8.5 gCOD/d, which was gradually increased to 12.8 gCOD/d by day 84. During these 18 days, anoxic TSS and VSS values increased markedly, regardless of the daily wasting (which was started on day 82 in both systems) to reach an ASRT of 20 days. In system I, anoxic TSS and VSS values increased by approximately 1,600 mg/l (33%) and 1,500 mg/l (38%), respectively. In system II, anoxic TSS and VSS values increased by approximately 2,000 mg/l (43%) and 1,500 mg/l (54%), respectively. During the time period, there was no increased VSS loss from the effluent.

Because of the drop in temperature at day 104, nitrification failure was observed. In an attempt to determine if reducing the methanol addition would help reintroduce nitrification at the low temperature, on day 199, methanol addition was suddenly reduced from 14 gCOD/d to 4 gCOD/d in both system I (ASRT = 60 days) and System II (ASRT = 40 days), and then kept at this dosage for two weeks. Within these two weeks, the anoxic TSS value in system I had dropped from 4780 mg/l to 2830 mg/l (by 40 %), and the VSS value had dropped from 2,660 mg/l to 1230 mg/l (by 53%) (effluent VSS also dropped). In system II, the anoxic TSS value had dropped from 5,080 mg/l to 2,910 mg/l (by 43%), and the VSS value had dropped from 2,640 mg/l to 1,220 mg/l (by 54%) (effluent VSS also dropped). Despite the solids dropping, three weeks after the reduction in methanol addition (commencing on day 199), the nitrification level recovered from zero to 92% in system I, and from zero to 118% (see discussion later for nitrification performance) in system II. This pattern indicated that excess carbon was probably utilized by facultative anaerobic bacteria in the anoxic reactor (*Wilder et al, 1987 and Mavinic and Randall, 1989*) and heterotrophic bacteria in the aerobic reactor. Their growth was limited by the reduction in methanol addition, thus, resulting in the earlier solids drop.

Aerobic TSS and VSS

The aerobic TSS and VSS values were also observed to correspond to the changes in methanol dosage (Figure 5.10 and 5.11), because of excess COD added to the system. However, aerobic ammonia-N removal and nitrification levels were observed to change in a contrary way with the changes in methanol dosage. It was possible that heterotrophic growth was "encouraged" in the aerobic basin due to the excess carbon contribution flowing from the anoxic basin.

5.5 Carbon Loading

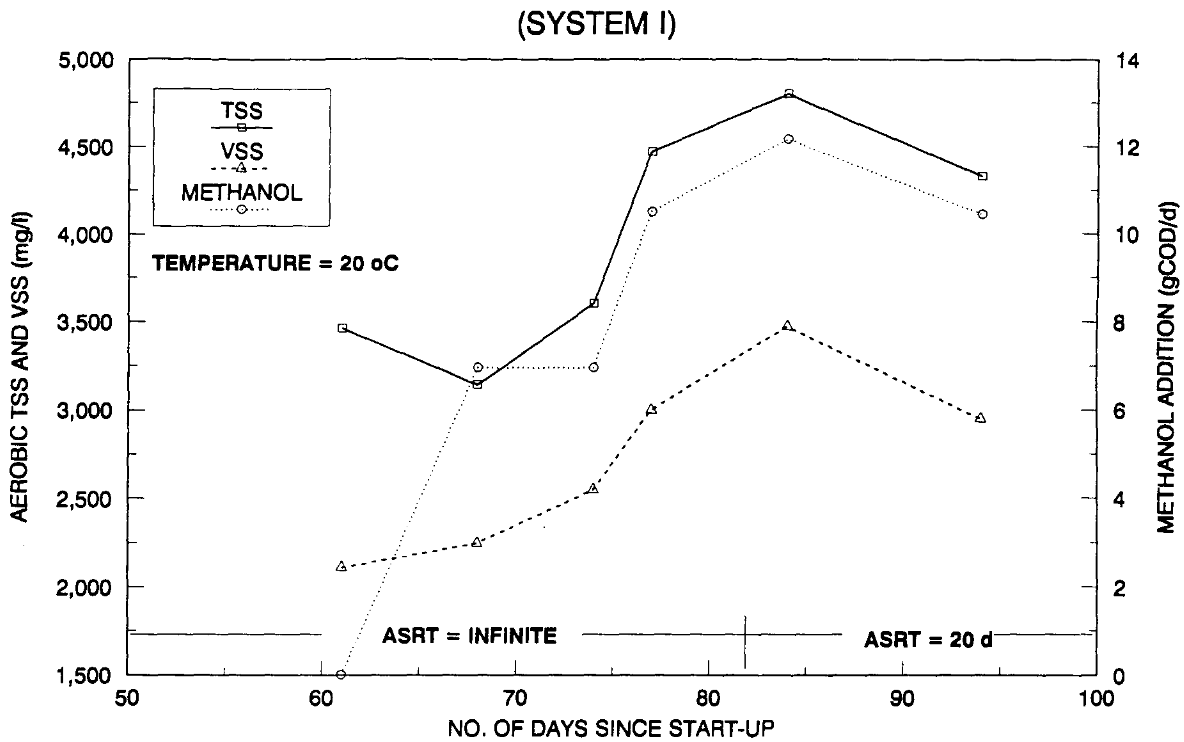
The COD level of the leachate was relatively low, averaging 400 mg/l. The BOD_5 level of the leachate was measured and averaged about 35 mg/l. The average BOD_5 to COD ratio was 1:11, which indicated that the organic materials remaining in the leachate were mostly non-biodegradable. In order to achieve denitrification, methanol was used as an external source of carbon (*Carley, 1988*).

The COD and BOD_5 values were obtained using unfiltered samples. This caused some difficulty in explaining the results because of the complexities of the MLE system. Both COD and BOD_5 removal rates were therefore lower than those of filtered sample analyses obtained by previous researchers.

5.5.1 COD

The effluent COD came from two sources. A portion of effluent COD was derived from the original leachate (the refractory COD), and the remaining portion came from the unutilized excess methanol travelling through the system.

Commencing on day 66, equal dosages of methanol were added to the anoxic reactors of both system I and II. After day 66, effluent COD levels ranged from 300 mg/l to 800



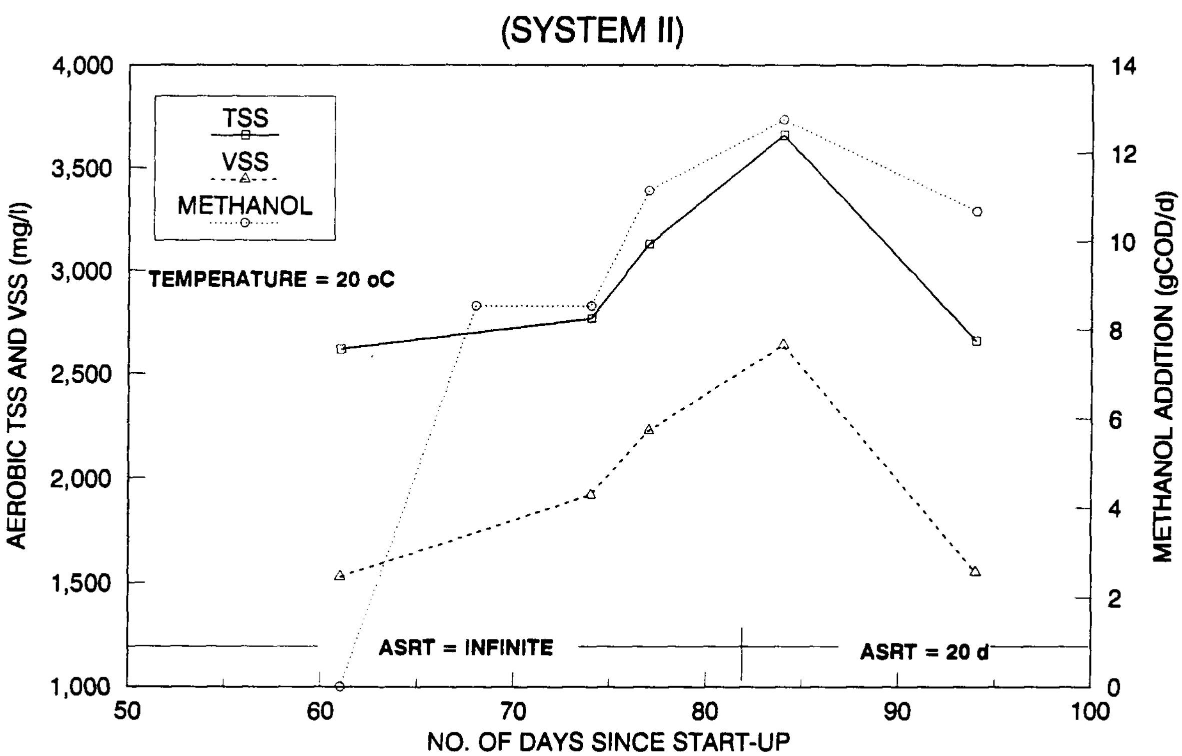


Figure 5.10: Effect of Methanol Addition on the Aerobic TSS and VSS (A)

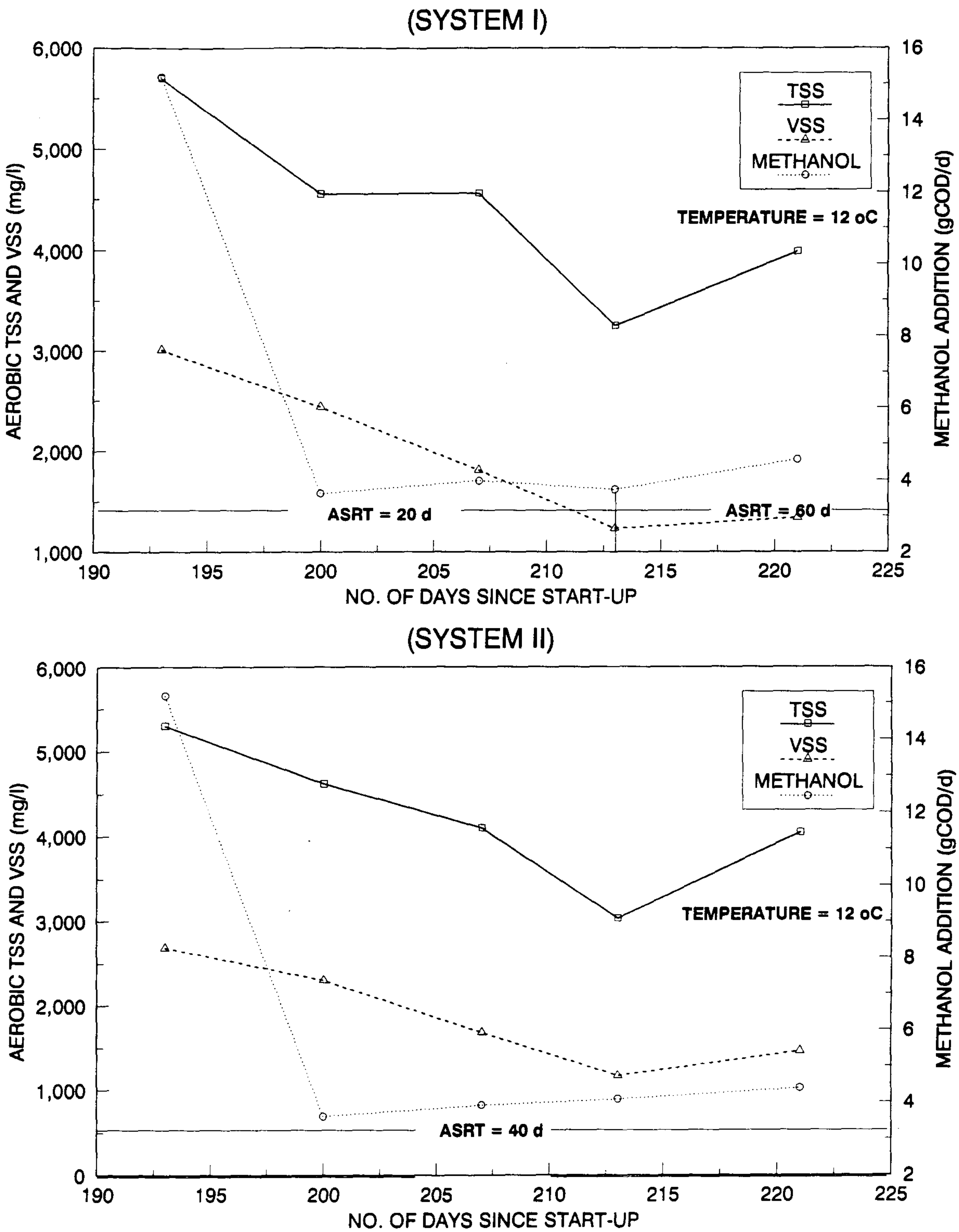


Figure 5.11: Effect of Methanol Addition on the Aerobic TSS and VSS (B)

mg/l in both systems; these were slightly higher than influent COD levels. However, measurements of effluent COD levels taken on day 200 showed that a sharp increase had occurred to 5064 mg/l in system I (ASRT = 20 days) and 3325 mg/l in system II (ASRT = 40 days) (see Figure 5.12). At the same time, effluent VSS showed a sharp increase and then decrease (from 150 mg/l to 850 mg/l in system I and from 360 mg/l to 590 mg/l in system II). This occurred because excess carbon passed through the system unutilized. Cell lysis and poor solids settleability at low temperature might be the additional reasons for this high effluent COD.

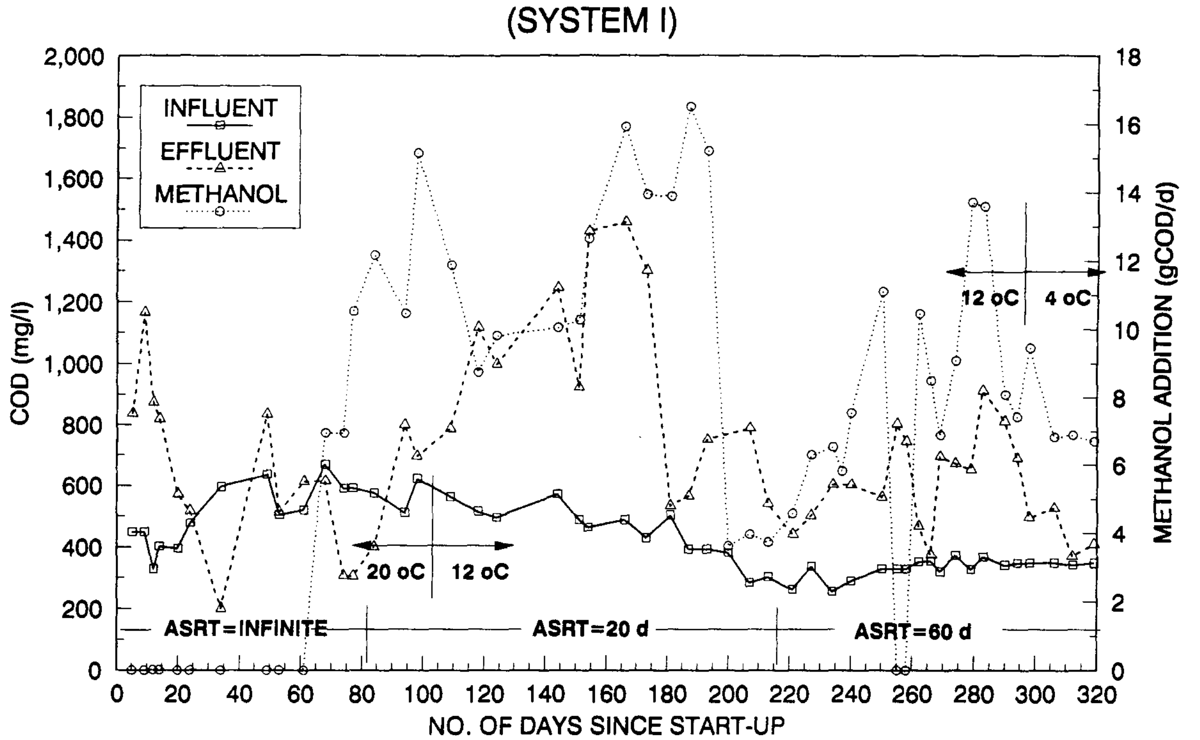
Total COD Removal

The total level of COD removal ranged generally from 40% to 80%. It was directly affected by the methanol dosage (Appendix B). As presented in Figure 5.13, total COD removal increased with the addition of methanol starting on day 66. This rate of removal dropped to lower than 20% in both system I and system II, just after methanol dosage was reduced sharply on day 199. COD removal dropped again when the addition of methanol was discontinued altogether after day 250. Direct carbon addition was the main reason for these changes. Temperature and SRTs did not appear to have a significant effect on the total level of COD removal.

Anoxic COD Removal

Anoxic COD removal was generally less than 20%; occasionally, a negative value was observed. This was probably due to the excess carbon addition, the inaccuracy of chemical measurement, the build-up of solids in the anoxic reactor and the method of data analysis (Figure 5.14).

The anoxic COD removal was calculated by determining the difference between the total COD entering the anoxic reactor and the total COD leaving the anoxic reactor(see



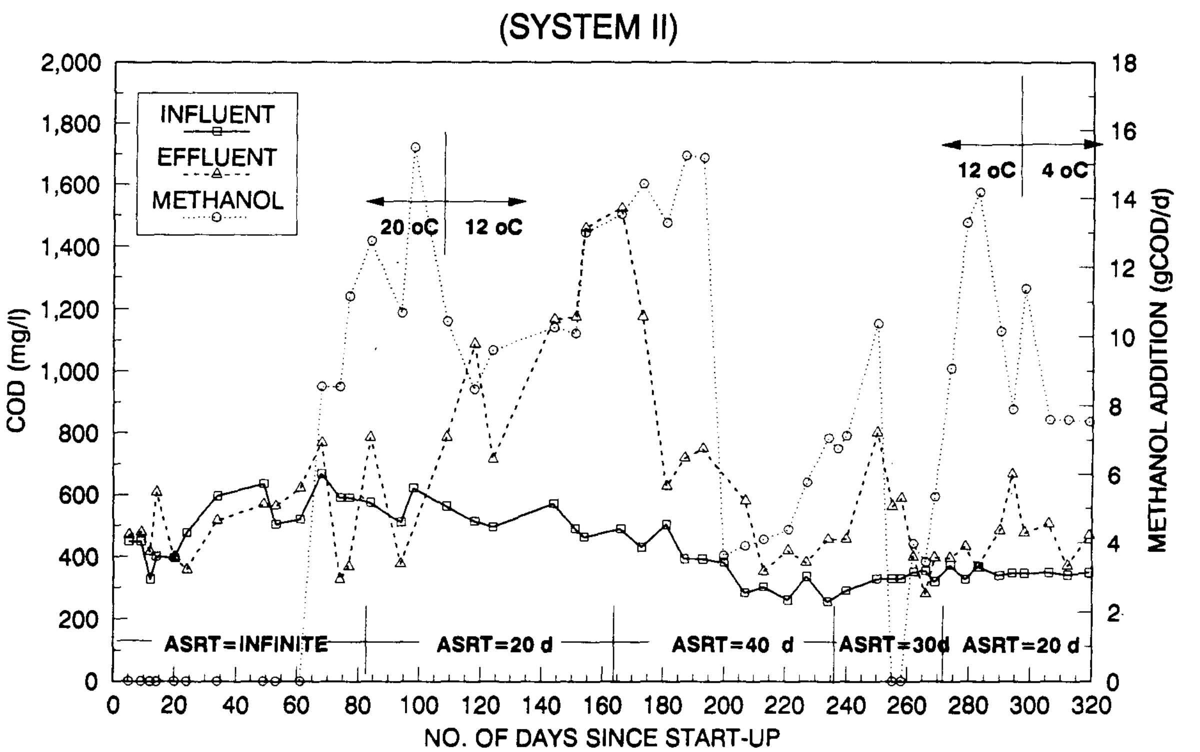


Figure 5.12: Influent and Effluent COD vs. Time

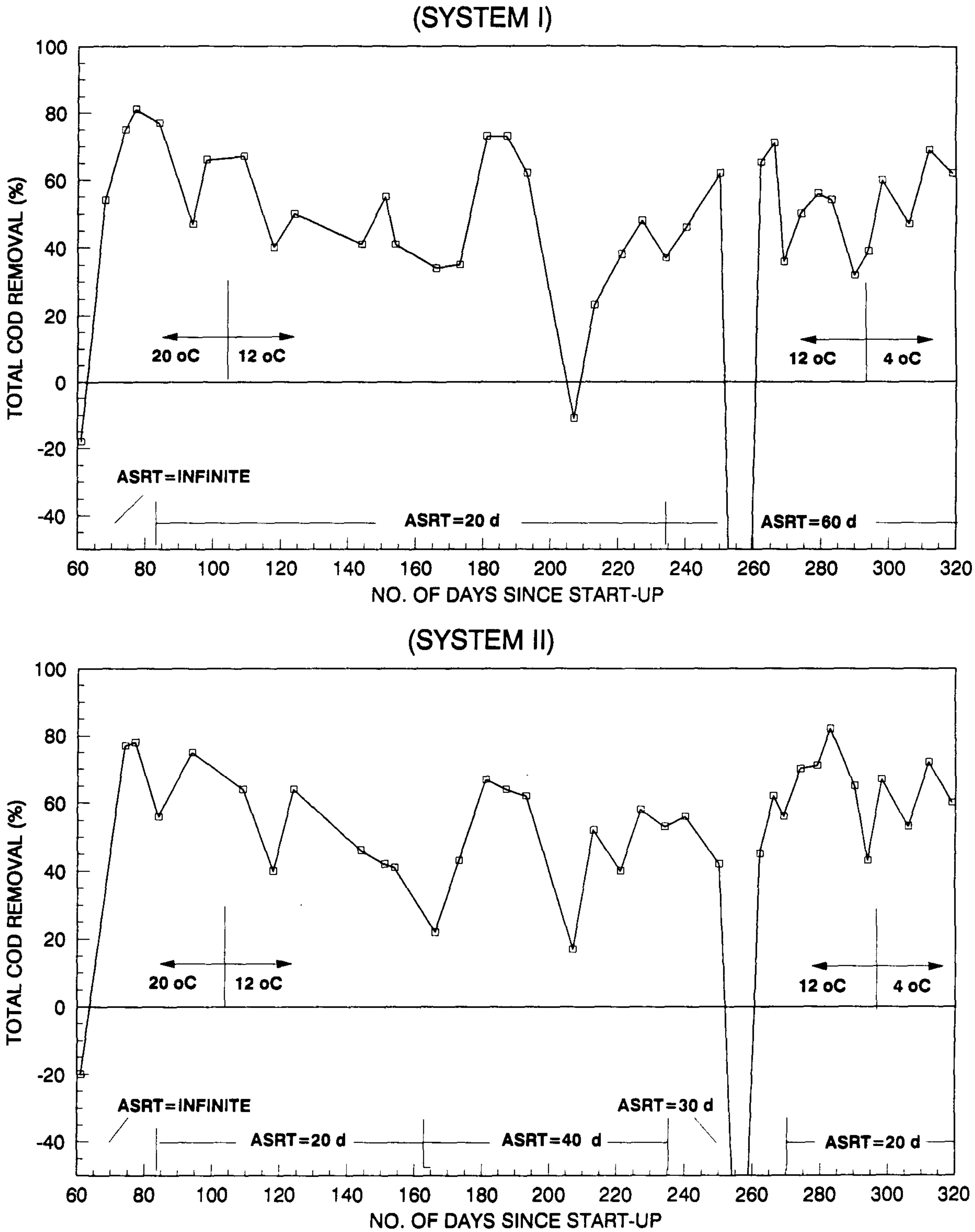
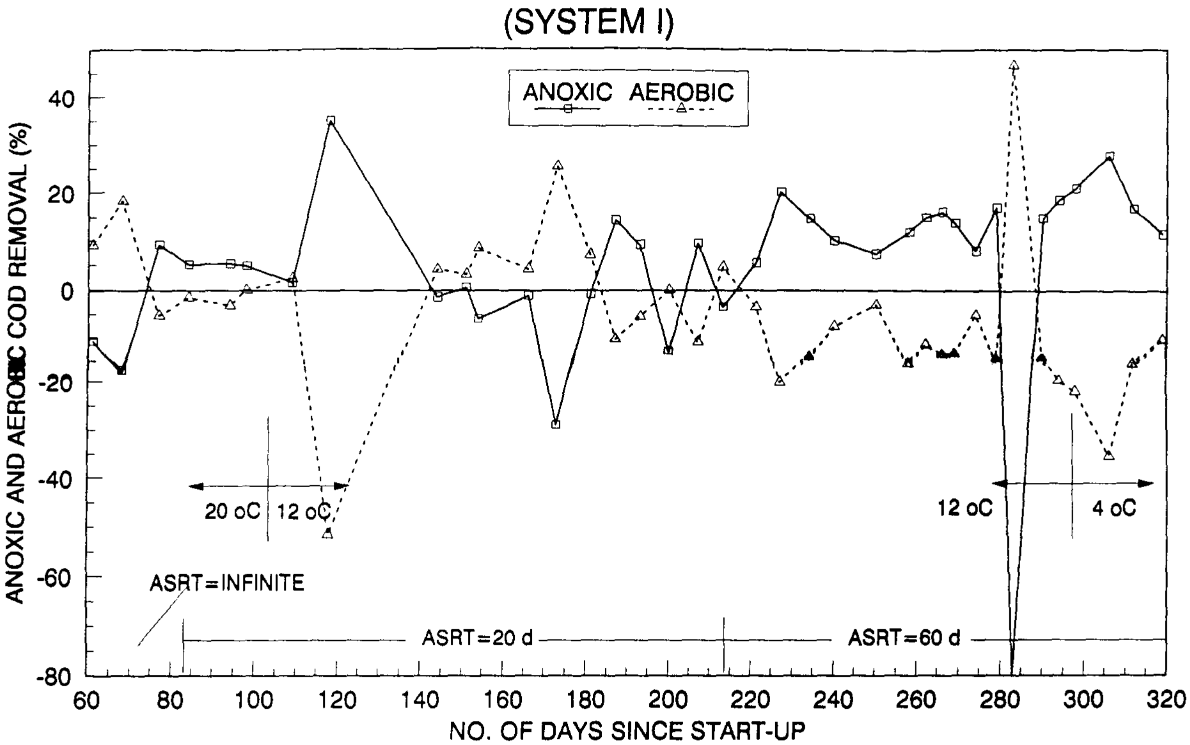


Figure 5.13: Total COD Removal vs. Time



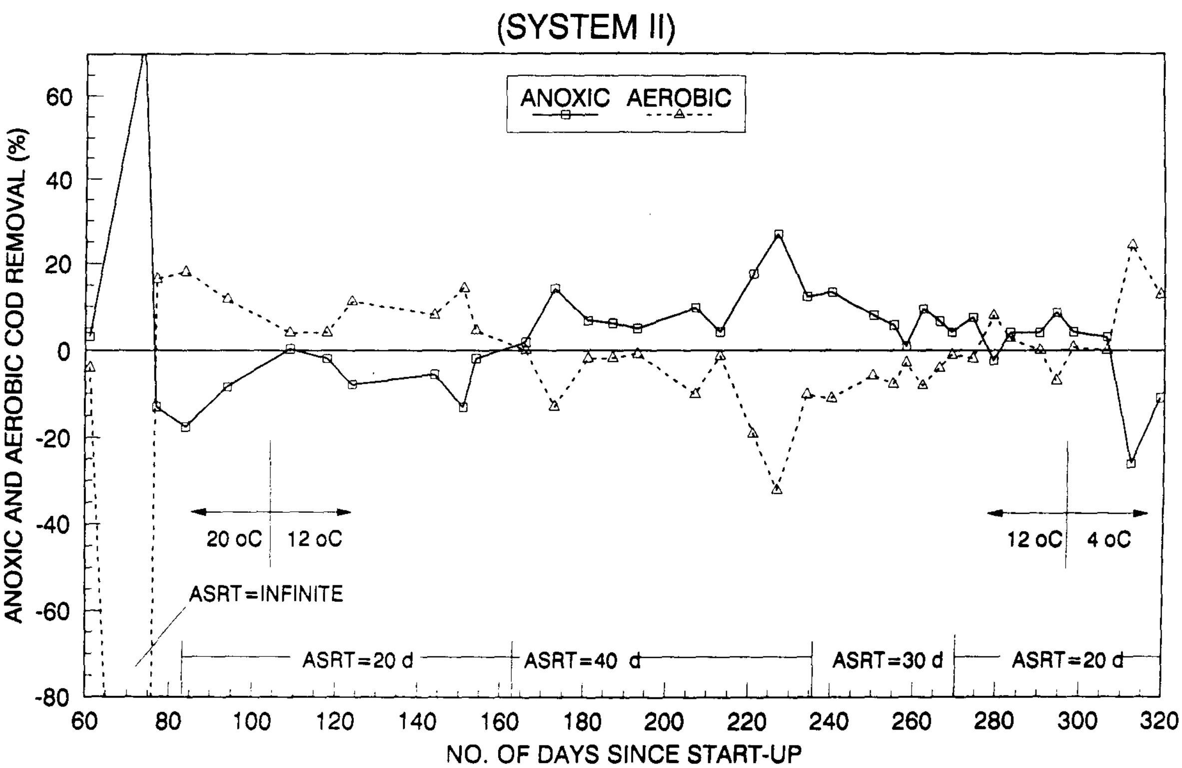


Figure 5.14: Anoxic and Aerobic COD Removal vs. Time

Appendix B). The total COD entering the anoxic reactor was the sum of methanol added, influent COD and COD recycled. COD recycled was indirectly calculated through determining the net mass balance in the clarifier, i.e., COD recycled = COD entering the clarifier - COD leaving the clarifier. Because the solid content was not uniform throughout the entire depth of the clarifier, the actual COD level at the bottom (which was utilized for recycling) would have been higher than that calculated through mass balance. If a sample from the bottom of the clarifier had been taken, the actual total COD entering the anoxic reactor would have been higher than that calculated through mass balance. In other words, the actual anoxic COD removal level would have been higher than that obtained through calculation. Suffice it to say that excess carbon, low temperatures, plus the problems in data analysis resulted in lower-than-expected COD removals across the anoxic basin.

Aerobic COD Removal

During this research, negative aerobic COD removal values were often observed (Figure 5.14), regardless of changes in temperature and SRTs . Coincidentally, in these same samples, the aerobic VSS happened to be higher than anoxic VSS(see Figure 5.7). This pattern indicated that the VSS build up in the aerobic reactor and the VSS loss from the effluent (which caused less VSS returning to the anoxic reactor), could have resulted in the COD level in the aerobic reactor being higher than in the anoxic reactor, thus, a negative removal value. Filtered COD samples were not run; if they had, perhaps a clearer picture would have been obtained.

Clarifier COD Removal

Clarifier COD removal measurements generally exceeded 90 percent (see Figure 5.15). This indicated that a high particulate COD was associated with the MLVSS, which was then settled out.

5.5.2 BOD_5

The measuring of BOD_5, from unfiltered samples, was started on day 207. The effluent BOD_5 values generally ranged from 100 mg/l to 400 mg/l; these values were considerably higher than the leachate influent BOD_5 values, due to excess methanol addition (and temperature effects). Variations in BOD_5 removal change can be related directly to those of COD removal (Figure 5.16 and 5.17).

5.6 Phosphorus

Membrane-filtered ortho-P sample analysis was performed. The leachate had a very low ortho-P content, averaging only 0.4 mgP/l(see Figure 5.18). Commencing on day 94 (at 20°C and ASRT of 20 days in both systems), 1.7 mgP/d of ortho-P was added to both systems (Chapter 3). On day 104, when complete nitrification and denitrification were achieved, the ambient temperature was reduced to 12°C; the ortho-P dosage remained at around 1 mgP/d. The ortho-P value in the anoxic and aerobic reactors of both systems remained at around 0.5 mgP/l, which was the same as the ortho-P values before the temperature was reduced.

The effect of the low temperature on the bio-systems was so significant that the total ammonia removal efficiency dropped from 98% to 28% in system I and from 84% to 28% in system II. In an attempt to determine if there was a phosphorus deficiency problem and to see if excess phosphate could stimulate the return of healthy nitrification at lower temperatures, commencing on day 116, the phosphate addition was increased to 3.3 mgP/d in both systems and then further increased gradually to an average high of 167 mgP/d, by day 200. During this time period, the anoxic ortho-P values of both systems

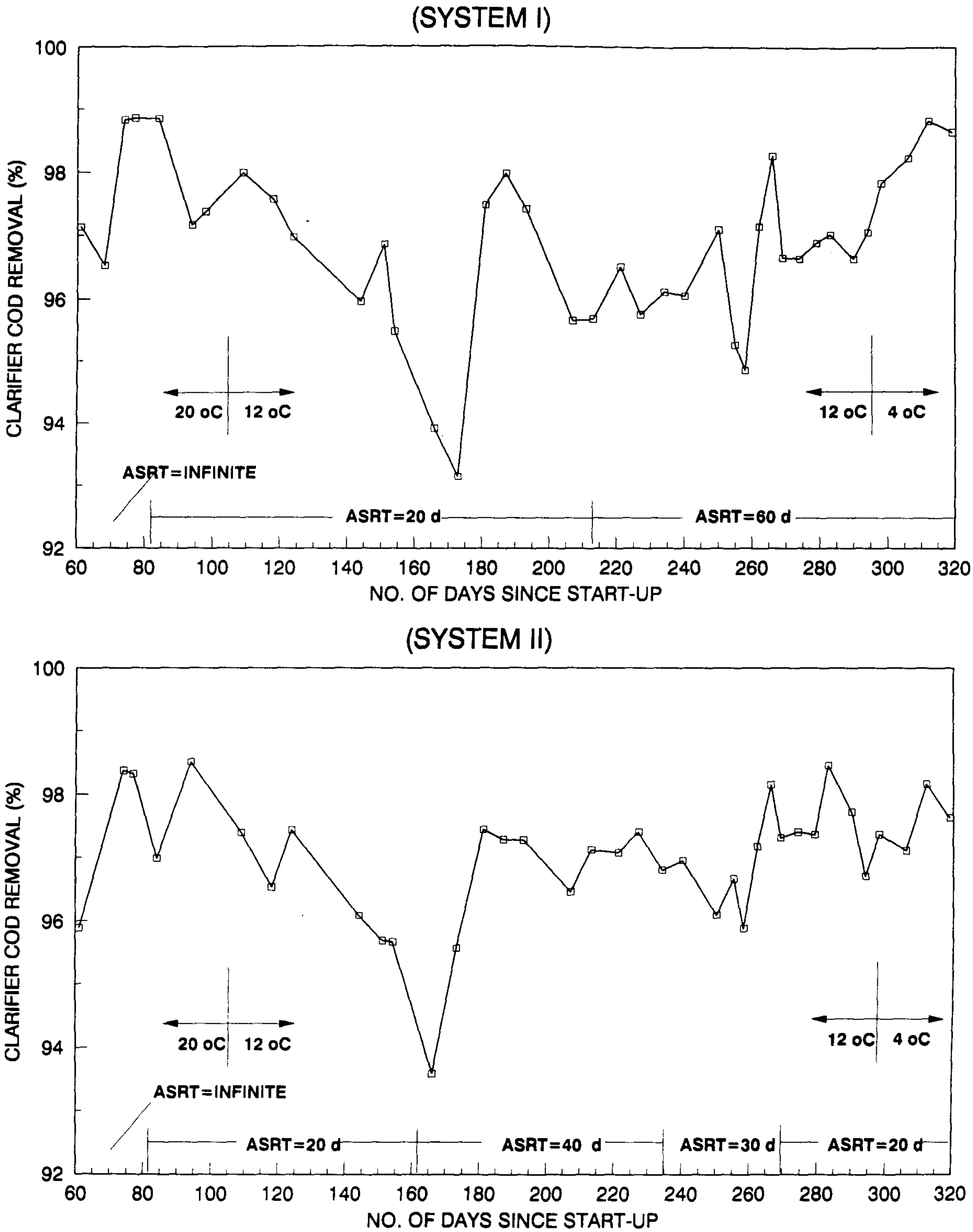


Figure 5.15: Clarifier COD Removal vs. Time

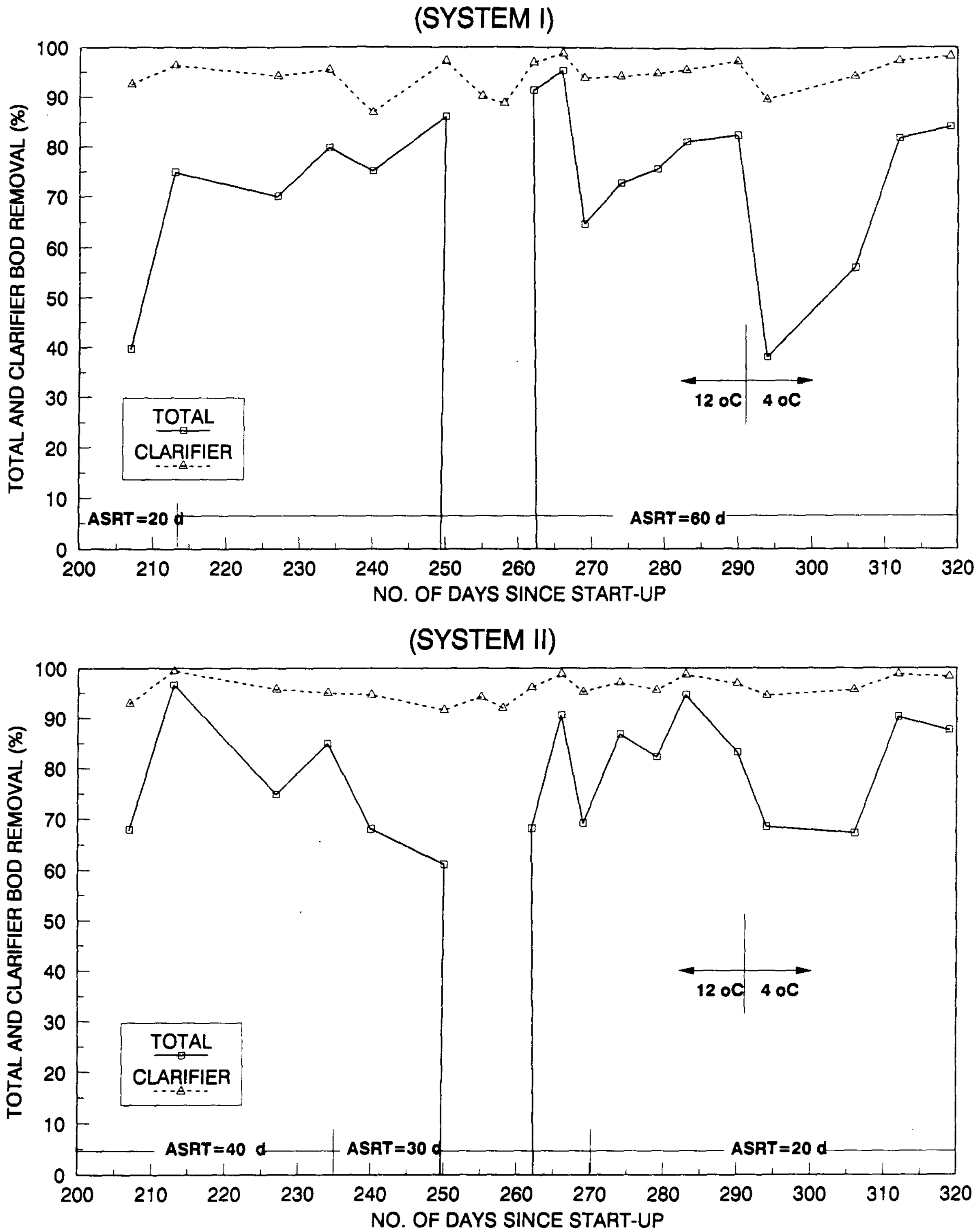


Figure 5.16: Total and Clarifier BOD_5 Removal vs. Time

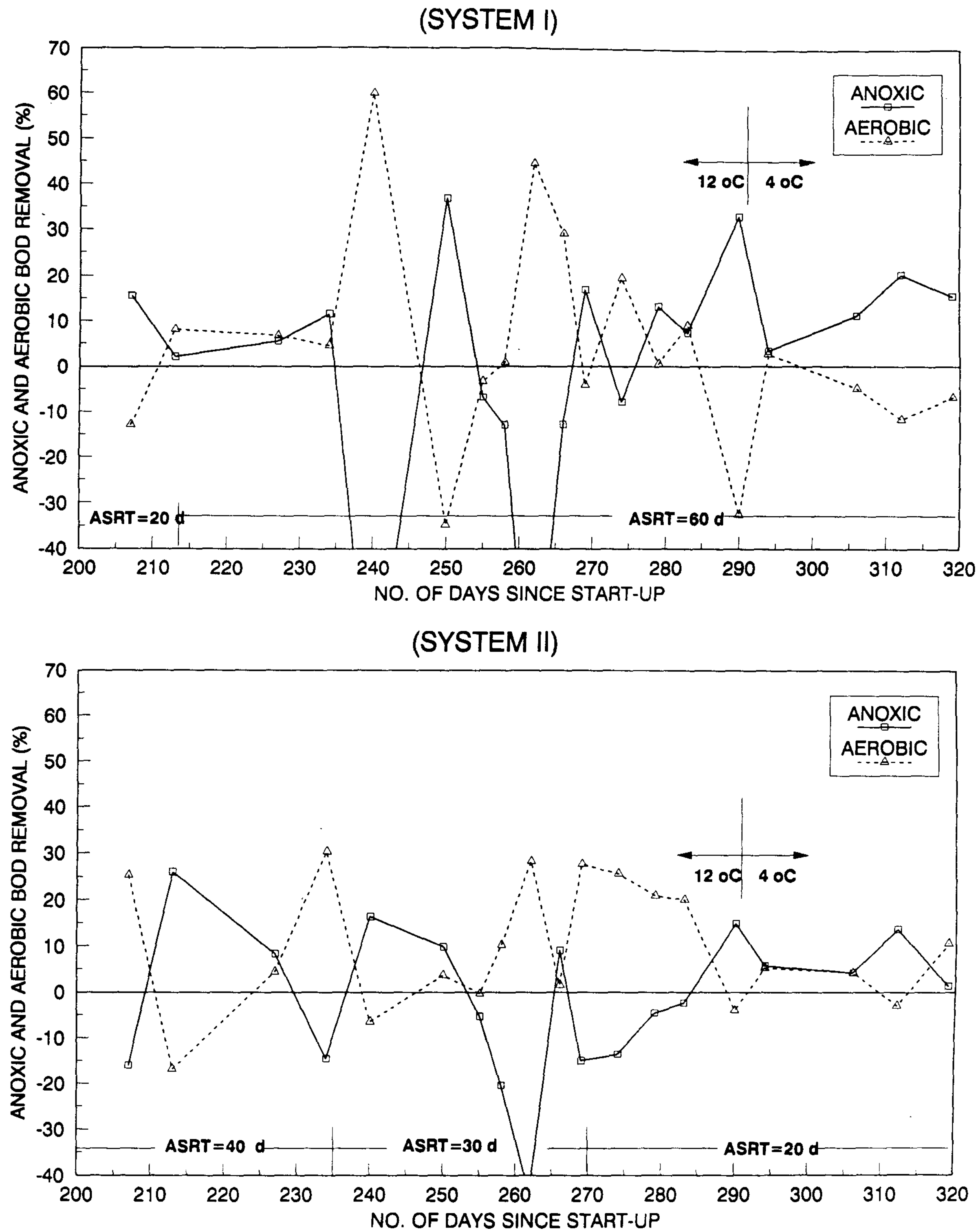


Figure 5.17: Anoxic and Aerobic BOD_5 Removal vs. Time

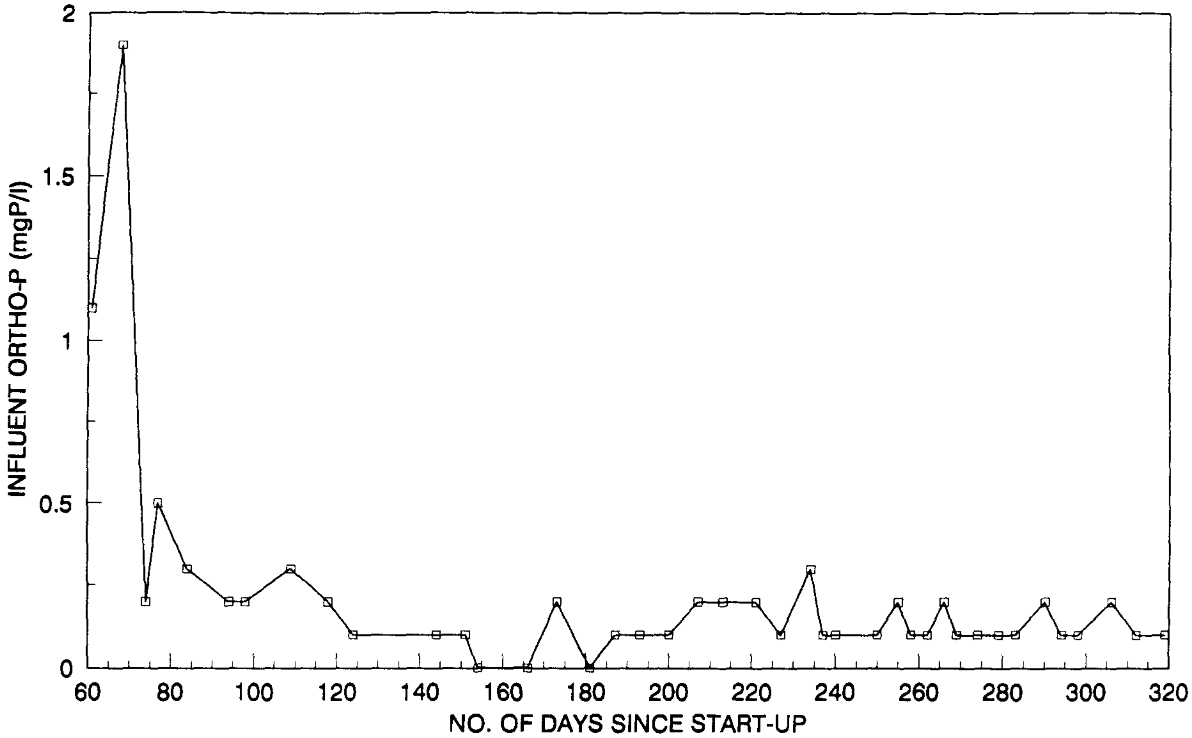


Figure 5.18: Influent Ortho-P vs. Time

I and II remained at less than 0.7 mgP/l until day 193, when the values jumped to 4.1 mgP/l in system I (ortho-P addition was around 153 mgP/d) and 3.9 mgP/l in system II (ortho-P addition was around 157 mgP/d) (Figure 5.19). The aerobic ortho-P values of these two systems were similar to those observed in the anoxic reactors. The results also indicated that there was some phosphorus depletion occurring in the anoxic reactor, due to nutrient demands by the denitrifying population (Ortho-P concentration of 0.8 mgP/l might be needed in both anoxic and aerobic reactors at 12°C to support the denitrification and nitrification process). Over the temperature ranges studied, phosphorus removal was usually around 70%.

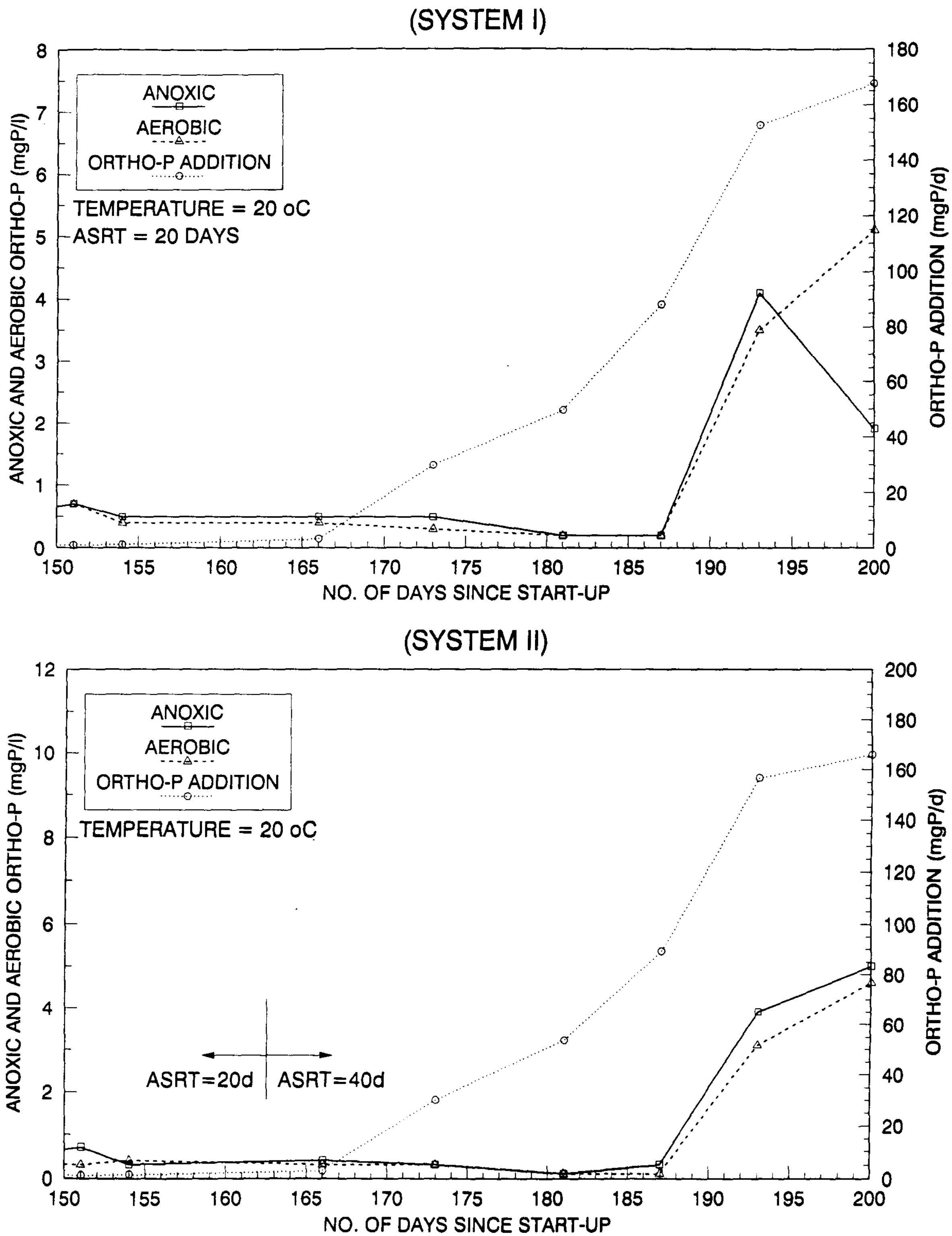


Figure 5.19: Anoxic and Aerobic Ortho-P vs. Time

5.7 Ammonia-N Removal

Ammonia-N may be removed by biomass assimilation, air stripping, or by nitrification in the aerobic reactor. At 20°C, the percentage of unionized ammonia is about zero at pH of 7.0, 5% at pH of 8.0, 50% at pH of 9.4 and 100% at pH of 11.5. At 10°C, the percentage of unionized ammonia is about zero at pH of 7.7, 3% at pH of 8.0, 10% at pH of 8.7 and 100% at pH of 11.8 (*U.S. EPA, 1975*). Since the pH readings obtained in all samples were mostly below 8.0 when ambient temperature was 20°C and below 8.7 when ambient temperature was 12°C or 4°C, the amount of ammonia removed by air stripping can be assumed to be about 6% to 10%. Therefore, most of ammonia-N would have been removed by nitrification and bacterial assimilation.

5.7.1 Anoxic Ammonia-N Removal

Anoxic ammonia-N removal appeared to be affected by changes in temperature. At a temperature of 20°C, when bacterial acclimation was achieved, the level of anoxic ammonia-N removal was generally below 5%, with mean unit removal of less than 0.5 mg/h/gVSS. Whereas, at temperatures of 12°C and 4°C, the level of anoxic ammonia-N removal reached more than 15%, with mean unit removal of over 2 mg/h/gVSS, in both system I and system II at all ASRT ranges studied (Figure 5.20). A possible reason for this pattern might be that the denitrifying bacteria responded to the stress of low temperature, thus requiring higher ammonia-N for assimilation. The negative value of anoxic ammonia-N removal could reflect the results of cell lysis. Methanol addition and SRTs did not appear to have a significant effect on anoxic ammonia-N removal.

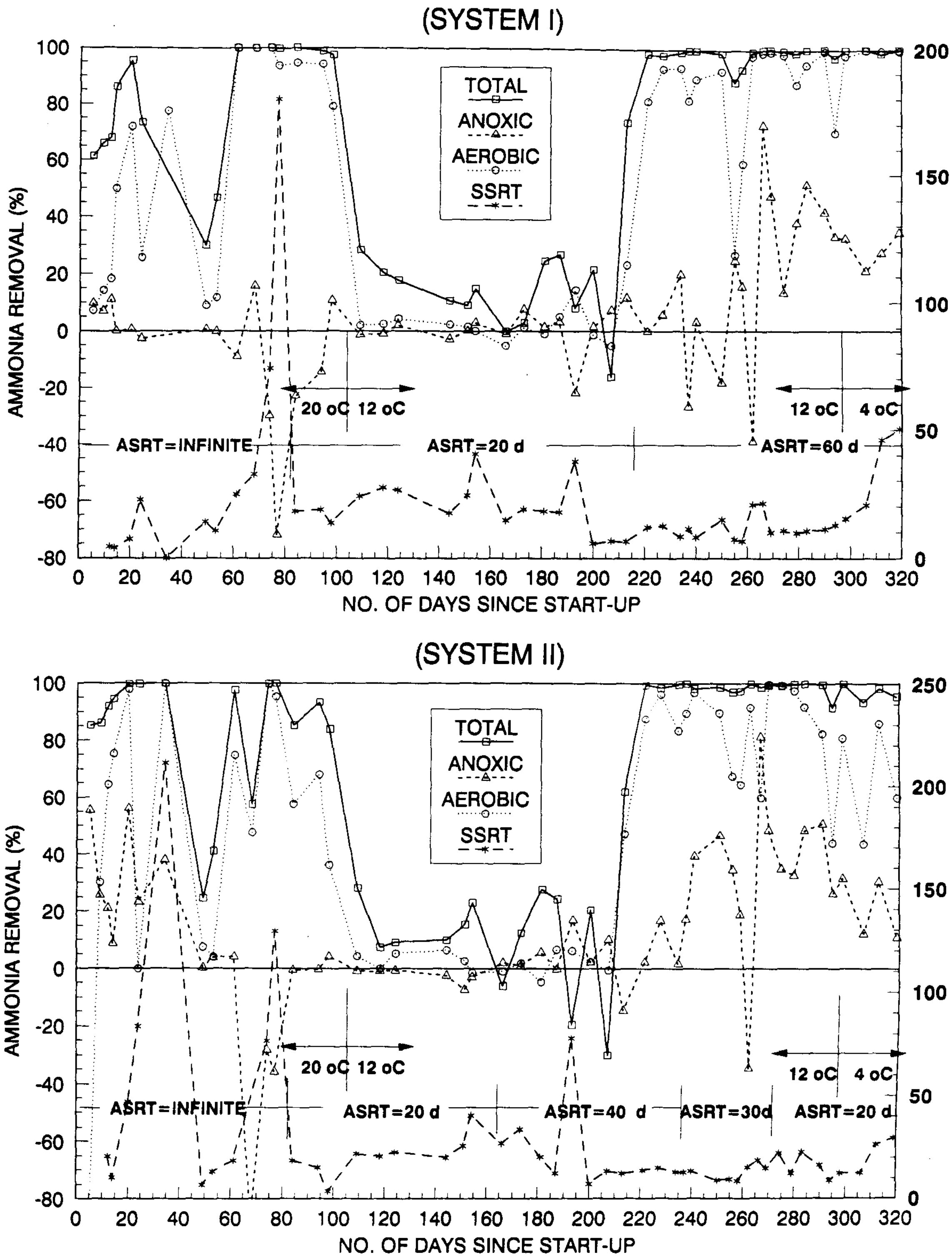


Figure 5.20: Anoxic, Aerobic and Total Ammonia-N Removal vs. Time

5.7.2 Aerobic Ammonia-N Removal

Aerobic ammonia-N removal appeared to be affected by changes in ambient temperature and methanol addition, and less affected by SRTs (Figure 5.20). In addition, aerobic ammonia-N removal followed the pattern of nitrification performance, thus indicating that most ammonia-N was removed through nitrification.

Effect of Temperature on Aerobic Ammonia-N Removal

The effects of a reduction in temperature were greater on aerobic ammonia-N removal than on anoxic ammonia-N removal, especially, when the temperature dropped from 20°C to 12°C. When bacterial acclimation was reached at a temperature of 20°C, an ASRT of 20 days (mean SSRT of 17 days in system I and 13 days in system II) and methanol addition of 12 gCOD/d in both systems, more than 80% of aerobic ammonia-N removal (mean unit removal of over 4.5 mg/h/gVSS) was achieved in both system I and system II. On day 104, with other variables remaining unchanged, the ambient temperature was suddenly reduced from 20°C to 12°C. Within one week from this date, the aerobic ammonia-N removal dropped to 2% (mean unit removal dropped to 0.7 mg/h/gVSS, mean SSRT increased to 24 days) in system I and 4% (mean unit removal dropped to 1.2 mg/h/gVSS, mean SSRT increased to 22 days) in system II. In an attempt to assist nitrifying bacterial acclimation and reduce the possibility of heterotrophic competition, methanol addition was reduced to around 10 gCOD/d for about 40 days in both systems. However, recovery was not observed. Not being aware of what had happened in the biosystem at such a low temperature, methanol addition was attempted at original dosages before the temperature was dropped. However due to feeding problems and experimental technique, the dosage ended up being 14 gCOD/d. Not surprisingly, system recovery still did not commence. The bacterial acclimation was not achieved until the methanol addition was reduced from 14 gCOD/d to around 4 gCOD/d in both systems (in the time period, phosphate addition was adjusted to around 60 mgP/d in both systems, and, the ASRT of system I was increased to 60 days and the ASRT of system II was increased to 40 days). On day 291, when the ASRT of system I was 60 days and ASRT of system II was 20 days, the ambient temperature was further reduced from 12°C to 4°C, while methanol addition was reduced from 8 to 7.4 gCOD/d in system I and from 10.1 to 7.9 gCOD/d in system II. Within 3 days of this date, the aerobic ammonia-N removal dropped from 99% to 70% in system I and from 83% to 44% in system II. The unit rates did not drop in either two systems, indicating that at lower temperatures, the drop of temperature did not affect the unit aerobic ammonia removal as much as it did at higher temperatures. The reduction of methanol dosage might have assisted in the nitrifying bacterial acclimation.

Effect of Methanol Addition on Aerobic Ammonia-N Removal

At 20°C, after bacterial acclimation was properly established, the aerobic ammonia-N removal reached over 90% and its average unit removal reached over 5 mg/h/gVSS, with an aerobic NO_x^--N concentration of over 100 mgN/l in both systems. After the temperature was reduced to 12°C on day 104, aerobic ammonia-N removal dropped to lower than 10%, its unit removal dropped to 0.5 mg/h/gVSS, and, aerobic NO_x-N concentration remained under 1 mg/l in both systems. This indicated that there was little or no nitrification occurring. Ortho-phosphorus concentration then was below 0.5 mg/l in both systems. In an attempt to determine if increase phosphorus addition could stimulate the return of healthy nitrification at lower temperatures, commencing on day 161, the ortho-P addition was increased from 1.4 mgP/d to 4.2 mgP/d and further increased to a point where 155 mgP/d was being added. The ASRT of system I was increased from 20 days to 60 days on day 213, and the ASRT of system II was increased from 20 days to 40 days on day 162. Ammonia-N removal and nitrification in the two systems did not re-establish themselves to healthy levels until day 199, when finally the methanol addition was reduced from 14 gCOD/d to 4 gCOD/d. Within three weeks, system I reached an aerobic ammonia-N removal of 81% and its average unit removal reached 2.8 mg/h/gVSS. System II reached an aerobic ammonia-N removal of 88% and its average unit removal reached around 3 mg/h/gVSS. At the same time, aerobic NO_x^--N reached 10 mgN/l in system I and 24 mgN/l in system II (which were lower than at 20°C due to coincidental lower influent ammonia-N concentration in the time period). This recovery pattern, due to the lower methanol concentration, could involve an increase in the growth rate of nitrifying bacteria (which produced more NO_x^--N), and possibly reduced the growth of heterotrophic bacteria in the aerobic reactors.

Commencing on day 252, methanol addition was stopped completely for one week. Within three days, mean unit aerobic ammonia-N removal increased from 2.8 to 2.9 mg/h/gVSS in system I (ASRT remained at 60 days, whereas, SSRT dropped from 15 days to 7 days) and from 1.7 to 3.1 mg/h/gVSS in system II (ASRT remained at 30 days, whereas, SSRT dropped from 14 days to 9 days). However, at the same time, percentage aerobic ammonia-N removal dropped from 92% to 27% in system I and from 90% to 68% in system II. During this time period, NO_x^--N production increased from 20 mg/l to 94 mg/l in system I and from 25 mg/l to 112 mg/l in system II (This was partly due to a new leachate sample, which contained higher ammonia-N).

The unit aerobic ammonia-N removal versus the ratio of methanol addition to the NO_x^--N nitrogen entering the anoxic reactor is represented in Figure 5.21 (Note: The data in this figure is collected from both systems). Aerobic ammonia removal dropped with the increase in this ratio. At a temperature of 20°C, unit ammonia-N removal of over 7 mg/h/gVSS was achieved when the ratio of methanol addition to NO_x^--N entering the anoxic reactor ranged from zero to 5:1. At a temperature of 12°C, unit ammonia-N

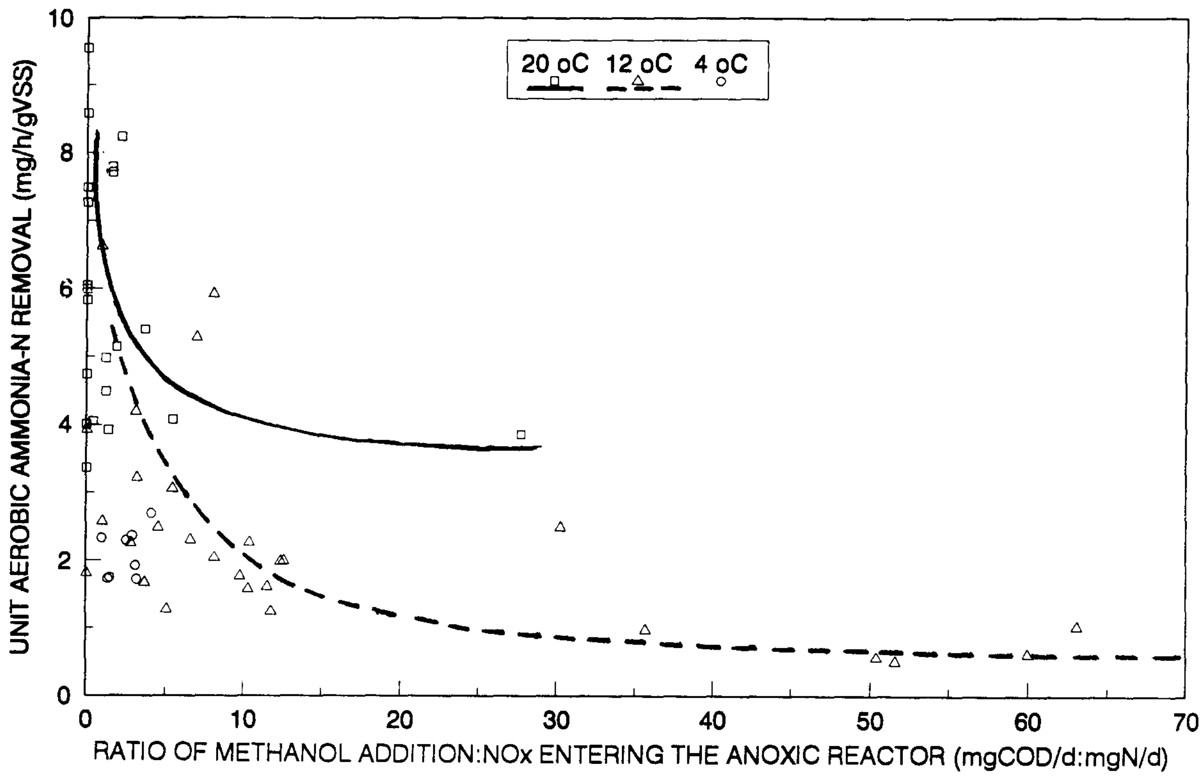


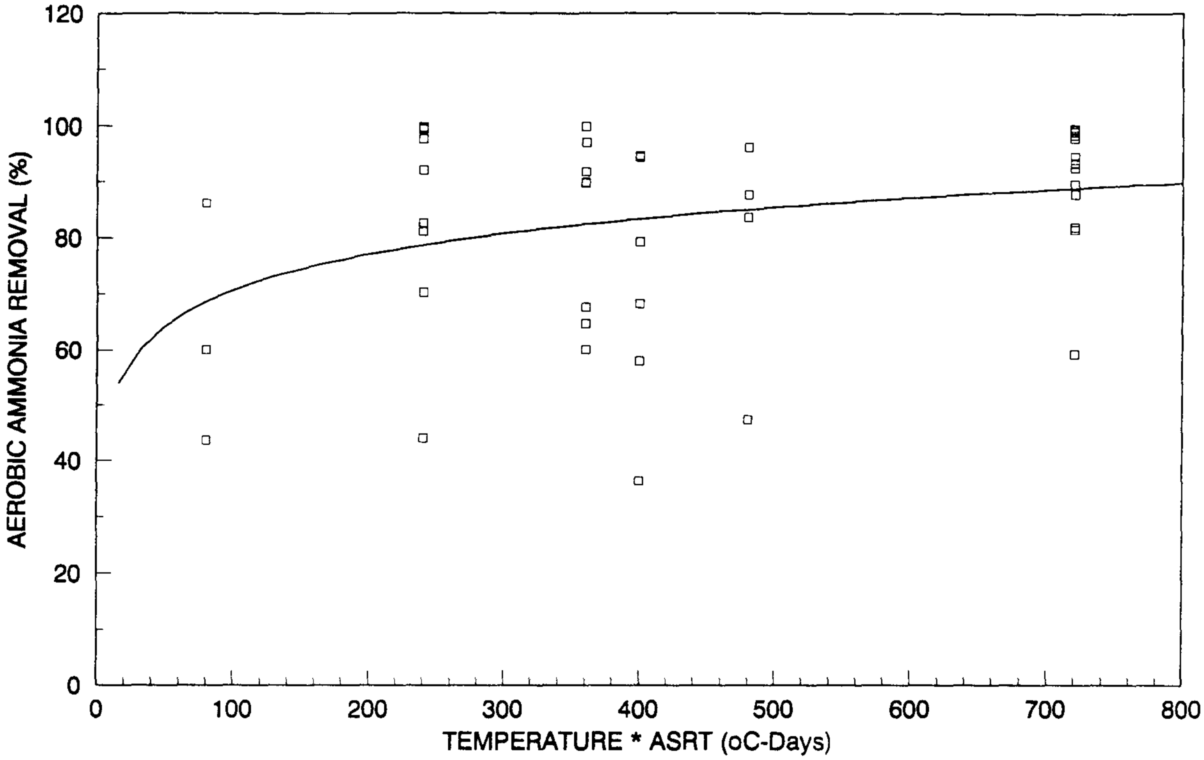
Figure 5.21: Unit Aerobic Ammonia-N Removal vs. Ratio of COD Addition:NO_x^--N Entering the Anoxic Reactor

removal of over 4 mg/h/gVSS was achieved when this ratio ranged between zero and 5:1. It was noticed that when this ratio was higher than 30:1, a unit aerobic ammonia-N removal of higher than 1 mg/h/gVSS was difficult to be achieve. Because of time constraints for this project, not enough data was collected to show the optimum ratio range needed to achieve higher levels of aerobic ammonia-N removal at a temperature of 4°C.

Effect of SRT on Aerobic Ammonia-N Removal

As shown in Figure 5.20, at 12°C, there was no significant difference in terms of aerobic ammonia-N removal between ASRTs of 60 days, 40 days and 30 days. However, an ASRT of 20 days exhibited a lower level of ammonia-N removal (average of less than 80%) at the end of a 20 day cycle (mean SSRT was 18 days). At 4°C, during an ASRT of 60 days (mean SSRT was 29 days), the aerobic ammonia-N removal rate was still as high as 99% to 100%, with effluent ammonia-N concentration averaging 1.9 mg/l (average methanol addition was 7 gCOD/d). Whereas, during an ASRT of 20 days (mean SSRT was 18 days), the aerobic ammonia-N removal rate was unstable, fluctuating between 40% and 83%, with effluent ammonia-N concentration averaging 9.2 mgN/l (average methanol addition was 7.6 gCOD/l). However, during this time period, the system with an ASRT of 20 days had an average unit aerobic ammonia-N removal of 2.3 mg/h/gVSS, higher than the system with an ASRT of 60 days (average 1.9 mg/h/gVSS).

A possible combined effect of temperature and SRTs on aerobic ammonia-N removal is presented in Figure 5.22 and Figure 5.23 (Note: The data in these figures is collected from both systems). The curve were drawn through a logarithm regression (by using Freelance software). The level of ammonia-N removal appeared to increase with the degree-days, as shown in these figures. At 20°C, with an ASRT of 20 days, the degree-days was $20 \times 20 = 400$. At 12°C, with ASRTs of 20, 30, 40, and 60 days, the degree-days were 240, 360, 480 and 720, respectively. At 4°C, with ASRTs of 20 and 60 days, the degree-days were 80 and 240, respectively. Under a careful methanol addition and operation, it was possible to obtain ammonia-N removal of over 75% at a degree-ASRTdays product of 100 or degree-SSRTdays product of 50. In order to obtain a unit aerobic ammonia-N removal of over 2 mg/h/gVSS, degree-ASRTdays of over 100 was needed, whereas, degree-SSRT days of only 50 was needed for the same amount of aerobic ammonia-N removal (because a large portion of VSS was lost from the clarifier effluent, which had caused the SSRT to be much lower than the ASRT). More studies would be needed, however, to confirm this system response and to expand on the performance when the degree-ASRTdays product drops below 100. The graphic scenario shown in Figure 5.22 and Figure 5.23 are interesting ones and could be very useful in application to full-scale design of such an ammonia-N treatment system.



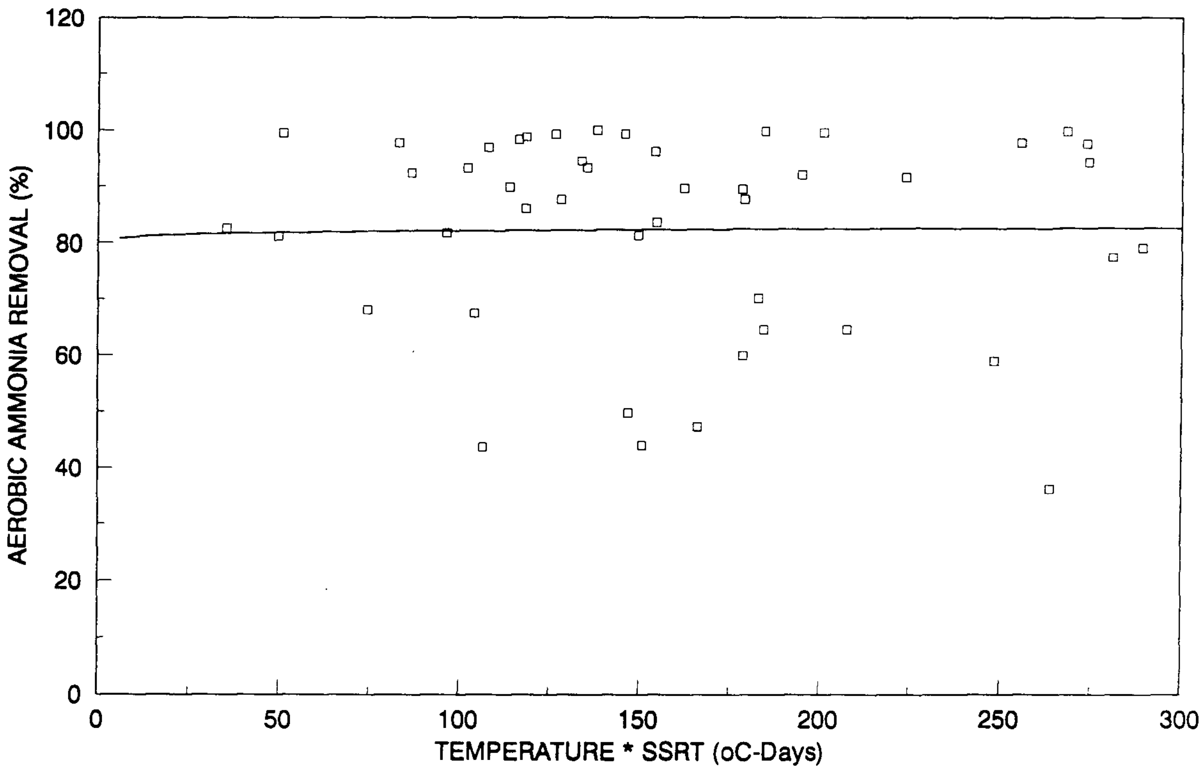


Figure 5.22: Aerobic Ammonia-N Removal vs. Temperature and SRTs

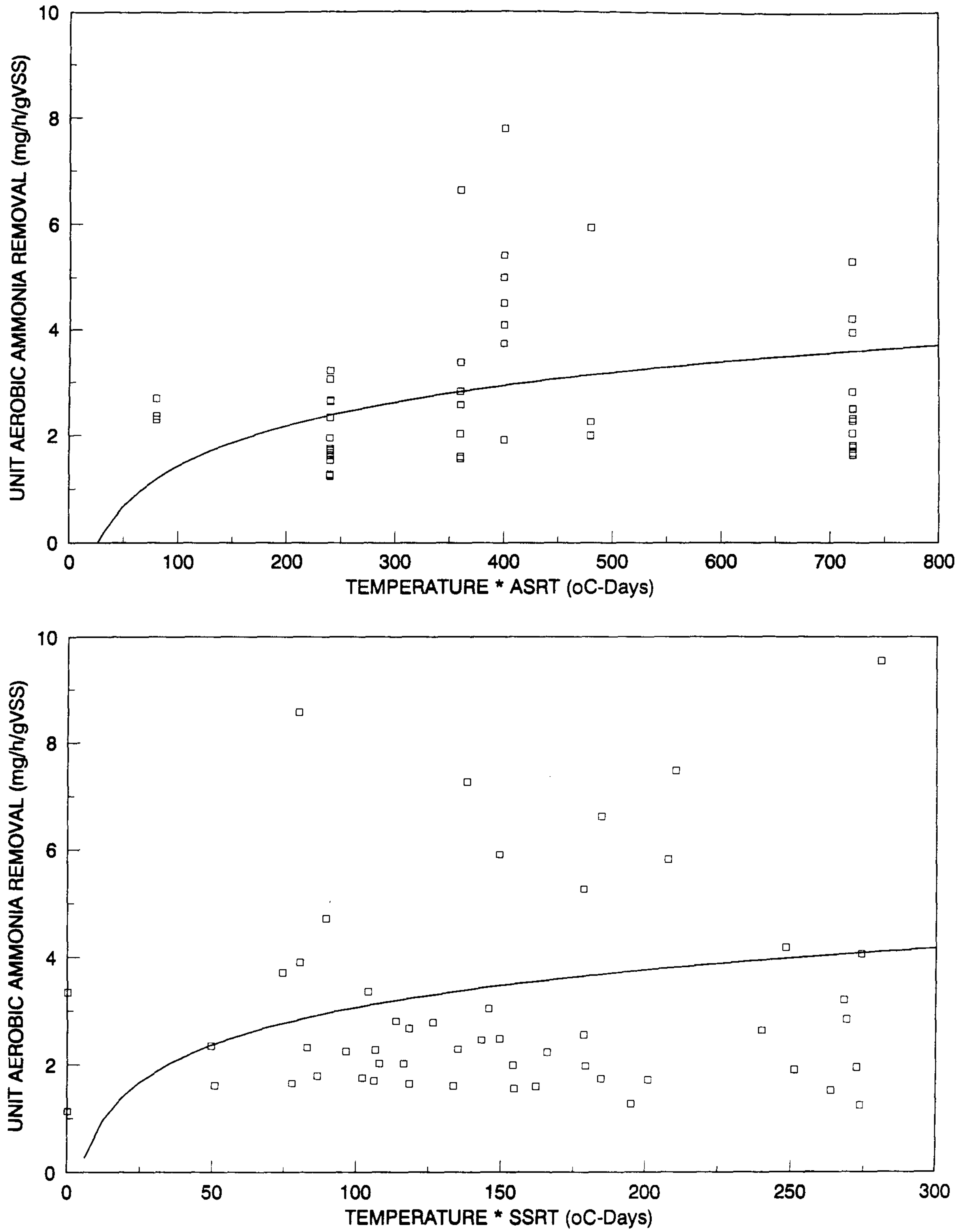


Figure 5.23: Unit Aerobic Ammonia-N Removal vs. Temperature and SRTs

5.7.3 Total Ammonia Removal

Total ammonia-N removal is also shown in Figure 5.20. Increases and decreases in total ammonia-N removal occurred simultaneously with changes in aerobic ammonia-N removal, with most of the ammonia-N removed by nitrifying bacteria in the aerobic reactor. The ammonia-N concentration in the raw leachate ranged from 85 mgN/l to 320 mgN/l. When bacterial acclimation was achieved at any of the three temperatures studied, and different SRTs, the effluent ammonia-N concentration was reduced to less than 1 mgN/l (Figure 5.24). This pattern indicated that it was possible to achieve a satisfactory level of ammonia-N removal at low operating temperatures, through proper acclimation and careful system control.

5.7.4 Effect of Ortho-P on Ammonia Removal

At an ambient temperature of 20°C, total ammonia-N removal of more than 80% and aerobic ammonia removal of over 60% were reached when ortho-P concentrations in the aerobic reactor of the two systems measured only 0.1 to 0.5 mgP/l. However, at an ambient temperature of 12°C, this ortho-P content might be insufficient to support this high level of ammonia-N removal through nitrification. Greater than 0.8 mgP/l of ortho-P appeared to be needed in the aerobic reactor to maintain good nitrification at this low temperature. However, an increase in ASRT from 20 days to 60 days in system I and from 20 days to 40 days in system II, during the low temperature acclimation period, might also have attributed to the recovery of nitrifying bacteria. Additional work on the exact relationship between phosphate requirements, SRTs and nitrification performance at low liquid temperatures is required to clarify specific bacterial responses to excess phosphate stimulation.

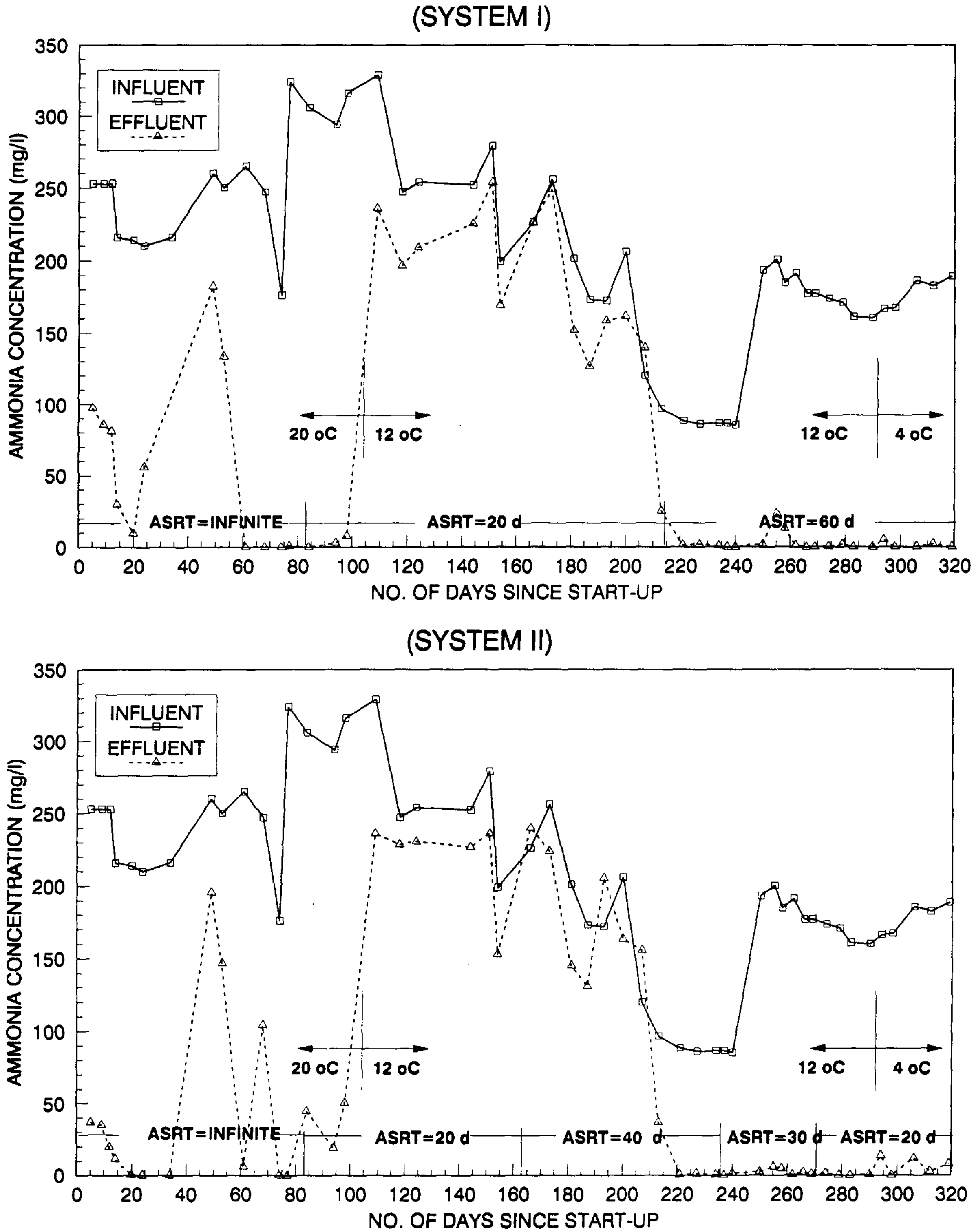


Figure 5.24: Influent and Effluent Ammonia-N vs. Time

5.8 Nitrification

The percent nitrification was calculated by dividing the net NO_x^--N produced in the aerobic reactor by the amount of ammonia-N entering the aerobic reactor. Ammonia-N removed by air stripping and aerobic assimilation was disregarded in this calculation (assumed to be potentially up to 15%), so that a conservative estimate of nitrification percent was obtained. Potentially, however, a larger amount of ammonia-N would be removed by air stripping in the aerobic reactor than in the anoxic reactor. Also, some ammonia-N existing in either reactor would be of microbial origin, due to cell lysis; this portion of ammonia-N would also be oxidized to NO_x^--N, but it was not taken into account in this calculation (filtered TKNs were not regularly monitored in this study). This additional ammonia-N resulted in frequent readings of over 100% nitrification, as illustrated in Figure 5.25. The alkalinity in Burns Bog leachate, being over seven times as ammonia-N, was assumed to be sufficient for the nitrification in this study.

Ammonia-N undergoing nitrification was significantly affected by changes in ambient temperature and the dosage of methanol. SRTs manipulation had a somewhat lesser effect on nitrification at 12°C.

5.8.1 Effect of Temperature on Nitrification

As shown in Figure 5.25 and Figure 5.26, on about day 82, when complete nitrification appeared to be established in both systems, daily wasting from the aerobic reactor started to reach an ASRT of 20 days. Methanol and phosphorus dosages were controlled at identical rates between the two systems. Within 20 days (one ASRT cycle), system I maintained a nitrification value of about 97% with mean unit nitrification of 5.7 mg/h/gVSS. System II maintained a nitrification value of about 56% with mean unit nitrification of 5.9 mg/h/gVSS. On day 104, the ambient temperature was reduced from

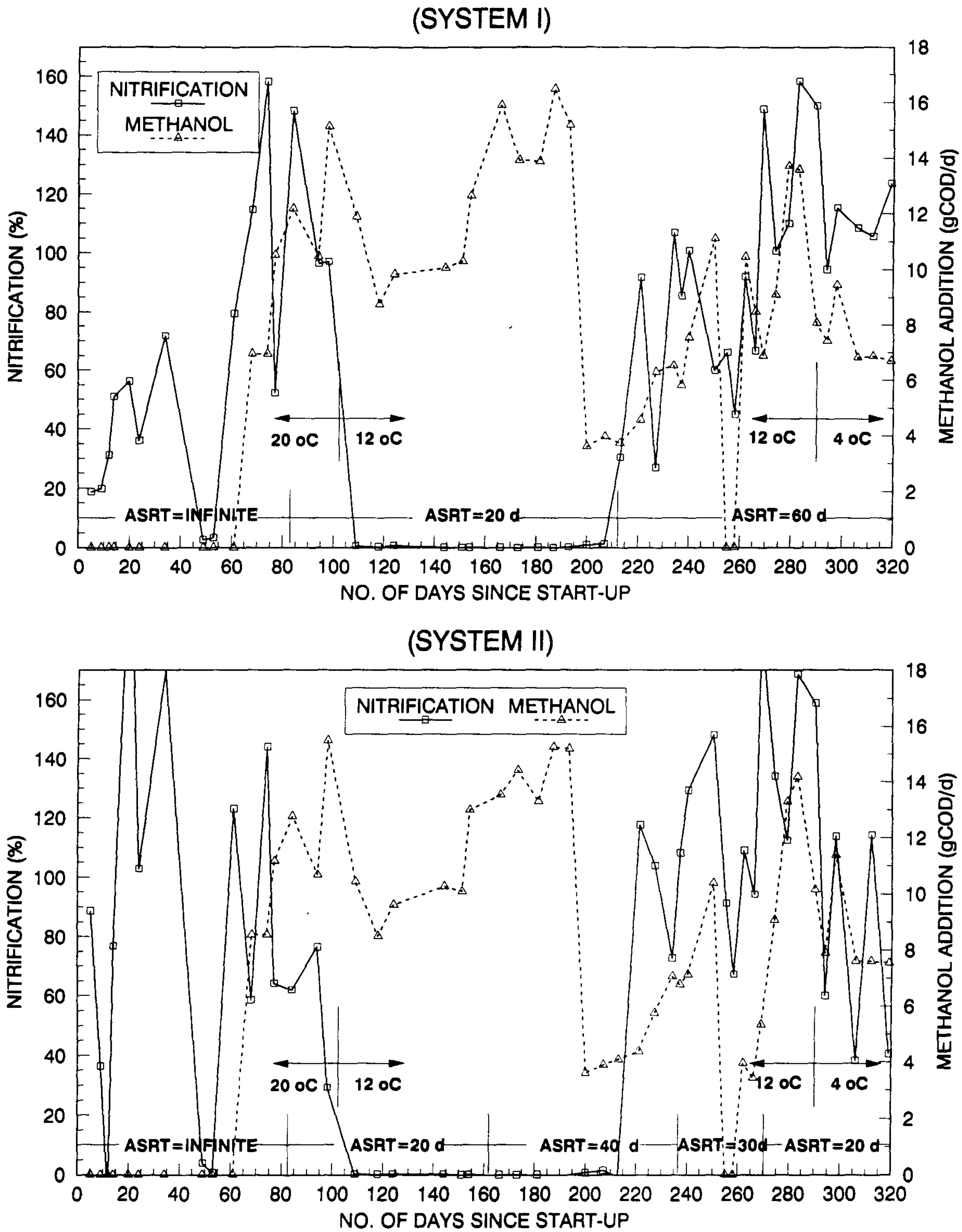


Figure 5.25: % Nitrification vs. Time

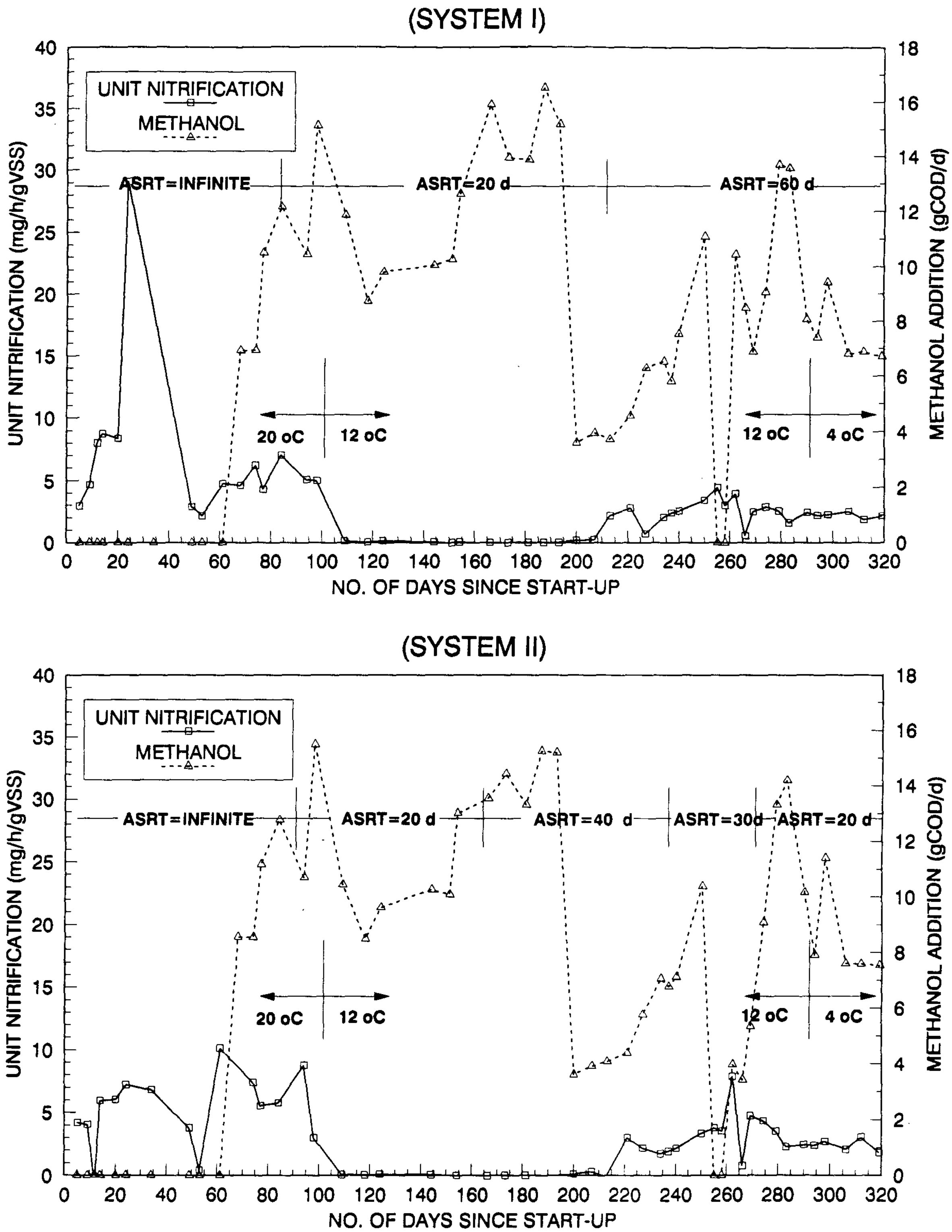


Figure 5.26: Unit Nitrification vs. Time

20°C to 12°C, with ASRT remaining unchanged and methanol addition slightly reduced. Within four days of this date, the nitrification level dropped to less than 1% with mean unit nitrification of less than 0.2 mg/h/gVSS in both systems. After the adjustment (ie, decrease and increase, respectively) of methanol and phosphate addition, as well as increasing the ASRT to 60 days (at day 212) in system I and 40 days in system II (at day 160), the level of nitrification finally increased to around 100%, with mean unit nitrification of around 2 mg/h/gVSS in both system I and II.

System I kept operating under an ASRT of 60 days till the end of this study, while the ASRT in system II was reduced to 30 days and finally reduced to 20 days. Neither system experienced major operational problems. On day 291, the ambient temperature was reduced from 12°C to 4°C, with methanol addition being reduced from 8 gCOD/d to 7.4 gCOD/d in system I and 10.1 to 7.9 in system II. Within three days, the nitrification level dropped from 150% to 95% and mean unit nitrification remained at 2.2 mg/h/gVSS in system I (ASRT = 60 days, SSRT increased from 11.1 days to 12.7 days) and from 159% to 60% and mean unit nitrification dropped from 3.2 to 2.3 mg/h/gVSS in system II (ASRT = 20 days, SSRT reduced from 16.2 days to 8.9 days). This indicated that the nitrifying bacteria were significantly inhibited by the sharply reduced temperature from 20°C to 12°C, but not as much from 12°C to 4°C. The reduction of methanol dosage might have helped the nitrifying bacteria better acclimate when the temperature was dropped.

On day 294, after sampling, a laboratory power breakdown caused both systems I and II to stop operating for one day, until a temporary power system was connected. However, the temperature rose to 23°C and lasted for three days until day 297. The temperature was re-adjusted at 12°C for one day. On day 298, after sampling, the temperature was reduced back to 4°C. Within three weeks, the nitrification level returned to over 100% in system I (ASRT = 60 days) and fluctuated between 40% and 110% in system II

(ASRT = 20 days). This pattern indicated that, at low temperature conditions, a sudden increase and decrease in temperature over a short time period did not adversely affect the nitrification process in treatment of this leachate.

5.8.2 Effect of Methanol Addition on Nitrification

On day 66, when the nitrification level reached 80% in system I and 120% in system II, methanol addition was started, with the exact same dosage between the two systems (started at about 7 gCOD/d and increased to around 12 gCOD/d on day 77, and then kept constant). On day 82, both systems started operating with an ASRT of 20 days. On day 85, phosphate addition was started in both systems at 1.7 mgP/d. Within these 20 days (one SRT cycle), the average nitrification level reached 97% in system I and 56% in system II. On day 104, the ambient temperature was reduced from 20°C to 12°C. Within four days, the nitrification levels dropped to less than 1% and unit levels dropped to less than 0.2 mg/h/gVSS in both systems, as noted in section 5.8.1.

In an attempt to aid bacterial acclimation, on day 108, methanol addition was adjusted downward to around 10 gCOD/d in both systems. For about one month, the nitrification level still remained less than 5%, or 0.2 mg/h/gVSS. During this time period, percent denitrification was above 80%; however, unit denitrification level was below 1 mg/h/gVSS in both systems. As it was not clear what had happened in the bio-system at the low temperature, on day 152, methanol addition was attempted to increase the dosage back to the level prior to the temperature drop. However, because of poor control in the pumping equipment, the dosage ended up around 14 gCOD/d. At the same time, phosphate addition was increased from around 1 mgP/d to 3.3 mgP/d, and then gradually increased to 150 mgP/d (by day 193). On day 162, the ASRT of system II was increased from 20 days to 40 days and on day 213, the ASRT of system I was increased from 20 days to 60 days. On day 199, the methanol addition was reduced from 14 gCOD/d to 4 gCOD/d in both systems. Within three weeks after this final reduction, the nitrification value recovered from zero to 92%, with its mean unit level 2.3 mg/h/gVSS in system I, and from zero to 118%, with its mean unit level 1.7 mg/h/gVSS in system II.

On day 291, while the ASRT of system I was 60 days and the ASRT of system II was 20 days, the ambient temperature was further reduced from 12°C to 4°C. Meanwhile, methanol addition was reduced from 8 gCOD/d to 7.4 gCOD/d in system I and from 10.1 gCOD/d to 7.9 gCOD/d in system II (phosphorus addition remained around 95 mgP/d in system I and around 140 mgP/d in system II). As noted previously, within three days, nitrification level dropped from 150% to 95% in system I and from 159% to 60% in system II. However, unit nitrification level remained at 2.2 mg/h/gVSS in system I but dropped from 3.2 mg/h/gVSS to 2.3 mg/h/gVSS in system II.

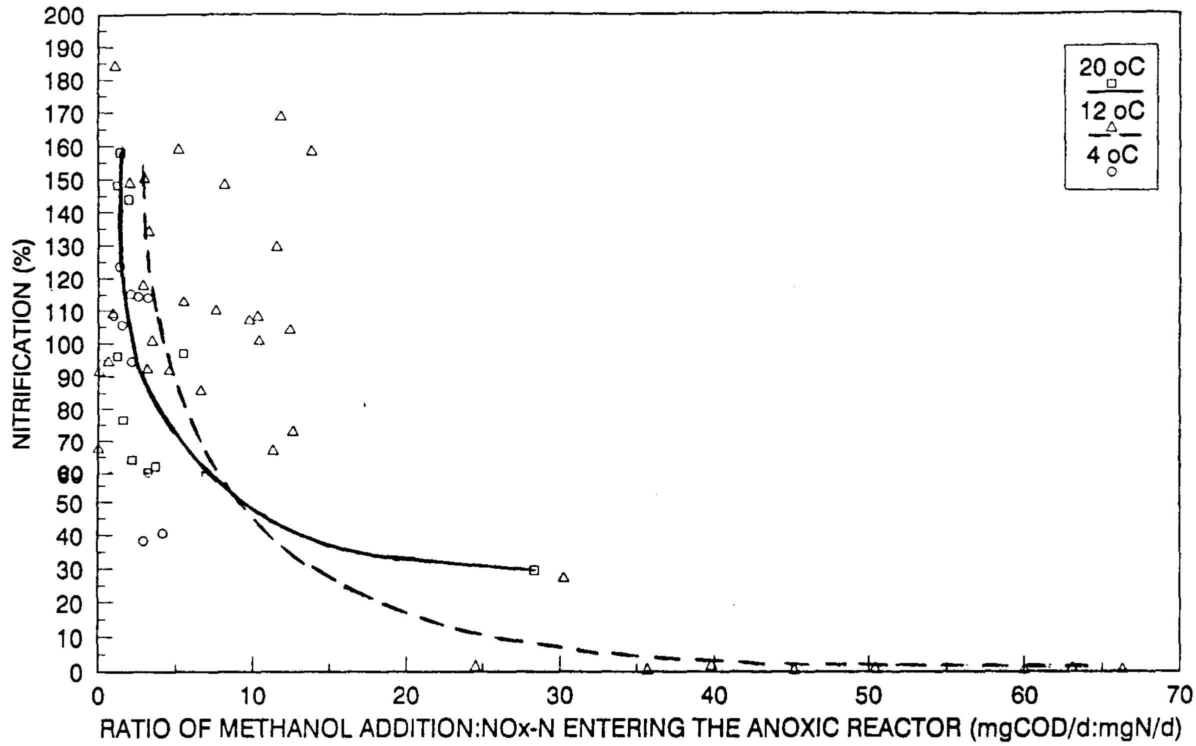
During this entire operating period, it became clear that methanol addition must be carefully monitored and adjusted accordingly, in response to changes in system performance stemming from temperature reductions. Nitrification performance was shown to be closely tied to both variables, and less effected by changes in SRTs.

Commencing on day 252, the methanol addition was stopped completely (for one week). Within 6 days, the mean unit nitrification rates had increased from 2.3 to 3.7 mg/h/gVSS in system I and from 2.5 to 3.7 in system II, confirming the presence of autotrophic nitrifying bacteria. However, during this time period, the nitrification value dropped from 60% to 45% in system I and from 148% to 67% in system II; effluent NO_x^--N level increased from average 20 mg/l to 94 mg/l in system I and from 25 mg/l to 112 mg/l in system II. A new leachate feed (started before day 252), containing higher ammonia-N, was responsible for this result.

The relationship between the nitrification level and the ratio of COD addition to NO_x^--N entering the anoxic reactor is illustrated in Figure 5.27 (Note: The data in this figure is collected from both systems). Higher levels of nitrification did not appear to require higher ratios of COD:NO_x^--N (beyond about 15:1). Furthermore, if this ratio was higher than 30:1, the level of nitrification was inhibited at both 20°C and 12°C (*Carley, 1988*, when doing a very similar leachate biotreatment study at room temperature, observed that, for methanol as a carbon source, nitrification decreased to between 60% to 70% as the COD-to-NO_x^--N ratio increased beyond approximately 20:1). Overall, the change in methanol addition was observed to have a greater effect on system performance than the drop in temperature from 20°C to 12°C.

5.8.3 Effect of SRTs on Nitrification

ASRTs of 20, 30, 40 and 60 days did not cause much of a change in the level of nitrification at the temperature of 12°C (as also presented in Figure 5.25). However, when the temperature was reduced from 12°C to 4°C, the nitrification level at an ASRT of 20 days exhibited a sharper decrease (from 159% to 60%, mean unit level decreased from 3.2 mg/h/gVSS to 2.3 mg/h/gVSS) than that at a 60-day ASRT (from 150% to 95%, mean unit level remained 2.2 mg/h/gVSS unchanged). At 4°C, the effluent ammonia level was higher at a 20-day ASRT (average 9.2 mgN/l, with average methanol addition of 7.6 gCOD/d) than at a 60-day ASRT (average 1.9 mgN/l, with average methanol addition of 7 gCOD/d). However, 9.2 mgN/l of effluent ammonia-N was still relatively low, compared with the influent ammonia-N level (around 300 mg/l during that time period). Figure 5.28 and Figure 5.29 present the relationship (similar to Figure 5.22 and Figure 5.23) between nitrification and temperature × SRTs (degree-days). The level of nitrification appeared to increase with the increase in degree-days. The curves were drawn through logarithm regression (by using Freelance software). As shown in Figure 5.28 (Note: The data in this figure is collected from both systems), in order to obtain a percent nitrification of over 80%, 100 degree-ASRTdays or 50 degree-SSRTdays was



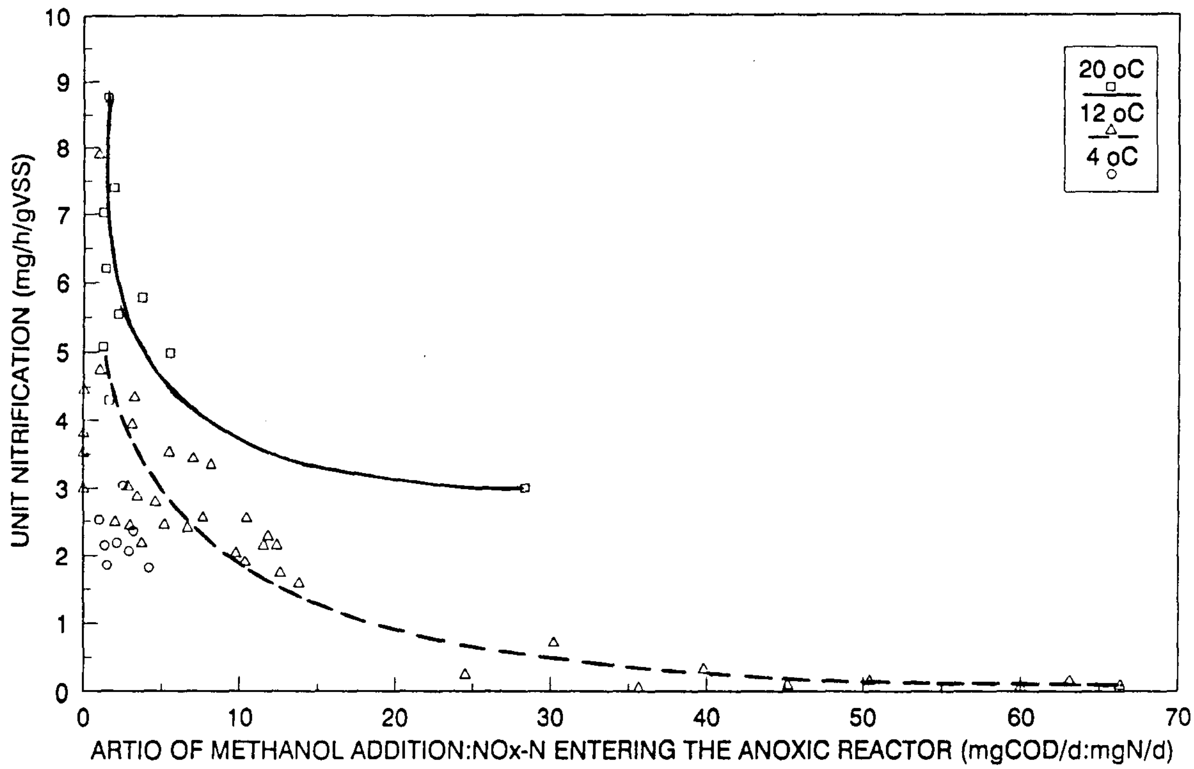


Figure 5.27: Nitrification vs. Ratio of COD Addition:NO_x^--N Entering the Anoxic Reactor

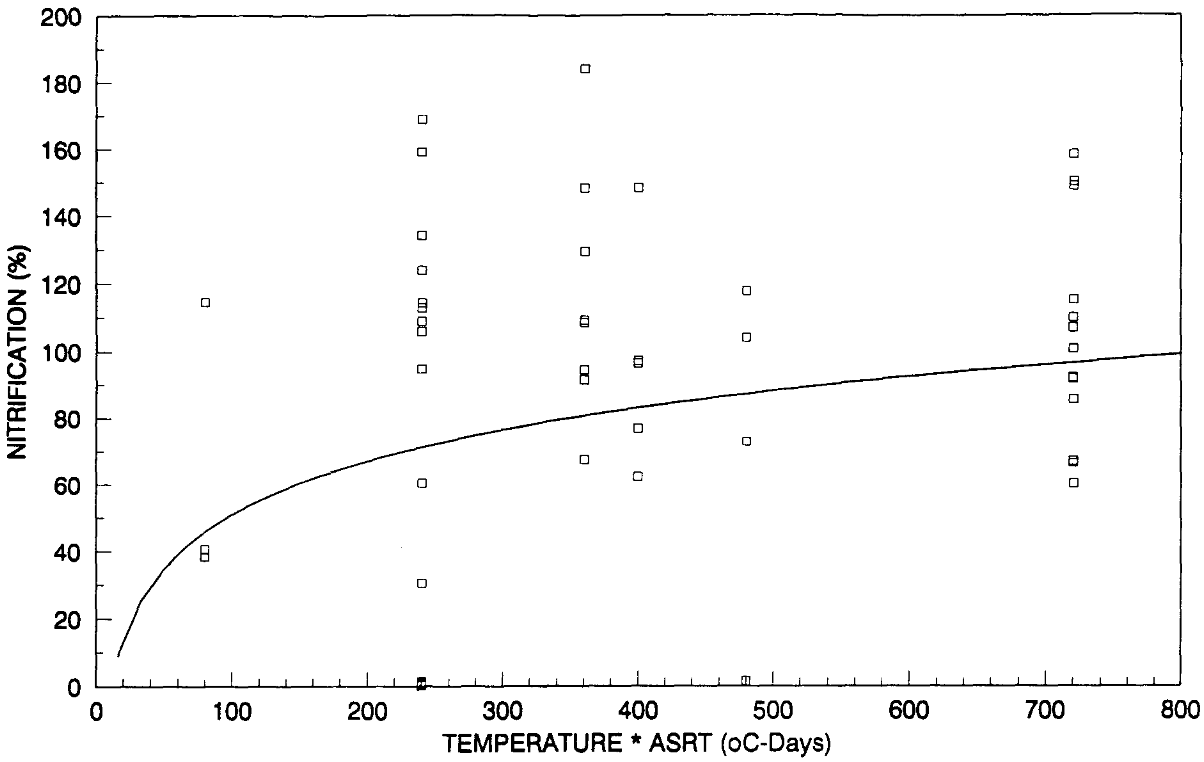
sufficient. As shown in Figure 5.29 (Note: The data in this figure is collected from both systems), in order to obtain a unit nitrification of over 2 mg/h/gVSS, degree-ASRTdays of 100 was needed, whereas, degree-SSRTdays of only 50 was needed to obtain the same unit nitrification (because a large portion of VSS was lost to the effluent, which caused the SSRT to be lower than the ASRT). However, a careful operational control and methanol dosage control is also important, and cannot be ignored for this type of treatment configuration. More studies are needed to confirm system response for a degree-ASRTdays product less than 100.

5.8.4 Effect of Ortho-P on Nitrification

At a temperature of 20°C, low aerobic ortho-P concentration did not affect the nitrification process, as presented in Figure 5.30 (Note: The data in this figure is collected from both systems). When the aerobic ortho-P concentration was less than 0.5 mgP/l, the level of nitrification still ranged from 60% to 160%; the unit level of nitrification reached over 4 mgN/h/gVSS. However, at temperature of 12°C, with an identical amount of aerobic ortho-P, the nitrification level was basically zero. Extra carbon in form of methanol was the main reason for this zero level. However, lack of phosphorus might be an additional reason affecting the nitrifying process. In order to reach higher levels of nitrification, an aerobic ortho-P of 0.8 mg/l appeared to be needed at a temperature of 12°C, regardless of the SRTs and methanol addition. However, the results are not conclusive with the limited data base available in this study.

5.8.5 Optimum pH Value for Nitrification

As illustrated in Figure 5.31 (Note: The data in this figure is collected from both systems), at a temperature of 20°C, higher levels of nitrification were reached when the pH value in the aerobic reactor varied between 7.5 and 8.1. At temperature of 12°C, this range was



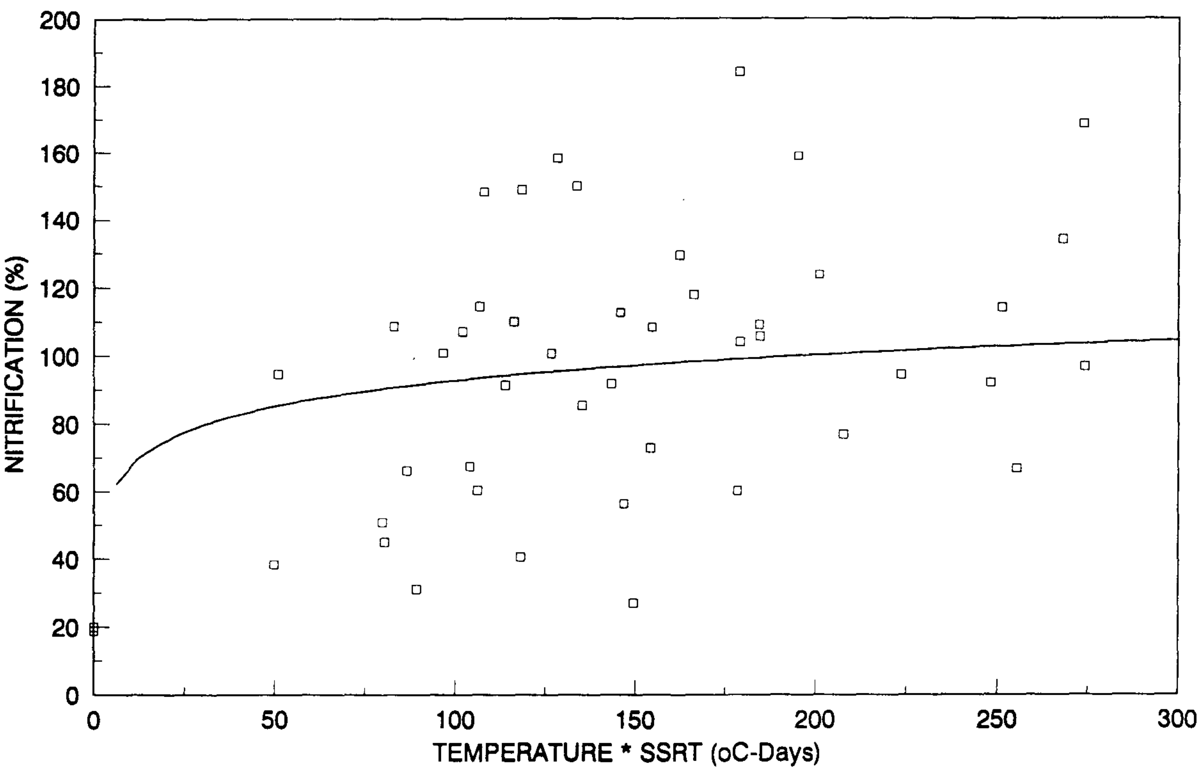
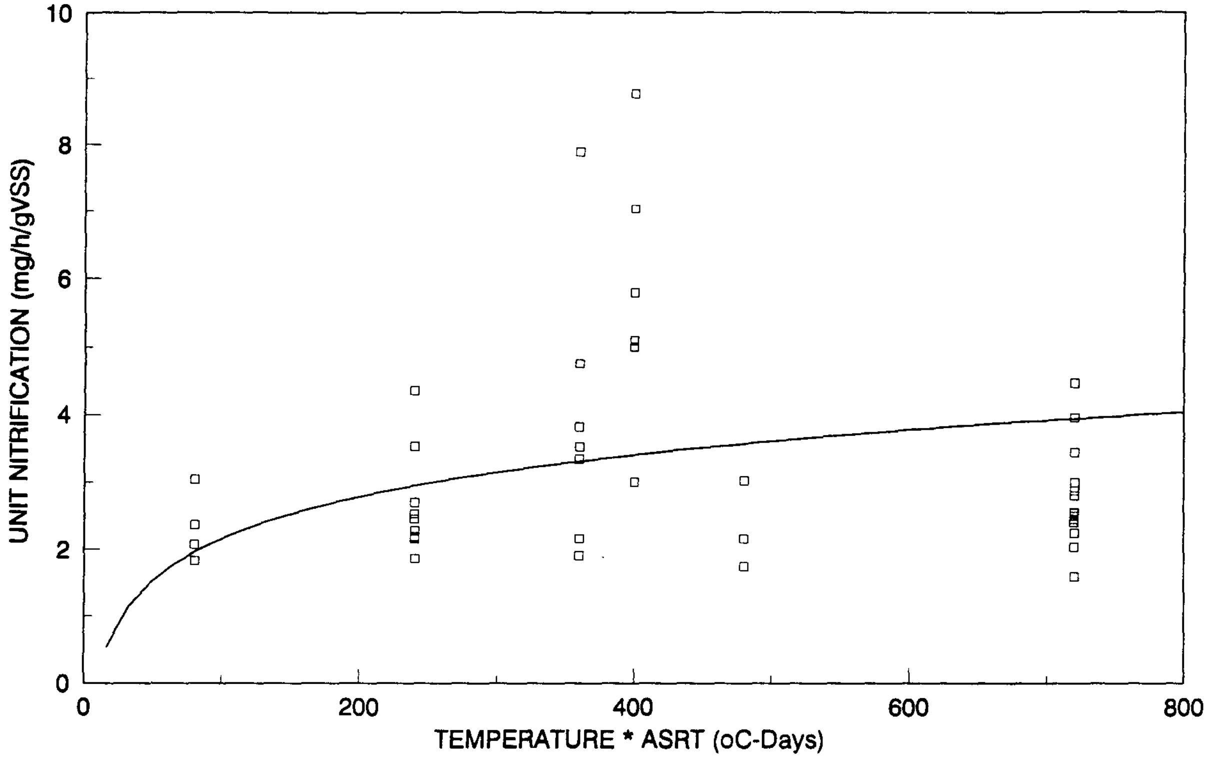


Figure 5.28: Nitrification vs. Temperature and SRTs



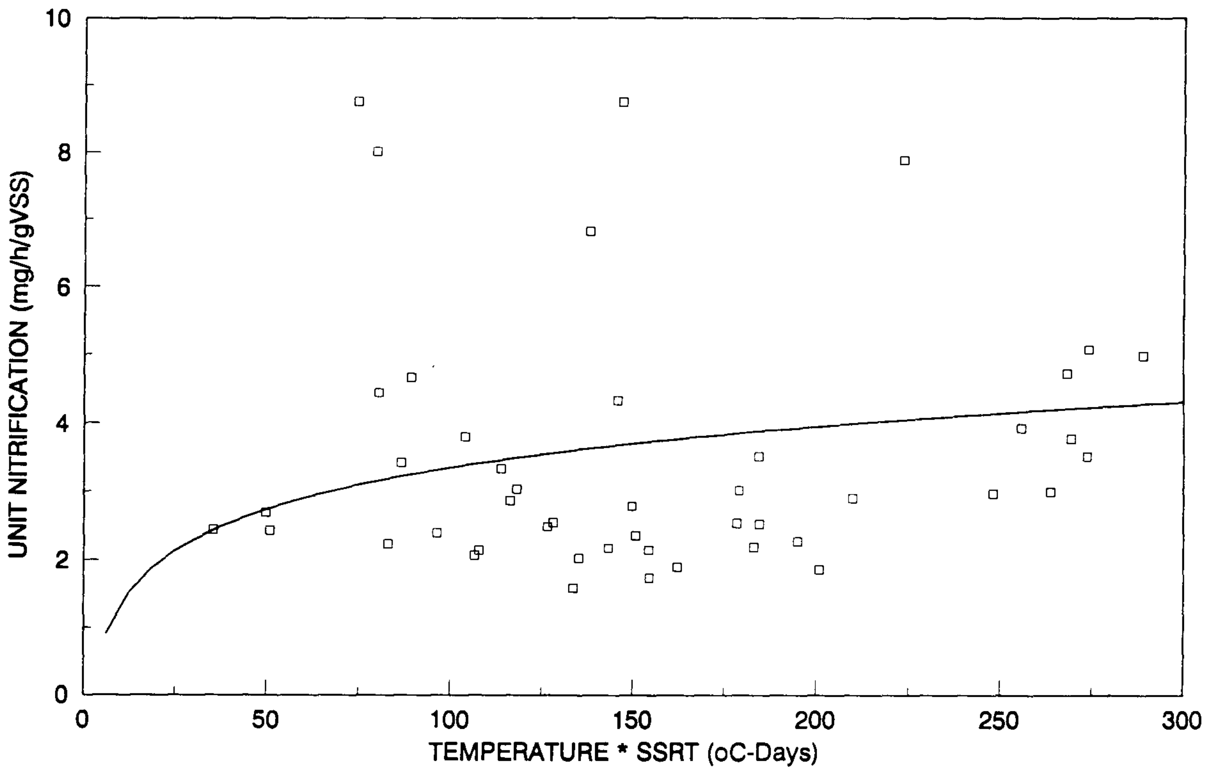


Figure 5.29: Unit Nitrification vs. Temperature and SRTs

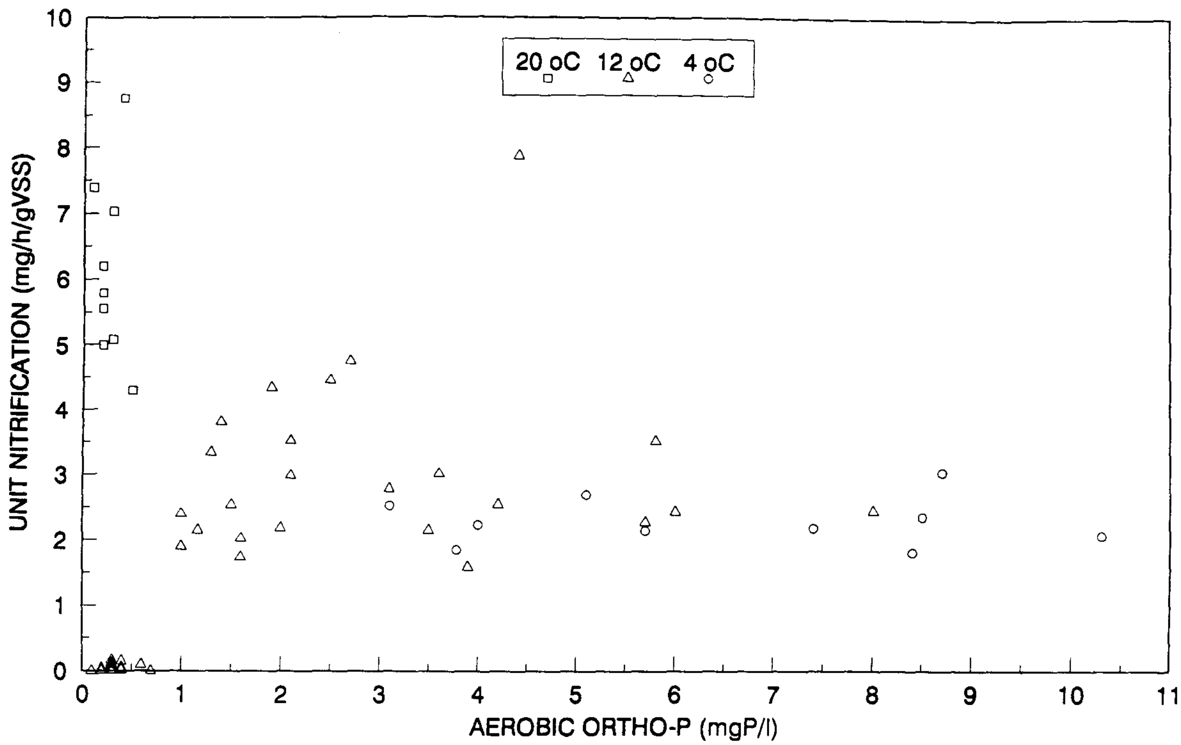


Figure 5.30: Nitrification vs. Aerobic Ortho-P

7.6 to 8.3. Over the range of the temperatures studied, the highest level of nitrification was achieved when the aerobic pH value was around 7.8. This is identical to the results obtained by *Antoniou et al*, (1990). pH values higher than 8.3 were found to be toxic to the process of nitrification.

5.9 Denitrification

The level of denitrification was calculated by dividing the net NO_x^--N removed from the anoxic reactor by the amount of total NO_x^--N entering the anoxic reactor. The level of denitrification was significantly affected by changes in the ambient temperature and the amount of methanol added, and lesser affected by SRTs (Figure 5.32 and Figure 5.33).

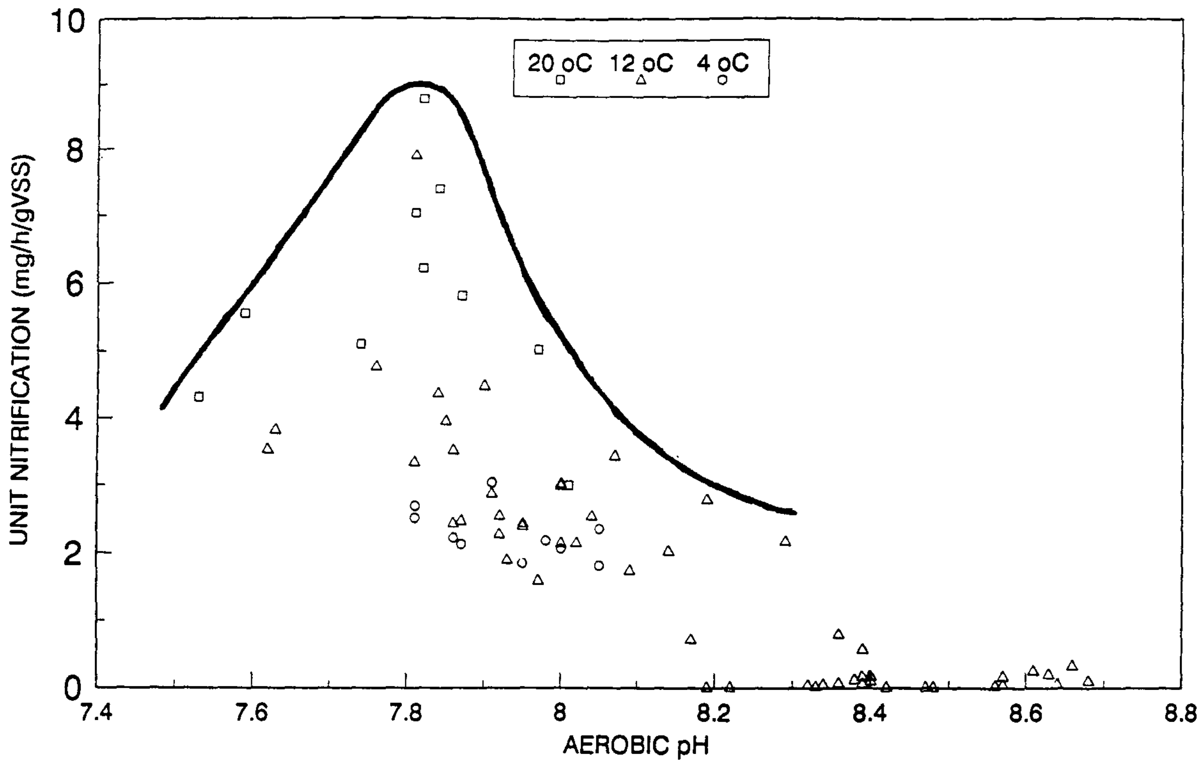


Figure 5.31: Nitrification vs. Aerobic pH

5.9.1 Effect of Temperature on Denitrification

At 20 °C, when bacterial acclimation was established, the percent denitrification level reached 100% and unit denitrification level reached average 10 mg/h/gVSS in both systems (ASRT = 20 days, methanol addition = 12 gCOD/d). On day 104, the ambient temperature was reduced from 20°C to 12°C and methanol addition was reduced to around 10 gCOD/d in both systems. The percentage denitrification level did not drop in either system I or system II (ASRT = 20 days in both systems), as illustrated in Figure 5.32. However, within four days, the unit denitrification level dropped from 8.32 mgN/h/gVSS to 0.75 mgN/h/gVSS in system I and from 1.82 mgN/h/gVSS to 0.63 mgN/h/gVSS in system II (Figure 5.33).

On day 291, the ambient temperature was again reduced, from 12°C to 4°C, methanol addition was reduced from 8 to 7.4 gCOD/g in system I and from 10.1 gCOD/d to 7.9

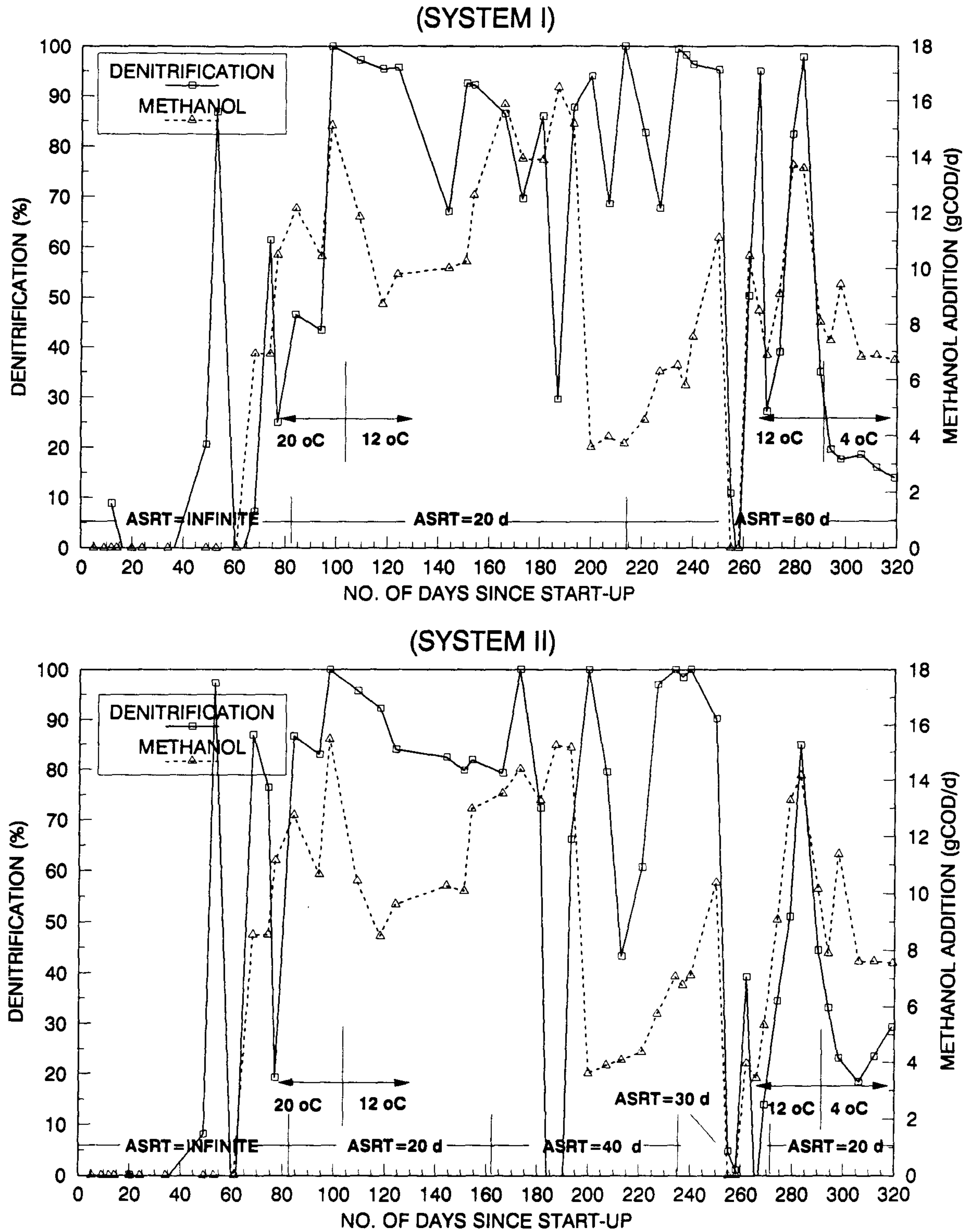


Figure 5.32: % Denitrification vs. Time

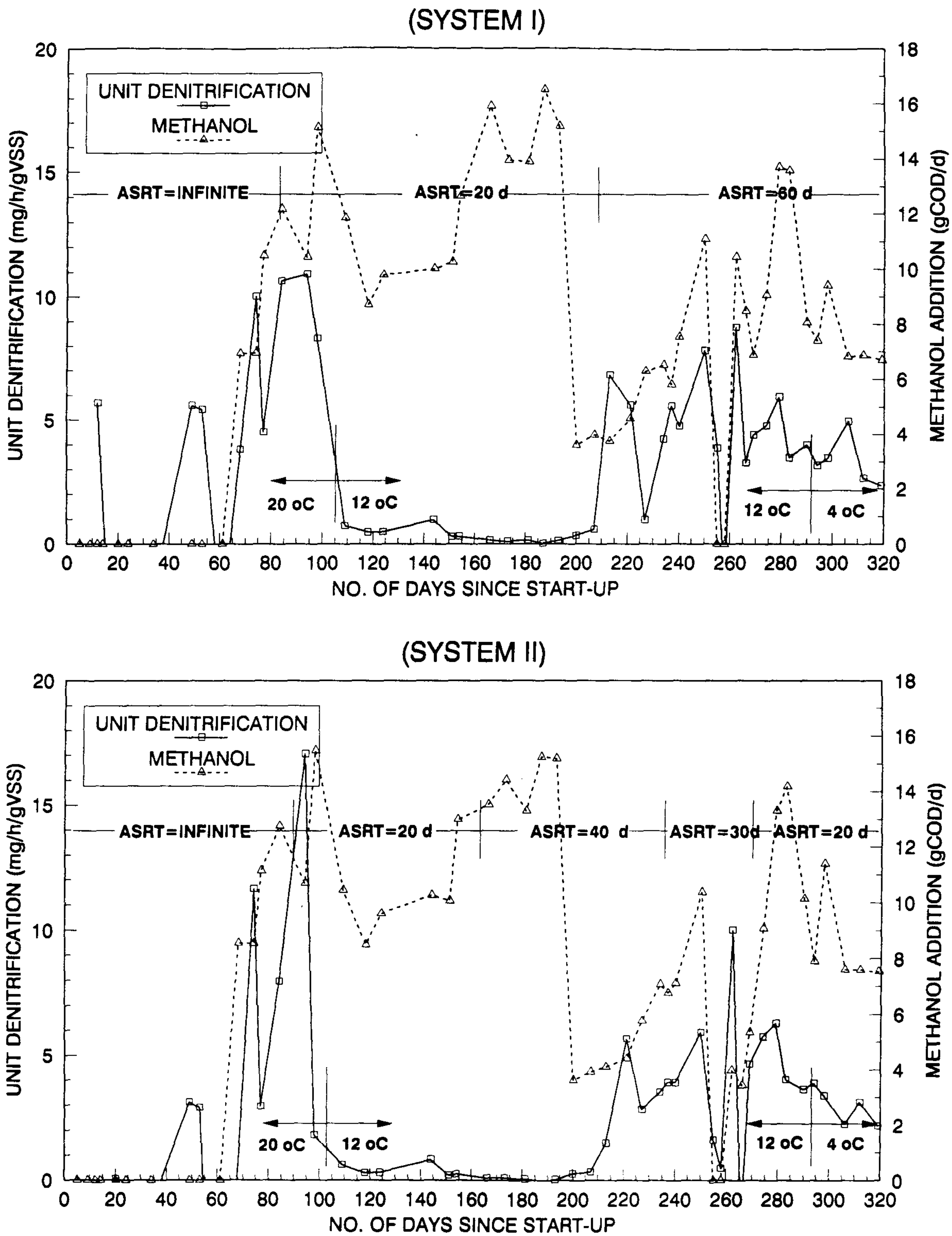


Figure 5.33: Unit Denitrification vs. Time

gCOD/d in system II. Within three days, the percentage denitrification level dropped from 35% to 20% in system I (ASRT = 60 days, average methanol addition = 7 gCOD/d) and from 44% to 33% in system II (ASRT = 20 days, average methanol addition = 7.6 gCOD/d). The unit denitrification level dropped from 4.02 mgN/h/gVSS to 3.19 mgN/h/gVSS in system I but increased marginally from 3.66 mgN/h/gVSS to 3.90 mgN/h/gVSS in system II, before decreasing again. Insufficient methanol addition, at this time in the experimental program, is believed to be at least partially responsible for this decrease. An anoxic VSS dropping from 2000 mg/l to 1760 mg/l might have contributed to the increase in the unit denitrification level in system II.

This irregular pattern indicated that the heterotrophic denitrifying bacteria were less affected by a sudden drop in temperature from 12°C to 4°C than from 20°C to 12°C, as long as sufficient organic carbon was available in the anoxic basin. However, because of the coincident temperature inhibition of nitrifying bacteria, less NO_x^--N was produced in the aerobic reactor and thus, less NO_x^--N was available to the biomass in the anoxic basin for further denitrification. This would cause the percent denitrification to remain relatively high but reduce the unit denitrification, accordingly.

5.9.2 Effect of Methanol Addition on Denitrification

Commencing on day 66, methanol was added to the anoxic reactor of the two systems. Within one month, the level of denitrification increased from zero to 100% in both system I and II (unit denitrification level increased to around 10 mg/h/gVSS). At the same time, an increase in VSS was observed. Thus, it was immediately confirmed that the denitrifying bacteria were very much dependent on the methanol addition, due to biodegradable carbon shortage in the leachate itself.

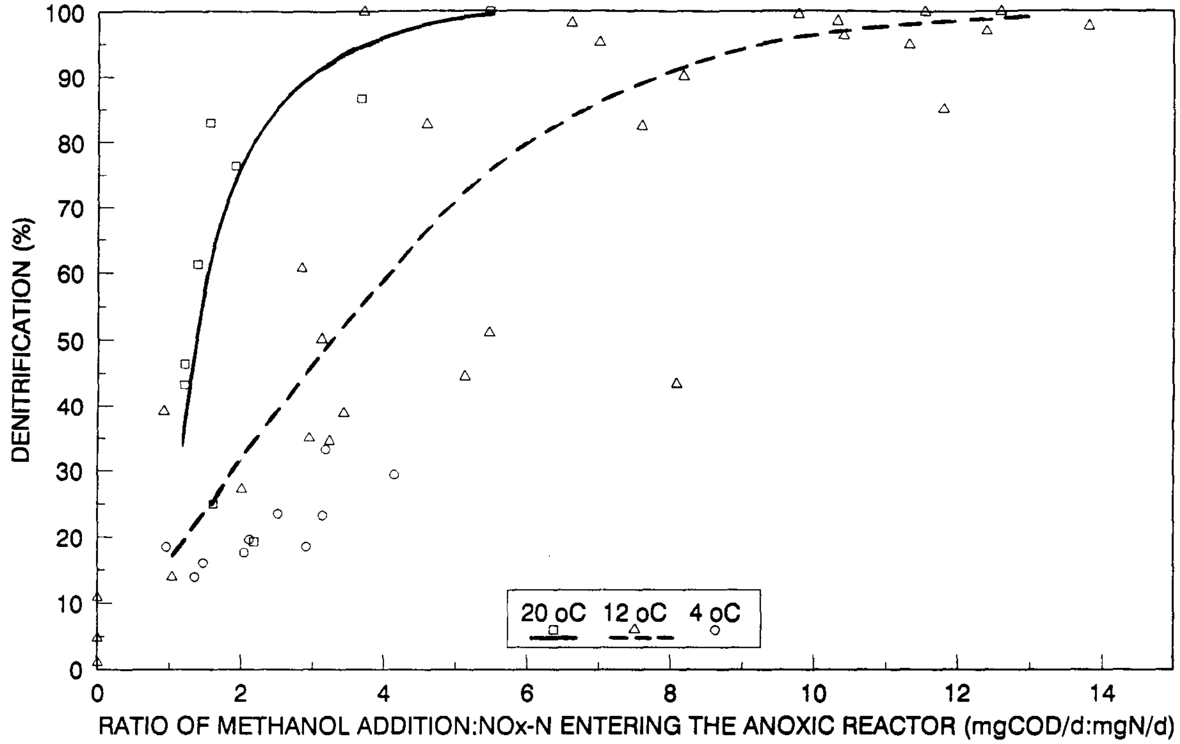
In an attempt to observe how a drastic change in methanol addition would affect the systems, commencing on day 252, the methanol addition was completely stopped. Within

6 days, the level of denitrification dropped from 95% to -6% in system I (Mean unit denitrification dropped from 4.8 mg/h/gVSS to 1 mg/h/gVSS, ASRT = 60 days) and from 90% to 1% in system II (Mean unit denitrification dropped from 4.6 mg/h/gVSS to 1 mg/h/gVSS, ASRT = 30 days). Accordingly, the VSS in the anoxic reactors were also reduced, reflecting the lack of biodegradable carbon in the systems. The level of denitrification rose again only after the methanol supply was resumed on day 259; likewise, the anoxic VSS also increased.

The level of denitrification was very much dependent on the methanol addition. As shown in Figure 5.32, for the same temperature, the percent denitrification level increased and decreased, corresponding to the increase and decrease in methanol addition. Suffice it to say that, at 4°C, if a higher dosage of methanol were added, a higher level of denitrification might have been achieved.

The relationship between denitrification and the ratio of methanol COD addition to NO_x^--N entering the anoxic reactor is illustrated in Figure 5.34 (Note: The data in this figure is collected from both systems). It is clear that in order to reach more than 80% denitrification, the ratio of methanol COD addition to NO_x^--N entering the anoxic reactor had to be at least 2:1 at temperature of 20°C, 6:1 at 12°C and possibly even higher at 4°C (As observed by *Carley, 1988*, at room temperature, for methanol as the carbon source, the minimum COD-NO_x^--N ratio of approximately 6.2:1 was required for complete denitrification). The unit denitrification level decreased with the increase in COD-NO_x^--N ratio, because the VSS in the anoxic basin increased when a higher dosage of carbon was added to support the nitrifying bacteria.

In summary, to achieve high levels of denitrification at lower temperatures, it appears that higher ratios of methanol addition to NO_x^--N entering the anoxic basin was required, regardless of SRTs.



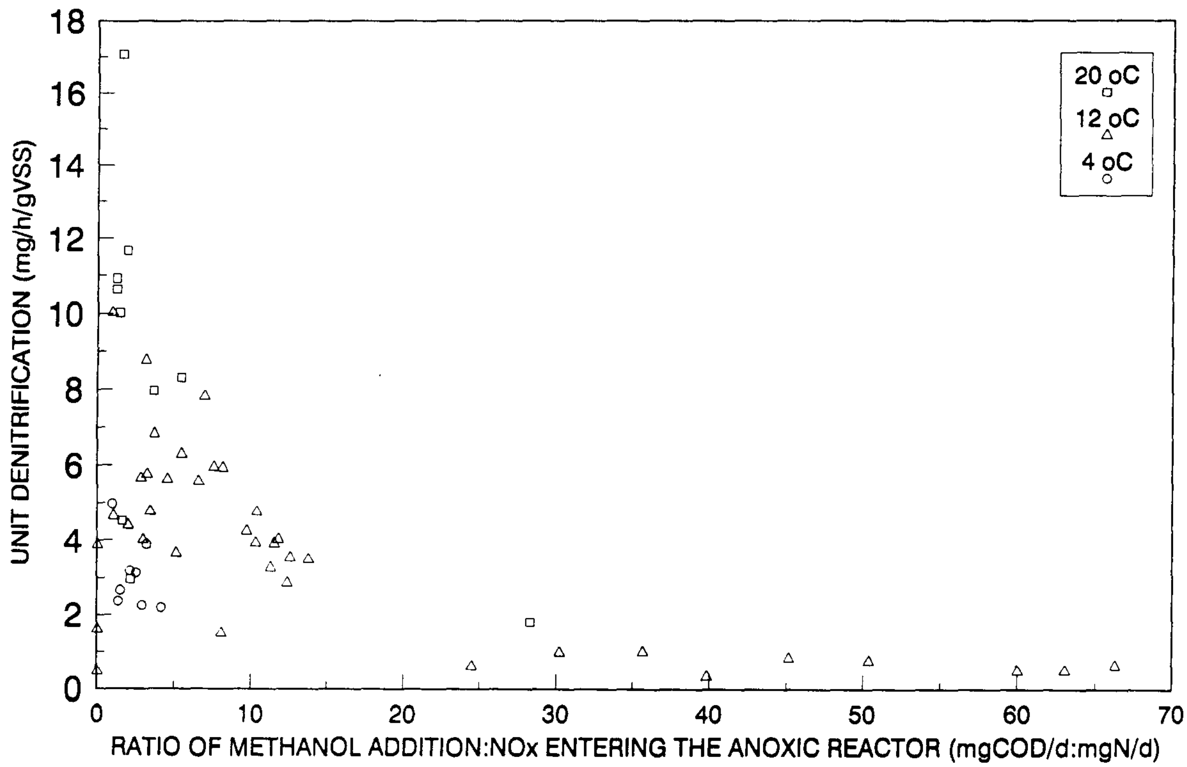


Figure 5.34: Denitrification vs. Ratio of COD Addition:NO_x^--N Entering the Anoxic Reactor

5.9.3 Effect of SRT on Denitrification

SRTs were not observed to have a large effect on the level of denitrification, at least within the ranges studied herein. Results of a 20-day ASRT did not differ greatly from those of a 60-day ASRT, at the respective temperatures of 12°C and 4°C.

5.9.4 Effect of Ortho-P on Denitrification

The phosphate level did not greatly affect the level of denitrification at a temperature of 20°C. When the anoxic ortho-P concentration was as low as 0.1 mgP/l, the unit level of denitrification still reached more than 8 mg/h/gVSS (Figure 5.35) (Note: The data in this figure is collected from both systems). However, at a temperature of 12°C, ortho-P concentrations of higher than 0.8 mgP/l appeared necessary in order to achieve higher levels of denitrification, regardless of the SRT. Additional research is needed to further expand on this interrelationship.

5.9.5 Optimum pH Value for Denitrification

Optimum pH values for denitrifying bacteria ranged from 7.7 to 8.3 at 20°C, and fluctuated between 7.9 and 8.3 at 12°C(Figure 5.36) (Note: The data in this figure is collected from both systems). The highest levels of denitrification were reached when the pH value was around 8.1. In this study, denitrifying bacteria appeared to be especially sensitive to pH values of higher than 8.3. However, more research is needed to confirm it.

5.10 Nitrate and Nitrite

5.10.1 Nitrate+Nitrite (NO_x^--N)

Raw leachate NO_x^--N content was very low (average 0.61 mgN/l). It was stored at 4°C in a refrigerated chamber before use. Every other day an aliquot leachate feed was

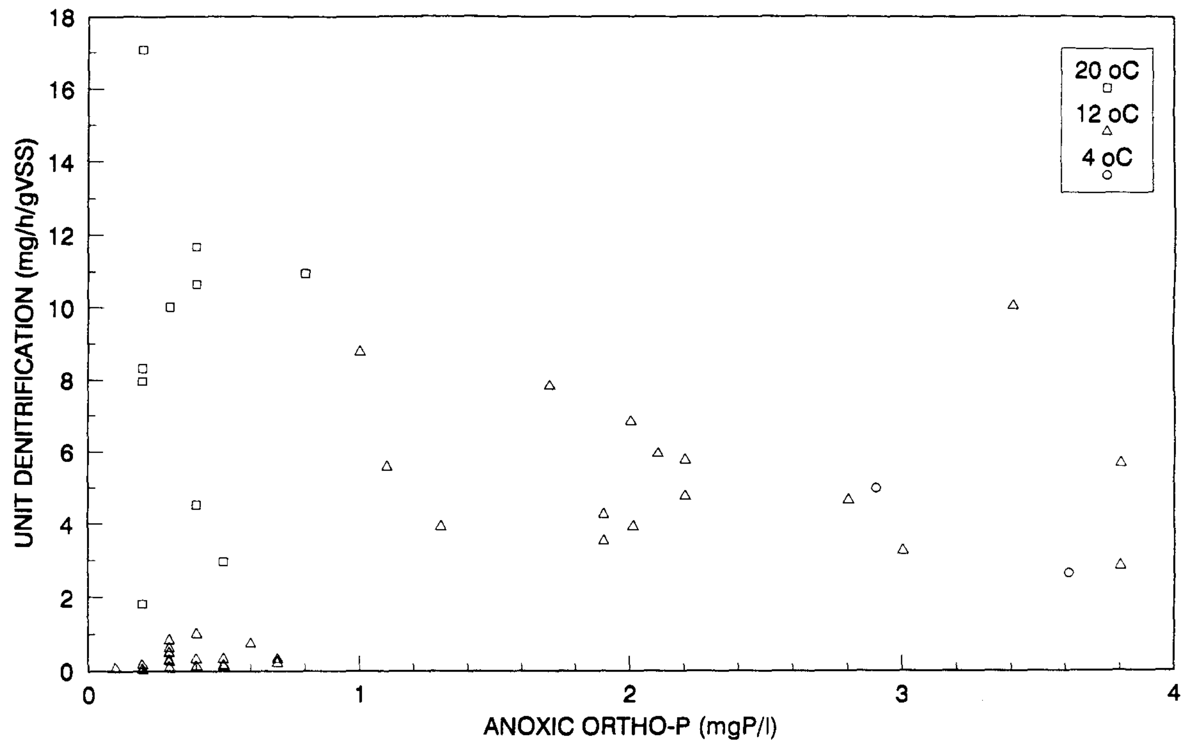


Figure 5.35: Unit Denitrification vs. Anoxic Ortho-P

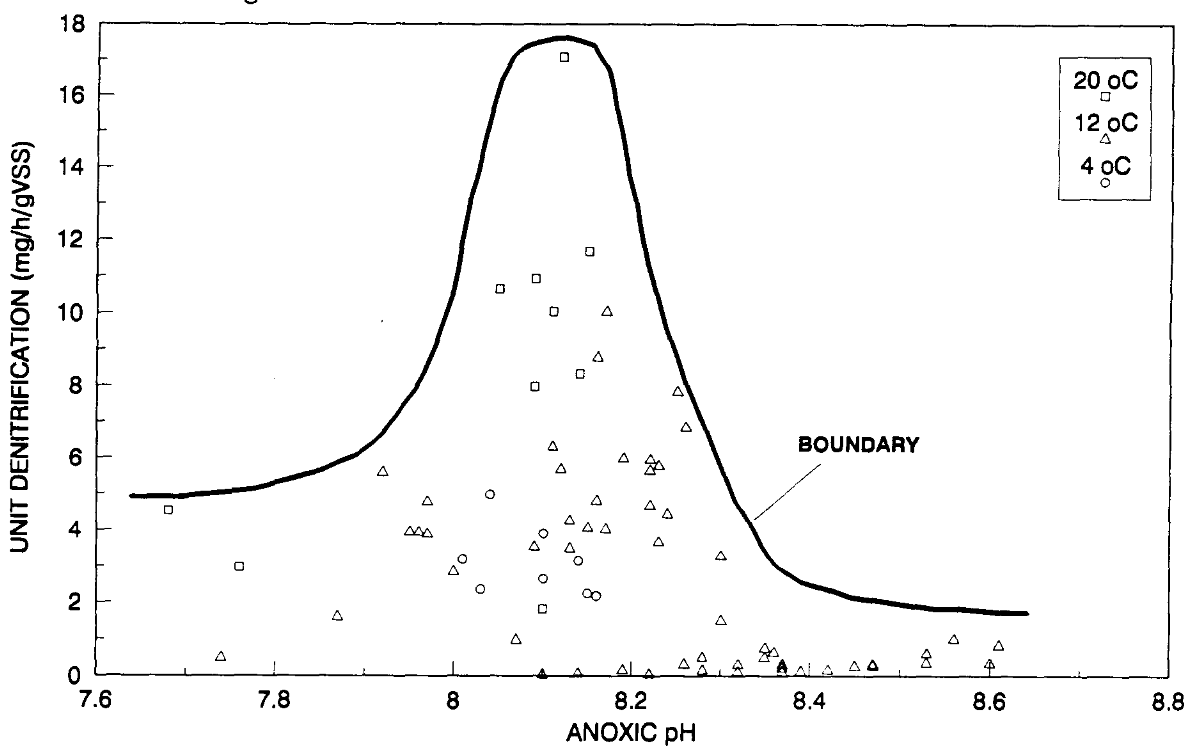


Figure 5.36: Unit Denitrification vs. Anoxic pH

taken out to the lab allowing it to acclimate to the lab temperature before addition to the system. The actual influent was found to contain an average NO_x^--N of 15 mgN/l at 20°C, 3 mgN/L at 12°C and 1 mgN/l at 4°C (Figure 5.37), indicating that influent nitrification had already started before the additions were made to the system. When high levels of nitrification and denitrification occurred, the effluent NO_x^--N concentration was approximately 50 mgN/l in system I and 70 mgN/l in system II at 20°C (when methanol addition and ASRT were controlled at the same level in the two systems), and 40 mgN/l at 12°C (partly due to lower influent ammonia-N during that time period), regardless of SRTs. A lower level of denitrification (average 17% in system I with 60-day ASRT, and 26% in system II with 20-day ASRT) was obtained in this project at 4°C; this would lead to higher NO_x^--N levels in the effluent (average 80 mgN/l in system I and 50 mgN/l in system II). The sludge recycle ratio was controlled at 6 to 1 in this study. An optimum sludge recycle ratio study is needed in order to obtain the lowest possible effluent NO_x^--N concentration at different temperatures.

5.10.2 Nitrite (NO_2^--N)

For the same reason noted in Section 5.9.1, influent average NO_2^--N level was 0.4 mgN/l, which was higher than the raw leachate NO_2^--N level (average 0.18 mgN/l). Effluent NO_2^--N levels generally measured were less than 2 mgN/l (Figure 5.38). No significant nitrite build-up was observed in the leachate effluent; however, it was not known whether high nitrite levels were built-up between day 151 and day 250, when nitrite was not measured. However, effluent NO_2^--N concentration could not exceed 0.6 mgN/l between day 151 and day 191, because the effluent nitrate+nitrite (NO_x^--N) concentration was below 0.6 mgN/l in both systems.

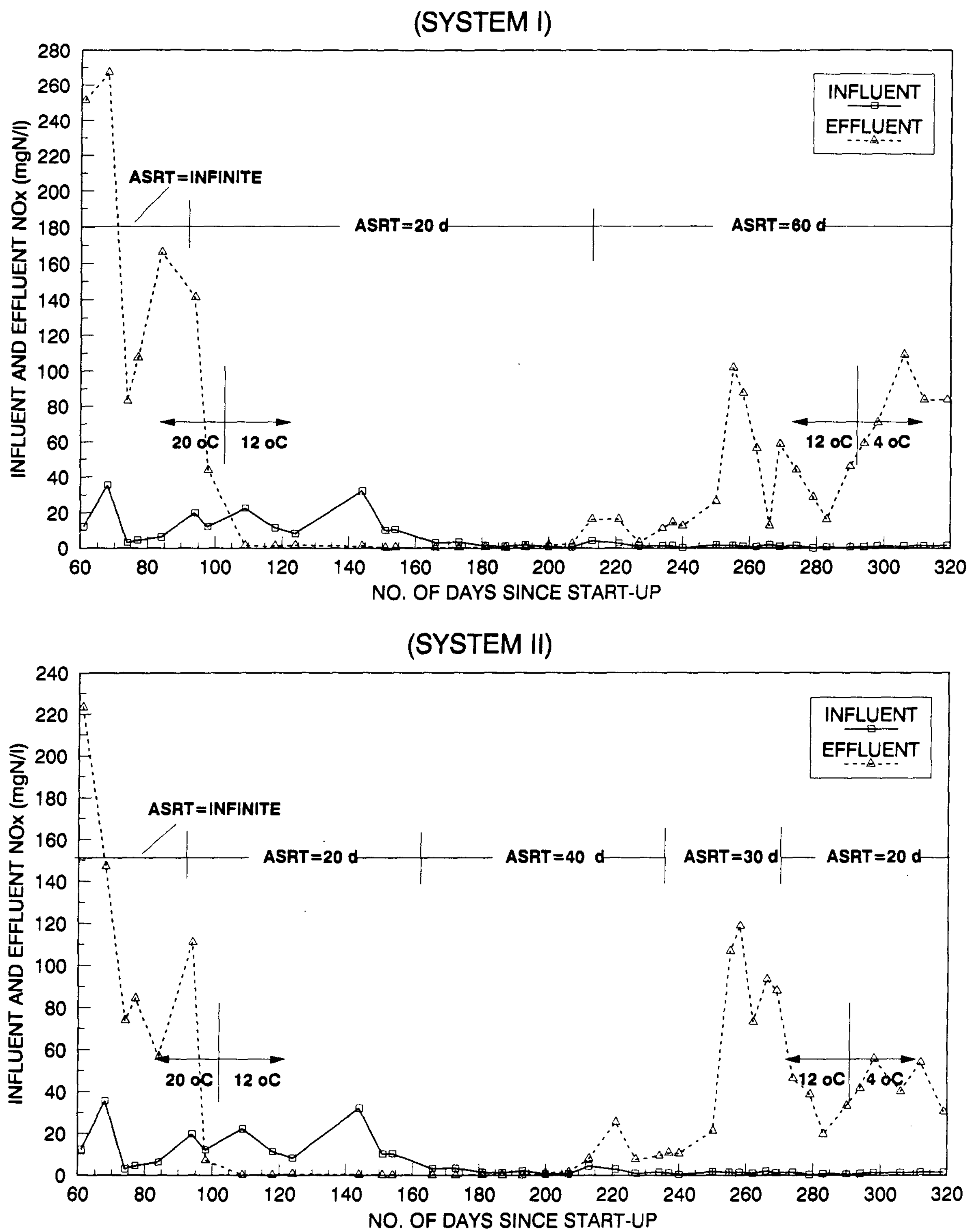
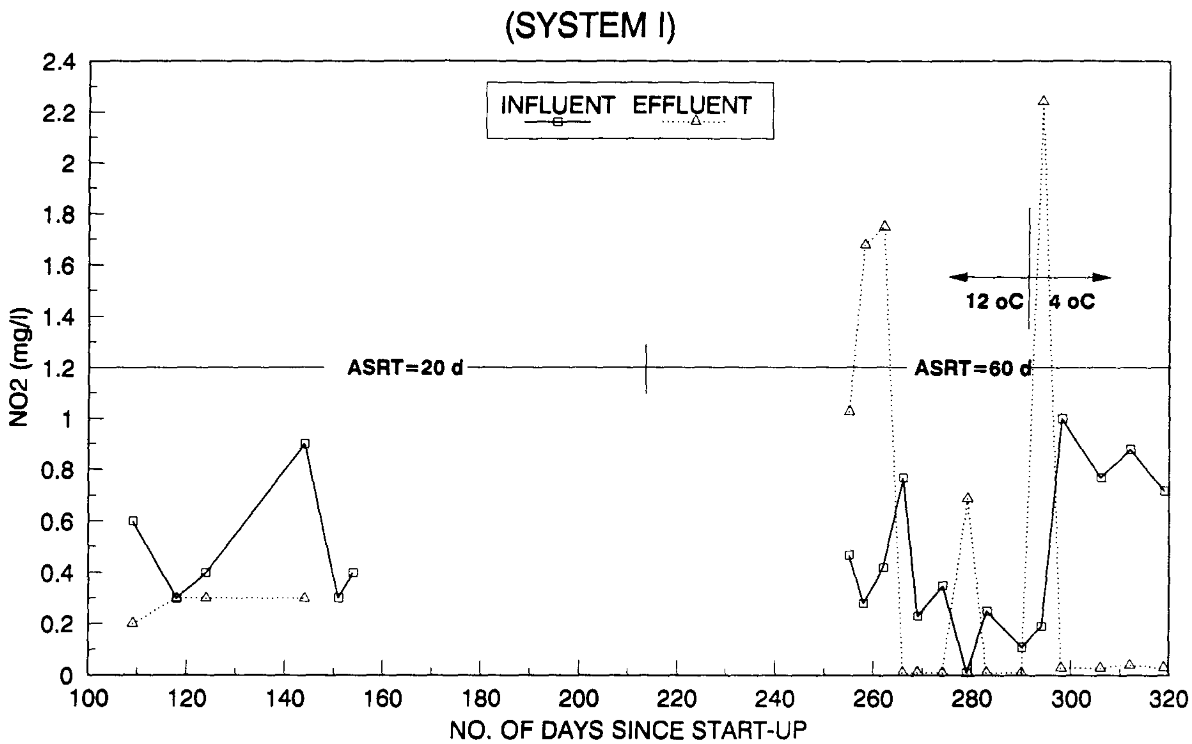


Figure 5.37: Influent and Effluent NO_x^--N



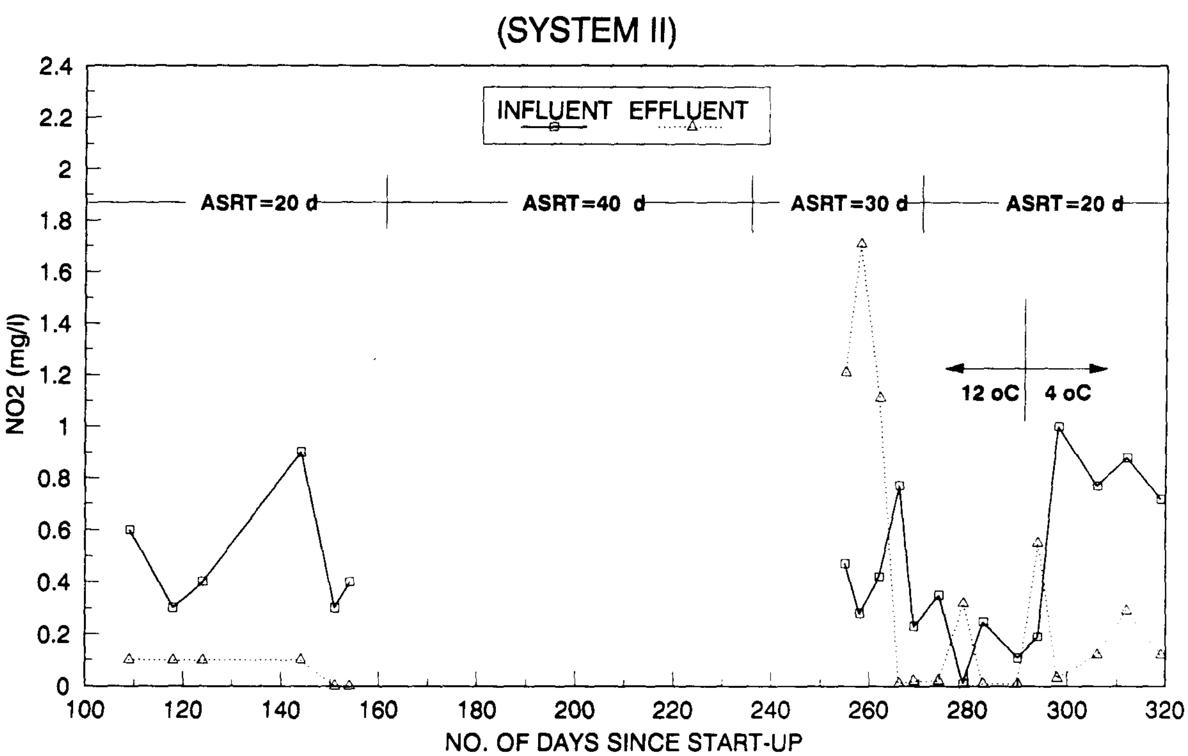


Figure 5.38: Influent and Effluent NO_2^-

5.11 Summary of Nitrogen Removal

The mean temperature, ASRT, SSRT, methanol addition, aerobic ammonia-N removal, nitrification and denitrification levels are summarized in Table 5.2. Figure 5.39 was drawn according to these mean data.

It can be observed that the mean aerobic ammonia removal followed the pattern of nitrification performance, indicating that most leachate ammonia-N was removed through nitrification. The aerobic ammonia-N removal and nitrification level varied in a contrary way with the methanol dosage, confirming that extra carbon could inhibit the growth of nitrifying bacteria. The mean unit denitrification level was affected by at least three factors: methanol addition, the amount of NO_x-N entering the anoxic reactor and the changes in anoxic VSS. Therefore, the unit denitrification level did not always change in the same way as did the methanol addition, despite the fact that the percent denitrification level did. The level of nitrification and denitrification, especially the latter, were less affected by the reduction in temperature from 12°C to 4°C than from 20°C to 12°C, indicating that nitrifying and denitrifying bacteria could grow well at low temperatures, under careful operation and proper methanol addition.

Table 5.2: Mean Data for Nitrogen Removal

SYSTEM I

DAY	TEMP	ASRT	SSRT	MEANCOD ADD	MEAN AER AMM REM		MEAN NITR		MEAN DENITR	
	oC	DAYS	DAYS	gCOD/d	%	UNIT mg/h/gVSS	%	UNIT mg/h/gVSS	%	UNIT mg/h/gVSS
68-77	20	INFI	103	8.1	98	5.2	108	5	31	6.1
84-98	20	20	17	12.6	89	4.5	114	5.7	63	10
109-151	12	20	24	10.1	2.4	0.74	0.2	0.1	90	0.6
154-193	12	20	17.5	14.7	2.8	0.3	0	0.01	75	0.16
200-213	12	20	6.2	3.8	5.7	0.1	10.7	0.9	87	2.6
221-250	12	60	11.2	7	88.5	2.8	78.7	2.3	90	4.8
255-258	12	60	7	0	43	2.9	55.5	3.7	2.5	0.95
262-274	12	60	15.6	8.7	98.5	2.4	102	2.5	52.8	5.3
279-290	12	60	10.5	11.8	94	1.5	139	2.2	72	4.5
294-319	4	60	32.5	7	92.2	1.86	108.5	2.2	17.3	3.3

SYSTEM II

DAY	TEMP	ASRT	SSRT	MEANCOD ADD	MEAN AER AMM REM		MEAN NITR		MEAN DENITR	
	oC	DAYS	DAYS	gCOD/d	%	UNIT mg/h/gVSS	%	UNIT mg/h/gVSS	%	UNIT mg/h/gVSS
68-77	20	INFI	103	9.4	81	6.7	89	6.5	60.7	7.3
84-98	20	20	13	13	54	5.6	56	5.9	90	9
109-154	12	20	22.3	10.3	3	1.2	0	0.06	86	0.42
166-193	12	40	23.4	14.3	1.8	0.3	0	0	47	0.06
200-207	12	40	10.4	3.8	1	0.2	1	0.2	89.5	0.3
213-234	12	40	13.5	5.3	78.8	3.04	73.5	1.7	75	3.4
237-250	12	30	11.8	8.1	92.3	1.74	128	2.5	96	4.6
255-258	12	30	9.1	0	66.5	3.1	79	3.7	3	1.05
262-269	12	30	16.3	4.3	84	3.2	129	4.5	16	4.3
274-290	12	20	18.4	11.7	93	2.2	144	3.2	53.8	5
294-319	4	20	18	7.7	58.5	2.3	63.3	2.3	25.8	2.9

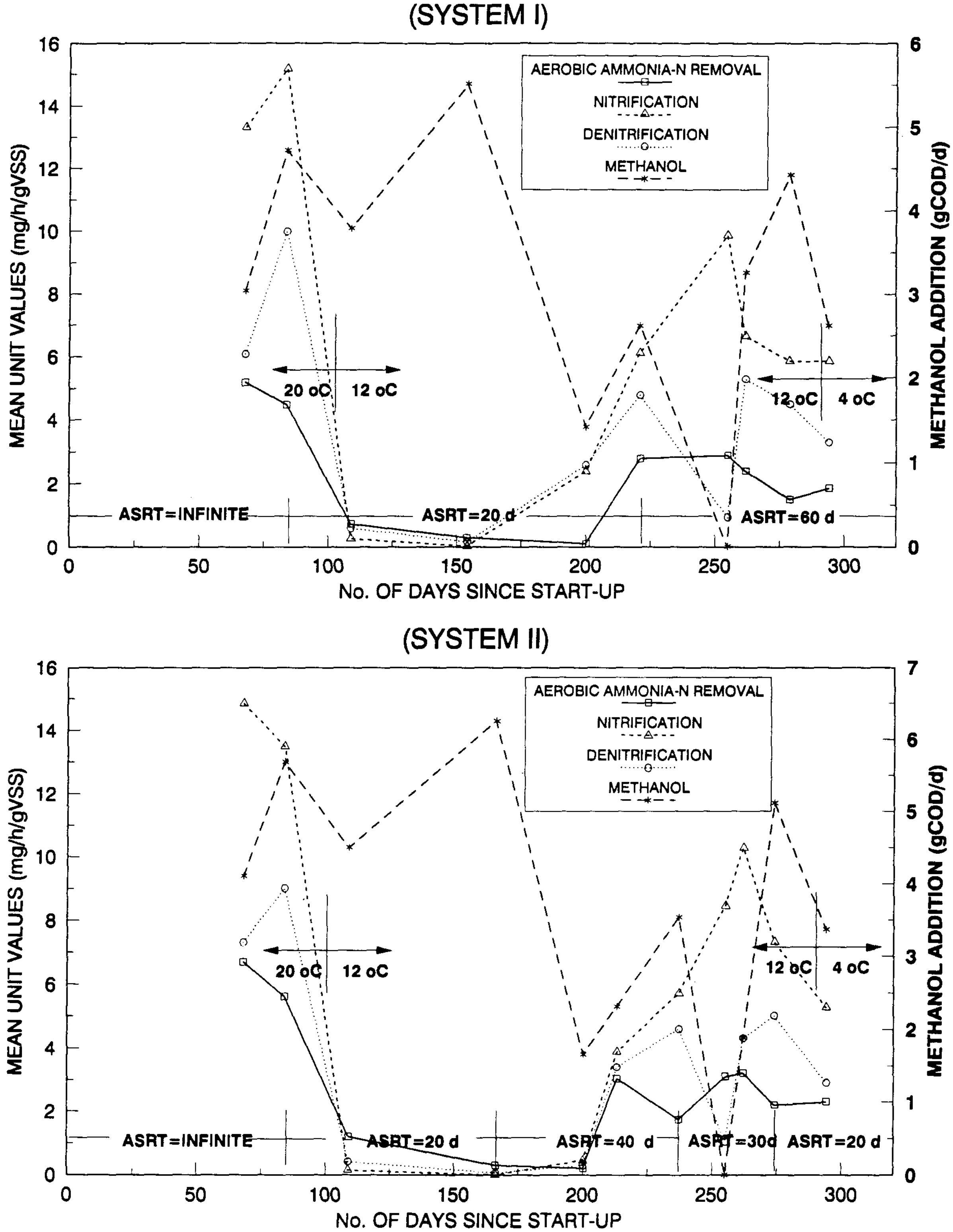


Figure 5.39: Mean Unit Nitrogen Values vs. Time

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Research on low temperature, high ammonia-N (average 210 mgN/l) removal from municipal landfill leachate, using a single-sludge predenitrification system, produced the following conclusions:

1. It was possible to remove more than 90 percent of the ammonia-N from the landfill leachate (influent ammonia-N) at operating temperatures of 20°C, 12°C and 4°C, a sludge recycle ratio of 6:1, and operating theoretical Aerobic Solids Retention Times (ASRTs) of 20 to 60 days.

2. An ASRT of 20 days was long enough for the adequate growth of both nitrifier and denitrifier at temperature of 20°C and 12°C. At a temperature of 4°C, these organisms exhibited a lower adaptability at an ASRT of 20 days than at 60 days, resulting in lower quality effluent in the treatment system, however, the effluent ammonia-N level still remained below 14 mgN/l (average 9.2 mgN/l), which was much lower than the influent ammonia-N level.

3. Methanol addition, as an external carbon source for denitrification purposes in the anoxic basin, had a greater effect on the treatment system than did SRTs at lower temperatures. In order to reach a denitrification level of more than 80%, a ratio of methanol addition (as COD) to NO_x^--N entering the anoxic reactor had to be at least 2:1 at 20°C, about 6:1 at 12°C and possibly even higher at 4°C. However, this ratio of over

30:1 appeared to hinder the aerobic nitrifiers, when operating temperatures dropped to 12°C or lower.

4. In addition to temperature and carbon addition, the unit level of denitrification was affected by at least two other factors: NO_x^--N entering the anoxic reactor and the anoxic VSS level. Sufficient carbon encourages the growth of denitrifiers; however, since it can inhibit nitrifier growth, less NO_x^--N would be produced and returned to the anoxic reactor. In addition, excess carbon encourages aerobic heterotrophic bacterial growth and increases the VSS value in the system. Therefore, the unit denitrification level would not always be proportional to the carbon addition at certain temperatures, despite the fact that percent denitrification would be.

5. Low operating temperatures effected both the nitrifiers and denitrifiers, especially the former. When the temperature was suddenly reduced, a system recovery from temperature inhibition required a lengthy acclimatization by the nitrifying bacteria; this came about through a combination of increased ASRT and reduction in the methanol addition (to protect the nitrifiers against possible heterotrophic competition). When a high level of nitrification was restored, increased methanol addition was possible, to support the subsequent increase in denitrifying bacterial growth.

6. In this research, SRTs $\times$ Temperature value of about 100 degree-ASRTdays or 50 degree-SSRTdays was sufficient for reaching an ammonia removal of over 75% or 2 mg/h/gVSS and nitrification level of over 80% or 2 mg/h/gVSS, under proper operating and methanol addition control. SSRT was not correlated to ASRT, because a large portion of VSS was lost to the effluent.

7. A membrane-filtered ortho-phosphate concentration of 0.5 mgP/l was found adequate for the operation of the treatment systems at 20°C; however, a higher level of 0.8 mgP/l appeared to be needed in both the anoxic and aerobic reactors at a temperature of 12°C or lower, to support satisfactory nitrifier and denitrifier growth.

8. At any temperature, a pH of around 7.8 was observed to be optimal for the nitrifying bacteria. A pH of around 8.1 was believed to be optimum for the denitrifying bacteria.

9. The anoxic ORP value dropped with an increase in the level of methanol addition; the effect of methanol was more pronounced on ORP readings than was the effect of a reduction in temperature.

10. The percentage of COD and BOD_5 removal was very much dependant on the amount of methanol added. Over-dose of methanol caused excess carbon to pass through the system unutilized, and therefore reduced the percentage of COD and BOD_5 removal.

6.2 Recommendations

1. A sudden drop in temperature significantly affected this biological treatment system. However, in a full-scale situation, the temperature drop would usually be more gradual, with the arrival of winter operating conditions. It is not known if a gradual decrease in operating temperatures would affect the biotreatment system as much as a sudden drop in temperature, therefore, a follow-up study on this aspect is recommended, whereby incremental temperature drops of 2 to 3 °C would be imposed on the pre-denitrification system.

2. More studies are needed to obtain an information on the level of nitrification affected by the operation condition of lower than 100 degree-ASRTdays or 50 degree-SSRTdays (SRT $\times$ temperature).

3. *Elefsiniotis et al, (1989)* noted that the best sludge recycle ratio on nitrification-denitrification performance in biological treatment of leachate was 6 to 1 at room temperature. However, it is not known if this "optimum" ratio would change with lower operating temperatures. There is a need to further study this relationship.

4. Although the average ammonia-N concentration in the studied leachate was 210 mgN/l, the ammonia-N level of leachate, in general, varies with different landfills. Higher strength ammonia levels (say>600 mg/l) may require different operating conditions, and this aspect also requires further investigation.

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Appendix A

LIST OF ABBREVIATIONS

ADDN	Addition
AER	Aerobic
AMM	Ammonia
ANOX	Anoxic
ASRT	Theoretical aerobic solids retention time
BOD_5	Five day biochemical oxygen demand
C	Carbon as Filtered COD
CLAR	Clarifier
COD	Chemical oxygen demand
Cu^{2+}	Copper
d	Day
DENIT	Denitrification
EFFL	Effluent
g	Gram
h	Hour
HRT	Hydraulic retention time
INFL	Influent
kg	Kilogram
l	Liter
MF	Membrane-filtered
mg	Milligram
MLSS	Mixed liquor suspended solids
MLVSS	Mixed liquor volatile suspended solids
mV	Millivolt
N	Nitrogen

NH_4^+-N	Ammonia expressed as nitrogen
NITR	Nitrification
N	All forms of nitrogen are expressed as N in this research (even if not written)
NO_x^--N	Nitrate and nitrite expressed as nitrogen
ORP	Oxidation-reduction potential
P	Phosphorus, All forms of nitrogen are expressed as P in this research (even if not written)
RECL	Recycle
REM	Removal
SOLN	Solution
SRT	Solids retention time (aerobic)
SSRT	System solids retention time
TEMP	Temperature
TKN	Total Kjeldahl nitrogen
TSS	Total suspended solids
VOL	Volume
VSS	Volatile suspended solids
WF	Whatman-filtered
Zn^{2+}	Zinc

Appendix B

DEFINITIONS

CARBON ADDITION As g COD/d = Concentration of Carbon solution (mls CH3OH /l) x 0.7915 (g/ml) x Carbon flow (l/d) x 1.5 (C:COD)

TOT COD IN (mg/d) = INFL COD (mg/l) x INFL FLOW (l/d) + COD ADDN (gCOD/d) x 1000 (mg/g) + (INFL FLOW + RECL FLOW) (l/d) x AER COD(mg/l) - INFL FLOW (l/d) x EFFL COD (mg/l)

ANOXIC COD REMOVAL (mg/d) = TOT COD IN - ANOX COD x (INFL FLOW + RECL FLOW) (l/d)

ANOXIC COD REMOVAL (%) = ANOX COD REM (mg/d) x 100 ÷ TOT COD IN (mg/d)= % of carbon entering anoxic basin that is removed there

AEROBIC COD REMOVAL (%) = (ANOX COD - AER COD) (mg/l) x 100 ÷ ANOX COD (mg/l) = % of carbon entering aerobic basin that is removed there

TOT COD REMOVAL (%) = [INFL COD (mg/l) x INFL FLOW (l/d) + COD ADDN (gCOD/d) x 1000 (mg/g) - EFFL COD (mg/l) x INFL FLOW (l/d)] x 100 ÷ [INFL COD (mg/l) x INFL FLOW (l/d) + COD ADDN (gCOD/d) x 1000 (mg/g)]

CLARIFIER COD REMOVAL (%) = [AER COD (mg/l) x (INFL FLOW + RECL FLOW) (l/d) - EFFL COD (mg/l) x INFL FLOW (l/d)] x 100 ÷ [AER COD (mg/l) x (INFL FLOW + RECL FLOW) (l/d)]

AEROBIC UNIT COD REMOVAL (%) = (UNIT ANOX COD - UNIT AERB COD) x 100 ÷ UNIT ANOX COD

ANOXIC AMM REMOVAL (mg/d) = INFL AMM (mg/l) x INFL FLOW (l/d) + EFFL AMM (mg/l) x RECYCLE FLOW (l/d) - (INFL FLOW + RECL FLOW) (l/d) x ANOX AMM (mg/l)

ANOXIC AMM REMOVAL (%) = ANOX AMM REM (mg/d) x 100 ÷ (INFL FLOW (l/d) x INFL AMM (mg/l) + RECL FLOW (l/d) x EFFL AMM(mg/l))

AEROBIC AMM REMOVAL (mg/d) = (INFL FLOW + RECL FLOW) (l/d) x ANOX AMM (mg/l) - (INFL + RECL FLOW) (l/d) x AER AMM (mg/l)

AEROBIC AMM REMOVAL (%) = AER AMM REM (mg/d) x 100 ÷ (INFL FLOW + RECL FLOW) (l/d) x ANOX AMM (mg/l)

ANOXIC UNIT SPECIFIC AMM REMOVAL (mg/h/g VSS) = ANOX AMM REM (mg/d) ÷ ANOX VSS ÷ 0.12 = (mg/d/SYSTEM) x (1/24 d/h) x (1/5 SYST/l) x (1000 (mg/g) ÷ ANOX VSS (mg/l))

AEROBIC UNIT AMM REMOVAL (mg/h/g VSS) = AEROBIC AMM REM (mg/d) ÷ AER VSS / 0.24 = (mg/d/SYSTEM) x (1/24 d/h) x (1/10 SYST/l) x (1000 mg/g) ÷ AER VSS (mg/l))

NITRIFICATION (mg/d) = (INFL FLOW + RECL FLOW) (l/d) x (AER NOx - ANOX NOx) (mg/l) = TOTAL FLOW x (NOx OUT - NOx IN)

NITRIFICATION (%) = NITR (mg/d) x 100 ÷ [(INFL FLOW + RECL FLOW (l/d) x ANOX AMM (mg/l)]

UNIT NITRIFICATION RATE (mg/h/g VSS) = NITR (mg/d) ÷ AER VSS (mg/L) ÷ 0.24

DENITRIFICATION (mg/d) = [INFL FLOW (l/d) x INFL NOx (mg/l) + RECL FLOW (l/d) x EFFL NOx (mg/l)] - (INFL FLOW + RECL FLOW) (l/d) x ANOX NOx(mg/l)

DENITRIFICATION (%) = DENIT (mg/d) x 100 ÷ [INFL FLOW (l/d) x INFL NOx (mg/l) + RECL FLOW (l/d) x EFFL NOx (ng/l)]

UNIT DENITRIFICATION RATE (mg/h/g VSS) = DENIT (mg/d) ÷ ANOX VSS ÷ 0.12

CARBON ADDN PER NOx ENTERING THE ANOXIC REACTOR (gCOD/d/syst per gN/d/syst) = COD ADDN (gCOD/d) x 1000 (mg/g) ÷ [INFL FLOW (l/d) x INFL NOx (mg/l) + RECL FLOW (l/d) x EFFL NOx (mg/l)]

TOT BOD IN (mg/d) = INFL BOD (mg/l) x INFL FLOW (l/d) + BOD ADDN (gBOD/d) x 1000 (mg/g) + (INFL FLOW + RECL FLOW) (l/d) x AER BOD (mg/l) - INFL FLOW (l/d) x EFFL BOD (mg/l)

TOT BOD REMOVAL (%) = [INFL BOD (mg/l) x INFL FLOW (l/d) + BOD ADD (g/d) x 1000 (mg/g) - EFFL BOD (mg/l) x INFL FLOW (l/d)] x 100 ÷ [INFL BOD (mg/l) x INFL FLOW (l/d) + BOD ADD (g/d) x 1000 (mg/g)]

ANOXIC BOD REMOVAL (mg/d) = TOT BOD IN (mg/d) - ANOX BOD (mg/l) x (INFL FLOW + RECL FLOW) (l/d)

ANOXIC BOD REMOVAL (%) = ANOX BOD REMOVAL (mg/d) x 100 ÷ TOT BOD IN (mg/d)

AEROBIC BOD REMOVAL (%) = [ANOX BOD (mg/l) - AER BOD (mg/l)] x 100 ÷ ANOX BOD (mg/l)

CLARIFIER BOD REMOVAL (%) = [AER BOD (mg/l) x (INFL FLOW + RECL FLOW) (l/d) - EFFL BOD (mg/l) x INFL FLOW (l/d)] x 100 ÷ [AER BOD (mg/l) x (INFL FLOW + RECL FLOW) (l/d)]

UNIT AEROBIC BOD REMOVAL (%) = (UNIT ANOX BOD - UNIT AER BOD) x 100 ÷ UNIT ANOX BOD

PO43- ADDN (mgP/d) = PO43- ADDN (lP/d) x PO43- SOLN (gP/l) x 1000 (mg/g)

TOT PO43- REMOVAL (%) = [INFL FLOW (l/d) x INFL PO43-(mgP/l) + PO43- ADDN (mgP/d) - INFL FLOW (l/d) x EFFL PO43- (mgP/l)] x 100 ÷ [INFL FLOW (l/d) x INFL PO43- (mgP/l) + PO43- ADDN (mgP/d)]

ANOXIC PO43- REMOVAL (mgP/d) = [INFL FLOW (l/d) x INFL PO43- (mgP/l) + PO43-ADDN (mgP/d) + RECL FLOW (l/d) x EFFL PO43- (mgP/l)] - [(INFL FLOW + RECL FLOW) (l/d) x ANOX PO43- (mgP/l)]

ANOXIC PO43- REMOVAL (%) = ANOX PO43- REM (mgP/d) x 100 ÷ [INFL FLOW (l/d) x INFL PO43- (mgP/l) + PO43- ADDN (mgP/d) + RECL FLOW (l/d) x EFFL PO43- (mgP/l)]

AEROBIC PO43- REMOVAL (%) = [ANOX PO43- (mgP/l) - AER PO43- (mgP/l)] x 100 ÷ ANOX PO43- (mgP/l)

CLARIFIER PO43- REMOVAL (%) = [(INFL FLOW + RECL FLOW) (l/d) x AER PO43- (mgP/l) - INFL FLOW (l/d) x EFFL PO43- (mgP/l)] x 100 ÷ [(INFL FLOW + RECL FLOW) (l/d) x AER PO43- (mgP/l)]

VOLUME WASTED (L/d) = VOL OF AEROBIC REACTOR (10 L) ÷ ASRT (d))

ASRT (days) = THEORETICAL AEROBIC SOLIDS RETENTION TIME = MASS SUSP SOLIDS IN THE AEROBIC REACTOR ÷ MASS SUSP SOLIDS WASTED DAILY FROM THE REACTOR = AER VOL ÷ DAILY AER SOLIDS WASTED

SSRT (days) = SYSTEM SOLIDS RETENTION TIME = MASS SUSP SOLIDS IN THE SYST ÷ TOT MASS SUSP SOLIDS WASTED FROM THE SYSTEM = [ANOX VSS x ANOX VOL + AER VSS x (AER + CLAR + RECL)VOL] ÷ (AER VSS x DAILY AER VSS WASTED + EFFL VSS x INFL FLOW)

SLUDGE RECYCLE RATIO = SLUDGE RECL FLOW ÷ LEACHATE INFL FLOW

Appendix C

LOG OF OPERATION

	07/06/90	First leachate sample was taken
1	07/20/90	Systems operation started
21	08/09/90	Second leachate sample was taken
23	08/11/90	Started feeding with second leachate sample
42	08/29/90	third leachate sample was taken
47	09/04/90	Started feeding with third leachate sample
55	09/12/90	Poor settlability had caused the sludge loss. Filled half of every reactor with sewage sludge seed, which was taken from the pilot plant.
66	09/23/90	Started adding methanol into the two systems ($\sim$ 6.3 gCOD/d).
69	09/26/90	System II clarifier's sludge return tubing was plugged which caused the anoxic reactor of system II appeared less denser. Filled the anoxic reactor of system II with 200 ml sludge taken from the anoxic reactor of system I after fixing the tubing.
75	10/02/90	Forth leachate sample was taken.
77	10/04/90	Started feeding with forth leachate sample.
82	10/09/90	Started wasting from the aerobic reactors of the two systems with SRT of 20 days.
85	10/12/90	Started PO_4^{3-} addition ($\sim 1.7mgP/d$).
104	10/31/90	educed ambient temperature from original 20°C to 12°C.
108	11/04/90	Fifth leachate sample was taken.
108	11/05/90	educed methanol addition from around 11 gCOD/d to around 9 gCOD/d.
110	11/07/90	Started feeding with fifth leachate sample.
114	11/10/90	The mix stir in the aerobic reactor of system I stopped for several hours which caused the increase of ORP value.

119	11/15/90	Influent tubings were changed.
125	11/21/90	Power supply failed for about half an hour before the reading was taken.
130	11/26/90	Turned the chemical flow a little bit down; power supply failed for an hour.
137	12/03/90	Tubings for chemical pump were changed.
150	12/16/90	ORP switch of system II might be touched by somebody which caused the anoxic ORP value of system II being lower.
152	12/19/90	Increased the COD addition to 13 gCOD/d and phosphate addition to 4 mgP/d.
161	12/27/90	Increased phosphate addition to 13 mgP/d; sixth leachate sample was taken.
162	12/28/90	Started operating system II with SRT of 40 days; All pumps' tubings were changed.
164	12/30/90	Stated feeding with sixth leachate sample.
168	01/03/91	Started addition methanol and phosphate with separate pumps.
169	01/04/91	Effluent tubing of anoxic reactor in system II was plugged.
173	01/08/91	Increased phosphate addition to 30 mgP/d and started to further increase gradually.
175	01/10/91	The phosphate chemical pump was not stable, changed to a newer one.
178	01/13/91	System II influent tubing was plugged for hole day.
181	01/16/91	Increased phosphate addition to 50 mgP/d.
182	01/17/91	The tubing of methanol pump was changed.
184	01/19/91	Increased phosphate addition to 80 mgP/d.
190	01/25/91	Increased phosphate addition to 150 mgP/d.

199	02/03/91	Reduced methanol addition from 14 gCOD/d to 4 gCOD/d.
200	02/05/91	Seventh leachate sample was taken.
205	02/10/91	Started feeding with seventh leachate sample.
208	02/13/91	Phosphate tubings were changed.
210	02/15/91	Phosphate addition was reduced tp 60 mgP/d.
212	02/17/91	Effluent tubing of Anoxic reactor of system II was overspilled after sampling. Refilled some of the spill back with a mob.
213	02/18/91	Started operating system I with SRT of 60 days.
214	02/19/91	Power supply failed for about 20 hours.
219	02/23/91	Increased phosphate addition to around 80 mgP/d.
224	02/28/91	COD addition was increased from 4 g/d to 6 g/d.
233	03/09/91	Phosphate addition was reduced to around 40 gP/d.
235	03/11/91	Started operating system II with SRT of 30 days (from previous 40 days).
239	03/15/91	ORP value of System I rose by about 100 mV. Increased phosphate addition to 70 mgP/d.
240	03/16/91	Eighth leachate sample was taken.
242	03/18/91	Methanol addition was increased from 6.8 g/d to 10 g/d (within one day, ORP value of system I dropped from -172 to -406).
248	03/24/91	Leachate supply of system I stopped with caused the rise of ORP value in the anoxic reactor in that system (-105 mV).
249	03/25/91	Mix stir in system I stopped which caused the aerobic reactor looked less denser.
252	03/28/91	Stopped the methanol addition.
259	04/04/91	Resumed the methanol addition with different dosage between

		system I and II. Started using two separate pumps for methanol and two separate pumps for phosphate addition.
266	04/11/91	Influent flow of system II stopped before sampling.
268	04/13/91	Increased methanol addition of system II from 3 g/d to 7.9 g/d.
270	04/15/91	Started operating system II with SRT of 20 days (from previous 30 days).
276	04/21/91	All pumps' speed became higher which might be caused by the unstable power supply. Influent tubing of system I was plugged for one day.
277	04/22/91	Ninth leachate sample was taken.
278	04/23/91	Air supplying tubing was cleaned. Turned the air flow higher.
283	04/28/91	Started feeding the systems with Ninth leachate sample.
285	04/30/91	Methanol addition of both system I and II was reduced from around 12 g/d to around 7.5 g/d.
291	05/06/91	Dropped the ambient temperature from 12°C to 4°C after reading.
294	05/09/91	Power supply failed after sampling until day 297 when the breakdown was fixed. During these days, the ambient temperature rose to 23°C.
297	05/12/91	Power breakdown was fixed. The ambient temperature was adjusted at 12°C.
298	05/13/91	Dropped the ambient temperature back to 4°C after sampling.
319	06/03/91	Stopped the lab operation after sampling.

Appendix D

RAW DATA, SYSTEM I

SYSTEM I

DATE	INFLUENT							(memb.)				
	NH4 mg/L	NOx mg/L	NO2 mg/L	TKN mg/L	TP mg/L	TSS mg/L	VSS mg/L	PO4 mg/L	BOD mg/L	COD mg/L	NH4/ TKN	pH
90-07-24	253								38	449		
90-07-28	253									449		
90-07-31	253	0.2		242	0.1	190	10	0.7		328	1.05	
90-08-02	216	11.4		167	0.0	310	250	0.2		401	1.29	
90-08-08	214	11.2	12.90	96	1.4	258	75	0.0		395	2.23	
90-08-12	210	42.7	34.60	175	0.1	60	32	19.1		477	1.20	
90-08-22	216	32.1		238	0.1	60	14	1.1		596	0.91	8.10
90-09-06	260	21.0		264	10.9	106	98	0.7		636	0.98	7.89
90-09-10	250	14.4		265	0.7	195	130	2.0		504	0.94	7.93
90-09-18	265	12.3		121	0.7	684	38	1.1		520	2.19	7.77
90-09-25	247	35.7		243	4.3	585	300	1.9		668	1.02	8.10
90-10-01	176	3.1		174	0.0	116	66	0.2		591	1.01	7.93
90-10-04	324	4.5		315	0.0	240	110	0.5		591	1.03	7.60
90-10-11	306	6.2		320	0.0	183	93	0.3		575	0.96	7.97
90-10-21	294	19.8		303	0.0	46	20	0.2		511	0.97	7.93
90-10-25	316	12.1		280	0.0	64	32	0.2		622	1.13	7.88
90-11-05	329	22.4	0.60	300	0.0	40	30	0.3		563	1.10	8.27
90-11-14	247	11.3	0.30	191	0.0	56	32	0.2		515	1.29	8.15
90-11-20	254	8.2	0.40	259	0.0	58	30	0.1		496	0.98	7.93
90-12-10	252	32.2	0.90	216	0.0	357	150	0.1		572	1.17	8.39
90-12-17	279	10.1	0.30	239	0.0	70	38	0.1		489	1.17	8.04
90-12-20	199	10.4	0.40	263	0.0			0.0		463	0.76	
91-01-01	226	3.2		239	0.0	60	30	0.0		489	0.95	8.12
91-01-08	256	3.3		195	0.0	60	32	0.2		429	1.31	7.91
91-01-16	201	1.4		198	1.0	80	37	0.0		503	1.02	8.00
91-01-22	173	1.2		195	0.0	97	53	0.1		392	0.89	7.98
91-01-28	172	2.1		188	0.0			0.1		392	0.91	8.26
91-02-04	206	0.7		202	0.0	75	33	0.1		381	1.02	8.05
91-02-11	120	0.6		114	0.0	98	42	0.2	43	284	1.05	7.93
91-02-17	97	4.3		100	0.0	5	3	0.2	19	303	0.97	7.27
91-02-25	88	2.9		100	0.0	34	22	0.2		261	0.88	8.18
91-03-03	86	1.0		100	0.0	387	180	0.1	78	337	0.86	7.34
91-03-10	86	1.5		97	0.0	63	38	0.3	17	255	0.89	8.21
91-03-13	86	1.2				53	7	0.1				8.07
91-03-16	85	0.3		100	0.0	83	47	0.1	18	290	0.85	7.54
91-03-26	193	1.8		131	0.0	60	2	0.1	8	329	1.47	8.65
91-03-31	200	1.5	0.47	136	0.0	78	10	0.2	15	329	1.47	8.57
91-04-03	185	1.1	0.28	127	0.0	54	32	0.1	20	329	1.45	8.12
91-04-07	191	0.8	0.42	124	0.0	86	46	0.1	12	352	1.54	8.57
91-04-11	177	2.0	0.77	132	0.0	154	64	0.2	65	354	1.34	8.48
91-04-14	177	1.0	0.23	123	0.0	154	64	0.1	42	320	1.44	
91-04-19	174	1.3	0.35	124	0.0	272	108	0.1	38	372	1.40	8.65
91-04-24	171	0.2	0.01	125	0.0	102	50	0.1	23	327	1.37	8.27
91-04-28	161	0.6	0.25	130	0.0	94	54	0.1	23	368	1.24	8.05
91-05-05	160	0.5	0.11	192	0.0	174	74	0.2	39	340	0.83	8.74
91-05-09	167	0.7	0.19	192	0.0	58	30	0.1	47	348	0.87	8.16
91-05-13	167	1.2	1.00	192	0.0	74	36	0.1		347	0.87	8.31
91-05-21	186	1.2	0.77	190	0.0	190	92	0.2	88	349	0.98	8.41
91-05-27	182	1.5	0.88	192	0.0	124	66	0.1	41	341	0.95	8.76
91-06-03	189	1.3	0.72	180	0.0	160	70	0.1	42	349	1.05	8.46

SYSTEM I

DAY	ANOXIC NH4 mg/L	NOx mg/L	NO2 mg/L	TKN mg/L	TP mg/L	MLSS mg/L	MLVSS mg/L	(memb.) PO4 mg/L	BOD mg/L	COD mg/L	VSS/TSS	ORP	pH
5	109	72.7		324	93	2595	2295	10.2		3433	0.88	109	8.15
9	103	112.5		241	79	1650	1630	4.7		2947	0.99	126	7.82
12	95	118.2		191	24.7	1550	1180	4.6		1806	0.76	121	7.65
14	58	195.5		132	18.7	1420	1060	0.9		1681	0.75	120	7.50
20	40	175.5	84.5	96	5.7	1045	715	0.2		947	0.68	96	7.69
24	81	128.3	42.3	119	6.6	920	570	0.3		1093	0.62	90	7.70
34	29	217.5		67	2.3	70		0.3		756	0.00	98	7.60
49	193	21.0		192	8.3	960	570	0.7		1233	0.59	64	8.11
53	151	1.0		214	4.3	1170	710	1.9		1023	0.61	-14	8.18
61	43	228.0		172	57.7	3370	2240	2.6		3510	0.66	83	7.43
68	31	216.1		239	47.7	3410	2560	2.8		3223	0.75	63	7.77
74	34	27.5		225	40.5	3700	2560	0.3			0.69	21	8.11
77	84	69.3		282	45.9	4310	3000	0.4		3817	0.70	30	7.68
84	56	76.3		349	42.3	5010	3650	0.4		5094	0.73	-49	8.05
94	53	69.9		277	32.1	4220	2870	0.8		4055	0.68	-63	8.09
98	48	0.0			6.5	3820	2770	0.2		3943	0.73	-105	8.14
109	248	0.1	0.00	206	3.5	2780	2540	0.6		3899	0.91	-264	8.35
118	203	0.1	0.00	164	3.5	4020	2340	0.3		2948	0.58	-342	8.35
124	209	0.1	0.00			4170	2460	0.3			0.59	-428	8.28
144	234	1.4	0.50	213	2	2630	1570	0.4		3131	0.60	-453	8.56
151	256	0.1	0.10	214	2	4000	2250	0.7		2952	0.56	-425	8.37
154	167	0.1	0.10	326	7.9	4380	2070	0.5		3365	0.47	-415	8.47
166	228	0.1		351	8.8	4360	2040	0.5		3778	0.47	-427	8.42
173	231	0.2		313	15.2	3460	1970	0.5		3746	0.57	-436	8.37
181	156	0.1		305	18.1	4610	2150	0.2		3082	0.47	-465	8.19
187	129	0.3		356	33.8	4480	2280	0.2		3516	0.51	-469	8.10
193	195	0.1		392	51.5	4780	2660	4.1		3854	0.56	-460	8.28
200	165	0.1		400	57.6	4460	2450	1.9		3606	0.55	-482	8.53
207	127	0.8		265	49.0	3380	1540	5.0	467	2263	0.46	-465	8.53
213	31	0.0		147	34.3	2830	1230	2.0	424	1786	0.43	-412	8.26
221	14	2.5		119	42.9	2810	1220	4.1		1765	0.43	-420	8.22
227	13	0.9		97	31.9	2130	1200	4.1	547	1365	0.56	-440	8.07
234	10	0.1		130	38.0	2390	1300	1.9	451	1846	0.54	-449	8.13
237	15	0.2				2280	1290	1.1			0.57	-444	7.92
240	11	0.4		133	31.9	2140	1220	2.2	541	1909	0.57	-350	7.97
250	35	1.1		149	38.3	2570	1610	1.7	605	2631	0.63	-390	8.25
255	38	77.1	0.73	142	37.2	2280	1400	4.4	597		0.61	-15	7.97
258	33	78.5	1.96	109	30.0	2030	1230	2.2	655	1881	0.61	-5	7.91
262	42	24.0	0.05	123	30.0	2270	1590	1.0	760	2218	0.70	10	8.16
266	6	0.6	0.00	113	35.2	2540	1810	3.0	695	2515	0.71	-40	8.30
269	13	37.1	0.26	132	34.1	2490	1760	0.7	599	2444	0.71	-25	8.24
274	21	23.3	0.49	138	34.1	2460	1790	0.8	810	2556	0.73	-65	8.16
279	18	4.3	0.53	146	39.3	2790	2080	4.3	910	2857	0.75	-157	8.19
283	9	0.3	0.01	168	55.8	2900	2290	4.7	955	6903	0.79	-230	8.13
290	13	26.0	1.75	235	52.2	3590	1980	4.7	615	2874	0.55	-136	8.17
294	18	41.1	4.64	190	43.6	2380	1790	7.3	710	2672	0.75	-95	8.01
298	16	50.4	0.29	218	51.2	2550	1940	5.2		2591	0.76	-42	8.04
306	21	76.7	0.39	235	51.2	2780	2200	2.9	756	3021	0.79	-102	8.04
312	18	61.7	0.49	259	56.9	2950	2340	3.6	683	3333	0.79	-117	8.10
319	17	62.4	0.62	259	65.4	3110	2420	5.8	826	3704	0.78	-136	8.03

SYSTEM I

DAY AEROBIC--(memb.)-----------------------------------+

DAY	NH4 mg/L	NOx mg/L	NO2 mg/L	TKN mg/L	TP mg/L	MLSS mg/L	MLVSS mg/L	PO4 mg/L	BOD mg/L	COD mg/L	VSS/TSS	DO	pH
5	101.1	93.2		286	83.0	2370	2030	13.0		3148	0.86	1.9	8.12
9	88.3	133.0		245	76.0	1440	1290	4.3		2534	0.90	6.6	7.85
12	77.6	147.7		160	24.7	1550	1080	1.6		1661	0.70	1.9	7.58
14	29.1	225.0		109	18.7	1310	990			1387	0.76	5.1	7.43
20	11.2	198.0		67	5.7	1370	790	0.2		937	0.58	2.7	7.40
24	60.1	157.5	48.40	84	3.1	505	295	0.2		696	0.58	4.6	7.62
34	6.5	238.3		41	3.1	80		0.3		815		3.2	7.49
49	175.6	26.3		191	6.6	825	535	0.6		1233	0.65	3.2	8.14
53	133.4	6.0		191	4.3	1100	690	0.8		997	0.63	1.4	8.20
61	0.0	262.1		127	54.1	3460	2110	4.7		3190	0.61	2.2	7.12
68	0.0	251.6		151	44.1	3140	2250	1.7		2634	0.72	2.7	7.37
74	0.0	81.3		206	34.2	3600	2550	0.2		3897	0.71	4.0	7.82
77	5.3	113.2		218	42.3	4470	3000	0.5		4017	0.67	1.9	7.53
84	3.0	159.3		275	42.3	4800	3470	0.3		5174	0.72	3.3	7.81
94	3.0	120.9		254	32.9	4330	2950	0.3		4181	0.68	3.2	7.74
98	10.0	46.5			8.0	3870	2740	0.2		3943	0.71	3.6	7.97
109	243.0	1.4	0.30	211	4.3	3660	2470	0.4		3805	0.67	4.2	8.39
118	198.0	0.6	0.30	167	4.3	4110	2270	2.1		4466	0.55	2.9	8.36
124	200.0	1.5	0.50	331	12.0	4020	2410	0.3		3208	0.60	5.2	8.40
144	228.6	1.7	0.50	204	2.0	3660	1540	0.4		3000	0.42	6.5	8.64
151	252.0	0.1	0.00	221	2.0	3810	2170	0.7		2857	0.57	5.3	8.47
154	166.9	0.3	0.20	334	7.0	3700	1790	0.4		3079	0.48	5.4	8.57
166	239.7	0.2		341	7.9	4460	1910	0.4		3619	0.43	4.8	8.56
173	228.3	0.2		284	11.6	4090	1800	0.3		2794	0.44	4.5	8.42
181	157.5	0.3		157	19.0	4530	2140	0.2		2861	0.47	5.9	8.32
187	122.5	0.3		395	39.1	5400	2640	0.2		3884	0.49	3.3	8.19
193	166.8	0.5		422	57.6	5700	3010	3.5		4069	0.53	5.2	8.34
200	167.3	1.8		419	64.9	4550	2440	5.1		3606	0.54	7.5	8.63
207	133.7	2.3		293	60.0	4560	1810	4.0	527	2512	0.40	6.4	8.61
213	23.7	9.4		133	39.2	3240	1230	2.0	390	1703	0.38	5.8	8.29
221	2.6	15.5		117	46.6	3980	1340	3.1		1828	0.34	3.6	8.19
227	0.9	4.4		108	38.0	3020	1440	3.4	510	1647	0.48	4.7	8.17
234	0.7	10.9		139	45.3	3530	1520	1.6	431	2116	0.43	8.5	8.14
237	2.8	13.2				3210	1540	1.0			0.48	8.7	7.95
240	1.2	11.8		139	39.2	2510	1260	1.5	217	2054	0.50	8.2	8.04
250	2.6	21.8		144	41.4	2930	1730	0.8	815	2711	0.59	6.4	8.07
255	27.6	102.1		122	44.5	3120	1630	2.5	617	2570	0.52	8.5	7.90
258	13.6	93.4	2.21	109	37.2	2860	1450	2.1	650	2198	0.51	9.0	8.00
262	0.9	62.7	2.18	110	39.3	2940	2850	0.4	421	2475	0.97	7.4	7.85
266	0.1	4.8	0.01	121	42.4	3810	2150	1.5	493	2871	0.56	9.5	8.39
269	0.1	55.7	0.03	137	42.4	3840	2100	0.5	624	2782	0.55		7.87
274	0.3	44.1	0.08	141	37.2	3050	2100	0.5	653	2688	0.69	4.7	7.91
279	2.2	23.9	0.64	157	56.8	3330	2390	4.2	905	3308	0.72	1.0	7.92
283	0.5	15.3	0.01	183	67.2	2670	2710	3.9	870	3684	1.01	4.9	7.97
290	0.1	45.4	0.35	330	79.7	3120	2270	6.0	815	3320	0.73	5.8	7.95
294	5.5	58.4	2.26	220	59.7	2990	2260	7.4	691	3219	0.76	9.5	7.98
298	0.3	68.6	0.19	247	70.2	3380	2540	4.0		3178	0.75	7.0	7.86
306	0.0	99.0	0.02	286	73.0	3560	2760	3.1	793	4113	0.78	7.9	7.81
312	0.1	80.7	0.02	275	68.3	3440	2690	3.8	763	3899	0.78	8.0	7.95
319	0.1	83.4	0.02	284	81.5	3610	2790	5.7	883	4094	0.77	6.2	7.87

SYSTEM I

DAY	EFFLUENT----							(memb)			
	NH4 mg/L	NOx mg/L	NO2 mg/L	TKN mg/L	TP mg/L	SS mg/L	VSS mg/L	PO4 mg/L	BOD mg/L	COD mg/L	pH
5	97.6	97.7		144	33.0			12.8		837	
9	86.0	134.1		220	65.0			4.7		1167	
12	81.3	152.3		111	10.9	540	460	1.4		872	
14	30.3			73	8.3	640	470			819	
20	9.8	191.3	87.40	37	3.1	425	195	0.2		572	
24	56.0			67	0.1	170	30			517	
34		239.3		35	0.0	38	16	0.7		199	7.50
49	182.3	27.4		160	2.3	94	72	1.3		835	8.15
53	133.4	6.4		186	1.6	180	123	0.8		512	8.20
61	0.0	251.3		24	6.1	230	160	2.1		613	7.11
68	0.0	267.3		15	6.1	187	133	1.5		614	7.34
74	0.0	83.1		7	0.7	72	64	0.1		307	7.80
77	0.7	107.8		7	1.1	49	31	0.2		307	7.61
84	0.0	166.3		22	3.4	287	193	0.2		399	7.83
94	3.0	141.4		21	1.5	222	148	0.1		798	7.78
98	7.8	44.0		3	0.0	326	242	0.1		696	8.02
109	235.8	1.5	0.20	204	0.0	175	120	0.3		786	8.42
118	196.2	1.2	0.30	172	0.0	110	76	0.3		1115	8.40
124	208.8	1.7	0.30	205	0.0	140	88	0.3		996	8.43
144	225.0	1.2	0.30	203	0.0	227	147	0.3		1246	8.65
151	253.8	0.4		214	0.0	193	103	0.5		921	8.48
154	169.1	0.3		246	0.7			0.3		1429	8.57
166	226.0	0.3		237	1.6	310	177	0.4		1460	8.56
173	248.8	0.2		172	0.0	170	110	0.3		1302	8.47
181	151.6	0.6		300	0.6	183	130	0.1		535	8.32
187	126.6	0.3		157	2.4	190	150	0.1		565	8.21
193	158.1	0.6		158	9.8			3.0		750	8.34
200	161.5	1.8		229	23.3	1220	820	4.6		5064	8.63
207	139.6	2.7		172	19.6	665	445	4.5	282	789	8.61
213	25.2	16.4		67	12.3	480	330	2.2	105	540	8.23
221	1.5	16.4		26	11.0	325	190	4.4		441	8.08
227	1.8	3.2		26	9.8	290	190	3.4	210	502	8.37
234	0.9	11.1		20	9.8	440	330	1.8	143	602	8.12
237	0.2	14.7				343	247	1.1			8.03
240	0.2	12.5		31	7.4	445	310	1.8	210	602	8.04
250	2.2	26.6		18	3.2	260	200	1.3	160	562	7.82
255	23.3	101.7	1.03	43	9.4	510	375	2.5	398	803	7.80
258	13.1	87.4	1.68	46	10.4	510	360	2.2	480	745	7.82
262	1.3	56.5	1.75	17	3.2	230	180	0.7	86	467	7.91
266	0.0	12.6	0.01	11	1.1	225	170	1.2	47	374	8.14
269	0.0	58.7	0.01	26	6.3	535	400	0.4	284	695	7.91
274	0.4	43.9	0.01	30	6.3	475	360	0.5	273	671	7.97
279	2.0	28.8	0.69	31	11.4	465	360	4.6	288	652	7.92
283	0.0	16.2	0.01	41	16.6	645	515	4.6	311	911	8.04
290	0.0	46.2	0.01	41	13.3	460	365	5.8	156	810	7.97
294	5.0	59.2	2.24	37	14.2	400	305	7.4	513	688	7.94
298	0.0	70.9	0.03	14	8.6	310	250	5.2		497	7.96
306	0.1	109.2	0.03	7	5.7	260	190	3.1	325	526	7.85
312	2.3	83.8	0.04	4	4.8	112	82	3.4	166	370	7.98
319	0.2	83.7	0.03	4	6.7	106	62	5.8	121	409	7.93

SYSTEM I

DAY	PUMP FLOWS INFL L/d	RECL L/d	Carbon L/d	PO L/d	[Carbon] ml/L	C ADDN gCOD/d	Othor-P gP/l	ADD mgP/d	CODADD: P ADD	TOT COD IN, mg/d	TOTCOD IN mg/l	U COD ANOX mg/gVSS	U COD AER mg/gVSS
5	10.5	60.0	0.000	0.000	0	0.000	0.000	0.0		217860	3090	1.50	1551
9	10.5	60.0	0.000	0.000	0	0.000	0.000	0.0		171108	2427	1.81	1964
12	10.5	60.0	0.000	0.000	0	0.000	0.000	0.0		111389	1580	1.53	1538
14	10.5	60.0	0.000	0.000	0	0.000	0.000	0.0		93395	1325	1.59	1401
20	10.5	60.0	0.000	0.000	0	0.000	0.000	0.0		64200	911	1.32	1186
24	10.5	60.0	0.000	0.000	0	0.000	0.000	0.0		48648	690	1.92	2359
34	10.5	60.0	0.000	0.000	0	0.000	0.000	0.0		61626	874		
49	10.5	60.0	0.000	0.000	0	0.000	0.000	0.0		84837	1203	2.16	2305
53	10.5	60.0	0.000	0.000	0	0.000	0.000	0.0		70205	996	1.44	1445
61	10.5	60.0	0.000	0.000	0	0.000	0.000	0.0		223919	3176	1.57	1512
68	10.5	60.0	0.117	0.000	50	6.945	0.000	0.0		193209	2741	1.26	1171
74	10.5	60.0	0.117	0.000	50	6.945	0.000	0.0		284665	4038		1528
77	10.5	60.0	0.177	0.000	50	10.506	0.000	0.0		296686	4208	1.27	1339
84	10.5	60.0	0.205	0.000	50	12.168	0.000	0.0		378783	5373	1.40	1491
94	10.5	60.0	0.176	0.176	50	10.446	0.010	1.7	6.06	302193	4286	1.41	1417
98	10.5	60.0	0.255	0.255	50	15.136	0.006	1.6	9.57	292340	4147	1.42	1439
109	6.5	60.0	0.200	0.200	50	11.871	0.006	1.2	9.57	263454	3962	1.54	1540
118	6.5	60.0	0.147	0.147	50	8.725	0.006	0.9	9.57	301814	4539	1.26	1967
124	6.5	60.0	0.165	0.165	50	9.794	0.006	1.0	9.57	219876	3306		1331
144	6.5	60.0	0.169	0.169	50	10.031	0.006	1.0	9.57	205150	3085	1.99	1948
151	6.5	60.0	0.173	0.173	50	10.268	0.006	1.1	9.57	197451	2969	1.31	1317
154	6.5	60.0	0.213	0.213	50	12.643	0.006	1.3	9.57	211117	3175	1.63	1720
166	9.2	51.8	0.268	0.268	50	15.907	0.012	3.3	4.79	227733	3733	1.85	1895
173	8.9	51.8	0.235	0.306	50	13.948	0.098	30.0	0.47	175832	2895	1.90	1552
181	9.4	59.8	0.234	0.254	50	13.889	0.196	49.7	0.28	211456	3057	1.43	1337
187	9.6	59.0	0.278	0.225	50	16.501	0.392	88.1	0.19	281282	4100	1.54	1471
193	9.5	58.0	0.256	0.195	50	15.195	0.783	152.7	0.10	286451	4244	1.45	1352
200	9.0	58.0	0.061	0.214	50	3.621	0.783	167.6	0.02	203076	3031	1.47	1478
207	9.4	58.0	0.067	0.167	50	3.977	0.783	130.8	0.03	168458	2501	1.47	1388
213	9.4	59.0	0.063	0.080	50	3.739	0.783	62.7	0.06	118006	1725	1.45	1385
221	10.1	59.0	0.077	0.062	50	4.570	0.783	48.6	0.09	129107	1868	1.45	1364
227	10.1	61.9	0.106	0.119	50	6.292	0.783	93.2	0.07	123212	1711	1.14	1144
234	9.4	59.0	0.110	0.103	50	6.529	0.783	80.7	0.08	148086	2164	1.42	1392
237	9.3	59.0	0.098	0.03	50	5.817	0.783	23.5	0.25	5817			
240	9.1	58.0	0.127	0.052	50	7.538	0.783	40.7	0.19	142522	2124	1.56	1630
250	9.7	59.0	0.187	0.091	50	11.099	0.783	71.3	0.16	195193	2840	1.63	1567
255	10.6	59.0	0	0.06	50	0.000	0.783	47.0	0.00	173950	2498	0.00	1577
258	10.6	59.0	0	0.059	50	0.000	0.783	46.2	0.00	148659	2135	1.53	1516
262	10.6	59.0	0.176	0.031	50	10.446	0.783	24.3	0.43	181586	2608	1.39	868
266	9.0	58.3	0.143	0.042	50	8.488	0.783	32.9	0.26	201583	2994	1.39	1335
269	9.1	58.3	0.116	0.04	50	6.885	0.783	31.3	0.22	190963	2834	1.39	1325
274	9.4	60.0	0.153	0.054	50	9.081	0.783	42.3	0.21	192818	2778	1.43	1280
279	11.8	62.6	0.231	0.155	50	13.711	0.783	121.4	0.11	256124	3441	1.37	1384
283	8.4	60.5	0.229	0.159	50	13.592	0.783	124.5	0.11	262628	3816	3.01	1359
290	9.5	59.0	0.136	0.122	50	8.072	0.783	95.5	0.08	231160	3373	1.45	1463
294	9.5	59.0	0.125	0.116	50	7.419	0.783	90.8	0.08	224820	3280	1.49	1424
298	10.5	64.8	0.159	0.199	50	9.437	0.783	155.8	0.06	247196	3282	1.34	1251
306	10.5	64.8	0.115	0.114	50	6.826	0.783	89.3	0.08	314716	4179	1.37	1490
312	7.9	55.4	0.116	0.107	50	6.885	0.783	83.8	0.08	253696	4004	1.42	1449
319	9.4	59.0	0.113	0.094	50	6.707	0.783	73.6	0.09	286175	4184	1.53	1467

SYSTEM I SYSTEM I

DAY	+---------COD	REM--	-----------		UNITAER	TOTPO4	+-----PO4	REMOVAL AS P---+			
	TOT	ANOX	ANOX	AER	CLAR	COD REM	INmgP/l	TOT	ANOX	ANOX	AER	CLAR
	%	mg/d	%	%	%	(%)		%	mgP/d	%	%	%
5	-86	-24167	-11	8	96	-3.67	10.9				-27	85
9	-160	-36656	-21	14	93	-8.65	4.0				9	84
12	-166	-15935	-14	8	92	-0.49	1.3	-100	-233	-255	65	87
14	-104	-25116	-27	17	91	11.66	0.0					
20	-45	-2564	-4	1	91	10.45	0.1				15	87
24	-8	-28409	-58	36	89	-23.04	2.8				47	
34	67	8328	14	-8	96		0.8	36	32	61	0	65
49	-31	-2090	-2	0	90	-6.54	1.2	-86	36	42	14	68
53	-2	-1917	-3	3	92	-0.28	1.0	60	-65	-94	58	85
61	-18	-23537	-11	9	97	3.52	2.0	-91	-46	-33	-81	93
68	54	-34013	-18	18	97	7.01	1.6	21	-87	-80	39	87
74	75				99		0.1	58	-10	-115	23	93
77	81	27588	9	-5	99	-5.24	0.2	56	-11	-69	-25	94
84	77	19656	5	-2	99	-6.84	0.2	41	-13	-81	25	90
94	47	16316	5	-3	97	-0.31	0.2	64	-44	-350	63	93
98	66	14359	5	0	97	-1.09	0.2	58	-3	-27	-15	92
109	67	4171	2	2	98	-0.35	0.3	32	-19	-91	33	93
118	40	105772	35	-51	98	-56.16	0.3	3	0	0	-600	99
124	50				97		0.3	-12	0	-1	0	90
144	41	-3062	-1	4	96	2.32	0.3	-3	-7	-34	0	93
151	55	1143	1	3	97	-0.35	0.5	-82	-15	-46	0	93
154	41	-12655	-6	8	95	-5.81	0.3	-23	-14	-70	20	93
166	34	-2725	-1	4	94	-2.31	0.4	0	-6	-25	20	85
173	35	-51662	-29	25	93	18.37	0.8	91	16	35	40	85
181	73	-1695	-1	7	97	6.74	0.8				0	93
187	73	40085	14	-10	98	4.60	1.4	99	81	85	0	93
193	62	26306	9	-6	97	6.70	4.9	81	51	15	15	88
200	-546	-38526	-19	0	81	-0.41	6.5	75	308	71	-168	88
207	-11	16023	10	-11	96	5.56	5.8	68	56	14	20	84
213	23	-4156	-4	5	96	4.65	2.8	68	57	29	0	85
221	38	7110	6	-4	96	5.71	4.5	12	27	9	24	79
227	48	24932	20	-21	96	-0.55	4.2	64	13	4	16	86
234	37	21746	15	-15	96	1.96	2.8	79	63	33	17	84
237							1.3	58	15	17	7	85
240	46	14428	10	-8	96	-4.18	2.2	60	2	1	32	83
250	62	14338	7	-3	97	4.11	2.1	83	29	20	52	78
255	-144				95		2.8	47	-113	-58	44	85
258	-126	17666	12	-17	95	0.88	2.5	51	22	13	6	84
262	65	27125	15	-12	97	37.75	0.9	73	-9	-14	62	75
266	71	32274	16	-14	98	3.90	1.6	69	-98	-92	51	89
269	36	26262	14	-14	97	4.60	0.8	89	10	17	28	89
274	50	15432	8	-5	97	10.36	1.1	89	19	26	41	85
279	56	43448	17	-16	97	-0.77	5.5	56	86	21	2	83
283	54	-212506	-81	47	97	54.90	5.9	69	84	21	17	86
290	32	34176	15	-16	97	-0.76	6.4	43	117	26	-26	86
294	39	41681	19	-20	97	4.58	7.7	23	28	5	-2	86
298	60	52068	21	-23	98	6.32	6.6	65	103	21	23	82
306	47	87204	28	-36	98	-8.52	3.9	64	74	25	-7	86
312	69	42517	17	-17	99	-1.76	4.3	68	45	17	-5	89
319	62	32822	11	-11	99	4.13	6.1	27	21	5	1	86

SYSTEM I

DAY	TOT BOD IN (mg/d)	U ANOX BOD (mg/l: mg/lVSS	U AER BOD (mg/l: mg/lVSS)	TOT BOD REI (%)	U ANOX BOD REM (mg/d)	ANOX BOD REM (%)	AER BOD REMOVAL (%)	CLAR BOD REMOVAL (%)	+--- BOD:COD ---+ INFL	ANOX	AERB	EFFL
5	399											
9												
12												
14												
20												
24												
34												
49												
53												
61												
68												
74												
77												
84												
94												
98												
109												
118												
124												
144												
151												
154												
166												
173												
181												
187												
193												
200												
207	37238	0.30	0.29	40	5781	16	-13	93	0.15	0.21	0.21	0.36
213	29610	0.34	0.32	75	609	2	8	96	0.06	0.24	0.23	0.19
221												
227	41681	0.46	0.35	70	2297	6	7	94	0.23	0.40	0.31	0.42
234	34842	0.35	0.28	80	3976	11	4	95	0.07	0.24	0.20	0.24
237	5817											
240	20352	0.44	0.17	75	-15950	-78	60	87	0.06	0.28	0.11	0.35
250	65648	0.38	0.47	86	24060	37	-35	97	0.02	0.23	0.30	0.28
255	38908	0.43	0.38	-2553	-2667	-7	-3	90	0.05		0.24	0.50
258	40390	0.53	0.45	-2300	-5224	-13	1	89	0.06	0.35	0.30	0.64
262	38981	0.48	0.15	91	-13946	-83	45	97	0.03	0.34	0.17	0.18
266	41839	0.38	0.23	95	-4949	-13	29	99	0.18	0.28	0.17	0.13
269	46742	0.34	0.30	65	6375	17	-4	94	0.13	0.25	0.22	0.41
274	52191	0.45	0.31	73	-4023	-8	19	94	0.10	0.32	0.24	0.41
279	77952	0.44	0.38	76	10212	13	1	95	0.07	0.32	0.27	0.44
283	71070	0.42	0.32	81	5159	7	9	96	0.06	0.14	0.24	0.34
290	62821	0.31	0.36	82	20669	33	-33	97	0.11	0.21	0.25	0.19
294	50354	0.40	0.31	38	1690	3	3	90	0.14	0.27	0.21	0.75
298	9437											
306	64056	0.34	0.29	56	7121	11	-5	94	0.25	0.25	0.19	0.62
312	54239	0.29	0.28	82	10964	20	-12	97	0.12	0.20	0.20	0.45
319	66365	0.34	0.32	84	10341	15	-7	98	0.12	0.22	0.22	0.30

SYSTEM I

DAY	AMMONIA REMOVAL					UNIT AMM REMOVAL			
	TOT %	ANOX mg/d	ANOX %	AER mg/d	AER %	ANOX ıg/h/gVS.	ANOX g/m3/d	AER ıg/h/gVS.	AER g/m3/d
5	61	828	10	557	7	3.01	166	1.14	56
9	66	555	7	1036	14	2.84	111	3.35	104
12	68	837	11	1227	18	5.91	167	4.73	123
14	86	-3	0	2037	50	-0.02	-1	8.58	204
20	95	15	1	2030	72	0.17	3	10.71	203
24	73	-146	-3	1473	26	-2.13	-29	20.81	147
34				1586	78				159
49	30	62	0	1227	9	0.90	12	9.55	123
53	47	-17	0	1241	12	-0.19	-3	7.49	124
61	100	-249	-9	3032	100	-0.93	-50	5.99	303
68	100	408	16	2186	100	1.33	82	4.05	219
74	100	-549	-30	2397	100	-1.79	-110	3.92	240
77	100	-2478	-72	5548	94	-6.88	-496	7.71	555
84	100	-735	-23	3737	95	-1.68	-147	4.49	374
94	99	-470	-14	3525	94	-1.36	-94	4.98	353
98	98	402	11	2679	79	1.21	80	4.07	268
109	28	-206	-1	333	2	-0.67	-41	0.56	33
118	21	-122	-1	333	2	-0.43	-24	0.61	33
124	18	281	2	599	4	0.95	56	1.03	60
144	11	-423	-3	359	2	-2.25	-85	0.97	36
151	9	18	0	266	2	0.06	4	0.51	27
154	15	334	3	7	0	1.34	67	0.02	1
166	0	-122	-1	-714	-5	-0.50	-24	-1.56	-71
173	3	1145	8	164	1	4.84	229	0.38	16
181	25	158	1	-104	-1	0.61	32	-0.20	-10
187	27	281	3	446	5	1.03	56	0.70	45
193	8	-2359	-22	1904	14	-7.39	-472	2.63	190
200	22	166	1	-154	-1	0.56	33	-0.26	-15
207	-16	665	7	-451	-5	3.60	133	-1.04	-45
213	74	280	12	492	23	1.89	56	1.67	49
221	98	-3	0	798	81	-0.02	-1	2.48	80
227	98	55	6	860	93	0.38	11	2.49	86
234	99	171	20	647	93	1.09	34	1.77	65
237	100	-220	-27	850	82	-1.42	-44	2.30	85
240	100	25	3	683	90	0.17	5	2.26	68
250	99	-368	-18	2193	92	-1.91	-74	5.28	219
255	88	868	25	707	27	5.17	174	1.81	71
258	93	425	16	1363	59	2.88	85	3.92	136
262	99	-824	-39	2864	98	-4.32	-165	4.19	286
266	100	1163	73	427	99	5.36	233	0.83	43
269	100	761	47	838	99	3.60	152	1.66	84
274	100	222	13	1412	98	1.04	44	2.80	141
279	99	814	38	1164	88	3.26	163	2.03	116
283	100	693	52	616	95	2.52	139	0.95	62
290	100	637	42	883	99	2.68	127	1.62	88
294	97	621	33	883	70	2.89	124	1.63	88
298	100	572	33	1159	98	2.46	114	1.90	116
306	100	413	21	1540	100	1.56	83	2.33	154
312	99	433	28	1132	100	1.54	87	1.75	113
319	100	616	35	1159	99	2.12	123	1.73	116

SYSTEM I SYSTEM I

DAY	NITRIFICATION mg/d	%	UNIT mg/h/gVSS	DENITRIFICATION mg/d	%	UNIT mg/h/gVSS
5	1445	19	2.97			
9	1445	20	4.67			
12	2080	31	8.02	807	9	5.70
14	2080	51	8.75			
20	1586	56	8.37	-777	-7	-9.06
24	2059	36	29.08			
34	1466	72		-639	-4	
49	374	3	2.91	384	21	5.61
53	353	3	2.13	465	87	5.45
61	2404	79	4.75	-867	-6	-3.22
68	2503	115	4.63	1178	7	3.83
74	3793	158	6.20	3080	61	10.03
77	3095	52	4.30	1630	25	4.53
84	5852	148	7.03	4664	46	10.65
94	3596	96	5.08	3764	43	10.93
98	3278	97	4.99	2767	100	8.32
109	87	1	0.15	229	97	0.75
118	33	0	0.06	139	95	0.49
124	93	1	0.16	149	96	0.50
144	20	0	0.05	188	67	1.00
151	0	0	0.00	83	93	0.31
154	13	0	0.03	79	92	0.32
166	6	0	0.01	39	86	0.16
173	0	0	0.00	28	70	0.12
181	14	0	0.03	42	86	0.16
187	0	0	0.00	9	30	0.03
193	27	0	0.04	48	88	0.15
200	114	1	0.19	104	94	0.35
207	104	1	0.24	111	68	0.60
213	643	30	2.18	1009	100	6.83
221	899	92	2.79	825	83	5.63
227	249	27	0.72	141	67	0.98
234	741	107	2.03	665	99	4.26
237	887	85	2.40	865	98	5.58
240	768	101	2.54	699	96	4.77
250	1425	60	3.43	1512	95	7.82
255	1739	66	4.45	652	11	3.88
258	1039	45	2.99	-293	-6	-1.99
262	2696	92	3.94	1674	50	8.77
266	288	67	0.56	712	95	3.28
269	1257	149	2.49	933	27	4.42
274	1445	101	2.87	1029	39	4.79
279	1461	110	2.55	1487	82	5.96
283	1031	158	1.59	963	98	3.50
290	1331	150	2.44	955	35	4.02
294	1190	95	2.19	685	20	3.19
298	1366	115	2.24	812	18	3.49
306	1676	109	2.53	1313	19	4.98
312	1202	106	1.86	746	16	2.66
319	1442	124	2.15	689	14	2.37

SYSTEM I

DAY	Temp oC	AerSolids Wasting ml/d	ASRT day	Temp* ASRT oC*day	SSRT (day)	Temp* SSRT oC-days	ANOX COD REM:DENIT mg/d:mg/d	COD ADD: NOxENTD mgCOD/d: mgN/d	C ADDN: NOxPROD G/d/syst: G/d/syst	AnoxpH- Lea'tpH	AnoxpH- AerbpH
5	20	0	500	10000		0		0	0.00	0.61	0.03
9	20	0	500	10000		0		0	0.00		-0.03
12	20	0	500	10000	4.5	89.3	-19.75	0	0.00	-0.30	0.07
14	20	0	500	10000	4.0	79.7		0	0.00		0.07
20	20	0	500	10000	7.3	146.8	3.30	0	0.00		0.29
24	20	0	500	10000	22.6	452.5		0	0.00		0.08
34	20	0	500	10000	0.0		-13.04	0	0.00		0.11
49	20	0	500	10000	14.0	280.6	-5.44	0	0.00	0.55	-0.03
53	20	0	500	10000	10.5	209.9	-4.13	0	0.00	0.63	-0.02
61	20	0	500	10000	24.9	497.6	27.15	0	0.00	-0.13	0.31
68	20	0	500	10000	32.5	650.6	-28.88	0	2.77	0.19	0.40
74	20	0	500	10000	74.1	1481.4	0.00	1	1.83	0.46	0.29
77	20	0	500	10000	179.7	3594.5	16.93	2	3.39	0.25	0.15
84	20	500	20	400	18.2	364.6	4.21	1	2.08	0.63	0.24
94	20	500	20	400	18.9	377.2	4.33	1	2.91	0.65	0.35
98	20	500	20	400	13.7	274.0	5.19	5	4.62	0.68	0.17
109	12	500	20	240	24.1	288.9	18.22	50	136.27	0.92	-0.04
118	12	500	20	240	27.4	328.7	762.05	60	262.41	0.92	-0.01
124	12	500	20	240	26.6	319.0	0.00	63	105.19	0.86	-0.12
144	12	500	20	240	17.5	209.9	-16.27	36	502.81	1.11	-0.08
151	12	500	20	240	24.3	292.2	13.77	115		0.85	-0.10
154	12	500	20	240	40.6	486.8	-160.30	148	950.57	0.93	-0.10
166	12	500	20	240	14.7	176.0	-70.09	354	2607.73	1.15	-0.14
173	12	500	20	240	19.1	229.2	-1866.21	350		1.11	-0.05
181	12	500	20	240	18.3	219.2	-40.29	284	1004.13	0.83	-0.13
187	12	500	20	240	18.0	216.0	4639.43	565		0.77	-0.09
193	12	500	20	240	37.8	454.0	548.05	278	562.77	0.94	-0.06
200	12	500	20	240	5.5	66.5	-370.45	33	31.79	1.14	-0.10
207	12	500	20	240	6.7	80.3	144.32	25	38.34	1.51	-0.08
213	12	500	20	240	6.5	77.7	-4.12	4	5.82	1.24	-0.03
221	12	167	60	720	11.9	143.2	8.62	5	5.09	1.13	0.03
227	12	167	60	720	12.5	149.6	177.40	30	25.26	0.91	-0.10
234	12	167	60	720	8.5	102.1	32.71	10	8.82	0.93	-0.01
237	12	167	60	720	11.3	135.2	0.00	7	6.56		-0.03
240	12	167	60	720	8.0	96.5	20.65	10	9.81	0.74	-0.07
250	12	167	60	720	14.9	178.4	9.49	7	7.79	1.00	0.18
255	12	167	60	720	7.2	86.6	0.00	0	0.00	0.63	0.07
258	12	167	60	720	6.7	80.4	-60.27	0	0.00	0.57	-0.09
262	12	167	60	720	20.7	248.0	16.20	3	3.88	0.84	0.31
266	12	167	60	720	21.3	255.5	45.30	11	29.42	0.94	-0.09
269	12	167	60	720	9.9	118.4	28.16	2	5.48	0.84	0.37
274	12	167	60	720	10.5	126.6	15.00	3	6.29		0.25
279	12	167	60	720	9.7	116.3	29.21	8	9.39		0.27
283	12	167	60	720	10.7	128.1	-220.77	14	13.18	0.73	0.16
290	12	167	60	720	11.1	133.6	35.78	3	6.06		0.22
294	4	167	60	240	12.7	51.0	60.84	2	6.24		0.03
298	20	167	60	1200	15.2	304.9	64.13	2	6.91		0.18
306	4	167	60	240	20.8	83.0	66.39	1	4.07		0.23
312	4	167	60	240	46.2	184.6	56.99	1	5.73		0.15
319	4	167	60	240	50.2	200.9	47.66	1	4.65		0.16

SYSTEM I SYSTEM I

DATE	DAY	UNITANOX TKN (mg/l: mg/lVSS)	UNITAERB TKN (mg/l: mg/lVSS)	UNITANOX TP (mg/l: mg/lVSS)	UNITAERB TP (mg/l: mg/lVSS)	TKN/TSS ANOXIC ratio	TKN/TSS AEROBIC ratio	Nitrogen Wasted mg/d
90-07-24	5	0.14	0.14	0.04	0.04	0.125	0.12	2538
90-07-28	9	0.15	0.19	0.05	0.06	0.146	0.17	3718
90-07-31	12	0.16	0.15	0.02	0.02	0.123	0.10	2764
90-08-02	14	0.12	0.11	0.02	0.02	0.093	0.08	768
90-08-08	20	0.13	0.09	0.01	0.01	0.092	0.05	2398
90-08-12	24	0.21	0.28	0.01	0.01	0.129	0.17	708
90-08-22	34					0.957	0.51	2882
90-09-06	49	0.34	0.36	0.01	0.01	0.200	0.23	1970
90-09-10	53	0.30	0.28	0.01	0.01	0.183	0.17	2015
90-09-18	61	0.08	0.06	0.03	0.03	0.051	0.04	2894
90-09-25	68	0.09	0.07	0.02	0.02	0.070	0.05	2962
90-10-01	74	0.09	0.08	0.02	0.01	0.061	0.06	948
90-10-04	77	0.09	0.07	0.02	0.01	0.065	0.05	1208
90-10-11	84	0.10	0.08	0.01	0.01	0.070	0.06	2199
90-10-21	94	0.10	0.09	0.01	0.01	0.066	0.06	1890
90-10-25	98			0.00	0.00			
90-11-05	109	0.08	0.09	0.00	0.00	0.074	0.06	1443
90-11-14	118	0.07	0.07	0.00	0.00	0.041	0.04	1212
90-11-20	124	0.00	0.14	0.00	0.00	0.000	0.08	1511
90-12-10	144	0.14	0.13	0.00	0.00	0.081	0.06	1427
90-12-17	151	0.10	0.10	0.00	0.00	0.054	0.06	1505
90-12-20	154	0.16	0.19	0.00	0.00	0.074	0.09	1769
91-01-01	166	0.17	0.18	0.00	0.00	0.080	0.08	2352
91-01-08	173	0.16	0.16	0.01	0.01	0.090	0.07	1683
91-01-16	181	0.14	0.07	0.01	0.01	0.066	0.03	2892
91-01-22	187	0.16	0.15	0.01	0.01	0.080	0.07	1704
91-01-28	193	0.15	0.14	0.02	0.02	0.082	0.07	1717
91-02-04	200	0.16	0.17	0.02	0.03	0.090	0.09	2291
91-02-11	207	0.17	0.16	0.03	0.03	0.078	0.06	1779
91-02-17	213	0.12	0.11	0.03	0.03	0.052	0.04	852
91-02-25	221	0.10	0.09	0.04	0.03	0.042	0.03	446
91-03-03	227	0.08	0.08	0.03	0.03	0.046	0.04	310
91-03-10	234	0.10	0.09	0.03	0.03	0.055	0.04	319
91-03-13	237	0.00	0.00	0.00	0.00			139
91-03-16	240	0.11	0.11	0.03	0.03	0.062	0.06	422
91-03-26	250	0.09	0.08	0.02	0.02	0.058	0.05	456
91-03-31	255	0.10	0.07	0.03	0.03	0.062	0.04	1576
91-04-03	258	0.09	0.07	0.02	0.03	0.053	0.04	1442
91-04-07	262	0.08	0.04	0.02	0.01	0.054	0.04	803
91-04-11	266	0.06	0.06	0.02	0.02	0.044	0.03	237
91-04-14	269	0.08	0.07	0.02	0.02	0.053	0.04	799
91-04-19	274	0.08	0.07	0.02	0.02	0.056	0.05	725
91-04-24	279	0.07	0.07	0.02	0.02	0.052	0.05	736
91-04-28	283	0.07	0.07	0.02	0.02	0.058	0.07	514
91-05-05	290	0.12	0.15	0.03	0.04	0.066	0.11	891
91-05-09	294	0.11	0.10	0.02	0.03	0.080	0.07	961
91-05-13	298	0.11	0.10	0.03	0.03	0.085	0.07	941
91-05-21	306	0.11	0.10	0.02	0.03	0.085	0.08	1285
91-05-27	312	0.11	0.10	0.02	0.03	0.088	0.08	752
91-06-03	319	0.11	0.10	0.03	0.03	0.083	0.08	880

DATE	DAY	LEACHATE------- NH4 mg/L	NOx mg/L	NO2 mg/L	TKN mg/L	TP mg/L	TSS mg/L	VSS mg/L	(memb.)------- PO4 mg/L	BOD mg/L	COD mg/L	pH	Conductivity uS/cm	Zn mg/L	Cu mg/L
07/06/90												7.63	4923		
90-07-24	5									38	449	7.54		0.01	0
90-07-28	9													0.06	0.71
90-07-31	12	253	0.2						0.7			7.95		0.02	0.07
90-08-02	14	216							0.2					0	0
90-08-08	20	260	0	0					0.11					0.11	0
90-08-12	24				261	0.1					477		4984	0.06	0
90-08-22	34	242	0.8						0.9		517				
90-09-06	49	238	0				116	62	0.4		507	7.56	5366	@.04	@.13
90-09-10	53	309			227	0.7	185	115	1.6		110	7.55			
90-09-18	61	242	3		235	0.7			1.5		482	7.56			
90-09-25	68	247	0.5		246	2.5	140	97	1.5		442	7.58			
90-10-01	74	302	0.4		233	0	128	56	0.2			7.65			
90-10-04	77	304	1.9		305	0	88	40	0.2		567	7.43	6158		
90-10-11	84	299	1.6		349	0	92	60	0.3		559	7.42			
90-10-21	94	313	1.8		303	0	66	30	0.2		508	7.44			
90-10-25	98	307	1.6		286	0	64	38	0.1		544	7.46			
90-11-05	109	270	1.5	0.2	216	0	46	24	0.1		456	7.43	5347		
90-11-14	118	270	1.5	0.3	216	0	56	32	0.1		499	7.43			
90-11-20	124	274	1.2	0.2	259	0	54	28	0.1		471	7.42			
90-12-10	144	281	1.4		234	0	100	57	0.05		392	7.45			
90-12-17	151	275	1.7		234	0	80	50	0.06		486	7.52			
90-12-20	154	199	1.9		259	0			0.1		486	7.54			
91-01-01	166	176	0.1		201	0	70	34	0.1		368	7.27	4299		
91-01-08	173	256	0.1		197	0	52	20	0.1		378	7.26			
91-01-16	181	197	0.2		195	0.16	97	50	0.3		406	7.36			
91-01-22	187	176	0.1		187	0	77	40	0.4		416	7.33			
91-01-28	193	167	0.2		183	0			0.2		410	7.34			
91-02-04	200	202	0		196	0	23	13	0.3		399	7.39			
91-02-11	207	110	1.2		100	0	54	28	0.1	58	267	7.02	2779		
91-02-17	213	92	0		100	0	60	30	0.1	23	307	7.02			
91-02-25	221	95	0.1		106	0	38	22	0.4		305	7.09			
91-03-03	227	85	0.06		97	0	18	13	0.4	39	261	7.16			
91-03-10	234	87	0.17		97	0	38	27	0.27	21	288	7.2			
91-03-13	237	86	0.05						1.1						
91-03-16	240	84	0.09		125	1.3	90	33	0.38	17	278	7.23	3788		
91-03-26	250	184	0.16		209	0.2	56	18	0.38	26	327	7.25			
91-03-31	255	208	0.35	0.12	123	0	75.5	40.7	0.096	27	295	7.34			
91-04-03	258	205	0.35	0.21	126	0.1	54	26	2.04	56	288	7.34			
91-04-07	262	207	0	0.33	120	0	52	32	0.04	41	354	7.32			
91-04-11	266	180	0.5	0.2	13.5	8.3	74	36	0.123	28	323	7.36			
91-04-14	269	203	1.04	0.23	123	0	68	32	0.082	42	320	7.4			
91-04-19	274														
91-04-24	279												3993		
91-04-28	283	161	0.17	0.06	125	0	38	26	0.317	32	362	7.4			
91-05-05	290														
91-05-09	294														
91-05-13	298														
91-05-21	306														
91-05-27	312														
91-06-03	319														

Appendix E

RAW DATA, SYSTEM II

DATE	SYSTEM II INFLUENT							(memb.)				
	NH4 mg/L	NOx mg/L	NO2 mg/L	TKN mg/L	TP mg/L	TSS mg/L	VSS mg/L	PO4 mg/L	BOD mg/L	COD mg/L	NH4/ TKN	pH
90-07-24	253								38	449		
90-07-28	253									449		
90-07-31	253	0.2		242	0.1	190	10	0.7		328	1.05	
90-08-02	216	11.4		167	0.0	310	250	0.2		401	1.29	
90-08-08	214	11.2	12.90	96	1.4	258	75	0.0		395	2.23	
90-08-12	210	42.7	34.60	175	0.1	60	32			477	1.20	
90-08-22	216	32.1		238	0.1	60	14	1.1		596	0.91	8.10
90-09-06	260	21.0		264	10.9	106	98	0.7		636	0.98	7.89
90-09-10	250	14.4		265	0.7	195	130	2.0		504	0.94	7.93
90-09-18	265	12.3		121	0.7	684	38	1.1		520	2.19	7.77
90-09-25	247	35.7		243	4.3	585	300	1.9		668	1.02	8.10
90-10-01	176	3.1		174	0.0	116	66	0.2		591	1.01	7.93
90-10-04	324	4.5		315	0.0	240	110	0.5		591	1.03	7.60
90-10-11	306	6.2		320	0.0	183	93	0.3		575	0.96	7.97
90-10-21	294	19.8		303	0.0	46	20	0.2		511	0.97	7.93
90-10-25	316	12.1		280	0.0	64	32	0.2		622	1.13	7.88
90-11-05	329	22.4	0.60	300	0.0	40	30	0.3		563	1.10	8.27
90-11-14	247	11.3	0.30	191	0.0	56	32	0.2		515	1.29	8.15
90-11-20	254	8.2	0.40	259	0.0	58	30	0.1		496	0.98	7.93
90-12-10	252	32.2	0.90	216	0.0	357	150	0.1		572	1.17	8.39
90-12-17	279	10.1	0.30	239	0.0	70	38	0.1		489	1.17	8.04
90-12-20	199	10.4	0.40	263	0.0			0.0		463	0.76	
91-01-01	226	3.2		239	0.0	60	30	0.0		489	0.95	8.12
91-01-08	256	3.3		195	0.0	60	32	0.2		429	1.31	7.91
91-01-16	201	1.4		198	1.0	80	37	0.0		503	1.02	8.00
91-01-22	173	1.2		195	0.0	97	53	0.1		392	0.89	7.98
91-01-28	172	2.1		188	0.0			0.1		392	0.91	8.26
91-02-04	206	0.7		202	0.0	75	33	0.1		381	1.02	8.05
91-02-11	120	0.6		114	0.0	98	42	0.2	43	284	1.05	7.93
91-02-17	97	4.3		100	0.0	5	3	0.2	19	303	0.97	7.27
91-02-25	88	2.9		100	0.0	34	22	0.2		261	0.88	8.18
91-03-03	86	1.0		100	0.0	387	180	0.1	78	337	0.86	7.34
91-03-10	86	1.5		97	0.0	63	38	0.3	17	255	0.89	8.21
91-03-13	86	1.2				53	7	0.1				8.07
91-03-16	85	0.3		100	0.0	83	47	0.1	18	290	0.85	7.54
91-03-26	193	1.8		131	0.0	60	2	0.1	8	329	1.47	8.65
91-03-31	200	1.5	0.47	136	0.0	78	10	0.2	15	329	1.47	8.57
91-04-03	185	1.1	0.28	127	0.0	54	32	0.1	20	329	1.45	8.12
91-04-07	191	0.8	0.42	124	0.0	86	46	0.1	12	352	1.54	8.57
91-04-11	177	2.0	0.77	132	0.0	154	64	0.2	65	354	1.34	8.48
91-04-14	177	1.0	0.23	123	0.0	154	64	0.1	42	320	1.44	
91-04-19	174	1.3	0.35	124	0.0	272	108	0.1	38	372	1.40	8.65
91-04-24	171	0.2	0.01	125	0.0	102	50	0.1	23	327	1.37	8.27
91-04-28	161	0.6	0.25	130	0.0	94	54	0.1	23	368	1.24	8.05
91-05-05	160	0.5	0.11	192	0.0	174	74	0.2	39	340	0.83	8.74
91-05-09	167	0.7	0.19	192	0.0	58	30	0.1	47	348	0.87	8.16
91-05-13	167	1.2	1.00	192	0.0	74	36	0.1		347	0.87	8.31
91-05-21	186	1.2	0.77	190	0.0	190	92	0.2	88	349	0.98	8.41
91-05-27	182	1.5	0.88	192	0.0	124	66	0.1	41	341	0.95	8.76
91-06-03	189	1.3	0.72	180	0.0	160	70	0.1	42	349	1.05	8.46

DAY	SYSTEM II ANOXIC NH4 mg/L	NOx mg/L	NO2 mg/L	TKN mg/L	TP mg/L	MLSS mg/L	MLVSS mg/L	(memb.) PO4 mg/L	BOD mg/L	COD mg/L	VSS/TSS	ORP	pH
5	31	140.9		255	85.0	2310	2140	16.9		3507	0.93	63	7.93
9	50	164.8		151	44.0	1480	1310	5.1		2452	0.89	91	7.71
12	43	163.6		143	27.3	1510	1280	1.5		1890	0.85	99	7.22
14	38	195.5		145	26.4	1840	1430	1.3		2059	0.78		7.53
20	14	164.3	1.30	297	58.3	2130	1460	0.2			0.69	68	7.59
24	24	175.5	1.40	113	19.5	1920	910	0.2		1869	0.47	95	7.44
34	20	229.5		130	20.4	1670	1090	0.8		2107	0.65	108	7.53
49	205	32.1		215	7.5	820	535	1.2		1193	0.65	73	8.16
53	156	0.1		233	4.3	1100	740	2.0		921	0.67	-9	8.21
61	43	221.1		102	32.4	2150	1340	2.3		2169	0.62	97	7.49
68	235	17.1		243	4.3	950*	550*	1.8				67	8.09
74	34	15.0		218	30.6	3430	2440	0.4		826	0.71	-27	8.15
77	66	58.6		241	35.1	3840	2770	0.5		3897	0.72	2	7.76
84	84	6.6		299	28.7	4320	3150	0.2		4755	0.73	-64	8.09
94	60	16.6		278	25.1	3930	2780	0.2		4286	0.71	-58	8.12
98	86	0.0		101	6.5	3440	2500	0.2		3786	0.73	-206	8.10
109	247	0.1	0.00	228	2.7	3180	2000	0.3		3082	0.63	-320	8.36
118	232	0.1	0.00	228	2.0	3400	2200	0.3		3210	0.65	-404	8.32
124	234	0.2	0.00	341	8.5	3530	1890	0.4		3085	0.54	-414	8.26
144	235	0.6	0.20	209	1.6	3830	1860	0.3		3183	0.49	-442	8.61
151	257	0.2	0.00	209	1.2	4040	1950	0.7		3111	0.48	-558	8.37
154	162	0.2	0.00	324	6.6	4210	1950	0.3		3460	0.46	-649	8.45
166	233	0.1		341	7.5	4180	1670	0.4		3587	0.40	-665	8.39
173	226	0.0		290	12.5	4760	2190	0.3		3460	0.46	-660	8.32
181	144	0.1		339	24.2	5310	2400	0.1		3270	0.45	-660	8.14
187	137	0.3		362	35.6	4640	2370	0.3		3577	0.51	-657	8.10
193	167	0.1		389	55.1	5080	2640	3.9		3854	0.52	-665	8.22
200	166	0.0		386	51.5	4220	2170	5.0		1355	0.51	-677	8.47
207	136	0.3		271	50.2	5080	1930	5.4	388	2076	0.38	-690	8.60
213	51	4.2		141	31.9	2910	1220	1.6	297	1661	0.42	-670	8.30
221	13	8.8		122	36.8	3300	1380	3.8		1765	0.42	-460	8.12
227	11	0.2		111	31.9	2930	1320	3.8	583	1627	0.45	-648	8.00
234	12	0.0		108	29.4	2480	1320	1.9	461	1846	0.53	-659	8.09
237	10	0.1				2620	1370	1.3			0.52	-654	7.95
240	8	0.0		150	36.8	2550	1310	2.0	617	1888	0.51	-655	7.96
250	16	1.8		128	39.3	2570	1610	2.1	735	2771	0.63	-672	8.22
255	23	86.6	0.78	124	36.2	2640	1550	1.9	638	2369	0.59	-239	7.87
258	26	99.8	1.38	98	31.0	2180	1300	1.8	643	2099	0.60	-220	7.74
262	39	37.8	0.09	122	37.2	2070	1410	3.4	675	1980	0.68	-207	8.17
266	5	85.6	0.97	81	37.2	2120	1400	5.9	456	1941	0.66	-236	8.21
269	13	65.7	0.13	92	31.0	2010	1280	2.8	750	1974	0.64	-224	8.22
274	16	26.5	0.22	102	32.1	1940	1400	2.2	835	2030	0.72	-280	8.23
279	18	16.0	0.61	119	46.5	2160	1640	5.5	905	2801	0.76	-364	8.11
283	10	2.6	0.70	144	61.0	2750	2100	6.1	1045	2935	0.76	-473	8.15
290	11	16.0	1.96	235	62.6	2690	2000	6.2	785	2955	0.74	-397	8.23
294	26	24.2	0.71	208	56.0	2330	1760	8.5	735	2632	0.76	-318	8.10
298	16	37.0	0.33	202	60.7	2810	2060	5.4		2552	0.73	-268	8.11
306	32	28.3	0.20	182	57.8	2380	1780	9.9	883	2456	0.75	-322	8.15
312	17	36.6	0.51	235	74.9	2460	1880	8.3	903	3216	0.76	-303	8.14
319	29	18.9	0.04	408	131.8	2660	2030	8.3	943	3021	0.76	-318	8.16

SYSTEM II

DAY	AEROBIC NH4 mg/L	NOx mg/L	NO2 mg/L	TKN mg/L	TP mg/L	MLSS mg/L	MLVSS mg/L	(memb.) PO4 mg/L	BOD mg/L	COD mg/L	VSS/TSS	DO	pH
5	59.3	168.2		198	91.0	2345	1905	18.9		2919	0.81	7.5	7.80
9	34.9	183.0		128	34.2	1320	1320	5.6		2452	1.00	3.2	7.61
12	15.2	160.2		126	29.0	1800	1350	1.4		1744	0.75	1.8	7.49
14	9.4	225.0		109	23.8	1900	1460	1.0		2185	0.77	2.3	7.21
20	0.3	195.8	0.30	92	17.8	2020	1530	0.1		2082	0.76	2.2	7.20
24	24.1	200.3	0.20	71	16.1	1800	1010	0.1		2028	0.56	3.2	7.10
34	0.0	263.4		92	24.7	2210	1460	0.6		2306	0.66	0.5	7.17
49	189.0	40.2		204	4.0	820	630	1.6		915	0.77	6.2	8.21
53	148.9	1.1		225	5.2	1110	690	1.2		972	0.62	3.6	5.24
61	10.7	273.8		93	37.8	2620	1530	2.1		2255	0.58	3.2	7.27
68	123.0	155.2		123	3.4	480*	290*	1.2		928		5.7	8.15
74	0.0	63.4		165	29.6	2770	1920	0.1		3000	0.69	4.6	7.84
77	3.0	100.7		191	31.5	3130	2230	0.2		3259	0.71	3.5	7.59
84	35.4	58.6		250	28.7	3660	2640	0.2		3897	0.72	1.2	7.87
94	19.2	62.8		241	26.8	2660	1550	0.4		3782	0.58	1.9	7.82
98	54.7	25.2		47	5.8	3450	2470	0.2		3492	0.72	3.2	8.01
109	235.8	0.7	0.20	218	3.5	2950	1950	0.6		2956	0.66	5.2	8.40
118	232.2	0.4	0.20	199	2.0	3220	1680	0.3		3079	0.52	5.2	8.39
124	221.4	0.9	0.30	328	7.6	3390	1780	0.3		2737	0.53	5.4	8.38
144	219.6	1.1	0.30	203	1.6	3430	1600	0.3		2922	0.47	4.0	8.68
151	250.2	0.1	0.00	221	1.2	3590	1570	0.3		2667	0.44	6.2	8.46
154	164.6	0.3	0.20	332	6.6	3820	1720	0.4		3302	0.45	6.3	8.56
166	235.1	0.1		330	7.9	4420	1720	0.3		3587	0.39	4.4	8.48
173	221.5	0.1		299	12.5	4800	2170	0.3		3905	0.45	2.7	8.33
181	150.6	0.1		341	25.1	5650	2510	0.1		3333	0.44	3.7	8.22
187	127.6	0.1		377	35.6	4410	2680	0.1		3639	0.61	1.7	8.20
193	156.3	0.0		403	53.9	5300	2690	3.1		3884	0.51	0.5	8.25
200	161.8	1.2		397	58.8	4620	2300	4.6		3146	0.50	7.5	8.57
207	136.4	2.2		389	55.1	4100	1680	4.2	290	2284	0.41	8.2	8.66
213	27.1	3.9		141	39.2	3040	1170	1.8	347	1682	0.38	8.3	8.24
221	1.6	24.1		125	42.9	4050	1460	3.6		2101	0.36	7.2	8.00
227	0.4	12.0		100	34.3	3480	1580	3.5	557	2149	0.45	4.3	8.02
234	2.0	9.0		130	40.4	3090	1480	1.6	321	2033	0.48	8.2	8.09
237	1.0	11.0				3440	1630	1.0			0.47	8.6	7.93
240	0.2	10.3		136	35.5	2690	1340	1.2	657	2095	0.50	8.8	8.00
250	1.6	25.4		131	44.5	3450	2020	1.3	708	2932	0.59	5.2	7.81
255	7.5	107.7	1.15	109	36.2	2720	1600	1.4	640	2550	0.59	7.6	7.63
258	9.2	117.2	1.48	95	36.2	2510	1440	2.1	577	2158	0.57	7.2	7.62
262	3.3	80.6	1.82	79	40.3	2460	1570	4.4	484	2139	0.64		7.81
266	1.9	90.1	0.00	92	44.5	2580	1580	4.9	449	2020	0.61		8.36
269	0.0	89.0	0.01	81	34.1	2250	1380	2.7	543	1992	0.61	6.7	7.76
274	0.1	48.0	0.02	102	35.2	2170	1430	1.9	621	2068	0.66	3.4	7.84
279	0.4	36.5	0.26	119	49.6	2390	1800	5.8	716	2575	0.75	2.7	7.86
283	0.8	19.7	0.00	132	58.9	2890	2140	5.7	836	2854	0.74	4.7	7.92
290	1.9	33.7	0.00	212	63.5	2790	2060	8.0	816	2955	0.74	4.6	7.86
294	14.4	39.7	0.71	196	56.0	2520	1880	8.5	696	2814	0.75	7.5	8.05
298	3.0	55.2	0.16	188	60.7	2910	2120	5.1		2532	0.73	5.9	7.81
306	17.8	40.4	0.18	175	61.6	2450	1840	10.3	846	2456	0.75	7.7	8.00
312	2.4	56.2	0.41	161	56.0	2110	1690	8.7	930	2437	0.80		7.91
319	11.5	30.5	0.18	192	64.5	1480	1820	8.4	843	2632	1.23	5.0	8.05

DAY	SYSTEM II EFFLUENT---- NH4 mg/L	NOx mg/L	NO2 mg/L	TKN mg/L	TP mg/L	SS mg/L	VSS mg/L	(memb) PO4 mg/L	BOD mg/L	COD mg/L	pH
5	37.2	163.6		144	24.0			12.8		470	
9	34.9	181.8		60	8.3			5.6		479	
12	19.8	190.9		30	3.1	120	120	1.6		415	
14	11.7			30	2.3	340	260			609	
20	0.4	191.3	0.50	18	0.1	92	60	0.1		399	
24	0.2			22	4.0	90	22			358	
34	0.0	261.5		22	0.6	38	12	0.2		517	7.21
49	195.7	37.4		173	2.3	213	163	1.3		569	8.22
53	147.0	1.9		191	0.7	110	97	0.8		563	8.24
61	6.1	223.5		26	6.1	230	147	1.9		622	7.23
68	104.6	147.2		104	2.5	127	100	1.4		771	8.13
74	0.0	74.1		13	0.7	72	50	0.1		327	7.83
77	0.0	84.5		7	1.1	82	34	0.1		367	7.64
84	44.6	56.9		41	3.4	227	150	0.2		786	7.92
94	19.2	111.0				210	150	0.1		378	7.87
98	50.2	7.0		39	2.0	1515	1120	0.1			8.02
109	235.8	0.2	0.10	218	0.0	168	118	0.3		786	8.42
118	228.6	0.2	0.10	196	0.0	206	132	0.4		1089	8.38
124	230.4	0.5	0.10	167	0.0	162	102	0.2		716	8.38
144	226.8	0.3	0.10	203	0.0	190	127	0.2		1168	8.67
151	235.8	0.0	0.00	216	0.0	183	73	0.2		1175	8.47
154	153.2	0.1	0.00	237	0.7			0.3		1460	8.55
166	239.7	0.0		225	1.6	145	88	0.2		1524	8.50
173	223.8	0.0		169	0.0	102	80	0.2		1175	8.39
181	145.2	0.2		162	2.4	240	187	0.1		628	8.22
187	130.9	0.0		183	4.9	457	357	0.1		719	8.16
193	205.5	0.0		166	9.8			3.1		750	8.25
200	163.7	1.1		221	18.4	800	590	0.9		3325	8.56
207	156.1	1.6		174	12.3	325	225	3.9	148	581	8.61
213	36.7	7.9		59	7.4	243	167	5.6	15	353	8.23
221	0.5	25.7		20	7.4	250	165	4.0		420	7.92
227	1.3	7.7		20	7.4	217	157	3.7	163	382	8.05
234	0.3	9.3		17	6.1	225	185	1.9	111	456	8.03
237	0.0	10.9				260	190	1.0			7.99
240	1.4	10.6		17	3.7	227	157	1.6	247	456	7.95
250	2.6	21.3		65	6.3	465	355	0.7	415	803	8.11
255	5.9	106.9	1.21	25	5.2	360	260	1.8	242	562	7.63
258	4.8	118.6	1.71	22	6.3	340	255	2.1	305	588	7.54
262	0.3	73.2	1.11	14	8.3	170	135	5.2	124	400	7.87
266	2.1	93.7	0.01	14	6.3	170	120	4.8	42	279	8.03
269	0.8	88.1	0.02	9	4.2	230	145	2.6	194	397	
274	1.2	46.6	0.02	11	3.2	78	56	1.8	133	395	7.91
279	0.2	38.8	0.32	14	11.4	220	165	6.4	206	432	7.97
283	0.1	19.8	0.01	13	8.3	122	90	6.4	92	364	7.97
290	0.4	33.4	0.01	17	10.5	217	150	7.0	186	486	7.90
294	13.8	41.9	0.55	49	15.2	415	330	9.4	276	668	8.02
298	0.0	55.8	0.03	17	11.4	295	210	5.7		477	7.90
306	11.9	40.1	0.12	25	15.2	255	185	11.2	265	507	7.96
312	2.8	54.2	0.29	10	10.5	72	56	8.3	101	370	7.88
319	8.2	30.6	0.12	8	8.6	50	36	8.5	108	468	8.01

SYSTEM II

DAY	PUMP FLOWS-- INFL L/d	RECL L/d	Carbon L/d	PO L/d	[Carbon] ml/L	C ADDN gCOD/d	Othor-P gP/l	P ADD mgP/d	CODADD: P ADD	TOT COD IN,mg/d	TOTCOD IN mg/l	U COD ANOX mg/gVSS	U COD AER mg/gVSS
5	10.5	60.0	0.000	0.000	0	0.000	0.000	0.0		205569	2916	1.64	1532
9	10.5	60.0	0.000	0.000	0	0.000	0.000	0.0		172551	2448	1.87	1858
12	10.5	60.0	0.000	0.000	0	0.000	0.000	0.0		122039	1731	1.48	1292
14	10.5	60.0	0.000	0.000	0	0.000	0.000	0.0		151859	2154	1.44	1497
20	10.5	60.0	0.000	0.000	0	0.000	0.000	0.0		146739	2081	0.00	1361
24	10.5	60.0	0.000	0.000	0	0.000	0.000	0.0		144224	2046	2.05	2008
34	10.5	60.0	0.000	0.000	0	0.000	0.000	0.0		163403	2318	1.93	1579
49	10.5	60.0	0.000	0.000	0	0.000	0.000	0.0		65211	925	2.23	1452
53	10.5	60.0	0.000	0.000	0	0.000	0.000	0.0		67907	963	1.24	1409
61	10.5	60.0	0.000	0.000	0	0.000	0.000	0.0		157907	2240	1.62	1474
68	10.5	60.0	0.144	0.000	50	8.547	0.000	0.0		72890	1034		
74	10.5	60.0	0.144	0.000	50	8.547	0.000	0.0		222819	3161	0.34	1563
77	10.5	60.0	0.188	0.000	50	11.159	0.000	0.0		243270	3451	1.41	1461
84	10.5	60.0	0.215	0.000	50	12.761	0.000	0.0		285284	4047	1.51	1476
94	10.5	60.0	0.180	0.180	50	10.684	0.010	1.8	6.06	278711	3953	1.54	2440
98	10.5	60.0	0.261	0.261	50	15.492	0.006	1.6	9.57			1.51	1414
109	6.5	60.0	0.176	0.176	50	10.446	0.006	1.1	9.57	205571	3091	1.54	1516
118	6.5	60.0	0.143	0.143	50	8.488	0.006	0.9	9.57	209510	3151	1.46	1833
124	6.5	60.0	0.162	0.162	50	9.616	0.006	1.0	9.57	190196	2860	1.63	1538
144	6.5	60.0	0.173	0.173	50	10.268	0.006	1.1	9.57	200707	3018	1.71	1826
151	6.5	60.0	0.170	0.170	50	10.090	0.006	1.1	9.57	182987	2752	1.60	1699
154	6.5	60.0	0.219	0.219	50	12.999	0.006	1.4	9.57	226101	3400	1.77	1920
166	9.2	51.8	0.228	0.228	50	13.533	0.012	2.8	4.79	222818	3653	2.15	2085
173	8.9	51.8	0.243	0.307	50	14.423	0.098	30.1	0.48	244912	4033	1.58	1800
181	9.4	59.8	0.224	0.274	50	13.296	0.196	53.6	0.25	242636	3508	1.36	1328
187	9.5	59.8	0.257	0.228	50	15.254	0.392	89.3	0.17	264330	3814	1.51	1358
193	9.5	58.0	0.256	0.200	50	15.195	0.783	156.6	0.10	273964	4059	1.46	1444
200	9.1	58.0	0.061	0.212	50	3.621	0.783	166.0	0.02	187935	2799	0.62	1368
207	9.4	58.0	0.066	0.147	50	3.917	0.783	115.1	0.03	154988	2301	1.08	1360
213	9.4	59.0	0.069	0.063	50	4.095	0.783	49.3	0.08	118676	1735	1.36	1438
221	10.1	59.0	0.074	0.058	50	4.392	0.783	45.4	0.10	148011	2141	1.28	1439
227	10.1	59.0	0.097	0.115	50	5.757	0.783	90.1	0.06	153843	2226	1.23	1360
234	9.8	59.0	0.119	0.095	50	7.063	0.783	74.4	0.09	145045	2107	1.40	1374
237	9.6	59.0	0.114	0.029	50	6.766	0.783	22.7	0.30				
240	9.4	58.0	0.12	0.049	50	7.123	0.783	38.4	0.19	146765	2178	1.44	1563
250	9.8	59.0	0.175	0.076	50	10.387	0.783	59.5	0.17	207581	3015	1.72	1451
255	10.5	59.0	0	0.055	50	0.000	0.783	43.1	0.00	174881	2515	1.53	1594
258	10.5	59.0	0	0.067	50	0.000	0.783	52.5	0.00	147348	2119	1.61	1499
262	10.5	59.0	0.067	0.099	50	3.977	0.783	77.5	0.05	152219	2189	1.40	1362
266	9.0	58.3	0.058	0.091	50	3.443	0.783	71.3	0.05	140104	2081	1.39	1278
269	9.1	58.3	0.09	0.085	50	5.342	0.783	66.6	0.08	138884	2061	1.54	1443
274	9.4	60.0	0.153	0.087	50	9.081	0.783	68.1	0.13	152384	2196	1.45	1446
279	11.7	62.6	0.224	0.184	50	13.296	0.783	144.1	0.09	203394	2737	1.71	1431
283	8.4	60.5	0.239	0.186	50	14.186	0.783	145.7	0.10	210660	3061	1.40	1334
290	9.5	59.0	0.171	0.184	50	10.150	0.783	144.1	0.07	211298	3083	1.48	1434
294	9.5	59.0	0.133	0.173	50	7.894	0.783	135.5	0.06	197726	2885	1.50	1497
298	10.5	64.8	0.192	0.239	50	11.396	0.783	187.2	0.06	200715	2665	1.24	1194
306	10.5	64.8	0.128	0.151	50	7.597	0.783	118.3	0.06	190898	2535	1.38	1335
312	7.6	55.4	0.128	0.158	50	7.597	0.783	123.7	0.06	161078	2554	1.71	1442
319	9.1	59.0	0.127	0.166	50	7.538	0.783	130.0	0.06	185724	2727	1.49	1446

SYSTEM II DAY	+---------COD TOT %	ANOX mg/d	REM-- ANOX %	----------- AER %	CLAR %	UNITAER COD REM (%)	SYSTEM II TOTPO4 INmgP/l	+-----PO4 TOT %	ANOX mgP/d	REMOVAL AS ANOX %	P---+ AER %	CLAR %
5	-5	-41675	-20	17	98	6.50	10.9				-12	90
9	-7	-315	0	0	97	0.76	4.8				-10	85
12	-27	-11207	-9	8	96	12.51	1.5	-129	-2	-2	7	83
14	-52	6699	4	-6	96	-3.94	0.0				23	
20							0.1				50	
24	25	12459	9	-9	97	2.24	0.0				50	
34	13	14859	9	-9	97	18.29	0.3	82	-33	-139	25	95
49	11	-18896	-29	23	91	34.87	1.2	-86	1	1	-33	88
53	-12	2976	4	-6	91	-13.19	1.0	60	-72	-104	40	90
61	-20	4992	3	-4	96	8.95	1.8	-73	-37	-29	9	87
68							1.5	26	-23	-22	33	83
74	77	164586	74	-263	98	-361.56	0.1	58	-20	-231	75	85
77	78	-31468	-13	16	98	-3.88	0.2	78	-25	-229	60	93
84	56	-49943	-18	18	97	2.21	0.2	41	1	9	0	85
94	75	-23452	-8	12	99	-58.26	0.2	65	-2	-12	-100	95
98						6.65	0.1	68	-5	-52	0	93
109	64	618	0	4	97	1.63	0.3	28	1	4	-100	95
118	40	-3955	-2	4	97	-25.61	0.4	-31	6	23	0	87
124	64	-14956	-8	11	97	5.80	0.2	24	-13	-94	25	93
144	46	-10962	-5	8	96	-6.72	0.2	32	-6	-43	0	93
151	42	-23895	-13	14	96	-6.48	0.2	27	-33	-238	57	93
154	41	-3989	-2	5	96	-8.19	0.3	-21	0	-2	-33	93
166	22	4011	2	0	94	2.91	0.2	42	-11	-80	25	90
173	43	34786	14	-13	96	-13.90	0.7	94	24	56	0	90
181	67	16483	7	-2	97	2.54	0.9				0	86
187	64	16444	6	-2	97	10.03	1.3	99	72	78	67	93
193	62	13819	5	-1	97	1.09	5.0	81	74	22	21	86
200	-328	96960	52	-132	86	-119.05	3.3	95	-117	-53	8	97
207	17	15148	10	-10	96	-26.39	5.1	69	-21	-6	22	87
213	52	5064	4	-1	97	-5.59	5.6	-3	272	71	-13	57
221	40	26014	18	-19	97	-12.51	4.1	14	21	7	5	84
227	58	41384	27	-32	97	-10.35	4.5	59	47	15	8	85
234	53	17967	12	-10	97	1.78	2.7	76	57	30	18	83
237		*					1.2	60	-7	-8	18	87
240	56	19514	13	-11	97	-8.48	2.0	62	-4	-3	42	81
250	42	16825	8	-6	96	15.67	1.4	89	-44	-45	38	93
255	-71	10140	6	-8	97	-4.28	2.2	58	23	15	24	81
258	-79	1383	1	-3	96	7.18	2.6	58	52	29	-14	85
262	45	14530	10	-8	97	2.98	5.6	30	150	39	-30	82
266	62	9436	7	-4	98	7.79	5.3	41	-44	-12	17	87
269	56	5857	4	-1	97	6.40	3.2	65	29	13	3	87
274	70	11502	8	-2	97	0.27	2.5	76	22	13	16	87
279	71	-4721	-2	8	97	16.24	7.4	48	137	25	-5	83
283	82	8644	4	3	98	4.58	7.7	64	111	21	6	87
290	65	8763	4	0	98	2.91	8.2	54	136	24	-29	88
294	43	17328	9	-7	97	-0.09	10.1	35	106	15	0	85
298	67	8524	4	1	97	3.59	7.4	68	146	26	6	85
306	53	5937	3	0	97	3.26	11.3	1	106	12	-4	85
312	72	-41755	-26	24	98	15.70	9.3	49	61	10	-4	88
319	60	-20036	-11	13	98	2.82	9.3	41	66	10	-1	87

SYSTEM II

DAY	TOT BOD IN (mg/d)	U ANOX BOD (mg/l: mg/lVSS	U AER BOD (mg/l: mg/lVSS)	TOT BOD REI (%)	U ANOX BOD REM (mg/d)	ANOX BOD REM (%)	AER BOD REMOVAL (%)	CLAR BOD REMOVAL (%)	+--- BOD:COD ---+ INFL	ANOX	AERB	EFFL
5	399											
9												
12												
14												
20												
24												
34												
49												
53												
61												
68												
74												
77												
84												
94												
98												
109												
118												
124												
144												
151												
154												
166												
173												
181												
187												
193												
200												
207	22528	0.20	0.17	68	-3607	-16	25	93	0.15	0.19	0.13	0.25
213	27452	0.24	0.30	97	7137	26	-17	99	0.06	0.18	0.21	0.04
221	4630											
227	43935	0.44	0.35	75	3638	8	4	96	0.23	0.36	0.26	0.43
234	27705	0.35	0.22	85	-4030	-15	30	95	0.07	0.25	0.16	0.24
237	6054											
240	49667	0.47	0.49	68	8081	16	-6	95	0.06	0.33	0.31	0.54
250	56146	0.46	0.35	61	5549	10	4	92	0.02	0.27	0.24	0.52
255	42122	0.41	0.40	-1513	-2244	-5	0	94	0.05	0.27	0.25	0.43
258	37132	0.49	0.40	-1425	-7582	-20	10	92	0.06	0.31	0.27	0.52
262	32719	0.48	0.31	68	-14221	-43	28	96	0.03	0.34	0.23	0.31
266	33758	0.33	0.28	91	3060	9	2	99	0.18	0.23	0.22	0.15
269	43939	0.59	0.39	69	-6603	-15	28	95	0.13	0.38	0.27	0.49
274	50989	0.60	0.43	87	-6960	-14	26	97	0.10	0.41	0.30	0.34
279	64301	0.55	0.40	82	-2940	-5	21	95	0.07	0.32	0.28	0.48
283	70202	0.50	0.39	95	-1725	-2	20	99	0.06	0.36	0.29	0.25
290	63198	0.39	0.40	83	9394	15	-4	97	0.11	0.27	0.28	0.38
294	53423	0.42	0.37	69	3046	6	5	95	0.14	0.28	0.25	0.41
298	11396											
306	69449	0.50	0.46	67	2951	4	4	96	0.25	0.36	0.34	0.52
312	65913	0.48	0.55	90	8961	14	-3	99	0.12	0.28	0.38	0.27
319	65068	0.46	0.46	88	841	1	11	98	0.12	0.31	0.32	0.23

SYSTEM II

DAY	AMMONIA REMOVAL					UNIT AMM REMOVAL			
	TOT	ANOX	ANOX	AER	AER	ANOX	ANOX	AER	AER
	%	mg/d	%	mg/d	%	ıg/h/gVS.	g/m3/d	ıg/h/gVS.	g/m3/d
5	85	2717	56	-2009	-93	10.58	543	-4.39	-201
9	86	1226	26	1065	30	7.80	245	3.36	106
12	92	813	21	1960	65	5.29	163	6.05	196
14	95	263	9	2045	76	1.53	53	5.83	204
20	100	1277	56	973	98	7.29	255	2.65	97
24	100	518	23	0	0	4.74	104	0.00	0
34	100	865	38	1403	100	6.61	173	4.00	140
49	25	48	0	1100	8	0.74	10	7.27	110
53	41	475	4	472	4	5.35	95	2.85	47
61	98	131	4	2263	75	0.82	26		226
68	58	-7719	-87	7917	48		-1544		792
74	100	-521	-28	2369	100	-1.78	-104	5.14	237
77	100	-1216	-36	4406	95	-3.66	-243	8.23	441
84	85	-26	0	3419	58	-0.07	-5	5.40	342
94	93	-12	0	2898	68	-0.04	-2	7.79	290
98	84	267	4	2207	36	0.89	53	3.72	221
109	28	-112	-1	718	4	-0.47	-22	1.53	72
118	7	-120	-1	0	0	-0.45	-24	0.00	0
124	9	-86	-1	838	5	-0.38	-17	1.96	84
144	10	-375	-2	1017	7	-1.68	-75	2.65	102
151	15	-1156	-7	479	3	-4.94	-231	1.27	48
154	23	-307	-3	-153	-1	-1.31	-61	-0.37	-15
166	-6	289	2	-134	-1	1.44	58	-0.33	-13
173	13	154	1	273	2	0.59	31	0.52	27
181	28	605	6	-456	-5	2.10	121	-0.76	-46
187	24	-16	0	644	7	-0.06	-3	1.00	64
193	-19	2301	17	702	6	7.26	460	1.09	70
200	21	239	2	275	2	0.92	48	0.50	28
207	-30	1030	10	-40	0	4.45	206	-0.10	-4
213	62	-444	-14	1662	47	-3.03	-89	5.92	166
221	99	21	2	788	88	0.13	4	2.25	79
227	98	159	17	755	96	1.00	32	1.99	75
234	100	15	2	709	84	0.10	3	2.00	71
237	100	145	17	615	90	0.88	29	1.57	61
240	98	348	39	518	97	2.21	70	1.61	52
250	99	953	47	983	90	4.93	191	2.03	98
255	97	849	35	1082	68	4.57	170	2.82	108
258	97	420	19	1166	65	2.69	84	3.37	117
262	100	-699	-35	2498	92	-4.13	-140	6.63	250
266	99	1401	81	191	60	8.34	280	0.50	19
269	100	802	48	851	100	5.22	160	2.57	85
274	99	593	35	1103	99	3.53	119	3.21	110
279	100	652	33	1317	98	3.31	130	3.05	132
283	100	654	48	640	92	2.60	131	1.25	64
290	100	785	51	630	83	3.27	157	1.28	63
294	92	628	26	778	44	2.97	126	1.72	78
298	100	553	31	976	81	2.24	111	1.92	98
306	94	334	12	1042	44	1.56	67	2.36	104
312	98	470	30	929	86	2.08	94	2.29	93
319	96	240	11	1175	60	0.99	48	2.69	117

SYSTI	SYSTEM II +------NI TRIFICATI ON------+			-----DENI TRIFICATI ON------+			SYSTEM II	
DAY	mg/d	%	UNIT mg/h/gVSS	mg/d	%	UNIT mg/h/gVSS	DAY	Temp oC
5	1925	89	4.21				5	20
9	1283	36	4.05				9	20
12	-240	-8	-0.74	-78	-1	-0.51	12	20
14	2080	77	5.94				14	20
20	2221	223	6.05	12	0	0.07	20	20
24	1748	103	7.21				24	20
34	2390	170	6.82	-153	-1	-1.17	34	20
49	571	4	3.78	201	8	3.14	49	20
53	71	1	0.43	258	97	2.91	53	20
61	3715	123	10.12	-2048	-15	-12.74	61	20
68	9736	59		8001	87		68	20
74	3412	144	7.40	3421	76	11.68	74	20
77	2968	64	5.55	986	19	2.97	77	20
84	3666	62	5.79	3014	87	7.97	84	20
94	3257	77	8.76	5698	83	17.08	94	20
98	1777	29	3.00	547	100	1.82	98	20
109	40	0	0.09	151	96	0.63	109	12
118	20	0	0.05	79	92	0.30	118	12
124	47	0	0.11	70	84	0.31	124	12
144	33	0	0.09	187	82	0.84	144	12
151	-7	0	-0.02	52	80	0.22	151	12
154	7	0	0.02	60	82	0.26	154	12
166	0	0	0.00	23	79	0.12	166	12
173	6	0	0.01	29	100	0.11	173	12
181	0	0	0.00	18	72	0.06	181	12
187	-14	0	-0.02	-9	-82	-0.03	187	12
193	-7	0	-0.01	13	66	0.04	193	12
200	81	1	0.15	70	100	0.27	200	12
207	128	1	0.32	78	79	0.34	207	12
213	-21	-1	-0.07	219	43	1.50	213	12
221	1058	118	3.02	938	61	5.67	221	12
227	816	104	2.15	451	97	2.85	227	12
234	617	73	1.74	561	100	3.54	234	12
237	742	108	1.90	646	99	3.93	237	12
240	691	129	2.15	617	100	3.93	240	12
250	1621	148	3.34	1147	90	5.94	250	12
255	1463	91	3.81	300	5	1.61	255	12
258	1216	67	3.52	76	1	0.48	258	12
262	2971	109	7.89	1697	39	10.03	262	12
266	300	94	0.79	-280	-5	-1.67	266	12
269	1570	184	4.74	716	14	4.66	269	12
274	1489	134	4.34	969	35	5.77	274	12
279	1519	113	3.52	1240	51	6.30	279	12
283	1173	169	2.28	1020	85	4.05	283	12
290	1212	159	2.45	879	44	3.66	290	12
294	1063	60	2.36	823	33	3.90	294	12
298	1373	114	2.70	841	23	3.40	298	20
306	914	38	2.07	481	18	2.25	306	4
312	1234	114	3.04	708	23	3.14	312	4
319	794	41	1.82	533	29	2.19	319	4

SYSTEM II							SYSTEM II				
DAY	Temp	AerSolids Wasting	ASRT	Temp* ASRT	SSRT	Temp* SSRT	ANOX COD REM:DENIT	COD ADD: NOxENTD	C ADDN: NOxPROD	AnoxpH- Lea'tpH	AnoxpH- AerbpH
	oC	ml/d	day	oC*day	(day)	oC-days	mg/d:mg/d	mgCOD/d: mgN/d	G/d/syst: G/d/syst		
5	20	0	500	10000				0	0.00	0.39	0.13
9	20	0	500	10000				0	0.00		0.10
12	20	0	500	10000	20.6	412.3	144.23	0	0.00	-0.73	-0.27
14	20	0	500	10000	10.4	207.5		0	0.00		0.32
20	20	0	500	10000	46.8	936.0		0	0.00		0.39
24	20	0	500	10000	83.1	1661.9		0	0.00		0.34
34	20	0	500	10000	211.3	4225.4	-97.31	0	0.00		0.36
49	20	0	500	10000	6.9	138.0	-93.80	0	0.00	0.60	-0.05
53	20	0	500	10000	13.5	269.1	11.53	0	0.00	0.66	2.97
61	20	0	500	10000	18.7	374.3	-2.44	0	0.00	-0.07	0.22
68	20	0	500	10000				1	0.88	0.51	-0.06
74	20	0	500	10000	76.3	1525.3	48.11	2	2.50	0.50	0.31
77	20	0	500	10000	129.4	2587.4	-31.92	2	3.76	0.33	0.17
84	20	500	20	400	18.7	373.3	-16.57	4	3.48	0.67	0.22
94	20	500	20	400	15.5	309.6	-4.12	2	3.28	0.68	0.30
98	20	500	20	400	3.7	74.4	0.00	28	8.72	0.64	0.09
109	12	500	20	240	22.0	263.7	4.09	66	261.82	0.93	-0.04
118	12	500	20	240	20.8	249.9	-50.19	99	425.45	0.89	-0.07
124	12	500	20	240	22.7	272.5	-213.66	115	206.56	0.84	-0.12
144	12	500	20	240	20.0	239.9	-58.50	45	308.82	1.16	-0.07
151	12	500	20	240	25.8	309.8	-456.44	154	-1517.35	0.85	-0.09
154	12	500	20	240	40.3	484.0	-66.15	177	1954.70	0.91	-0.11
166	12	250	40	480	26.9	322.3	171.85	460		1.12	-0.09
173	12	250	40	480	33.7	404.9	1180.44	489	2374.98	1.06	-0.01
181	12	250	40	480	20.4	244.2	908.23	530		0.78	-0.08
187	12	250	40	480	12.5	149.8	-1751.26	1338	-1100.59	0.77	-0.10
193	12	250	40	480	77.6	931.5	1046.88	762	-2251.09	0.88	-0.03
200	12	250	40	480	7.4	88.9	1381.24	52	44.94	1.08	-0.10
207	12	250	40	480	13.5	161.6	193.69	40	30.61	1.58	-0.06
213	12	250	40	480	12.4	149.2	23.08	8	-199.59	1.28	0.06
221	12	250	40	480	13.8	166.1	27.72	3	4.15	1.03	0.12
227	12	250	40	480	14.9	179.1	91.79	12	7.06	0.84	-0.02
234	12	250	40	480	12.9	154.2	32.04	13	11.45	0.89	0.00
237	12	333	30	360	12.9	154.6	0.00	10	9.12		0.02
240	12	333	30	360	13.5	162.2	31.62	12	10.31	0.73	-0.04
250	12	333	30	360	9.0	107.9	14.66	8	6.41	0.97	0.41
255	12	333	30	360	9.5	113.8	33.80	0	0.00	0.53	0.24
258	12	333	30	360	8.7	104.1	18.30	0	0.00	0.40	0.12
262	12	333	30	360	15.4	184.4	8.56	1	1.34	0.85	0.36
266	12	333	30	360	18.6	223.5	-33.72	1	11.48	0.85	-0.15
269	12	333	30	360	14.9	178.6	8.18	1	3.40	0.82	0.46
274	12	500	20	240	22.3	268.1	11.87	3	6.10		0.39
279	12	500	20	240	12.1	145.8	-3.81	5	8.75		0.25
283	12	500	20	240	22.8	273.6	8.47	12	12.10	0.75	0.23
290	12	500	20	240	16.2	194.9	9.97	5	8.38		0.37
294	12	500	20	240	8.8	106.2	21.04	3	7.43		0.05
298	20	500	20	400	12.6	251.2	10.14	3	8.30		0.30
306	4	500	20	80	12.4	49.7	12.34	3	8.31		0.15
312	4	500	20	80	26.6	106.6	-59.00	3	6.16		0.23
319	4	500	20	80	29.6	118.2	-37.58	4	9.49		0.11

SYSTEM II DAY	UNITANOX TKN (mg/l: mg/lVSS)	UNITAERB TKN (mg/l: mg/lVSS)	UNITANOX TP (mg/l: mg/lVSS)	UNITAERB TP (mg/l: mg/lVSS)	TKN/TSS ANOXIC ratio	TKN/TSS AEROBIC ratio	Nitrogen Wasted mg/d
5	0.12	0.10	0.04	0.05	0.110	0.08	3230
9	0.12	0.10	0.03	0.03	0.102	0.10	2537
12	0.11	0.09	0.02	0.02	0.095	0.07	2314
14	0.10	0.07	0.02	0.02	0.079	0.06	310
20	0.20	0.06	0.04	0.01	0.139	0.05	2199
24	0.12	0.07	0.02	0.02	0.059	0.04	230
34	0.12	0.06	0.02	0.02	0.078	0.04	2976
49	0.40	0.32	0.01	0.01	0.262	0.25	2213
53	0.31	0.33	0.01	0.01	0.212	0.20	2028
61	0.08	0.06	0.02	0.02	0.047	0.04	2622
68							2637
74	0.09	0.09	0.01	0.02	0.064	0.06	914
77	0.09	0.09	0.01	0.01	0.063	0.06	963
84	0.09	0.09	0.01	0.01	0.069	0.07	1185
94	0.10	0.16	0.01	0.02	0.071	0.09	1317
98	0.04	0.02	0.00	0.00	0.029	0.01	518
109	0.11	0.11	0.00	0.00	0.072	0.07	1525
118	0.10	0.12	0.00	0.00	0.067	0.06	1374
124	0.18	0.18	0.00	0.00	0.097	0.10	1252
144	0.11	0.13	0.00	0.00	0.055	0.06	1420
151	0.11	0.14	0.00	0.00	0.052	0.06	1514
154	0.17	0.19	0.00	0.00	0.077	0.09	1706
166	0.20	0.19	0.00	0.00	0.082	0.07	2239
173	0.13	0.14	0.01	0.01	0.061	0.06	1654
181	0.14	0.14	0.01	0.01	0.064	0.06	1686
187	0.15	0.14	0.02	0.01	0.078	0.09	1923
193	0.15	0.15	0.02	0.02	0.077	0.08	1779
200	0.18	0.17	0.02	0.03	0.092	0.09	2131
207	0.14	0.23	0.03	0.03	0.053	0.09	1745
213	0.12	0.12	0.03	0.03	0.049	0.05	660
221	0.09	0.09	0.03	0.03	0.037	0.03	500
227	0.08	0.06	0.02	0.02	0.038	0.03	309
234	0.08	0.09	0.02	0.03	0.044	0.04	296
237	0.00	0.00	0.00	0.00		0.00	108
240	0.11	0.10	0.03	0.03	0.059	0.05	312
250	0.08	0.06	0.02	0.02	0.050	0.04	898
255	0.08	0.07	0.02	0.02	0.047	0.04	1455
258	0.08	0.07	0.02	0.03	0.045	0.04	1544
262	0.09	0.05	0.03	0.03	0.059	0.03	963
266	0.06	0.06	0.03	0.03	0.038	0.04	1025
269	0.07	0.06	0.02	0.02	0.046	0.04	941
274	0.07	0.07	0.02	0.02	0.053	0.05	620
279	0.07	0.07	0.03	0.03	0.055	0.05	687
283	0.07	0.06	0.03	0.03	0.052	0.05	346
290	0.12	0.10	0.03	0.03	0.087	0.08	606
294	0.12	0.10	0.03	0.03	0.089	0.08	980
298	0.10	0.09	0.03	0.03	0.072	0.06	891
306	0.10	0.09	0.03	0.03	0.077	0.07	795
312	0.13	0.10	0.04	0.03	0.096	0.08	595
319	0.20	0.11	0.06	0.04	0.153	0.13	458